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DIMENSIONAL CHANGES OF HYDRATED PORTLAND CEMENT PASTE AND MORTAR DUE TO SLOW COOLING AND WARMING

A THESIS

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by

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ABSTRACT

The introduction emphasizes the fact that water plays an important role in the volume change behaviour of cement paste. The theme of the dissertation is presented and involves examining the influence of some fundamental parameters on frost resistance. This is followed by a discussion of the current theories pertaining to the structure of hardened portland cement paste. A review of the theories relating to the mechanism of frost damage in cement paste is presented. This is followed by a discussion of freezing test methods and in particular previous application of the slow cooling method. The formulation of the experimental program and evaluation of the problem are presented.

The experimental studies were divided into three phases:

Part I - Measurement of hydration parameters and the effect of admixtures on strength-porosity relationships for hardened portland cement paste.

Part II - Volume changes of hardened portland cement paste due to selected slow cooling and warming regimes.

Part III - An extension of the cement paste studies to the mortar phase of the matrix and an attempt to assess the role fine aggregate plays in the transient strain behaviour of mortar.

The experimental results enabled the formulation of expressions relating the hydration parameters to observed length change phenomena. Collapse of strain-temperature hysteresis was found to be related to the degree of hydration or volume concentration of hydrate product. The presence f admixtures other than air entraining agents did not appear to affect the length-change-hydration relationships. Self desiccation and degree of saturation were both found to influence the collapse of strain-temperature hysteresis.

Evidence is given for the duality of the frost mechanism. Strain-temperature plots for benzene saturated pastes exhibited dilational tendencies even though the specific volume of benzene decreases with a decrease in temperature.

The water-cement ratio parameter is shown to influence dimensional behaviour only in so for as it influences the volume concentration of hydrate product.

Critical dilation is shown to be invariant for the cement-paste system and determines crtical

values of strength, volume concentration of hydrate and volume of free water (per unit volume of paste) in the pores.

Data illustrating the effect of aggregate restraint on the transient strain behaviour of mortar was obtained. It is shown that the length change behaviour of mortar is dependent on both the degree of hydration and aggregate restraint. The rigidity of the aggregate is shown to effect the collapse of time dependent strain temperature hysteresis.

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NOMENCLATURE

Δw	-Weight of water per unit weight of cement required to maintain paste in saturated condition.
w_o	-initial water-cement ratio by weight
f_c	-compressive strength in psi
f_t	-tensile strength in paste
w_n	-non evaporable water content per unit weight of cement
W_n^o	-chemically bound water per unit weight of cement at ultimate hydration
α	-degree of hydration or W_n/W_n^o
C	-weight of cement in mix
V_{uc}^o	-volume of unhydrated cement at any time "t"
V_{hc}^o	-volume of hydrated cement at time "t"
V_{uc}	-volume of unhydrated cement per unit volume of paste
V_{hc}	-volume of hydrated cement per unit volume of paste
V_s	-volume of solids
V_v	-volume of voids
V^*	-volume of free water per unit volume of paste

X	-hydrate-space ratio
ΔV_R	-residual volume change
D_o	-dilation at 0°F
k	-a constant
g	-specific gravity of cement
t	-time to zero expansion in hours (eqn.52)
σ_r	-strength of a specimen after cycling at a given age
σ	-strength of an uncycled specimen at a given age
$\frac{\sigma_r}{\sigma}$	-ratio of strength after cycling to strength without cycling
t	-time in hours (eqn.35)
ϵ_c	-volume of capillary space per unit volume of paste
V_w	-specific volume of capillary water
V_p	-volume of paste
m	-maturity or extent of hydration
P_c	-volume of capillary pores
G	-Gibbs Free Energy
μ_1	-chemical potential of the adsorbate
μ_2	-chemical potential of the adsorbent
n_1	-number of moles of adsorbate
n_2	-number of moles of adsorbent
γ	-surface energy per square centimeter

D_o^m -dilation of mortar at 0°F

δ -constant

CHAPTER I

INTRODUCTION

The destruction of concrete by frost action has been and still remains a nemesis for the building industry. Test methods in the past have proved inadequate. High rates of cooling have generally given overload tests and correlation of laboratory results with field performance has been poor. As a result of Powers (1) suggestion, much current research has focused on the behaviour of concrete when subjected to natural cooling cycles. The slow cooling test method is still in the infant stage although it has been proposed as a tenative standard. With the exception of the initial work by Powers and Helmuth (2), attention has been focused on slow cooling methods as criteria for aggregate acceptance. Usually the paste is well designed and the aggregate becomes the questionable constituent of the matrix. The coarse aggregate has its own unique pore system and can act as a microcosm of destruction when included in the paste matrix.

Although concrete is one of the oldest materials in existence the mechanisms explaining the behaviour of this porous material when it is subjected to mechanical or thermal loads are largely unresolved. Concrete, for example, exhibits negligible creep when it contains no moisture, but appreciable creep when water is introduced into the pore system. The fact that water plays an important role in the volume change behaviour of concrete is recognized; however the mechanisms responsible for creep, shrinkage, and frost action which involve the interaction of water in a porous body are not yet fully understood. It is interesting to note that over 1500 papers have been published on the creep of concrete without providing a definitive rationale for the creep phenomena.

Feldman and Sereda (3) indicate that the term moisture content of a sample may represent water in different states because of the different physical and chemical interactions with the material and also because of the geometric configuration of the space it may occupy. It is commonly assumed that moisture content refers to a definite and implicitly defined quantity of moisture present in the material. This is not necessarily the case. Much careful study may be necessary in order to define moisture content usefully for any given purpose, or to interpret the results obtained from a particular method of measurement.

Perhaps the most important Canadian concrete problem concerns itself with the production of durable concrete; however the basic mechanism or mechanisms responsible for frost action are not fully understood. The dilema may not be as serious as the creep problem, as a partial solution to frost destruction appears to be inherent in the successful use of air-entrainment. However, fundamental information obtained by studying the effects of dimensional change, hysteresis and hydration due to slow cooling, may provide valuable data useful in assessing the role water plays in a cement paste subject to a freezing environment. Furthermore this data may contribute information valuable in assessing the behaviour of other porous materials.

This dissertation examines the influence of some fundamental parameters on frost resistance and attempts to establish the interrelation between dimensional changes due to temperature and parameters associated with the hydration process.

It is intended to obtain a fundamental understanding of a slow cooling regime applied to cement paste and mortar and the intrinsic parameters which affect both the magnitude and interpretation of accompanying dimensional changes and their use as quality indices.

CHAPTER II

THE STRUCTURE OF HARDENED PORTLAND CEMENT PASTE

STATE OF WATER IN CEMENT PASTE

Water in cement paste may be divided into categories as follows:

1) Capillary water - water which resides in the coarse or capillary pore system. The nature of capillary water approaches that of bulk water. It can be removed by oven drying at 110°C

2) Adsorbed water - water which is adsorbed to the surface of the hydrate and which resides in the fine pore system of the hydrate. This water is physically held by surface forces and is attributed the properties of a more viscous fluid. It can be removed by oven drying at 110°C.

3) Chemically bound water - water which becomes chemically bound as hydrate water. It can be removed by igniting the hydrate at 1100°C.

4) Interlayer water - water which penetrates between the layers of the hydrate. It can add rigidity to the layered hydrate and can be removed at 110°C. The existence of interlayer water is a subject of much controversy, but there is strong evidence for its existence.

STRUCTURAL MODELS

Models of paste structure provide convenient means for explaining the behaviour of cement paste when subjected to mechanical load or changes in environment. They necessarily feature the different types of water as an integral component, since for cement paste - at moderate stress levels-irreversible creep strains do not occur unless water forms part of the system.

Powers model

The model developed by Powers and Brownyard (4) in 1947 was based on water sorption isotherms. Its essential features are as follows.

a) Paste is a system consisting essentially of hydrated cement, unhydrated cement, water and crystals of calcium hydroxide.

b) The paste system has within it two pore systems - a capillary pore system (20Å - 2000Å) and a gel pore system with an average pore diameter of approximately 15Å.

c) Gel water is that water which is adsorbed in the range of vapour pressure $0 < p/p_s < 0.45$.

d) Capillary water is water that enters the system in the range of vapour pressure $.45 < p/p_s < 1.0$

e) The cement hydrate possesses a characteristic minimum porosity of about 28 percent.

These cardinal features of the Powers model still remain widely accepted. Contemporary models challenge the nature and geometry of the morphological features of the primary particle in the gel.

Powers initially modeled the structure of paste as a system of uniform spheres in hexagonal packing. The porosity of the model approached the characteristic porosity of cement hydrate (28 percent).

However electron optical and x-ray diffraction studies depicted a fibrous morphology which was not consistent with an hexagonally packed geometry.

Typical contemporary models such as those proposed by Ishai (1966) Powers (1966) and Mills (1968) describe the hydrate as being composed of randomly oriented layers of buckled ribbons. Estimates of the thickness of solid, maximum, minimum and average separation distances have been given as 40Å, 30Å, 4Å and 15Å respectively.

Recent scanning-electron micrographs by Diamond (5) and Mills depict the hydrate growing as a more ordered "flowered" structure. Products are also seen to be deposited in an "ordered" basket weave arrangement.

Feldman and Sereda model

Feldman and Sereda consider water held in the lower region of the isotherm to be interlayer water and an integral part of the structure. This water is not "adsorbed" but is water of hydration and can be squeezed out when the system is subjected to mechanical load. Thus the essential feature of the Feldman and Sereda model which differentiates it from all the other models is the existence of interlayer water. It is interesting to note that the model does give explanations for many mechanical properties that are not offered by the other models. The principle features of the model are as follows:

a) The hydrate is of a layered nature.

b) Water penetrates between the layers and can impart stiffness to the hydrate.

c) The interlayer water enters the paste in the lower region of the isotherm.

d) After water has entered the layers additional water becomes adsorbed on the surfaces of the hydrate.

COLLAPSE OF STRUCTURE

Collapse of structure (6) describes a situation where the walls of space containing load bearing water come together and form inter-molecular bonds which are numerous and strong enough to resist penetration of water into the space on re-saturation. The layers of hydrate are oriented in random directions relative to the load; some may tend to be closed by the load and others opened. Thus an energy gradient would be established such as to cause water to migrate away from the narrow parts of spaces which close and into those which open. In this authors opinion the collapse mechanism is present irrespective of whether the load is mechanical or thermal. Recent electron micrographs (7) of cement paste at low temperatures depict clusters or aggregations of calcium silicate hydrates indicating a decrease in surface area available to water molecules consistent with a collapse mechanism.

Recent scanning electron micrographs taken by Mills (8) on creep and shrinkage specimens show a densification or compaction of the calcium silicate hydrate which is also consistent with a collapse of structure mechanism.

WATER SOLID INTERACTION

Feldman and Sereda (9) identified the major components of creep and shrinkage as being due to the movement of interlayer water. The response of the system to relaxation of meniscus forces and variations in surface energy due to sorption was considered to be of secondary importance. On the other hand Powers (10) suggested that gel water was responsible for one component of drying shrinkage due to relaxation of swelling pressure and consequent elastic recovery of the solid; and that the other component was due to compression of the porous solid by meniscus forces. The complex and ever-changing time dependent nature of cement paste has proved to be a serious barrier in fundamental studies of the energetics of solid-water interaction. Indeed volume change phenomena have yet to be fully explicated. The answer may be in full proof of the existence of interlayer water.

ORIGIN OF STRENGTH IN CEMENT PASTE

Philleo (11) attributed the origin of strength in cement paste to short range primary bonds acting across the minimum separation distances and much weaker secondary or van der Waal's bonds acting over separation distances of up to about 100 times the minimum distance. Relationships between strength and volume concentration of hydrate may be interpreted in terms of increase in the area over which surface bonds may be active. Czernin (12) showed that by compacting finely ground quartz powder under pressure cementing action could be produced by purely mechanical means. It is apparent then that cohesion can be imparted to an assembly of fine particles if the porous mass can be compacted so as to mobilize a sufficient number of molecular bonds in adjacent surfaces.

INFLUENCE OF WATER IN AREAS OF RESTRICTED ADSORPTION

The dilation of porous solids was described by Bangham (13) as the result of ".... a wedge-like action resulting from molecular bombardment at sharp re-entrant angles in the surface." Powers and others (14,15,16) have proposed models in which water in areas of restricted adsorption (the interstices of the wedge) is said to exert swelling or disjoining pressure. Cohesive forces (short range primary bonds existing at the apex of the wedge and long-range secondary or van der Waal's bonds acting over the remaining areas of solid surface) tend to close the wedge shaped space and be resisted by disjoining pressure in adsorbed water together with the elastic forces in the solid. On both counts a state of internal stress in the skeletal structure of the solid should exist at the time hydration products are laid down. According to Mills (17) this strain energy is stored in agglomerations of primary particles as distinct from that existing in individual particles due to surface energy. The "wedging" strain energy component would presumably act in reduction of the energy required to cause migration of the water molecules.

The two-phase system consisting of a solid surface covered or partially covered with water molecules is said to be in equilibrium with the ambient atmosphere when the probability of molecules escaping into the atmosphere is balanced by the probability than an equal number will in the same time interval be attracted to the surface. Water molecules in this state have comparative freedom to move laterally while their movement normal to the surface is constrained. If two such surfaces are brought into close contact, the solid surfaces come under the influence of long-range attractive forces while the incidence of repulsive impulses between water molecules will increase and equilibrium with the surrounding atmosphere will be disturbed. If the space between adjacent surfaces is wedge-shaped such repulsive forces will cause preferred migration of water molecules towards the wide part while the tendency to minimise surface energy requires that they migrate towards vacant sites near the narrow end.

The water in such areas of restricted adsorption is in a metastable state of equilibrium with respect to: the hydrostatic stress in capillary pores; the ambient atmosphere; and any mechanical loading which tends to alter the shape of the wedge-shaped space.

Application of uniaxial compression would tend to open wedge shaped spaces pointed in the direction of loading and close those with their axes transverse to the load. A system of pure shear would result in similar action due to the effect of principal tensile and compressive stresses. In general any system of mechanical loading other than hydrostatic would create differences in free energy of adsorbed water. Even in saturated pastes, therefore, water would tend to migrate away from some sites and be attracted to others. The accompanying creep may be said to result from "seepage", or removal of water from areas of restricted adsorption.

CHAPTER III

MECHANISMS OF FROST DAMAGE IN CEMENT PASTES

In order to appreciate the nature of freeze-thaw breakdown of concrete it is desirable to consider some of the theories relating to the mechanism of frost damage in cement pastes.

Powers (18) gives a detailed description of the void systems in cement pastes.

During hydration, cement grains in the paste become replaced by other physically and chemically different materials. Being granular it has a characteristic porosity, of approximately 25 percent. The granules called gel particles are exceedingly small, and interstitial spaces among them are correspondingly small. These spaces called gel pores are in fact so small that water cannot freeze in them at any temperature within the range of interest.

The space occupied by cement gel is more than twice that of the cement consumed in producing the gel. Consequently gel not only replaces original cement but also fills some of the originally water-filled space. The degree to which the originally water-filled space becomes filled with gel depends on how much of the cement has become hydrated and on the amount of water-filled space originally present. In other words it depends on the water-cement ratio of the paste and on the extent of hydration of the cement.

Residues of originally water-filled space constitute an interconnected network of channels through the gel, or cavities interconnected only by gel pores depending on the degree to which gel fills the available space. These spaces are called capillary pores or capillary cavities or in general, capillaries. They are large enough for water to freeze in them.

This account presents three main factors controlling the frost resistance of a cement paste. These are:

(1) The higher the original water-cement ratio the higher will be the percentage of water filled capillaries per unit volume of paste.

(2) The more complete the hydration, the lower will be the percentage of water-filled capillaries per unit volume of paste. (for a given water-cement ratio)

(3) The amount of water that freezes in any given hardened paste is greater, the lower the temperature.

Recent advances by Feldman and Sereda (19) give evidence for the layered nature of cement hydrate, and the existence of interlayer water. It is possible that this water plays a contributing role in freezing phenomena observed in the cement paste system.

An appreciation of the physical constitution of cement pastes as described in the foregoing is necessary in order to understand the various theories which have been developed to explain the nature of frost damage in cement pastes. A discussion of these various theories follows.

HYDRAULIC PRESSURE THEORY

Freezing and thawing damage cannot be attributed solely to direct crystal pressure resulting from ice formation. Even concrete with a moisture content considerably below the critical saturation value of about 0.90 will fail after successive cycles of freezing and thawing. Although concrete may have a high moisture content the adsorption and capillary forces are such that only part of the water is frozen at a given freezing temperature ranging from 21% at -.25 °C to 100% at -15 °C.

Powers (20) gives a concise analysis of the mechanism. Ice first forms at the cold surface sealing off the interior of the specimen. Pressure exerted by expansion due to ice formation forces water inward to less saturated regions. In a fine textured porous solid such as concrete the relatively high resistance to the flow of water sets up hydraulic gradients which exert pressure on the pore walls. This hydraulic pressure increases with increasing rates of freezing, degree of saturation and fineness of pores. When the hydraulic pressure exceeds the tensile strength of the solid, the pore walls are ruptured.

During freezing, the resistance to flow of water increases with the distance from the surface. The point at which rupture occurs as a result of hydraulic pressure is called the critical depth of saturation. The hydraulic pressures as calculated by Powers for a given set of conditions drop very rapidly with a small drop in degree of saturation. Entrained air increases the resistance of concrete by reducing the hydraulic pressures developed through freezing and thawing. Although nearly all concrete contains more than enough space to accommodate freezing expansion the spacing of the pores is such that destructive hydraulic pressures can develop in the paste.

As the spacing is reduced by air-entrainment the thickness of pore walls are reduced, thereby reducing the pressures which can be developed through resistance to flow of water. It is the proximity of air pockets which determines resistance. The spacing factor necessary to produce resistance to frost has been calculated by Powers to be in the order of 0.01 inch, the air requirement depending on the paste content.

In an analysis of the hydraulic pressure theory it is advantageous to consider critical thickness and saturation concepts. If the body is extremely large-that is, if it has virtually no boundaries at all and no air voids, all water that freezes must remain in the body and the body must increase in volume enough to accommodate the water-volume increase produced by freezing. Hence the volume increase would be about 9 percent of the volume of water that freezes. With a finite body however, some of the excessive water volume produced by freezing may escape from the body during freezing, and thus over-all dilation of the body will be less than what it would have been had none of the excess been expelled. Parts nearest "escape boundaries" (the surfaces through which excess water can be expelled) will not be directly damaged by freezing because all excess water can escape from those regions. If the body is sufficiently thick inner parts will become dilated during freezing, and this will affect outer parts too. Hence, the over-all effect of freezing in any given paste depends on thickness of the body. If the body is thinner than some critical limit, it can be frozen without damage.

For a given capillary space in hardened paste, 91.7 percent is a critical degree of saturation. Freezing in partially saturated paste may involve displacing water from smaller to larger spaces. Freezing in paste thus may produce some stress even when the over-all saturation coefficient is below the theoretical limit. Such stress is not likely to be destructive; indications are that a small loss of evaporable water enables a paste to withstand severe freezing.

One may think of the growing ice body in the capillary pore as a sort of pump forcing water through the paste toward the void boundary. Such a pumping out of water involves the generation of pressure. The most important factors are: (1) the coeifficient of permeability of the material through which the water is forced. (2) the distance from the capillary pore to the void boundary and (3) the rate at which freezing occurs.

In general, one can see that during the process of freezing, hydraulic pressure will exist throughout the paste, and this pressure will be higher the farther the point in question is from the nearest escape boundary. If a point in the paste is sufficiently remote from an escape boundary, the pressure may be high enough to stress the surrounding gel beyond its elastic limit. It becomes clear that every air void enveloped by the paste must be bordered by a zone or shell in which the hydraulic presssure cannot become high enough to cause damage. Theoretically the pressure increases approximately in proportion to the square of the distance from the void, the pressure being zero at the void boundary. By reducing the distance between voids to a point where the protective shells overlap, one can prevent the generation of disruptive hydraulic pressures during the freezing of water in the capillaries

The following table (21) gives the relation between degree of saturation and hydraulic pressure developed on freezing.

Degree of Saturation	Hydraulic Pressure Developed on Freezing (psi)
1.00	100
0.99	86
0.98	68
0.97	56
—	—
—	—
—	—
0.917	0

However generation of hydraulic pressure through the mechanism just described does not account for shrinkage that accompanies freezing when air voids are present nor for certain responses to change in rate of cooling.

PREFERRED ADSORPTION OF WATER

The argument advanced by this mechanism is that hydrostatic pressure in cement is generated by the changed interaction between the cement and the adsorbed water on its solidification. According to Litvan(43) when water freezes the molecules which are in a relative disarray in the liquid state, have to order themselves as required by the crystal structure of ice. The mobility of the adsorbed molecules however is limited owing to the surface forces. In the first two layers where the attraction to the surface is the strongest, no rearrangement can occur even at low temperatures, and in subsequent layers it may take place only below 0°C. (On formation of an adsorbed layer with ice-like structure the interaction between the cement surface and the water molecules decreases. As a direct consequence the maximum amount of water held in the surface is reduced. Thus part of the water required for saturation before freezing becomes excess after ice formation. As all the pores were completely filled at saturation, this excess water cannot the accommodated and pressure is generated. In an open system pressure differences cannot be maintained, so that the water has to leave the void system by diffusion.

DIFFUSION AND FREEZING OF GEL WATER

Each gel particle carries its adsorbed water "film" and the water film separates the gel particles from the ice, the degree of separation being submicroscopic-only a few molecular diameters. The body of ice is separated from the cavity wall by an unfrozen film, the adsorbed layer, which film is continuous with the adsorbed layers within the gel. The water molecules in the film tend to have the orientation demanded by the force field of gel particles. The same molecules are also subject to the force fields of the ice crystals which tend to produce the molecular orientation characteristic of the crystal. Thus the water in the film is subjected to competitive forces. At a given temperature below 0°C the ice crystal is able to capture some of the film water and reduce the thickness of the film below what it would be if no ice were present. As the temperature becomes still lower, more of the molecules in the film are captured by the ice and the film becomes thinner. Since the films are identical with the adsorbed layers on the gel particles in the interior of the gel (the gel water) the depletion of the film in the capillary cavity by the ice in the capillary cavity produces a free energy difference between the film in the cavity and the gel water. Consequently water creeps along the surfaces of the gel particles into the film in the ice bearing cavity as required to reduce the free energy potential created by depletion of the film in the cavity. The process is called surface diffusion.

Whenever the gel loses water it tends to shrink, no matter whether the water is lost by evaporation or by freezing. The tendency of the gel to shrink as water is extracted from it by freezing and the growth of the ice body, places the ice in the capillary cavities and the film around the ice under pressure. Such pressure increases the free energy of the ice and of the water in the film between the ice crystal and the gel particles and tends to prevent the replenishment of that film by diffusion of water from the gel. However the swelling pressure in the film is enough to produce dilation. For example if the gel were saturated and if the capillary cavities contained ice at -5°C the pressures in the film between the ice and the solid could be as much as 1200 psi. This amount of pressure would surely cause the paste to dilate appreciably. Thus, expansion can be caused by diffusion of water from the gel to the capillary cavities.

MACROSCOPIC SEGREGATION OF ICE LENSES

It is well known that water expands about 9% in volume when frozen. Although the disruptive effect caused by the freezing of a cement paste is related to this expansion it does not depend directly on the expansion of freezing water. Collins likened the action of freezing in concrete to the frost-heaving of soils with the growth of ice-lenses parallel to the cold surface. "The damage to concrete was considered to be caused, not so much by the actual increase of volume of the water in the pores on freezing as by the growth of the crystals afterwards and the consequent segregation and concentration of the ice into layers". Collins' theory was based on observations of concrete pavements damaged by severe frost action in the winter of 1941 which seemingly involved movement of water from the subgrade into the slab. He was able to devise labboratory experiments to confirm the field observations.

MICROSCOPIC SEGREGATION OF ICE LENSES

" 'Frozen capillary water tends to grow by drawing water from the gel'. This extends Collin's (1944) and Tabers' segregation theory (1929-30). Here we are dealing with the growth of a large number of microscopic ice-crystals, rather than crystals of macroscopic size." (Powers 1955)

This theory explains why some air-entrained mixes exhibit shrinkage during freezing. At the onset of freezing as ice is formed in the water-filled capillaries some water is forced into the air-voids. Subsequently, this water forms ice-crystals, in the air voids, which tend to grow by drawing water from the gel pores-and whenever the gel loses water it shrinks whether the water is lost by evaporation or in this case by freezing.

OSMOTIC PRESSURE THEORY

The material bordering each capillary is cement gel containing gel pores and solution and ice cannot form in these pores because of their smallness. Freezing concentrates the solution in the capillary cavities without producing an equal change in concentration in the gel pores. Thus freezing should immediately produce a tendency for the solute in the capillary water to diffuse into the region of lesser concentration, the contiguous gel water. At the same time gel water tends to diffuse into the concentrated solution in the capillary. While the concentration differential exists, a dilation tendency exists which, when opposed, will appear as osmotic pressure. The magnitude of osmotic pressure will depend on concentration difference. The kind of pressure produced by osmosis should not be much different from that due to growth of ice crystals. Pressure from growing ice is not due directly to the solid itself but to the drawing of water molecules into the adsorbed film that separates ice from the cavity wall. This gives rise to a swelling pressure closely akin to osmotic pressure. Thus whether or not capillary water contains dissolved alkalies, freezing in a relatively dense paste can produce dilation. It may be produced by water driven to ice bodies by a potential produced by falling temperature, or by water driven to a solution-osmosis-or it may be due to both causes. Experimental work has not yet revealed the relative importance of osmotic pressure.

DISCUSSION OF VARIOUS THEORIES

There thus seem to be four main mechanisms of expansive forces operating in cement pastes at freezing temperatures, all of which are a result of the peculiarties of the cement paste and all of which are compatible with each other.

The macroscopic growth of ice lenses, which is akin to the growth of ice lenses in soil is more likely to occur in fresh pastes or shortly after hardening when there is still an abundance of free water and the permeability of the paste is still rather high. If a concrete or a cement paste is frozen at an early age and cracks are formed, these cracks can be centres for macroscopic build up of ice lenses should freezing occur at some later age.

Hydraulic pressure and the microscopic growth of ice crystals are the mechanisms most likely to cause damage to hardenend cement pastes. Powers (22) claims that the forces operating at any instant of freezing depend mainly on the rate at which the sample is cooled, the length of time it has been at sub-freezing temperature and the permeability of the paste. If the paste porosity is relatively high and freezing is rapid, expansion will be due primarily to the growth of ice crystals in the capillaries. Closely spaced air voids are claimed by Powers to protect hardened cement paste from frost damage by either of the latter mechanisms. This is done by:

a) limiting hydraulic pressure

b) limiting the time during which capillary ice can increase the diffusion of gel water.

Preferred adsorption and the subsequent induced hydraulic pressure offers a new explanation for observed phenomena. Litvan (23) has offered experimental evidence in support of this theory. Long term experiments (5 months) in which dimensional changes were measured under fully controlled equilibrium conditions showed deviations from non equilibrium natural test conditions. His weight changes appeared to be incompatible with the 9% volume increase of ice. However it is felt more evidence is required to substantiate the hypothesis.

In summary it is felt that in mature concrete, the hydraulic pressure mechanism is the most important factor responsible for frost damage; Powers (24) has published data which seems to verify this point.

CHAPTER IV

DISCUSSION OF FREEZING TEST METHODS

Establishing standard testing procedures to assess the frost susceptibility of concrete is a difficult task. Variations in climate and field conditions add to the complexity of designing a meaningful test regime. It is not surprising, then, that test methods are still unsatisfactory.

A test which involves rapid freezing is unusually severe in developing hydraulic pressure in the hydrate structure but is too rapid to permit the buildup of ice crystals. Laboratory tests have often been unrealistic in simulating natural conditions. Conditioning specimens (eg. inundation) can at times misrepresent actual field moisture conditions. Present A.S.T.M. tests for freezing and thawing resistance of concrete are shown below.

ASTM Test Method	Type of Exposure
C290	Rapid freezing and thawing in water
C291	Rapid freezing in air and thawing in water

A.S.T.M. C290 involves lowering the temperature of the specimens from 40 to 0°F and raising it from 0 to 40°F in not less than 2 nor more than 4 hours. This involves unnatural freezing rates of more than 20°F/hr.

A.S.T.M. C291 involves lowering the temperature of the specimens from 40 to 0°F in a period of not more than 3 hours and raising it from 0 to 40°F in a period of not more than 1 hour. This method as well involves unnatural freezing rates in excess of 15°F/hr.

Deterioration is measured by loss in dynamic E. Usually the number of cycles to yield an E value of 60 per cent of the initial value is used as a measure of the durability.

A report (25) on cooperative freezing and thawing tests of concrete in which thirteen different laboratories were involved in a round-robin series of tests indicated that there was little evidence to show that the results correlated well with concrete subjected to natural freezing and thawing.

Indeed the A.S.T.M. tests are unnatural not only because the rates of freezing are considerably higher than usual in nature but because the specimens are never allowed to dry.

Powers proposed that length measurements could be used to tell whether or not at any given time a specimen is vulnerable to frost action. If the test specimen dilates in the freezing range it is frost susceptible; that is the process that eventually causes disintegration has begun.

This proposal showed promise because it utilized a natural freezing regime as a test condition. Dimensional changes were to be measured as a specimen was cooled slowly (ie. cooled naturally). Assessing the magnitude of dilation consistent with quality concrete was a basic difficulty. Because a slow cooling regime (about 5°F/hr.) best simulates natural exposure conditions Power's proposal appears to offer a promising approach to the diagnosis of frost problems. However much research needs to be done on the slow cooling regime and its effect on the properties of the matrix and its constituents.

From its own investigations (1948) the U.S.B.R. felt that length change (residual) or expansion of the concrete gave a more reliable early indication of failure than any other method used in the Denver laboratory of the Bureau. The modulus of elasticity had not proved to be as satisfactory in this laboratory as the length change method. While reduction in modulus of elasticity is quite rapid in concrete of poor quality, there is usually an increase in modulus for all concretes of fair, good, or excellent quality for some period after subjection to freezing and thawing. Thus it was believed that length change (residual) was the more effective criterion for durability judgements. It is this author's opinion however that residual length changes may be misleading, at least for concrete subjected to field conditions. The residual length change should depend on the environmental history of the concrete in service; properties influencing dimensional behaviour can be influenced greatly by temperature and moisture content. It is suggested, therefore, that a fundamental look at residual dimensions resulting from temperature loads may provide data which will be useful in attempting to design a realistic standard test.

Valore (26) initiated studies of volume change due to slow cooling in small concrete cylinders. As a result of his study Valore suggested the possibility of predicting durability on the basis of measurement of transient or residual strain for one or two cycles of freezing and thawing.

CHAPTER V

PREVIOUS APPLICATION OF SLOW COOLING METHOD

UNITED STATES

The California Department of Highways were the first organization to utilize a slow cooling regime as an acceptance criteria for frost susceptible aggregates. In testing the suitability of aggregates Tremper (27) adopted a cooling regime of about 5°F/hr. As a result of his investigations Tremper rationalized as to the nature of the cycle. In explaining shrinkage at a greater rate than that due to thermal contraction alone, he reasoned that it was because ice crystals under progressive cooling tend to attract moisture at the expense of that in the paste. Tremper adopted as the criterion of unsatisfactory dilation a measured elongation of 50 millionths in/in above the length at the apparent freezing point. This figure appeared to be workable for Tremper's aggregates and the California mountain environment. However it should be stressed that his criteria was strictly emperical and may not have proved satisfactory outside the locality under consideration.

The Pennsylvania State University has been involved in extensive studies of state aggregate supplies. Cady (28) has attempted to relate coarse aggregate properties (eg. absorption, specific gravity) to dimensional changes in a slow cooling regime. As a result of their investigations Larson and Cady have prepared a tentative test specification proposing the slow cooling test as a standard method for assessing the durability of aggregates. Since the effect of many fundamental parameters (eg. degree of hydration, effect of aggregate restraint etc.) is still unknown it is the opinion of this author that standardizing the slow cooling test is premature. For example the effect of drying is of considerable importance; Cady (29) observed a reduction in the magnitude of positive dimensional changes due to drying. However this work is for a particular concrete subjected to specific conditions and does not illustrate or quantify the factors which influence drying and subsequently affect a slow cooling regime.

The University of Maryland has been involved in research on the durability of concrete sponsored by the National Sand and Gravel and the National Ready-Mixed Concrete Associations. Wills (30) made an investigation of the behaviour of two frost susceptible concretes when exposed to a slow freeze-thaw test method. One fundamental error in Wills' work is embodied in his comparison of dilation results from slow cooling tests with loss in dynamic E for specimens subjected to standard freeze-thaw tests. It is the idea of forming the comparison which is not valid- that is the idea of comparing right with wrong. If freeze-thaw cycles are intrinsically in error then it would seem absurd to compare these results with a method which is substantially well founded. Wills' tests did however indicate that aggregate which does not meet A.S.T.M. freeze-thaw requirements may in the context of a slow cooling regime prove to be satisfactory under field conditions.

At the Virginia Polytechnic Institute Richard Walker (31) has carried out work on the identification of coarse aggregates that undergo destructive volume changes when frozen in concrete. In doing so he also has attempted to relate data from freeze-thaw cycles to data obtained from slow cooling tests. As pointed out in the previous discussion of the University of Maryland Studies this appears to be ill fated.

JAPAN

Koh Yoshiro, Kamada Eiji and Hasegawa Toshio (32) of Hokkaido University, Sapporo (Japan) have tried to tackle the problem of frost damage to concrete buildings, utilizing a slow cooling test method. They also have reported data relating loss in dynamic E due to freeze-thaw cycling with expansion obtained in a slow cycle. As mentioned previously this type of comparison does not have much merit. They concluded that, considering their climate, successive detailed experiments on the effect that freezing temperature, degree of saturation and various properties of aggregate, have on frost resistance, would be required.

FINLAND

The Imatra Power Company of Finland has had some experience with a slow cooling test to determine the frost susceptibility of their aggregates. As a result of their experience they have been able to make use of aggregate which has not complied with A.S.T.M. requirements.

CANADA

The University of Windsor has been involved in a continuing programme of research into the fundamental aspects of slow cooling regimes as quality indices of frost resistance. MacInnis and Beaudoin (33) have investigated the effect of degree of saturation on the frost resistance of mortar which is subjected to a slow cooling regime. Degree of saturation was found to be an important parameter; however it was noted that other properties of the matrix (eg. aggregate restraint) would probably affect the transient strain behaviour of the material.

MacInnis (34) applied a slow cooling test as a research tool to evaluate the frost resistance of cement grout mixtures for prestressed concrete. He obtained several strain-temperature patterns which enabled him to select frost resistant grouts. Air entrainment was found to be the most effective method of preventing expansion and cracking caused by freezing temperatures. Water-cement ratio appeared to be next in importance to air-entrainment in providing frost protection for grouts.

The Ontario Hydro has conducted research on the slow cooling method as a means for assessing the quality of questionable aggregates. In accepting some aggregates which have been rejected by standard freeze-thaw tests, Hydro will be able to economize considerably on some of their large construction projects.

The application of a slow cooling regime as a test method probably would not have evolved as rapidly if it were not for the many contributions of Powers. Indeed the organizations and individuals discussed above have been greatly assisted by the theories expressed by Powers.

Powers and Helmuth (35) summarized what they thought were the principle phenomena occurring in slow cooling tests. In view of greater current interest in slow cooling of concrete it may be useful to briefly mention some of Powers observations. They are as follows:

1) In all water soaked pastes not containing air-voids, expansion begins at the instant freezing begins.

2) When air voids are present and closely spaced, initial expansion, if any, begins with freezing and is followed by contraction.

3) When cooling is resumed after a constant temperautre period, pastes without voids begin abruptly to expand and those with voids begin gradually to contract.

4) In freezing water-soaked pastes of given porosity, expansion is smaller, the smaller the spacing factor of the air voids. These cardinal features of slowing cooling tests have been observed by all investigators and published in the literature.

CHAPTER VI

FORMULATION OF EXPERIMENTAL PROGRAMME

The general aim of this dissertation is to obtain a fundamental understanding of a slow cooling regime applied to cement paste and mortar and the basic parameters which affect both the magnitude and interpretation of accompanying dimensional changes and their use as quality indices.

DESIGN OF PROGRAMME

The experimental studies were divided into three parts:

Part I -Measurement of hydration parameters and the effect of admixtures on strength-porosity relationships for hardened portland cement paste.

Part II -Volume changes of hardened portland cement paste due to selected slow cooling and warming regimes.

Part III -An extension of the cement paste studies to the mortar phase of the matrix and an attempt to assess the role fine aggregate plays in the transient strain behaviour of mortar.

GENERAL PLAN OF INVESTIGATION

Part I

The progress of the hydration process was experimentally determined by measurement of the weight of water required to maintain the paste in a saturated condition. Thus the absolute volume change due to the reduction in specific volume of the products of hydration was measured. The measured hydration parameters ($\frac{\Delta w}{w_o}$, hydrate space ratio) provided data for establishing the interrelation between dimensional changes due to a selected slow cooling regime and the hydration process. Other measured parameters included compressive and tensile strength of paste.

Part II

Mixes of plain cement paste were subjected to a selected cooling and warming cycle $\frac{dT}{dt} = 5^{\circ}F/hr$. Continuous measurement of length change (axial deformation) throughout the cooling and warming cycle provided data for strain temperature plots.

Mixes of cement paste containing various replacements of fly ash were cast. Strain temperature plots for the system cement-water-fly ash provided data enabling an assessment of the effect of fly-ash on the durability of cement paste.

Mixes containing water reducing admixtures (lignosulphonic and hydrocarboxyllic) were cast. Strain temperature plots provided data aiding in the evaluation of the effect of water-reducing admixtures on the durability of cement paste, and the hypothesis that dilational response was uniquely dependent on volume concentration of hydrate product.

A series of mixes with air-entraining admixtures was included in order to illustrate the dramatic effect of an air-void system on the dilational response of the cement paste system.

In order to study the effect of self-desiccation, cement-paste specimens were moist cured 24 hours and subsequently sealed until subjected to a selected temperature regime. Experimental results were compared with a theoretical expression for the time to zero expansion. Multiple cycling of specimens sealed and subjected to the cooling cycle at 24 hours were intended to further demonstrate the effect of self-desiccation.

To get some appreciation of the effect of specimen size and shape a series of tests included cement paste specimens with the following dimensions (1" x 1" x 6"; 1" x 6" x 6"; 3" Ø x 6")

To illustrate the effect of the selected cooling cycle on compressive strength, specimens were either moist-cured, sealed and subjected to test or moist-cured, sealed and stored in air. After the test-cycle the crushing strength of both sets of specimens was obtained and the ratio of strengths for cycled to non-cycled was obtained. The effect of hydration parameters on the ratio was noted.

In an attempt to provide evidence that a mechanism other than hydraulic pressure may contribute to frost damage mixes saturated in benzol (a liquid with molecular diameter close to water but whose specific volume decreases with decrease in temperature) were prepared. Any dilational response in the "freezing zone" would not be attributable to hydraulic pressure.

A cooling rate of approximately 2°F/hr. provided a regime for a further series of tests intended to demonstrate the effect of a rate of cooling less than 5°F/hr. The length change response and collapse of hysteresis patterns were expected to be less pronounced as greater time would be allowed for the cement paste system to approach equilibrium conditions.

A cement-water-rockflour system was chosen to demonstrate the effect of degree of saturation on dilational response and frost-resistance for high water-cement ratio pastes (w/c = 0.70-1.00)

The effect of drying was hoped to be clearly demonstrated by comparison of moist cured to moist cured, dried and vacuum saturated specimens.

Part III

Mortar mixes of varying aggregate-cement ratio and water-cement ratio were prepared using two different Ontario sands. It was intended to assess the effect of aggregate restraint and extent of hydration on the dilational characteristics of mortar.

A series of mixes with spherical glass inclusions (5/8" Ø) of varying volume proportions was undertaken to simulate conditions of pure-restraint and maximum paste incompatability. All these mixes were to be tested at an early age in an effort to study the nature and orientation of the cracks at the paste-aggregate interface. Glass has a low coefficient of thermal expansion and hence would be thermally incompatible with the paste matrix.

CHAPTER VII

EQUIPMENT AND MATERIALS

POSITION TRANSDUCERS AND FRAMES

Position transducers (linear variable differential transformers) were used as measuring devices to monitor continuously length change due to temperature. The output from the transducers was recorded on a ± 50 mv Honeywell recorder. Transducer excitation was provided by two Hewlett Packard dc power supplies - 6 volts dc was required for each transducer. The sensitivity provided was 1×10^{-4} inches per division of chart paper. This is approximately dial gauge sensitivity but allows for the added facility of continuous output and gives a complete record of the transient strain performance of the cement-paste system.

The transducers were mounted vertically on specially designed invar frames as illustrated in fig. 1 . Photograph 1 shows the frame and test specimen ready for experimental testing. The experimental system included six test frames giving continuous output throughout the temperature cycle. Photograph 2 illustrates the test set up showing the six frames in the temperature chamber. A schematic representation is shown in fig. 2.

The supporting legs of the frames consisted

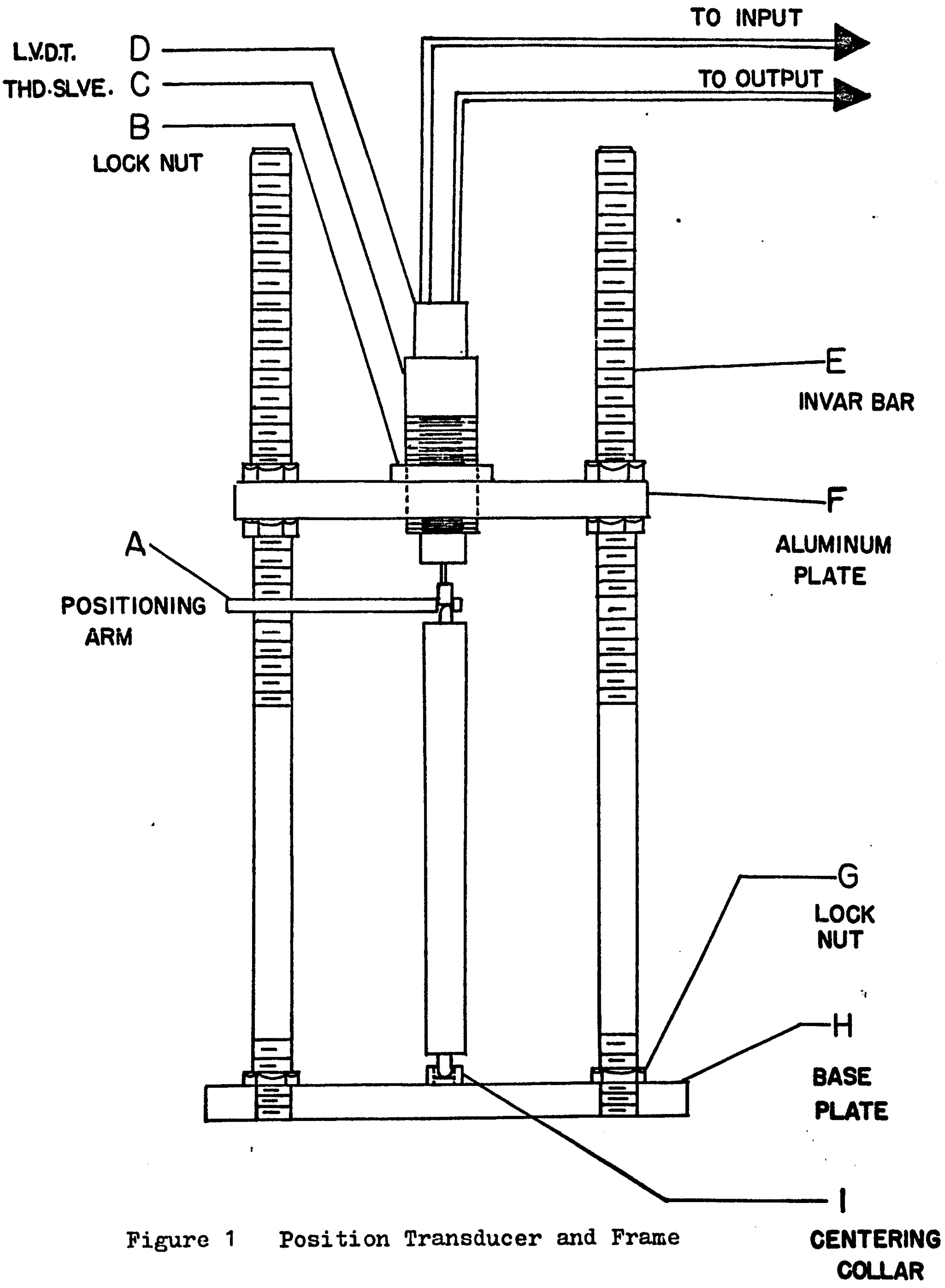


Figure 1 Position Transducer and Frame

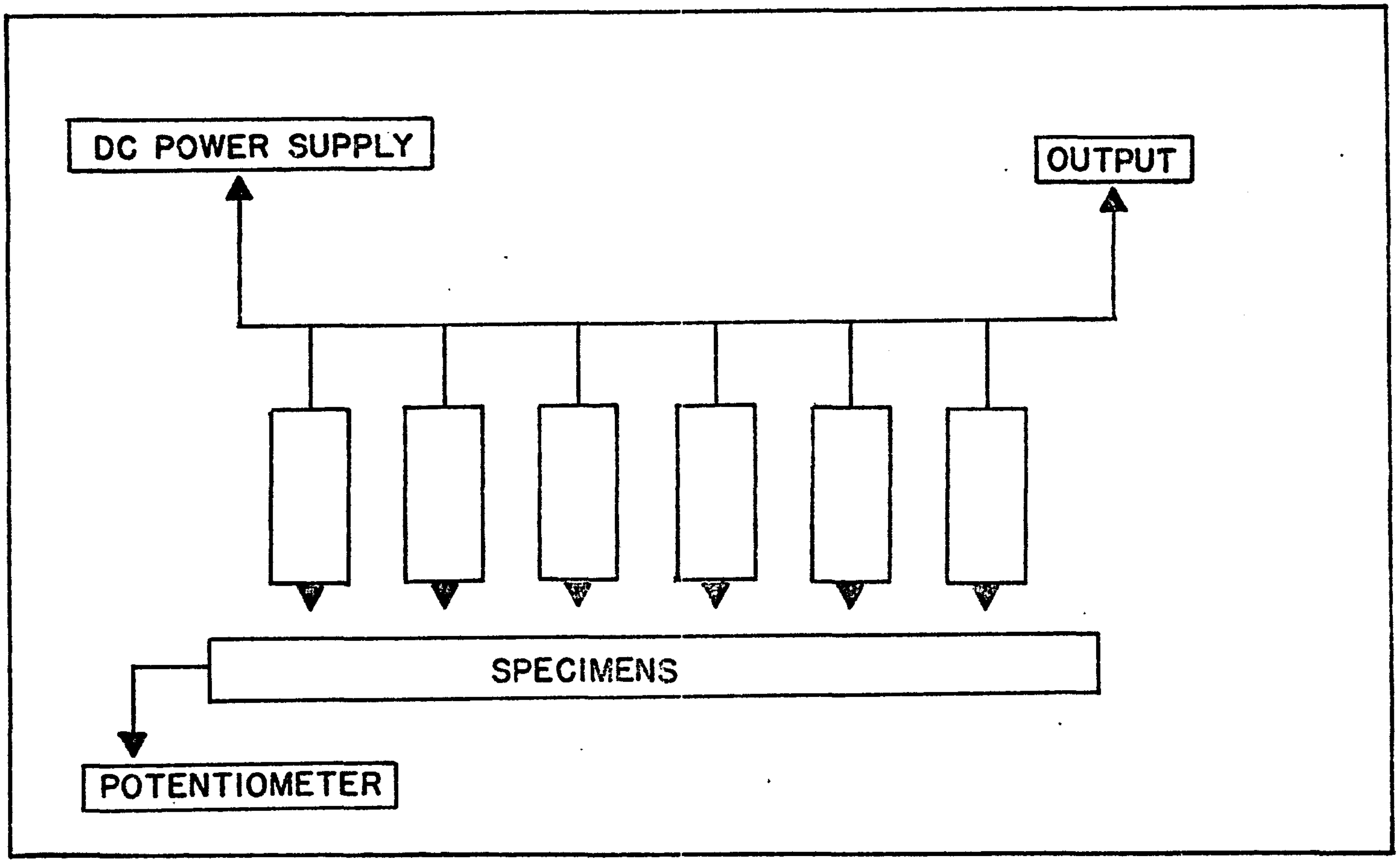
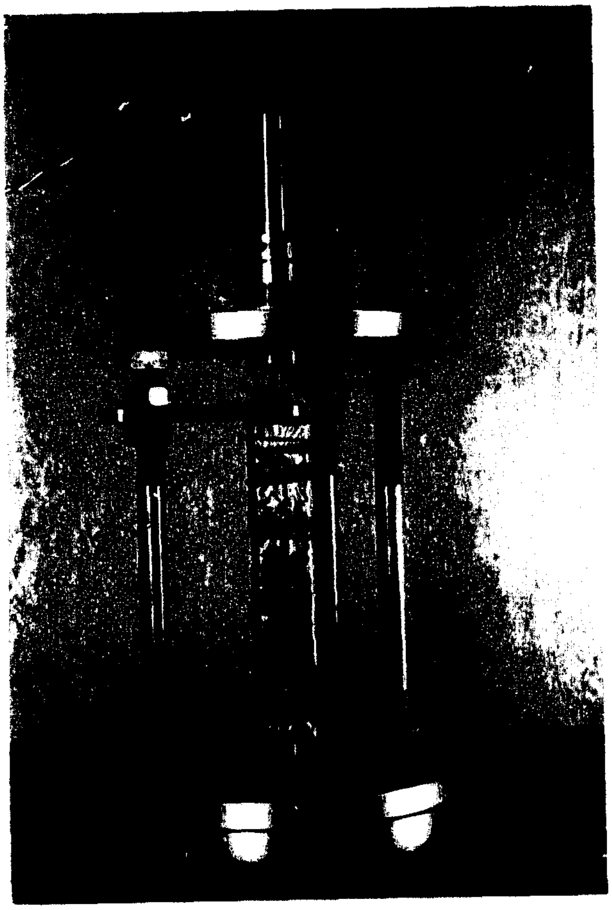
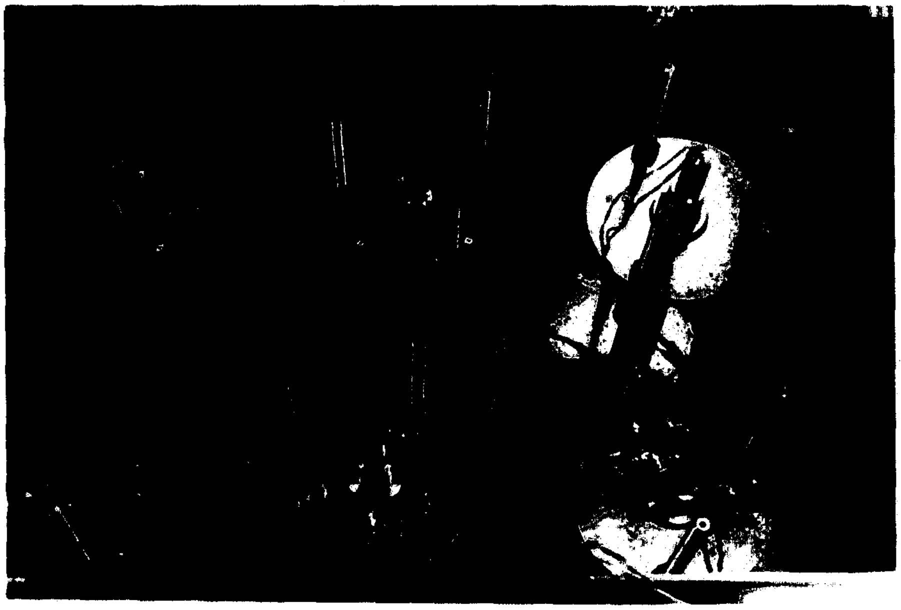


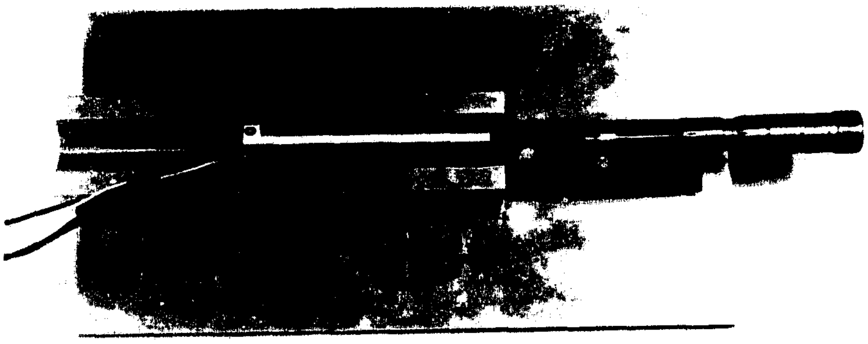
Figure 2 Schematic of Test Layout



P$_1$ - Transducer Frame Assembly



P_2 - Test Frame In Freezing Chamber



P_3 - Micrometer Calibrating Device

of 14 inch long inar rods. However to insure that the temperature effect of the frame itself was negligible the frames were calibrated using standard metal specimens of known coefficient of thermal expansion. Steel (1020) and aluminum (6061-T6) specimens were chosen as the reference materials. Also an experiment using a specimen of fused silica ($\alpha = 0.25 \times 10^{-6}$ in/in/°F) was performed. The slope of the length change-temperature curve provided a system coefficient of thermal expansion. The thermal coefficient value for the reference specimen deducted from the system value provided a correction for the thermal effect of the frame itself. The maximum frame effect was approximately 0.5×10^{-6} in/in/°F which is close to the value for invar itself. The frame effect was considered negligible and neglected in subsequent calculations. The transducers themselves were calibrated by producing known displacements of the probe with a micrometer device. (see photograph 3) Recorder output in mv. was plotted against mechanical displacement of the probe. The slope of the calibration curve in volts/in. was compared to the rated output of the transducer. In all cases transducer output varied less than 2 per cent from rated output. All calibration curves are included in the appendices.

According to manufacturer's data the transducers are operable in an environment at -50°F. The lowest temperature in the testing regime of this work was approximately 0°F; this is well within the operating region of the transducers.

MERCURY DISPLACEMENT DILATOMETER

A dilatometric method was also used in this investigation. There were two main reasons for employing the dilatometric method in this programme:

a) The method has been considered as a measuring device for a standard test to determine frost susceptibility of concrete (36).

b) It provides measurement of total volume change as well as a check on results using other devices such as transducers or extensometers. Two dilatometers were constructed from machine steel. Figure 3 gives the construction details. The head had a machined hemispherical surface with the inlet located at the high point to facilitate removal of entrapped air. "O" ring seals provided assurance against leaks and proved quite satisfactory. Stainless steel fittings with rubber gaskets provided inlets for thermocouples used for temperature measurements. Two 5 ml. calibrated pipettes allowed measurements of volume change to be

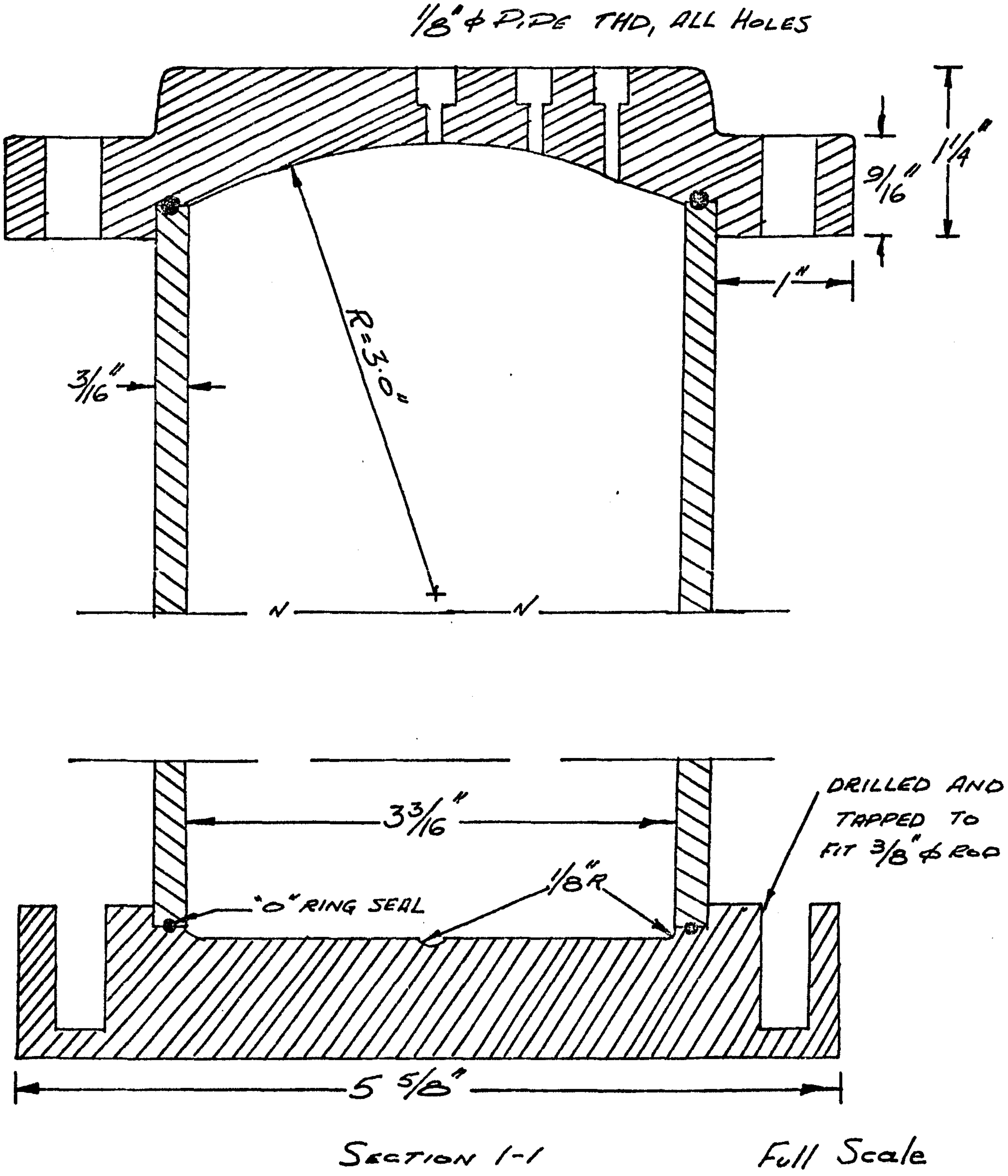


Figure 3 Section View of Dilatometer

estimated to 0.01 ml ± .01 ml. The pipettes were attached to a length of 3/16" ∅ transparent flexible hosining (tygon) which was attached to the stem of the dilatometer. The mercury in the tubing was neglected in the calculations as it was less than 1 per cent of the total volume of mercury. Mercury was used as a displacement medium because of its low specific heat, good conductivity, low coefficient of thermal expansion and high density. Mercury, because of its density, readily displaces air and is immiscible with water.

The dilatometers were calibrated using 3" ∅ x 6" long steel and aluminum specimens as reference materials. A check on the accuracy of the method was provided because using the reference material the coefficient of the chamber itself (steel) could be calculated. Agreement was good for both dilatometers. Calibration curves are included in the appendices. All test samples in this programme were also 3" ∅ x 6" long cylinders. In computing specimen volume change the temperature effects of both the mercury and the chambers were taken into account. The volume changes in porous materials such as cement paste can be extremely large (volumetric strains of 1 per cent or more have been observed). It is obvious then that an accuracy of 0.01 ± .01 is excellent considering the magnitude and range of strains measured. The dilatometric method has the disadvantage here of not being automated. Readings were taken manually by the author at specified intervals of time and temperature. The system works well; however for production use in a standard test method, dilatometry has obvious disadvantages. Dilatometers can be made automatic by using electrical resistance measurements to detect the changes in mercury level. However the transducer method appears to be the most convenient displacement measuring device for this application.

MIXING APPARATUS

Two mixers were used in this programme. A Hobart model N-50 was primarily used for paste mixes. This mixer meets the requirements of A.S.T.M. C305 and A.A.S.H.O. T-162, and is widely used for mixing small (1/6 cu. ft.) batches in cement laboratories.

A Blakeslee model B20 mixer with a 1/2 cu. ft. mixing capacity was primarily used for mixing mortar. It meets the requirements of the C.S.A.

SPECIMEN MOULDS

The 1" x 1" x 6" paste and mortar prisms.

were formed using steel gang moulds (standard A.S.T.M.) with base plates, removable partitions, and end plates. Steel spacers were used to give the required six-inch gauge length. Stainless steel reference points suitably threaded could be cast into the ends of the specimens for use in length determinations.

For casting 3" Ø x 6" cylinders, steel moulds were used.

VACUUM SATURATION EQUIPMENT

A 1/4 inch thick stainless steel cylindrical tank fitted with an "O" ring seal and 1" thick plexiglass lid provided a means for conditioning specimens to saturation. The tank was connected to a mechanical vacuum pump by a 6'-0" long x 1/4" Ø rubber vacuum hose.

FREEZING EQUIPMENT

Two freezing units each having 5 1/2 cubic foot capacity were used to perform the freezing studies. A Leeds and Northrup potentiometer calibrated to read directly in F was used to measure specimen temperature in the freezing chamber.

BOTTLES AND SYRINGES

Wide mouth bottles (250 ml) with ground glass stoppers were used for determining volume changes due to the hydration process. The under-surface of the stoppers was dome shaped and a 1 mm. hole was drilled in the centre of the stoppers. Hypodermic syringes were used to add water to the bottles through the 1 mm. holes.

BALANCE

A P1200 Mettler balance was used for gravimetric determinations. Accuracy of the balance is ± .02 gm.

A Mettler balance accurate to ± .0001 gm. was used for some non-evaporable water determinations.

FURNACE

A muffle furnace capable of maintaining 1000°C was used for non-evaporable water determinations.

MATERIALS

1) Cement: The cement used in this programme was a blended supply of Type I portland cement meeting A.S.T.M. specification. Properties of the cement are given in the appendix.

2) Sand: Two Ontario sands both meeting A.S.T.M. requirements were employed as test materials in this programme.

3) Rockflour: A linestone mineral powder of about the same fineness as Portland cement was used as an inert diluent in the paste studies.

4) Fly ash: A good quality fly ash was used as a cement replacement in an extensive series

of tests in this programme. Details of fly-ash properties are given in the appendix.

5) Water-reducers: Two water reducers were employed in this programme-calcium lignosulphonate and hydrocarboxyllic acid. These water reducers were commercially available.

6) Vinsol resin: A neutral vinsol resin air entraining agent was used in this programme. This commercially available agent was used in all mixes containing entrained air.

7) Glass inclusions: Spherical glass inclusions (5/8" Ø) were included in a series of mixes designed to study pure aggregate restraint.

8) Benzol: A series of experiments involved soaking dry cement paste in liquid benzol.

9) Mercury: Mercury was used as a displacement medium in several experiments involving dilatometry. Dilatometric data was used to compute volume change of cement paste.

CHAPTER VIII

EXPERIMENTAL STUDIES - PART I

In Part I an attempt is made to follow, quantitatively, the hydration process of cement paste, in order to provide data which can be correlated with transient strain behaviour due to selected cooling-warming regimes.

A QUANTITATIVE MODEL FOR THE CEMENT - WATER REACTION

When cement reacts with water the products that are formed occupy less volume than the reactants. Thus the cement-water system will absorb water from an external source if maintained in a saturated condition. By defining the extent or degree of hydration "α" as the ratio of non-evaporable water at any time "t" to the non-evaporable water at complete hydration, one can write the following expressions in terms of absolute volumes.

$$\text{at} \quad t=o \qquad V_o = w_o c + \frac{C}{g} \quad \text{--------}(1)$$

The volume of hydrated cement at time "t" is given by:

$$V^o_{hc} = \frac{dc}{g} + dW^o_n c - \frac{\alpha W^o_n C}{K} \quad \text{-----}(2)$$

The term $\alpha W^o_n C/$ is equal to the volume of water provided from an external source to maintain saturation or Δw.

The volume of unhydrated cement at time

"t" is given by:

$$V_{uc}^{o} = (1-\alpha)\frac{C}{g} \text{ ------------- } (3)$$

The volume of free water in the pores is then given by:

$$W_oC + \frac{C}{g} - \frac{\alpha C}{g} - \alpha W_n^o\left(1 - \frac{1}{K}\right) c - (1-\alpha)\, C/g \text{ --- } (4)$$

Dividing equation (3) by the initial volume of paste gives the volume concentration of unhydrated cement.

$$V_{uc} = \frac{1-\alpha}{gw_o + 1} \text{ ------------- } (5)$$

$$\Delta w = \frac{\alpha W_n^o}{K} \quad \text{for } (K = 3.87 \text{ and } W_n^o = .253)$$

$$\alpha = 15.3\Delta w$$

Equation (5) can be expressed in terms of $\frac{\Delta w}{w_o}$ as follows:

$$V_{uc} = \frac{\frac{1}{w_o} - 15.3\frac{\Delta w}{w_o}}{3.15 + \frac{1}{w_o}} \text{ --------- } (6)$$

Equation (6) shows that for a given water-cement ratio the volume concentration of unhydrated cement is a linear function of $\Delta w/w_o$.

The relation is expressed graphically in fig 4. Similary by dividing equation (2) by the initial volume of paste we obtain the volume concentration of hydrated cement at any time "t". This is given by the expression.

$$V_{hc} = \frac{\alpha \left[1 + gW_n^o \left(1 - \frac{1}{K}\right)\right]}{gW_o + 1} \qquad \text{------------ (7)}$$

By substituting for α, g, W_n^o and K we obtain

$$V_{hc} = \frac{24.41 \frac{\Delta w}{w_o}}{3.15 + \frac{1}{w_o}} \qquad \text{------------ (8)}$$

Equation (8) shows that for a given water-cement ratio the volume concentration of hydrated cement is a linear function of $\frac{\Delta w}{w_o}$ passing through the origin. Equation (8) is expressed graphically in figure 4.

The volume concentration of solids is the sum of the volume concentrations of hydrated cement and unhydrated cement.

$$V_s = V_{uc} + V_{hc} \qquad \text{------------ (9)}$$

$$\text{or} \quad V_s = \frac{1 + \alpha g W_n^o \left(1 - \frac{1}{K}\right)}{gW_o + 1} \qquad \text{--------- (10)}$$

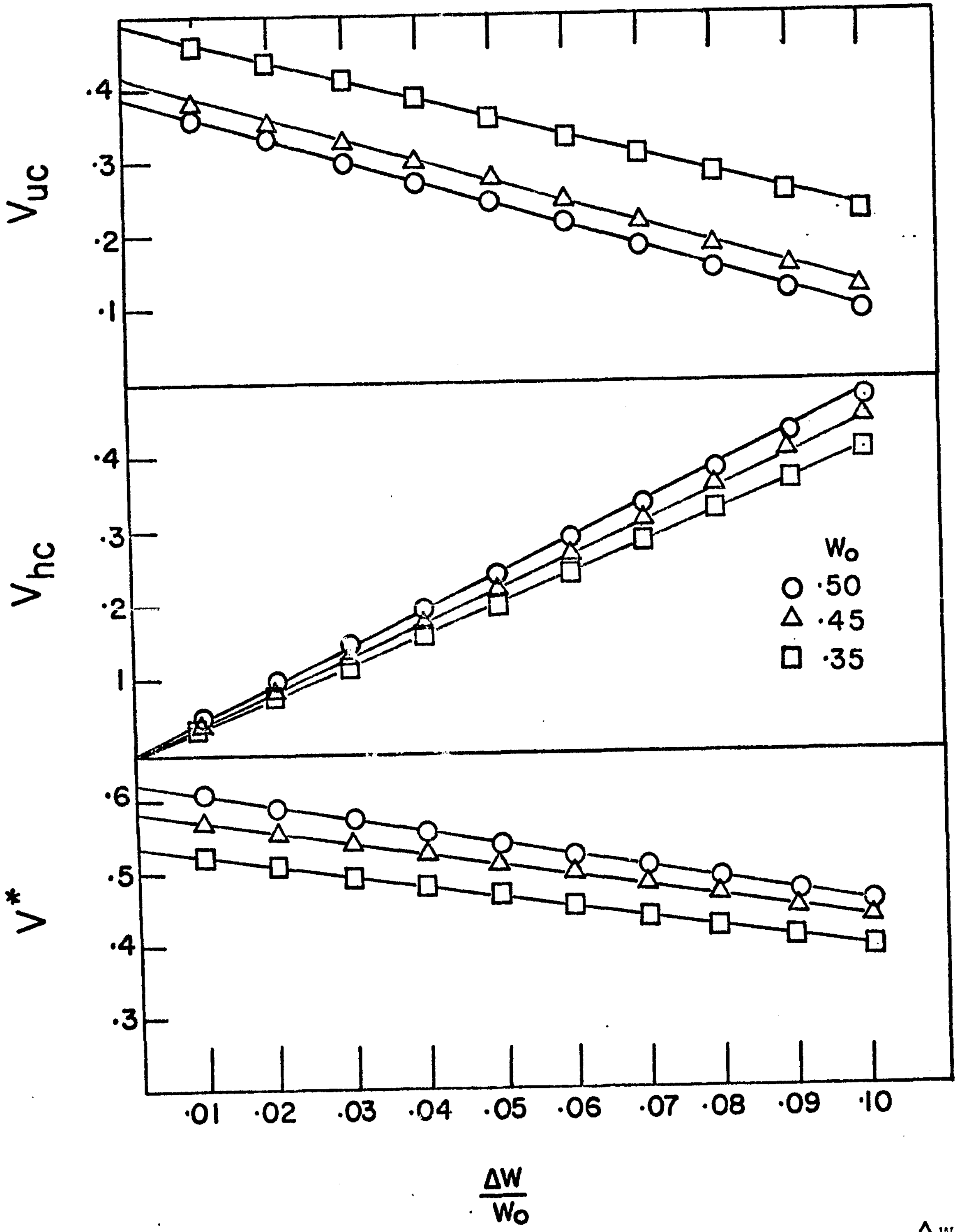


Figure 4 Volume Concentration Parameters vs $\frac{\Delta w}{w_o}$

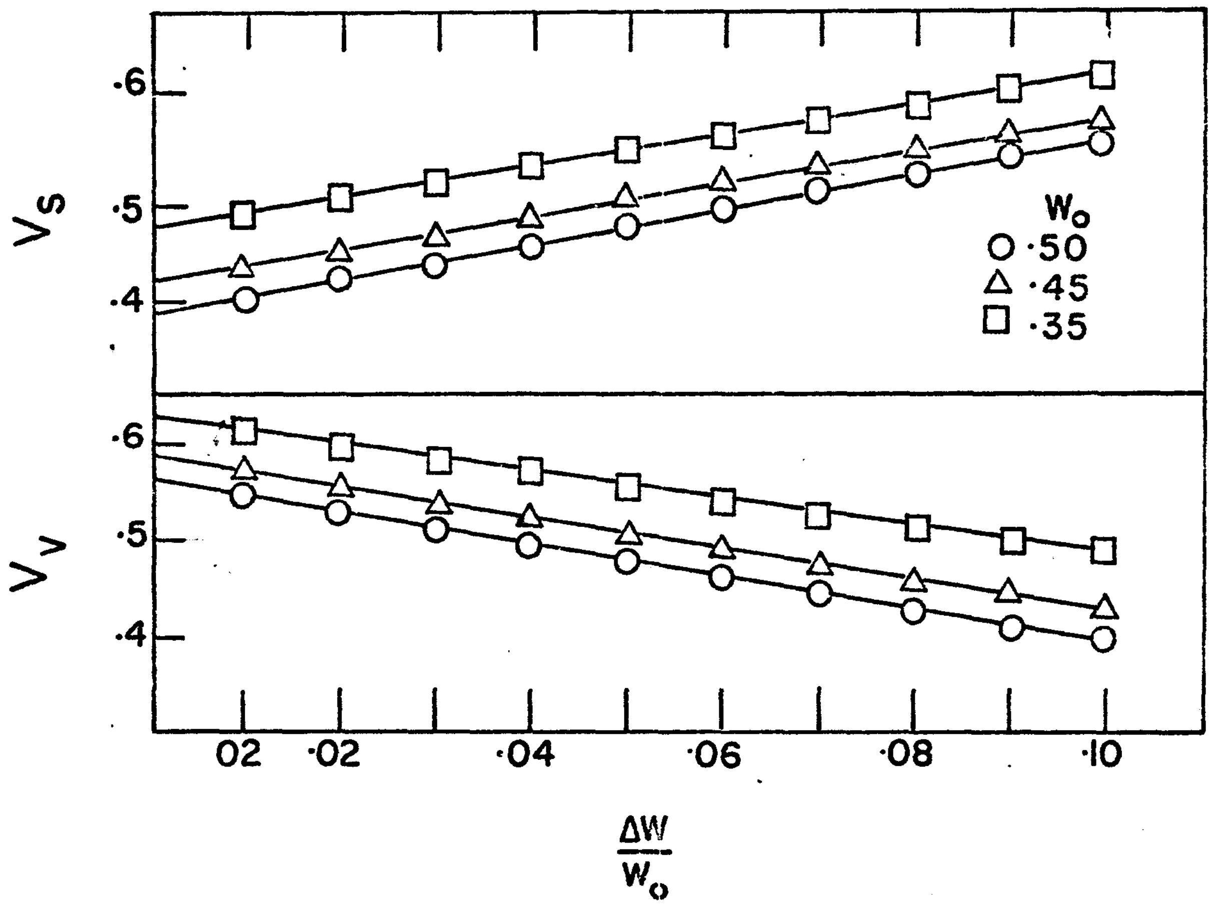


Figure 5 Volume of Solids and Volume of Voids vs $\frac{\Delta w}{w_o}$

and $$V_s = \frac{\frac{1}{w_o} + 9.11 \frac{\Delta w}{w_o}}{3.15 + \frac{1}{w_o}} \qquad \text{-----------} (11)$$

It is apparent that the volume concentration of solids is a linear function of $\frac{\Delta w}{w_o}$ for a given water-cement ratio. The volume concentration of voids is then

$$V_v = 1 - V_s \qquad \text{--------------} (12)$$

or $$V_v = \frac{3.15 - 9.11 \frac{\Delta w}{w_o}}{3.15 + \frac{1}{w_o}} \qquad \text{---------} (13)$$

Thus it is readily seen that V_{uc}, V_{hc}, V_s, and V_v are all linear functions of $\frac{\Delta w}{w_o}$ at a given water-cement ratio. Reference is made to figures 4 and 5.

Of considerable importance is the volume concentration of free water in the pores. It is this water which is responsaible for most of the non-linear thermal responses of the cement paste system. The volume concentration of free water is given by the following expression:

$$V^* = \frac{W_oC - \alpha W_n^oC + \frac{\alpha W_n^oC}{K}}{W_oC + \frac{C}{g}} \qquad \text{----------} (14)$$

Again substituting for α, W_n^o, K and g we obtain

$$V^* = \frac{1 - 2.59\frac{\Delta w}{w_o}}{1 + \frac{1}{3.15\ W_o}} \qquad \text{------------} (15)$$

V^* joins the family of concentration parameters which are functions of $\frac{\Delta w}{w_o}$.

The parameter $\frac{\Delta w}{w_o}$ takes on greater significance when we consider Powers gel space ratio. Powers (37) defined the gel space ratio as:

$$\text{Gel space ratio} = X = \frac{\text{space occupied by gel}}{\text{space available for deposition}} \qquad (16)$$

$$\text{or} \quad X = \frac{2.06\ V_c C\alpha}{V_c C\alpha + W_o C} \qquad \text{----------------} (17)$$

By substituting for V_c (.319 cc/gm) and α we obtain the following expression for the gel space ratio

$$X^o = \frac{10.40\frac{\Delta w}{w_o}}{5.05\frac{\Delta w}{w_o} + 1} \qquad \text{-------} (18)$$

$$K = 0.25$$

Mills (38) has shown that depending on the C_3A content of the cement, K (a constant of hydration)

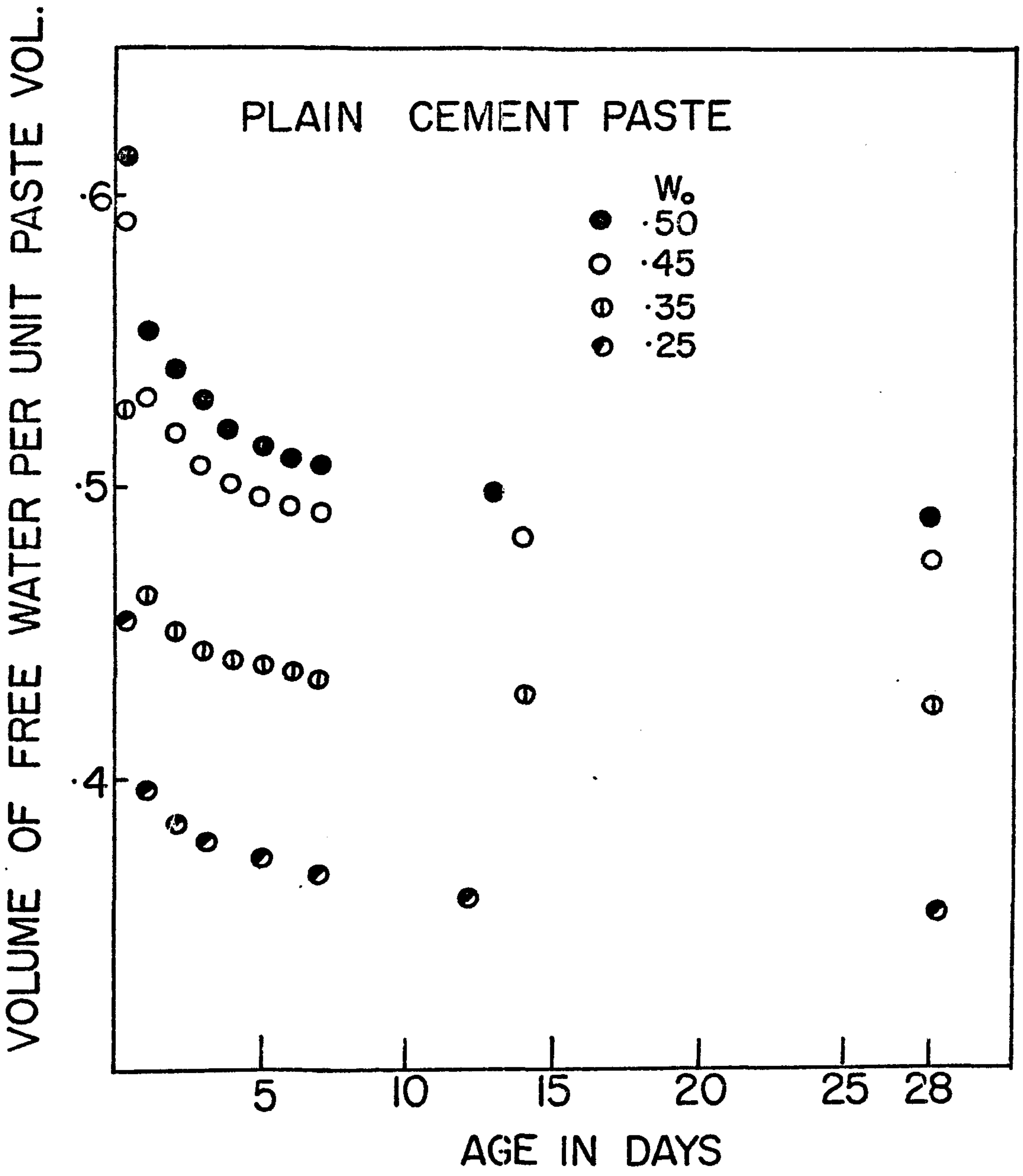


Figure 5-1 Volume of Free Water vs Age

may be slightly higher, viz K = 0.29. The C_3A content of the cement in this programme is approximately 9% - a value close to that for the cement used by Mills. Therefore we can express the gel space ratio as

$$X = \frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \qquad \text{------------} (19)$$

$$K = 0.290$$

We can see that equation(19) expresses the gel or hydrate space ratio as a function of a single independent variable, $\frac{\Delta w}{w_o}$. Thus in measuring the dimensionless parameter $\frac{\Delta w}{w_o}$ we have a means of measuring the volume concentration of hydrate product directly as well as all of the concentration variables previously described.

Examination of equation(19) reveals that the hydrate-space ratio in terms of $\frac{\Delta w}{w_o}$ can replace time as a fundamental parameter and this includes all water-cement ratios. It suggests that porosity in effect is a key parameter which governs the behaviour of the cement hydrate system. Thus porosity as expressed by the volume concentration of hydrate product appears to be a more valid basis of comparison than time per se. The volume concentration of hydrate product may be a key parameter

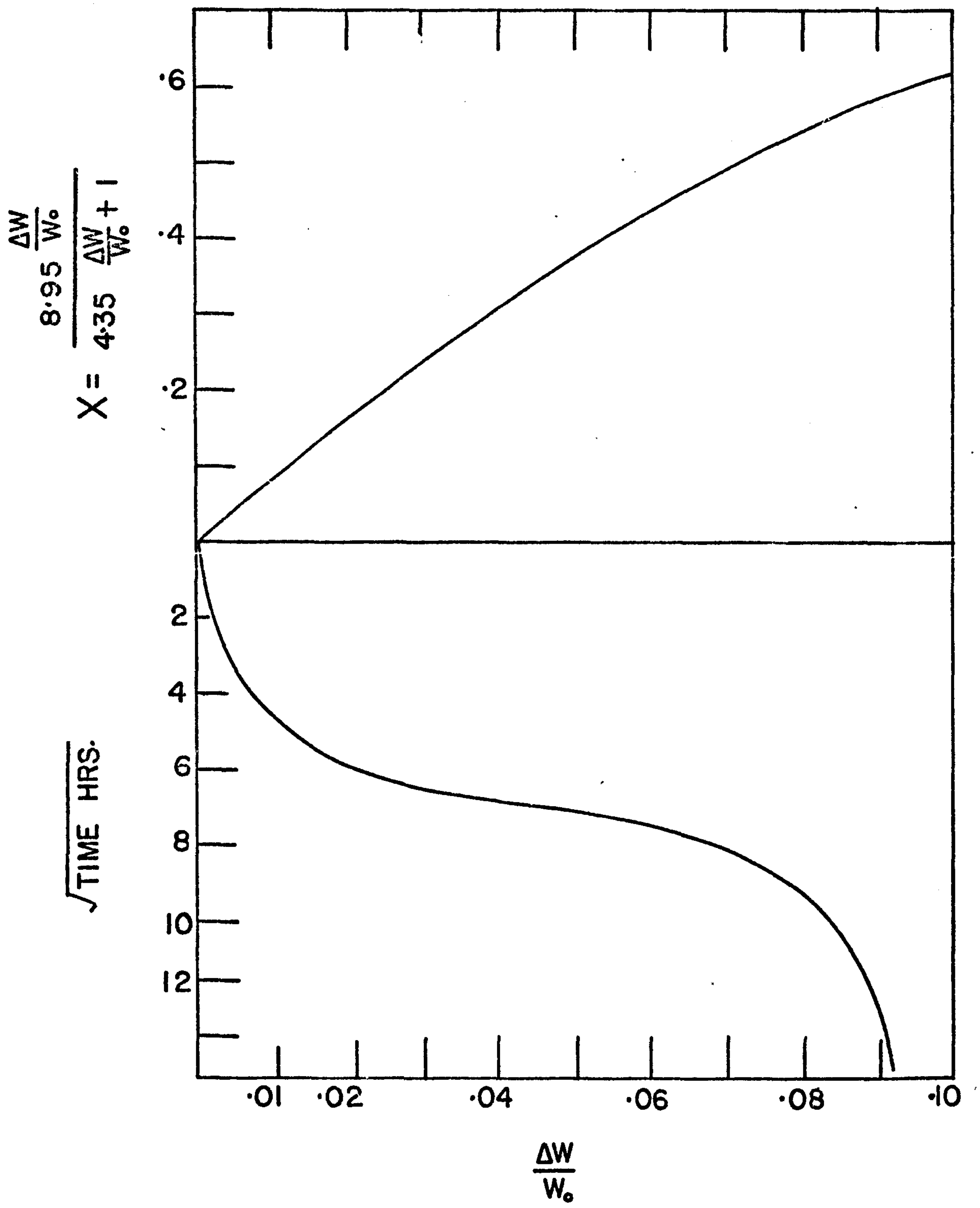


Figure 6 Hydrate Space Ratio And The Square Root of Time vs $\frac{\Delta w}{w_o}$

when comparing durability of different concretes, mortars, or pastes.

Testing the hypothesis that durability (dimensional stability due to slow natural cooling) of cement paste and mortar is dependent upon volume concentration of hydrate product and hence a function of $\frac{\Delta w}{w_o}$ is the object of the experiments to be described in the following chapters. The experiments in this chapter are designed to measure $\frac{\Delta w}{w_o}$ for cement paste mixes with and without several admixtures and to establish the interrelation of $\frac{\Delta w}{w_o}$ with compressive and tensile strength.

TEST PROCEDURES

Mixing procedure

The mixing procedure used involved mixing the paste for two minutes, no mixing for one minute and final mixing for two minutes. This routine was used as a precaution against false set. Then the mix was ready for the test procedure. Photograph 4 illustrates a typical paste in the mixing stage.

Δw Measurement

Immediately after mixing, the paste was funneled into 250 ml. wide-mouth bottles until they were approximately half filled, and subsequently weighed. The bottles were provided with ground glass stoppers having a 1 mm Ø hole drilled

P_4- Mixing of Cement Paste

in the centre. The lower surface of the stoppers was he ispherical in shape with the hole positioned at the apex. The remaining space in the bottles was filled with water. The bottles were weighed and topped up with a hypodermic syringe. As time progressed the water level in the bottle receded owing to a reduction in specific volume of the products of hydration. At specified intervals of time additions of water were made with a hypodermic syringe and recorded. Thus, by knowing the weight of cement in each bottle the weight change per unit weight of cement, $\underline{\Delta w}$, could be readily observed. The bottle experiments thus provided a means of monitoring Δw and $\frac{\Delta w}{w_o}$ with time. At least two bottle specimens for each mix in this programme were taken and readings monitored for at least 28 days.

AIR CONTENT MEASUREMENT

All paste mixes in Part I were tested for volumetric air content by a gravimetric method. A hollow copper tube (1" Ø x 6") with a copper base plate was used for the determinations. The volume of the copper tube was determined by carefully filling it with water at room temperature and smoothing the surface with a smooth glass plate. Several determinations gave a reliable value for the volume of the tube. After mixing, a sample of paste was used to fill the tube, with care being taken to ensure a level surface. The tube and contents were weighed, to determine a unit weight for the sample. Knowing the constituent specific gravities provides an absolute unit weight (ie. no air) and allows calculation of the air content.

Compressive and tensile strength

From each mix 2 inch cubes were cast for compressive strength determinations at specified time intervals. Also standard briquette tensile specimens were cast for tensile strength determinations. Thus it was possible to establish an experimental relationshop between $\frac{\Delta w}{w_o}$ and the strength parameter.

Admixtures

Several admixtures were used in this experimental programme. Specific details are given in Chapter VIII and the appendices. Bottle tests and strength tests were performed on pastes containing the following admixtures: water reducers (lignin and adipic acid types); neutralized vinsol resin; fly ash; and limestone mineral powder. It was intended to observe the effects of these admixtures on strength porosity relations. Both the lignin and adipic acid type water-reducers used in this programme did not entrain any significant amount of air.

COMPRESSIVE STRENGTH AND THE HYDRATE-SPACE RATIO

Powers (39) demonstrated that crushing strength of two inch cubes (for cement 15365) was a unique function of the gel-space ratio as expressed in equation (17). He found that the crushing strength conformed to the following relation:

$$f_c = 17{,}000\ X^{2.6} \qquad \text{-------}\ (20)$$

Equation (19) expresses hydrate-space ratio in terms of $\frac{\Delta w}{w_o}$. Hence plots of compressive strength vs. $\frac{\Delta w}{w_o}$ should conform to a similar relationship.

CHOICE OF MIXES

Mixes were designed to cover a broad range of water-cement ratios and to include a variety of admixtures. Tables I and II give a detailed description of the mixes tested in Part I of this work.

SERIES	MIX DESIGNATION	W/C OR W/C+F	ADMIXTURE	AIR
I	3	.35	NIL	0.80
I	2	.40	NIL	0.88
I	4	.45	NIL	0.88
I	5	.50	NIL	0.61
I	6-26	.35	LIGNIN	0.0
I	10-30	.40	LIGNIN	0.0
I	14-34	.45	LIGNIN	0.15
I	18-38	.50	LIGNIN	0.0
I	7-27	.35	ADIPIC ACID	0.69
I	11-31	.40	ADIPIC ACID	0.0
I	15-35	.45	ADIPIC ACID	1.79
I	19-39	.50	ADIPIC ACID	0.0
II	8-28	.35	VINSOL RESIN	9.99
II	12-32	.40	VINSOL RESIN	17.45
II	16-36	.45	VINSOL RESIN	18.22
II	20-40	.50	VINSOL RESIN	21.50
II	9-29	.35	VINSOL RESIN	3.65
II	13-33	.40	VINSOL RESIN	13.05
II	17-37	.45	VINSOL RESIN	8.89
II	21-41	.50	VINSOL RESIN	10.0

TABLE I Mix details for pastes with and without water reducing agents.

SERIES	MIX DESIGNATION	W/C OR W/C+F	ADMIXTURE	AIR
III	1-19	.50	RF	1.2
III	2-20	.50	RF-DE AIR	0.0
III	3-21	.50	RF-VR	2.1
III	4-22	.75	RF	0.0
III	5-23	.75	RF-DE AIR	0.0
III	6-24	.75	RF-VR	0.0
III	7-25	1.00	RF	1.00
III	8-26	1.00	RF-VR	9.32
III	9-27	1.00	RF-DE AIR	2.00
IV	10-28	.30	15% ASH	0.0
IV	11-29	.30	30% ASH	0.0
IV	12-30	.30	45% ASH	0.0
IV	13-31	.40	15% ASH	0.0
IV	14-32	.40	30% ASH	0.0
IV	15-33	.40	45% ASH	0.0
IV	16-34	.50	15% ASH	0.0
IV	17-35	.50	30% ASH	0.0
IV	18-36	.50	45% ASH	0.0

TABLE II Mix details for pastes containing rock flour and fly ash.

TEST RESULTS

The parameters Δw and $\frac{\Delta w}{w_o}$ give an "S" shaped curve when plotted against the square root of time. The point of inflection corresponds approximately to the time of final set. After final set there is a steep rise in Δw and a subsequent tapering off. An idealized curve for $\frac{\Delta w}{w_o}$ vs. the square root of time is shown in figure 6. A typical set of experimental results for Δw measurements is shown in figures 7-12. In the same figures the corresponding compressive strength-time plots are given.

Figure 13 illustrates experimental results for compressive strength vs. $\frac{\Delta w}{w_o}$. For all mixes the relation is coincident with the exception of the air entrained mixes. Little or no hydrate deposits in entrained air voids and thus a decrease in strength is expected as the effective porosity is increased. However it is noteworthy that water reducers, fly ash, and rock flour did not alter the relation between strength and porosity. Thus for the pastes and admixtures used in this programme strength can be expressed as follows:

$$f_c = 17{,}000 \left[\frac{8.95 \dfrac{\Delta w}{w_o}}{4.35 \dfrac{\Delta w}{w_o} + 1} \right]^{2.6} \quad \text{------} \; (21)$$

On the basis of these results Beaudoin and MacInnis (40) have pointed out that the volume concentration of hydrate substance and hence porosity appears to be the most important strength parameter <u>regardless</u> of the presence of admixtures.

DISCUSSION OF TEST RESULTS

It is seen that $\frac{\Delta w}{w_o}$ is easily measured and provides a convenient means of measuring the progress of hydration. Powers (41) has used loss on ignition at 1000°C to measure non evaporable water. The bottle method compares well with the loss on ignition method for degree of hydration determinations. However both methods have minor disadvantages. The loss on ignition method heats the sample and increases the extent of hydration somewhat before a gravimetric determination is made. With the bottle method there is a small time lapse between initial hydration and the first reading.

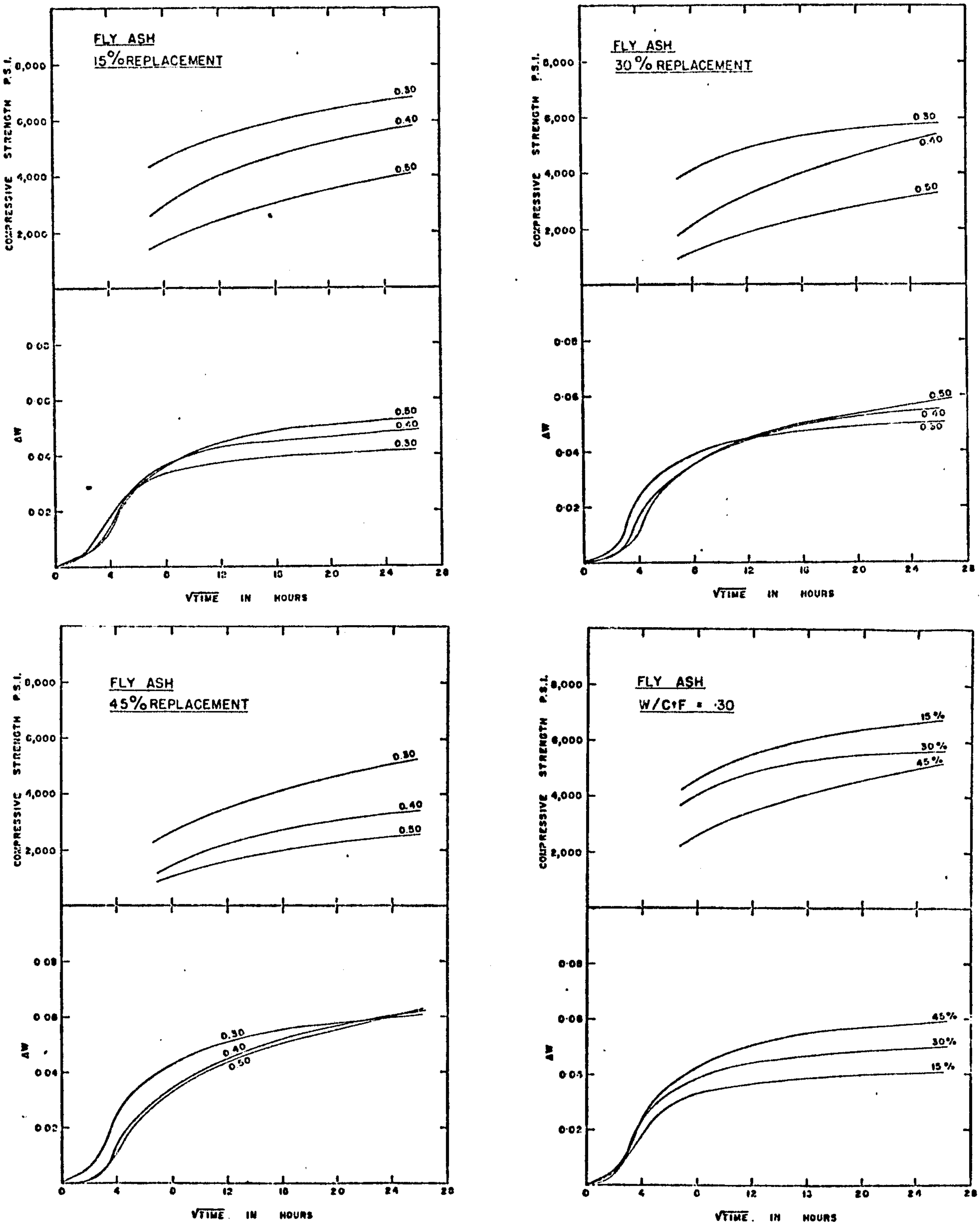


Figure 7 Compressive Strength And Δw vs The Square Root of Time

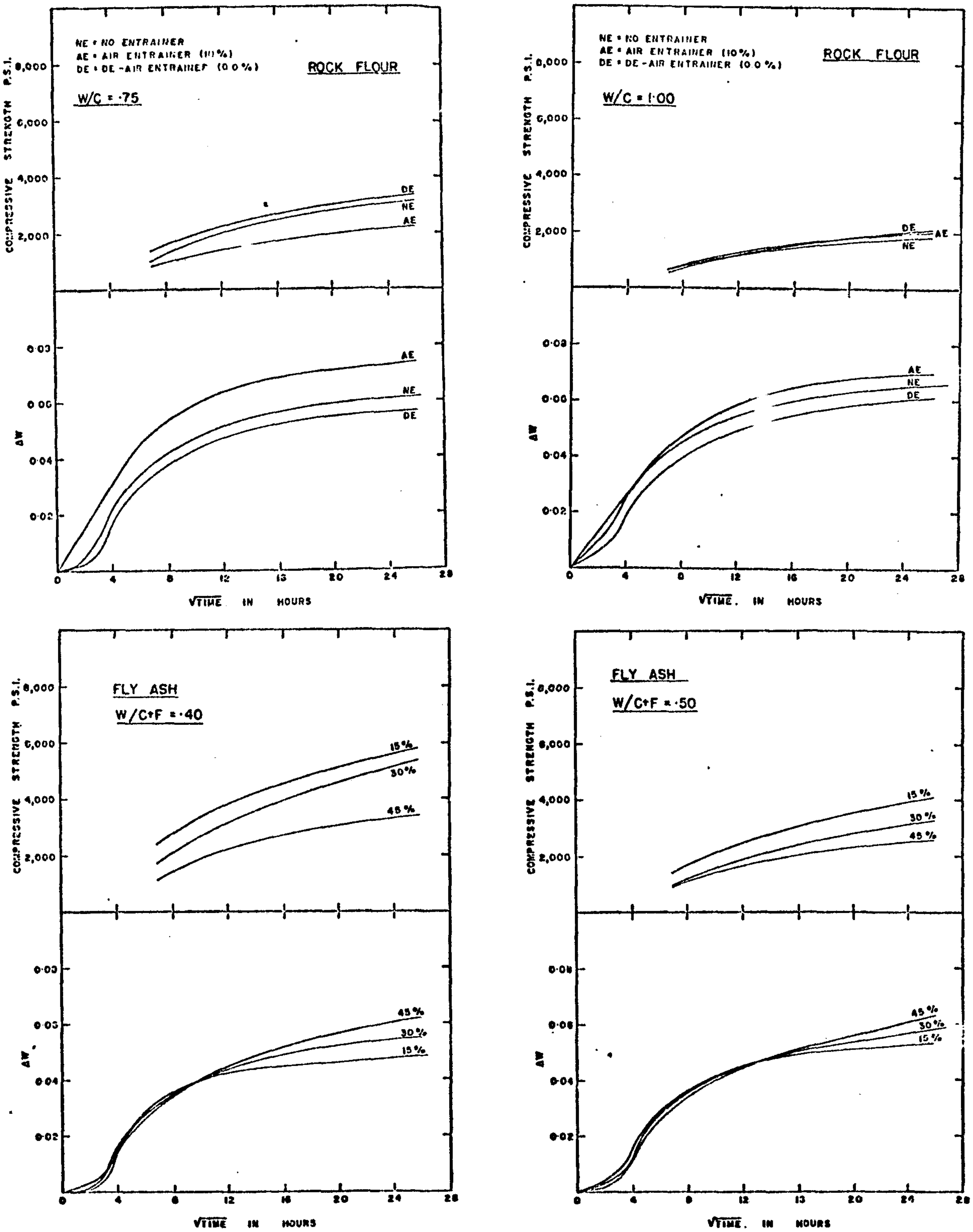


Figure 8 Compressive Strength And Δ w vs The Square Root of Time

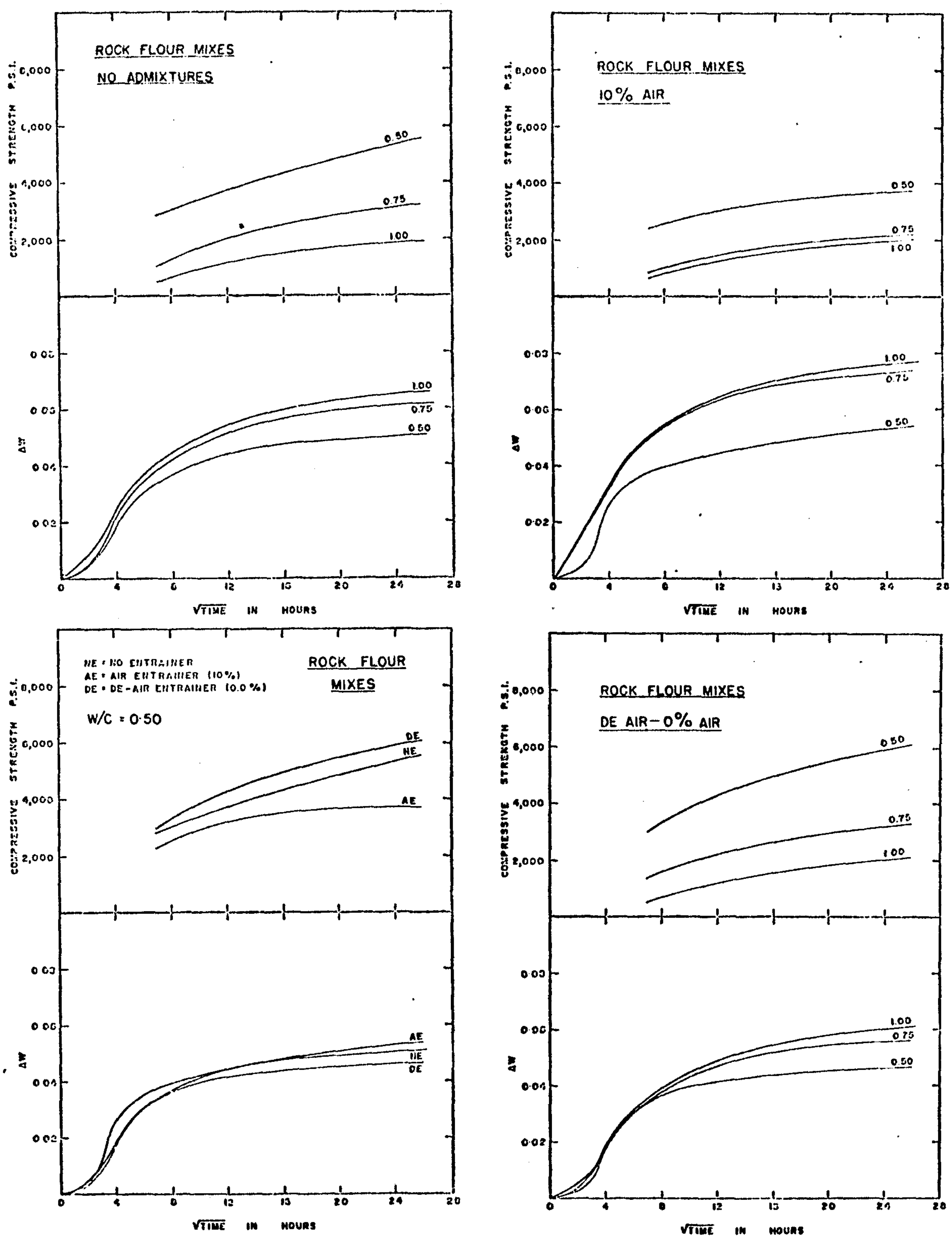


Figure 9 Compressive Strength And Δw vs The Square Root of Time

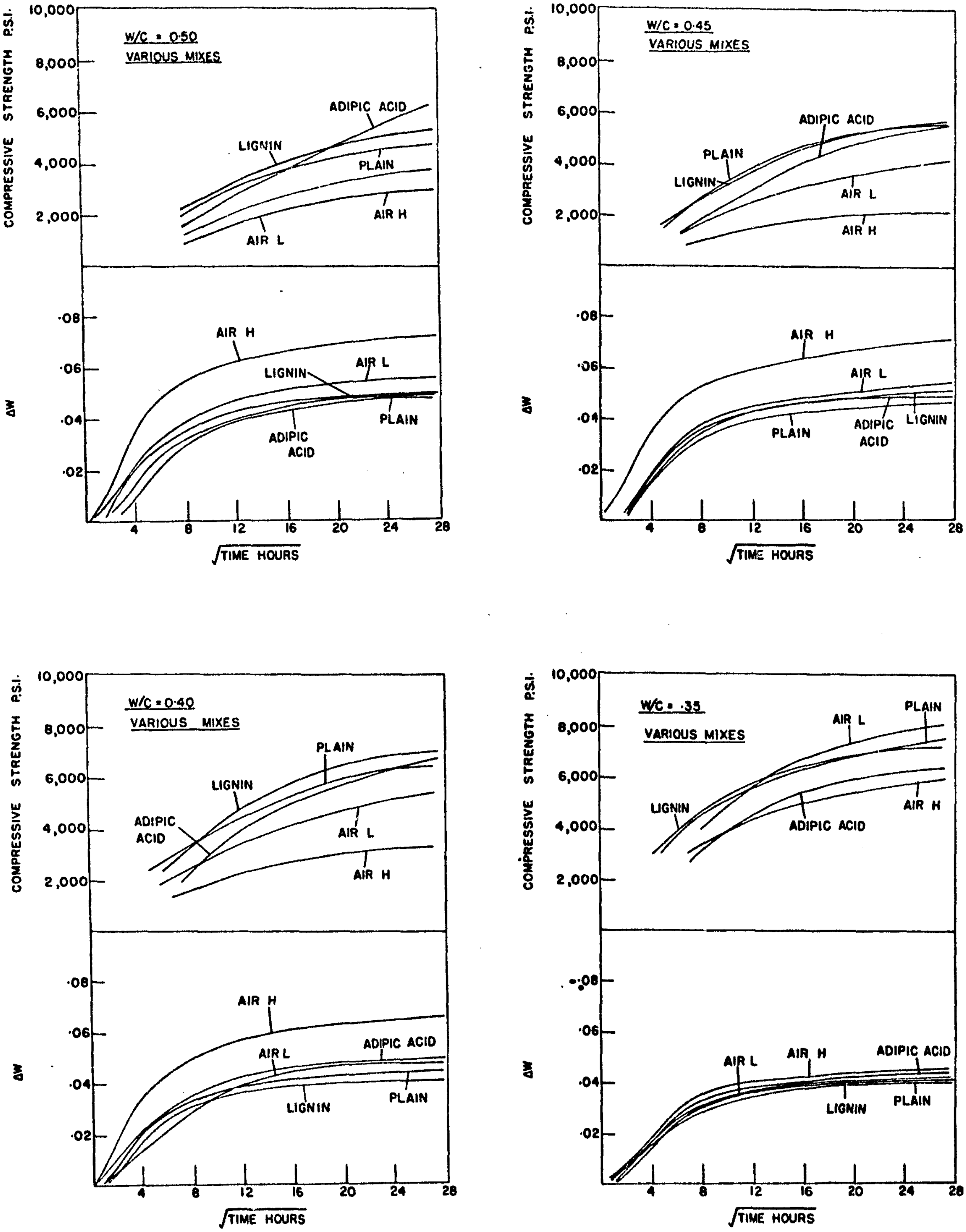


Figure 10 Compressive Strength And Δw vs The Square Root of Time

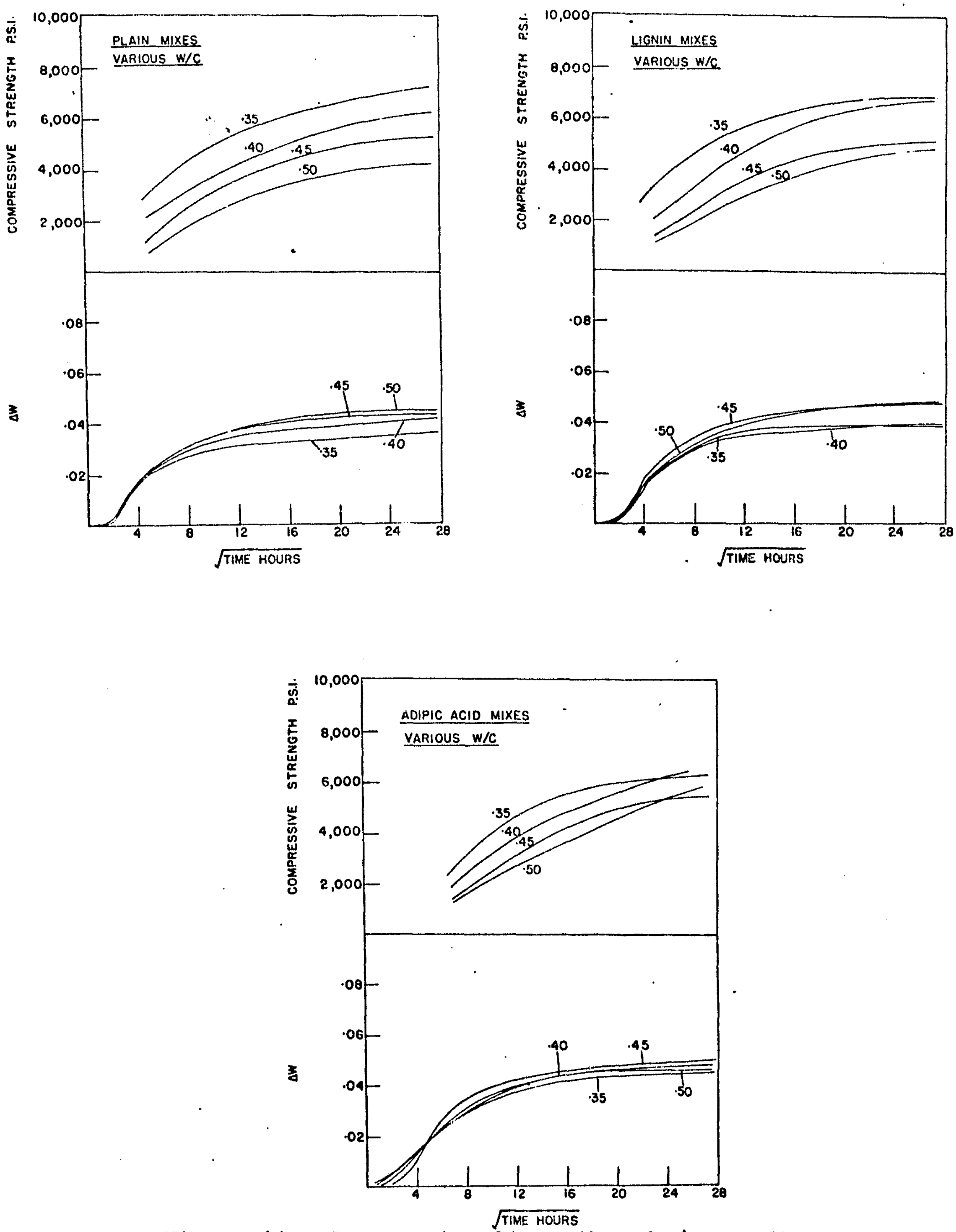


Figure 11 Compressive Strength And Δw vs The Square Root of Time

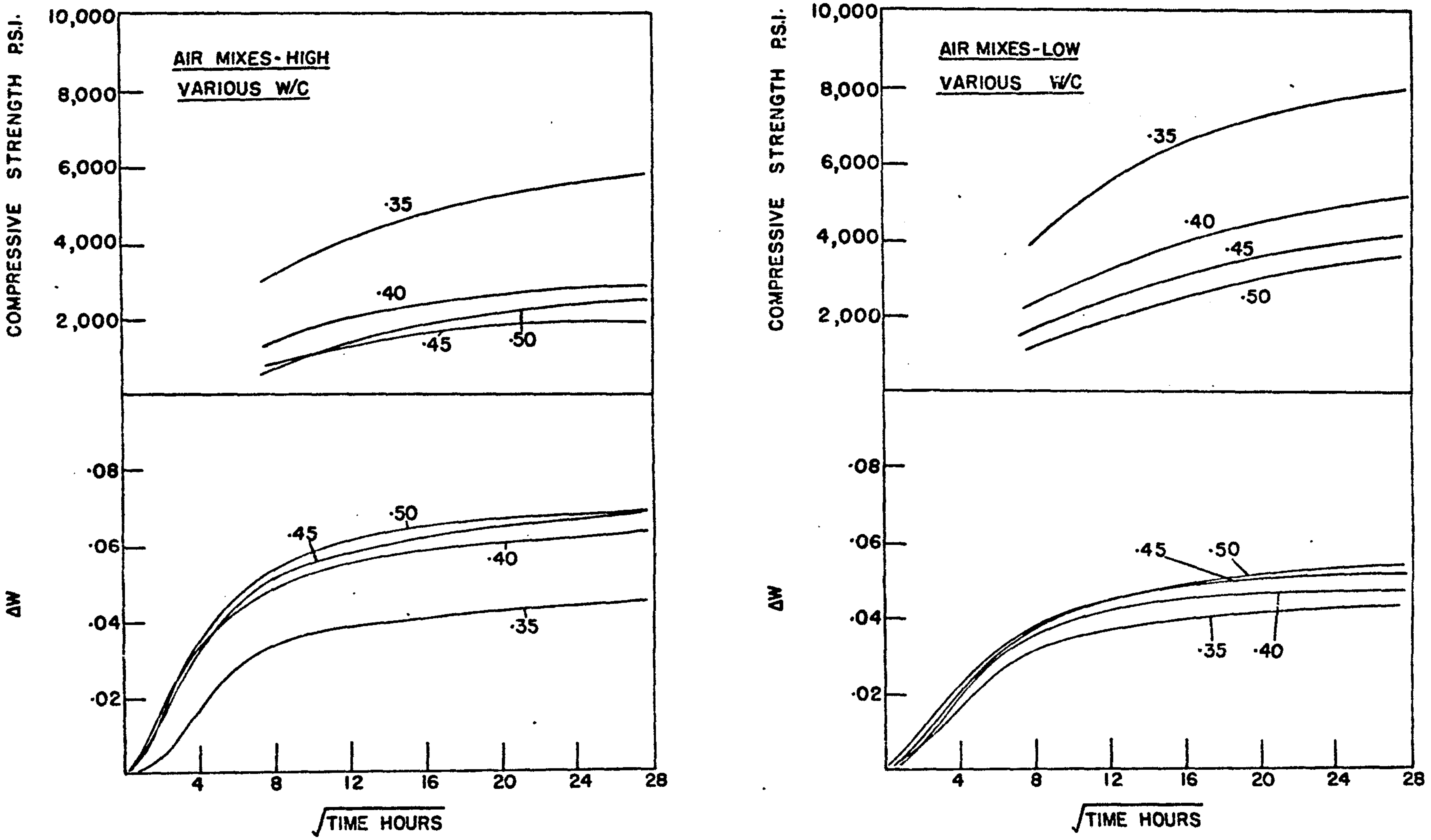


Figure 12 Compressive Strength And Δw vs The Square Root of Time

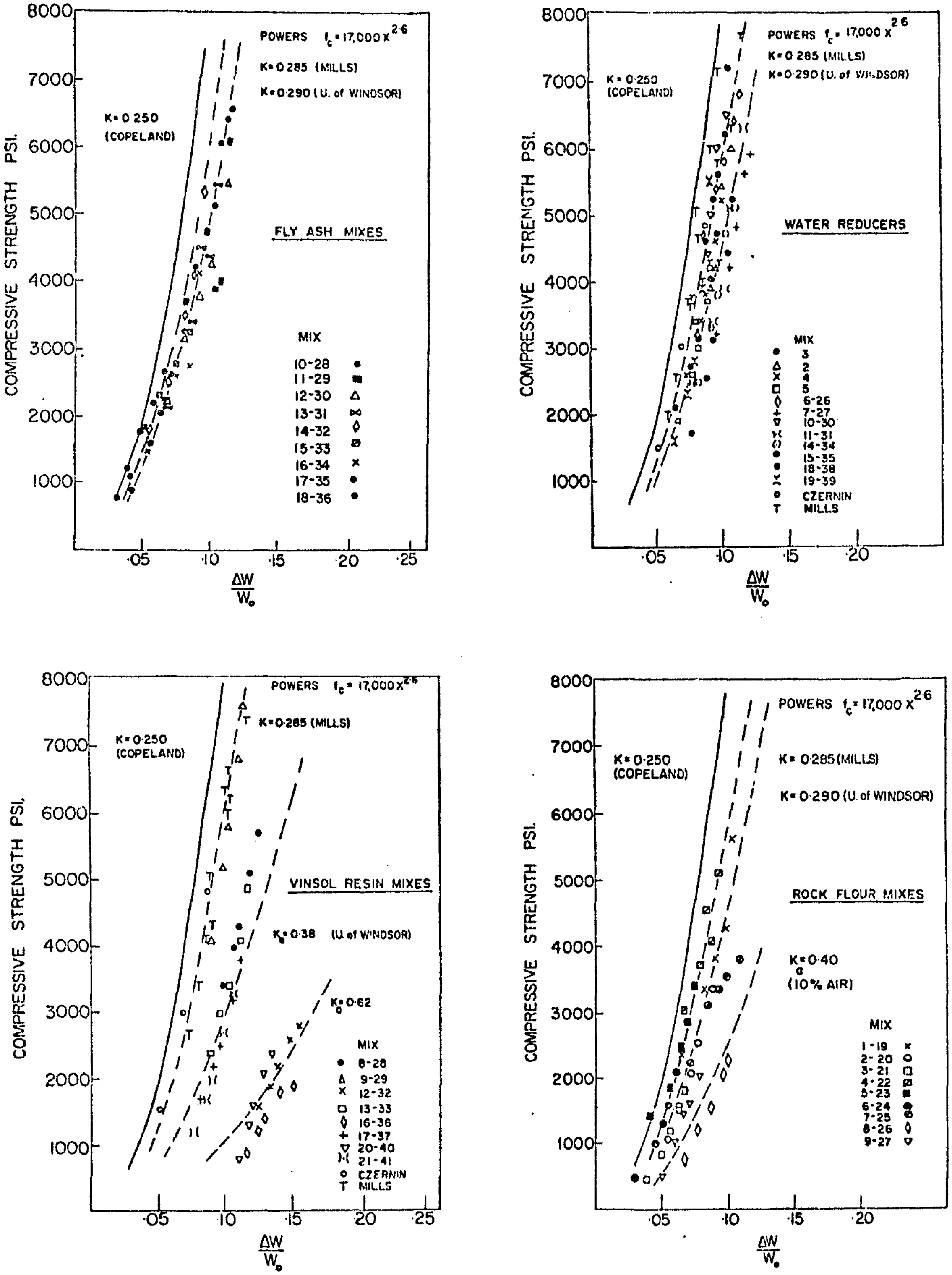


Figure 13 Compressive Strength vs $\frac{\Delta w}{w_o}$

CONCLUSIONS

1) Porosity appears to be the most important parameter influencing the strength properties of cement paste with and without admixtures.

2) Strength of cement paste with and without admixtures is an unique function of the independent variable $\frac{\Delta w}{w_o}$.

3) When comparing the effect of admixtures on such properties as creep and shrinkage it would appear that the volume concentration of hydrate substance as expressed by the hydrate space ratio is a better parameter than time per se.

4) The data in Part I would seem to support the premise that the origin of strength in cement paste is largely due to physical attraction of primary particles ie. Van der Waal's forces.

5) It would appear that one of the fundamental parameters influencing the durability of cement paste may be $\frac{\Delta w}{w_o}$ as the relation between frost resistance and strength has been the subject of much controversy.

CHAPTER IX

EXPERIMENTAL STUDIES - PART II

INTRODUCTION

Part II deals with volume changes of hardened portland cement paste due to selected slow cooling and warming regimes. From the volume change data obtained it is hoped to obtain a further understanding of dimensional changes associated with temperature changes for the cement paste system and to obtain a more comprehensive knowledge of slow cooling as a test method.

A. PLAIN CEMENT PASTE

A study was made of the time-dependent strain temperature behaviour of cement paste which has been continuously moist cured. An analysis of the measured transient strains as well as the mode of the hysteresis loops obtained provided some insight into the nature of frost resistance. Two specific parameters-dilation and residual volume change-as measured from the strain-temperature hysteresis loops were useful in seeking relationships with the hydration parameters ($\frac{\Delta w}{w_o}$, strength etc.) evaluated in Part I.

TEST PROCEDURES

Mixing: The mixing procedure, involved mixing two minutes, one minute delay, and further mixing for two minutes as described in Part I.

Air Content: Air content was measured gravimetrically as described in Part I.

Test Specimens: Mixes were cast in the form of 1" x 1" x 6" prisms, 1" x 6" x 6" slabs or 3" Ø x 6" cylinders.

Admixtures: Small additions of rock flour were added to some of the 3" Ø x 6" cylinder specimens as an added precaution against excess bleeding.

Curing Regime: Specimens in this series were continuously moist cured until time of test, unless otherwise stated.

Range of Water Cement Ratios: The plain paste series included mixes with the following water-cement ratios-0.25, 0.35, 0.45, 0.50 and 1.00. Rock flour was added to mixes with water-cement ratio of 1.00 at a 1.5:1 ratio, by weight of cement. Some of the 3" Ø x 6" cylinders for water-cement of 0.50 contained rock flour at a 0.25:1 ratio, by weight of cement.

FREEZING TEST PROCEDURE

At the time of test the 1" x 1" x 6" prisms were taken from the curing tank, surface dried with a hand towel, and wrapped in polyethylene. Rubber bands were used to secure the polyethylene. The ends were separately wrapped to facilitate measurements. The same procedure was used to prepare the

1" x 6" x 6" slabs.

The 3" Ø x 6" cylinders were surface dried with a hand towel and were surrounded with mercury in the test condition.

Freezing Regime

Two cooling-warming cycles were selected for this programme. The primary cycle (see figure 14) simulates a natural freezing and thawing cycle (ie. $\frac{dT}{dt} = 5^{\circ}$F/hr.) and is used for the major part of the test programme. The secondary cycle (see figure 14) represents a much slower freezing and thawing cycle and forms a minor part of the test programme. These cycles were reproduced to an accuracy of ± 1°F/hr., and represent the temperature cycle of the specimen itself. Temperature gradients existing between the centre of the specimen and the surface are negligible within the bounds of required experimental accuracy surface to centre gradients range from 0.2°F for the prisms to 1°F for the cylinders. The centre temperature was used as the reference temperature throughout the programme. It is pointed out that temperature gradients exist in all concrete structures exposed to a freezing environment. The standard A.S.T.M. specimens have a cross sectional area greater than 9 square inches; the gradients encountered then far exceed the gradient in a 1 square inch cross section employed in

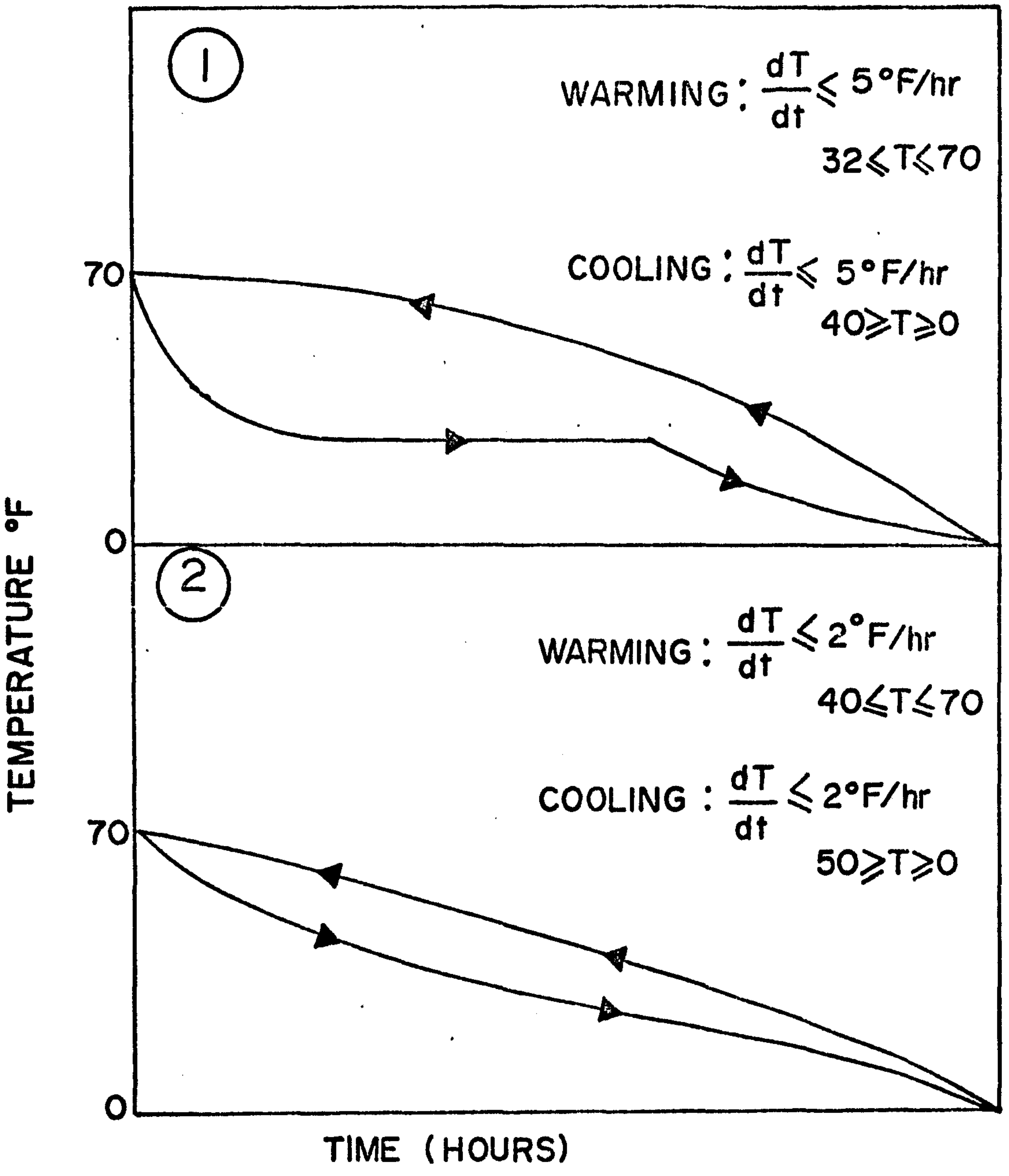


Figure 14 Selected Slow Cooling-Warming Regimes

most of this programme.

Instrumentation

As the temperature is cycled according to the selected regime the dimensional changes are continuously monitored by the Honeywell Recorder described in Chapter VII. Dilatometric output is visually recorded by the observor throughout the cycle.

TEST RESULTS - PLAIN PASTE

Test Results for plain paste prisms and cylinders will be discussed here. The transient strain behaviour of the paste due to the selected cooling-warming regime (5°F/hr.) was observed at various intervals throughout the hydration process. Plots of strain vs. temperature traced the dimensional stability of the system with time. Figures 15 to 19 illustrate the time dependence of the strain temperature behaviour.for the cement paste system.

Collapse of strain-temperature hysteresis

Figures 15 to 19 show a definite collapse of hysteresis with time. Furthermore the residual volume changes observed demonstrate a change in sign from positive at early ages to negative at subsequent ages. These two phenomena will be discussed in more detail at a later stage.

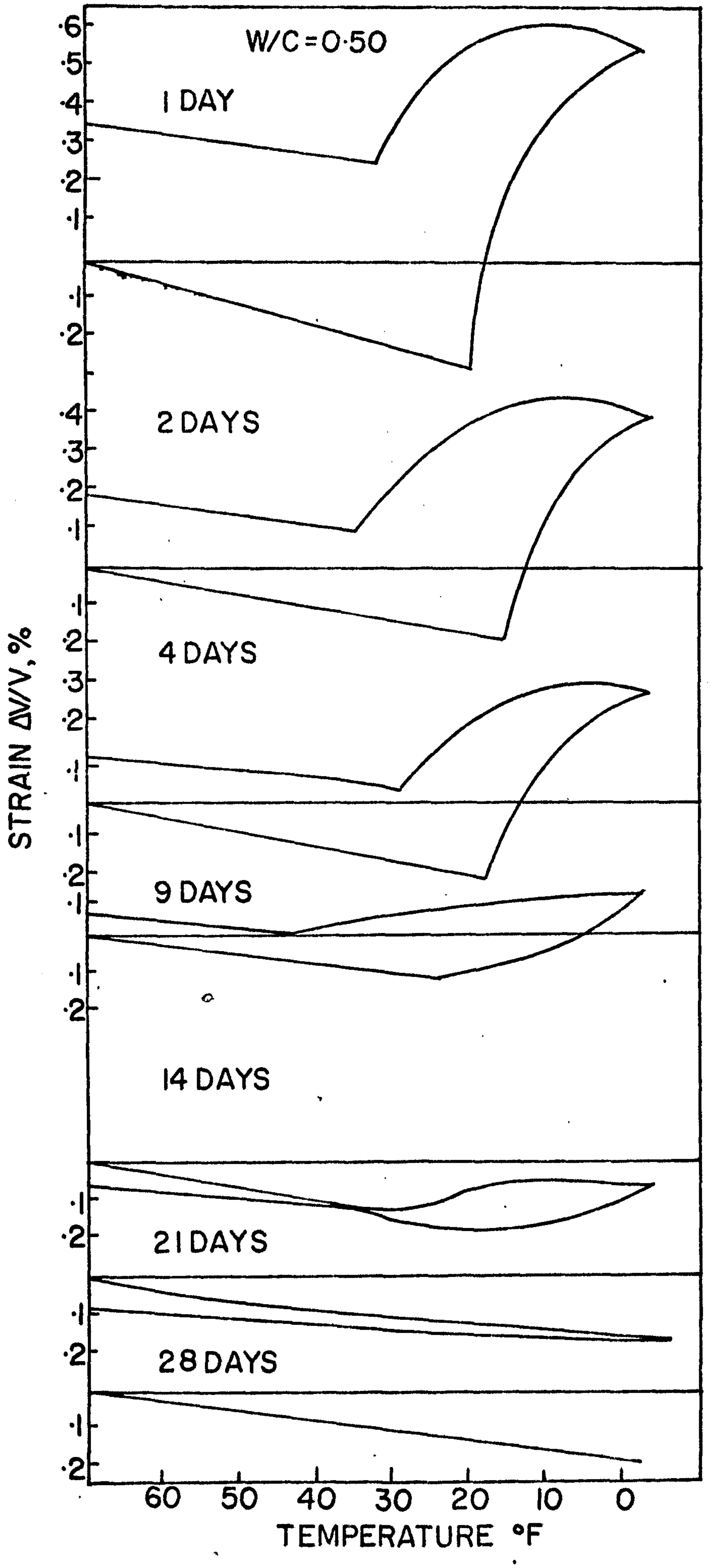


Figure 15 Strain-Temperature Plot At Various Ages; w/c=0.50

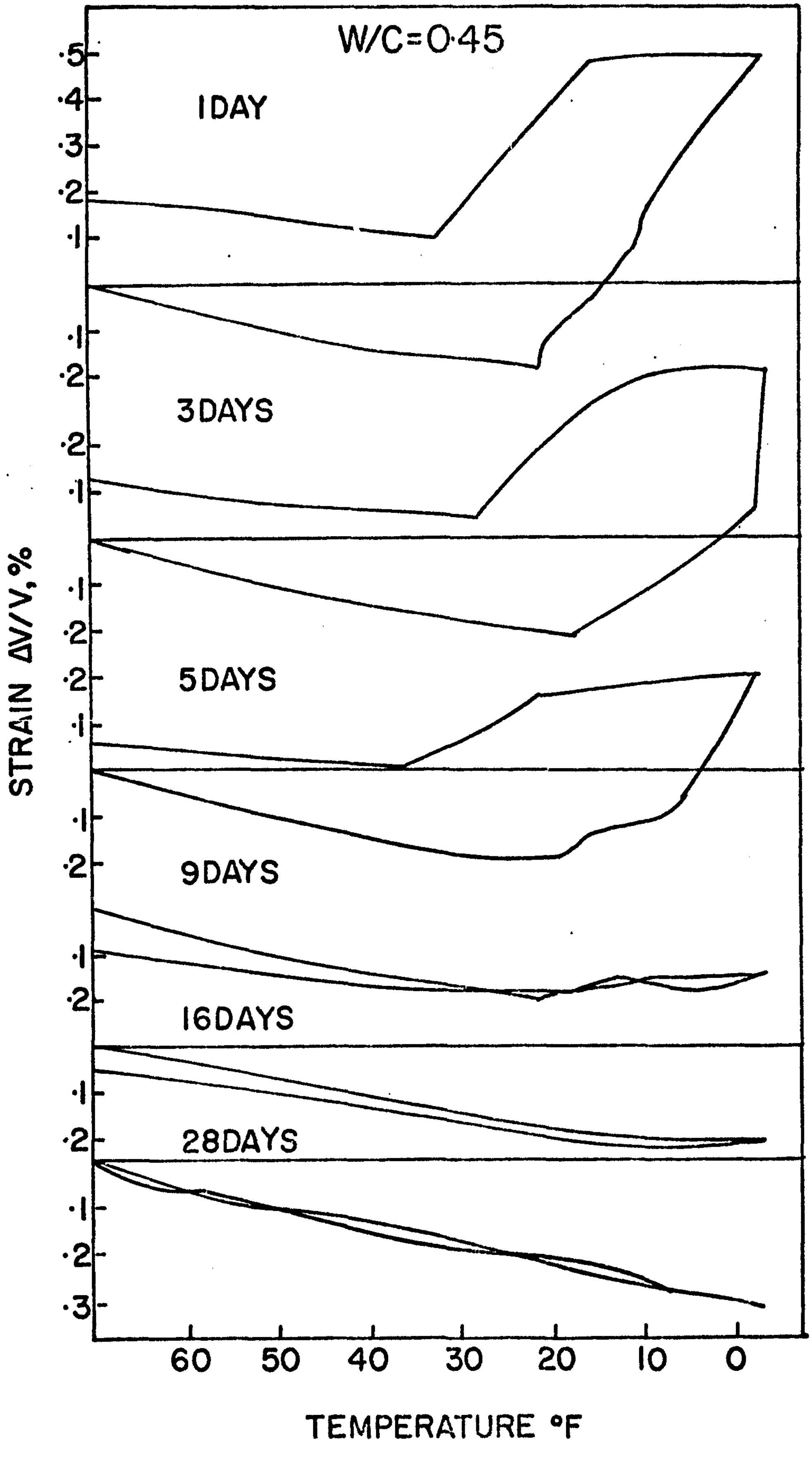


Figure 16 Strain-Temperature Plot At Various Ages; w/c=0.45

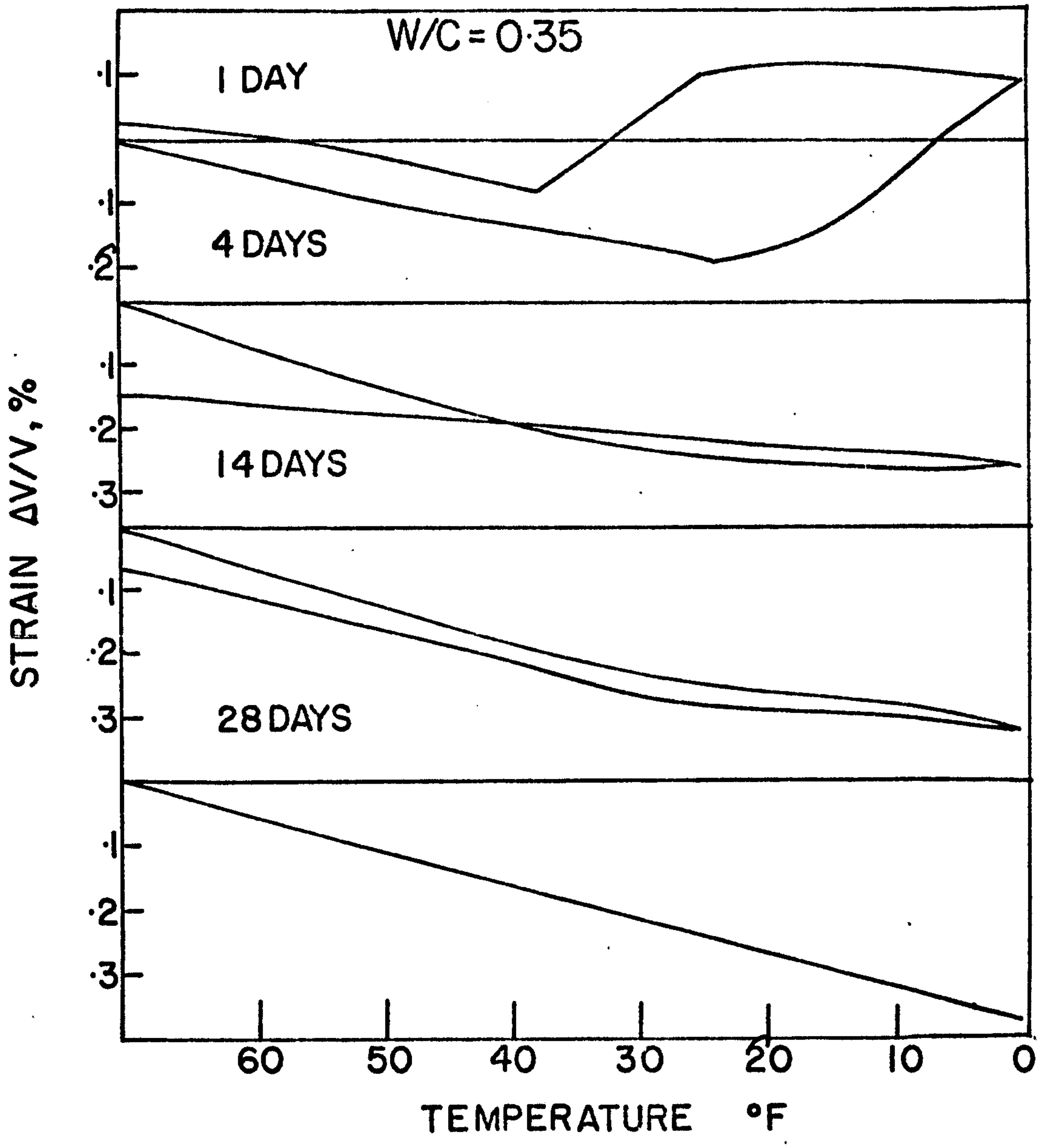


Figure 17 Strain-Temperature Plot At Various Ages; w/c=.35

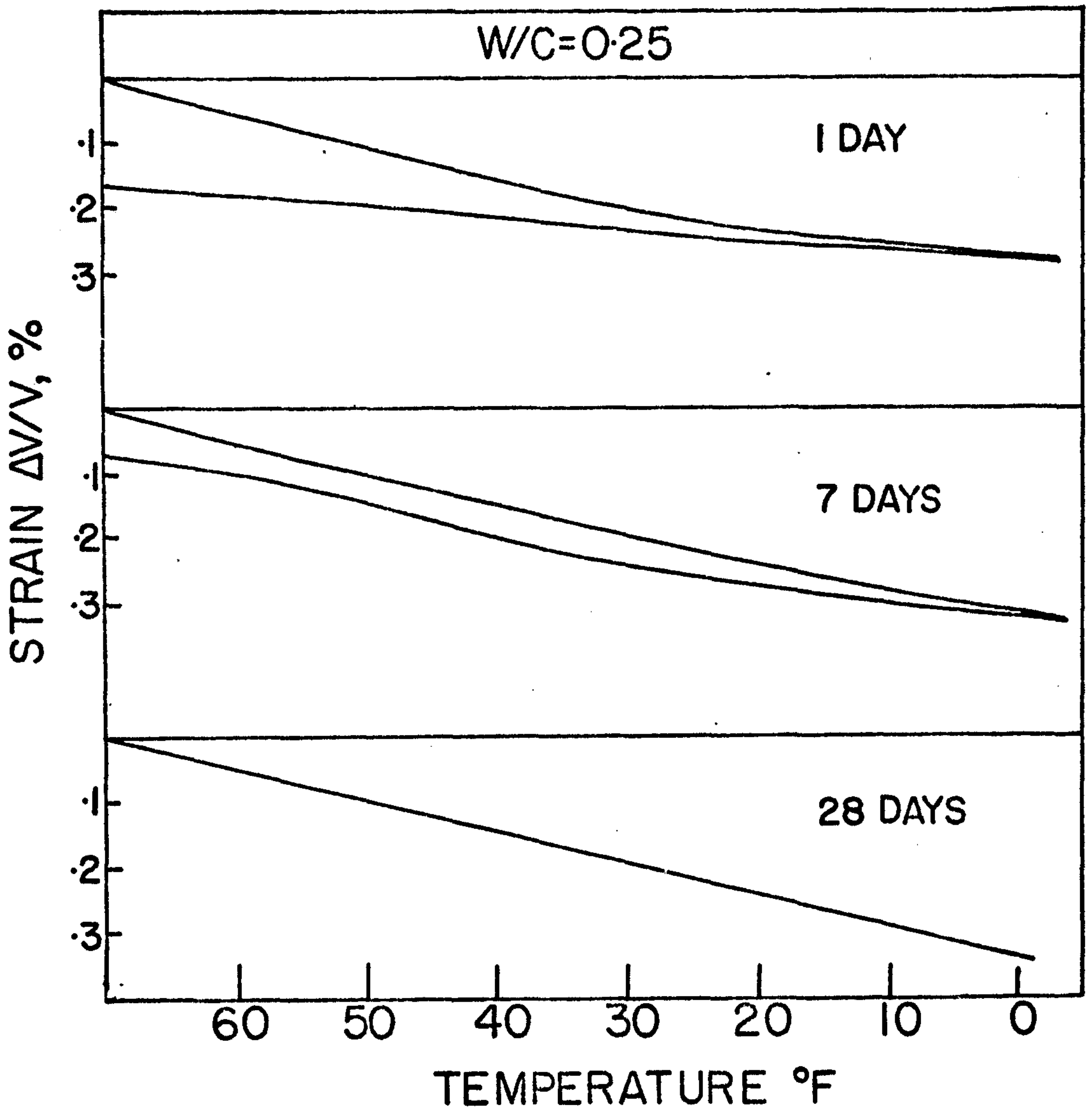


Figure 18 Strain-Temperature Plot At Various Ages; w/c=.25

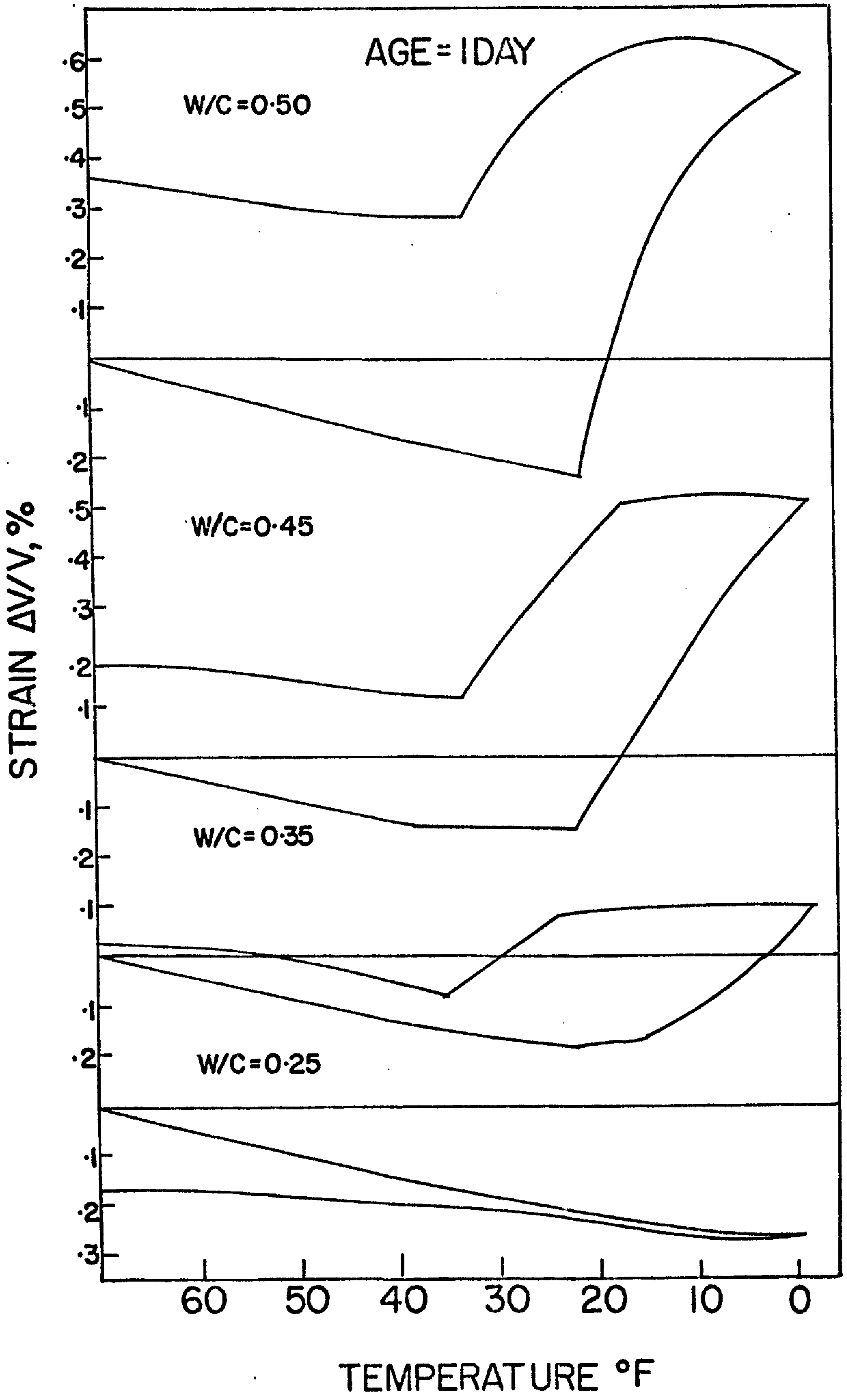


Figure 19 Strain-Temperature Plot At One Day; Various Water-cement Ratios

Dilation and residual volume change versus time

Two principle parameters measured from the hysteresis loops are herein termed dilation and residual volume change. A typical strain-temperature hysteresis loop shown in figure 20 serves to illustrate the definition of these two parameters.

Dilation is volumetric strain in excess of that strain due to normal thermal contraction alone. In most of the experiments in this programme dilation is a maximum at the lowest temperature (ie. at 0°F). There are exceptions. The maximum dilation (referred to as D_o) is the dilation parameter used in subsequent mathematical formulations.

Residual volume change (ΔV_R) is that volume change which is present when the specimen is returned to the initial test condition. It is a quantitative evaluation of the irreversability of the strain temperature behaviour of cement paste. Indeed, the presence of hysteresis itself, manifests the irreversible nature of volume change in the cement-paste system.

Although it will be shown later that time per se is not the most meaningful parameter in making volume change comparisons, dilation and

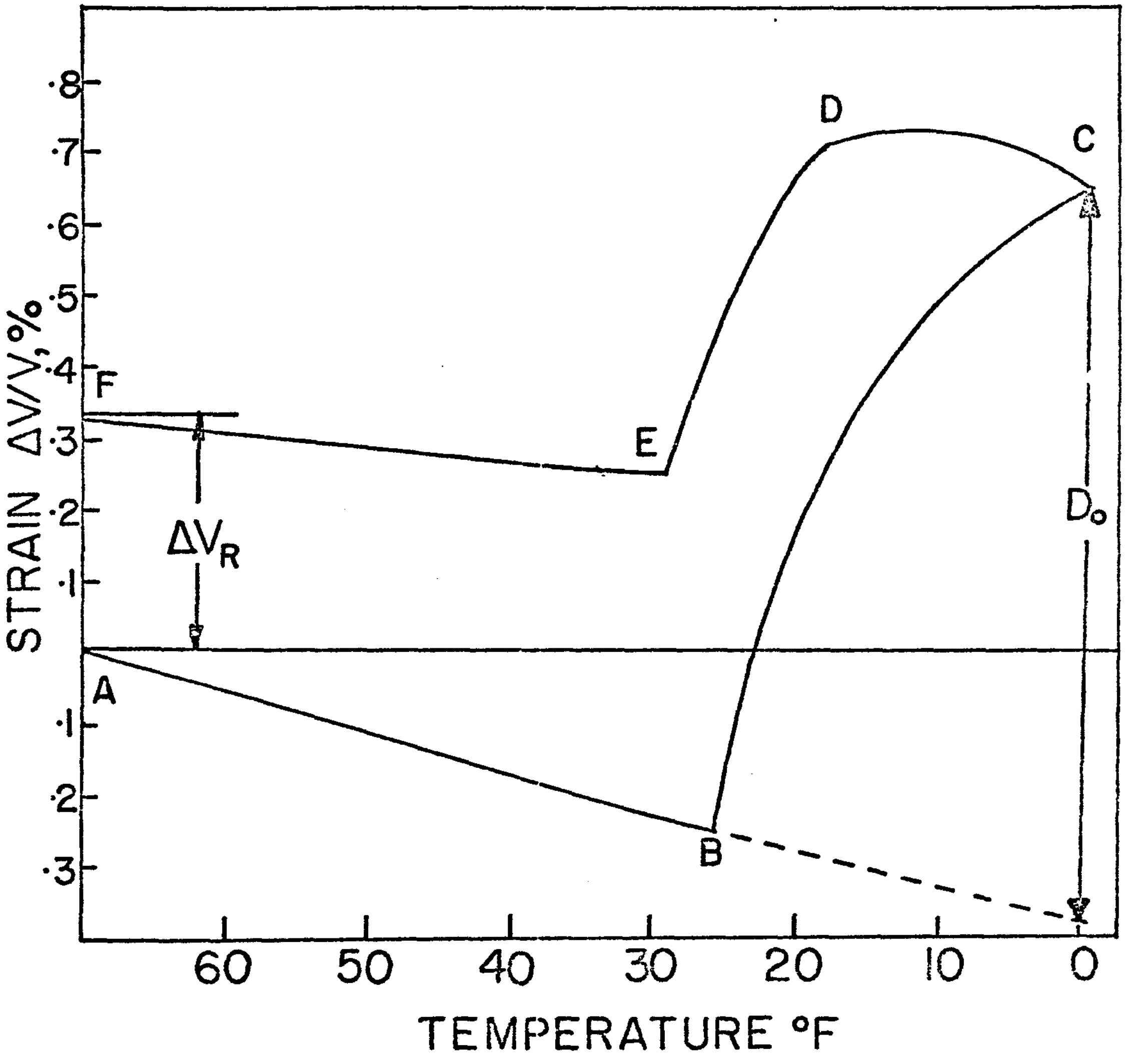


Figure 20 Typical Strain-Temperature Hysteresis Due To A Slow Cooling-Warming Cycle

residual volume change properties were observed as time dependent. Figures 21 and 22 illustrate the time dependent behaviour of these parameters for plain cement paste.

Figure 21 shows a more or less exponential decay of the dilation parameter with time for plain paste mixes with water cement ratios of 0.35, 0.45 and 0.50. Figure 22 shows that for plain pastes (water cement ratios of 0.25, 0.35, 0.45 and 0.50) residual volume change decreases more or less exponentially from positive to negative and then increases slightly in a linear fashion until it reaches an almost negligible value (ie. $\Delta V_R = 0 \pm \epsilon$) An interpretation of this behaviour will be given in the discussion.

Compressive strength vs. dilation

It was found that compressive strength (2 inch cubes of cement paste) was directly related to dilation. Figure 23 shows the experimental values of strength vs. dilation for plain paste. Regression analysis yielded the following expression:

$$f_c = 4957 - 4508\, D_o \qquad \text{----------(22)}$$

$$0.04 < \frac{\Delta w}{w_o} < .10$$

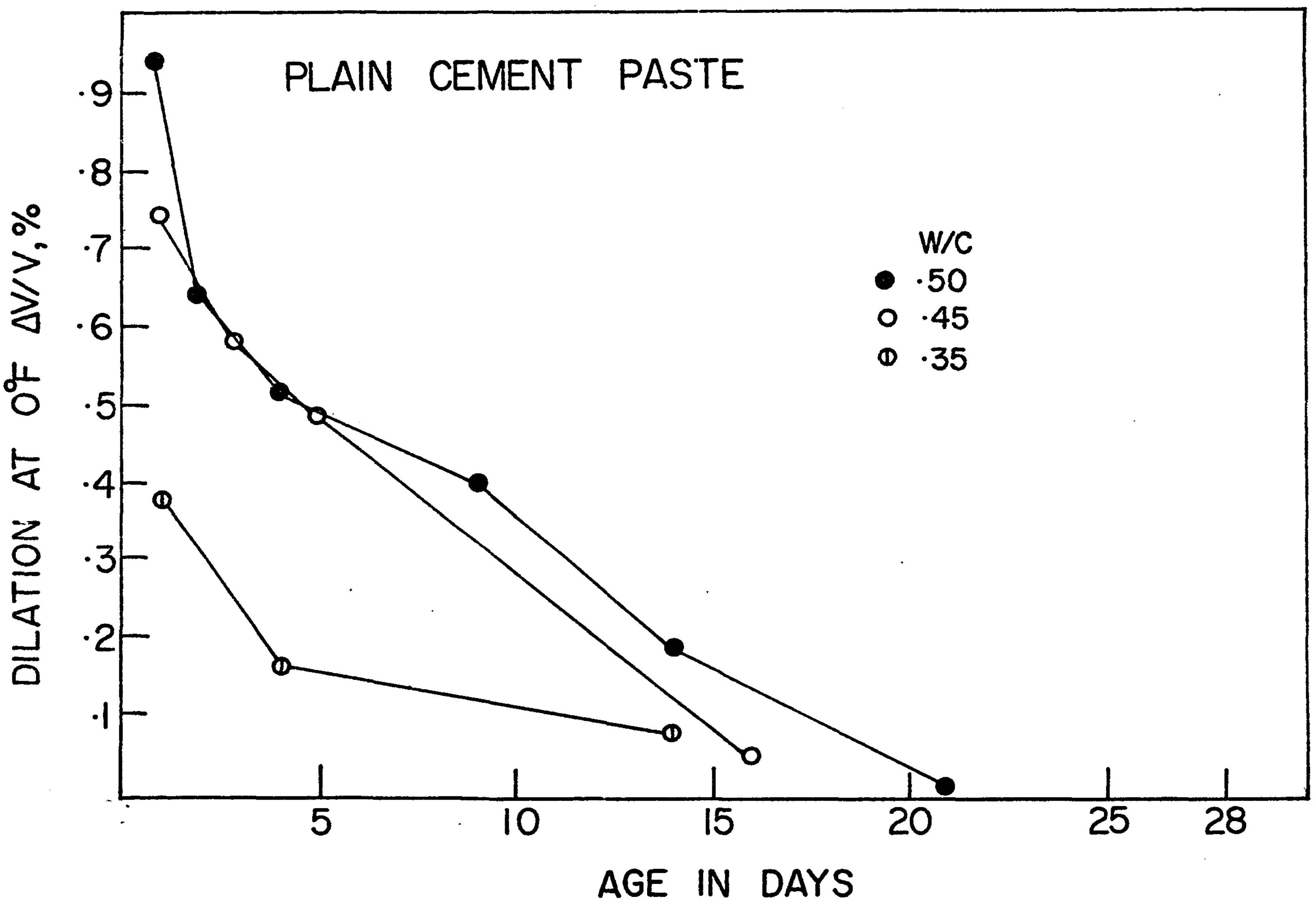


Figure 21 Dilation vs Age In Days

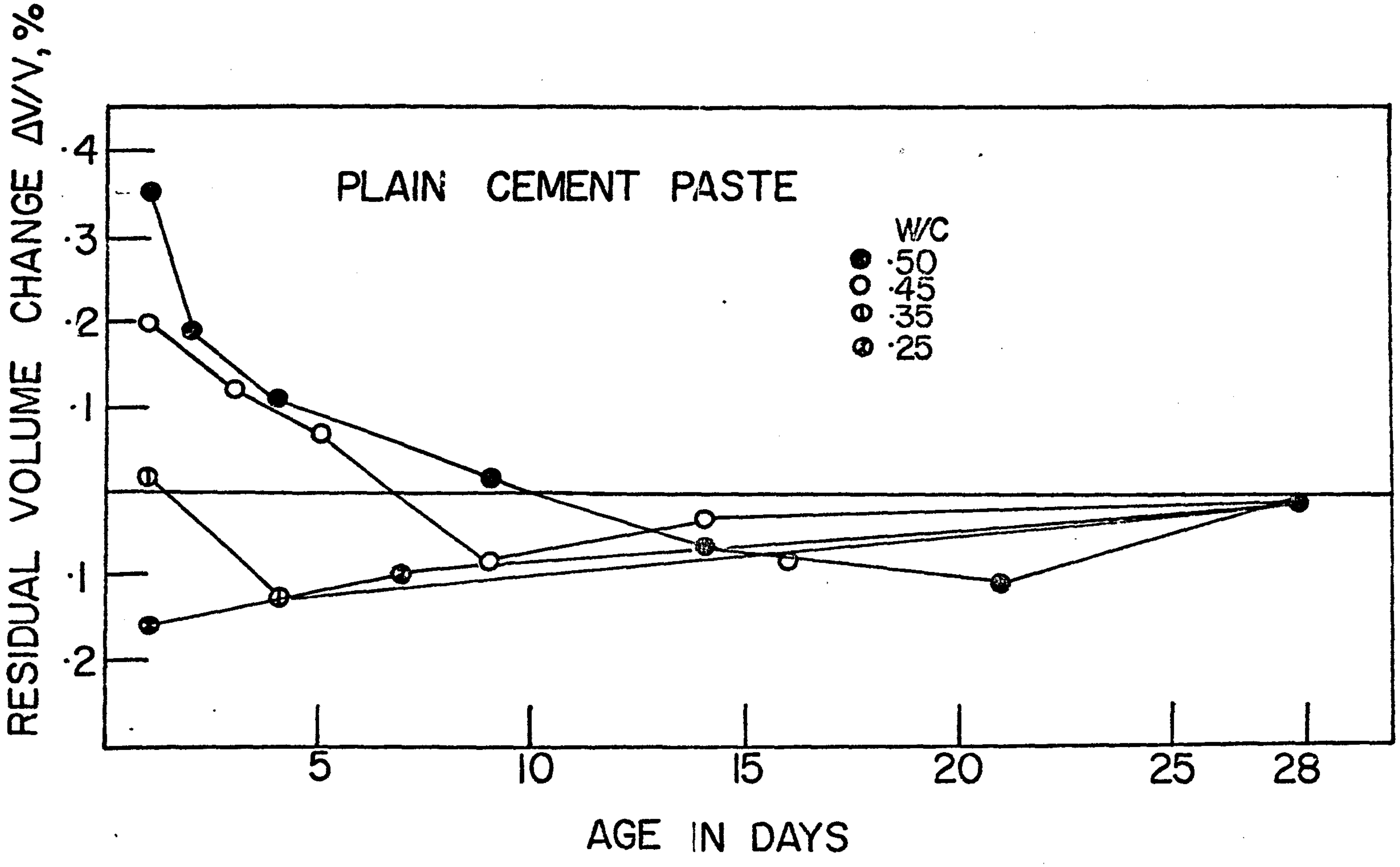


Figure 22 Residual Volume Change vs Age In Days

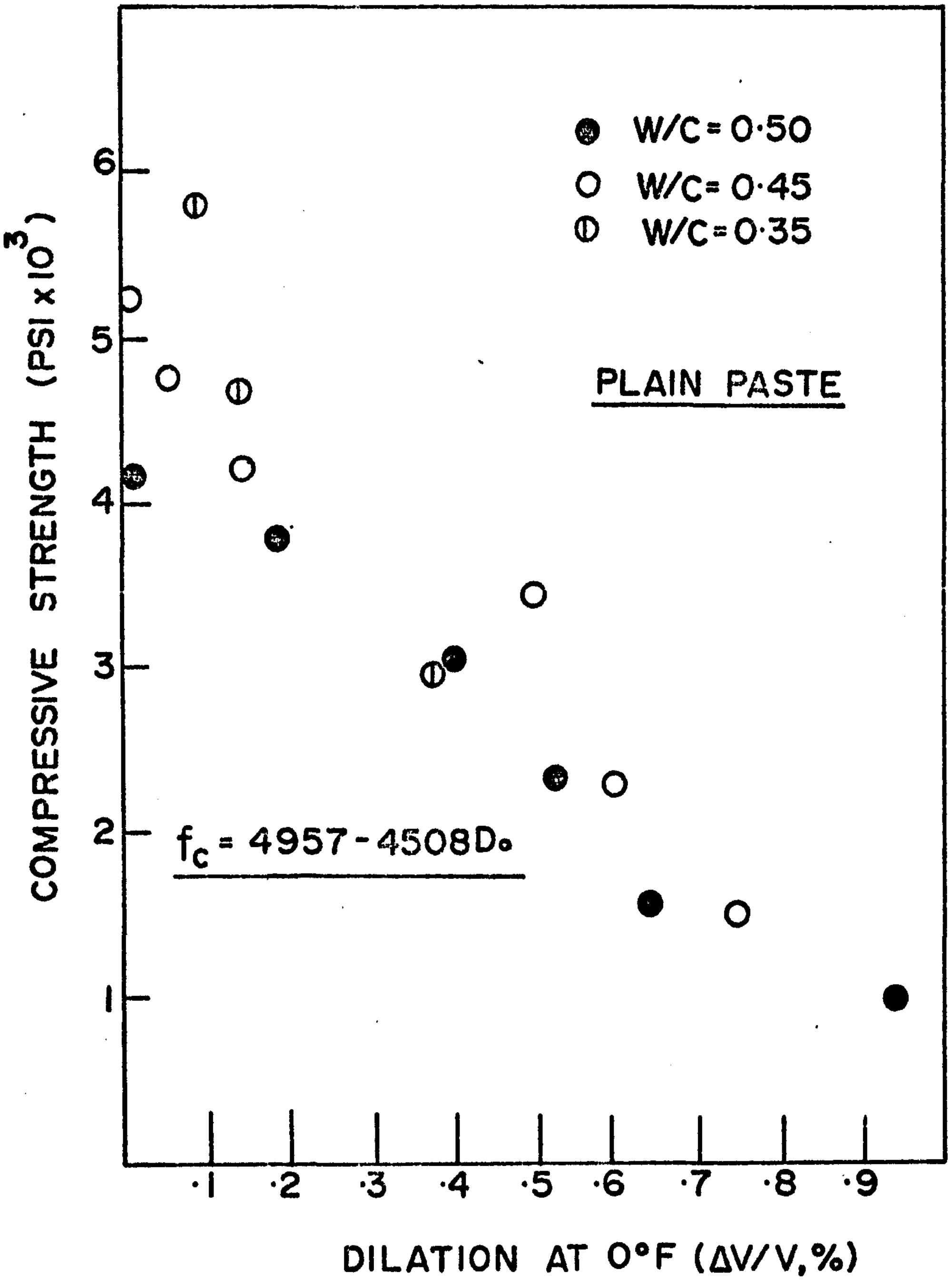


Figure 23 Compressive Strength vs Dilation- Plain Paste

RESIDUAL VOLUME CHANGE VS DILATION

Residual volume change was found to be related to dilation in a linear manner as illustrated in figure 24. Regression analysis yielded the following expression.

$$\Delta V_R = - 0.089 + 0.350\ D_o \qquad \text{---------(23)}$$

$$0.04 < \frac{\Delta w}{w_o} < 0.10$$

A similar expression can be obtained relating compressive strength and ΔV_R .

$$f_c = 3817 - 12{,}850\ \Delta V_R \qquad \text{----------(24)}$$

Equation(23) implies that for strengths greater than 3817 psi residual volume change ΔV_R is negative. This generally agree with experiment. Any weakness in equation(23) would occur when ΔV_R is negative as the experimental scatter is greatest in this region. It is noted however that the correlation coefficient for equation(23) is reasonably good and that the relation is reasonably representative of observed behaviour in the region $0.04 < \frac{\Delta w}{w_o} < 0.10$

Dilation vs $\frac{\Delta w}{w_o}$

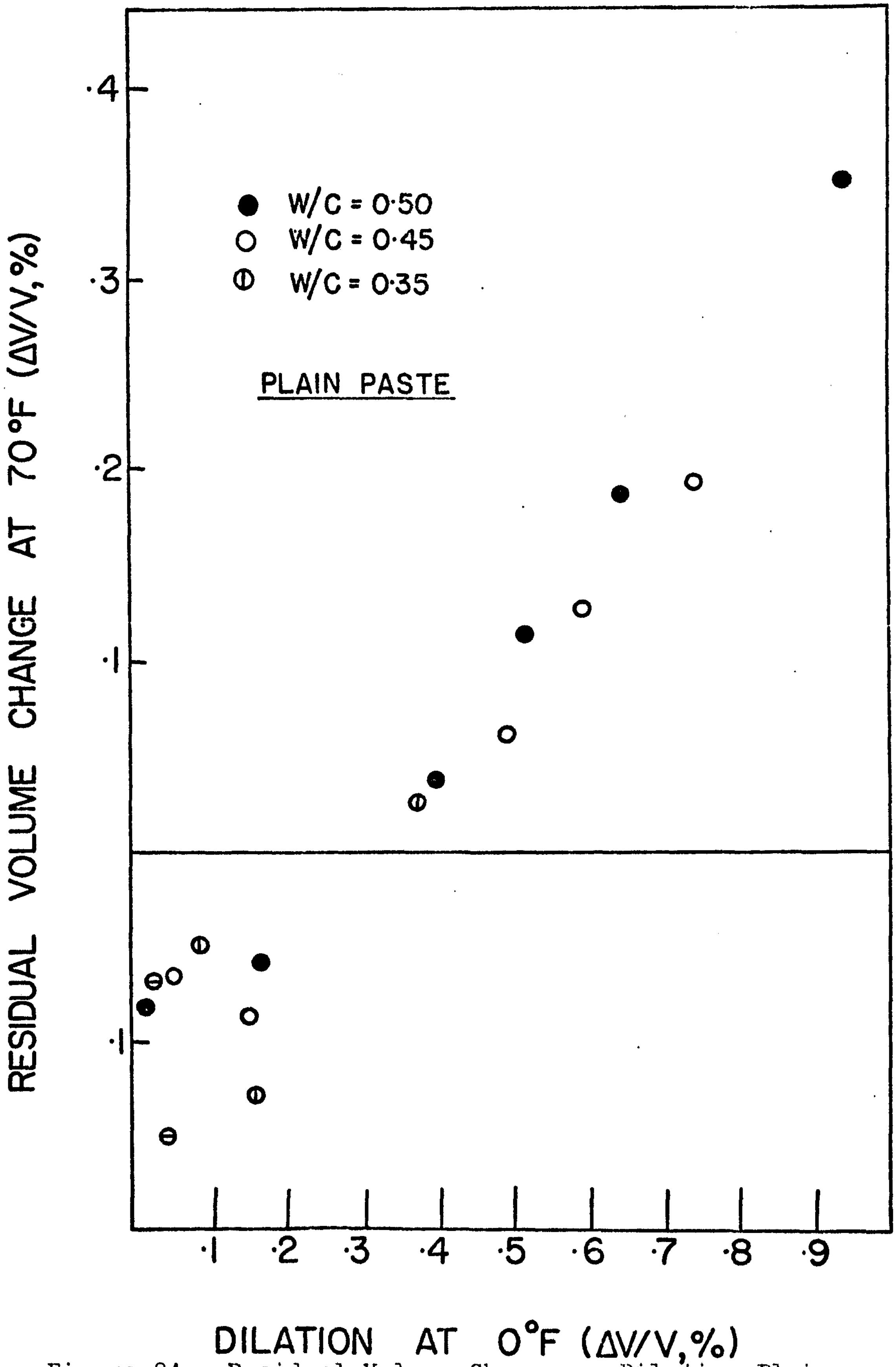


Figure 24 Residual Volume Change vs.Dilation-Plain Paste

Combining equation (22) relating strength and dilation and equation (21) relating strength and $\frac{\Delta w}{w_o}$ we can obtain an expression for dilation in terms of the dimensionless parameter $\frac{\Delta w}{w_o}$. Thus we have:

$$D_o = 1.081 - 3.75 \left[\frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \right]^{2.6} \quad \text{-----} (25)$$

$$.04 < \frac{\Delta w}{w_o} < .10$$

Thus the semi-emperical relation expressed in equation (25) demonstrates that dilation is a non-linear function of a single independent variable $\frac{\Delta w}{w_o}$ and hence dependent on the degree of hydration of the system. Since both dilation and $\frac{\Delta w}{w_o}$ were experimentally determined, verification of equation (25) can be readily obtained. Figure 25 shows the experimental values of dilation vs. $\frac{\Delta w}{w_o}$ for plain paste. Agreement is reasonably good.

RESIDUAL VOLUME CHANGE VS $\frac{\Delta w}{w_o}$

Substitution of D_o from equation (25) into equation (23) give residual volume change as a function of $\frac{\Delta w}{w_o}$.

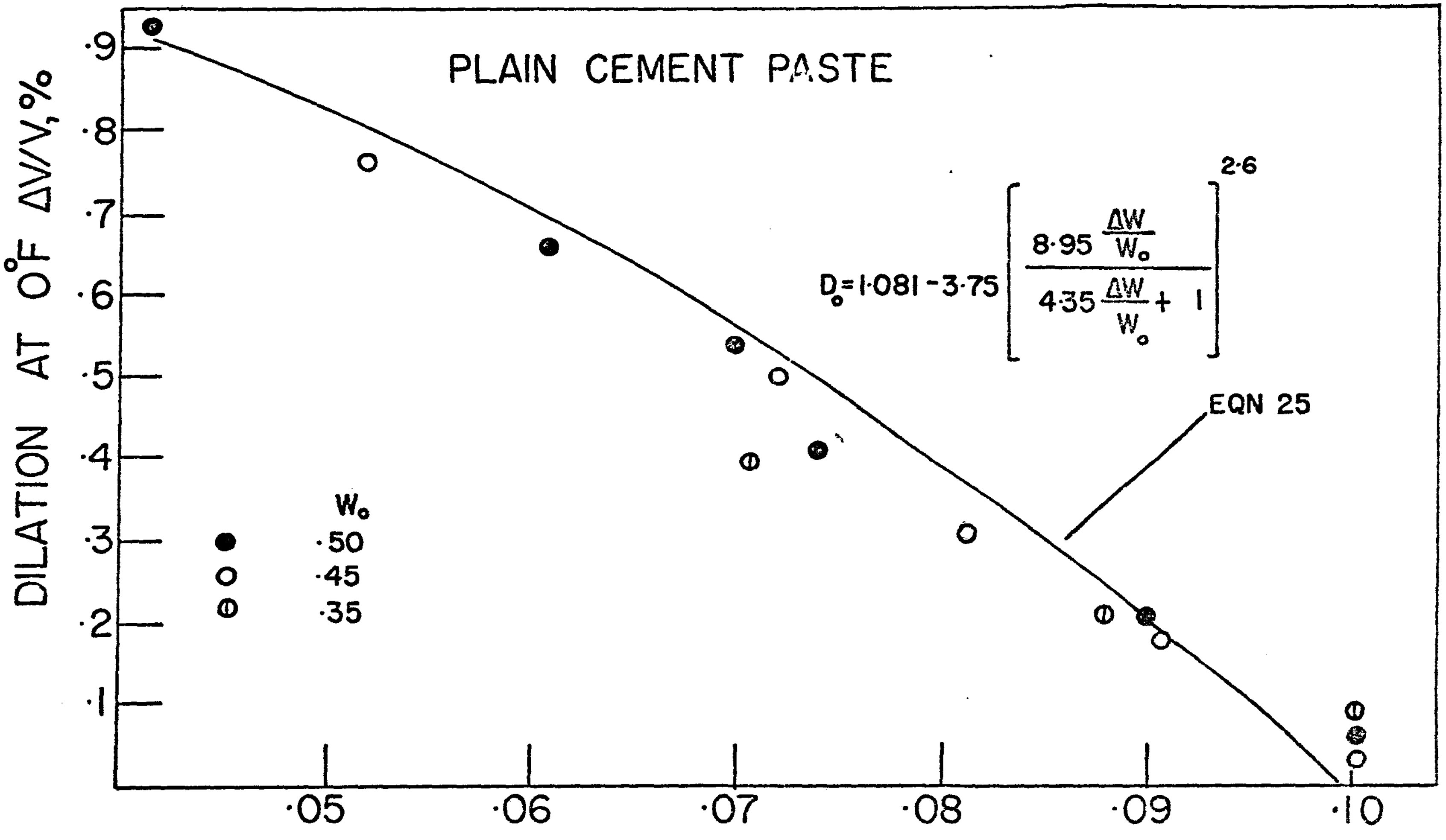


Figure 25 Dilation vs $\frac{\Delta w}{w_o}$ - Plain Paste

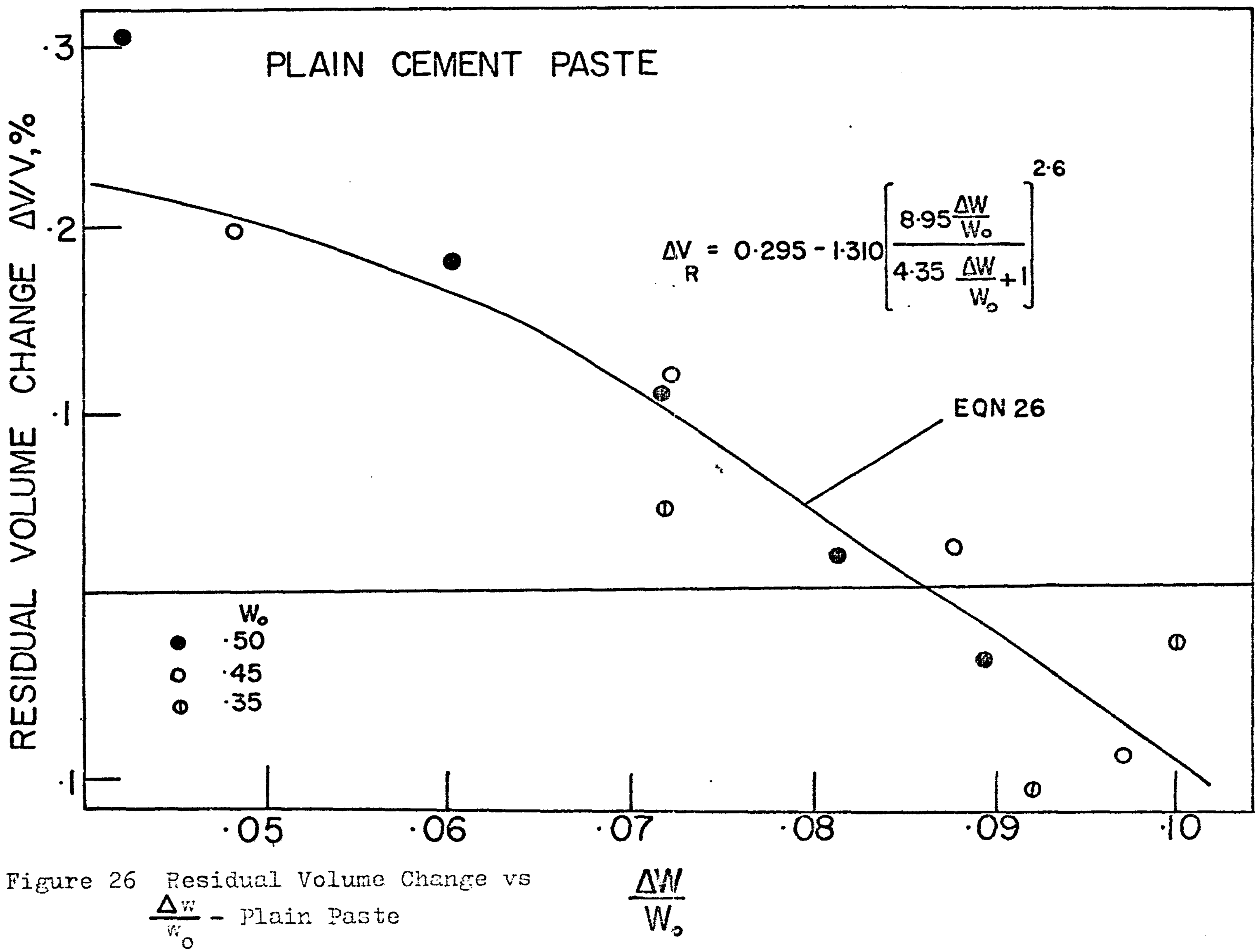


Figure 26 Residual Volume Change vs $\frac{\Delta w}{w_o}$ - Plain Paste

$$\Delta V_R = 0.295 - 1.310 \left[\frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \right]^{2.6} \quad \text{-----(26)}$$

$$.04 < \frac{\Delta w}{w_o} < .10$$

Experimental values of ΔV_R vs. $\frac{\Delta w}{w_o}$ are shown in figure.26 Agreement is reasonably good.

Free water per unit volume of paste

In Part I it was shown that the free water in the pores is a function of $\frac{\Delta w}{w_o}$ as expressed by equation(15). Expressing $\frac{\Delta w}{w_o}$ in term of V^* and substituting in equation(25) gives the following expression.

$$D_o = 1.081 - 3.75 \left[\frac{1.280 - 1.28V^* - \frac{.407V^*}{w_o}}{1 - 0.628V^* - \frac{.198V^*}{w_o}} \right]^{2.6} \quad \text{--(27)}$$

$$.04 < \frac{\Delta w}{w_o} < .10$$

Thus we see that dilation can be expressed as a function of the free water available to freeze and water-cement ratio. Figure.27 is a plot of the experimental results for D_o vs. V^*. Agreement of experiment with equation(27)is good.

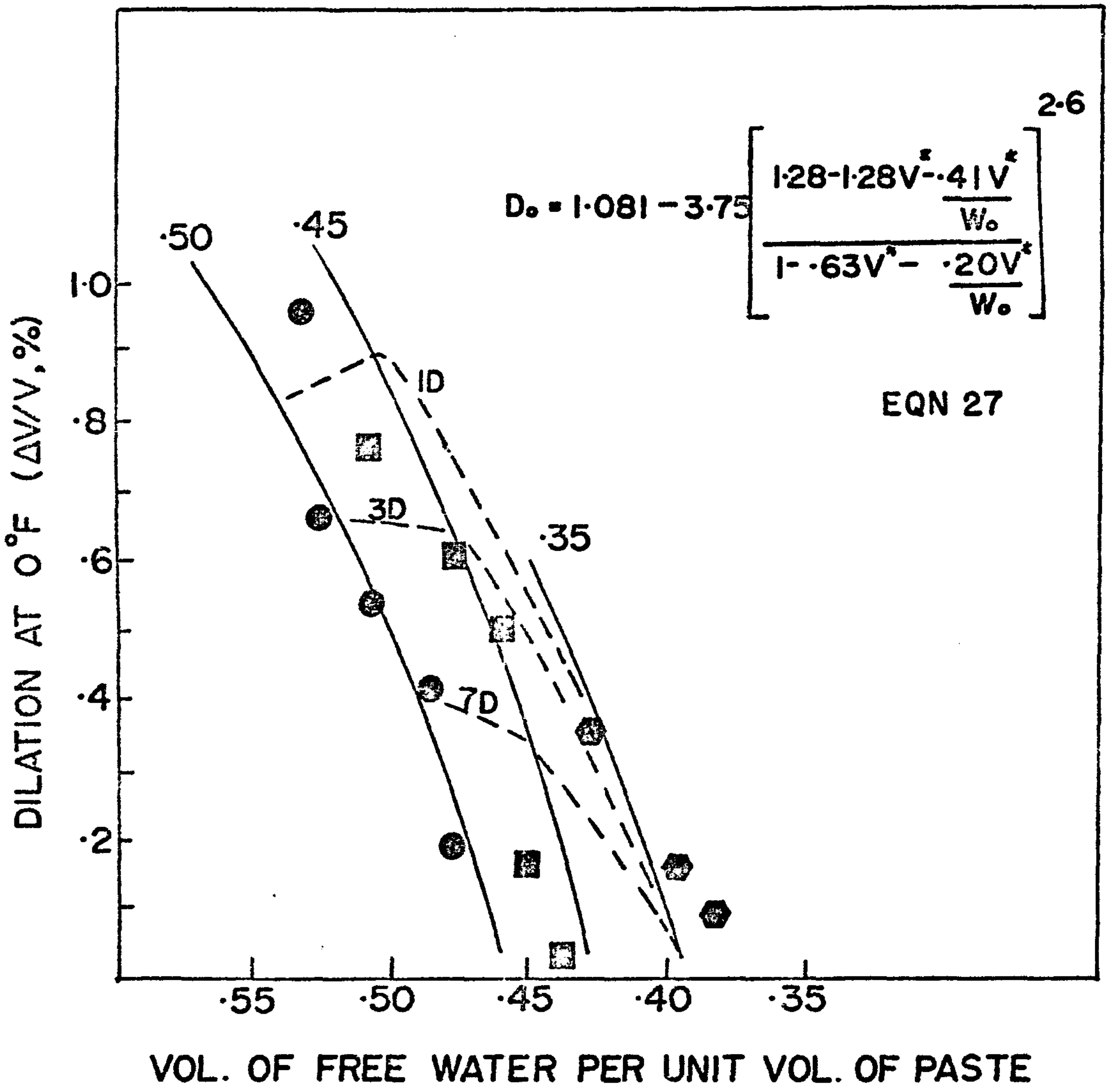


Figure 27 Dilation vs Volume of Free Water

By expressing $\frac{\Delta w}{w_o}$ in terms of V^* from equation(15) and substituting into equation(26) we obtain the following expression:

$$\Delta V_R = 0.295 - 1.310 \left[\frac{1.280 - 1.280V^* - \frac{.407V^*}{w_o}}{1 - 0.628V^* - \frac{0.198V^*}{w_o}} \right]^{2.6} \quad \text{--(28)}$$

$$.04 < \frac{\Delta w}{w_o} < .10$$

Thus, residual volume change as well, can be expressed as a function of V^* and w_o. Figure 28 plots experimental values of ΔV_R vs. V^* which appear to conform well with equation(28).

Strength reduction ratio

To observe the effect of the selected slow cooling cycle on strength it was decided to determine the strength ratio of cycled to non-cycled specimens. Two-inch cubes were cast from mixes with water-cement ratios of .35, .45, .50 and 1.00. Specimens were moist cured until time of test. Then half of the test specimens were sealed and cycled. The remaining half were sealed and left at 70°F. After cycling, both sets of specimens were tested to determine the strength parameter and the strength reduction ratio $\frac{\sigma_r}{\sigma}$ was evaluated. Regression analysis gave the following

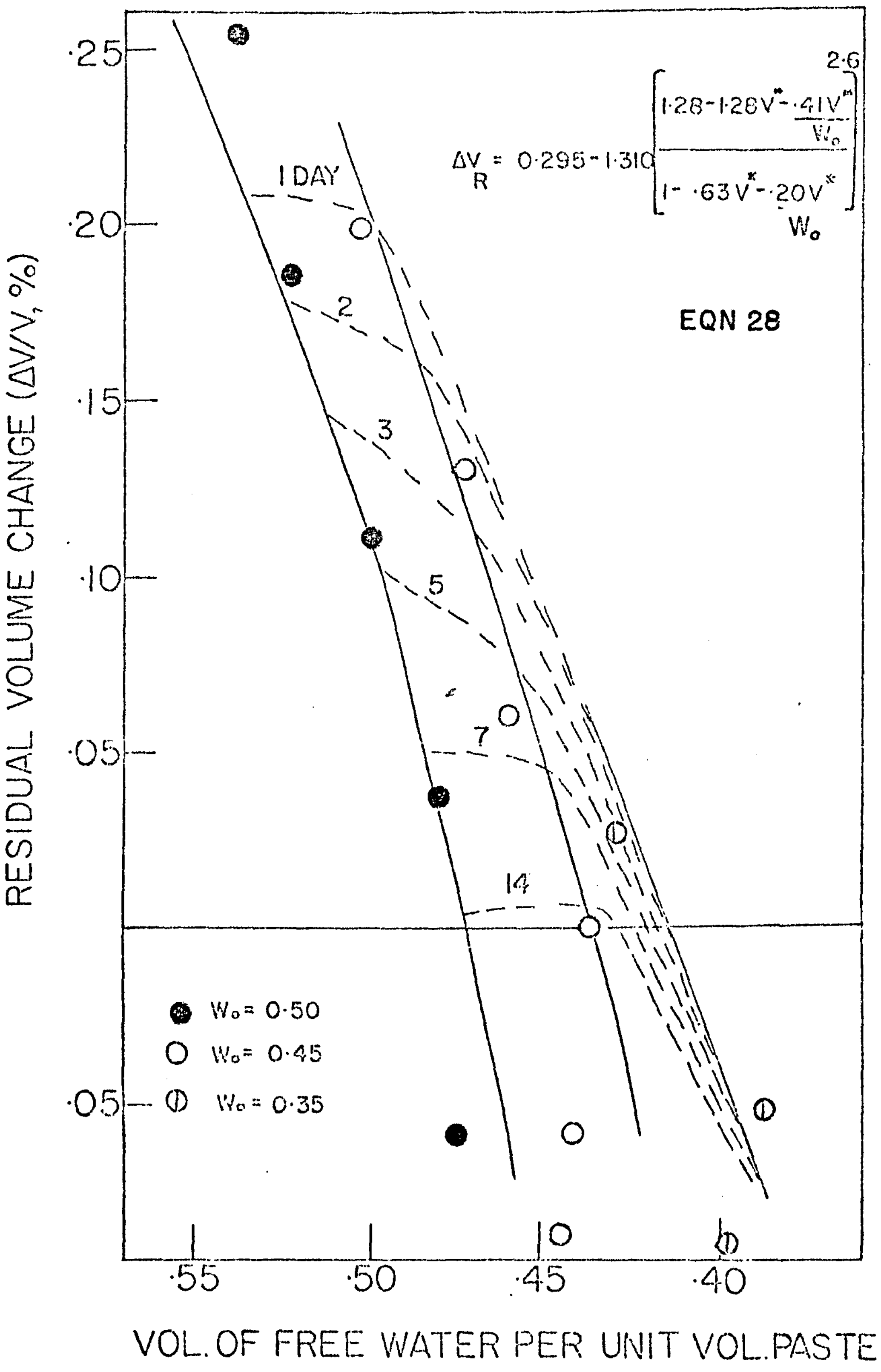


Figure 28 Residual Volume Change vs Volume of Free Water

relation:

$$\frac{\sigma_r}{\sigma} = 0.297 + 0.246 \log_{10} t \qquad \text{-----(29)}$$

where $\frac{\sigma_r}{\sigma}$ is the strength reduction ratio and t is the time in hours. Figure 29 shows the experimental values of $\frac{\sigma_r}{\sigma}$ vs. t.

By measuring $\frac{\Delta w}{w_o}$ or V^* at a given time t, we can plot $\frac{\sigma_r}{\sigma}$ vs. $\frac{\Delta w}{w_o}$ and $\frac{\sigma_r}{\sigma}$ vs. V^* for any given time t. Refer to figures 30 and 31. Thus we can see that the strength reduction ratio is a function of $\frac{\Delta w}{w_o}$ and water cement ratio or V^* and water-cement ratio:

$$\frac{\sigma_r}{\sigma} = \phi\left(\frac{\Delta w}{w_o}, w_o\right) = \phi_1\left(V^*, w_o\right) \qquad \text{-----(30)}$$

EFFECT OF SPECIMEN SIZE AND SHAPE

Although the majority of tests were performed on 1" x 1" x 6" prisms, two other sizes were included in the programme. Dilatometric tests were performed on 3" Ø x 6" cylinders and length change studies included 1" x 6" x 6" slabs.

Figures 32 and 33 show typical results for paste with a water-cement ratio of 0.50. At one day, figure 32 shows that the 3" Ø x 6" cylinder has a dilation response which is approximately 20% greater than that of the prisms or slab. The 1" x 1" x 6" prism and 1" x 6" x 6" slab demonstrate

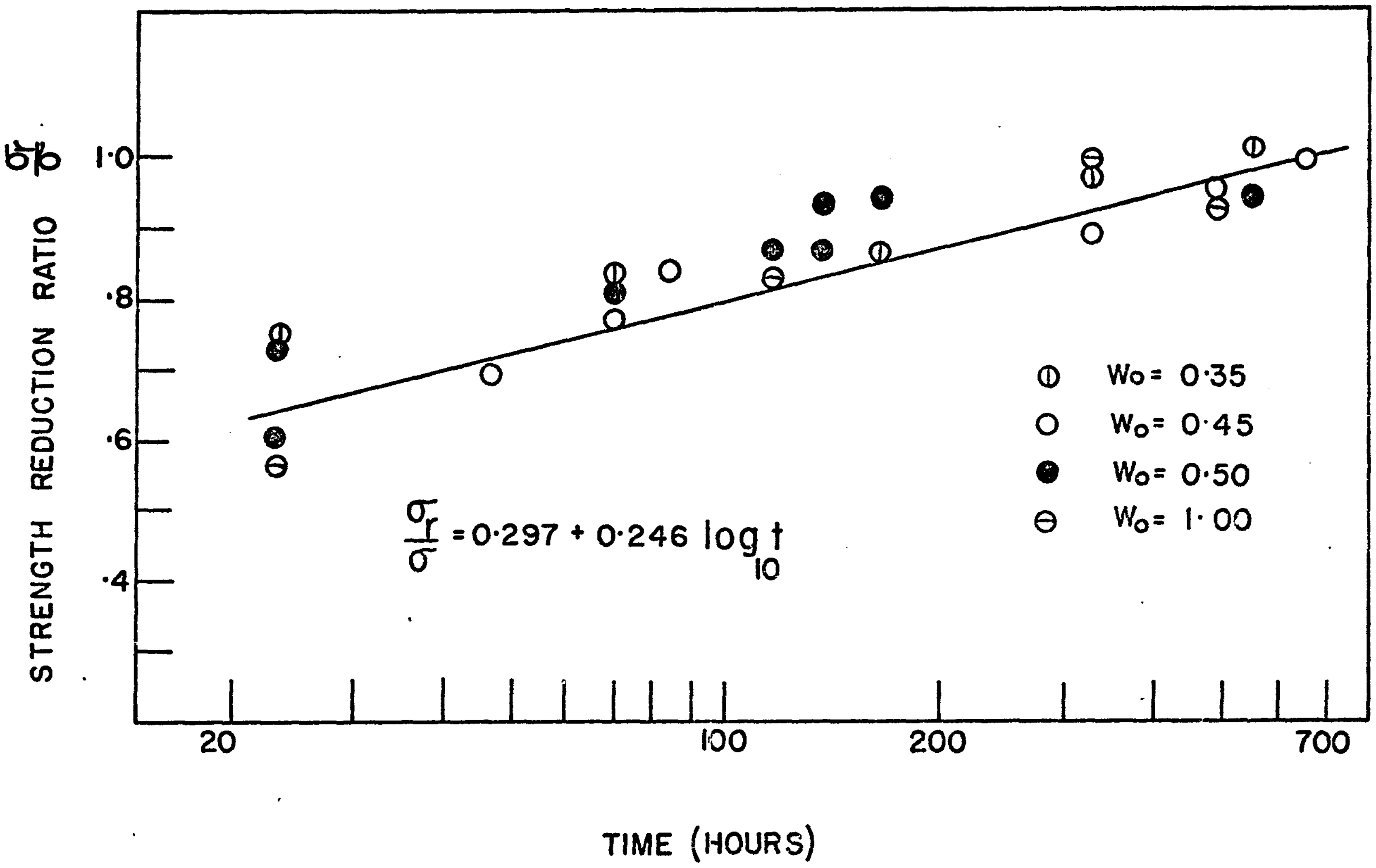


Figure 29   Strength Reduction Ratio vs Time-Plain Paste

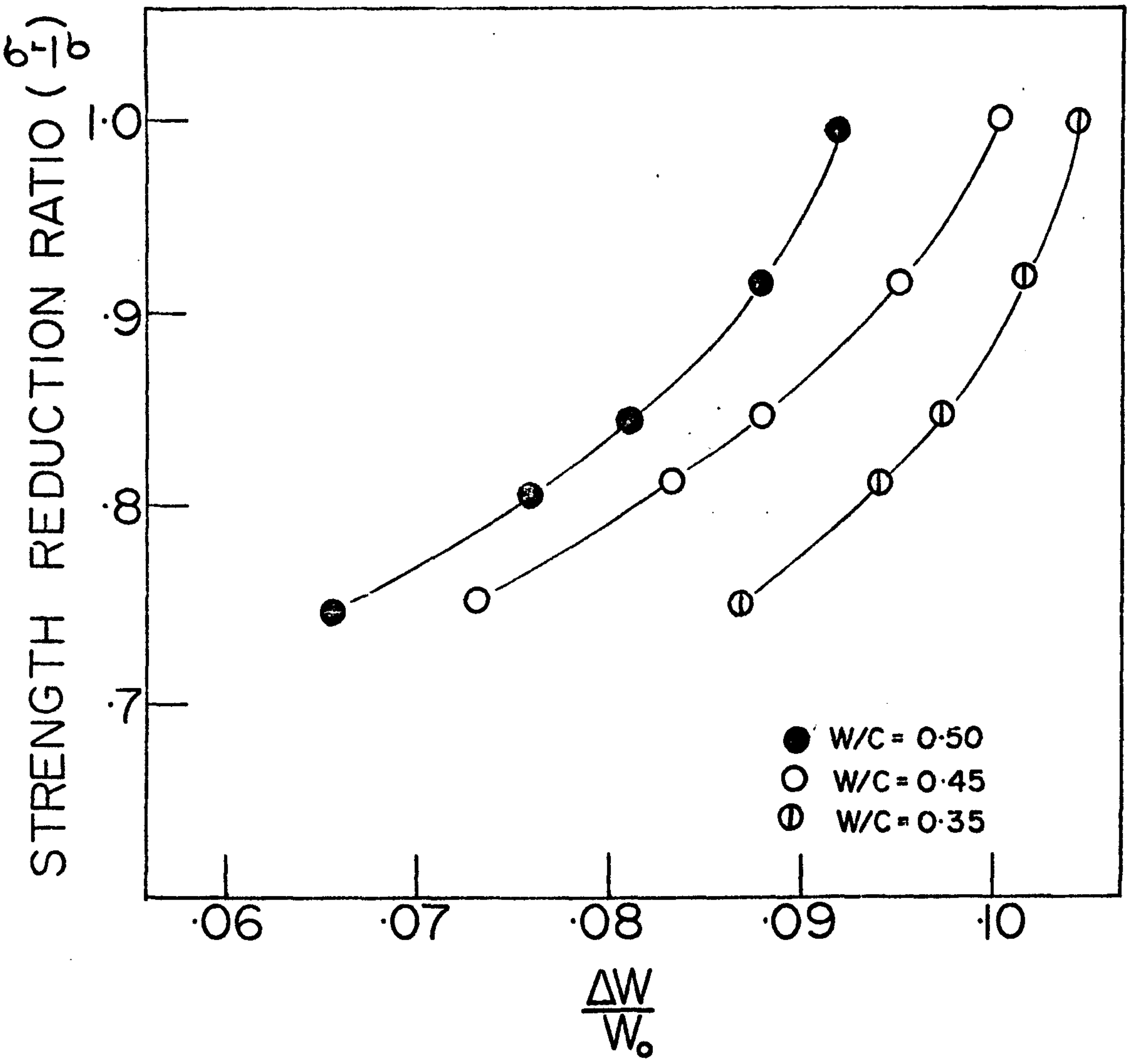


Figure 30 Strength Reduction Ratio vs $\frac{\Delta w}{w_o}$ - Plain Paste

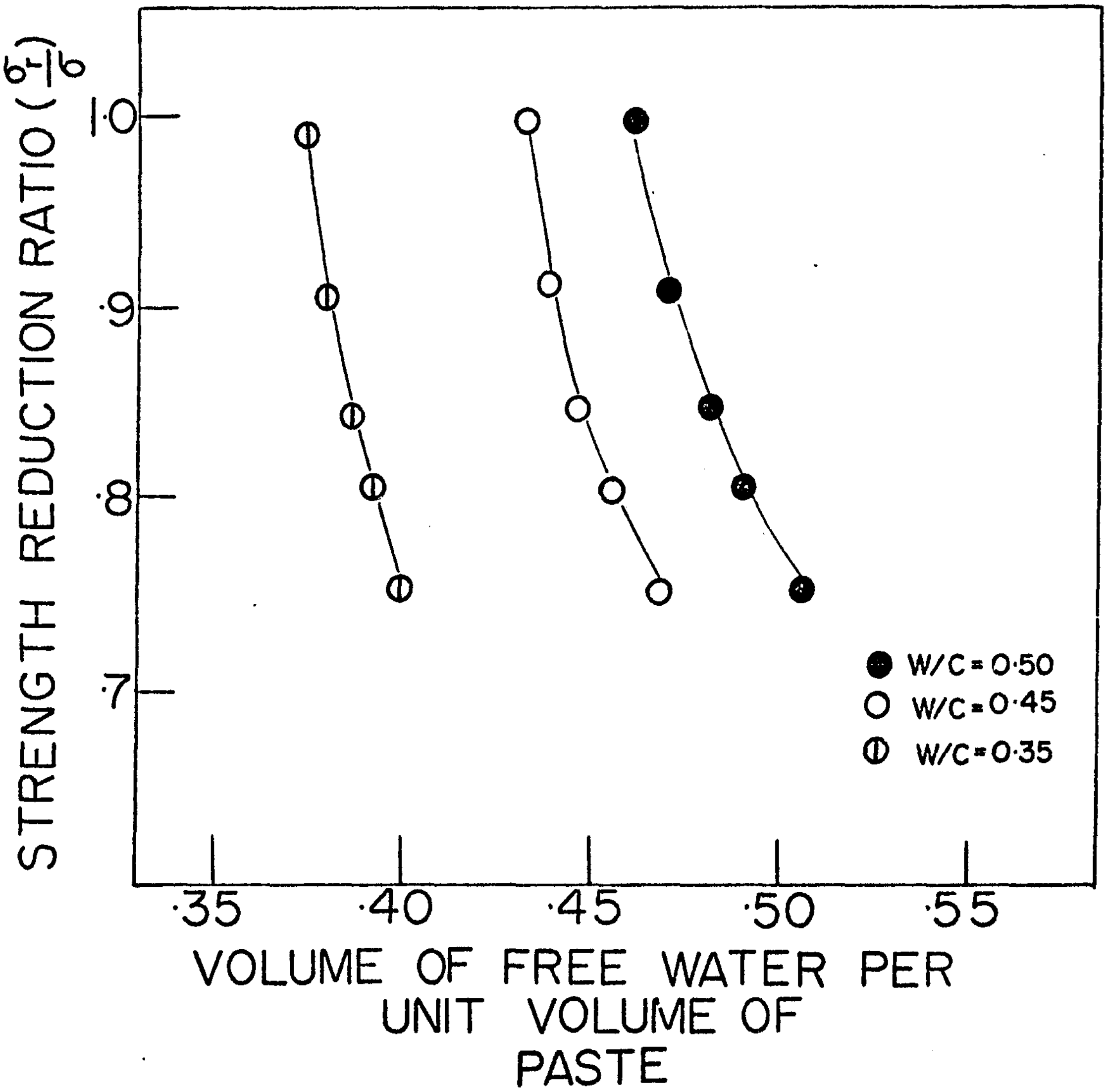


Figure 31 Strength Reduction Ratio vs Volume of Free Water-Plain Paste

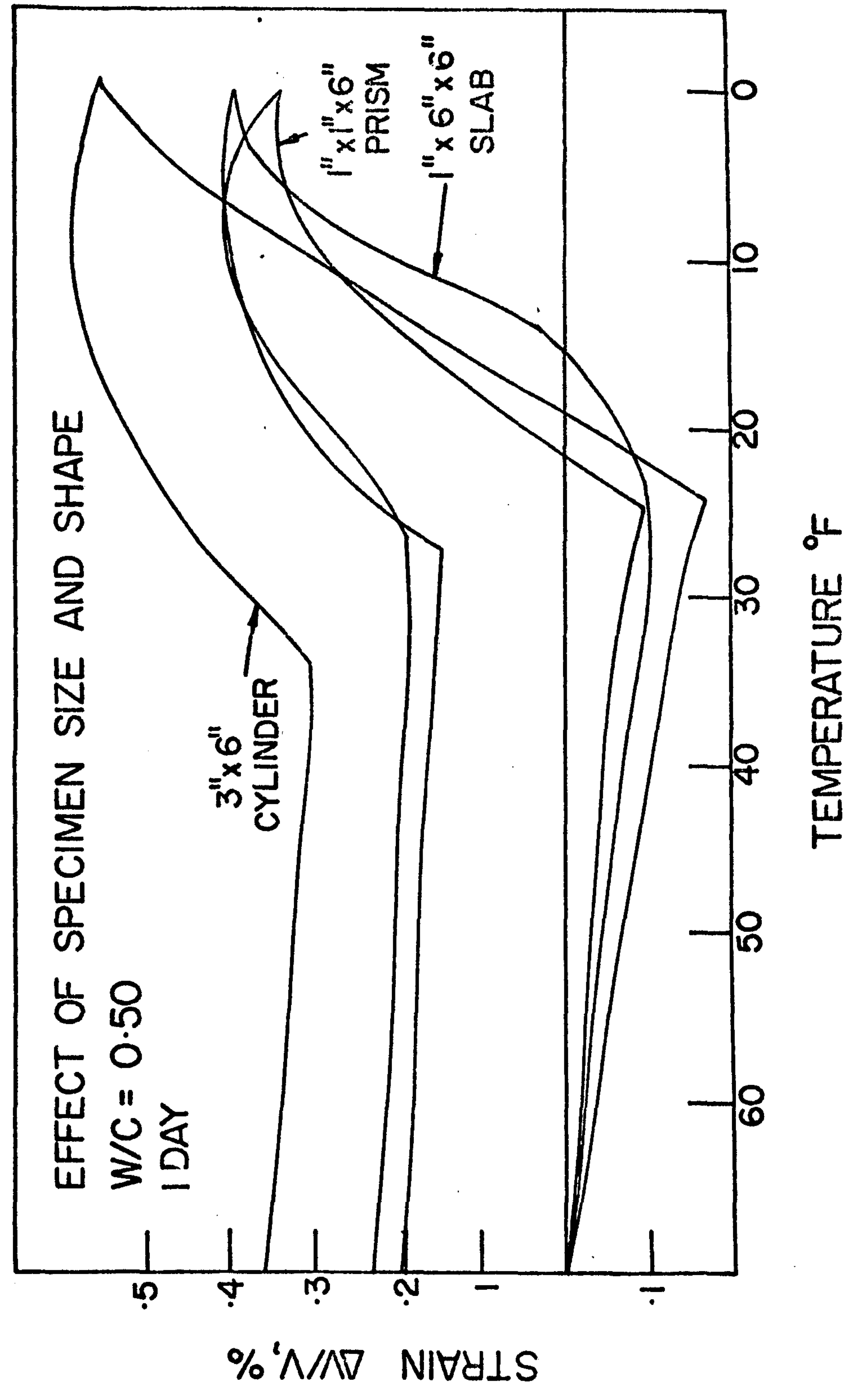


Figure 32 Effect of Specimen Size And Shape; w/c=0.50 At 1 Day

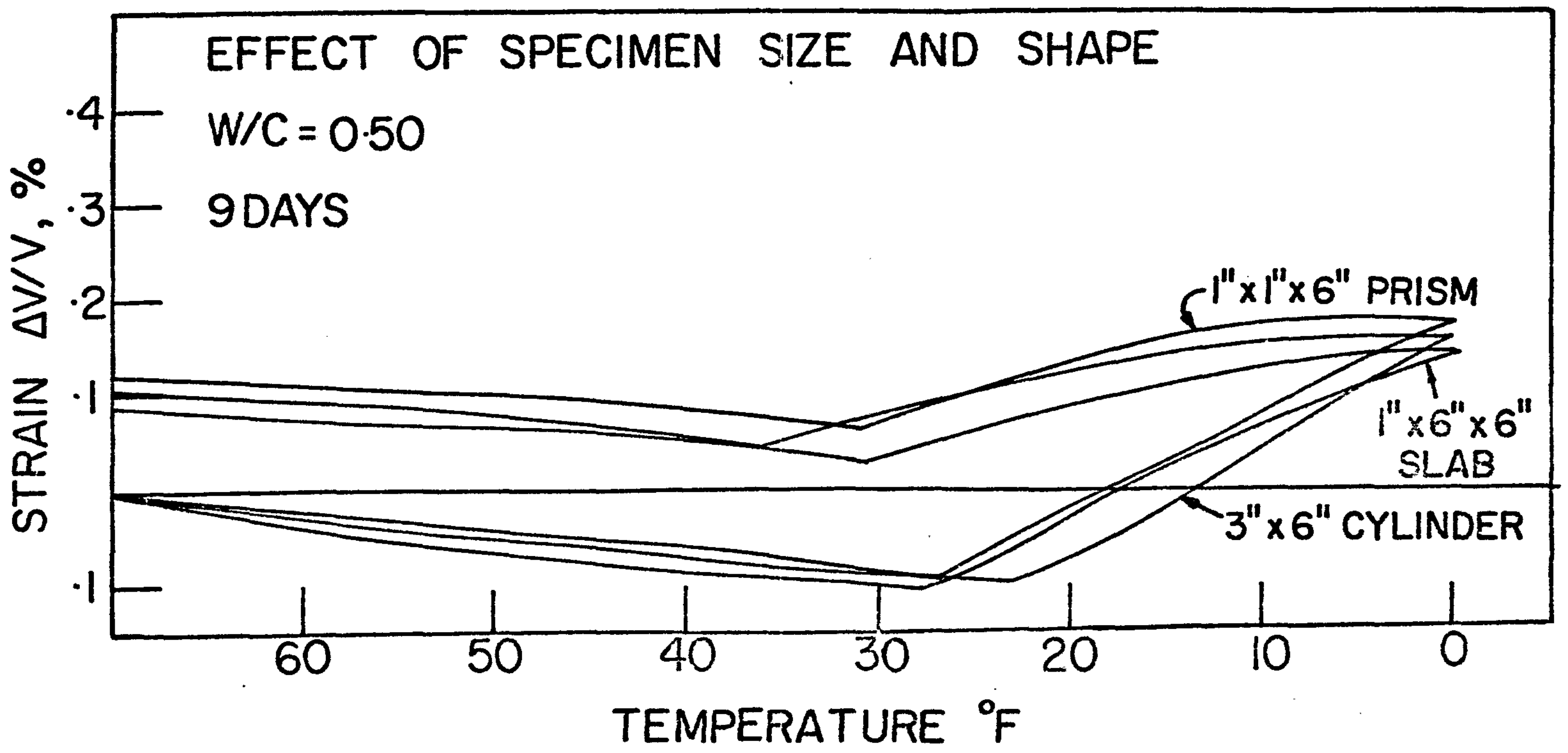


Figure 33 Effect of Specimen Size And Shape; w/c=0.50 At 9 Days

approximately the same dilational response. However figure 33 shows that at 9 days the dilational response is practically independent of the sizes and shapes tested. This suggests that at early ages dissipation of internal pressures is more difficult in the larger 3" Ø cylinder, but at later ages and greater concentrations of hydrate product, other volume change mechanisms present may be less sensitive to dimension.

It appears that the 1" x 6" x 6" slab acts as a series of 1" x 1" x 6" prisms ie. the slab consists of elements which have equal length change properties. The 1" mininum distance appears to be the critical dimension; this seems to be consistent with the larger volume change at early ages observed for the 3" Ø cylinder.

DISCUSSION OF TEST RESULTS - PLAIN PASTE SERIES

In discussing the transient strain behaviour of plain paste it is convenient to draw attention to the transient strain behaviour of a more stable micro-porous system.

Several studies (42, 43, and 44) on the dimensional changes of the porous glass-water system have recently been conducted. The vicor glass studied had a nitrogen surface area of $112.5 m^2/gm$. The pore-size distribution calculated from the nitrogen isotherm showed that 66% of the total pore volume consisted of pores with radii between 28 and 29Å. The distribution curve had a maximum at 21Å. The length of the adsorbent (glass rod) after completion of a temperature cycle was different from the initial length. This was thought to be due to damage suffered by the glass and to the fact that the length of the adsorbent is different for adsorption and desorption although the quantity adsorbed may be the same.

The hydrate product of the cement-water system has a pore system with an average pore diameter of about 20Å. Length changes, as a result of temperature cycling are irreversible (see figures 15 to 19). Since the pore systems and length change characteristics of the two systems appear to have similarities it was thought appropriate to compare length change data for cement paste obtained in this programme to published data for the glass-water system.

Negative Residuals were observed by Litvan (42) upon cycling porous Vicor glass. Table III indicates the behaviour of the porous glass with increasing water content.

Water Content g/g	Residual $(\Delta(\Delta L/L),\%)$
0.0000	0
0.0263	+25
0.0480	+15
0.0839	0
0.1389	-15
0.1754	-28

Difference in Rod Length Before and After Temperature Cycle, at +5°C for Various Amounts of Adsorbed Water

Table III

It is noticed that there is a reversal of sign for the residual strains as the water content of the Vicor glass is increased. Examining the data in Table IV we see a similar trend as there is a change in the sign of the residual with increasing age.

Age (days)	Residual $(\Delta(\Delta v/v),\%)$
1	+.350
2	+.185
4	+.110
9	+.035
14	-.060
21	-.080
28	0

Difference in Length of Cement Paste Before and After Temperature Cycle at 70°F (w/c=0.50)

Table IV

In cement paste the volume concentration of hydrate product increases with time. Thus the internal surface area and amount of adsorbed water increases. As the adsorbed water increases the amount of capillary water decreases as well as the total amount of free water.

If the cement were initially compacted in the raw state (ie. no water added) the residual would be zero. At early ages capillary water predominates and the residual is large and positive as adsorbed water is small. Note that in the glass water system the residual is positive at the lower water contents.

As the adsorbed water increases the residual strain diminishes to zero and becomes negative. At 28 days the residual is approximately zero and the amount of capillary water is decreased even further.

Table V is a summary of the effect of water-cement ratio on residual volume change.

Mechanisms

The results of the plain paste series suggest the presence of more than one basic mechanism. The following is a discussion of possible mechanisms.

1) Adsorption Phenomena

If the paste suffered internal cracking or micro-cracking during cooling, resulting in

W/C	AGE	RESIDUAL STRAIN $(\frac{\Delta V}{V}\%)$
0.50	1	+0.350
	2	+0.185
	4	+0.110
	9	+0.035
	14	−0.060
	21	−0.080
	28	0
0.45	1	+0.190
	3	+0.125
	5	+0.060
	9	−0.090
	16	−0.060
	28	0
0.35	1	0.025
	4	−0.135
	14	−0.050
	28	0
0.25	1	−0.160
	7	−0.075
	28	0

Table V Average Residual Volume Change for Plain Pastes greater length, negative residuals at 70 ± 2^oF would have been obtained only if an opposing contraction occurred. Cooling is synonomous with adsorption (due to lowering of the vapour pressure the system can be considered to be on the adsorption branch of the water isotherm). On warming (heating drives vapour off and increases vapour pressure) the system can be considered to be on the desorption branch of the isotherm. Since lengths corresponding with the desorption branch are less than those of the adsorption branch, it can be understood why $(\frac{\Delta v}{v})$ is negative, "for systems of higher water content". That is, as time progresses the dimensional change tendencies of the cement gel and its "sorbed water" override the expansive tendencies of any capillary or free water and the system experiences a negative residual. It will be recalled that sorption phenomena occurs in the gel phase only.

2) Collapse of Structure

As time progresses, the hydrate concentration reaches a state where the system experiences a negative residual. At this time there is a greater amount of gel than previously and consequently a larger amount of sorbed water and less capillary water. During freezing of more mature paste the probability of gel water diffusing to capillaries appears to be less likely than for green paste simply because there are fewer of them. It is suggested that on freezing some gel water which has been mobile (either due to internal transfer in the gel system or some diffusion to capillaries) gets trapped, because of structural reorientation (can not get back between layers) and is compressed in tinier spaces. The collapse of structure mobilizes increased bonding of primary particles or ' physical welding' and the 'compressed' water is prevented from re-entry.

3) Readsorption On Cooling

R.F. Feldman (46) in length change studies of the water-porous glass system has suggested that it is possible (in the dilation region) that some readsorption of expelled water into the small pores can take place because $(P_o(BS)/P_o(SL))_T < (P_o(BS)/P_o(ADS))_T$; ie., the effective relative vapor pressure has increased. Reference to figure 33-1 illustrates this feature of dilational response.

It is quite feasible that this mechanism is operable in the cement paste system for the following reasons:

a) similar average pore size of the hydrate.
b) both contain adsorbed water and supercooled water in the freezing zone.
c) hydraulic pressure accounts for length

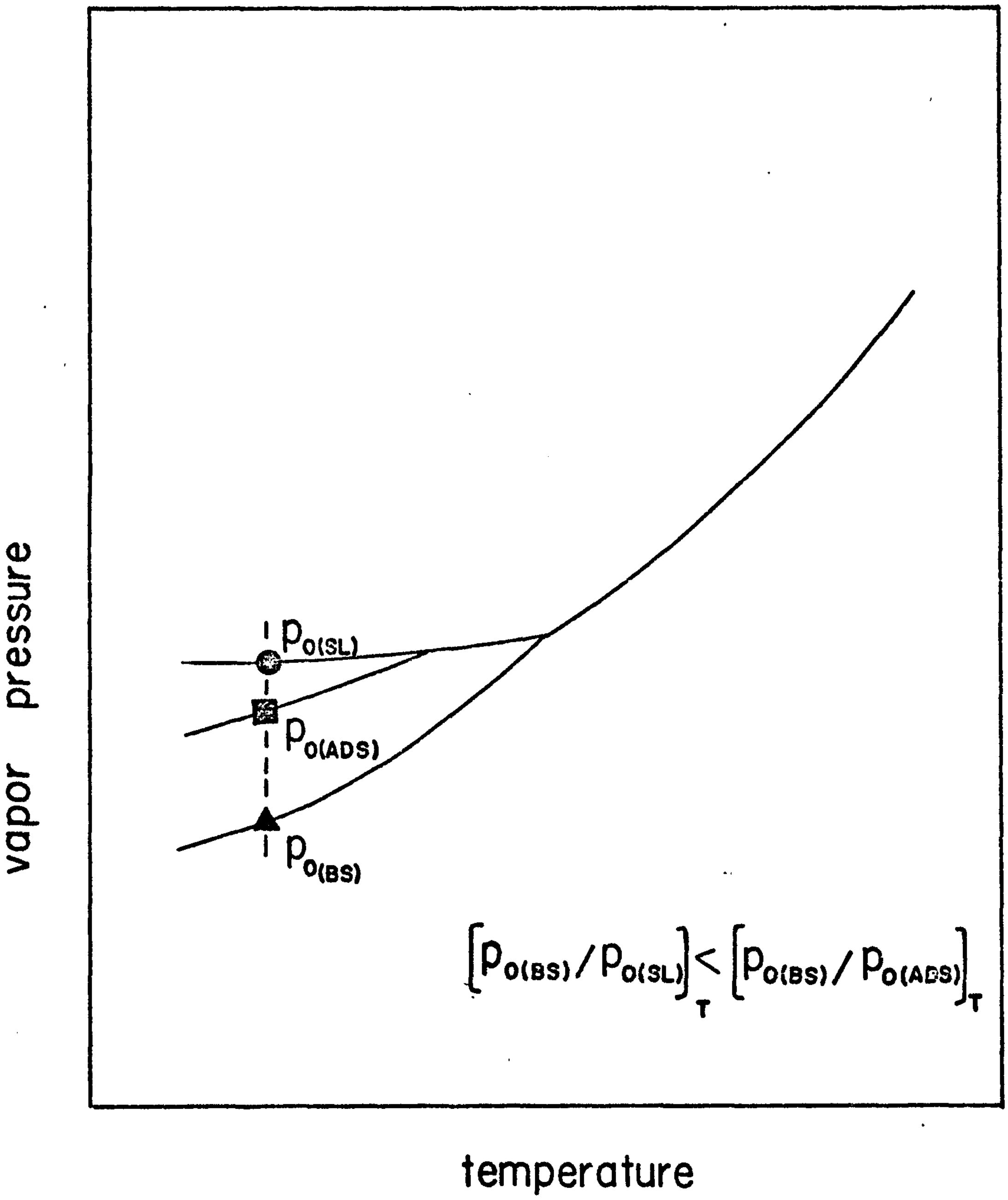


Figure 33-1 Vapor Pressure-Temperature Relationship For Water

changes at early ages, but does not necessarily explain dilational tendencies at later ages when the hydrate concentration is more appreciable.

Further comments on a readsorption mechanism will be made when considering dimensional changes of the cement paste-benzene system.

However it seems appropriate to comment here on the similarity of cooling and first drying shrinkage. Drying shrinkage is principally due to two phenomena:

a) Compressive stresses exerted through menisci as capillary water migrates to ambient regions due to a difference in vapor pressure.

b) Gel water migrating to capillaries because of a difference in vapor pressure. This accounts for the major portion of the drying shrinkage.

In the cooling-warming test in the plain paste series some of the specimens exhibited length changes (in the linear region) greater than that due to normal thermal contraction alone. This can be explained by referring to figure 33-1 We can see that the vapor pressure of super cooled water ($P_o(SL)$) is greater than the vapor pressure of water in the bulk state ($P_o(BS)$). The difference in relative vapor pressures causes the hydrate water to migrate out of the hydrate structure until equilibrium is restored.

CONCLUSIONS - PLAIN PASTE SERIES

Some conclusions will be drawn from the experiments on plain paste. These are as follows.

1) Cement paste exhibits a time-dependent collapse of strain-temperature hysteresis.

2) Dilation and residual volume change as measured from the hysteresis patterns are also time-dependent and decay exponentially.

3) Dilation is a linear function of compressive strength over the range $0.04 < \frac{\Delta w}{w_o} < .10$

4) Residual volume change is a linear function of both dilation and compressive strength, valid over the region $0.04 < \frac{\Delta w}{w_o} < .10$

5) Dilation can be expressed as a non-linear function of the dimensionless parameter $\frac{\Delta w}{w_o}$. This expression is valid for all water-cement ratios and essentially eliminates time as a variable.

6) Dilation is a function of the volume concentration of hydrate product.

7) Residual volume change can be expressed as a non-linear function of $\frac{\Delta w}{w_o}$ and hence as a function of the volume concentration of hydrate product.

8) Dilation and residual volume change can also be expressed as non-linear functions of V^* and w_o, ie. volume of free water per unit volume of paste and water cement ratio.

9) The strength-reduction ratio when plain paste is subjected to a slow cooling regime is a linear logarithmic function of time.

10) The strength reduction ratio is also a function of V^* and w_o or $\frac{\Delta w}{w_o}$ and w_o ie. free water or volume concentration of hydrate product and water-cement ratio.

11) There is a similarity between the cooling phenomenon observed in the porous glass-water system and the cement hydrate-water system eg. reversal in sign of residual strains.

12) In accounting for negative residuals it is possible to hypothesize that there exists a volume change mechanism other than hydraulic pressure. It is suggested that readsorption on cooling may occur, resulting in an increase in volume of the hydrate substance. Preferred adsorption may also be a contributory mechanism.

13) Size and shape have an effect on dimensional changes due to cooling especially at early ages. It appears that dimensional change (ie. dilation) due to cooling is directly related to the minimum specimen dimension.

B. TEST RESULTS - AIR ENTRAINED PASTES

The benefits of air entrainment have been known for over a decade. However the effect of an air void system on the selected cooling-warming regime and more directly on dilation and residual volume change is of interest.

Strain-temperature plots

The transient-strain behaviour of several air-entrained pastes were traced as the paste was subjected to the 5°F/hr. cooling-warming regime. Figures 34 to 37 follow the strain-temperature behaviour with time. It can be seen that at 1 day for pastes with water-cement ratios of 0.50 and 0.45 there is a small dilation ($D_o = .10\%$). Subsequent ages indicate no tendency for dilation but some hysteresis is still present until 28 days. Figure 38 shows the tremendous benefit of air as the strain-temperature function for a paste of water-cement ratio 0.50 with and without air is plotted. This figure shows a reduction in dilational response of about 800%.

A further illustration of the benefits an air-void system is dramatically illustrated in figure 39 , which shows strain-temperature patterns for a fly-ash mix with water-solids ratio of 0.50 (45% replacement). At one day the fly-ash paste without air exhibited a dilation of

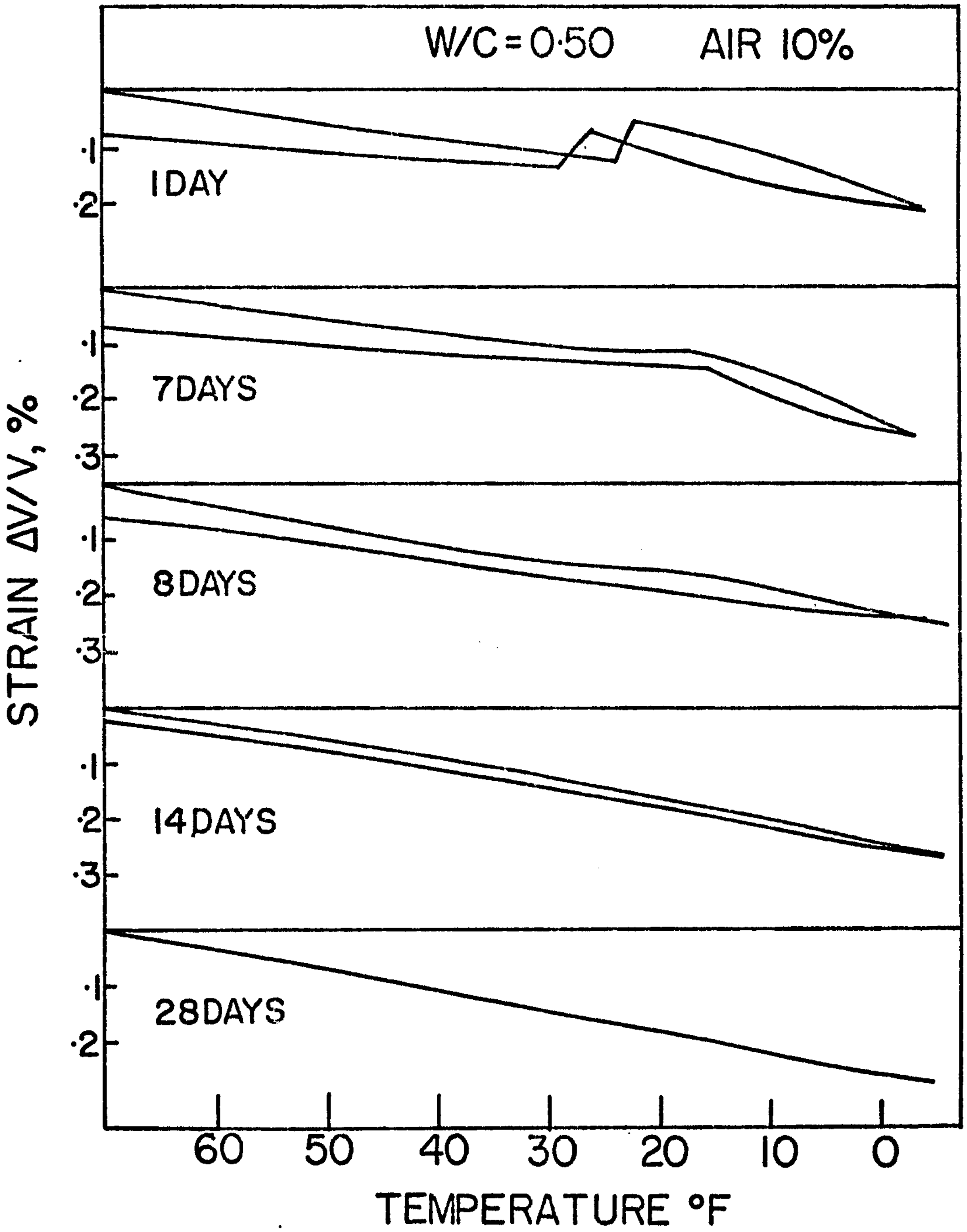


Figure 34 Strain-Temperature Plot For w/c=0.50; Air 10%

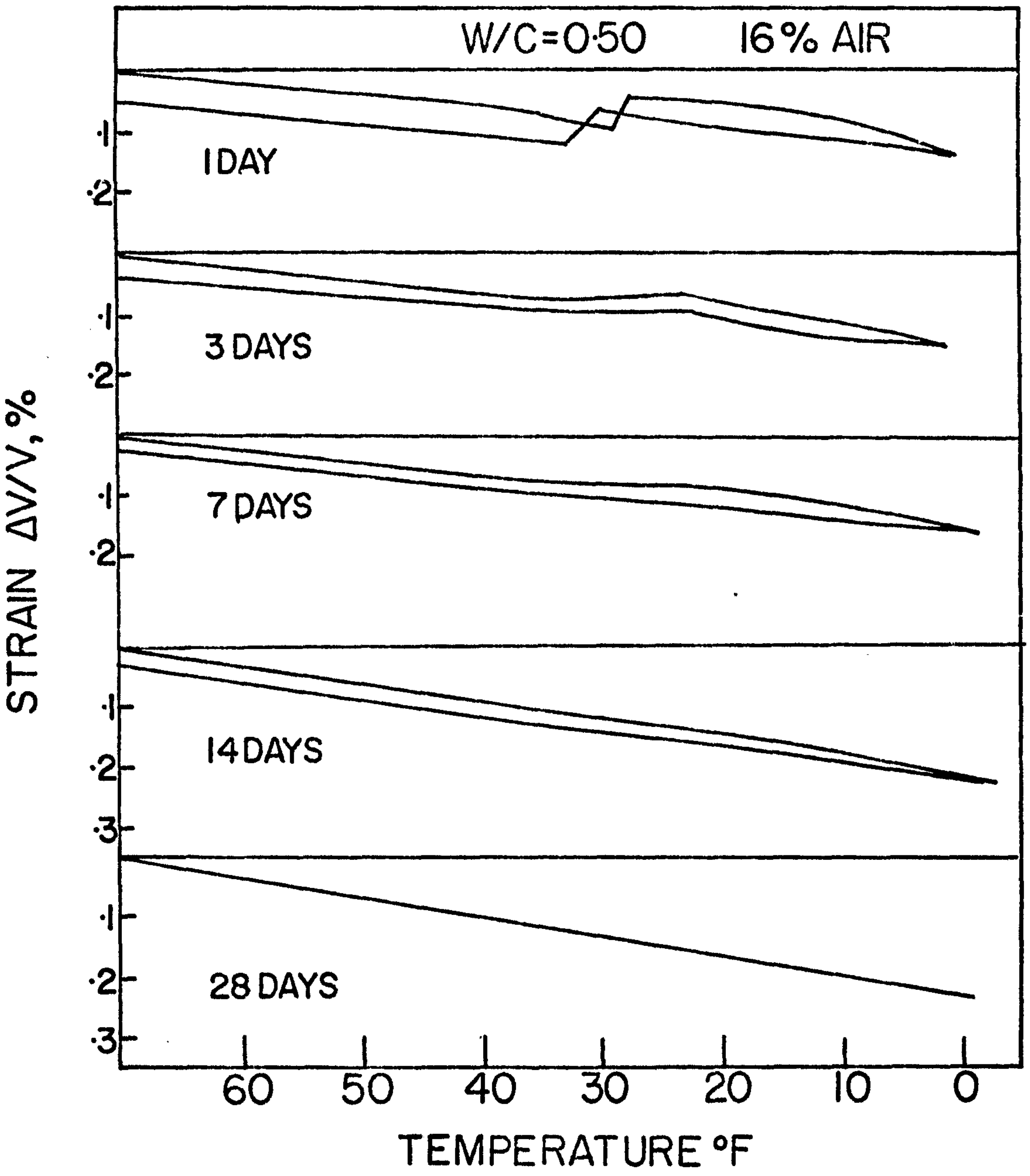


Figure 35 Strain-Temperature Plot For w/c=0.50; Air 16%

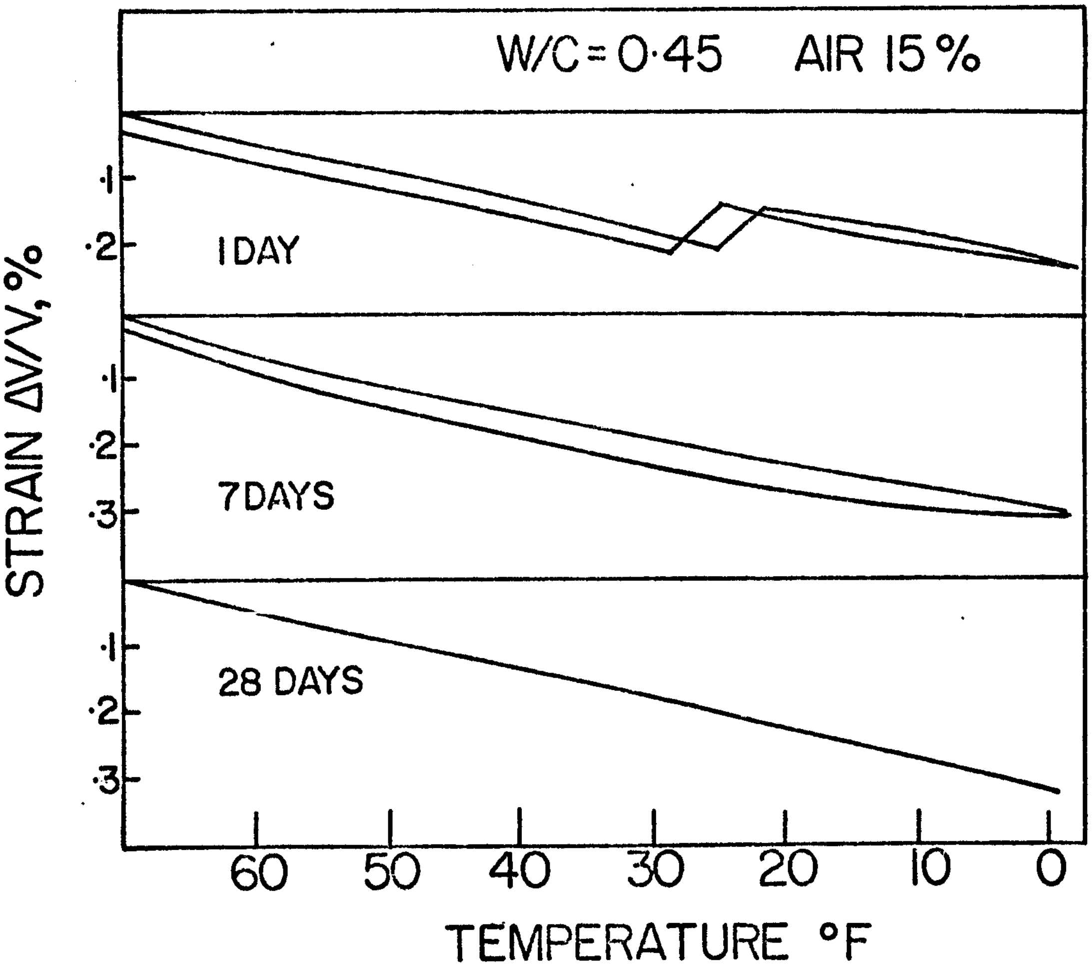


Figure 36 Strain-Temperature Plot For w/c=0.45; Air 15%

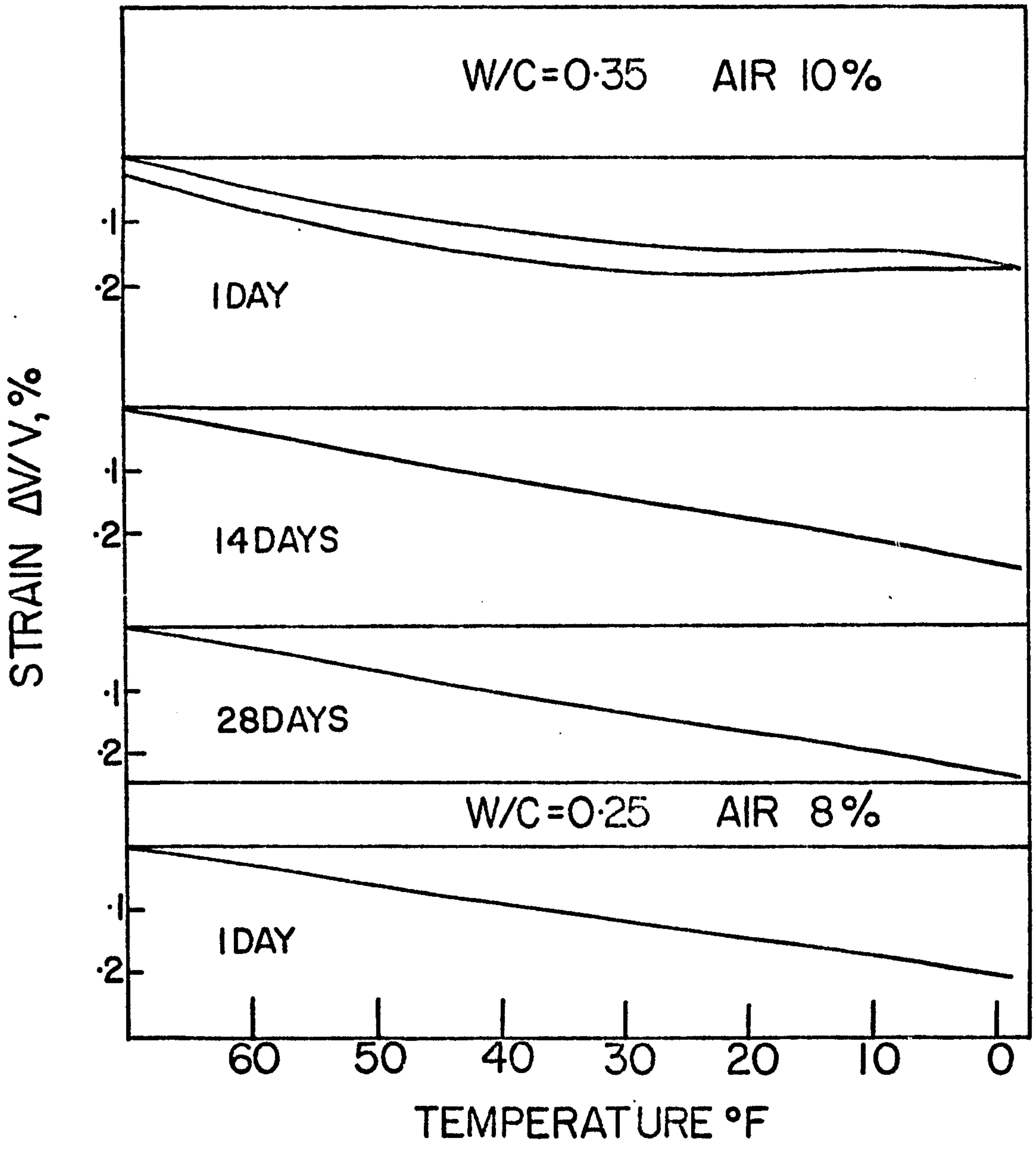


Figure 37 Strain-Temperature Plots For w/c=0.35 and 0.25; Air 10% And 8%

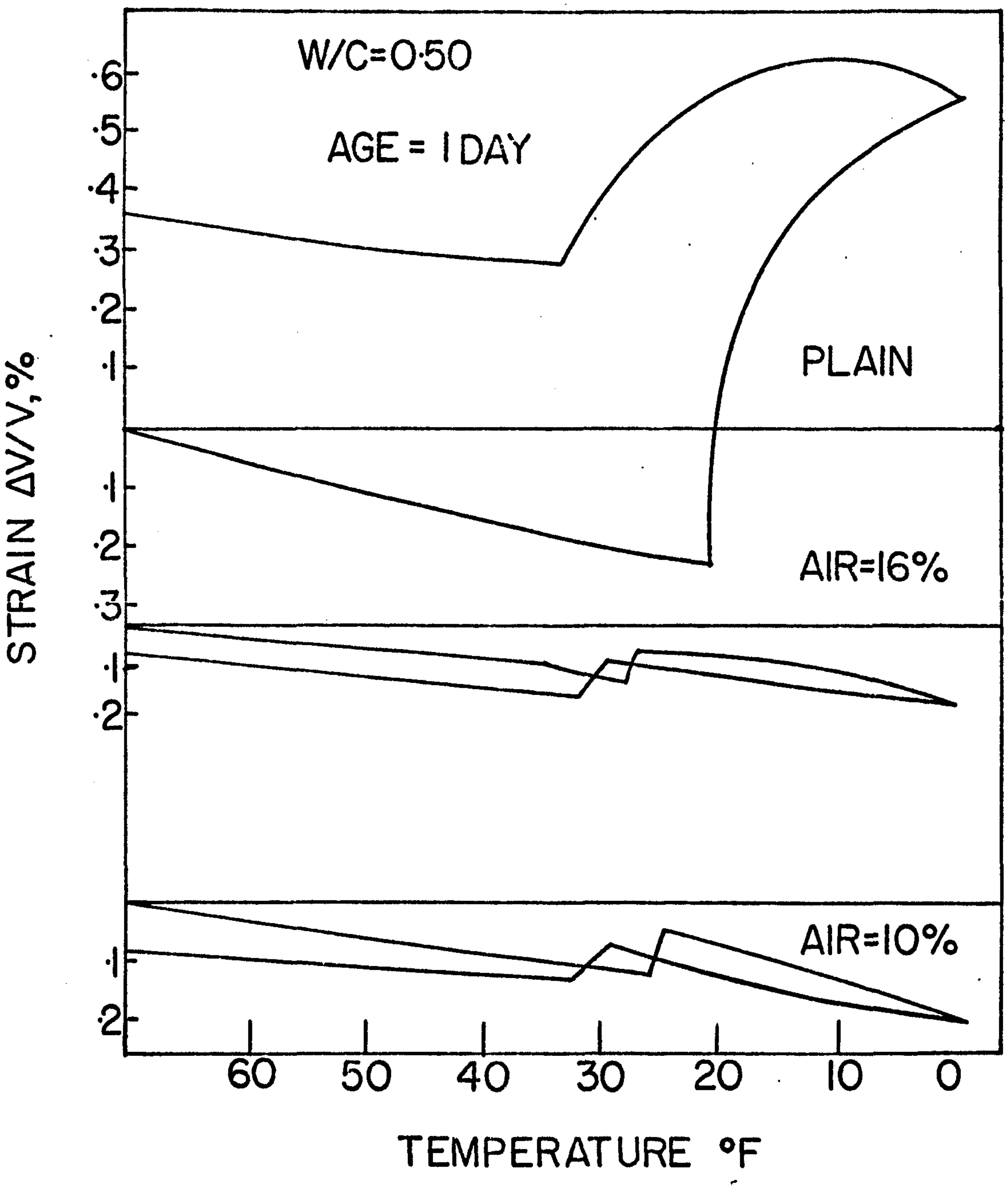


Figure 38 Strain-Temperature Plot For w/c=0.50 At 1 Day-Plain vs Air Entrained

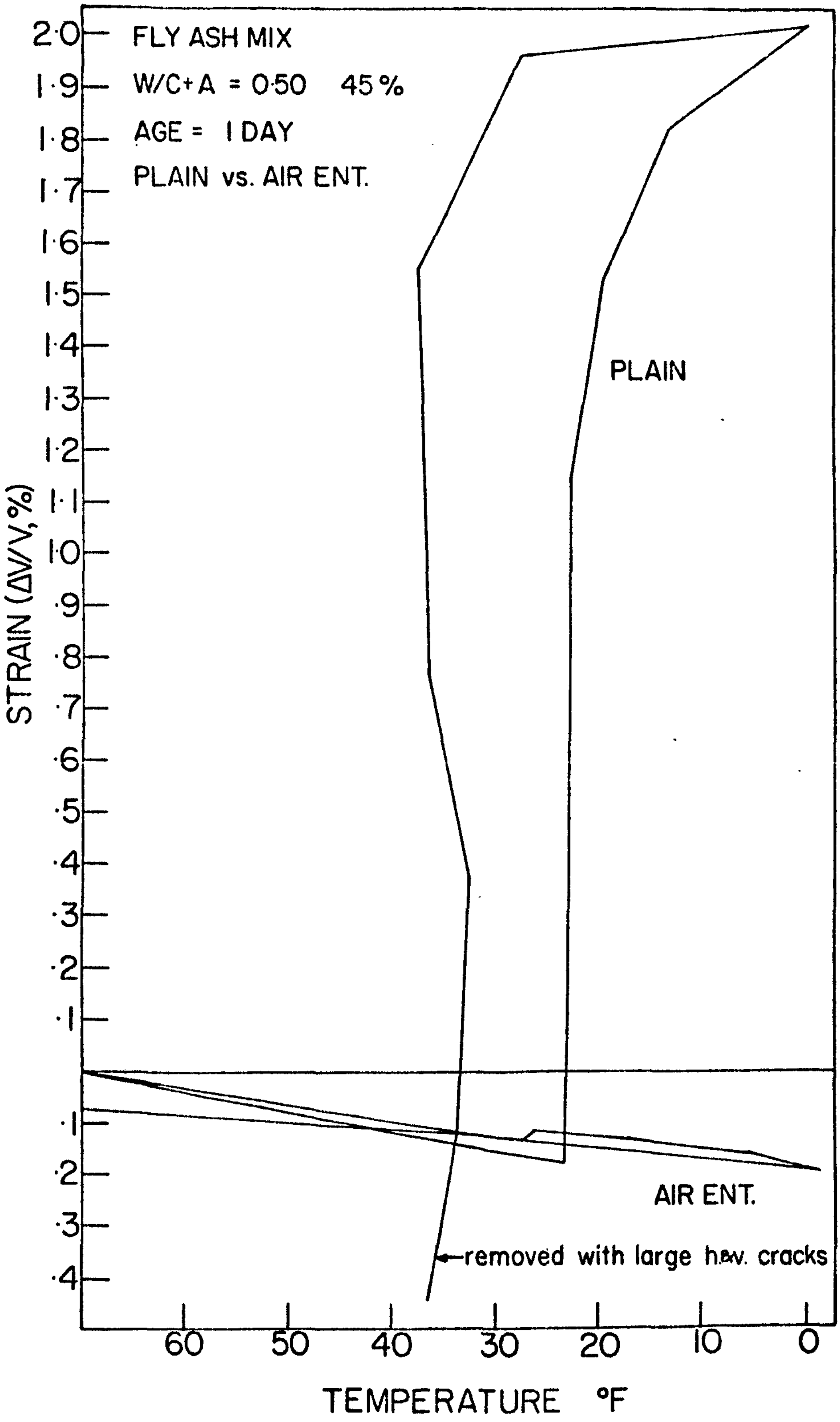


Figure 39 Strain-Temperature Plot For Fly Ash Paste At 1 Day-Plain vs Air Entrained

approximately 2.2%. In sharp contrast the fly ash paste containing the air void system (10% air) had a small dilation of less than 0.05%.

Residual volume change

The residual volume change parameters for the air-entrained pastes in this series were all negative. Figure 40 is a plot of residual volume change vs. age. From the figure it appears that the negative residual increases with water-cement ratio and decreases with age.

Table VI gives average values for residual strains of air-entrained pastes.

Limiting water-cement ratios

It has been demonstrated by Mac Innis and Beaudoin(47) that even air-entrained concrete can exhibit a damaging dilational tendency if the water-cement ratio as well as moisture content is high enough. Figures 41 to 42 show the effect of water cement ratio and degree of saturation on a series of mortar mixes. In this mortar series the limiting water-cement ratio, below which a nominal air content of 9 per cent was capable of preventing expansions during freezing was found to be 0.58. At water-cement ratios above this value expansions were produced in air-entrained mixes when the degree of saturation was above 90 per cent. Results from this programme will be discussed in the

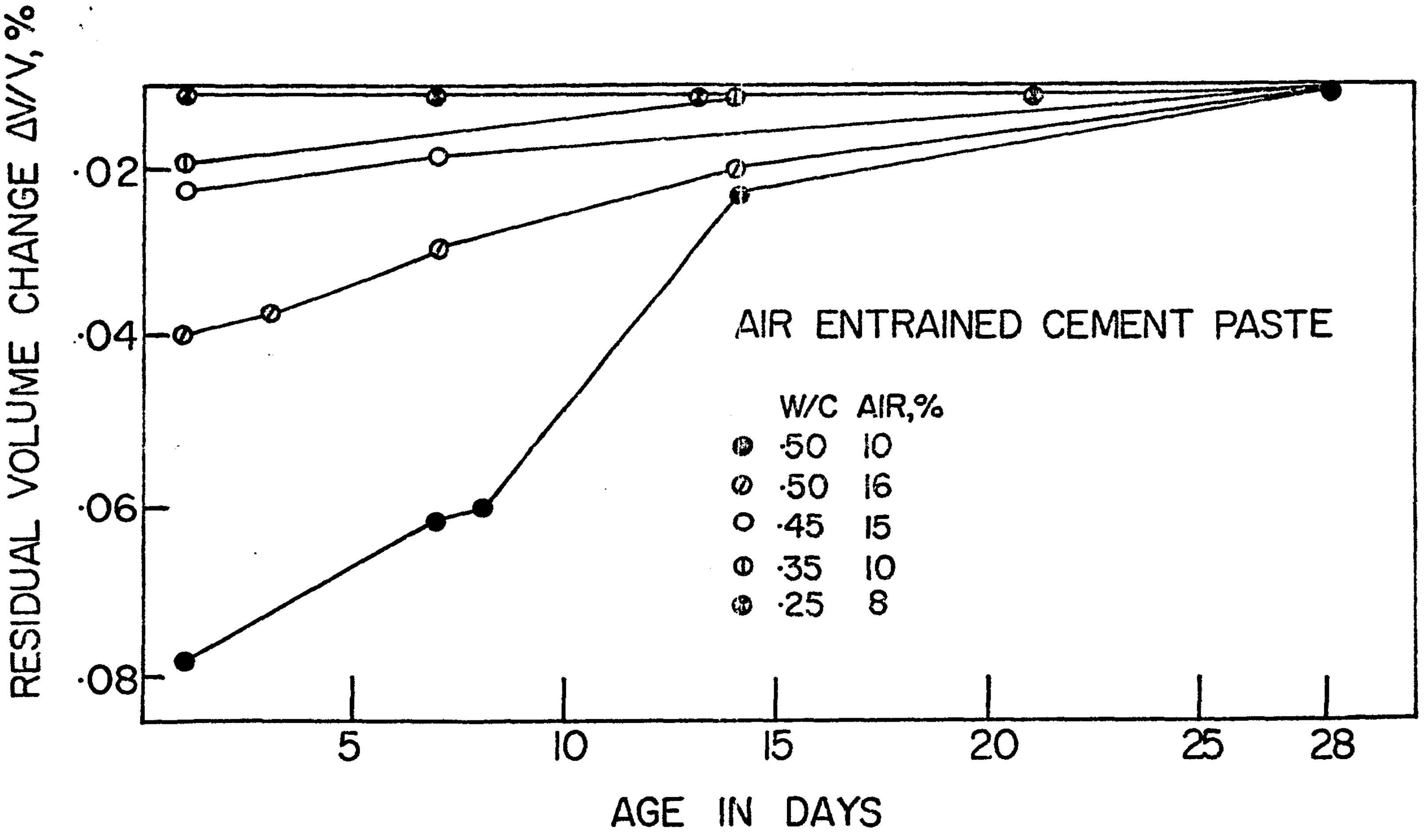


Figure 40 Residual Volume Change vs Age-Air Entrained Paste

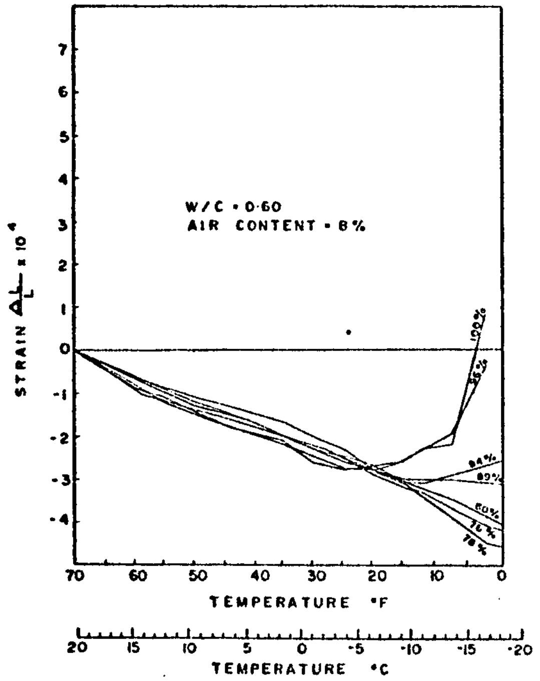


Fig. —Effect of degree of saturation on length change patterns (water-cement ratio = 0.60)

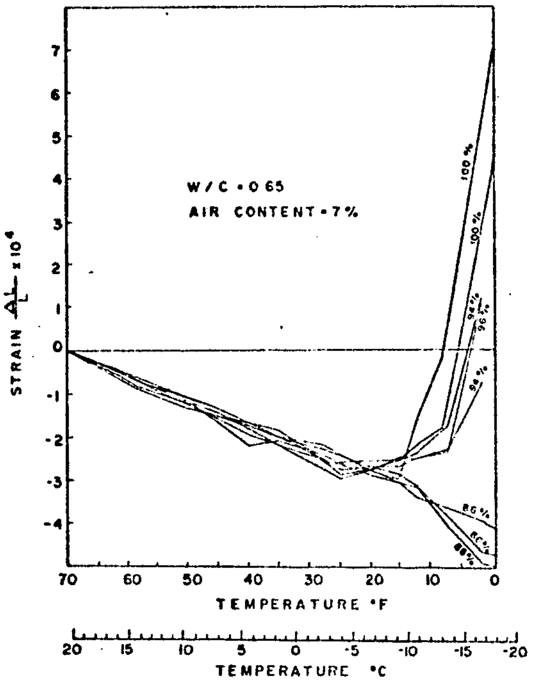


Fig. —Effect of degree of saturation on length change patterns (water-cement ratio = 0.65)

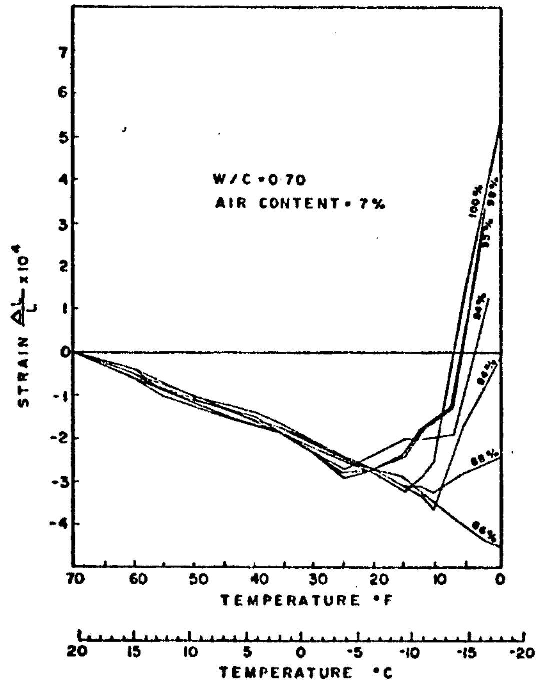


Fig. —Effect of degree of saturation on length change patterns (water-cement ratio = 0.70)

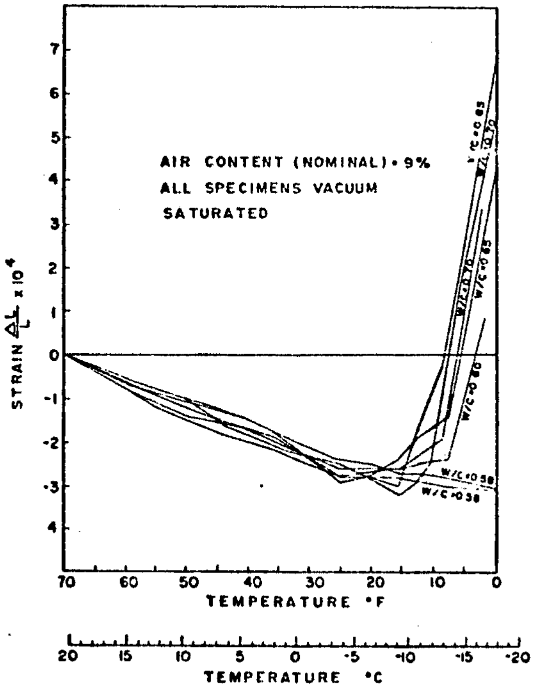


Fig. -Effect of water-cement ratio on length change patterns

Figure 41 Effect of Degree of Saturation On Length Changes of Mortar (After MacInnis and Beaudoin)

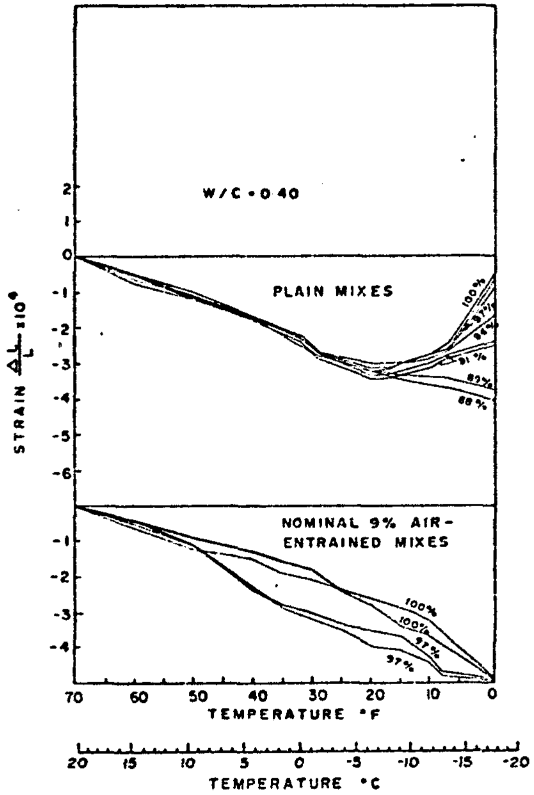


Fig. —Effect of air entrainment and degree of saturation on length change patterns (water-cement ratio = 0.40)

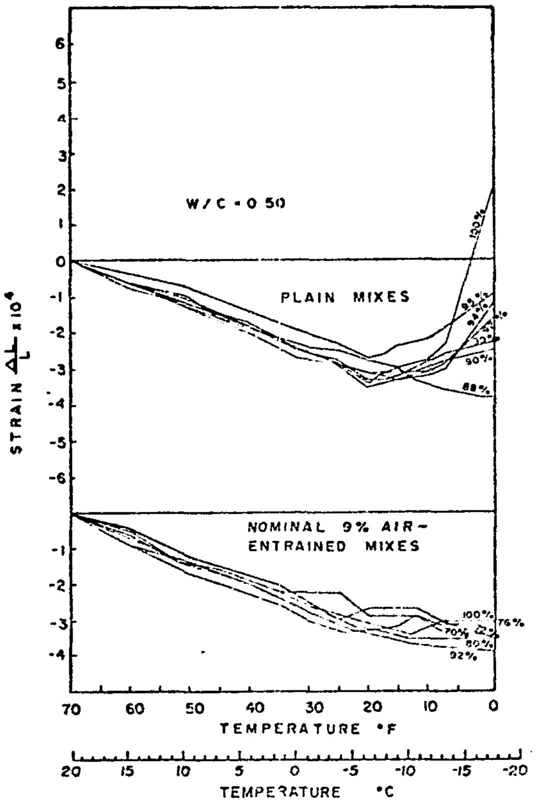


Fig. —Effect of air entrainment and degree of saturation on length change patterns (water-cement ratio = 0.50)

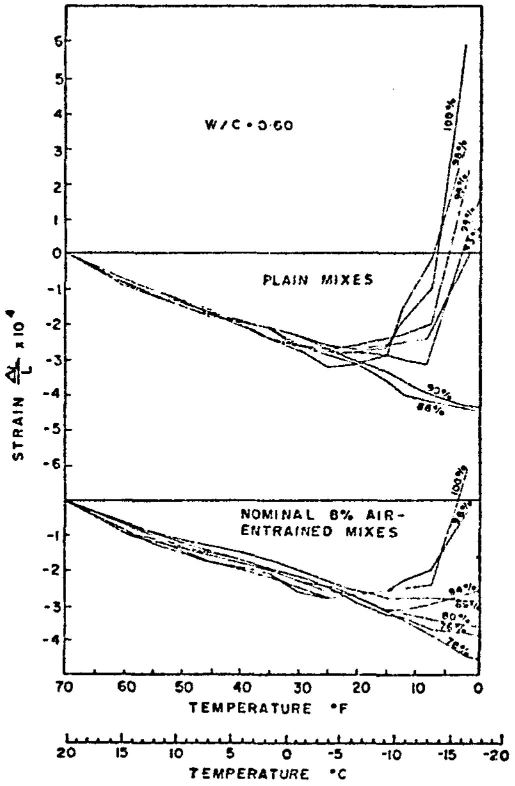


Fig. —Effect of air entrainment and degree of saturation on length change patterns (water-cement ratio = 0.60)

Figure 42 Effect of Air and Water-Cement Ratio on Length Changes of Mortar (After MacInnis and Beaudoin)

W/C	AGE	ADMIXTURE	RESIDUAL STRAIN ($\frac{\Delta V}{V}\%$)
0.50	1	AEA(10%)	-0.075
	7		-0.065
	8		-0.060
	14		-0.025
	28		0
0.50	1	AEA(16%)	-0.040
	3		-0.035
	7		-0.025
	14		-0.020
	28		0
0.45	1	AEA(15%)	-0.025
	7		-0.015
	28		0
0.35	1	AEA(10%)	-0.020
	14		0
	28		0
0.25	1	AEA(8%)	0

Table VI Average Residual Strains For Air-Entrained Pastes

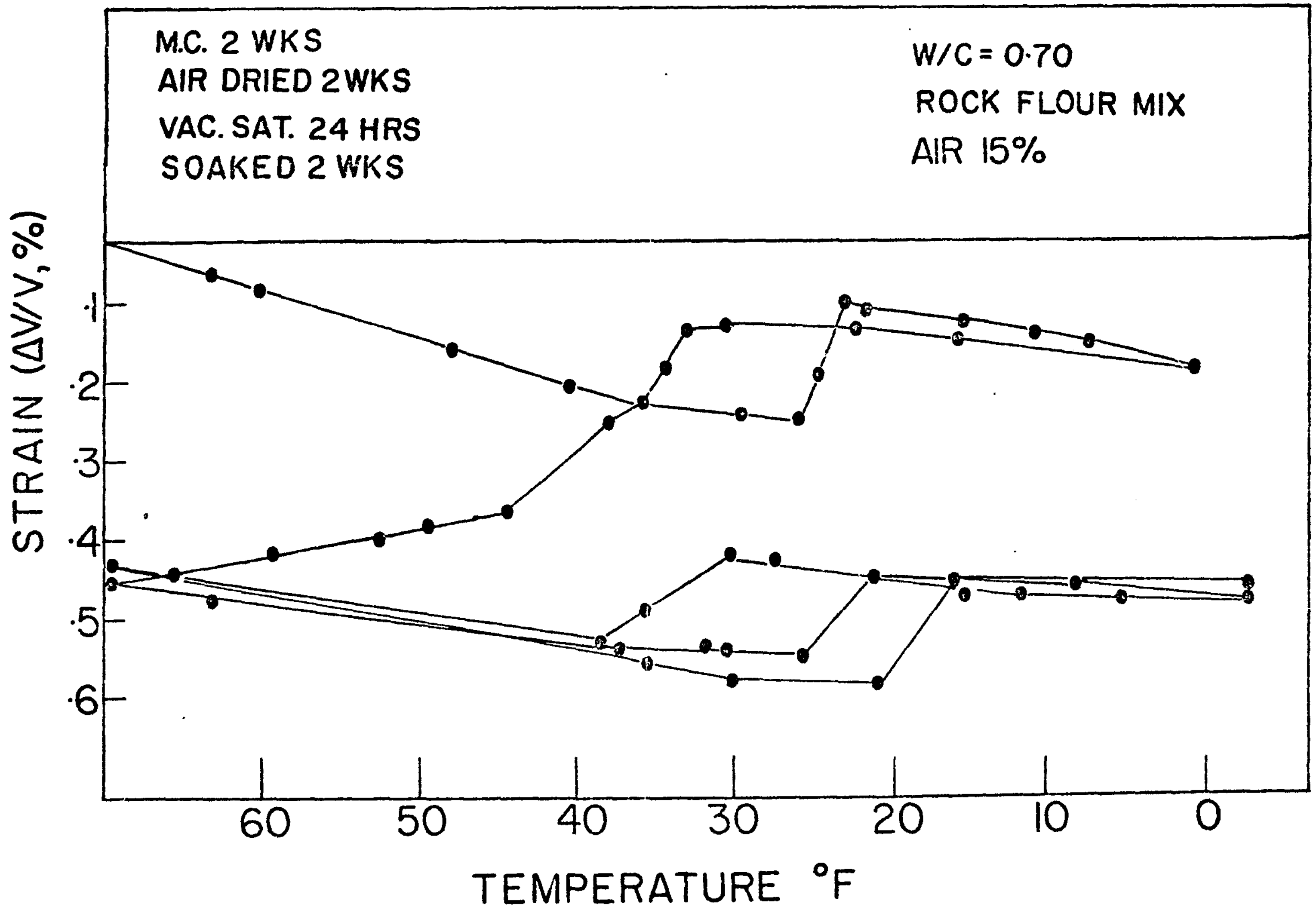


Figure 43 Multiple Cycle For Rock Flour Paste With w/c=0.70; Air 15%

following section on degree of saturation.

DISCUSSION OF TEST RESULTS - AIR ENTRAINED PASTE

The benefit of air was clearly established for a cooling warming cycle of 5°F/hr. Negative residuals (observed for all mixes in this programme) may have been due to shrinkage of the hydrate the vapor pressure of the hydrate water would have exceeded the vapor pressure in the air voids resulting in moisture migration to the air void system. Shrinkage of the hydrate system appears to be irreversible; this could be due to structural reorientation of the hydrate. Water-cement ratio appears to be the major factor controlling the dimensional stability of air-entrained paste. That is, for higher water-cement ratios, (0.70-1.00) the paste can be still vulnerable to frost.

Figure 43 shows a strain-temperature plot for a rock flour paste with water-cement ratio 0.70. This paste contains an air-void system with a total void volume of 15%. We can see that there is a dilational response of about .2% despite the air void system and a large negative residual of .45%. Subsequent cycling has the stabilizing effect of reducing the change in negative residual to a negligible amount. The salient feature of this figure is that it demonstrates the influence of a high water-cement ratio in the presence of an adequate air void system.

CONCLUSIONS - AIR ENTRAINED PASTE

1) Air-entrainment can adequately protect cement-paste when subjected to a natural cooling-warming regime.

2) There is a limiting water-cement ratio above which a given air void system may not prove adequate.

3) The observed negative residual volume changes appear to be consistent with a shrinkage mechanism inherent in the hydrate as cooling below freezing takes place.

4) Water-cement ratio appears to be the most important parameter influencing the dimensional stability of air entrained cement paste.

C. TEST RESULTS - WATER REDUCING ADMIXTURES

Two water-reducing admixtures were used for these tests-calcium lignosulphonate and adipic acid.

Strain-temperature plots

Pastes containing these admixtures were prepared with water-cement ratios of 0.35 and 0.50. Figures 44 to 47 trace the strain-temperature history with time. For both water reducers the strain-temperature hysteresis collapses continuously

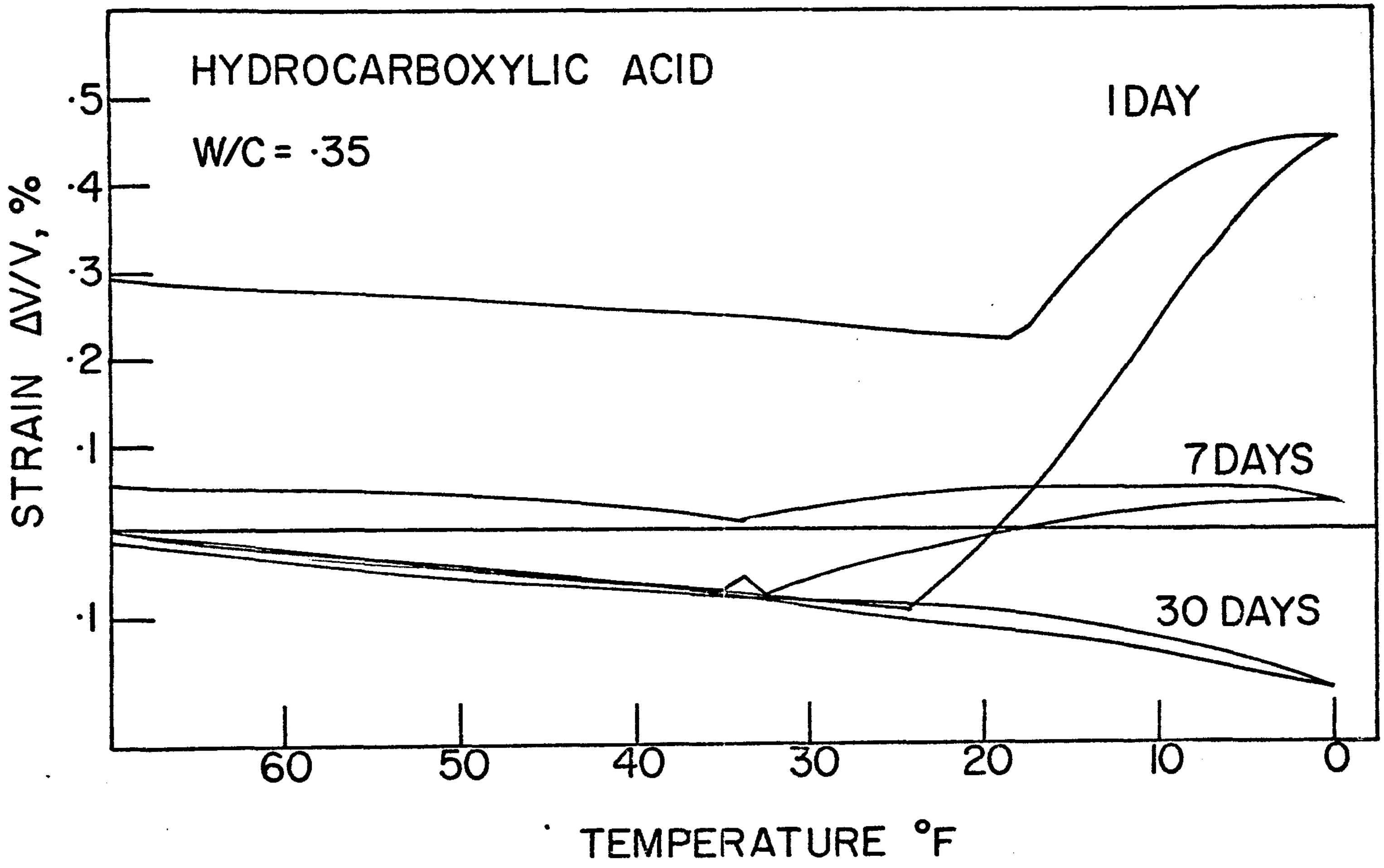


Figure 44 Strain-Temperature Plot For Paste With Adipic Acid; w/c=0.35

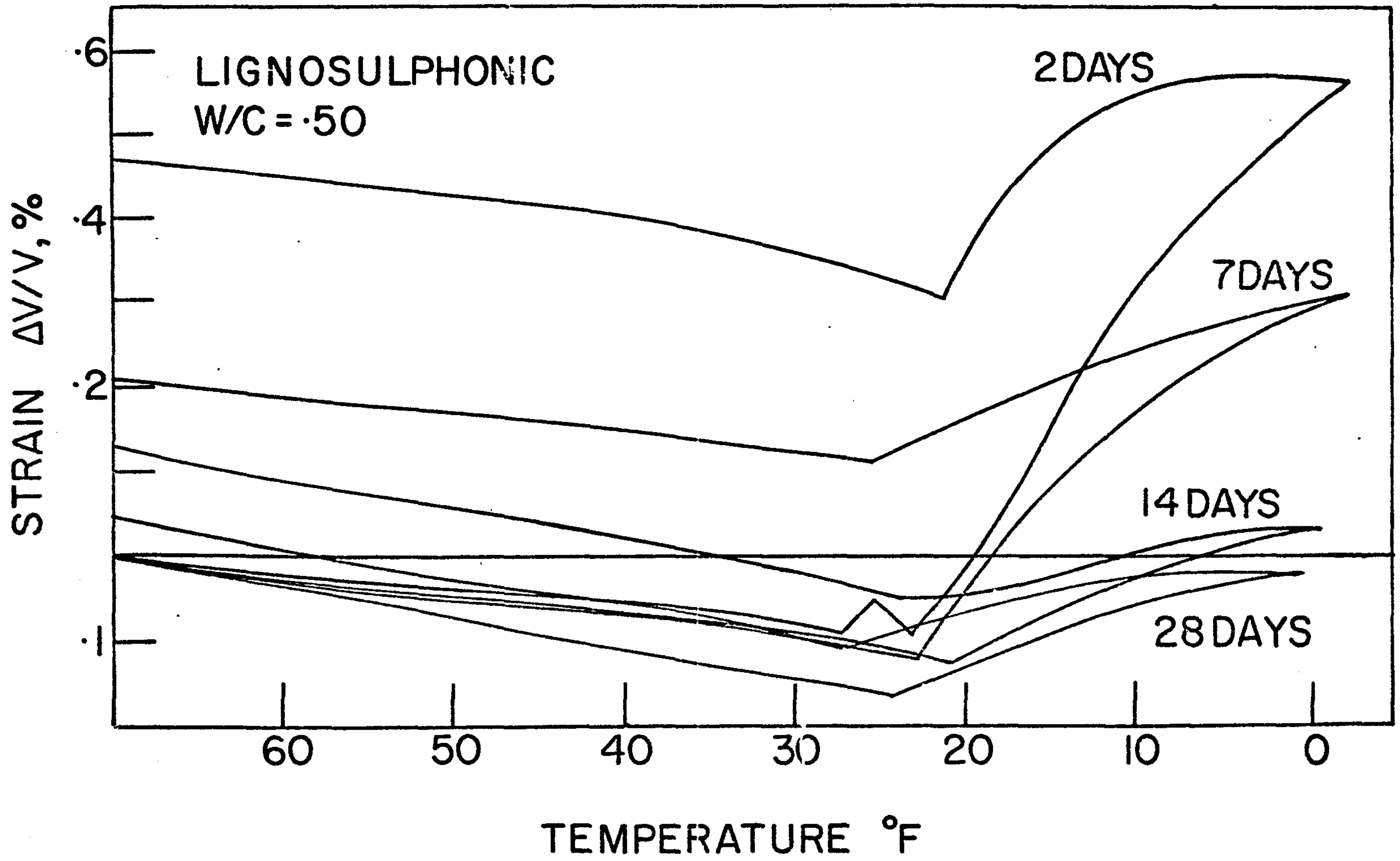


Figure 45 Strain-Temperature Plot For Paste With Lignosulphonic Water Reducer; w/c=0.50

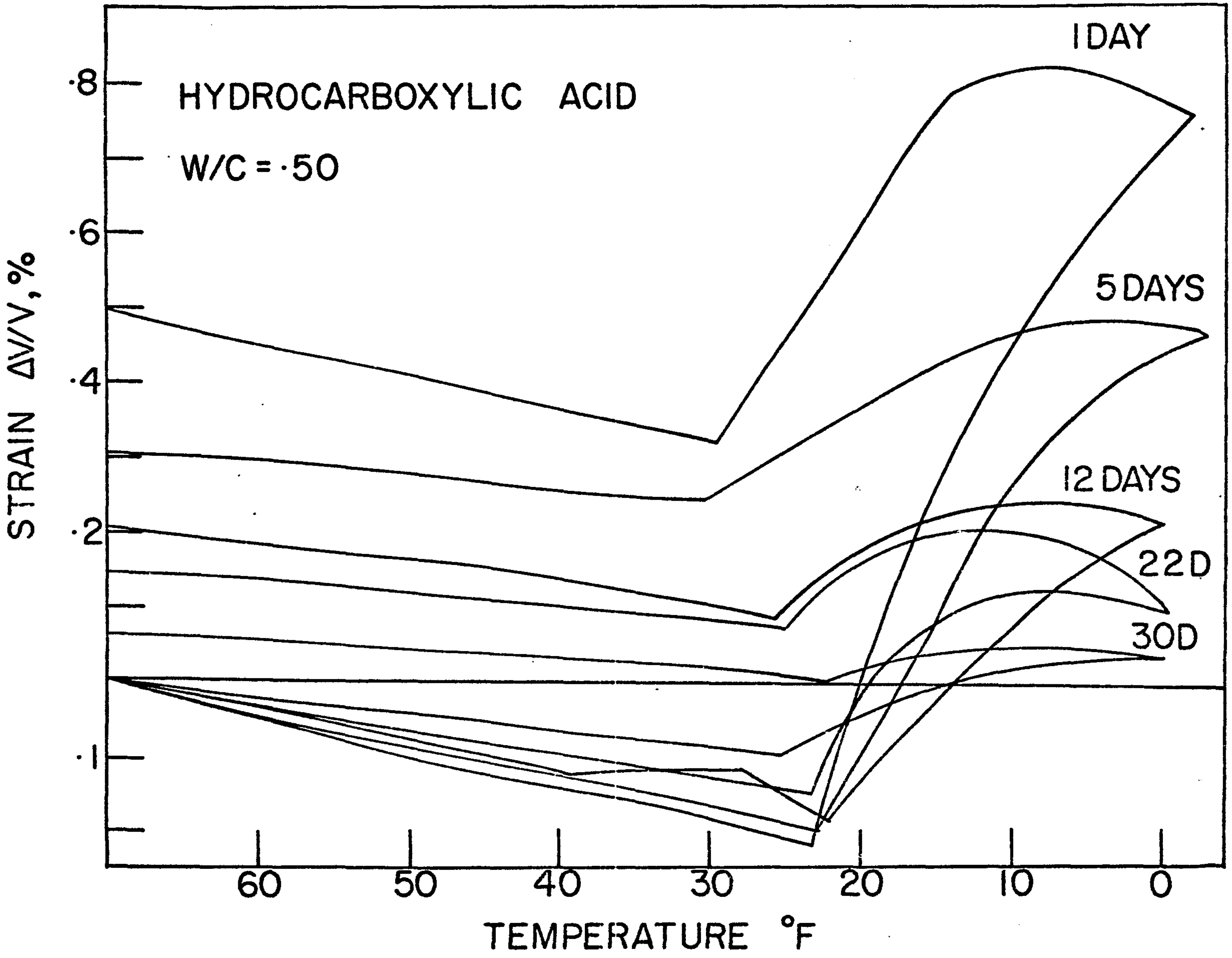


Figure 46 Strain-Temperature Plot For Paste With Adipic Acid; w/c=0.50

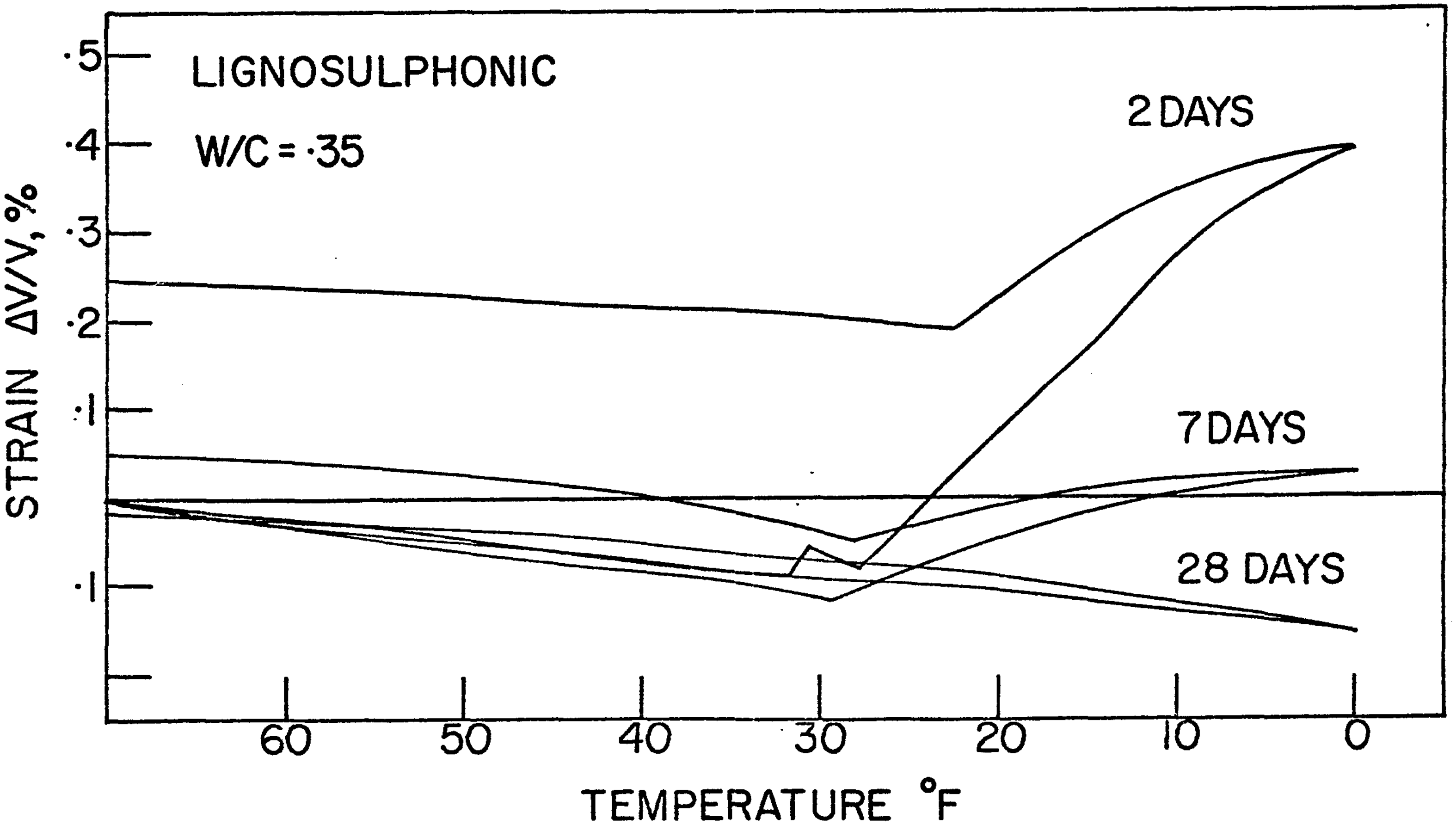


Figure [illegible] Strain-Temperature Plot For Paste With lignosulphonic Water Reducer; w/c=0.35

with time. The retarding effect is discernible from figures 44 and 45 as we can see that even at 28 and 30 days there is a dilation of about 0.25%.

Compressive strength vs. dilation

Compressive strength is plotted against dilation in figure 48 for the plain mixes as well as the mixes containing lignin and adipic acid. For all these mixes compressive strength appears to be a linear function of dilation as given by the following expression:

$$f_c = 4707 - 3845\, D_o \qquad \text{-----(31)}$$

This regression line is very similar to the expression for plain paste alone and is valid over the region $.035 < \frac{\Delta w}{w_o} < .10$. The relative influence of the water reducing admixtures on dilation and residual volume change will be discussed in a subsequent section.

DISCUSSION OF TEST RESULTS-WATER REDUCING ADMIXTURE SERIES

The linear relation between compressive strength and dilation appears to hold for pastes containing lignin and adipic acid. The nature of the hysteresis collapse appears unaltered and the retardation effect is clearly seen in the hysteresis

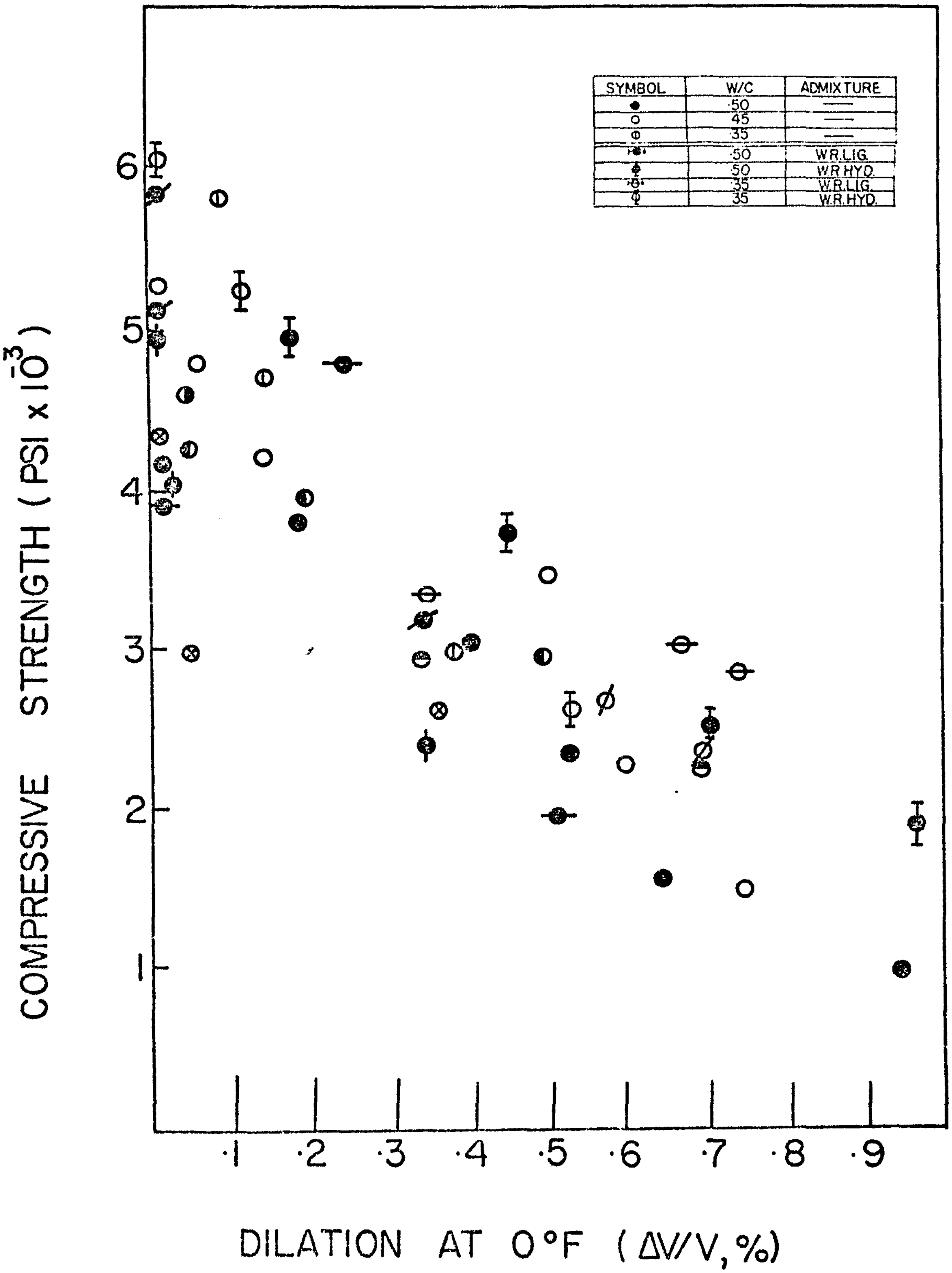


Figure 48 Strength vs Dilation-Pastes With and Without Water Reducers

at later ages. The relations connecting dilation and residual volume change with other hydration parameters will be discussed when other admixtures are considered.

CONCLUSIONS

1) Water-reducing admixtures do not appear to affect the strength-dilation relation for pastes and appear to have little affect on the dimensional stability of paste subjected to a slow cooling and warming cycle of 5°F/hr.

2) The retardation effect only delays the hysteresis collapse without altering the strength-dilation function.

D. PASTES CONTAINING FLY ASH

An extensive series of experiments were carried out on pastes using fly ash as a replacement. The following table gives a summary of the mixes employed in this series of tests.

WATER/CEMENT + ASH	REPLACEMENT
0.35	15,30,45%
0.45	15,30,45%
0.50	15,30,45%

Table VII Mix Parameters For Fly Ash Mixes

Strain-temperature plots

Figures 49 to 57 illustrate the transient strain behaviour of the various fly-ash mixes; they demonstrate the time dependent nature of the

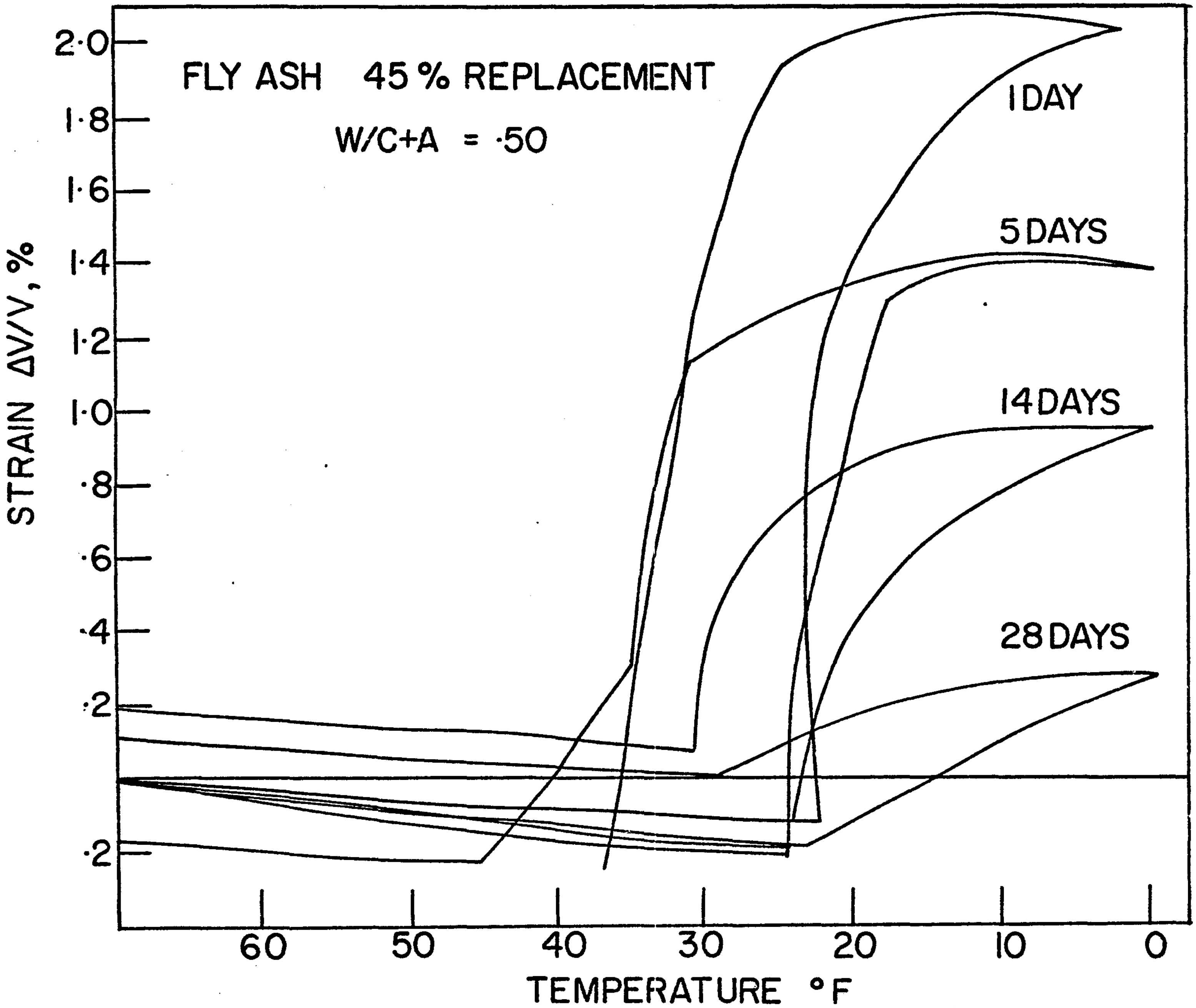


Figure 49 Strain Temperature Plot For Fly Ash Paste (45%); w/c+a=0.50

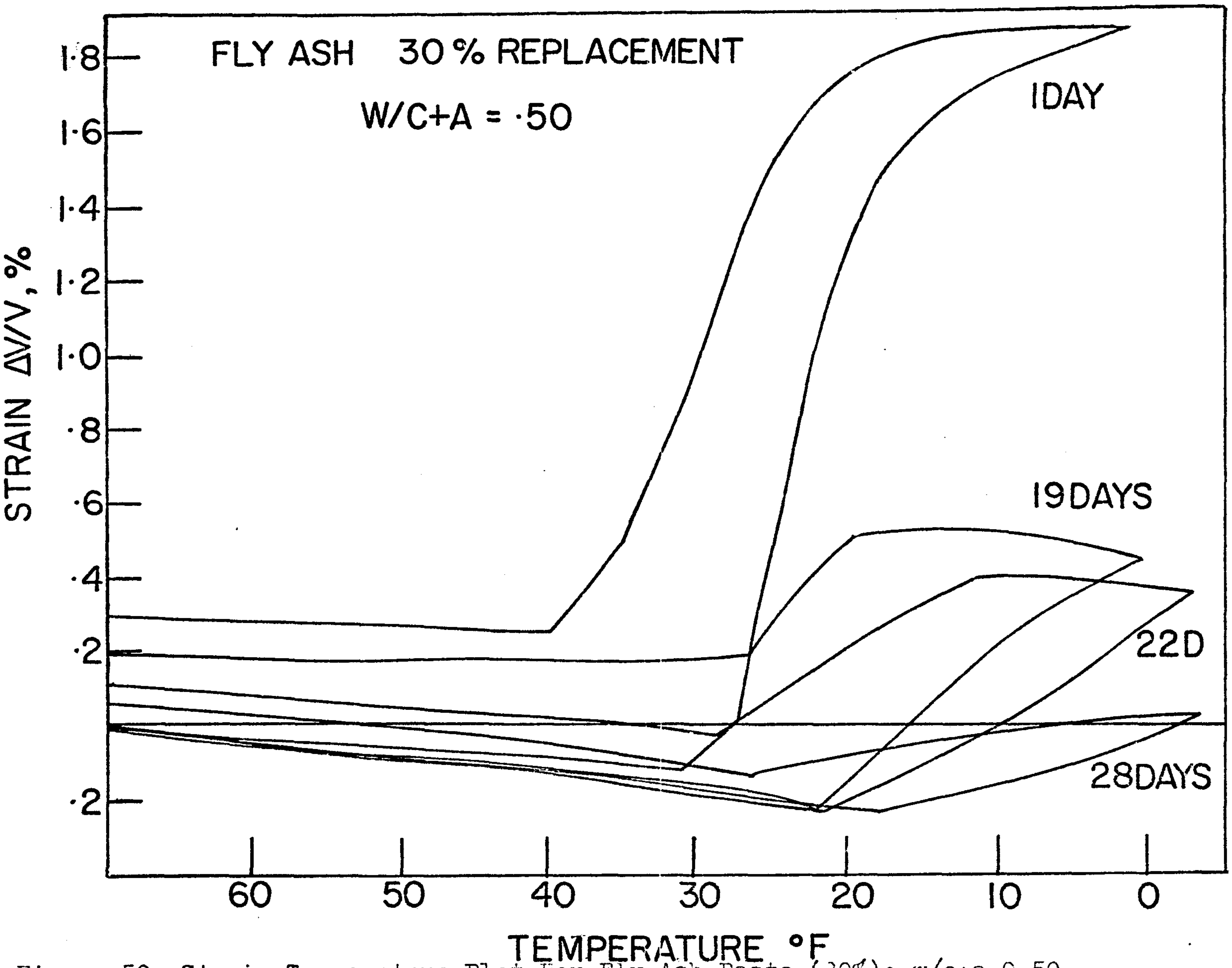


Figure 50 Strain-Temperature Plot For Fly Ash Paste (30%); w/c+a=0.50

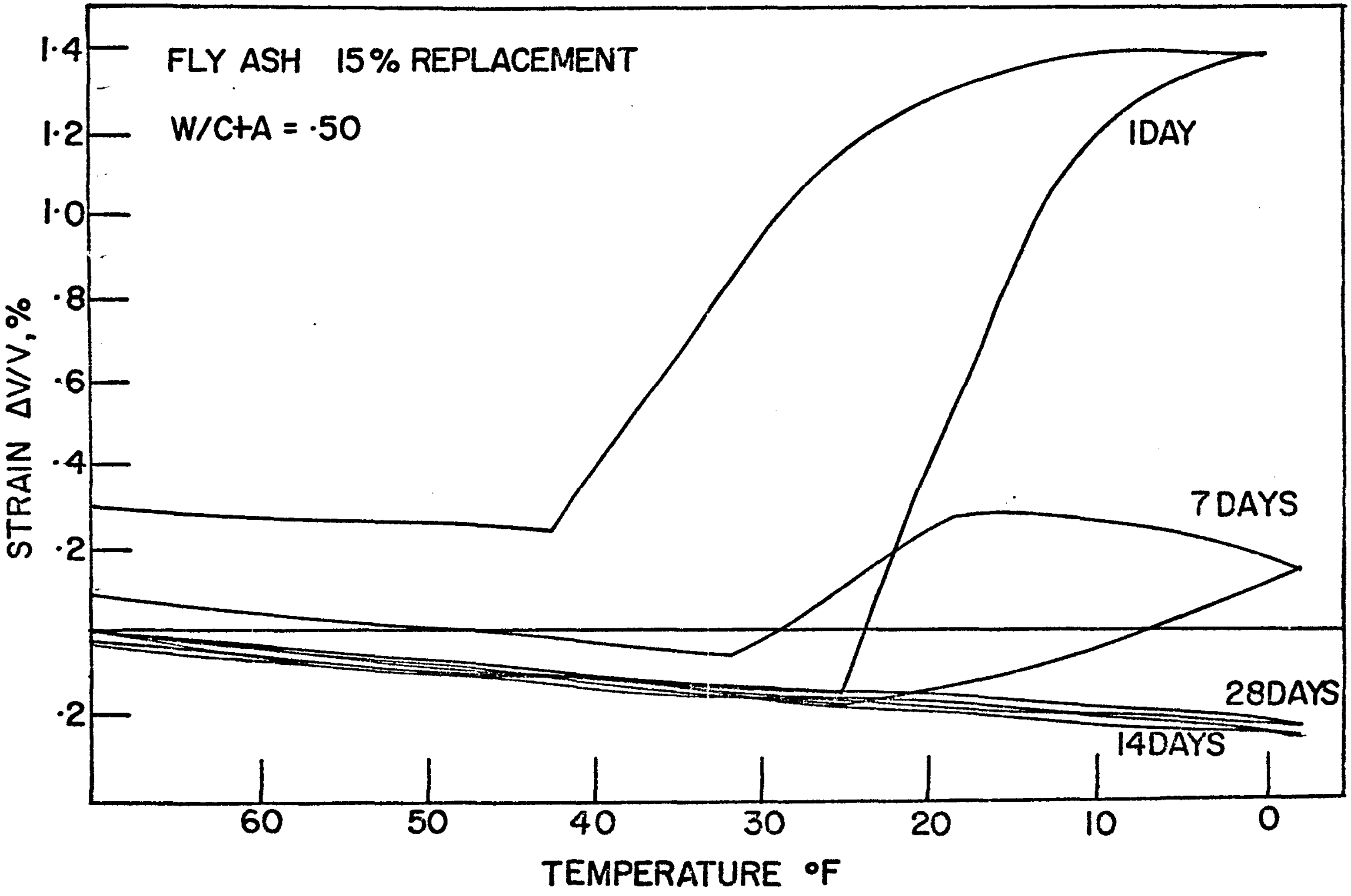


Figure 51 Strain-Temperature Plot For Fly Ash Paste (15%); w/c+a=0.50

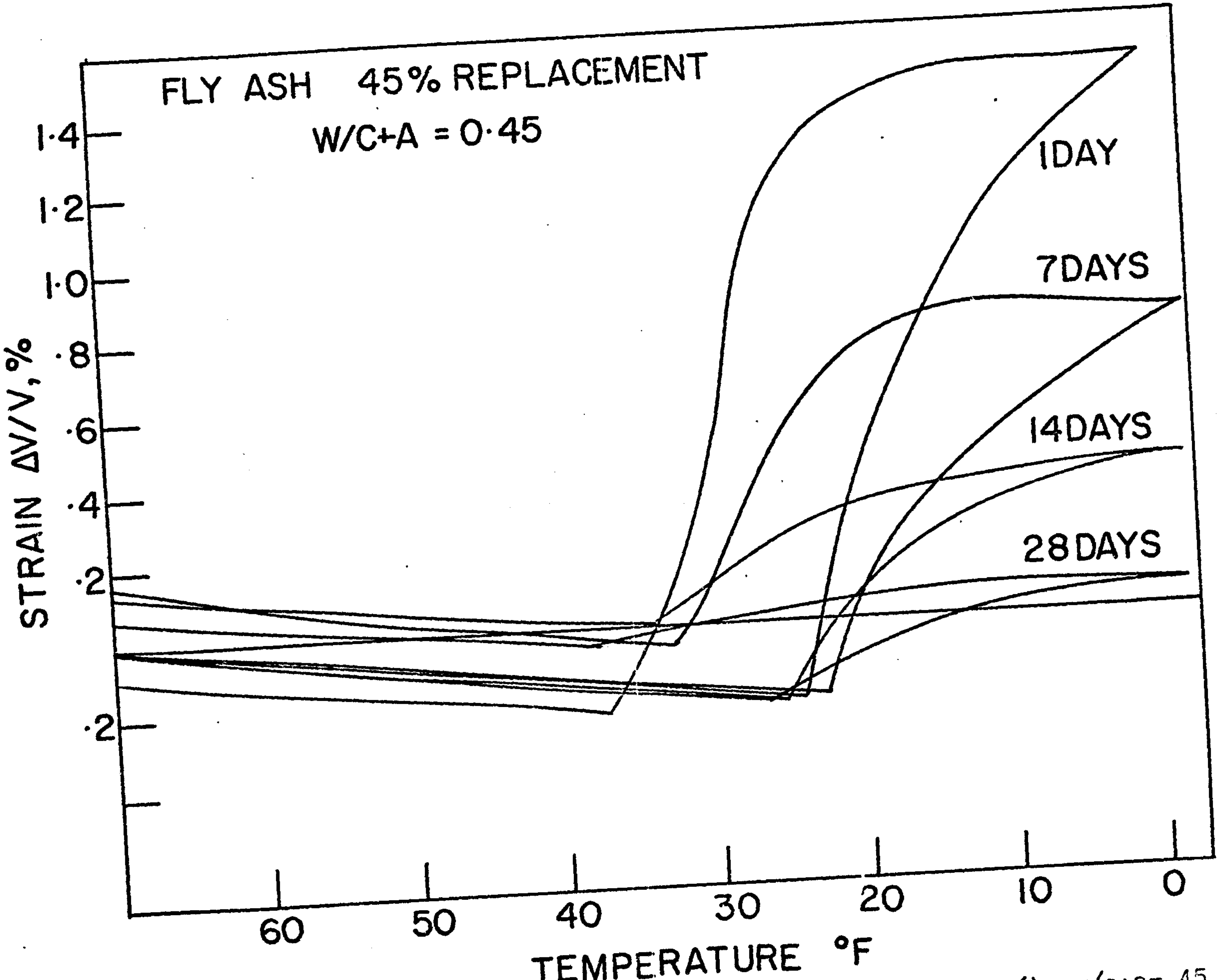


Figure 52 Strain-Temperature Plot For Fly Ash Paste (45%); w/c+a=.45

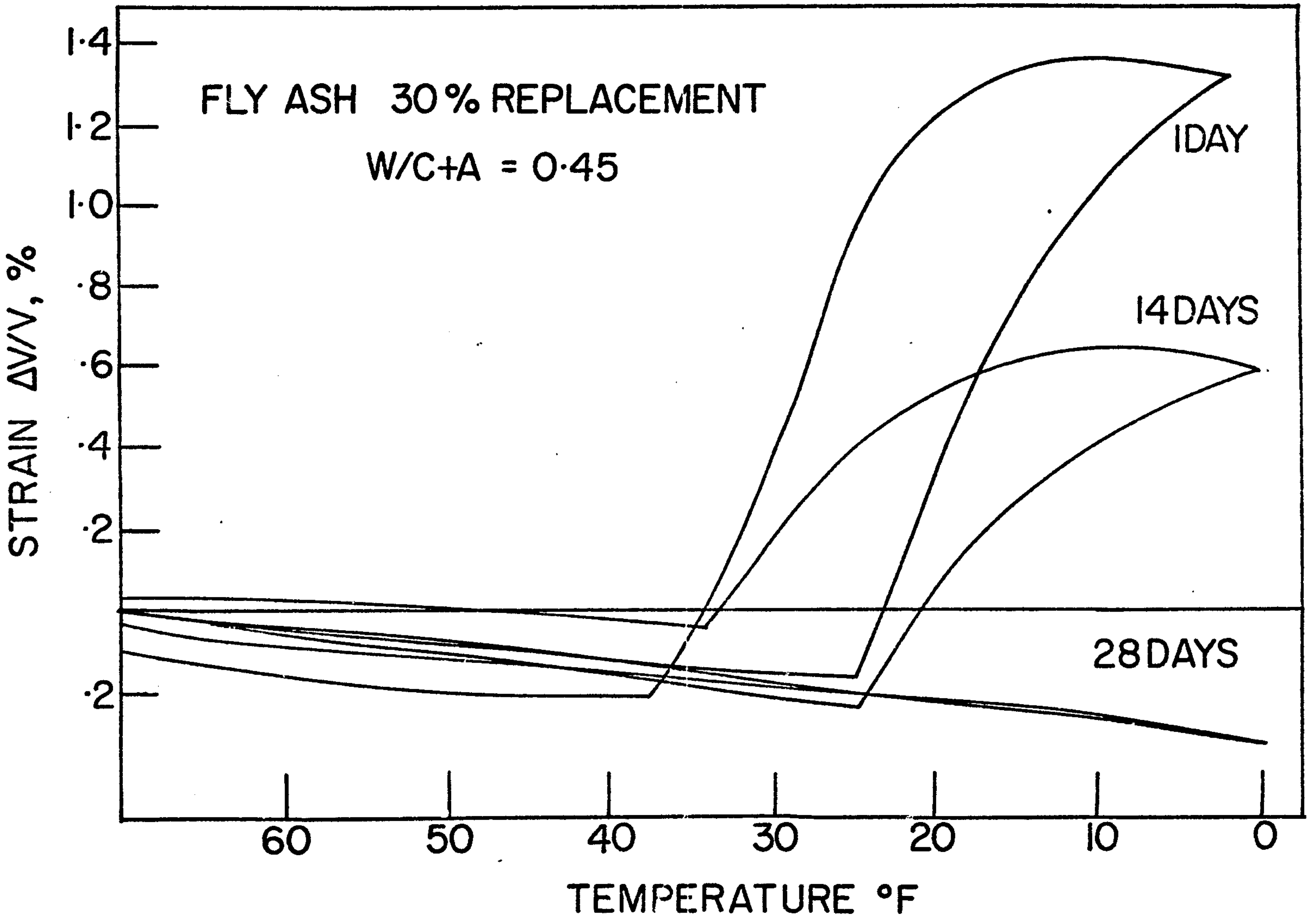


Figure 53 Strain-Temperature Plot For Fly Ash Paste (30%); w/c+a=.45

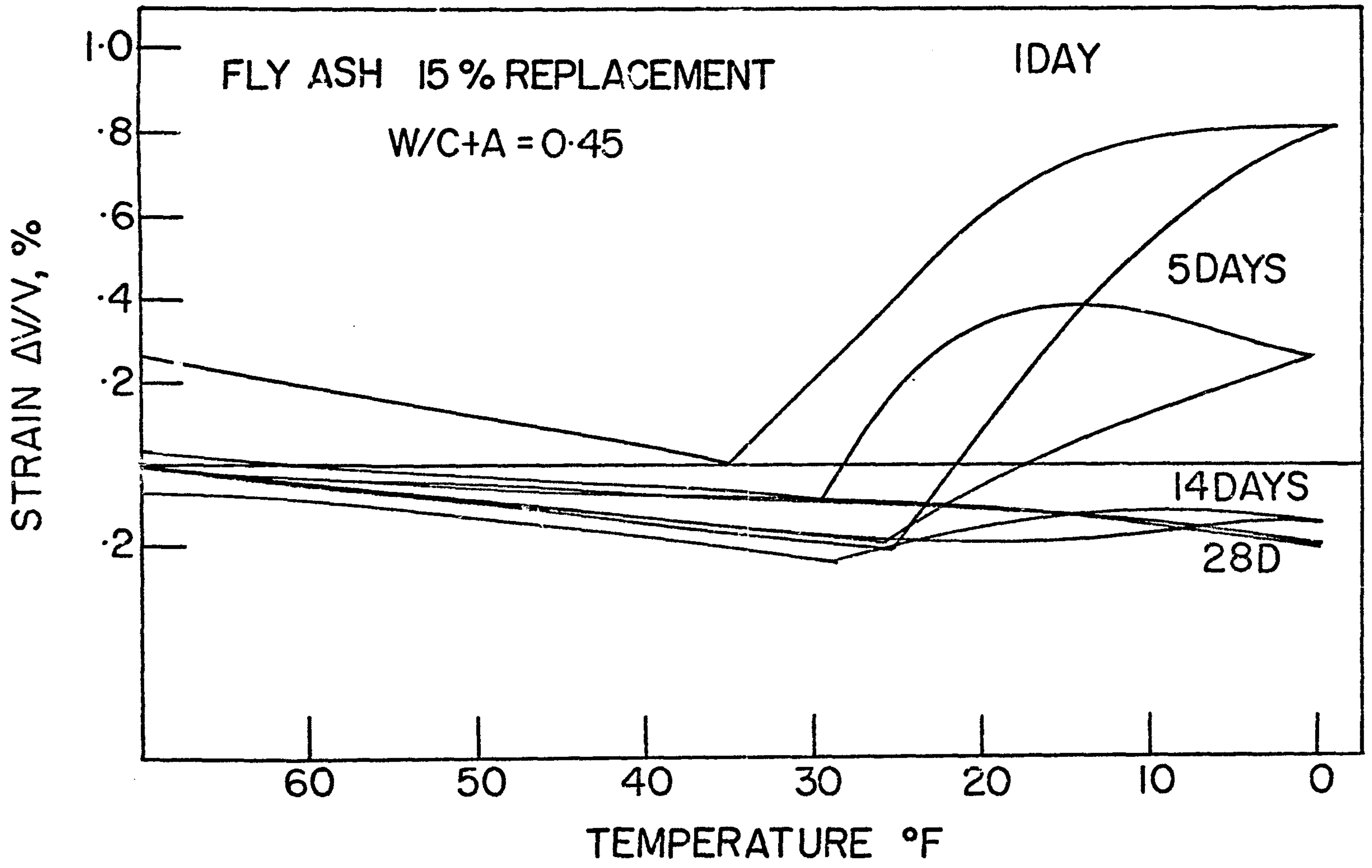
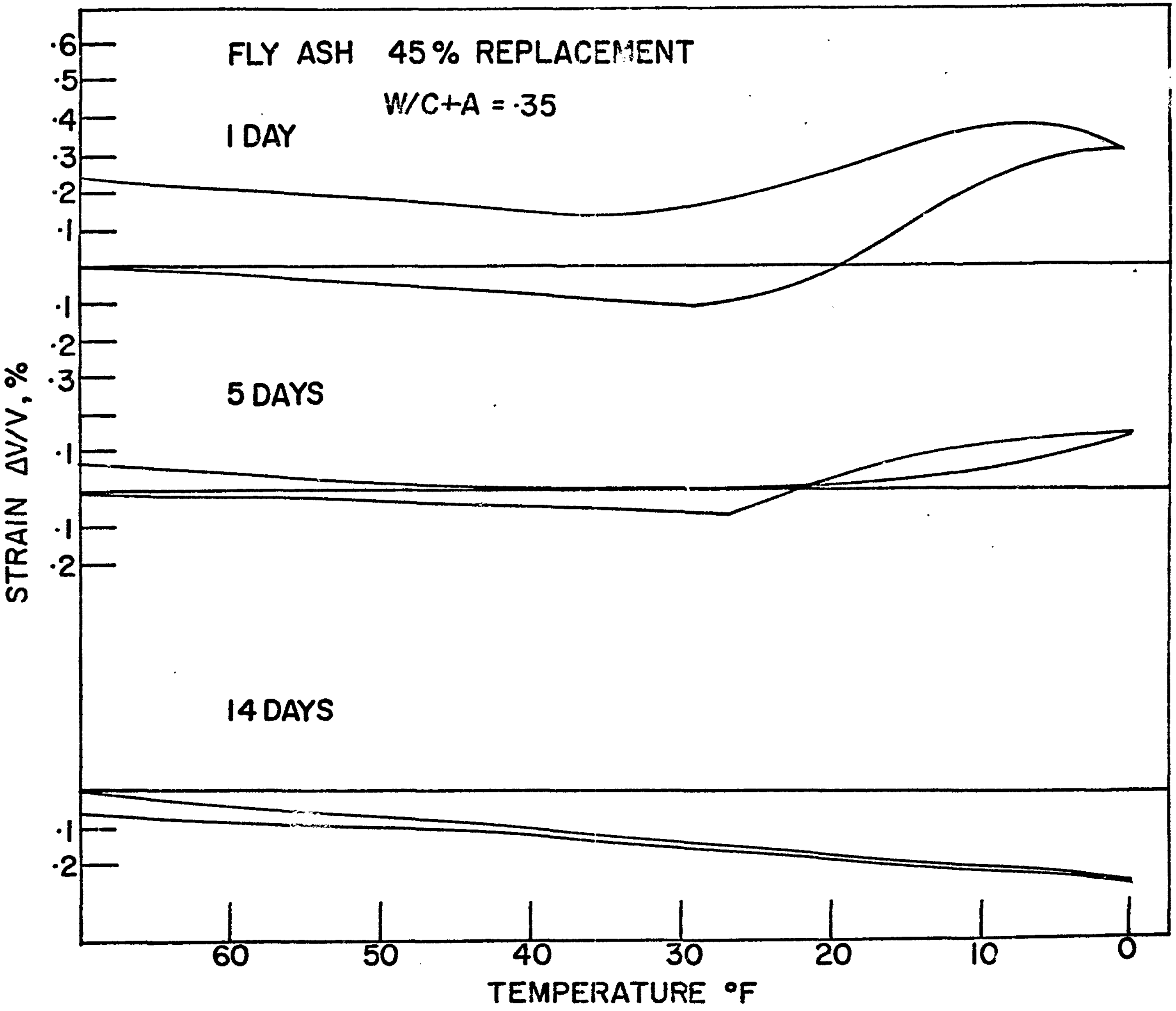


Figure 54 Strain-Temperature Plot For Fly Ash Paste (15%); w/c+a=.45

Figure 55 Strain-Temperature Plot For Fly Ash Paste (45%); w/c+a=.35



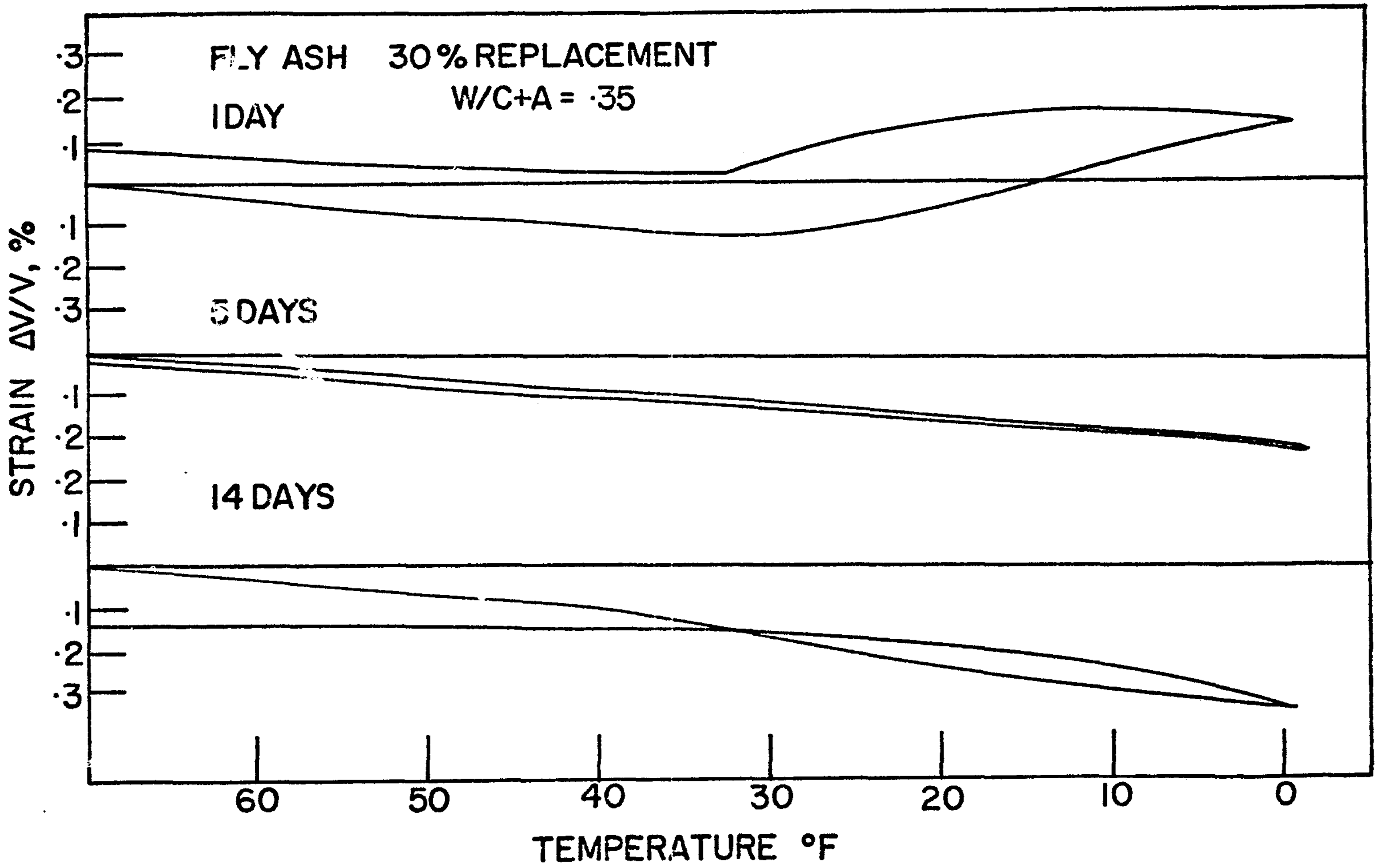


Figure 56 Strain-Temperature Plot For Fly Ash Paste (30%); w/c+a=.35

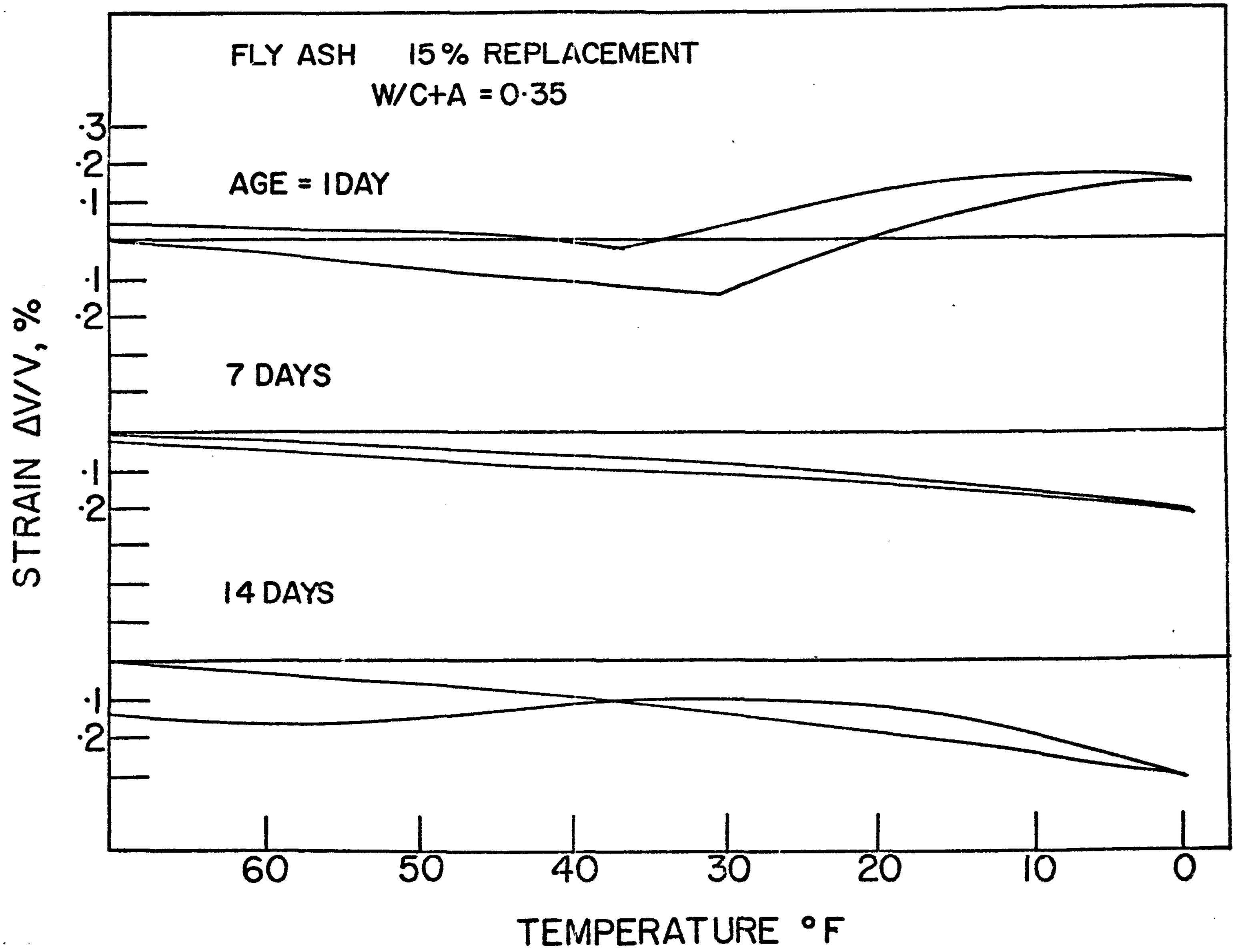


Figure 57 Strain-Temperature Plot For Fly Ash Paste (15%); w/c+a=.35

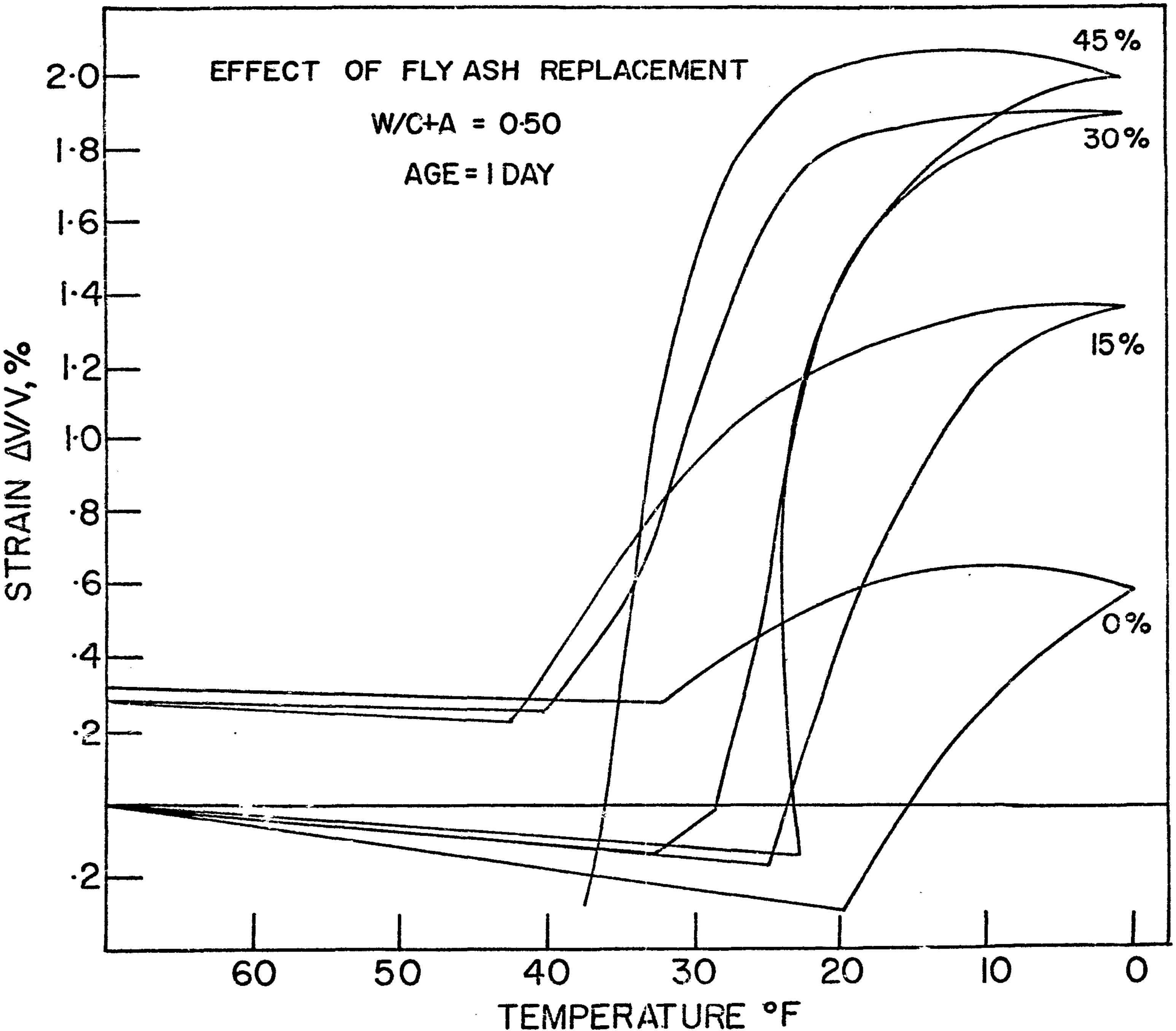


Figure 58 Effect of Fly Ash Replacement At 1 Day

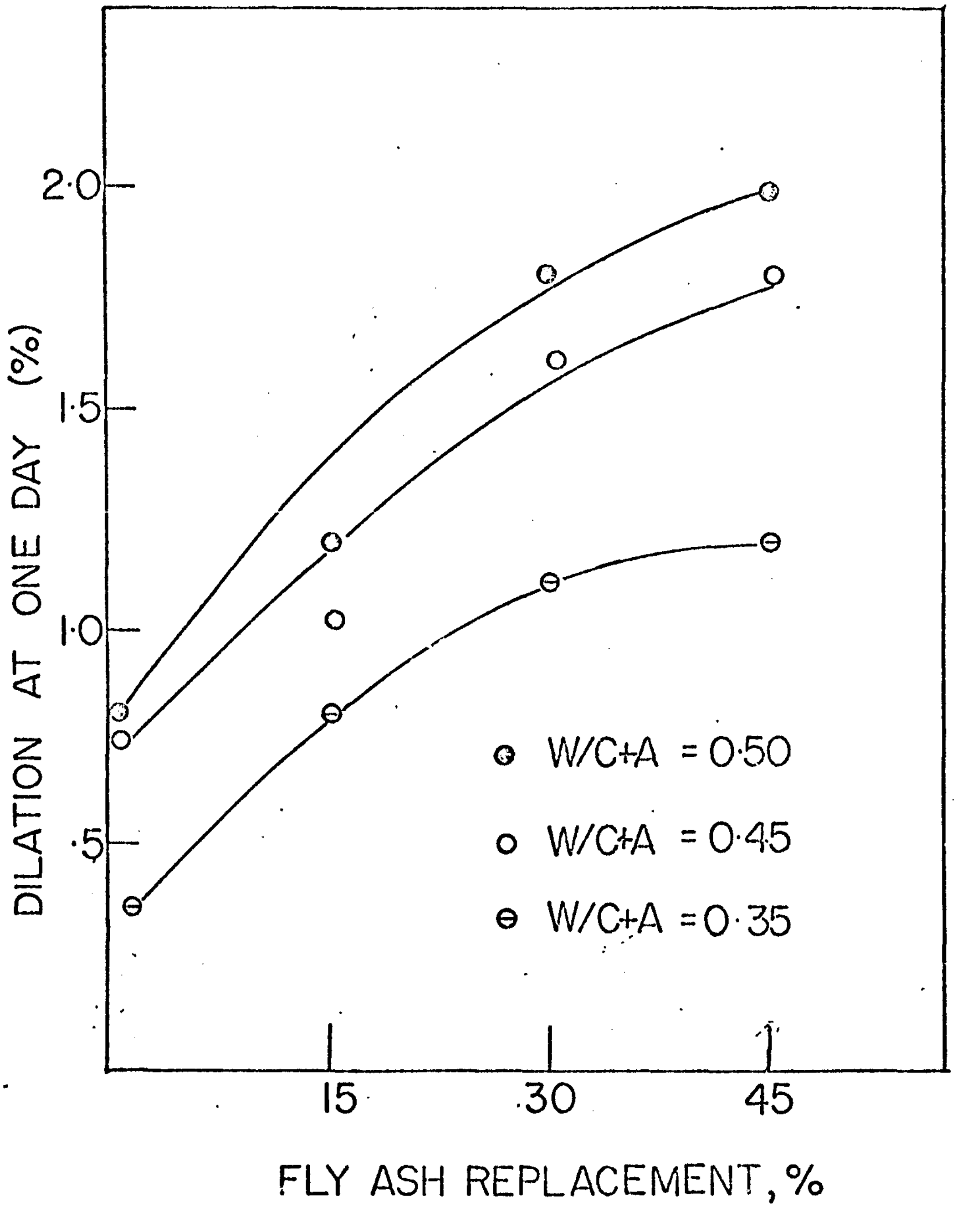


Figure 58-1 Dilation vs Fly Ash Replacement (1 Day)

collapse of hysteresis. The fly ash mixes exhibited the largest dilations eg. a mix with a water-solids ratio of 0.50 and 45% replacement had a measured dilation of approximately 2.2% at one day. This might be expected as fly-ash reduces the rate of heat evolution and consequently retards the progress of hydration. Figure 58 shows the effect of various fly-ash replacements on dilation at one day. It is seen that at a given age the higher the water-cement + ash ratio the higher is the dilation. However we will subsequently see that the dimensionless parameter $\frac{\Delta w}{w_o}$ effectively elimiates time and mix design as variables.

Compressive strength vs. dilation

Compressive strength determinations were made for all fly-ash mixes and an experimental relation for strength vs dilation was obtained which included all the mixes in the main programme. The expression is as follows:

$$f_c = 5.5\ e^{-1.12D_o} \qquad \text{--------(32)}$$

The addition of fly ash enables the paste to be cycled at an earlier stage in the hydration process ($\frac{\Delta w}{w_o} = 0.03$) and the realization of large values of D_o. Thus, the relation expressed

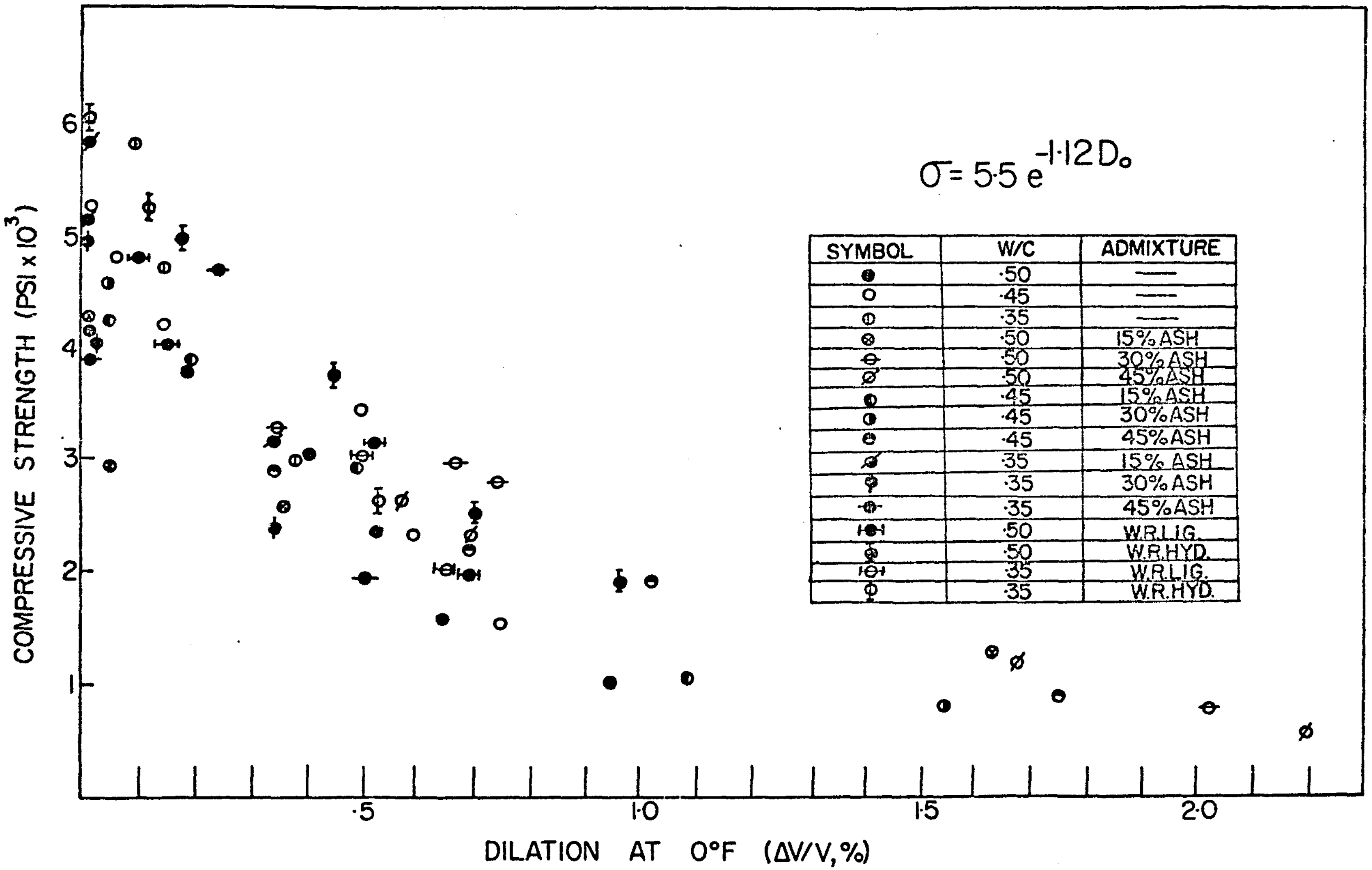


Figure 59 Compressive Strength vs Dilation-All Mixes

in equation(32)is valid over the extended range $0.03 < \frac{\Delta w}{w_o} < .10$

Dilation vs. $\frac{\Delta w}{w_o}$

Equating the relation given in equation (32)to equation(21) which relates strength and $\frac{\Delta w}{w_o}$ we obtain an expression for dilation in terms of $\frac{\Delta w}{w_o}$ which is valid over the range $0.03 < \frac{\Delta w}{w_o} < .10$. The expression is as follows:

$$D_o = -1 - 2.32 \ln \left[\frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \right] \text{------} (33)$$

$$0.03 < \frac{\Delta w}{w_o} < .10$$

Figure 60 is a plot of dilation vs $\frac{\Delta w}{w_o}$ for all the mixes in the main programme. Equation(33) represents the data quite well.

Residual volume change vs. $\frac{\Delta w}{w_o}$

Equation(23) expresses residual volume change as a function of dilation. Substitution of equation(33)into equation(23) gives an expression for residual volume change in terms of $\frac{\Delta w}{w_o}$ which should be valid over the range $0.03 < \frac{\Delta w^o}{w_o} < .10$. The expression is as follows:

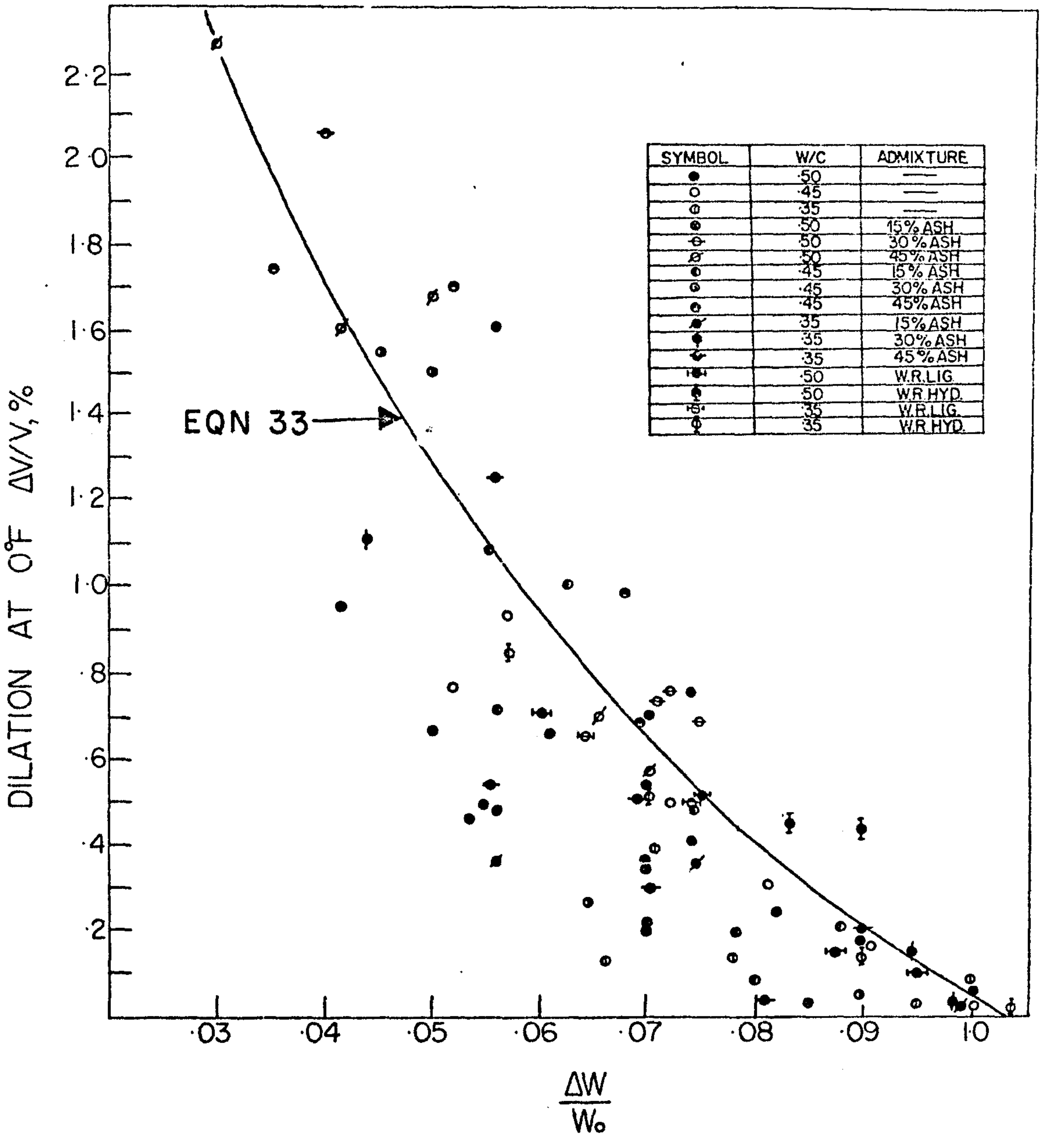


Figure 60 Dilation vs $\frac{\Delta w}{w_o}$ - All Mixes

$$\Delta V_R = 0.439 - 0.815 \ln \left[\frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \right] \quad \text{---(34)}$$

$$0.03 < \frac{\Delta w}{w_o} < .10$$

Figure 61 is a plot of experimental values for ΔV_R and $\frac{\Delta w}{w_o}$. The plot exhibits more scatter than the dilation plot, but is representative of equation (34). A more detailed analysis of all data will be given in the final chapter. It is noted that equations (33) and (34) are for all mixes in the main programme.

Strength reduction ratio

Figure 62 is a plot of strength reduction ratio vs. time in hours, for all mixes in the main programme. The following expression is the regression line for the experimental data.

$$\frac{\sigma_r}{\sigma} = .295 + .238 \log_{10} t \quad \text{-------(35)}$$

This expression is practically the same as equation (29) for plain pastes. It appears that the addition of admixtures does not significantly affect the linear logarithmic dependence of $\frac{\sigma_r}{\sigma}$ and time.

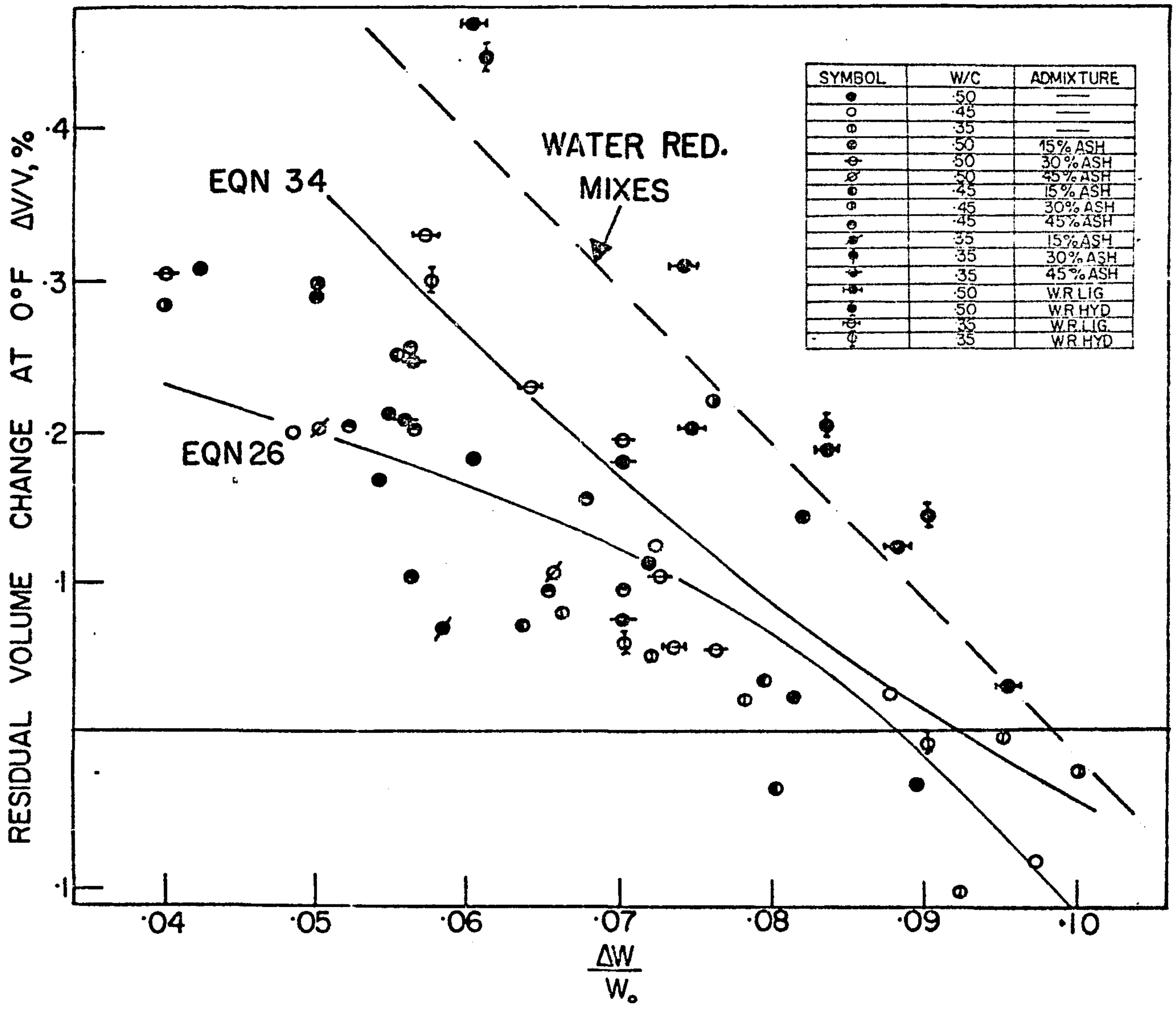


Figure 61 Residual Volume Change vs $\frac{\Delta w}{w_o}$ - All Mixes

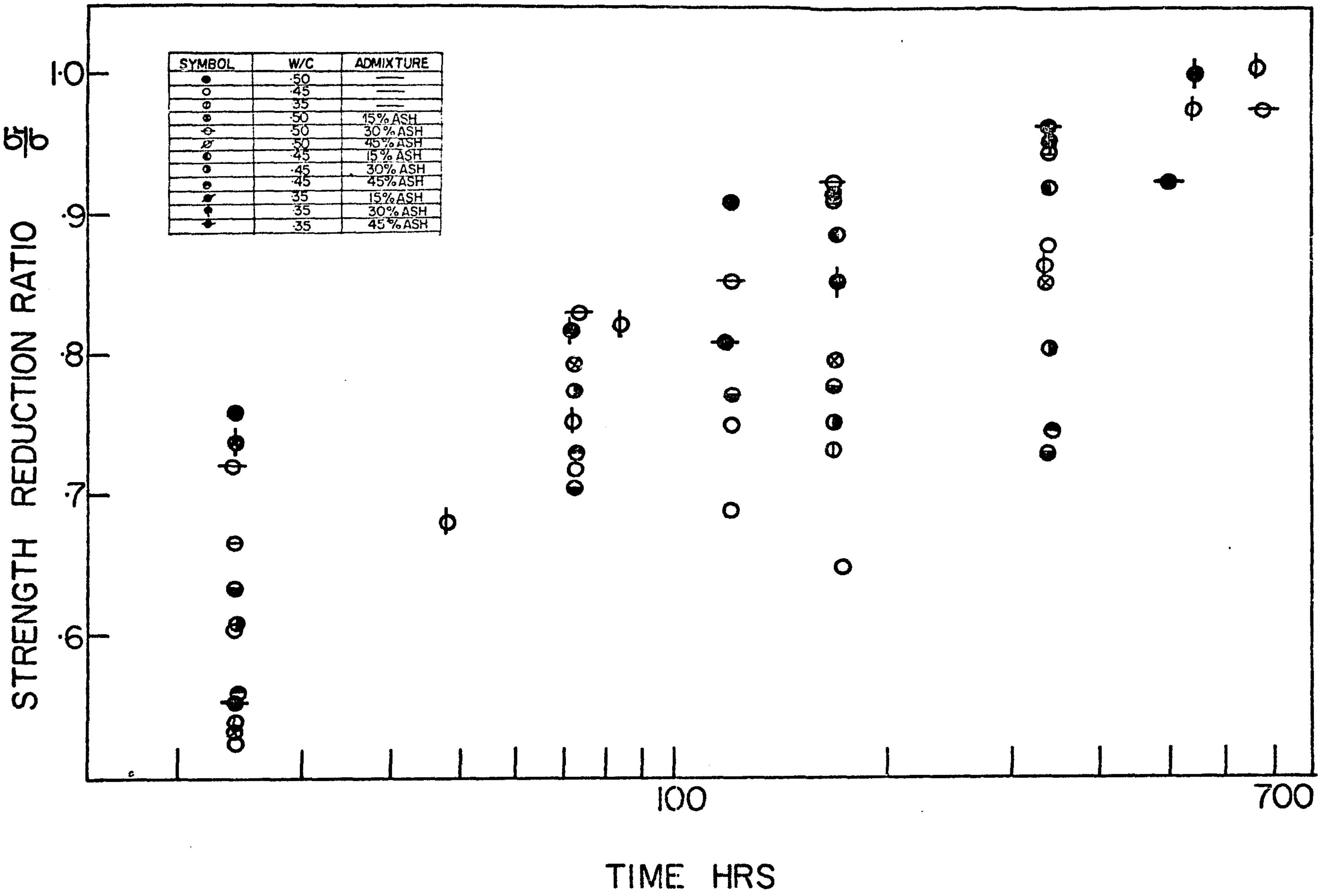


Figure 62 Strength Reduction Ratio vs Time-All Mixes

DISCUSSION OF TEST RESULTS

It appears that the addition of fly-ash does not change the nature of the transient strain behaviour of paste. Fly ash only alters the time at which hysteresis of a certain magnitude occurs. The use of fly-ash enabled studies on hardened paste when the value of $\frac{\Delta w}{w_o}$ was 0.03. That is, we could study the effect of the hydration process on dimensional stability at an earlier age. The water-reducing agents enabled studies on the hardened paste at a $\frac{\Delta w}{w_o}$ value of approximately 0.035. It is noted that the largest dilations were observed in the region $0.03 < \frac{\Delta w}{w_o} < .10$. The collapse of hysteresis for all fly ash mixes was systematic with respect to time; this is consistent with observed phenomenon for pastes with and without water-reducers.

CONCLUSION - FLY ASH SERIES

1) Compressive strength is an exponential function of dilation over the region $0.03 < \frac{\Delta w}{w_o} < .10$ for mixes with water-reducers and various replacements of fly-ash.

2) For fly-ash mixes, dilation and residual volume change are natural logarithmic functions of $\frac{\Delta w}{w_o}$.

3) For fly-ash mixes, dilation and residual volume change are functions of the volume concentration of hydrate product.

4) Strength-reduction ratio for fly-ash mixes is a linear logarithmic function of time. Indeed all the mixes in the main programme conform to this relationship.

5) Admixtures-at least the ones in this programme-therefore do not alter the dependence of dilation and residual volume change on the dimensionless parameter $\frac{\Delta w}{w_o}$.

6) Porosity-as expressed by the hydration parameters-appears to be the most important parameter influencing the dimensional stability of saturated pastes regardless of the presence of admixtures.

E. CRITICAL PARAMETERS FOR A TEST METHOD

For a design criteria it would be advantageous to be able to put limits on the dimensional stability of the paste phase ie. there should exist critical values of dilation, residual volume change etc. which would affect design criteria.

From elasticity, Hookes law states that:

$$\epsilon_z = \frac{1}{E}\left[\sigma_z - \mu\,(\sigma_x + \sigma_y)\right] \qquad \text{-----}(36)$$

Assuming hydraulic pressure as the main mechanism operative at a critical stage in the hydration process then:

$$\sigma_x = \sigma_y = \sigma_z \qquad \text{--------(37)}$$

At failure: $\sigma_z = f_t$ --------(38)

$$\text{and} \left(\frac{\Delta L}{L}\right)_c = \frac{1}{E}\left[f_t - \mu (f_t + f_t)\right]$$

$$\text{or} \left(\frac{\Delta L}{L}\right)_c = \frac{1}{E}(1 - 2\mu)\, f_t \qquad \text{------(39)}$$

$$\frac{\Delta V}{V} = 3\,\frac{\Delta L}{L}$$

$$\left(\frac{\Delta V}{V}\right)_c = (D_o)_c = \frac{3}{E}(1 - 2\mu)\, f_t \qquad \text{--(40)}$$

Assuming $E = 1000\ f_c$; $f_t = 0.1\ f_c$; $\mu = .15$

This gives:

$$(D_o)_c = \left(\frac{\Delta V}{V}\right)_c = 21 \times 10^{-5} cc/cc = .021\% \qquad \text{-----(41)}$$

Thus we see that equation (41) expresses the critical volume change as invariant. Knowing $(D_o)_c$ we can evaluate critical values for $\frac{\Delta w}{w_o}$ and X. Substitution of $(D_o)_c$ into equation (25) gives the following values:

$$\left[X\right]_c = 0.615 \text{ and } \left[\frac{\Delta w}{w_o}\right]_c = 0.0980 \qquad \text{-----(42)}$$

Substitution of $\left[\frac{\Delta w}{w_o}\right]_c$ into equation(21) yields critical values for compressive and tensile strength. Thus:

$$\left[f_c\right]_c = 4800 \text{ psi} \qquad \text{-----}(43)$$
$$\left[f_t\right]_c = 480 \text{ psi}$$

By substituting $\left[\frac{\Delta w}{w_o}\right]_c$ in equation(15) we can arrive at critical values for V^*. The following table tabulates critical values of V^* for different values of the water-cement ratio w_o.

w_o	V_c^*
.50	.457
.45	.437
.35	.392
.25	.333

Table VIII
Critical Values of Volume of Free Water Per Unit Volume of Paste

Figure 63 shows a log-log plot of compressive strength vs. dilation for all mixes. There are two distinct regions. For $0 < D_o < .1$ compressive strength is essentially constant at 4800 psi; compressive strength decreases in a linear fashion as $.1 < D_o < 2.2$. It appears that the estimate for critical strength ie. $(f_c)_c = 4800$ psi, is in accord with experiment. The estimate of critical dilation $(\frac{\Delta V}{V})_c = .021\%$, is conservative. However

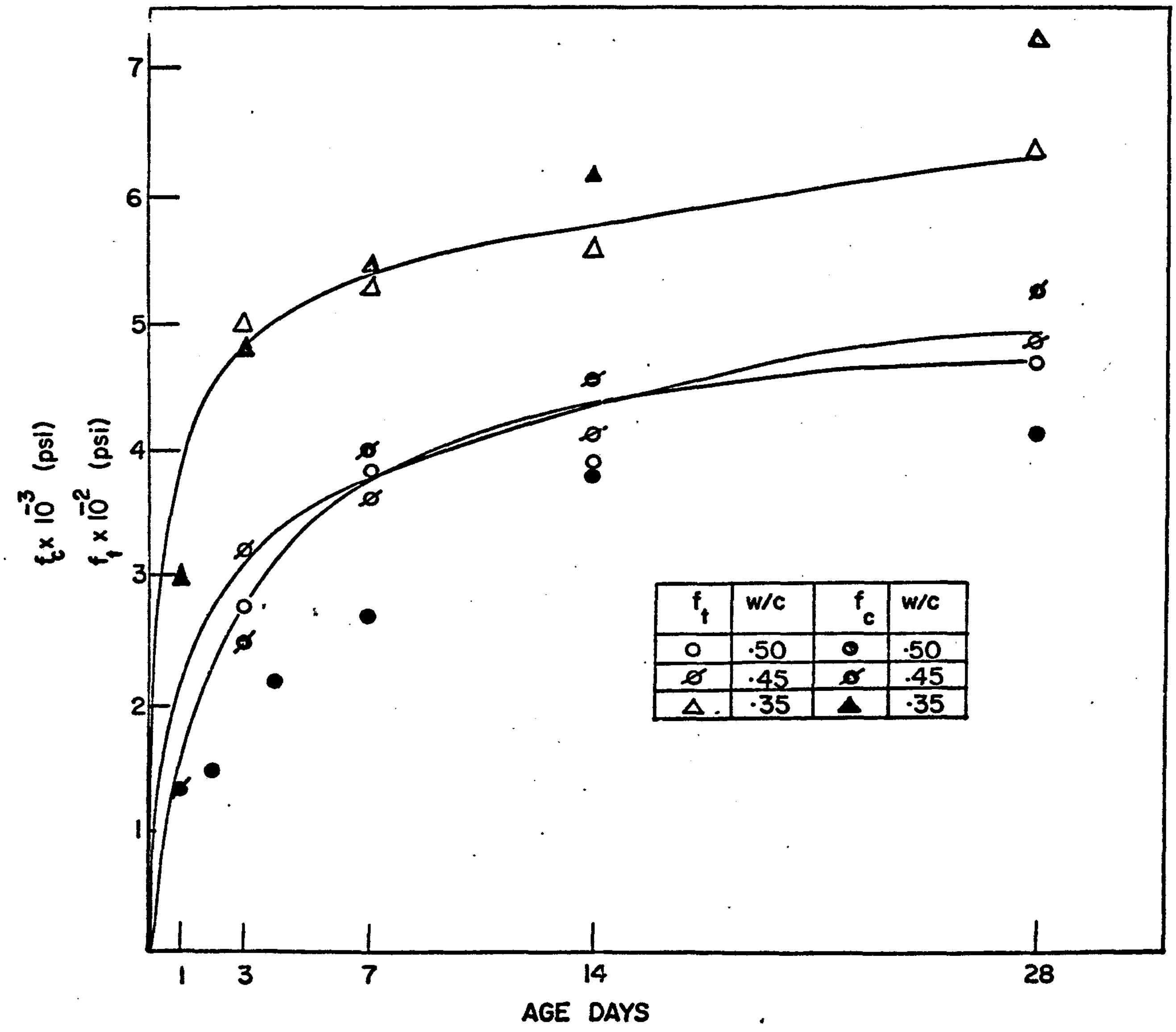


Figure 62-1 Compressive And Tensile Strength vs Time

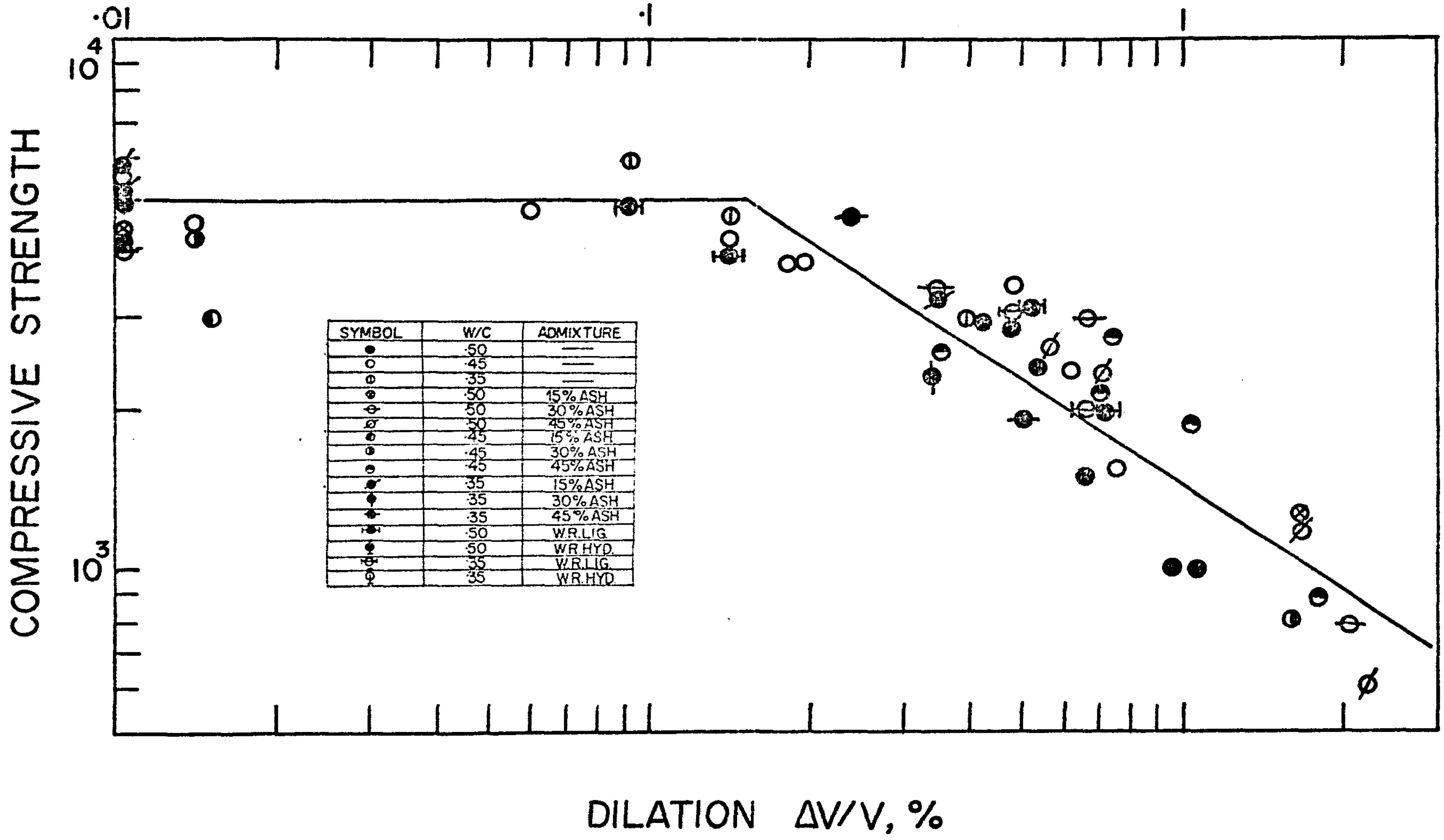


Figure 63 Compressive Strength vs Dilation-Log-Log Plot For All Mixes

this is not too different from a value of $\frac{\Delta L}{L} = 50 \times 10^{-6}$ in/in ($\frac{\Delta V}{V} = .015\%$) which is used by the California Department of Highways as an aggregate acceptance criteria. It is felt that the experimental evidence presented in figure 63 clearly indicates the existence of critical parameters which influence the dimensional stability of cement paste.

F. SELF-DESICCATION STUDIES

If no water movement to or from the cement paste is permitted the reactions of hydration use up the water until too little is left to saturate the solid surfaces, and the relative humidity within the paste decreases. This is known as self-desiccation.

According to Powers (48) if there is no exchange of water between a body of green concrete and its surroundings, autogenous desiccation will make the cement paste immune to damage by freezing after the time when the saturation coefficient.of the capillary spaces drops below a certain value. In order to demonstrate the effect of self-desiccation on length change due to slow-cooling a series of experiments was designed in which time to zero dilation was measured. The absence of a dilational response after a given time interval provided a measure of the influence of self desiccation on durability.

G. TIME TO ZERO DILATIONAL RESPONSE

Earlier work by Powers (49) provided an expression for the necessary prehardening time of concrete to withstand frost damage as a function of water-cement ratio. A modification of Powers theory based on the assumption that hydraulic pressure is operative (ie. the critical degree of saturation is approximately 90%) provided an analytic expression suitable for the prediction of zero dilational response. The derivation is as follows:

Let S_c represent the fraction of capillary space full of water.

$$S_c = \frac{\epsilon_c - (\Delta w)V_w / V_p}{\epsilon_c} = 1 - \frac{(\Delta w)V_w}{V_p \epsilon_c} \quad \text{--(44)}$$

ϵ_c - volume of capillary space per unit volume of paste.

Δw - weight of water lost from that space.

V_w - specific volume of capillary water.

V_p - volume of paste.

If there is a gain or loss of water from the environment during autogenous desiccation then:

$$\frac{\Delta w}{V_p} = .254 \frac{w_n^o}{C} \ m \ \frac{C}{V_p} + \frac{\Delta w^1}{V_p} \tag{45}$$

The volume of capillary pores, p_c is given by:

$$p_c = w_o V_w - (2.1 - 1) \ m \ c \ V_c \tag{46}$$

$$\frac{p_c}{V_p} = \epsilon_c = \frac{C}{V_p} \left[\frac{w_o}{C} \ V_w - (2.1 - 1) \ m \ V_c \right] \tag{47}$$

Substituting

$$1 - S_c = \frac{.254 \ \frac{w_n^o}{C} \ m \ \frac{C}{V_p} + \frac{\Delta w^1}{V_p} \quad V_w}{\frac{C}{V_p} \left[\frac{w_o}{C} \ V_w - (2.1 - 1) \ m \ V_c \right]} \tag{48}$$

Assuming $\Delta w^1 = 0$ (sealed specimen)

$V_w = .99$ cc/gm $\qquad$ $V_c = .319$ cc/g

$$\frac{w_n^o}{C} = .23$$

$$1 - S_c = \frac{1}{\frac{17}{m} \ \frac{w_o}{c} - 0.61} \tag{49}$$

Assuming S_c must not be larger than some critical value $\underline{s}$

$$m = \frac{17.0}{b} \frac{w_o}{c}$$

where $b = \frac{1}{1 - \underline{s}} + .60$

and assuming $\underline{s} = .90$

$b = 10.60$ (based on hydraulic pressure theory)

Maturity can be expressed as a logarithmic function of time over the range $0.5 > m > .1$. For normal portland cement (Type I) the following expression is applicable

$$m = -0.24 + 0.452 \log t \qquad \text{------}(50)$$

$$\log t = \frac{\frac{17.0}{b} \frac{w_o}{c} + 0.24}{0.452} \qquad \text{------}(51)$$

$$\text{or } \log t = 3.58 \frac{w_o}{c} + .530 \qquad \text{-----}(52)$$

Equation(52) is the expression for time to zero dilational response for a sealed specimen ie. a specimen that is undergoing self-desiccation.

Experimental

In an attempt to demonstrate the relative validity of equation(52) experimental length change data was obtained for sealed specimens at different ages.

Mixes of plain cement paste (water-cement ratios of 0.25, 0.35, 0.45 and 0.50) were cast in the form of prisms (1" x 1" x 6") and moist cured 24 hours. After moist curing 24 hours the prisms were wrapped in polyethylene and stored until tested. The 0.25 water-cement ratio mix was moist cured 12 hours, sealed and tested at 12 and 18 hours.

Specimens from the different mixes were cycled at different ages until the dilational response was negligible. Figure 64 plots the experimental time to zero expansion for mixes in this programme against water-cement ratio. The agreement with equation(52)appears satisfactory. Data obtained by MacInnis (50) is also plotted and generally conforms to the relation expressed by equation(52). Thus it is evident that as water-cement ratio increases so does the time required for the self-desiccation mechanism to render the paste immune to frost action.

Discussion of experimental results

The compliance of equation(52)with experimental observation suggests that hydraulic pressure is operative in the self desiccation process. A critical degree of saturation of approximately 90% appears to be substantiated by experiment. Dimensional stability in the paste phase is therefore influenced

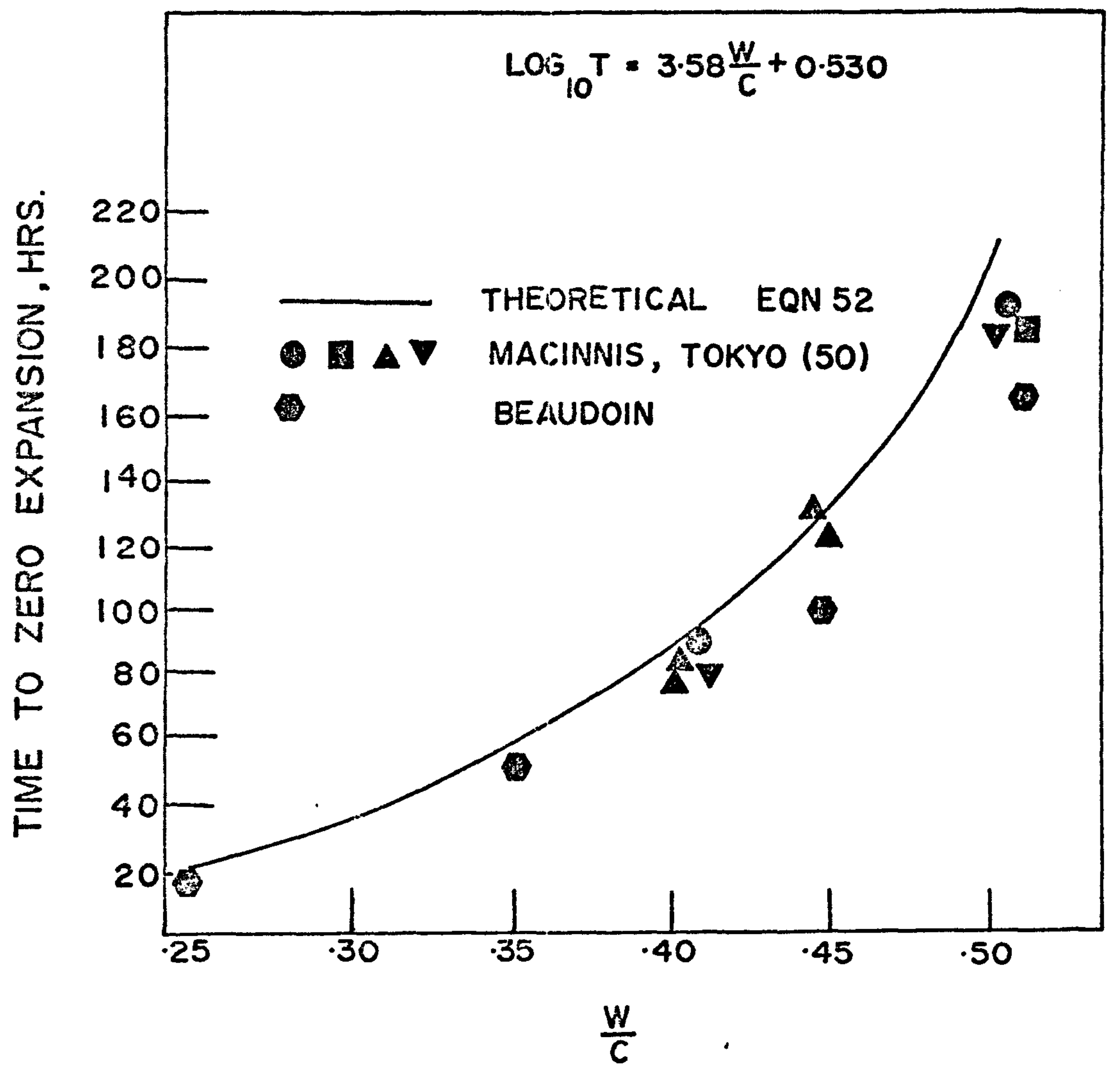


Figure 64 Time To Zero Expansion vs Water-Cement Ratio

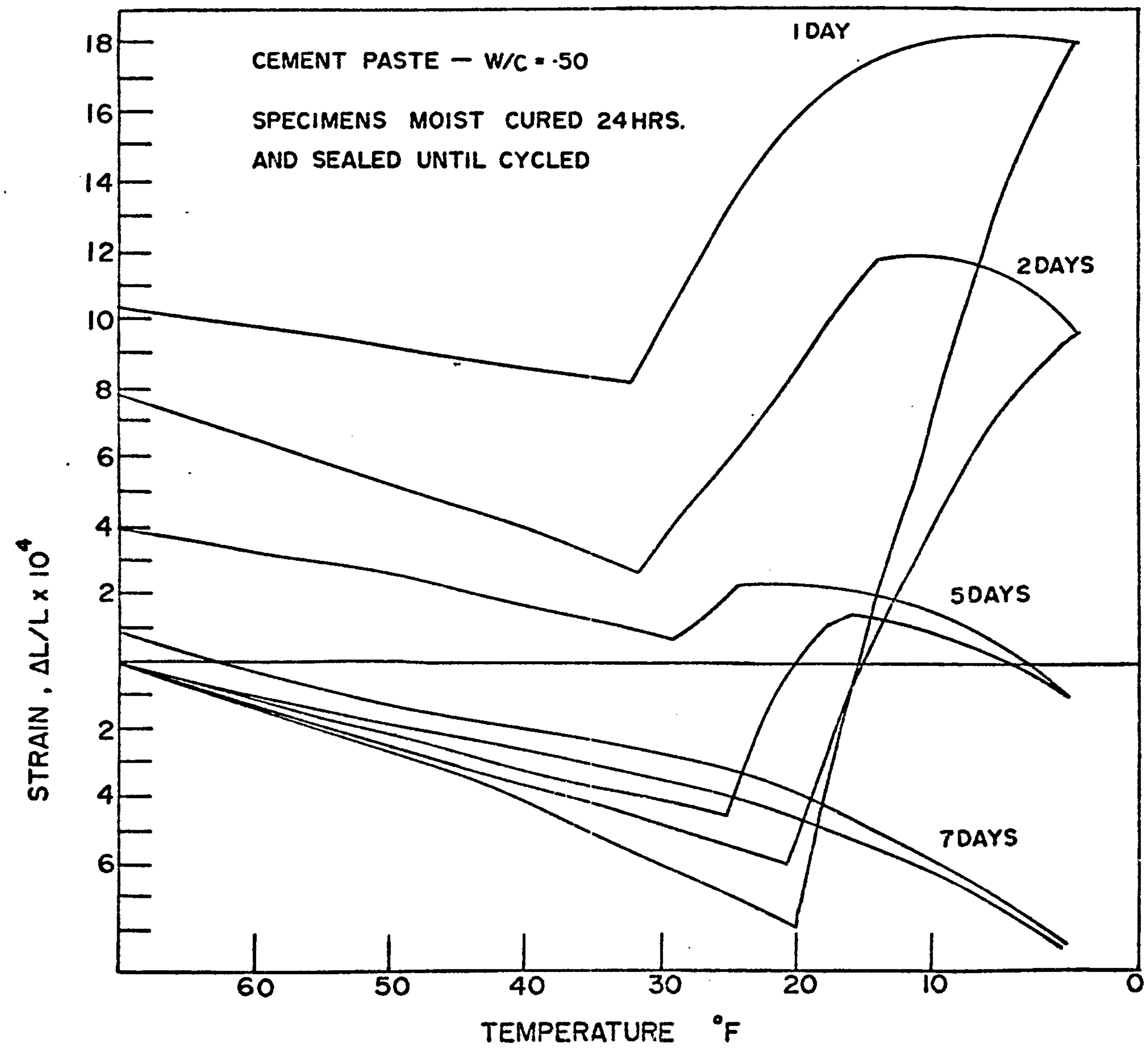


Figure 65 Strain Temperature Plot For Sealed Specimens; w/c=0.50

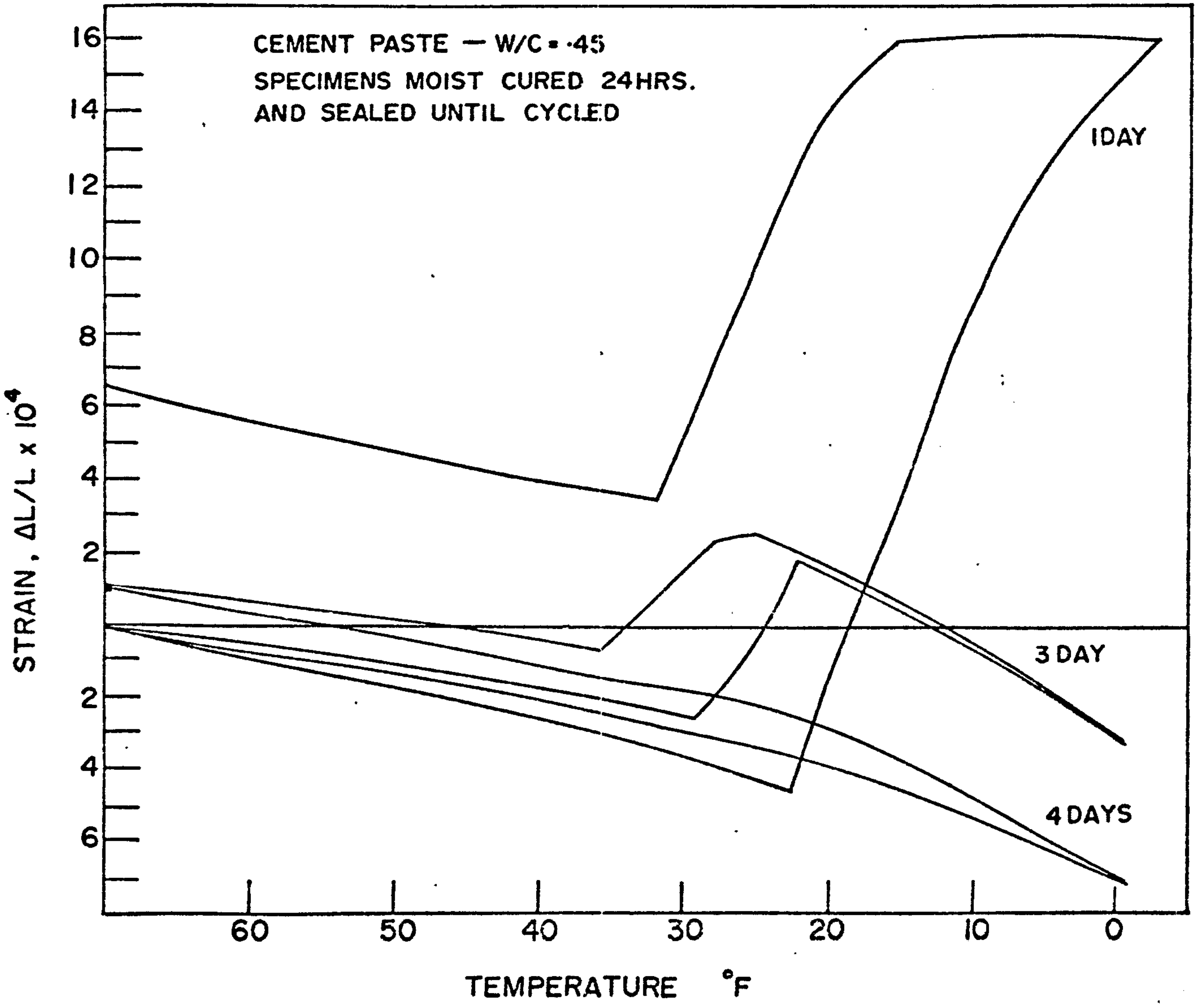


Figure 66 Strain Temperature Plot For Sealed Specimens; w/c=0.45

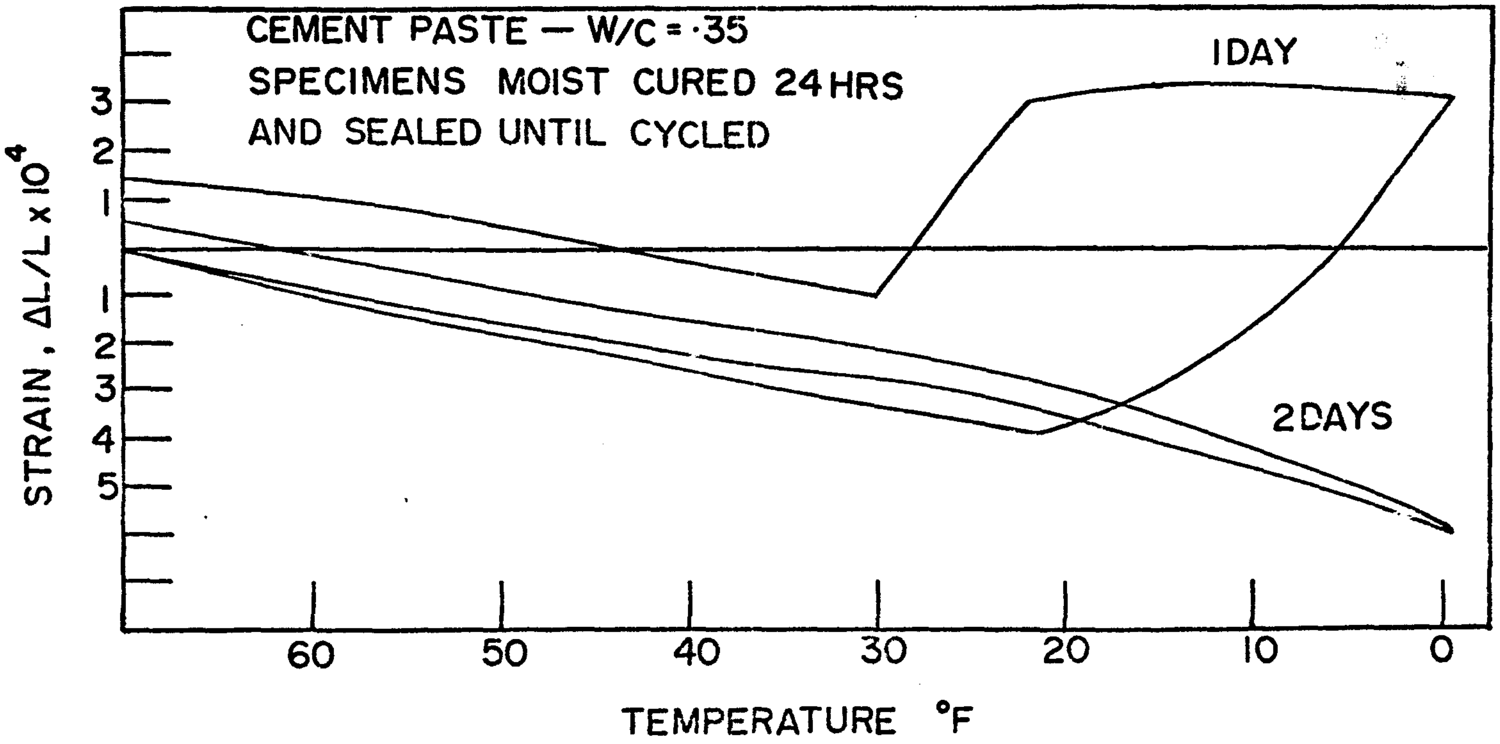


Figure 67 Strain Temperature Plot For Sealed Specimens; w/c=0.35

by the self desiccation process and is a reflection of the role the latter plays in the freezing phenomena.

H. MULTIPLE CYCLE STUDIES

Several specimens of both plain and fly-ash pastes were subjected to continuous cycling according to the selected slow cooling-warming regime (5°F/hr.) Plain paste mixes had water-cement ratios of 0.35, 0.45, and 0.50. Fly-ash mixes selected for multiple cycling had water-cement plus ash ratios of 0.50 with 15 and 30% replacement. Figures 68 to72 clearly show the strain temperature response to multiple cycling. The continuous cycles were all initiated when the specimens were one day old. Initially a large hysteresis is observed on warming after obtaining a large expansion during the cooling cycle. Subsequent cycles exhibit a systematic collapse of hysteresis and diminishing residual volume change. When the hysteresis collapse is complete the strain-temperature response oscillates along a linear reversible path; also the change in residual volume change ($\Delta(\Delta V_R)$) is negligible.

The slope of the final linear response was less than that of the initial response (ie. the response due to thermal contraction or expansion).

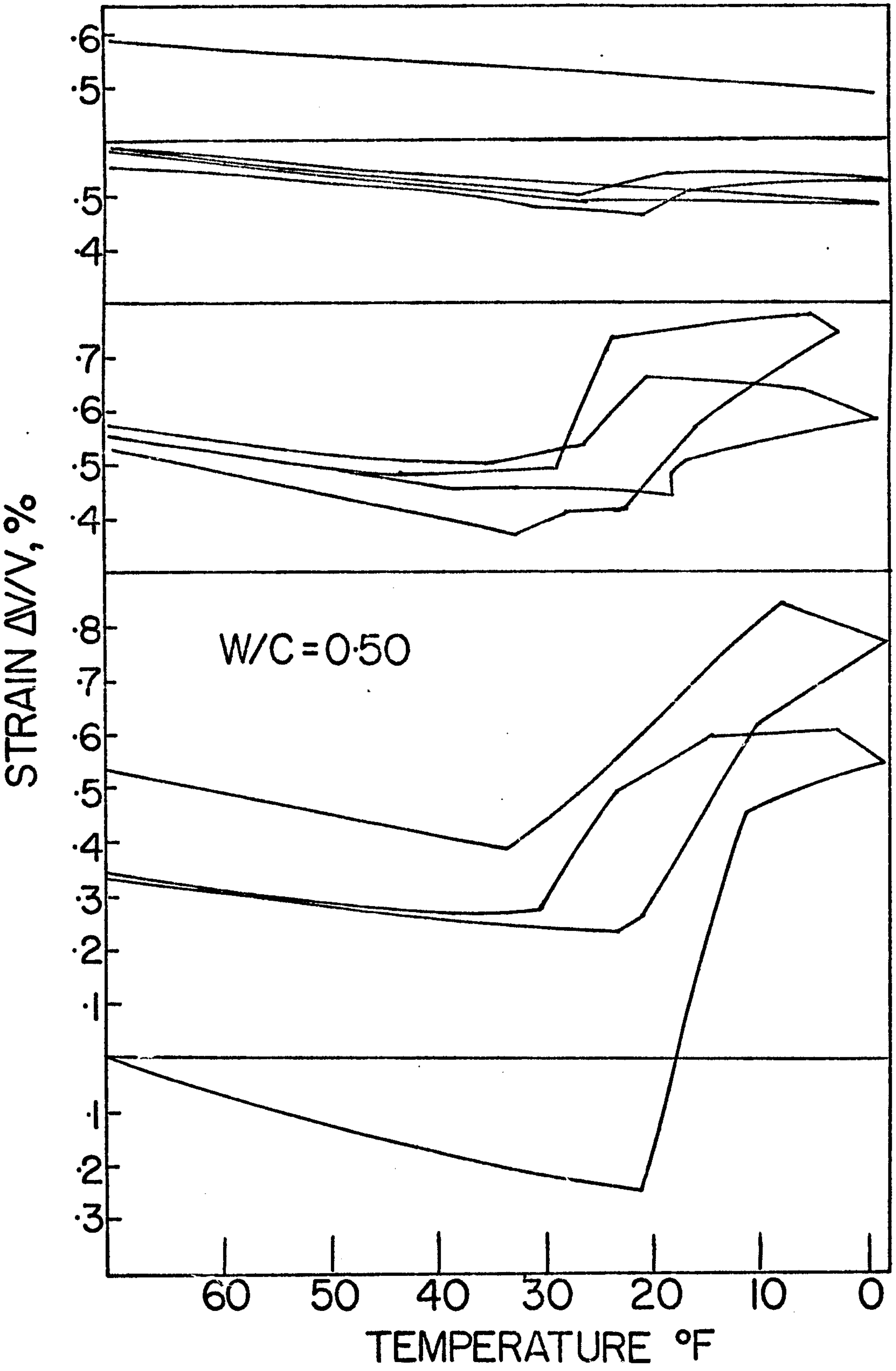


Figure 68 Multiple Cycle Test-w/c=0.50

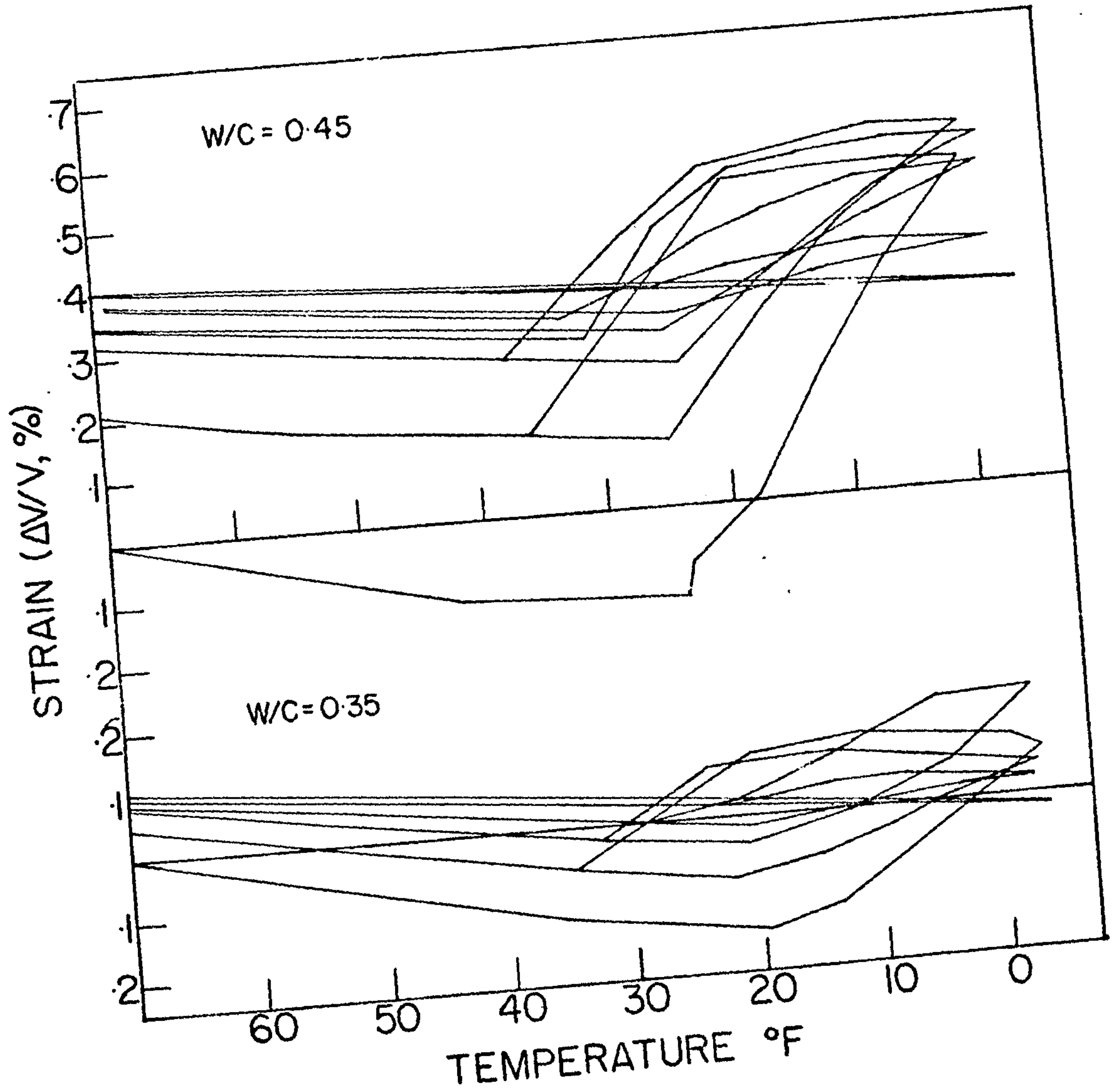


Figure 69 Multiple Cycle Test-w/c=0.45 and 0.35

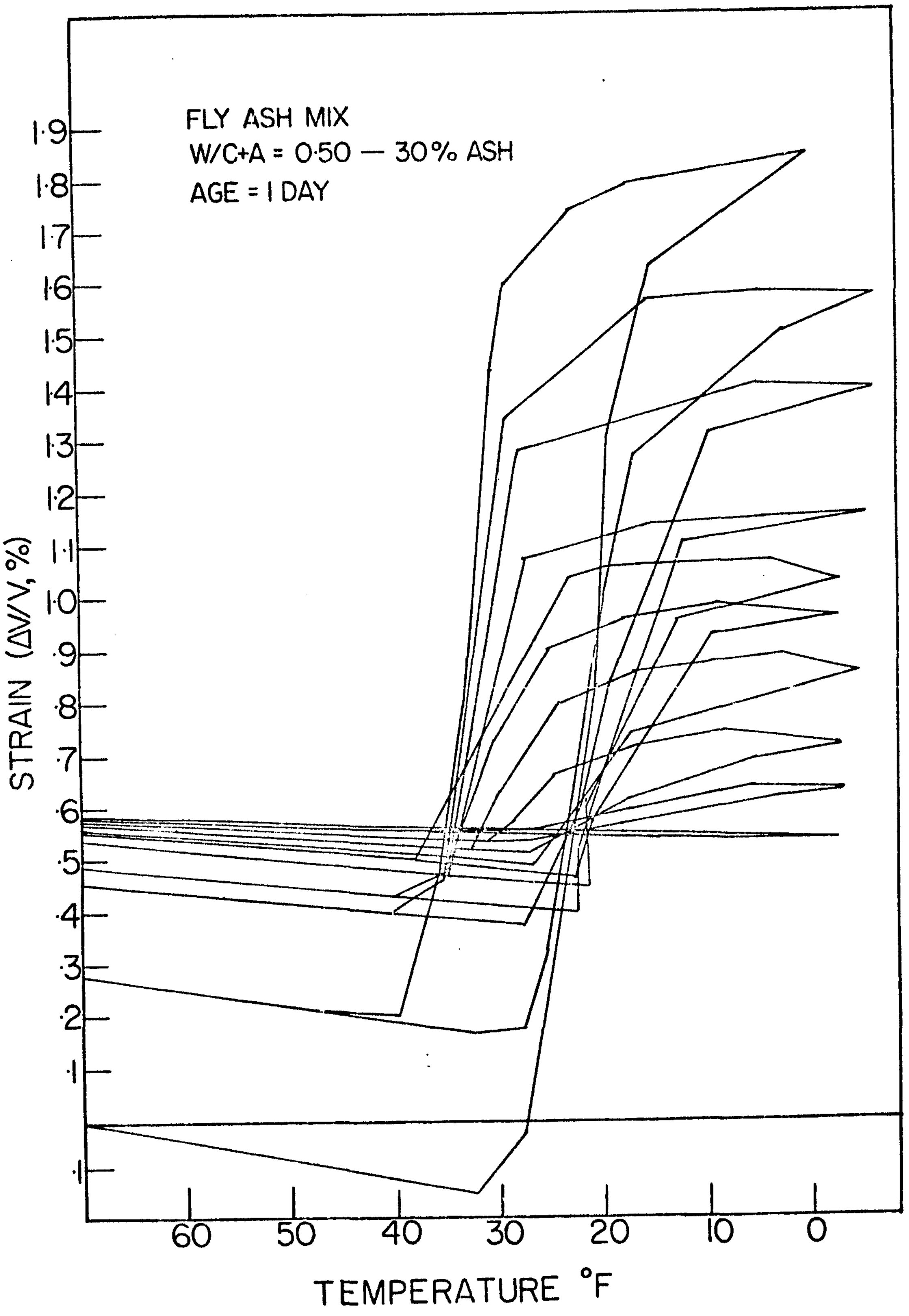


Figure 70 Multiple Cycle Test For Fly Ash Paste (30%) -w/c+a=0.50

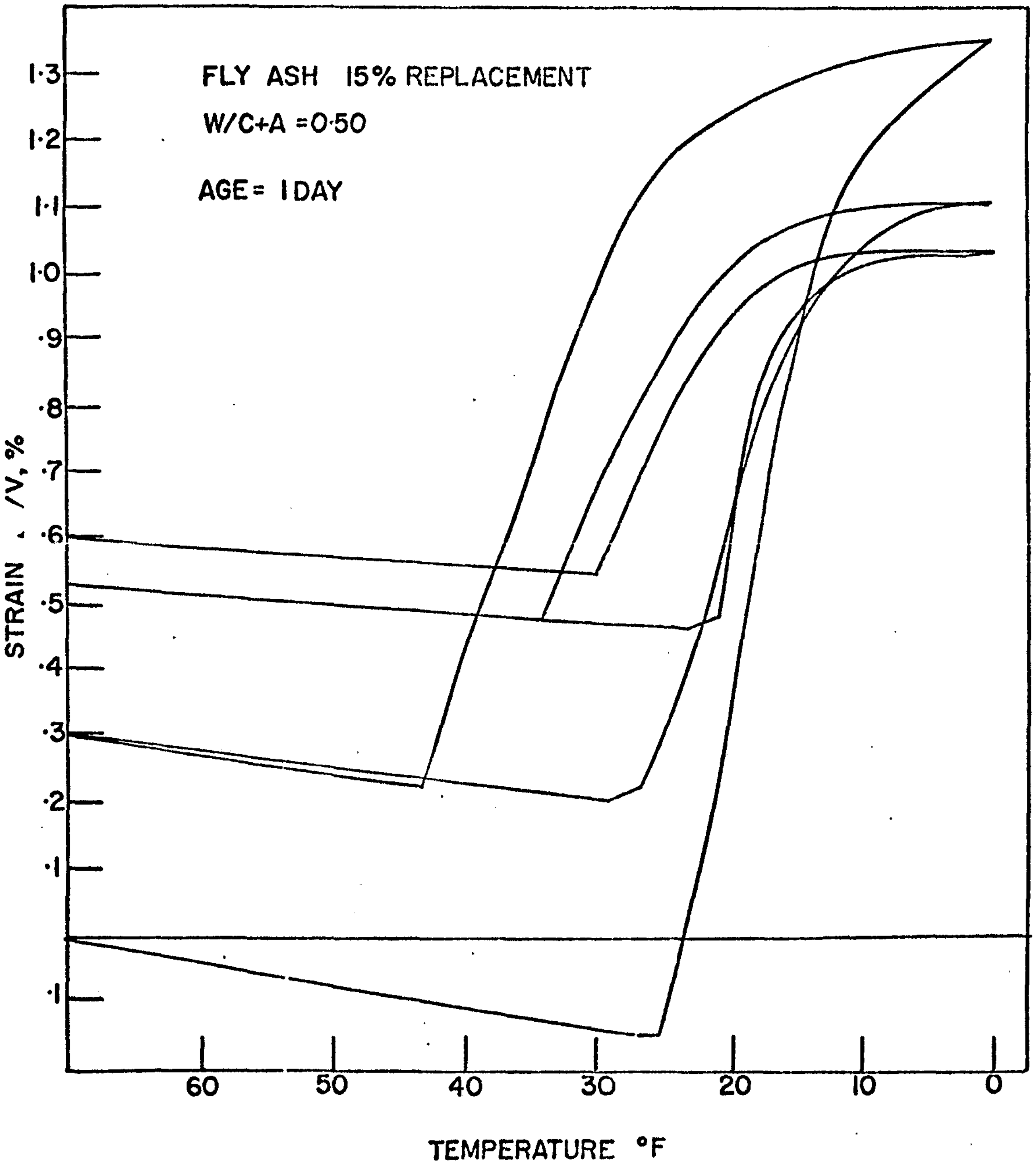


Figure 71 Multiple Cycle Test For Fly Ash Paste (15%) -w/c+a=0.50

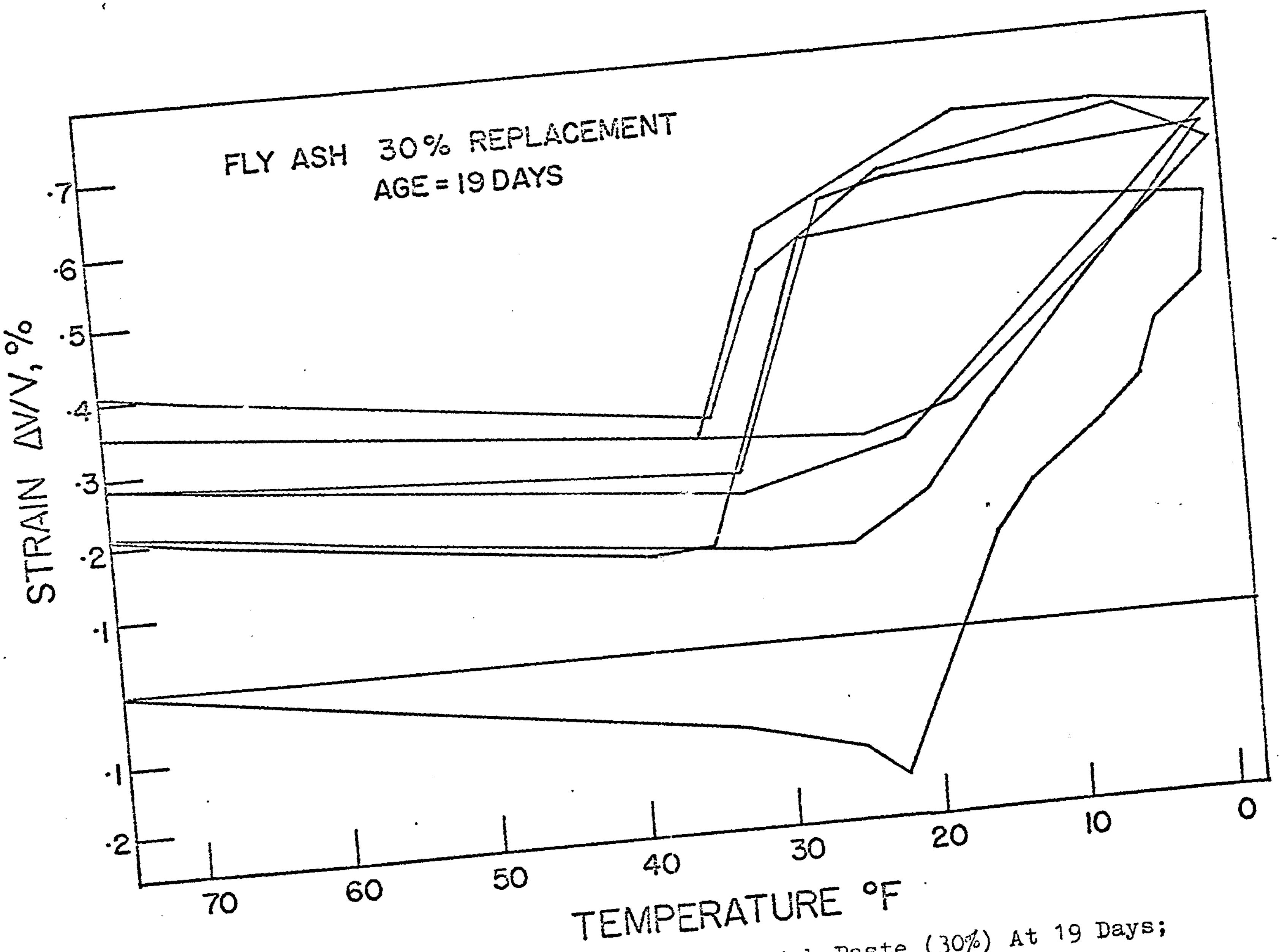


Figure 72 Multiple Cycle Test For Fly Ash Paste (30%) At 19 Days; w/c+a=0.50

The resulting hysteresis collapse may be due to the following:

1) Structural collapse due to internal shrinkage or self-desiccation-recent electron micrographs have shown that shrinkage is accompanied by a collapse of structure.

2) Structural collapse due to initial damage ie. by hydraulic pressure, internal moisture movement etc.

3) Mechanical welding due to removal of adsorbed water ie. primary particles come into closer proximity, multiplying the van der Waals bonds and decreasing the surface area-analogous to sintering in metals. This may account for the decrease in slope after the initial thermal response.

Figure 73 demonstrates the exponential decay of the dilation parameter as the number of cycles is increased. Similarly, figure 74 shows how residual volume change decreases with the number of cycles.

The number of hysteresis loops is greater for the fly-ash paste because there is more free water available to influence the dimensional behaviour due to temperature change. However the addition of fly-ash only prolongs the self-desiccation process and the attainment of a favourable

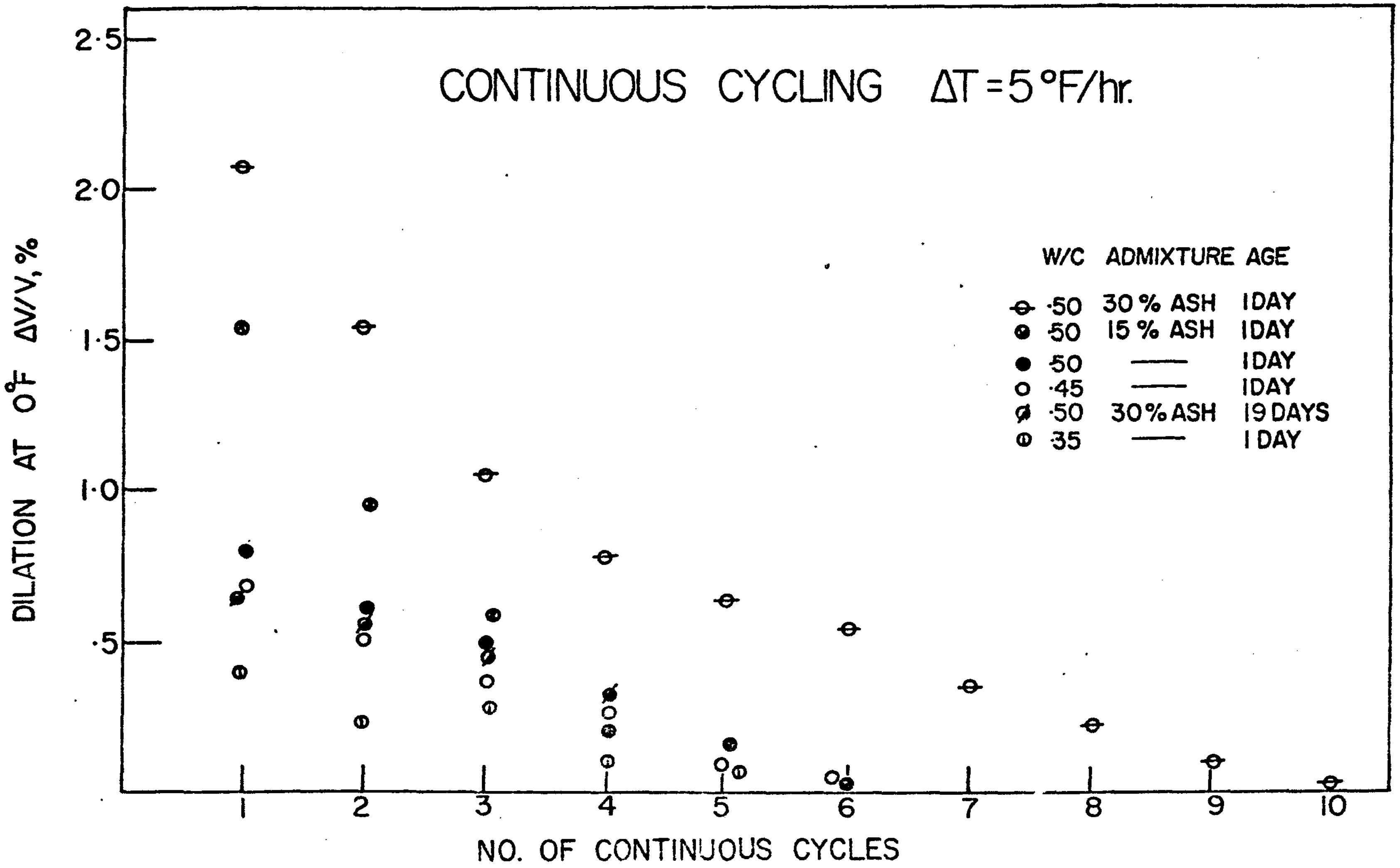


Figure 73 Dilation Vs Number of Continuous Cycles

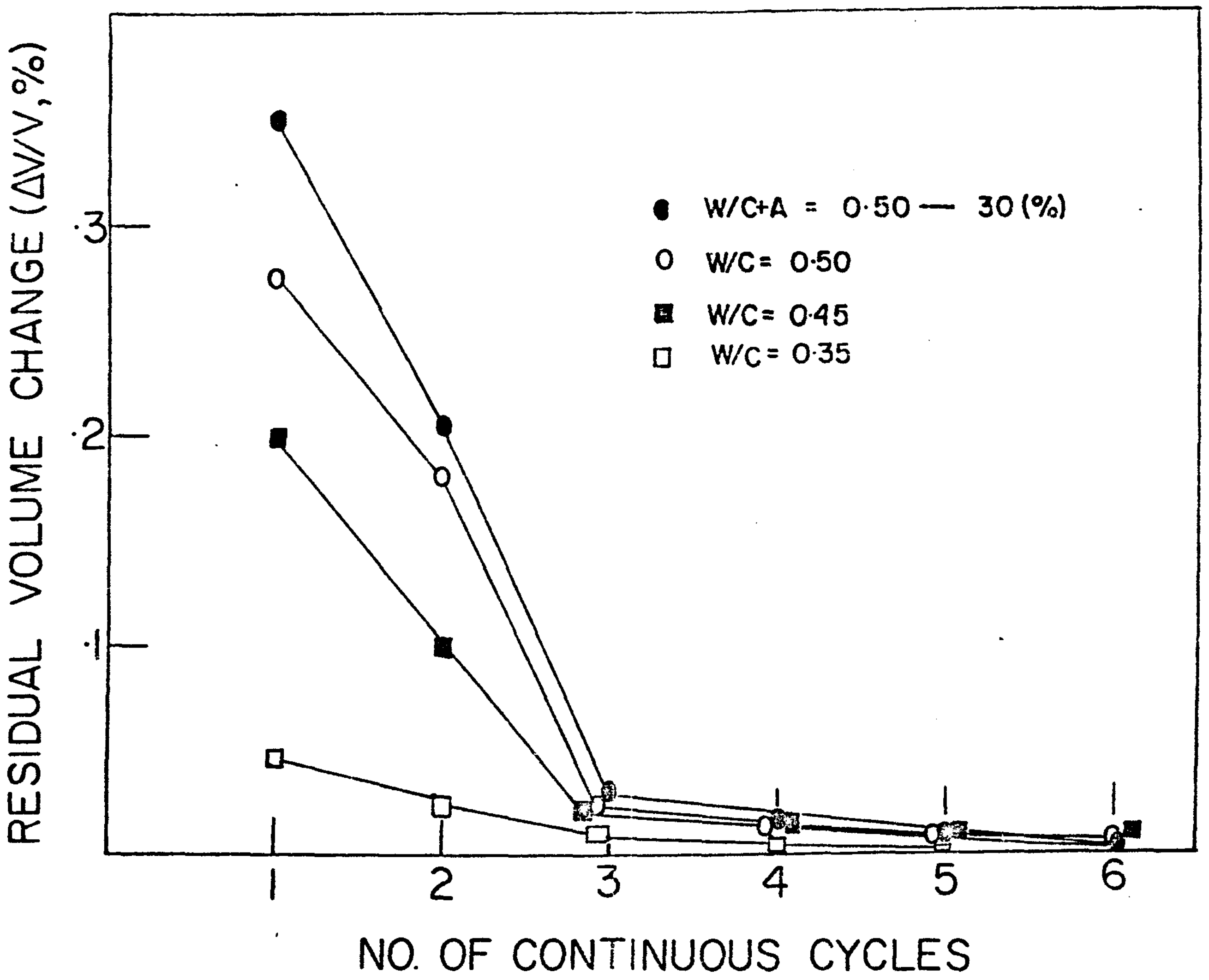


Figure 74 Residual Volume Change vs Number of Continuous Cycles

linear response. It is noted that the strain-temperature history of concrete in the field is extremely important if length change measurements are to be made on cores. Field results would be useless or clouded if the effect of self-desiccation and moisture as well as temperature conditions were not known accurately.

I. DEGREE OF SATURATION STUDIES

Experiments were designed to investigate the dimensional behaviour of high water-cement ratio pastes (w/c = 0.70-1.00) at various degrees of saturation. High water-cement ratio pastes are very sensitive to temperature change in the freezing range because they contain a large amount of freezable water due to high porosity. It was intended to demonstrate the validity of the critical saturation concept for high water-cement ratio pastes. Furthermore an attempt was made to induce failure (large cracks) by a single slow cycle in an endeavour to gain further insight into the freezing mechanisms responsible for dimensional change. Also the effect of drying is studied. It is of interest to note that the proposed recommendations (54) for a standard slow cooling test method include a two week drying period prior to moisture conditioning.

Conditioning of specimens

Specimens (3" Ø x 6" cylinders) were cast and moist cured for 2 weeks. Subsequently they were allowed to dry in laboratory air (50% R.H.) for approximately two weeks prior to conditioning for test. To achieve various degrees of saturation the specimens were placed in a water filled tank to which was connected a mechanical vacuum pump. (See photograph 5). The specimens were vacuum saturated for 24 hours and allowed to soak for various time intervals to achieve the required degree of saturation. The "percent of vacuum saturation" was used as a measure of the degree of saturation and was calculated as:

$$(W_1 - W_o/W_s - W_o) \times 100 \qquad \text{--------}(53)$$

in which W_1 is the weight of the in-test specimen, W_o is the weight after 24 hours of oven drying at 200F, and W_s is the weight after immersion to constant weight following saturation under vacuum at 1×10^{-4} mm . of mercury.

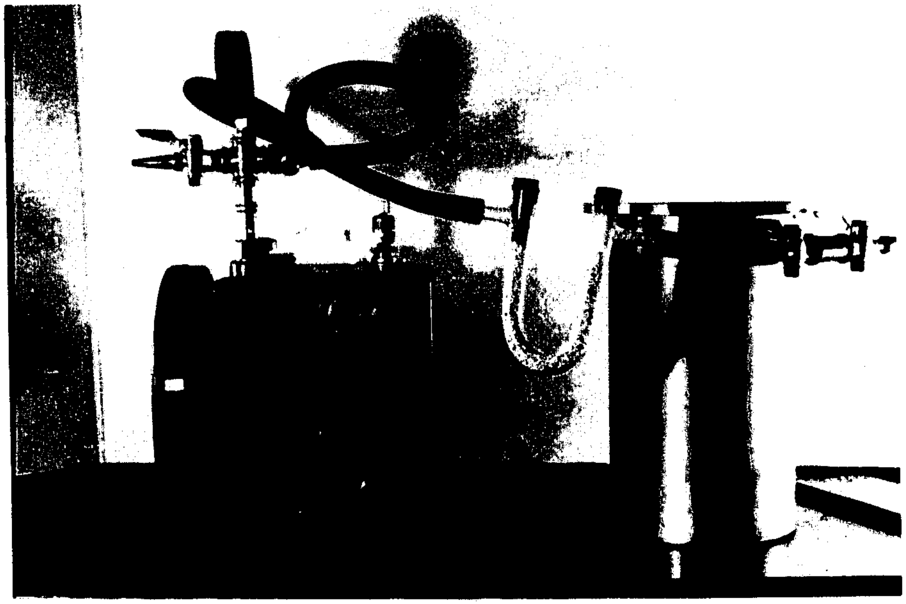
Mixes

The following rockflour mixes were designed for this test series.

Water/Cement	Cement:Rockflour	Air	Admixture
1.00	1:1.5	1.0%	-
1.00	1:1.5	8.0%	AEA
1.00	1:1.5	-	LIG.&ADIPIC
0.70	1:1	8.0%	AEA
0.70*	1:1	15.0%	AEA

Table IX Mix Parameters For High Water-Cement Ratio Mixes.

* Multiple Cycles.



P_5 - Vacuum Saturation Equipment

Test procedure

The vacuum saturated specimens, after being conditioned to the desired degree of saturation were subjected to the selected slow cooling regime. In order to achieve effective high water-cement ratios it was necessary to incorporate rockflour into the system. The addition of an inert diluent prohibits excess bleeding and enables the achievement of high porosity pastes. Volumetric strain as a function of temperature was plotted for all mixes tested.

Discussion of results

For all mixes 90% appears to be a limiting value for degree of saturation above which expansions take place. This critical value concept then appears to be valid for high porosity pastes and unaffected by water-reducing admixtures (ie. lignin and adipic acid types). The presence of an air void system in a paste of water-cement ratio 1.00 does not prevent large dilations but does reduce the magnitude of expansion in relation to a similar paste with no air. Expansions are still observed for the 0.70 water-cement ratio mix with a nominal air content of 8 percent. However these expansions are much less than those of the higher water-cement ratio mix, and demonstrate a tendency toward a

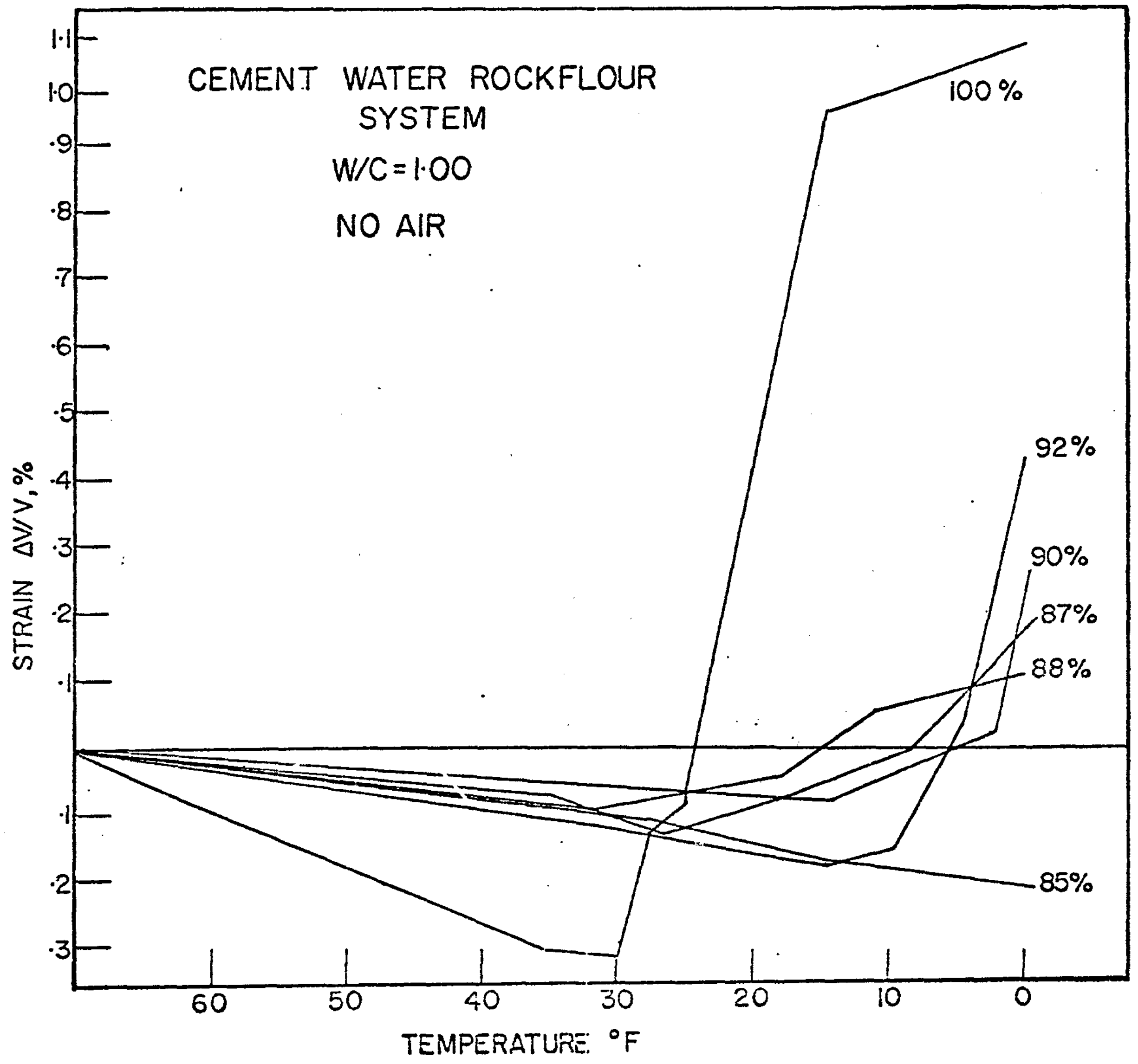


Figure 75 Effect of Degree of Saturation on Length Change Patterns; w/c=1.00

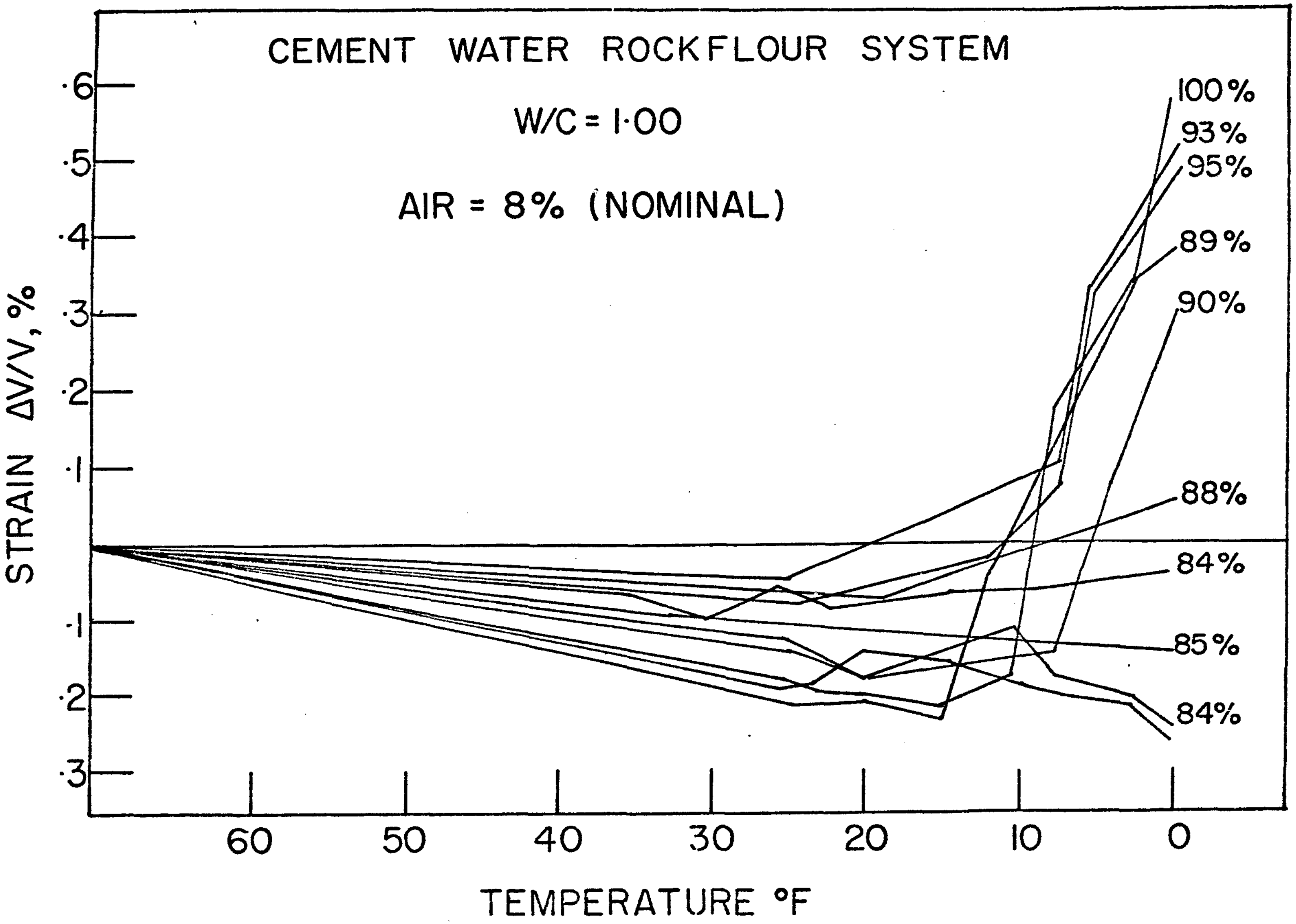


Figure 76 Effect of Degree of Saturation on Length Change Patterns; w/c=1.00 With Air=8%

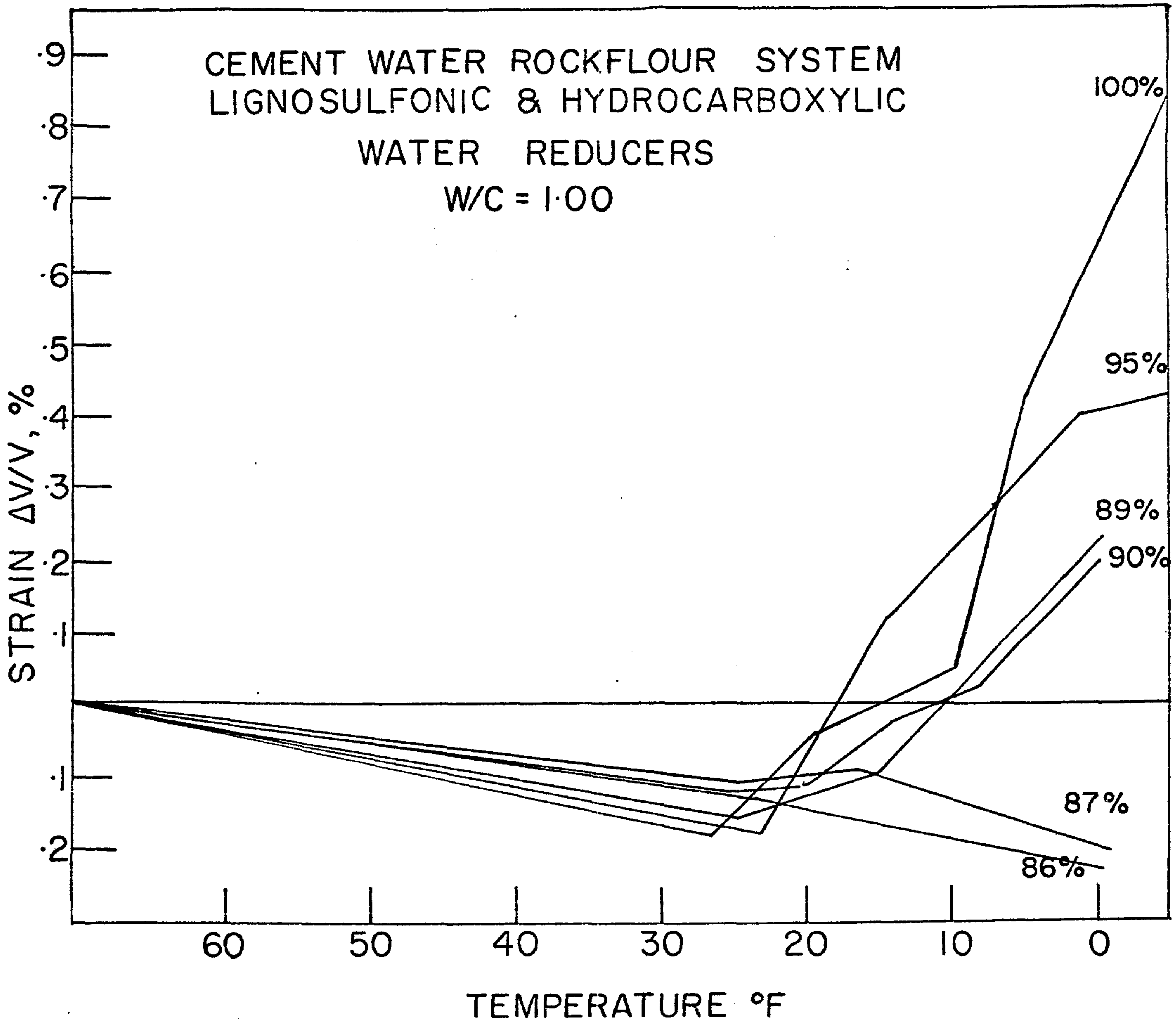


Figure 77 Effect of Degree of Saturation on Length Change Patterns For Pastes With Water Reducers

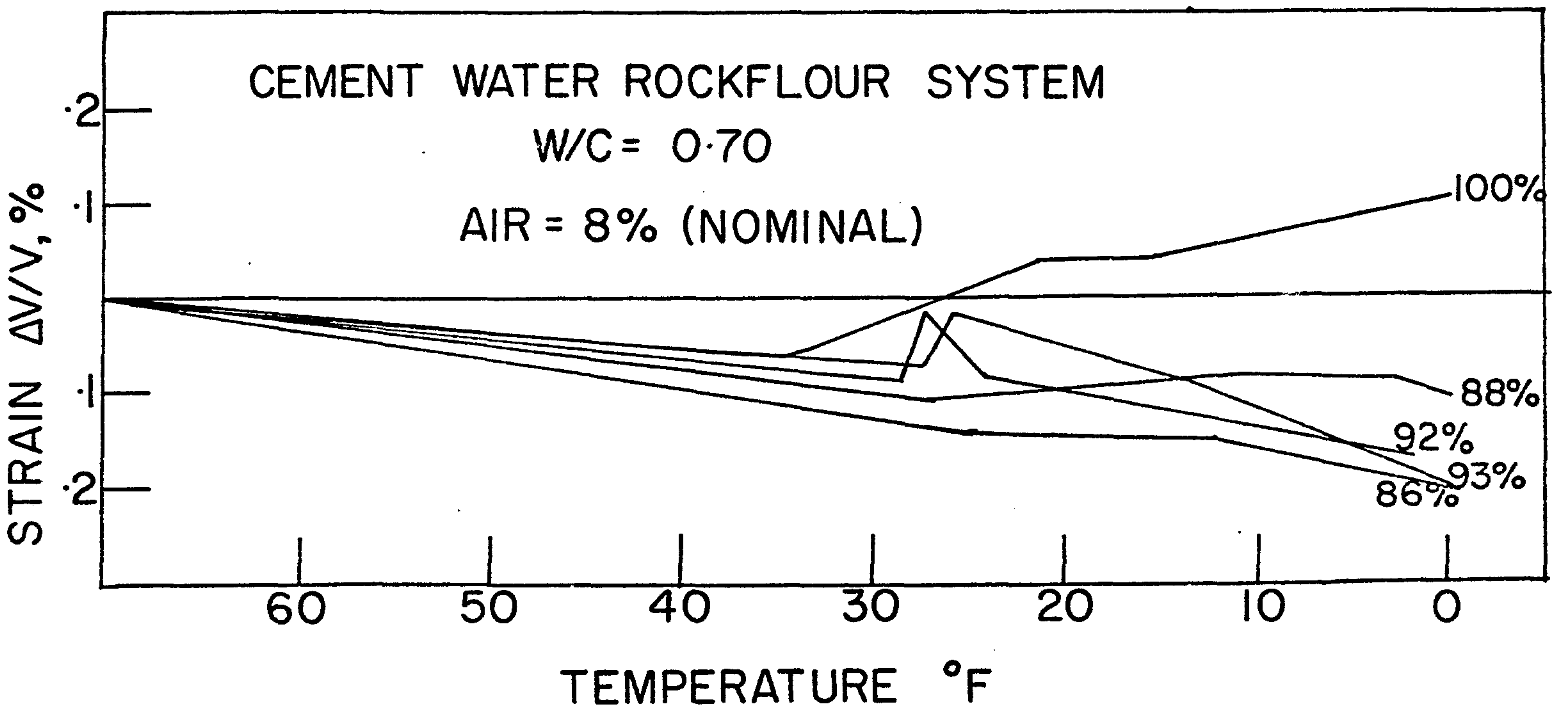


Figure 78 Effect of Degree of Saturation on Length Change Patterns; w/c=0.70 With Air 8%

limiting water-cement ratio ie. eventually, as the water-cement ratio is lowered there will be a linear volume change response over the whole temperature range $0 \leqslant T \leqslant 70^\circ F$. It is interesting to note that specimens of w/c = 1.0 (no air) failed after one cycle ie. they exhibited large vertical and horizontal cracks (1/32" wide). This is direct evidence of large tensile forces probably generated by hydraulic pressure.

Figure 43 shows a multiple cycling test for a rockflour paste of water-cement ratio 0.70 and 15% air. We see there is a slight dilation on the initial cycle even though the sample contains a large amount of entrained air (15%). There is a large initial residual strain. Subsequent cycles damp out the residual strain as continued hydration and self-desiccation combine with "frost damage" (dilation) to stabilize the system.

Effect of drying

All the specimens in the "saturation" series were dried for a period of two weeks (50% RH) prior to vacuum treatment. This was intended to simulate natural drying. However concrete in the field may not experience a drying regime of this nature. By arbitrarily drying in the laboratory (50%RH) we are changing the internal structure of the paste phase and accordingly may change the quantity of the water which the paste can readsorb. Figure 79 shows the transient strain behaviour of a rockflour paste (w/c = 1.00) at the age of one day. Also plotted is the pattern for a similar paste which was moist-cured for 14 days, air dried for 14 days, vacuum saturated 24 hours and soaked for 2 weeks. These results show that although the latter paste is more mature the dilational tendency is substantially greater. Obviously the drying and vacuum procedure affected the resulting length changes of the mix.

It is appreciated that a test method such as the one proposed by Larson and Cady et al.(55) cannot completely duplicate field conditions. Indeed this would be a formidable task. However figure 79 demonstrates that the laboratory conditioning procedure of drying and vacuum saturating can produce length changes in excess of those realized by specimens undergoing a natural moist curing process. In short the meteorlogical history of a particular environment should be incorporated into plans for any proposed standard test.

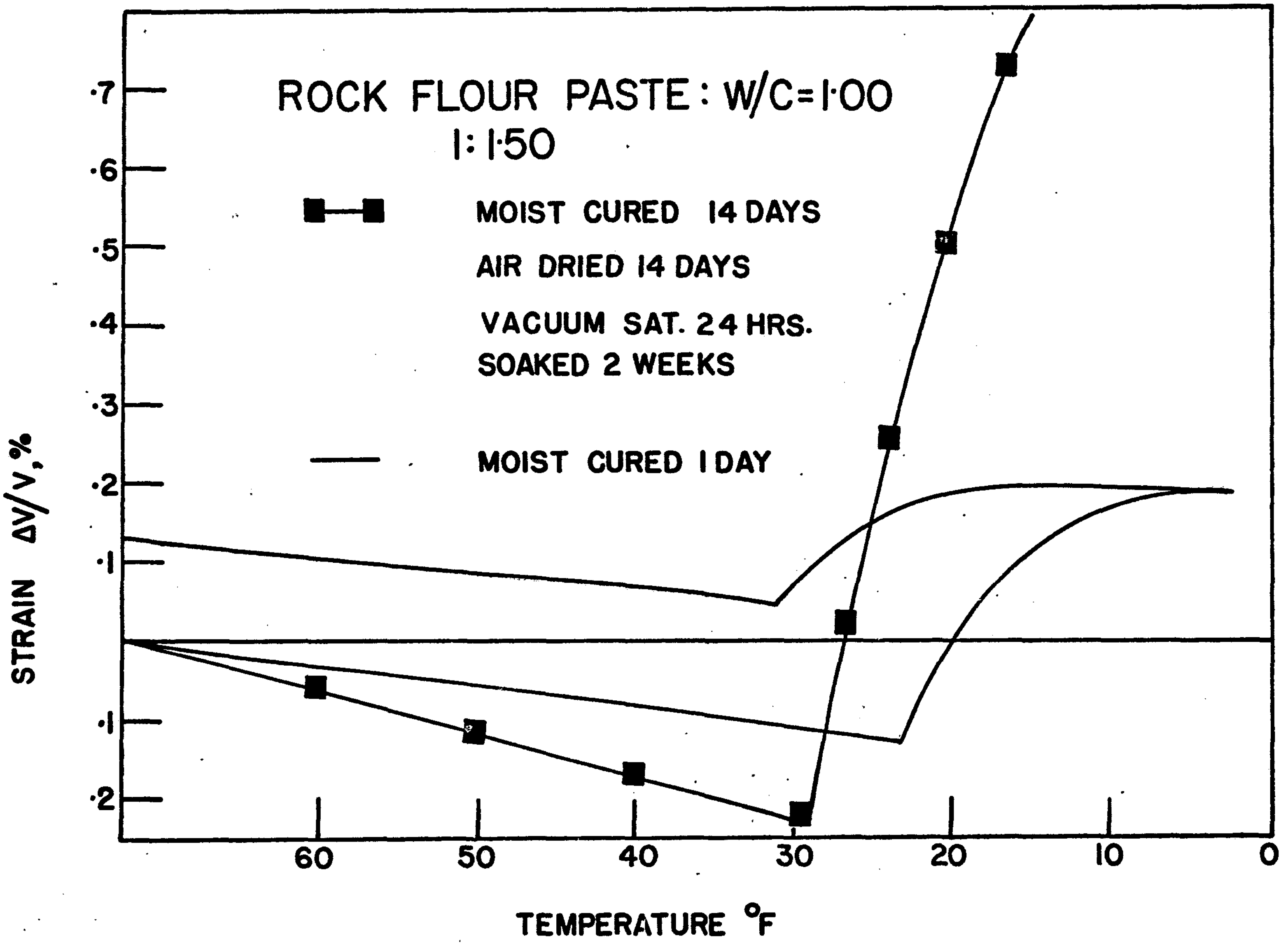


Figure 79 Effect of Drying on Dilational Response

Conclusions

1) There is a limiting value of degree of saturation above which there is danger of frost damage; this is approximately 90 percent.

2) There is a limiting water-cement ratio below which dilational response is negligible.

3) Hydraulic pressure appears to be operative when high porosity pastes are cooled below freezing.

4) Drying and vacuum saturation produce larger dilational response than is achieved by normal moist curing-even at early ages.

5) Any plan for a test method should take into account the particular environment in which the concrete is placed.

J. SLOW CYCLE EXPERIMENTS (2°F/HR.)

A series of experiments was designed to study the effect of a cooling-warming regime which allowed a greater time for the cement-paste system to approach equilibrium. The second drawing in figure 14 describes a slow cycle in which $\frac{dT}{dt} = 2^{\circ}$F/hr. The cycle itself had a duration of about 70 hours.

Mixes

The mixes selected included plain paste with water-cement ratios of 0.35, 0.45 and 0.50.

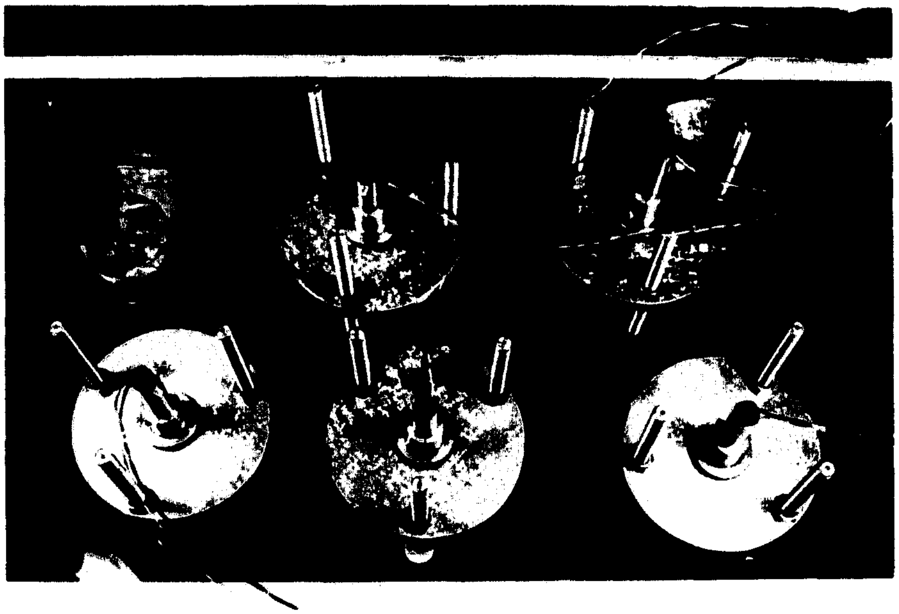
Fly-ash mixes having water-cement plus ash ratios of 0.45 and 0.50 with 30 and 45 percent replacement were chosen. The fly-ash mixes with large amounts of free water would provide an upper bound for the transient strain behaviour of paste cooled at 2°F/hr. All specimens were cast as 1" x 1" x 6" prisms.

Test procedure

The test frames were immersed in an ethylene glycol bath. The bath facilitated the employment of a slow 2°F/hr. cooling cycle. The prisms were sealed with polyethylene so as to prevent transfer of moisture in or out of the specimen while itwas being cycled.

Strain-temperature plots

Figure 80 is a strain-temperature plot for a paste with water-cement ratio 0.50. This plot demonstrates the transient strain behaviour of the paste at one day, when subjected to the selected slow cooling and warming regime ie. 2°F/hr. It is of interest to note that both the dilation and residual volume change are reduced substantially in comparison with an identical mix subjected to the 5°F/hr. cycle. Values of D_o and ΔV_R for the 5°F/hr. cycle are 0.90% and 0.36% respectively and for the 2°F/hr. cycle are .2% and .036%. It is thus apparent that the slower cooling cycle



P_6 - Specimens Immersed In Ethylene Glycol Bath

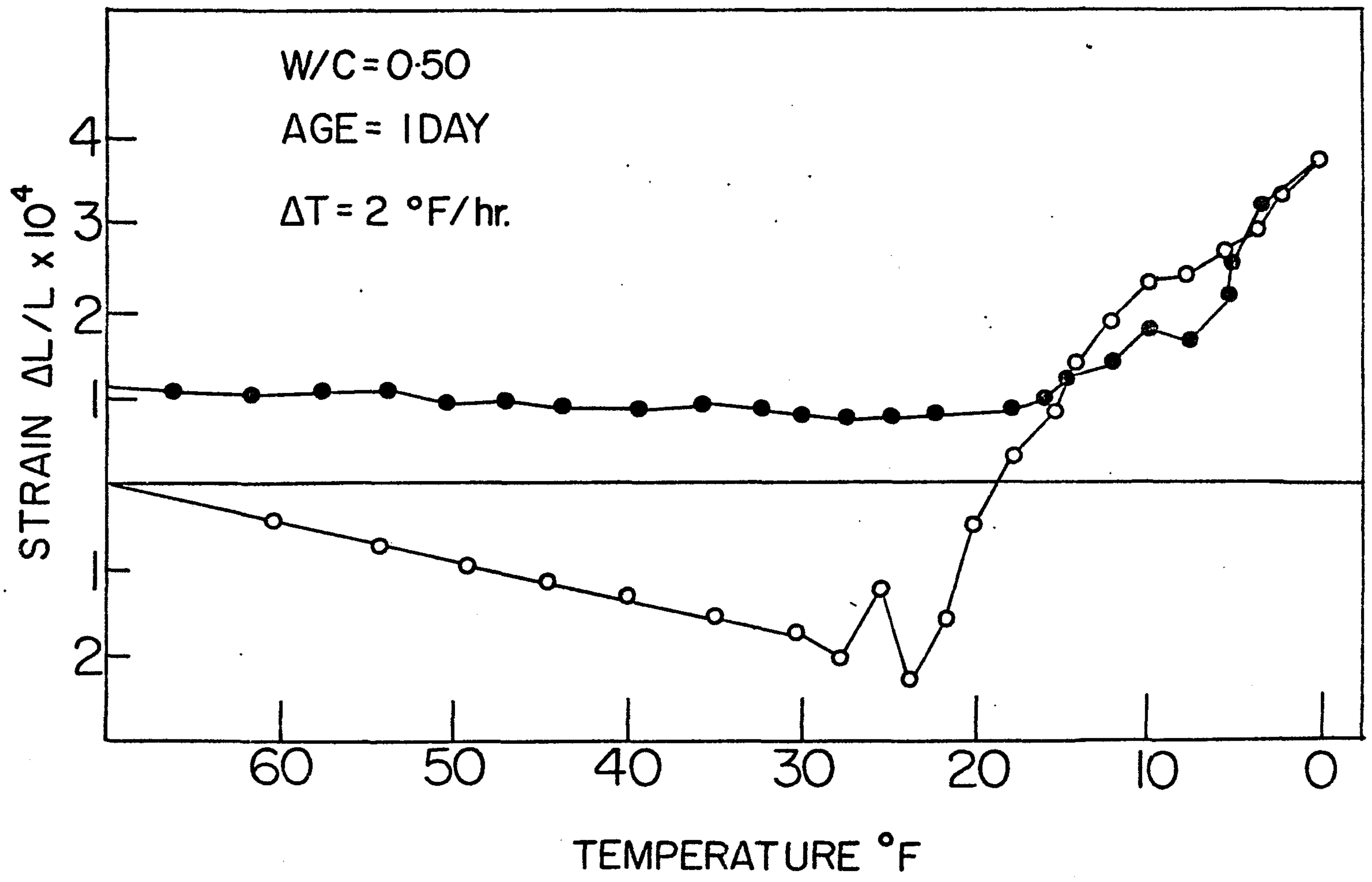


Figure 80 Strain-Temperature Plot For Slow Cooling Cycle ($2^{o}F/hr$); w/c=0.50

allows more time for the system to approach equilibrium and to relieve itself of the stresses produced by freezing. To illustrate the stress relaxation phenomena due to the selected slow cooling-warming regime, figure 81 shows the warming region of the strain temperature hysteresis for several mixes including a fly-ash paste with water-solids ratio 0.50 and 45 percent replacement. In all cases the strain response with warming is similar to the type of response one observes during the creep recovery process of concrete after the load has been removed. Creep recovery has been described as a form of stress relaxation. Indeed stress relaxation appears to be inherent in the warming behaviour of the pastes in this series. Referring again to figure 80 we see that the stress relaxation effect reduces the hysteresis as warming takes place up to about 15°F. Then the hysteresis is more pronounced as stress relaxation (constant strain with decrease in stress) continues until 70°F is reached. Litvan (56) performed an experiment on a cement-paste specimen (water-cement ratio= 0.70) under fully equilibrium conditions; that is, as the temperature was decreased he waited until the length changes had completely relaxed. Litvan's sample dilated only after a temperature of about

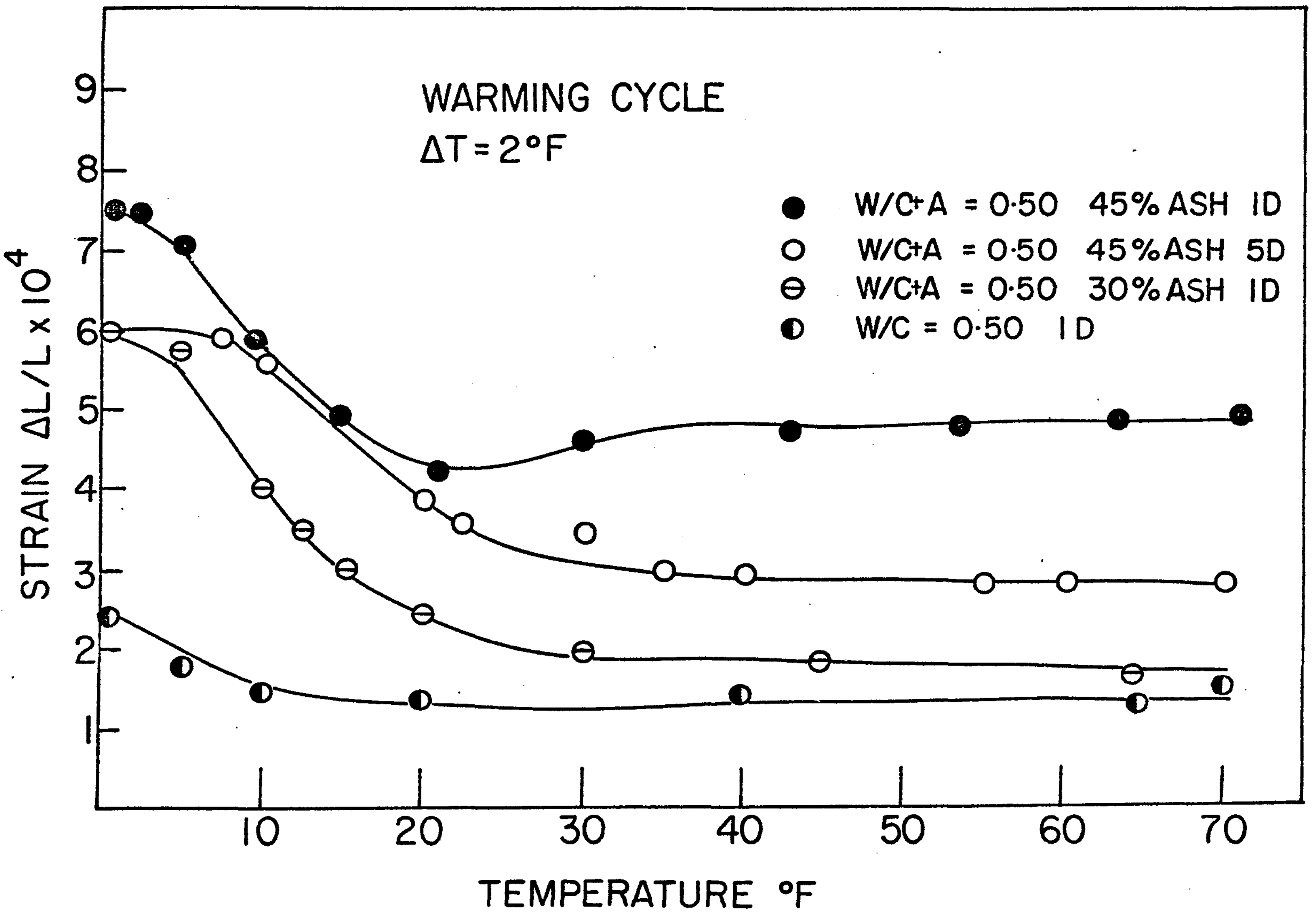


Figure 81 Warming Cycle ($2^{\circ}F/hr$) For Selected Pastes

$-20\ C^{\circ}$ was reached. Litvan's results apparently form an lower limit or bound for the dilation phenomena. However it is noted that tests under fully equilibrium conditions and conducted with extremely slow rates of cooling (ie. $<< 1\ ^{\circ}F/hr.$) although informative, are completely unnatural.

Conclusions

1) Temperature regimes which involve cooling warming cycles with $\frac{dT}{dt} < 5^{\circ}F/hr.$ experience a reduction in dilational response and residual volume change.

2) The reduction in strain on warming appears to be a stress relaxation phenomena similar to creep recovery, for rates of cooling where $\frac{dT}{dt} < 5\ ^{\circ}F/hr.$

3) Slower cooling rates allow the cement paste system more time to reach equilibrium and are less severe from the point of view of frost action.

4) For partially-hydrated paste ($\alpha < 1$) subjected to extremely slow cooling-warming regimes ($\frac{dT}{dt} << 1\ ^{\circ}F/hr.$) self-desiccation and continued hydration are contributory mechanisms accounting for a decrease in the magnitude of dilational response and residual volume change.

K. EXPERIMENTS WITH BENZENE SATURATED PASTE

Powers (57), in an attempt to explain the mechanism of frost action postulated that on freezing water is drawn from the gel to the larger capillaries because of a difference in Gibbs Free Energy between the gel water and the capillary water. Powers expressed this mechanism in terms of the following classical thermodynamic expression.

$$\left[\frac{\partial G}{\partial T}\right]_p = - S \qquad \text{------ (54)}$$

This expression however is clearly only valid for water in the bulk phase. Feldman and Sereda (58) have stressed that behaviour of gel water cannot be expressed by equations which are valid for the bulk phase only. They criticized Powers use of bulk phase thermodynamics in hypothesizing theories of creep and volume change (59). Clearly any application of thermodynamics to volume change studies of hydrated portland cement paste should include surface phase effects.

The fundamental differential equation for the total change in free energy of a homogeneous bulk phase is:

$$dG_{\text{bulk}} = VdP - SdT + \mu_1 dn_1 + \mu_2 dn_2 \qquad \text{-- (55)}$$

The analogous differential equation for a surface phase is

$$dG_{\text{surface phase}} = VdP - SdT + \sigma d\gamma + \mu_1 dn_1 + \mu_2 dn_2 \quad \text{-------(56)}$$

The '$\sigma\gamma$' term in the Gibbs-Duhem equation allows for the change in free energy resulting from an increase or decrease of surface energy.

In the two component system described, n_1 is the number of moles of adsorbate and n_2 is the number of moles of the adsorbent; μ_1, μ_2 are the respective chemical potentials, 'γ' is the surface energy per square cm. and 'σ' is the surface area (cm^2). It would seem appropriate to discuss freezing phenomena involving moisture transfer from the hydrate phase due to free energy gradients by reference to surface phase thermodynamics ie. Equation (56) is more correct than equation (55).

The above argument has been put forward to present the idea that the pressure developed on freezing may be a result of -at least partially- the change in surface energy of the solid.

Hoekstra, Chamberlain and Frote (60) performed tests on silt saturated with water and saturated with benzene. They measured the pressure due to freezing as a function of time for the silt saturated with the two fluids. It was reasoned that if the pressure developed is the result of the surface energy of a solid-liquid interface in a porous system, the pressure should not be a property of the ice-water system only, but should also occur when, eg; benzene solidifies in the system. This was verified with the silt tested. The pressure developed in the same manner for a benzene-saturated soil as for a soil saturated with water. The difference in pressure (100 psi for water to 10 psi for benzene) was assumed due to the different values of the surface tension of ice-water and liquid-solid benzene.

A series of tests was designed to study the dimensional changes of a benzene saturated cement paste to determine if any dilational tendencies would be present.

Choice of mixes

Fly-ash mixes with 45% replacement and a water-solids ratio of 0.50 were chosen because of high initial porosity due to slow initial reaction rate of the fly-ash paste system. All mixes were tested at one day. The majority of the mixes were cast in the form of 1" x 1" x 6" prisms. A few mixes were cast into 3" Ø x 6" cylinders.

Test procedure

After one day of moist curing the specimens were weighed and oven dried at 110°C for 24 hours. Then they were weighed, cooled in desiccators for 4 hours and vacuum saturated in benzene for 24 hours. On removal from the benzene, they were weighed, wrapped in polyethylene and subjected to the 5°F/hr. temperature regime.

The following table gives average values for the volumes of water and benzene contained in test samples (1" x 1" x 6" prisms) at one day.

Mix	V water	V benzene
1	48.86	43.10
2	48.68	43.20
3	48.19	43.60
4	48.22	43.15
5	47.66	42.40
6	48.58	44.00

Table X Volumes of benzene and water in saturated samples.

Test results

Figure 82 is a typical hysteresis pattern for a benzol saturated paste. As cooling begins there is a linear thermal contraction until the

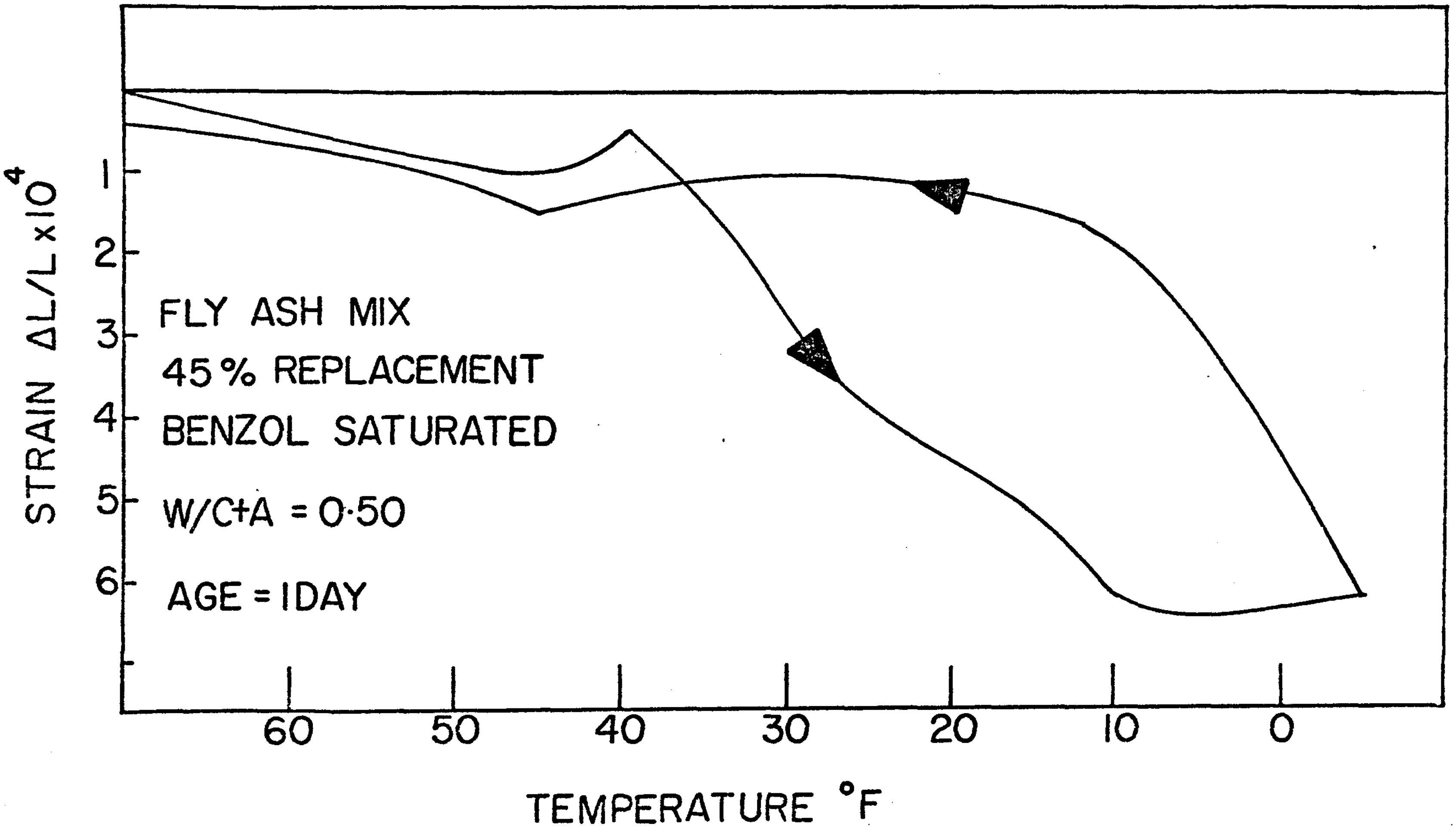


Figure 82 Slow Cycle Test For Benzene Saturated Paste

freezing point of benzene (41.9°F) is approximately reached. Then there is a small but positive dilation (about 1×10^{-4} in/in)followed by a thermal shrinkage at an increased rate. Warming introduces an expected hysteresis.

Figure 83 shows a comparison between a benzol and a water saturated mix. Both specimens experience a dilational response even though the specific volume of benzene decreases with a decrease in temperature in the freezing zone.

Discussion

The dilational response of a benzene saturated paste cannot be explained by the conventional hydraulic pressure theory, which relies on an increase in specific volume of water upon freezing. It suggests that perhaps changes in surface free energy of the solid surface may be responsible-at least in part-for the dilational behaviour of cement paste on freezing. A decrease in surface free energy of the adsorbate causing swelling or dilation is consistent with a readsorption mechanism discussed earlier.

Conclusion

The benzol saturated paste experiments just described give evidence for a surface free energy contribution to the dilation phenomena.

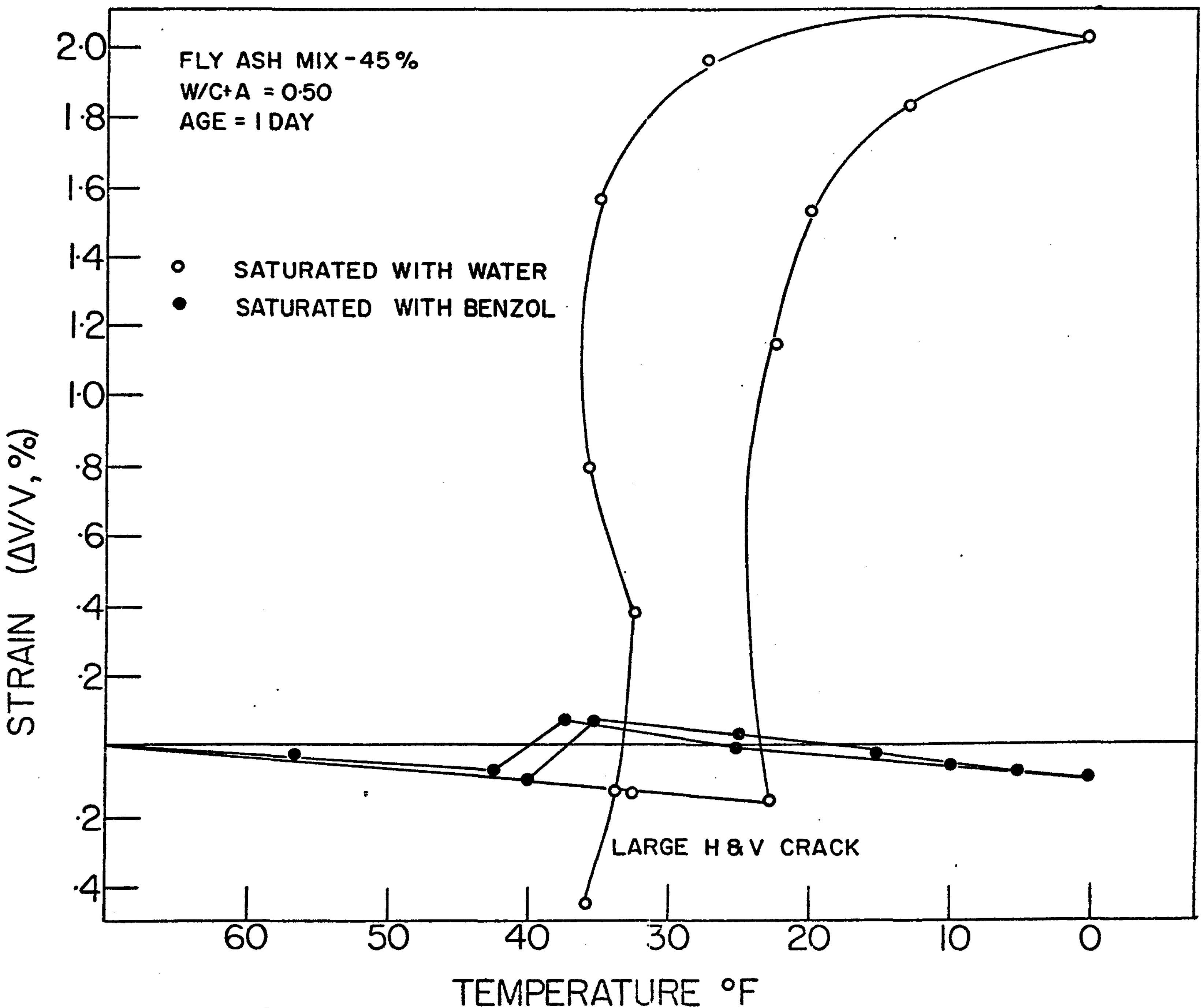

FLY ASH MIX - 45 %
W/C+A = 0·50
AGE = I DAY
○ SATURATED WITH WATER
● SATURATED WITH BENZOL
LARGE H & V CRACK
STRAIN (ΔV/V, %)
2·0
1·8
1·6
1·4
1·2
1·0
·8
·6
·4
·2
·2
·4
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 83

L. ELECTRON OPTICAL STUDIES

In order to obtain an appreciation of the effect of a slow cooling-warming regime on the structural reorientation (ie. damage) of the hydrate phase, a study of structure with a surface-scanning electron microscope was made. The surface-scanning electron microscope permits easy and rapid examination of the surface and also allows the viewer to scan the walls of capillaries and cracks.

Experimental

Specimens from the following two mixes were examined:

Mix	Design	Age
1	Fly Ash 45%; w/c+A=.050	1 day
2	Plain Paste; w/c=0.50	1 day

Half the specimens from each mix were cycled according to the selected slow-cooling warming regime; the other half were not cycled. After testing, slices about 1/8 inch thick were taken from the 1" x 1" x 6" prisms and mounted on a 1/2 inch diameter aluminum stub. After coating with approximately 100 Å thickness of gold they were examined in a stereoscan Mark II a electron microscope.

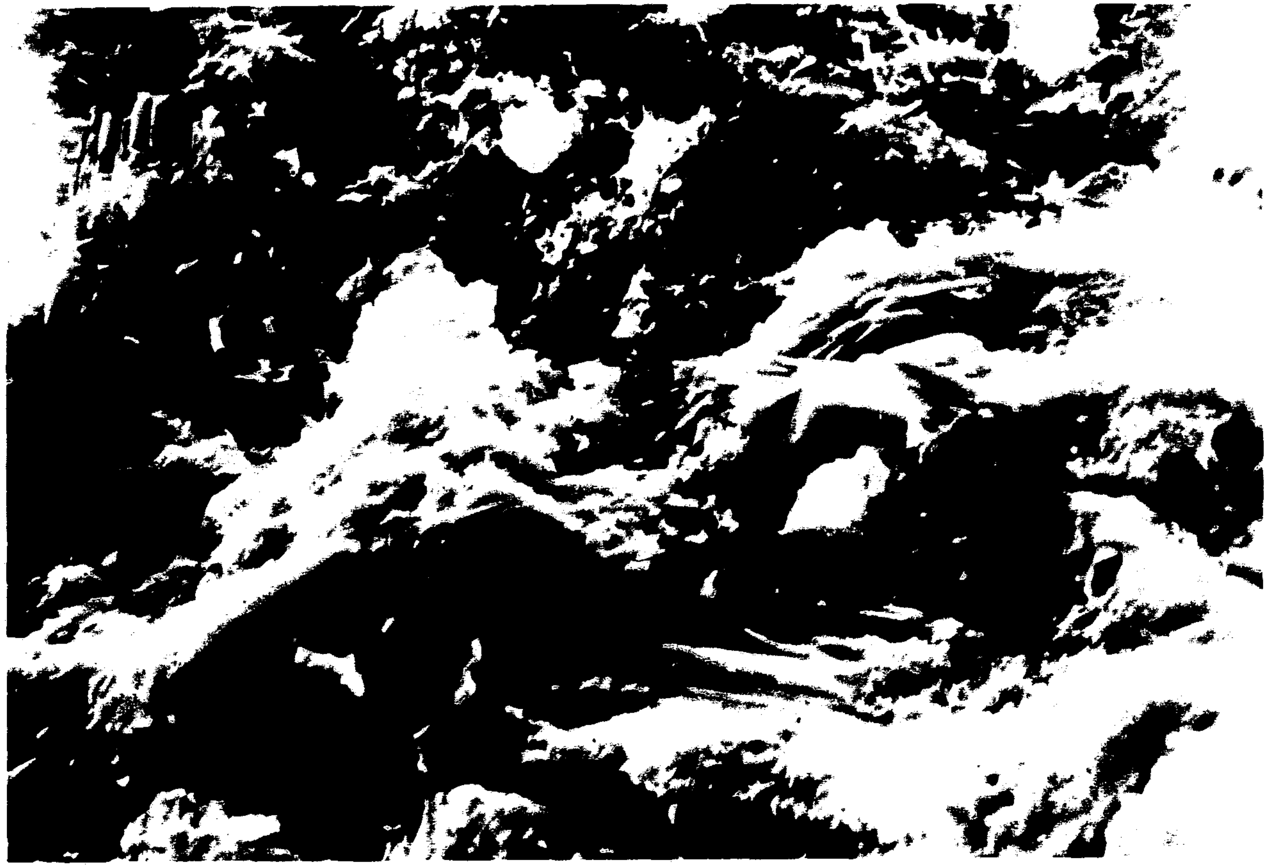
Results

Systematic scanning of the cycled specimens revealed sharp cracks in the fly ash grains and at the hydrate grain interface. Also observed was a general disorder or separation of structure at the grain-hydrate interface. This is clearly demonstrated in the series of electron micrographs EM1-EM6. In the plain paste which was cycled large cracks are noticeable throughout the hydrate as illustrated by EM2. The sides of the photographs EM1-EM6 measure 17.1 x 17.1 microns.

Discussion

A one cycle slow cooling test may cause internal damage to the hydrate structure as evidenced by the observed cracks in cycled specimens. There were no large cracks observed in uncycled specimens. It is possible then that in concrete cracks may occur at the paste aggregate interface and extend into the paste phase. It is the interaction at the paste-aggregate interface which may be a part of the difficult problem of assessing frost resistant qualities in aggregates.

EM$_1$ - Fly Ash Grains With Interstitial Hydrate Disrupted At Grain Hydrate Interface 2800 x

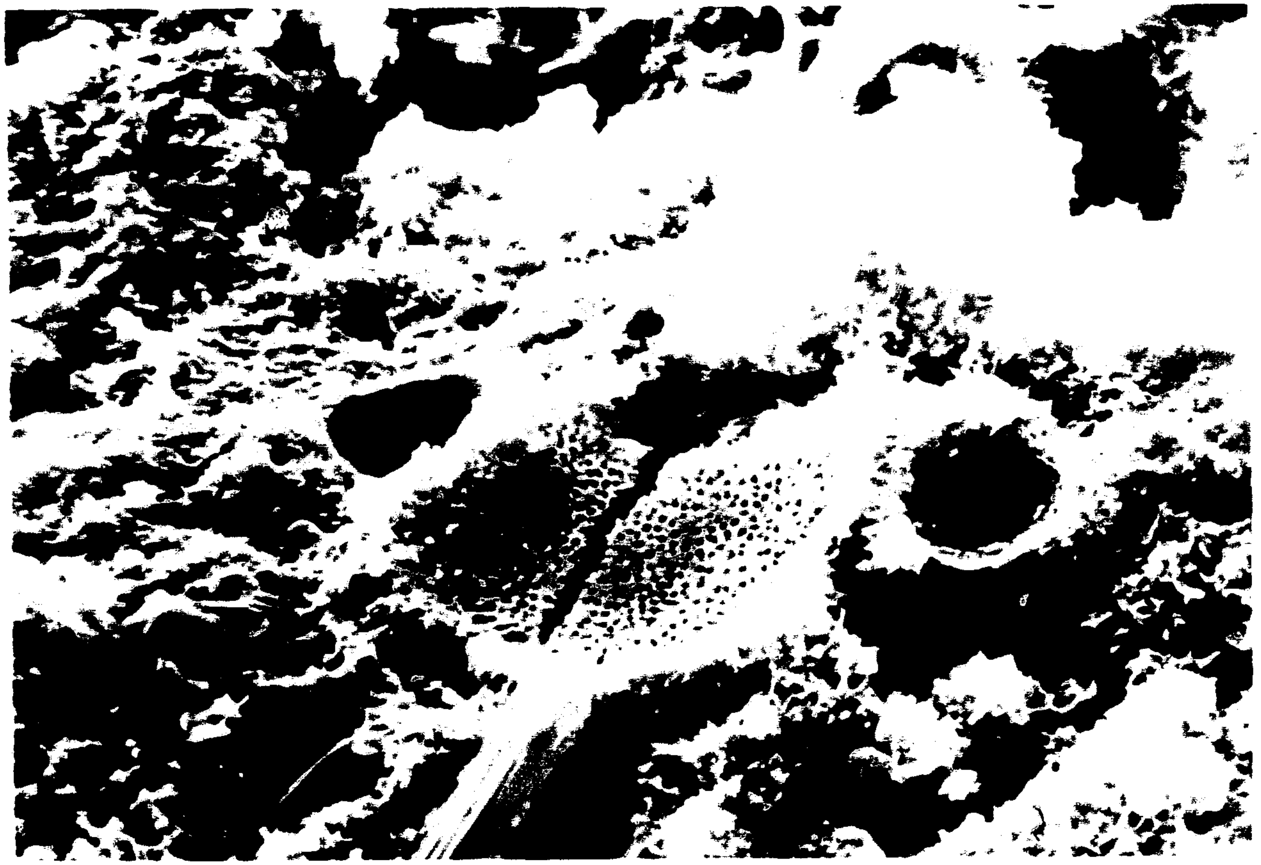


EM_2 – Hydrated Cement Paste Showing Cracks Due To Slow Cooling Warming Regime 2800 x

EM$_3$ — Fly Ash Grain With Hydrate 2800 x

EM$_4$- Fly Ash Grains In Hydrate Matrix Showing Crack
At Hydrate Grain Interface 2800 x

EM_5 – Grain And Hydrate Interface Showing Crack Through Skull 2800 x



EM$_6$ — Fly Ash Skull With Central Crack 2800 x

M. GENERAL CONCLUSIONS - EXPERIMENTAL STUDIES PART II

Although detailed concluding remarks follow individual experiments described in this chapter the following are general conclusions based on the experimental evidence presented in Part II.

1) Compressive strength is related quantitatively to two volume change hysteresis parameters-dilation and residual volume change.

2) Dilation and residual volume change are functions of the volume concentration of hydrate product and $\frac{\Delta w}{w_o}$.

3) Dilation and residual volume change are functions of the volume of free water per unit volume of paste.

4) Strength reduction ratio is a linear logarithmic function of time regardless of the presence of admixtures.

5) The strength reduction ratio is a function of $\frac{\Delta w}{w_o}$ and water-cement ratio; it is also a function of the volume of free water per unit volume of paste.

6) An air void system collapses the strain-temperature hysteresis almost completely.

7) The presence of water-reducing admixtures does not significantly change the nature of the strengh-dilation function or the dependence of dilation and residual volume change on the volume

concentration of hydrate product.

8) The use of fly ash allows cycles on hardened paste to be performed at lower values of $\frac{\Delta w}{w_o}$. The addition of ash does not alter significantly the nature of the strength dilation function or the dependence of the hysteresis parameters on the volume concentration of hydrate product. However it allows the strength dilation function to be extended to the region $0.03 < \frac{\Delta w}{w_o} < 0.04$.

9) Limits (quality indices) can be assigned to the volume change hysteresis response of the cement paste system. It was shown that "critical" dilation is invariant.

10) There are critical values of strength, volume concentration of hydrate product and volume of free water above or below which there is danger of frost damage.

11) The self desiccation process as reflected by multiple cycling influences degree of saturation and hence immunity from frost damage.

12) Critical "degree of saturation" appears to be approximately 90 per cent.

13) Drying and rate of cooling significantly affect the strain-temperature response of cement paste. Slower cooling-warming rates tend to collapse the volume change hysteresis loops.

14) Evidence provided by benzene experiments appears to indicate the presence of a freezing mechanism other than hydraulic pressure.

CHAPTER X

EXPERIMENTAL STUDIES - PART III

INTRODUCTION

It was intended to extend the cement paste studies to the mortar phase of the matrix and to attempt to assess the role fine aggregate plays in the transient-strain behaviour of mortar. Mortar mixes of varying aggregate-cement ratio and water-cement ratio were prepared using two different Ontario sands. It was intended to assess the nature of aggregate restraint on dilational characteristics of mortar as well as the effect of the hydration process.

A series of mixes with spherical glass inclusions (5/8" Ø) of varying volume proportions was undertaken to simulate conditions of pure restraint and maximum paste incompatability. All these mixes were tested at an early age in an effort to study the nature and orientation of the cracks at the paste-aggregate interface. Glass has a low coefficient of thermal expansion and hence is thermally compatible with the paste matrix.

SELECTION OF FINE AGGREGATE

Two good quality fine aggregates with fine service records-Paris and Erie-sand were chosen for this programme. Petrographic analysis is included in the appendix. In order to isolate the restraint variable the grading of the two sands was made identical and conformed to the ASTM requirement. Figure 84 gives the sand size gradation for the two sands.

ADSORPTION ISOTHERMS FOR SANDS

Adsorption isotherms were determined for the two sands. Approximately 50 gram samples were oven dried and cooled in a vacuum desiccator prior to obtaining the dry weight. Then the samples were placed in desiccators over saturated salt solutions to provide conditioning at the required relative humidity. The samples were conditioned at the various relative humidities for 30 days. The following table gives a summary of the range of relative humidities used.

Salt	p/p_s
NaOH	0.07
$CaCl_2$	0.34
KSCN	0.45
$MgNO_3$	0.54
NaCl	0.76
$CaCl_2$	0.86
H_2O	0.99

Table XI Saturated Salt Solutions For Conditioning Sand Samples.

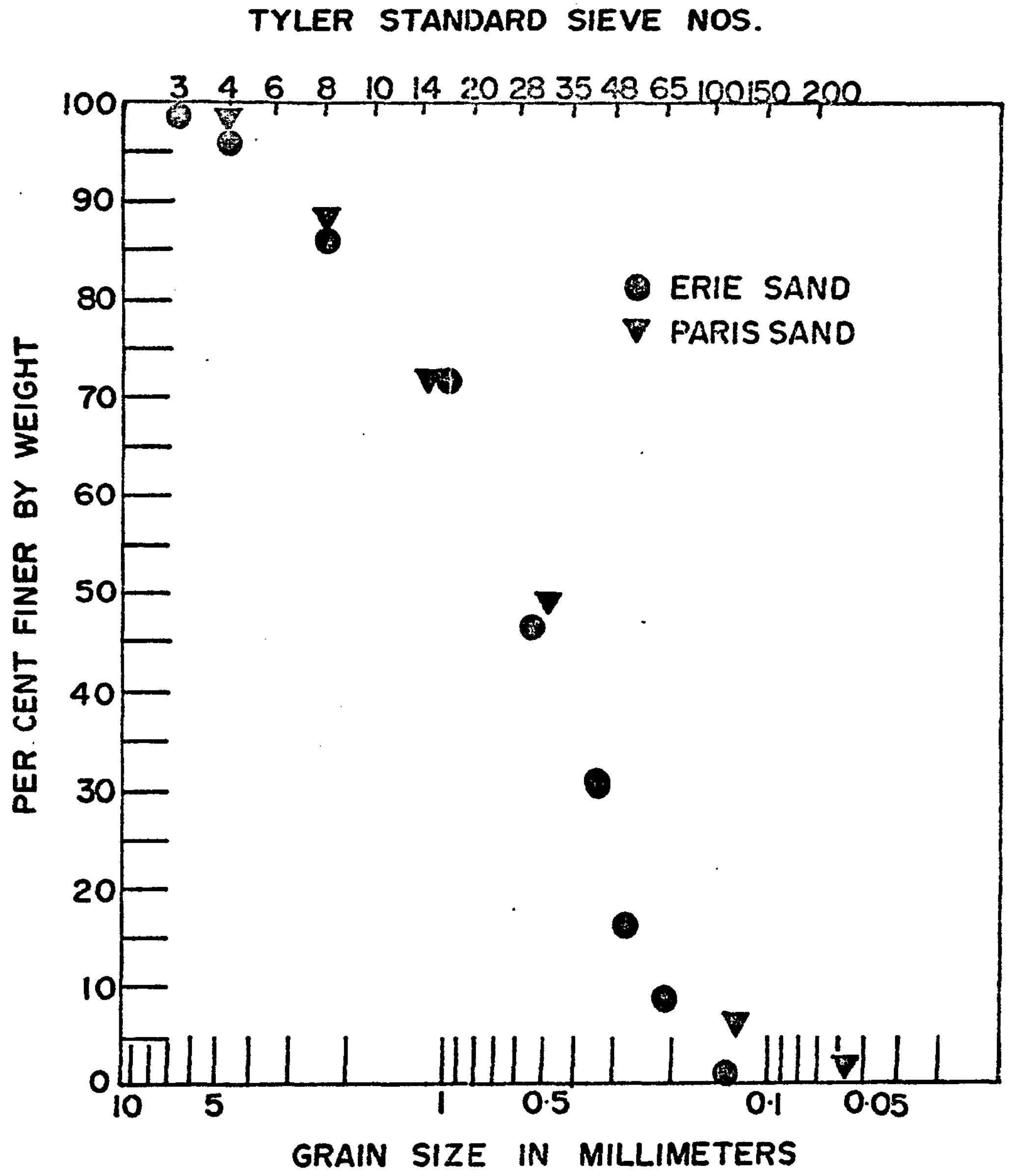


Figure 84 Grain Size Curves For Paris And Erie Sand

At the end of 30 days the samples were removed from the desiccators and the weights were recorded. The isotherm was then evaluated by plotting the ratio of water content to solid dry weight as a function of p/p_s. Figure 85 plots the isotherm for both sands; the isotherms appear to be very similar indicating that the porosities and pore size distribution of the two sands is similar.

Thus, the two test sands appear to have similar gradings and porosities.

TEST PROCEDURE

Selection of Mixes

Mixes were selected to provide a wide range of aggregate-cement ratios and water-cement ratios. The following table provides a summary of the mixes included in this test programme.

Sand	W/C	A/C
Paris	0.75	2:1; 2.75:1; 3.25:1 4.50:1; 6.00:1
	0.50	2:1; 3.25:1; 2.75:1
	0.60	3.25:1; 2:1
	0.65	3.25:1; 2.75:1
	0.45	2:1
Erie	0.75	2:1; 3.25:1; 2.75:1
	0.70	2.75:1; 3.25:1; 2:1
	0.60	2.75:1; 3.25:1; 2:1

Table Mix data for mortar series.
XII

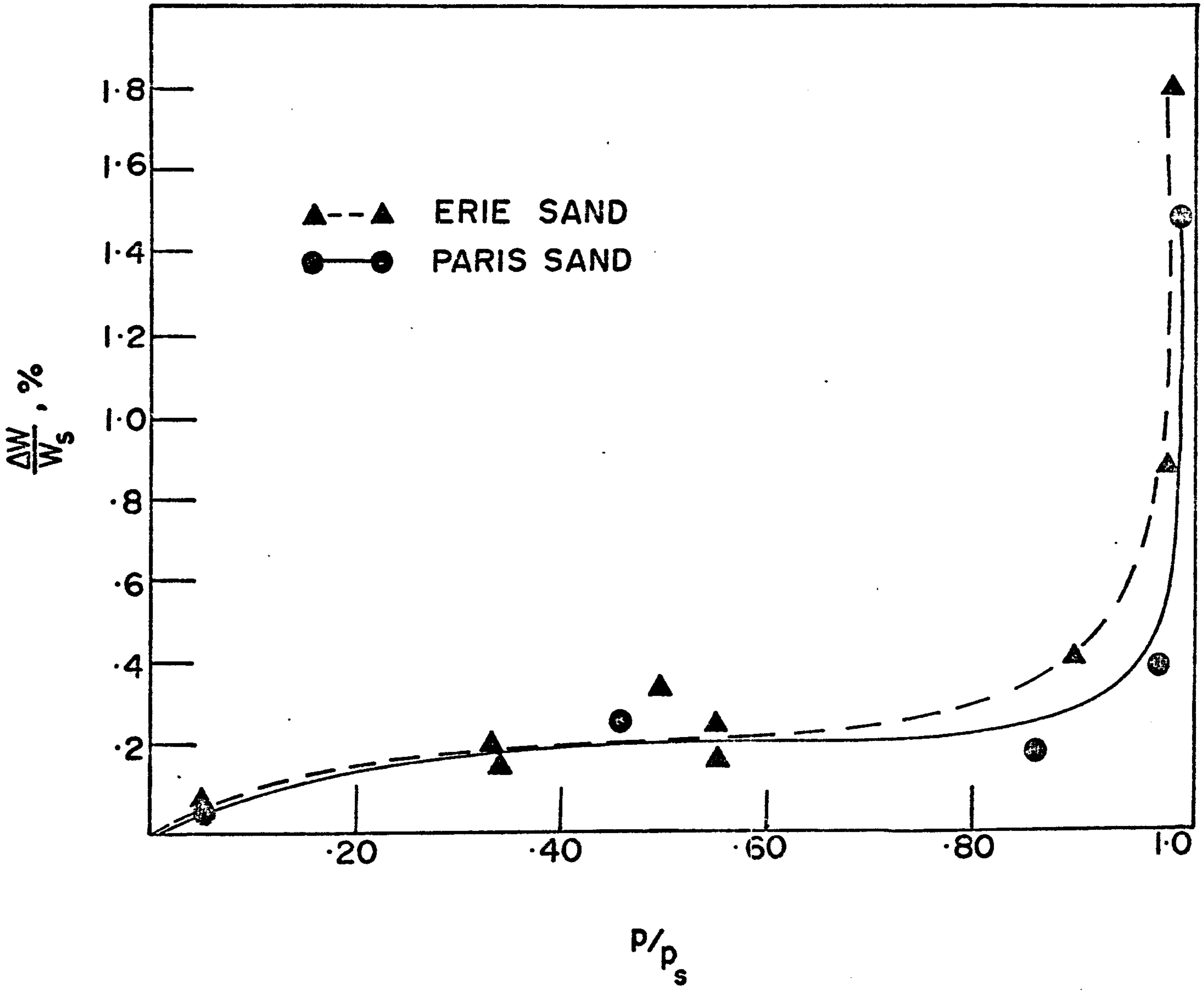


Figure 85 Adsorption Isotherms For Sands

Mixing

The mixing procedure involved mixing for 2 minutes followed by a one minute delay and then a further two-minute mixing period. After mixing, the mortar specimens were cast in the form of 1" x 1" x 6" prisms and continuously moist cured until the time of test.

Curing Regime

All mortar prisms were stripped from the moulds at 12 hours, during which time they were in the moist chamber at 70°F and 100 percent relative humidity. After stripping they were immersed in a lime saturated water bath (70°F) until the time of test.

Measurement of $\frac{\Delta w}{w_o}$

The progress of the hydration process for mortar mixes in this series was determined by continuous determination of the parameter $\frac{\Delta w}{w_o}$ using the bottle method described in Part I of the experimental studies. Experimental data is included in the appendix. It was hoped to non-dimensionalize the dilation parameter by expressing it as a function of the dimensionless parameter $\frac{\Delta w}{w_o}$ and to take into account the restraint provided by the inclusion of fine aggregate in the matrix.

Freezing Regime

All mortar prisms were subjected to the selected natural cooling-warming regime ie. $\frac{dT}{dt} = 5^{\circ}F/hr.$ and length changes were monitored continuously.

TEST RESULTS

Strain-temperature diagrams were constructed to illustrate the transient strain behaviour of the mortar mixes. For all mortar mixes there is a systematic collapse of hysteresis with time. It is immediately obvious that the inclusion of fine aggregate particles in the matrix produces a less pronounced degree of hysteresis than does pure cement paste. In fact for a given water-cement ratio, the hysteresis property of the strain-temperature function is dependent on the volume proportion of fine aggregate in the matrix. Figure 86 illustrates dramatically the effect of volume concentration of fine aggregate for a mortar mix with w/c = 0.75. In this figure the hysteresis is initially large for the 2:1 mix and continuously collapses as the concentration of fine aggregate increases. It is observed that a total collapse is practically achieved when the aggregate-cement ratio reaches 6:1. Although the higher aggregate-cement ratios are impractical where field practice is concerned (ie. they are too stiff) they demon-

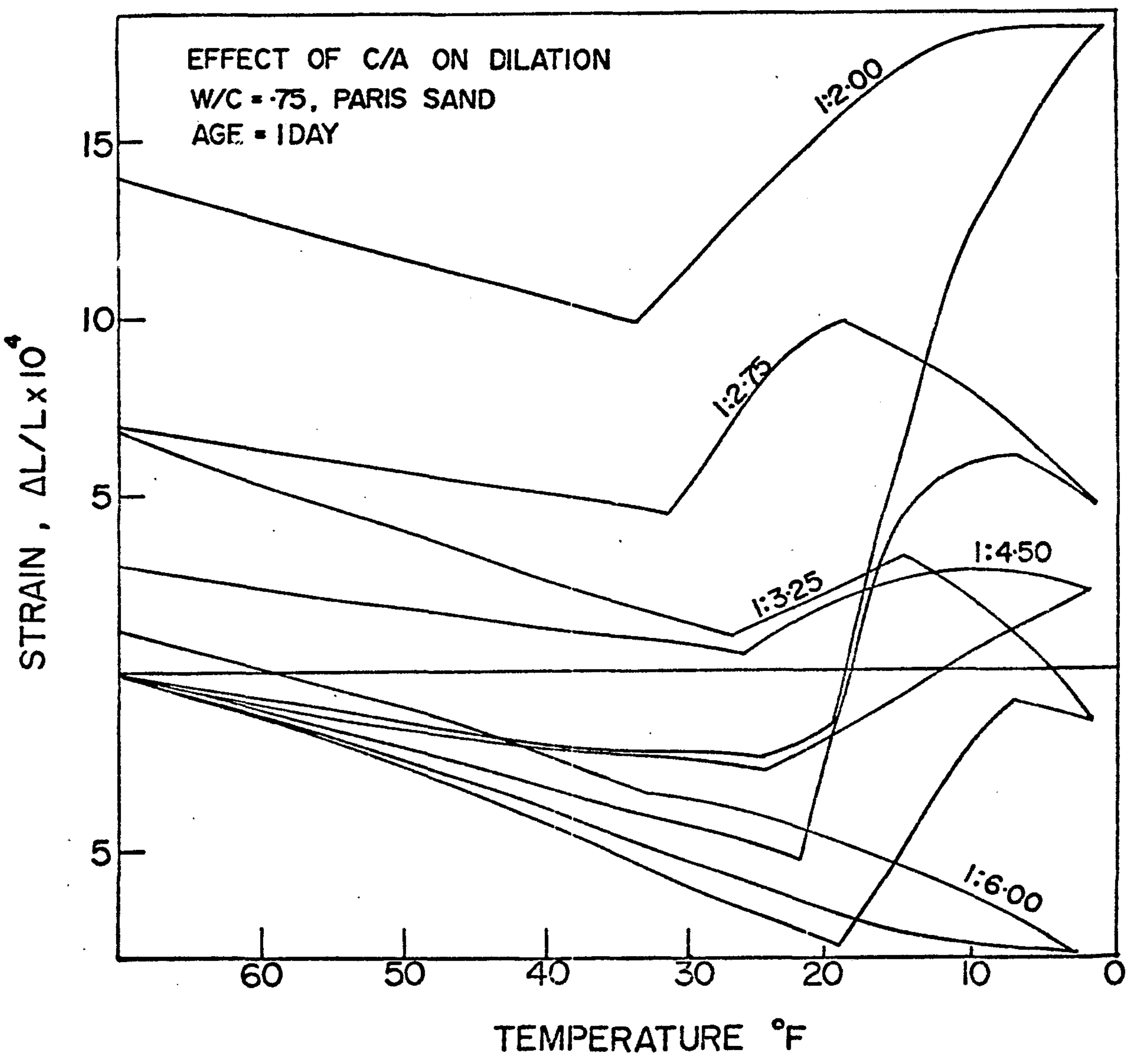


Figure 86 Effect of Cement-Aggregate Ratio on Dilation

strate remarkably the effect of aggregate-cement ratio on the dimensional stability of mortar mixes. Figures 87 through 99 illustrate the time dependent collapse of hysteresis for all the mortar mixes (including both Paris and Erie Sand). Figures 100 to 105 demonstrate the effect of water-cement ratio for a given aggregate-cement ratio. We can see that as the water-cement ratio is increased the hysteresis effect is magnified and the dilation response is increased.

Figures 106 and 107 give dilation as a function of water-cement ratio (at one day) for various aggregate-cement ratios. We can see that as the aggregate-cement ratio increases from 0:1 to 3.25:1 for both Erie and Paris Sand, the dilation decreases drastically. Figure 108 shows dilation vs. water-cement ratio for both Paris and Erie Sand through a range of aggregate-cement ratios. With no restraint on the system, pure cement paste exhibits much larger dilations than the mortar phase. The Paris sand exhibits larger dilations than the Erie Sand at a given water-cement ratio. As the grading and porosity of the two sands are practically identical the differences in dilation response are attributed to aggregate restraint or stiffness.

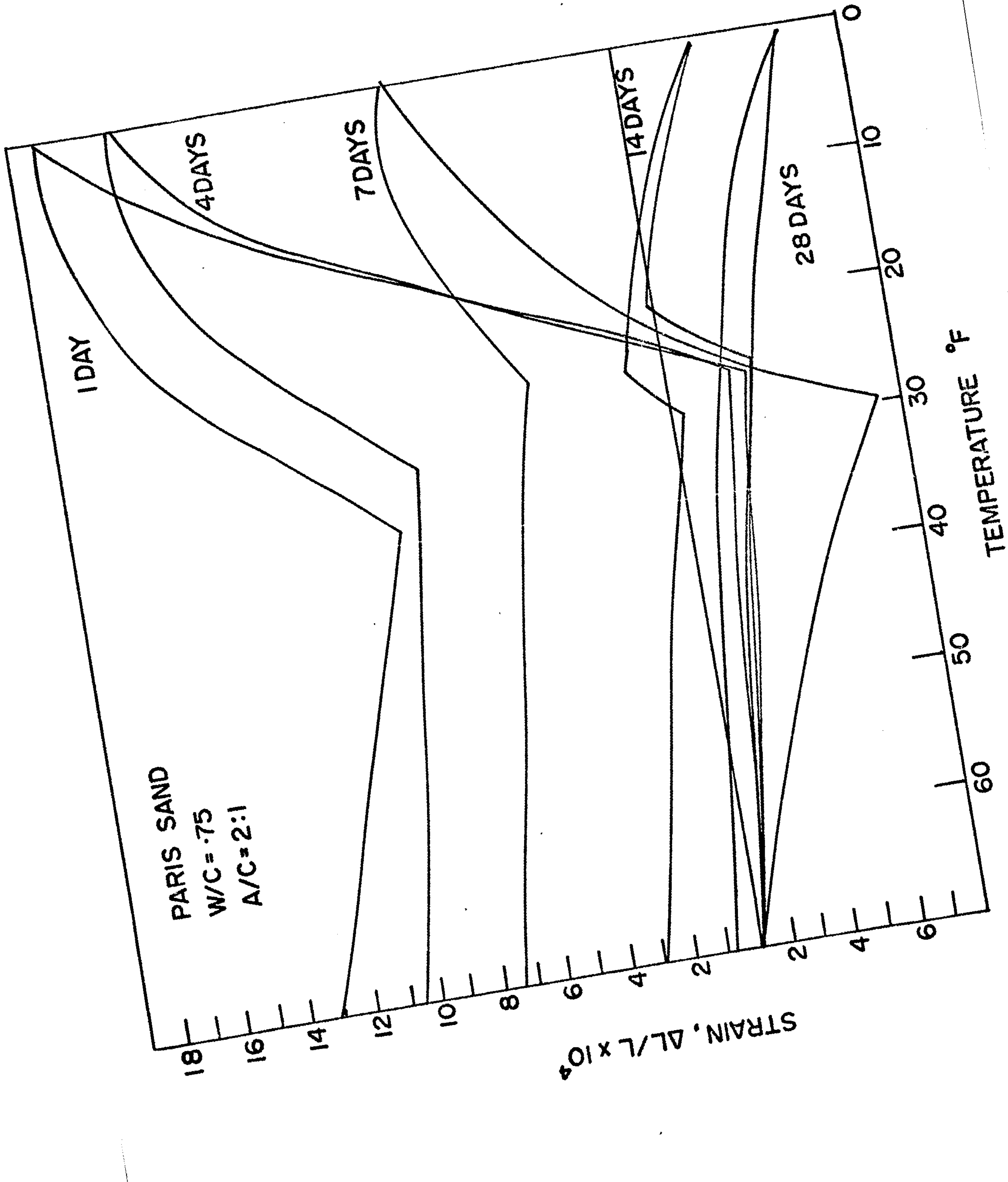

PARIS SAND
W/C = ·75
A/C = 2:1
1 DAY
4 DAYS
7 DAYS
14 DAYS
28 DAYS
TEMPERATURE °F
0
10
20
30
40
50
60
STRAIN, ΔL/L x 10⁴
18
16
14
12
10
8
6
4
2
2
4
6

Figure 87

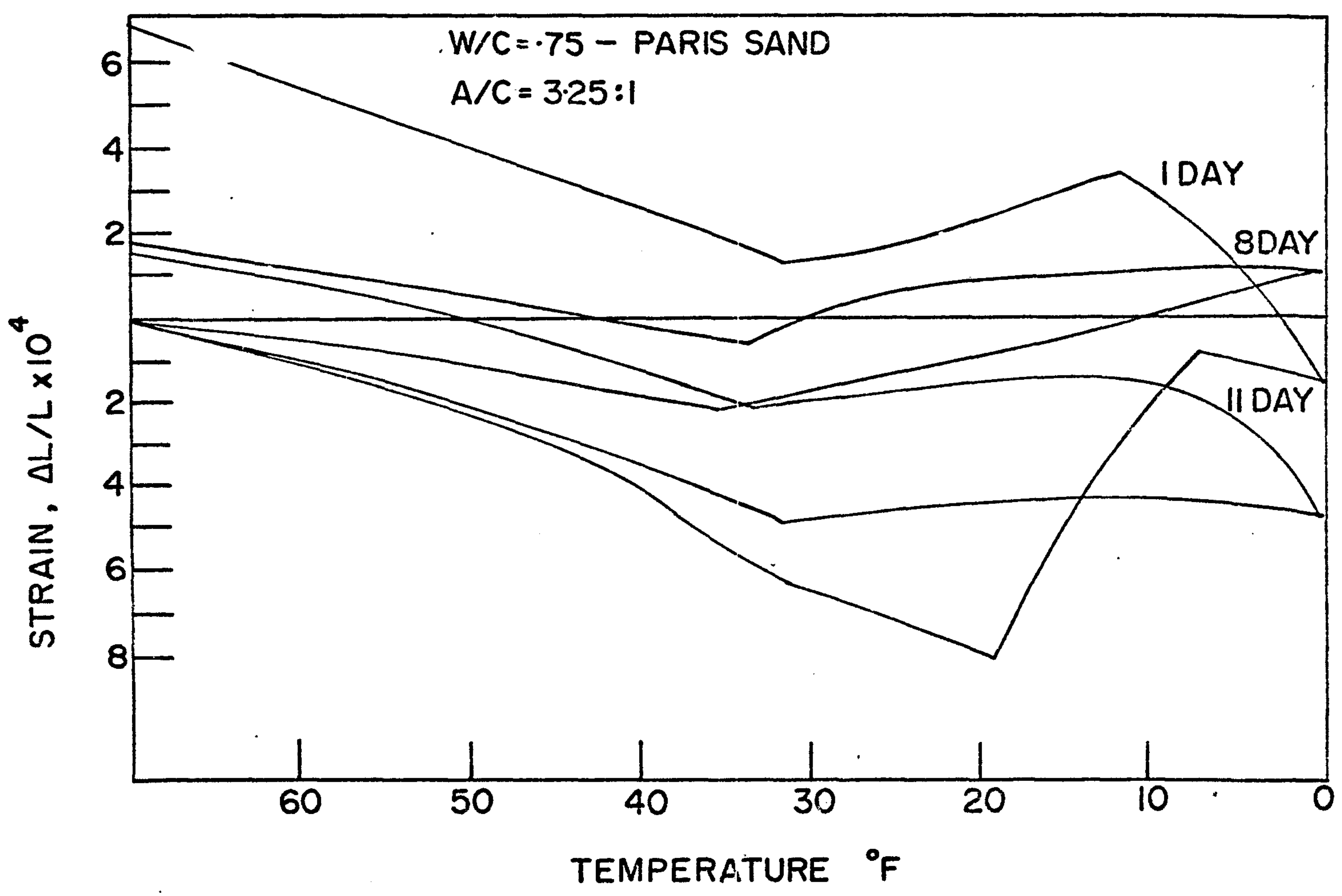


Figure 88 Strain-Temperature Plot For Paris Sand; w/c=0.75; a/c=3.25:1

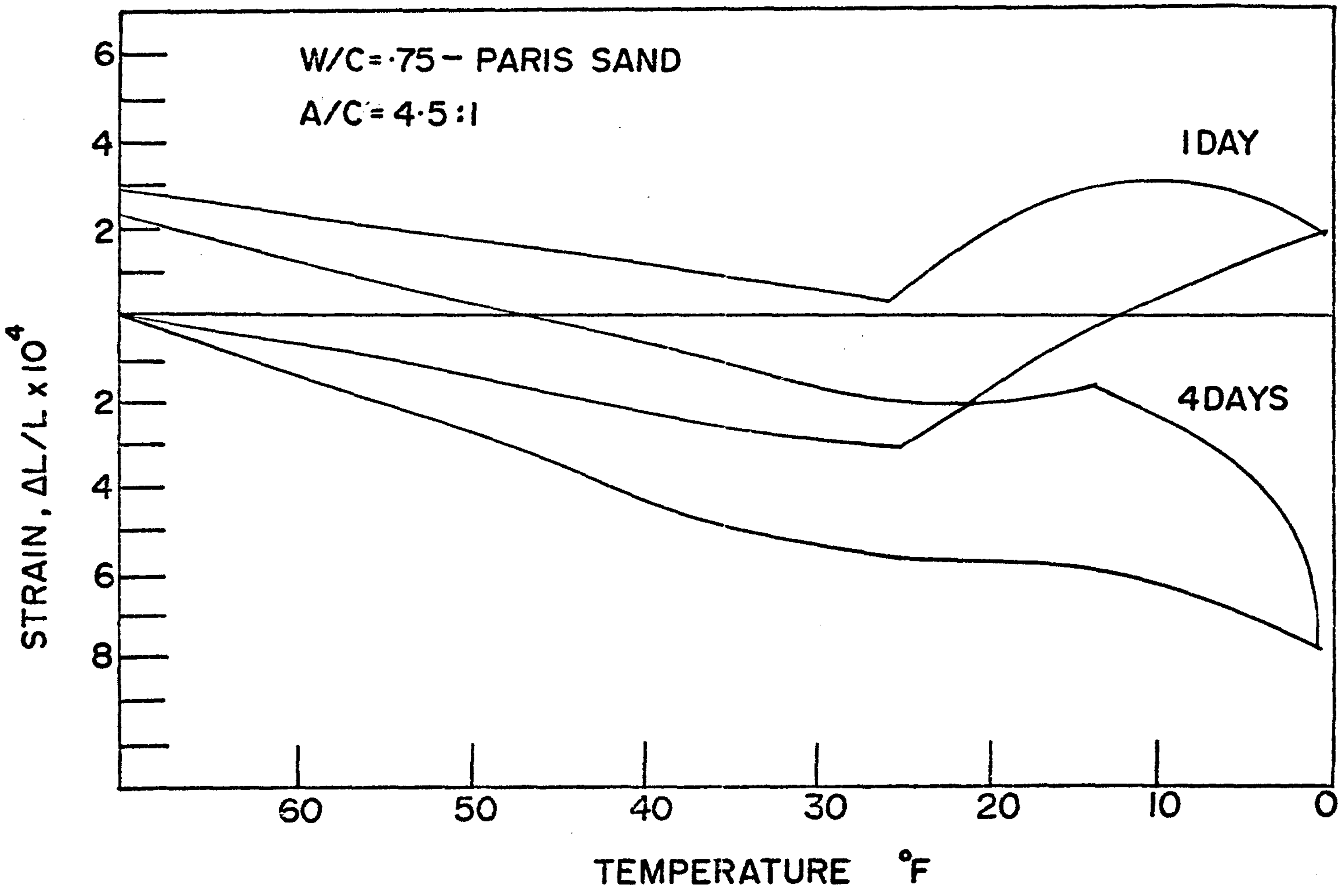


Figure 89 Strain-Temperature Plot For Paris Sand; w/c=0.75; a/c=4.50:1

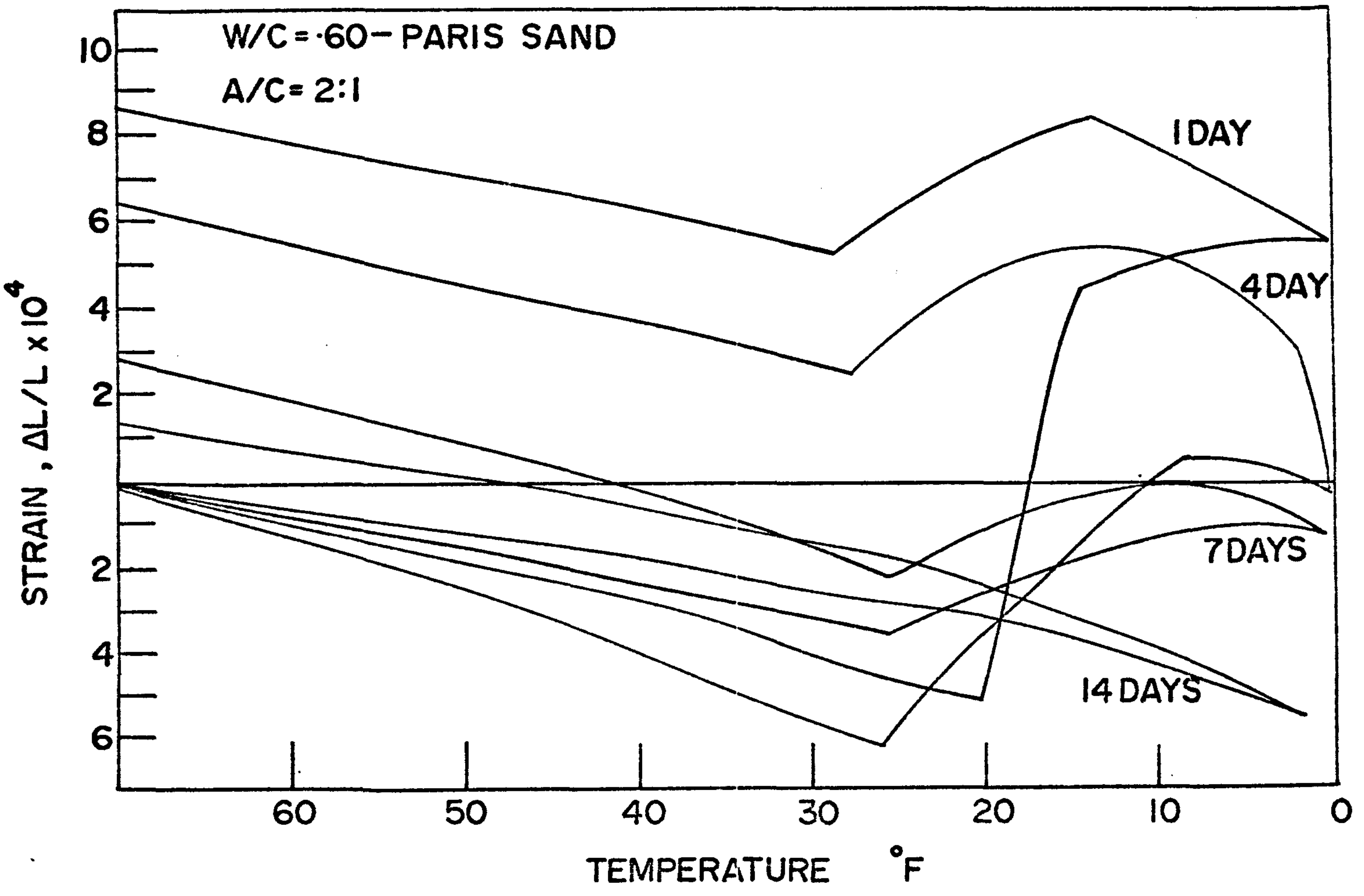


Figure 90 Strain-Temperature Plot For Paris Sand; w/c=0.60; a/c=2:1

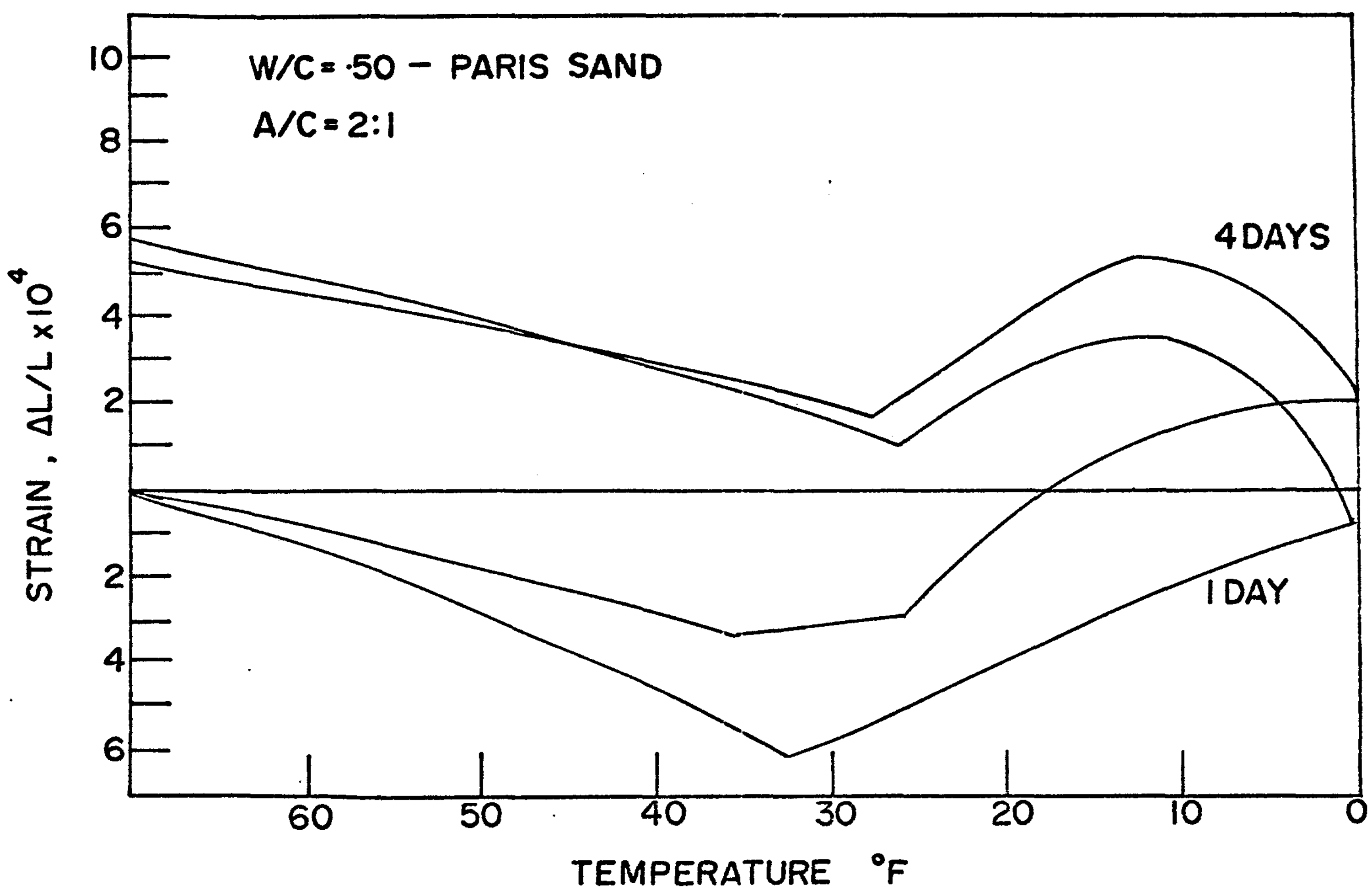


Figure 91 Strain-Temperature Plot For Paris Sand; w/c=0.50; a/c=2:1

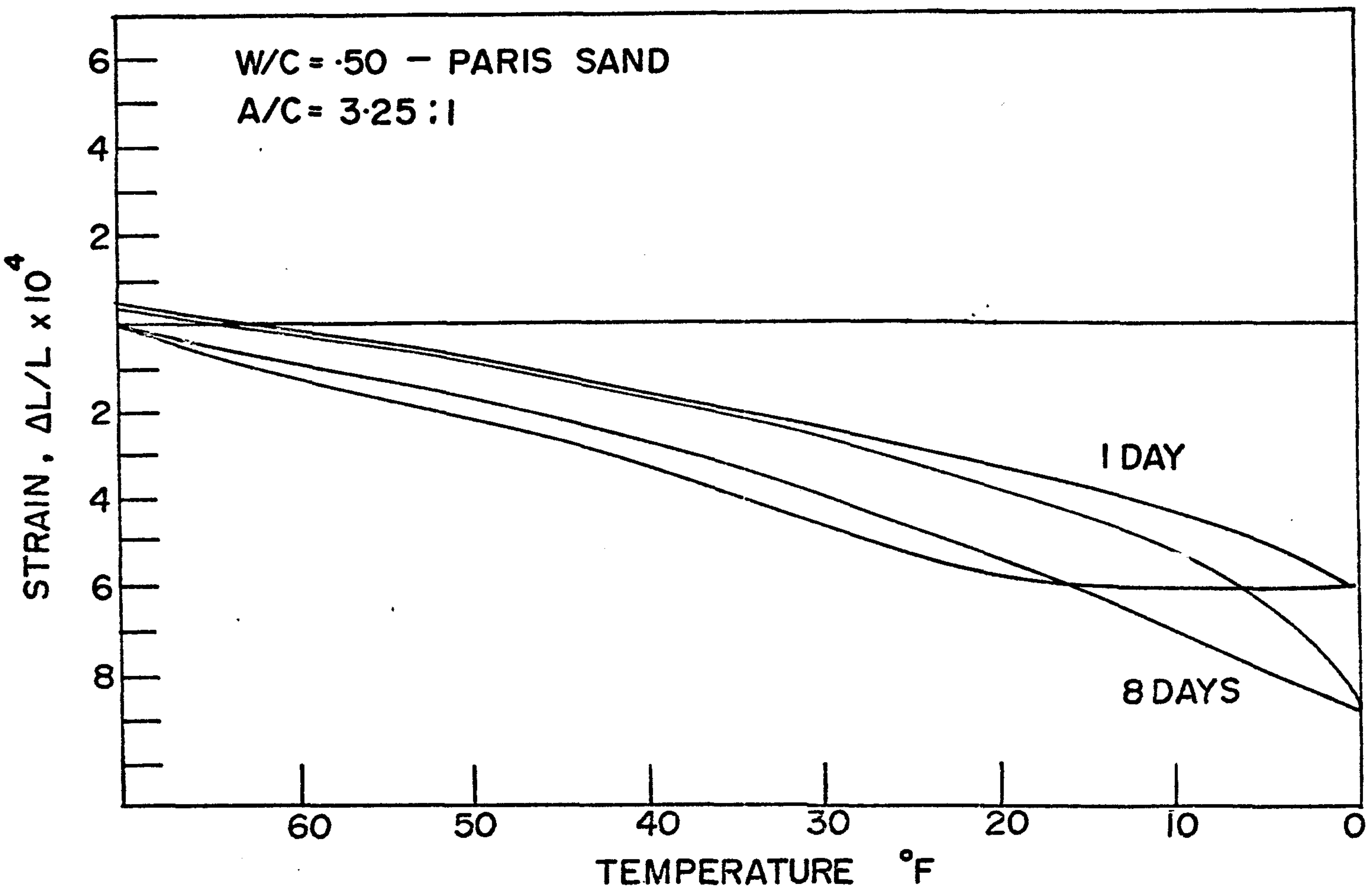


Figure 92 Strain-Temperature Plot For Paris Sand; w/c=.50; a/c=3.25:1

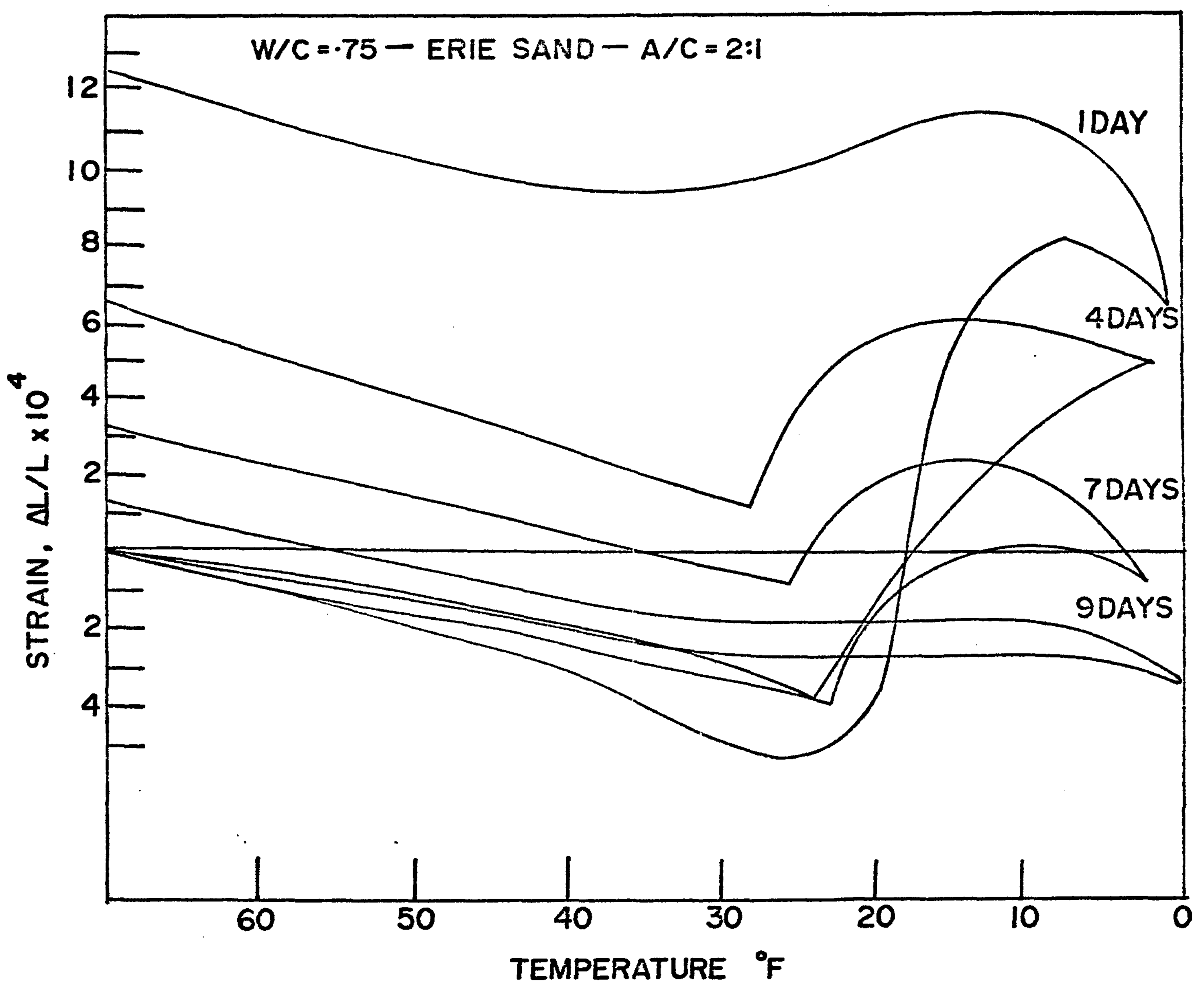


Figure 93 Strain-Temperature Plot For Erie Sand; w/c=.75; a/c=2:1

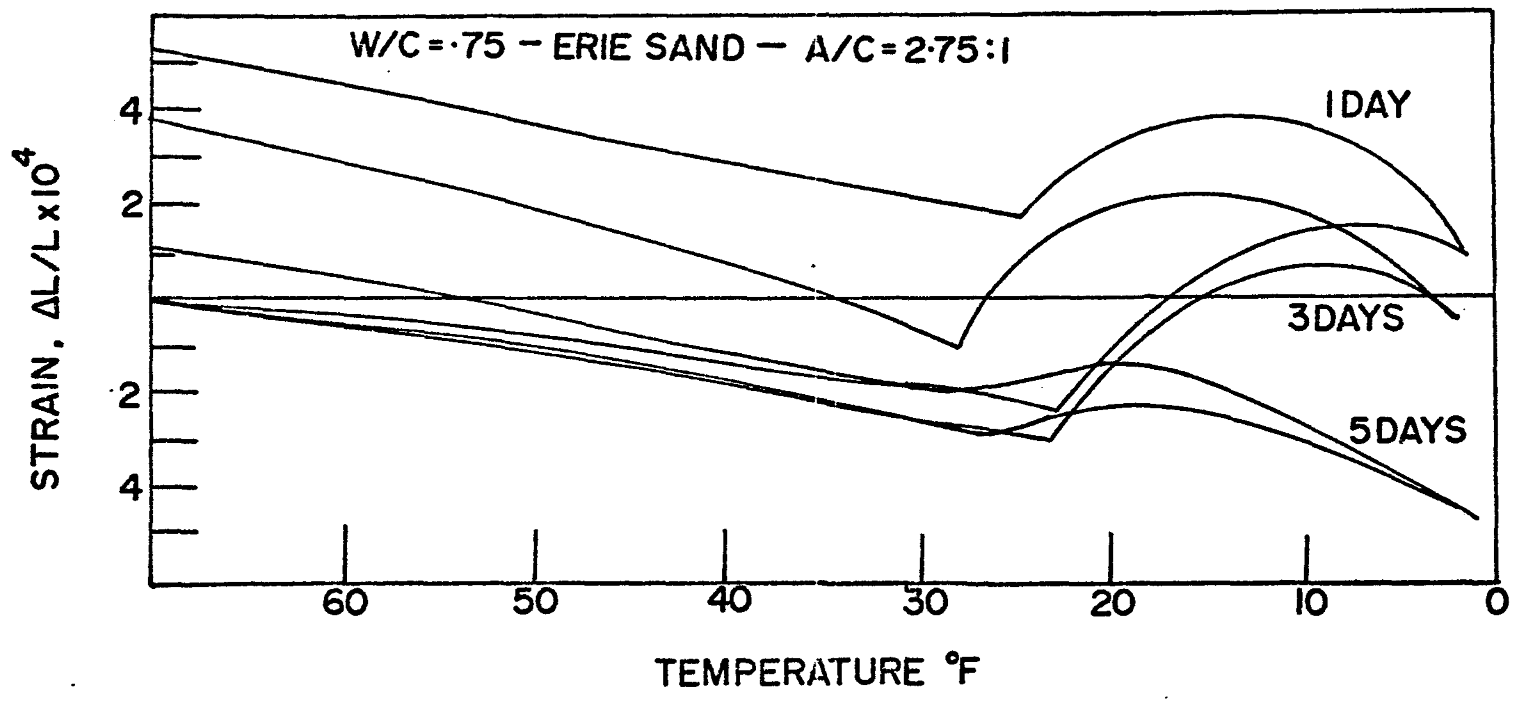


Figure 94 Strain-Temperature Plot For Erie Sand; w/c=.75; a/c=2.75:1

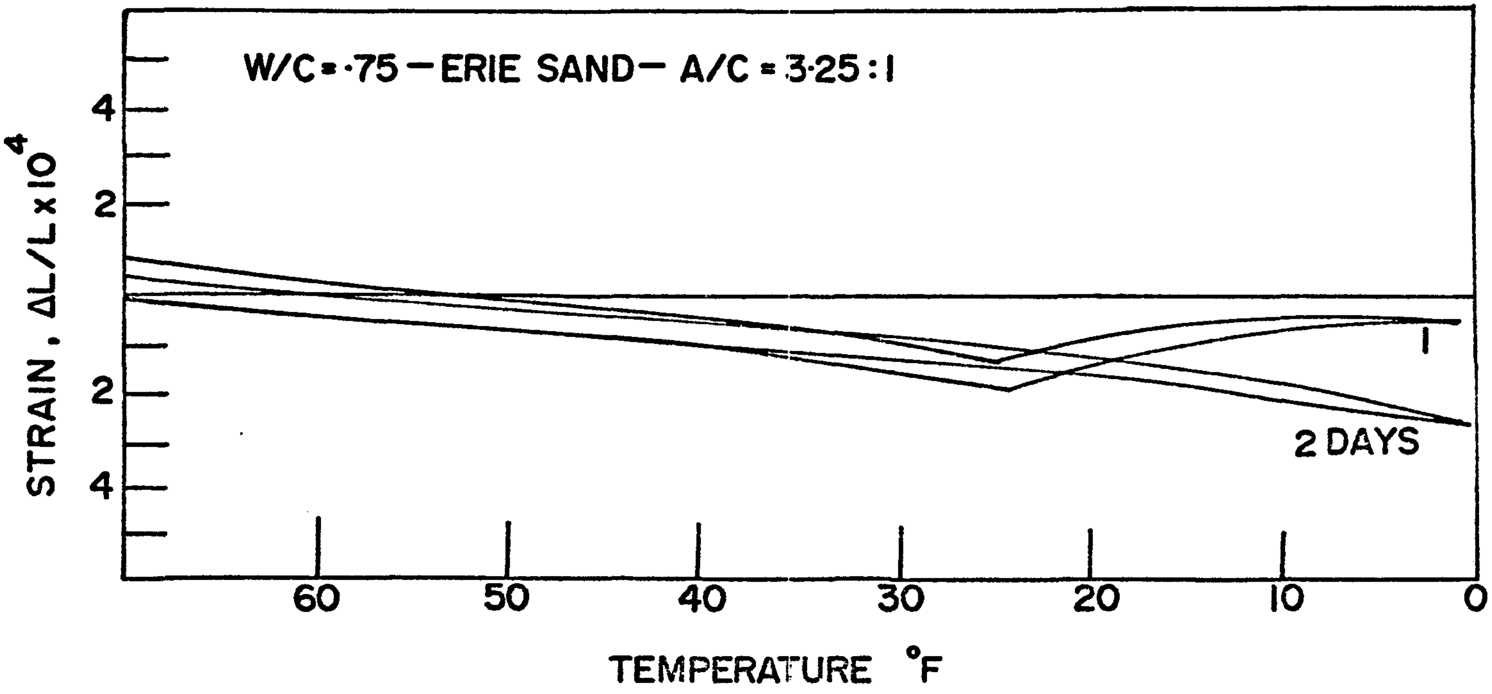


Figure 95 Strain-Temperature Plot For Erie Sand; w/c=.75; a/c=3.25:1

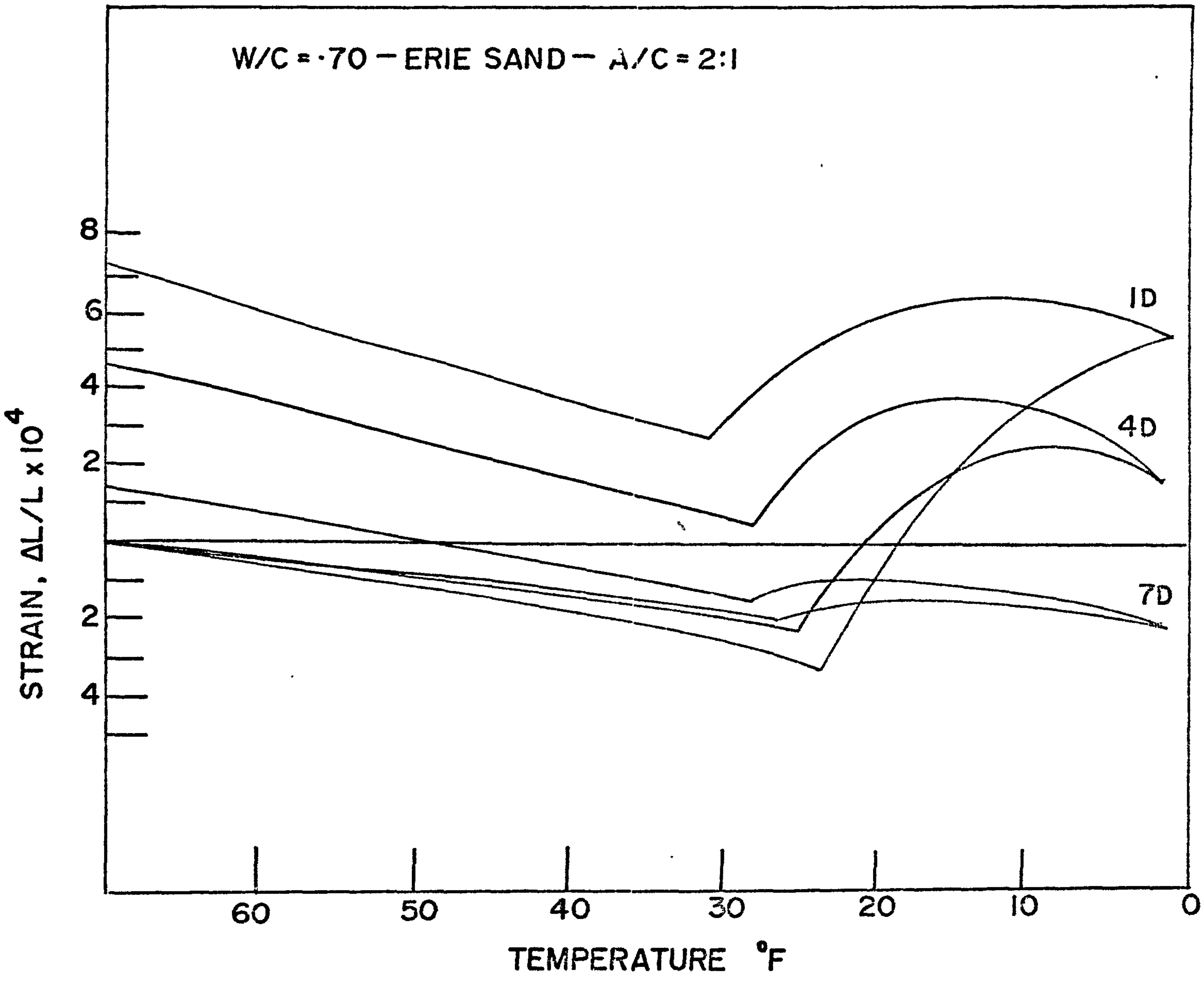


Figure 96 Strain-Temperature Plot For Erie Sand; w/c=.70; a/c=2:1

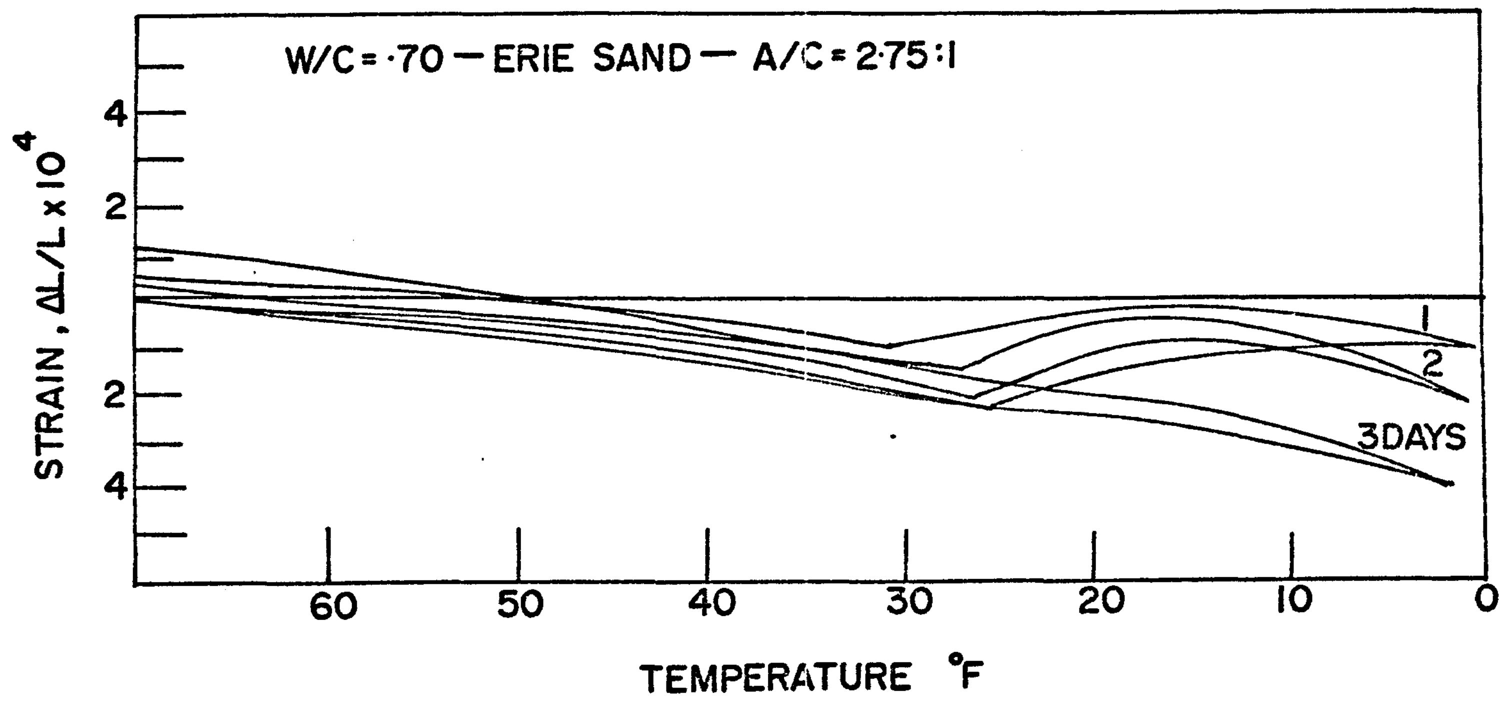


Figure 97 Strain-Temperature Plot For Erie Sand; w/c=.70; a/c=2.75:1

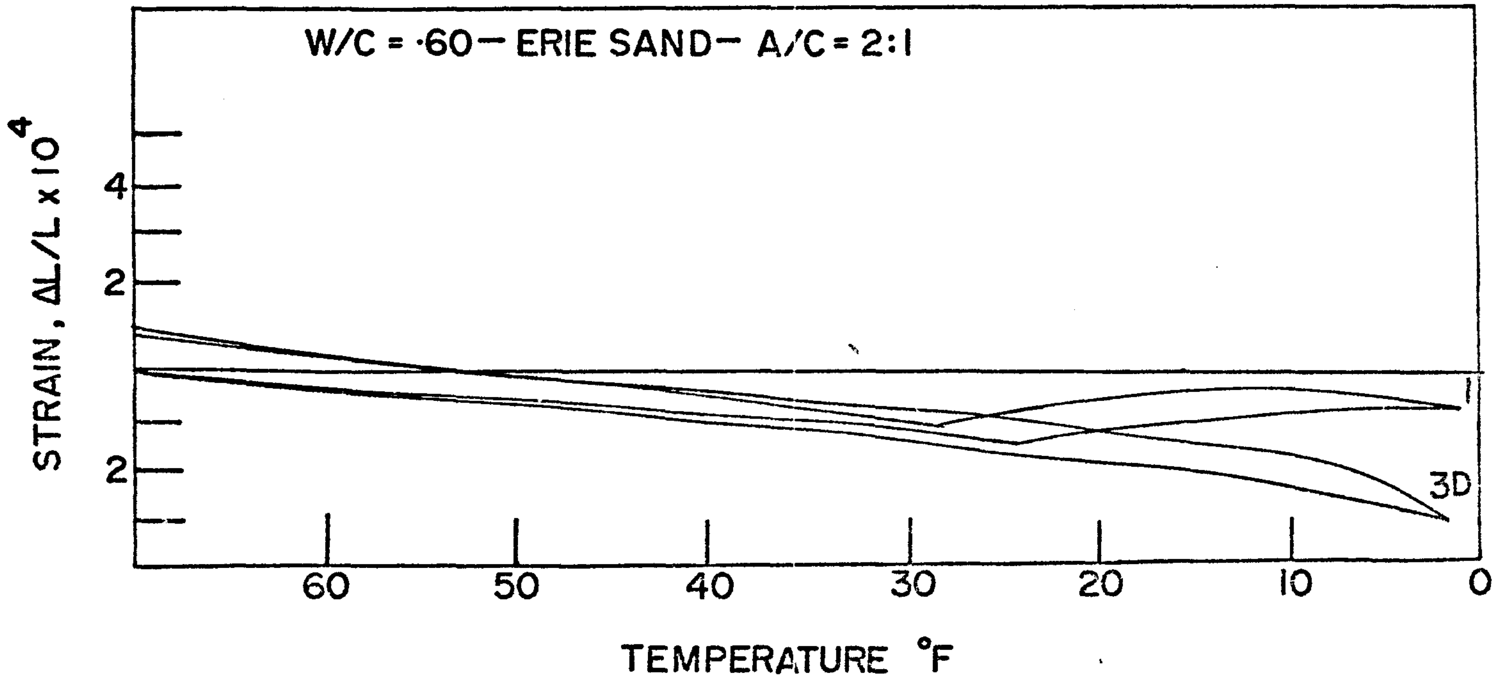


Figure 98 Strain-Temperature Plot For Erie Sand; w/c=.60; a/c=2:1

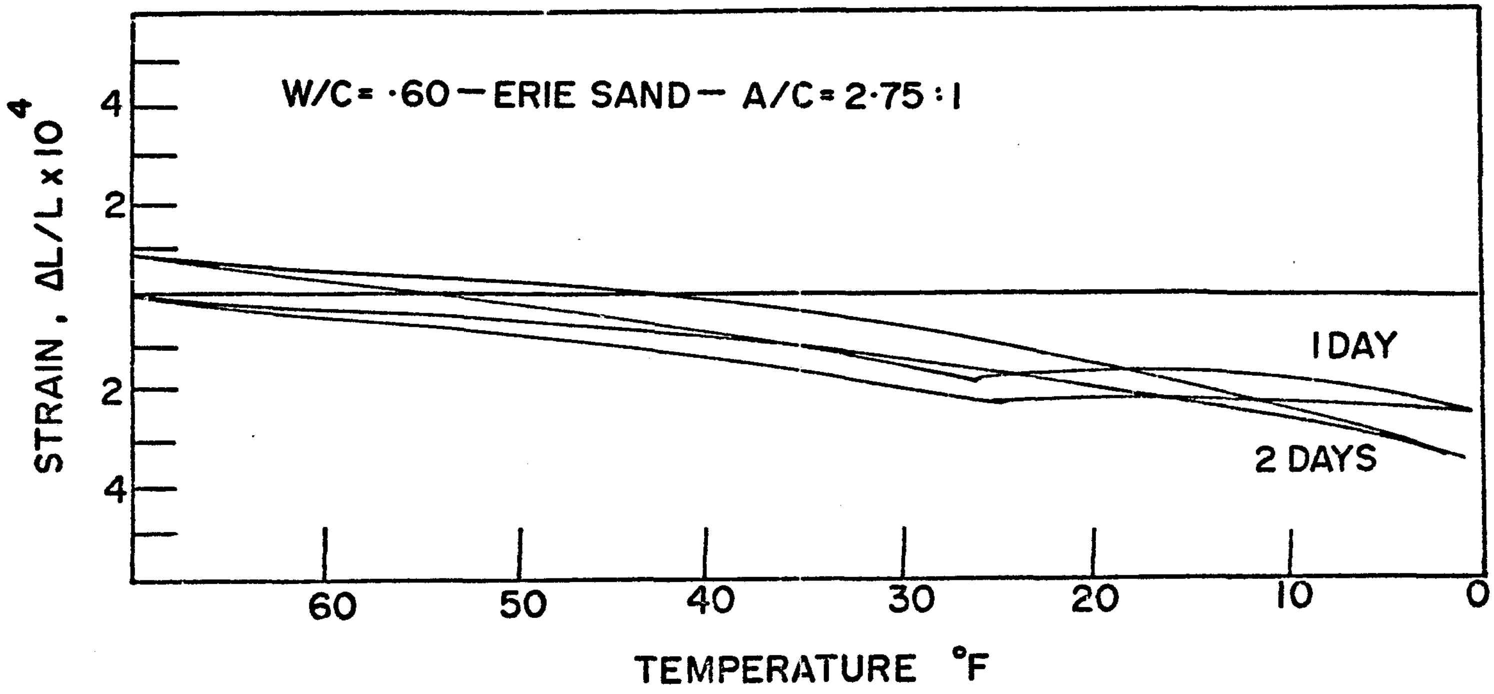


Figure 99 Strain-Temperature Plot For Erie Sand; w/c=.60; a/c=2.75:1

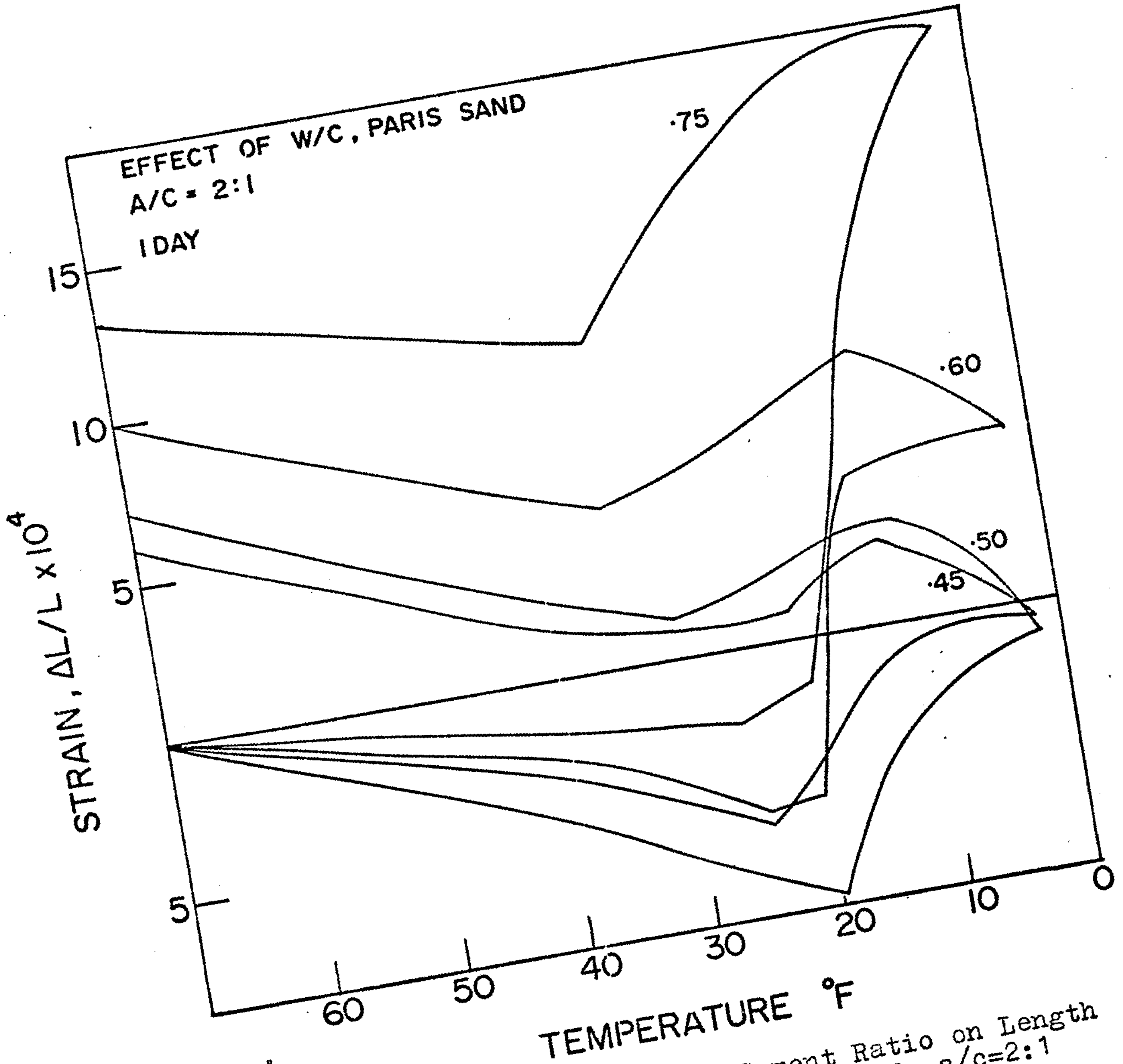


Figure 100 Effect of Water-Cement Ratio on Length Change Patterns-Paris Sand; a/c=2:1

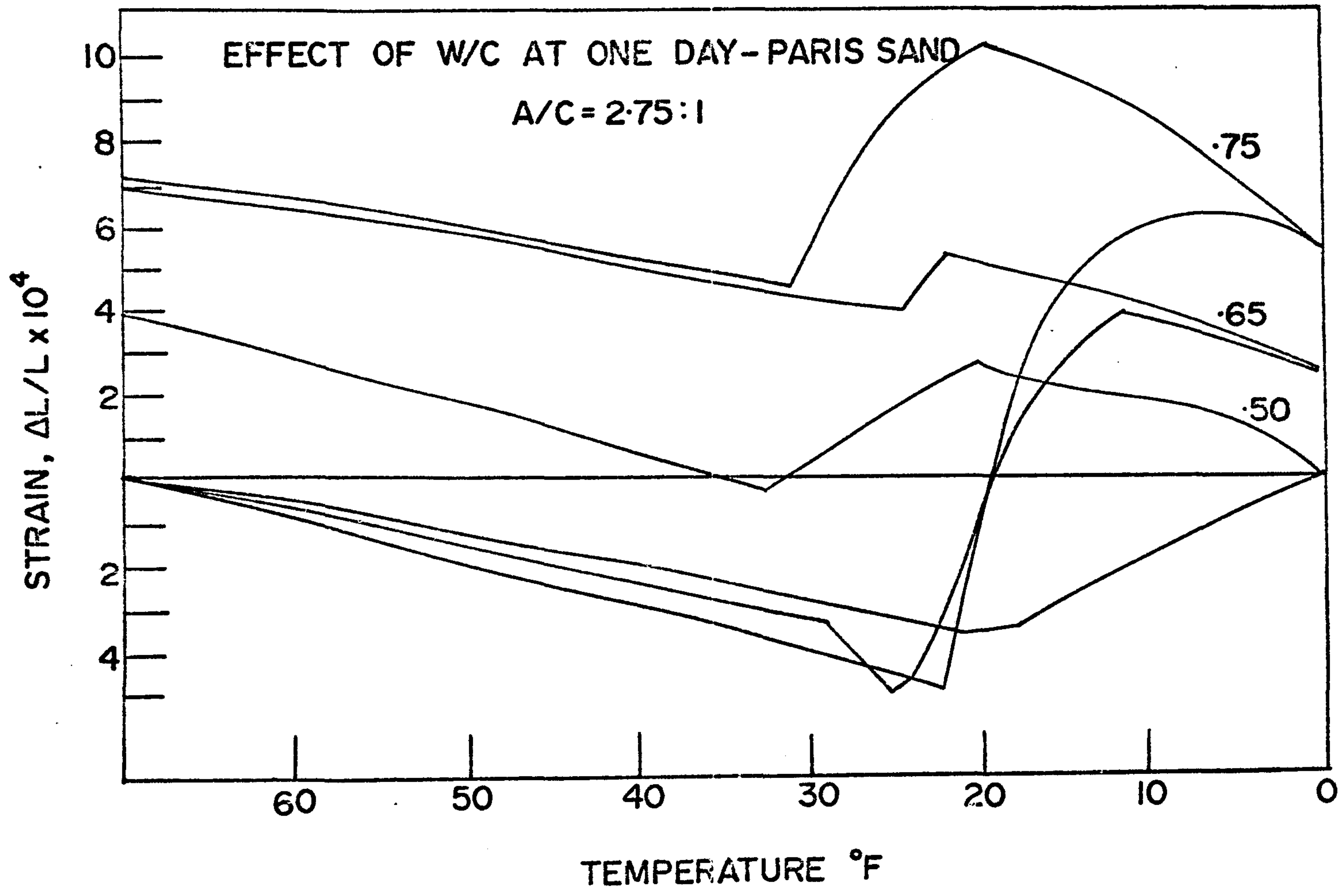


Figure 101 Effect of Water-Cement Ratio on Length Change Patterns-Paris Sand; a/c=2.75:1

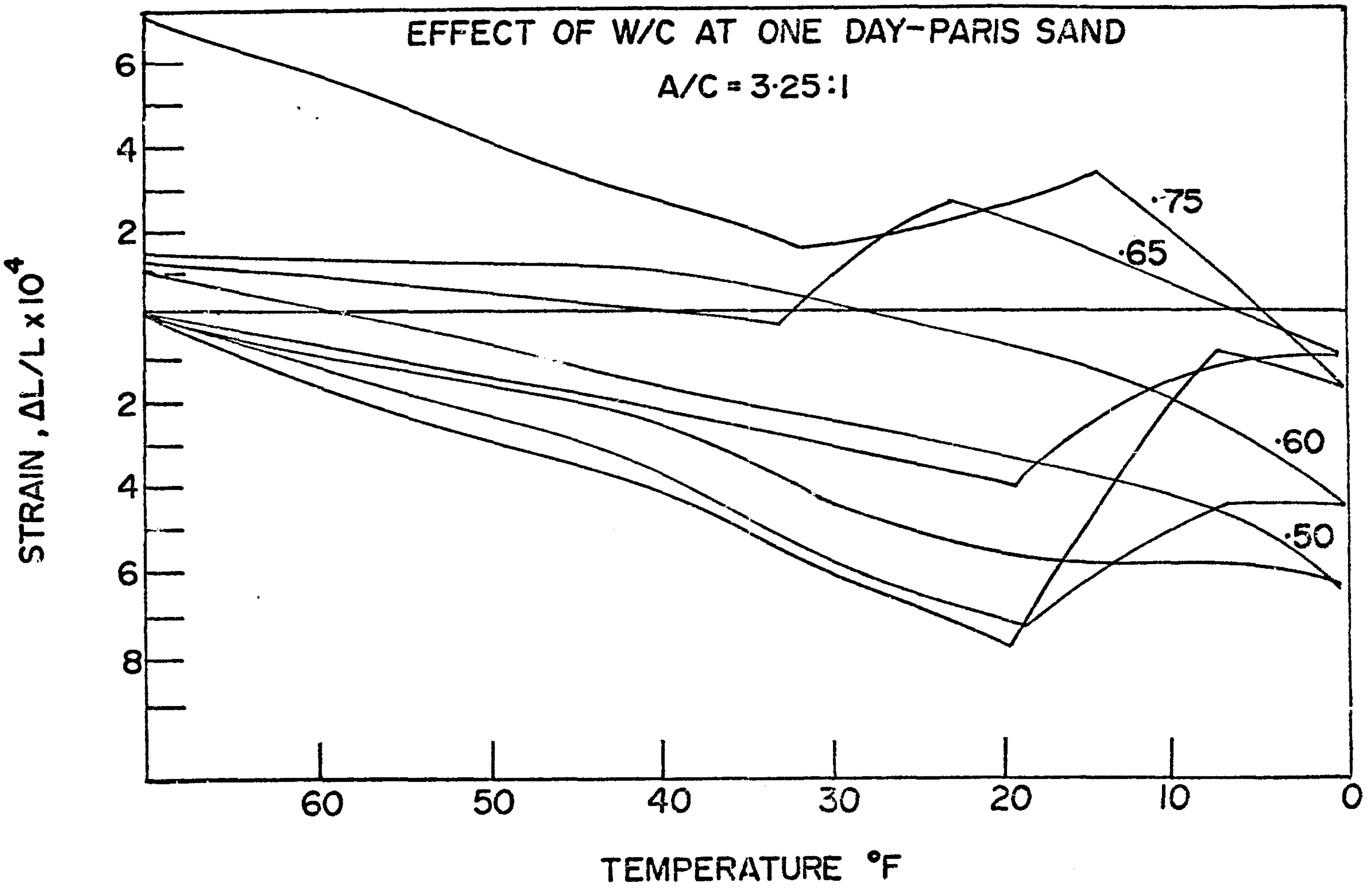


Figure 102 Effect of Water-Cement Ratio on Length Change Patterns-Paris Sand; a/c=3.25:1

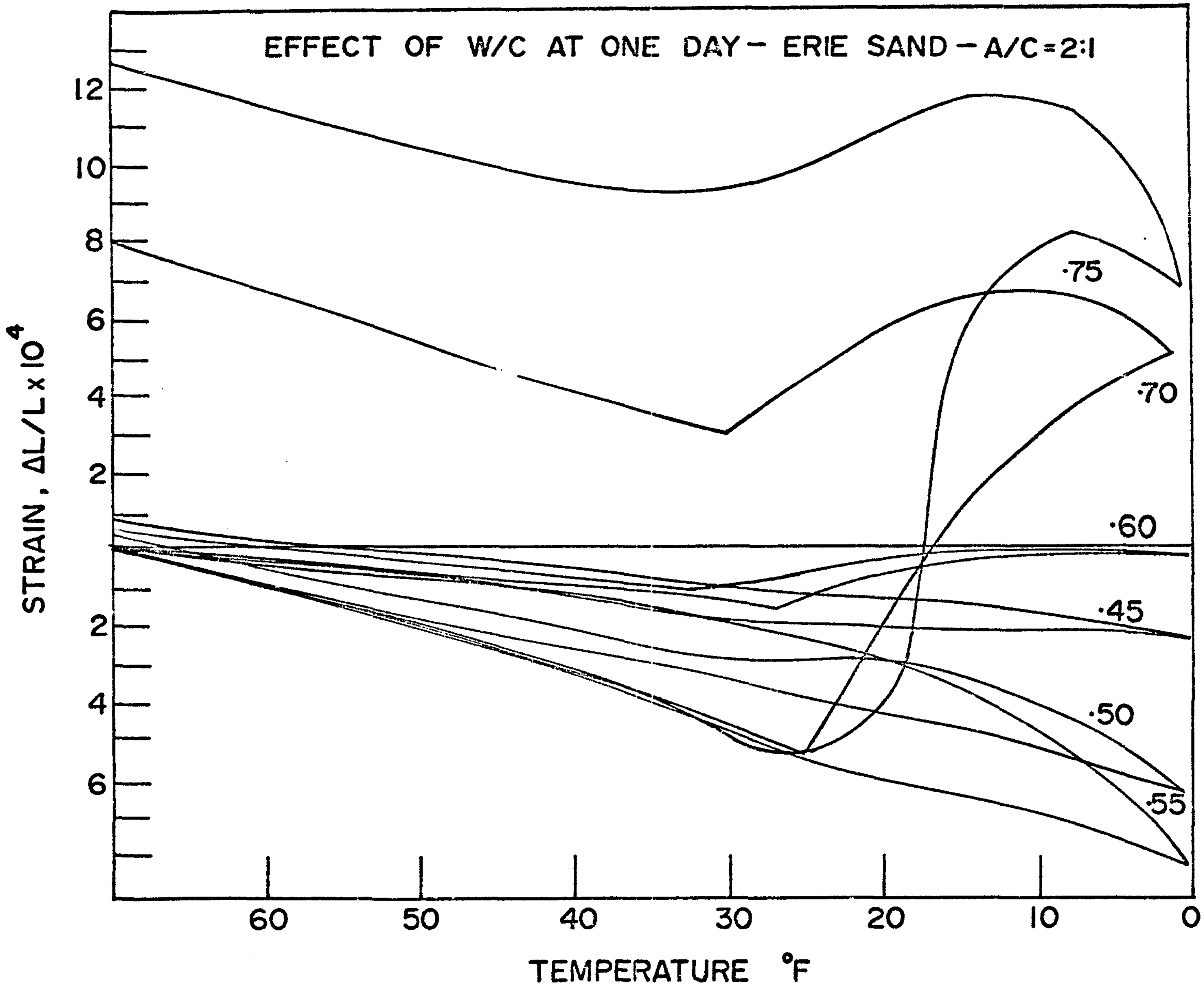


Figure 103 Effect of Water-Cement Ratio on Length Change Patterns-Erie Sand; a/c=2:1

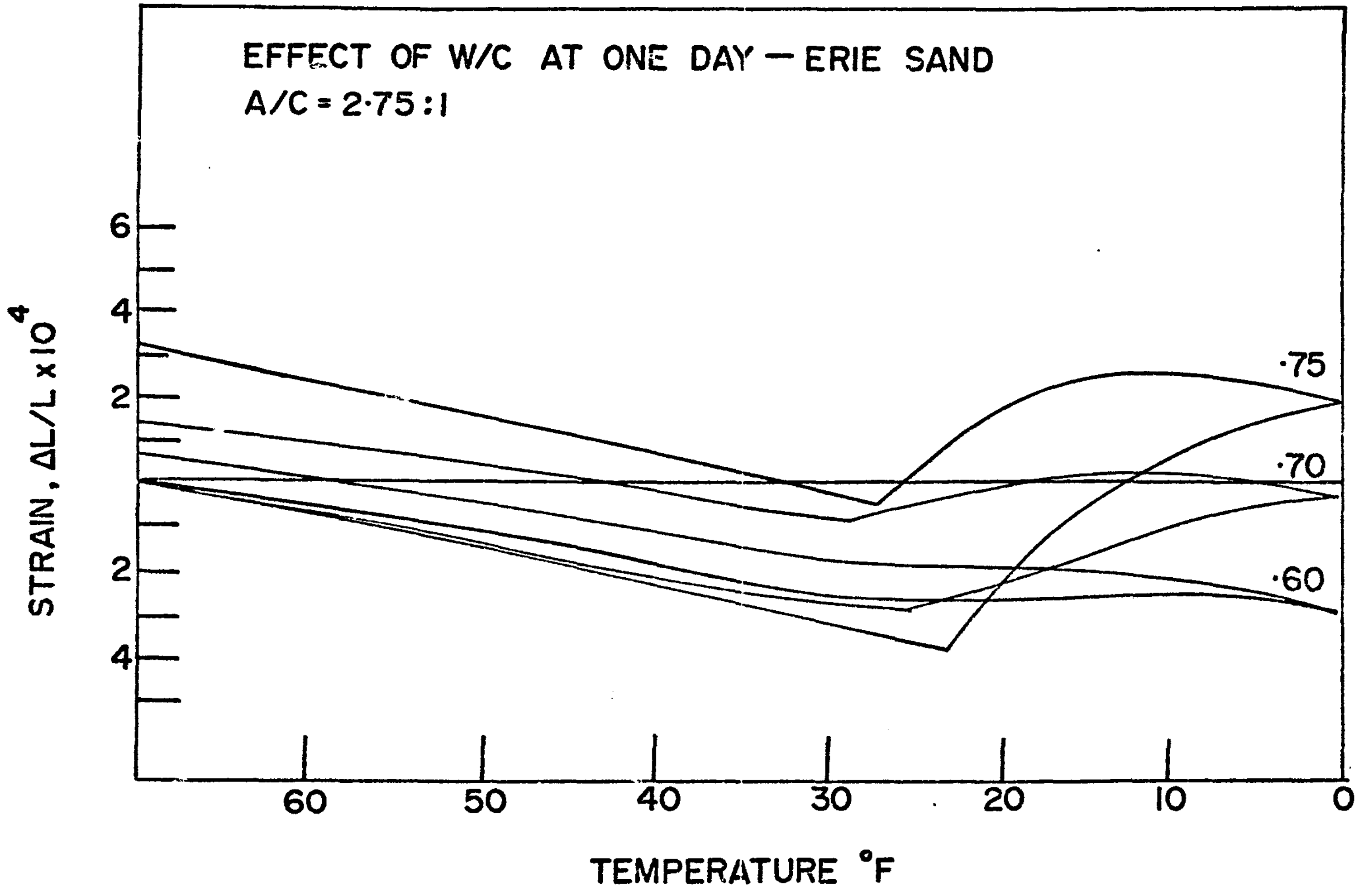


Figure 104 Effect of Water-Cement Ratio on Length Change Patterns-Erie Sand; a/c=2.75:1

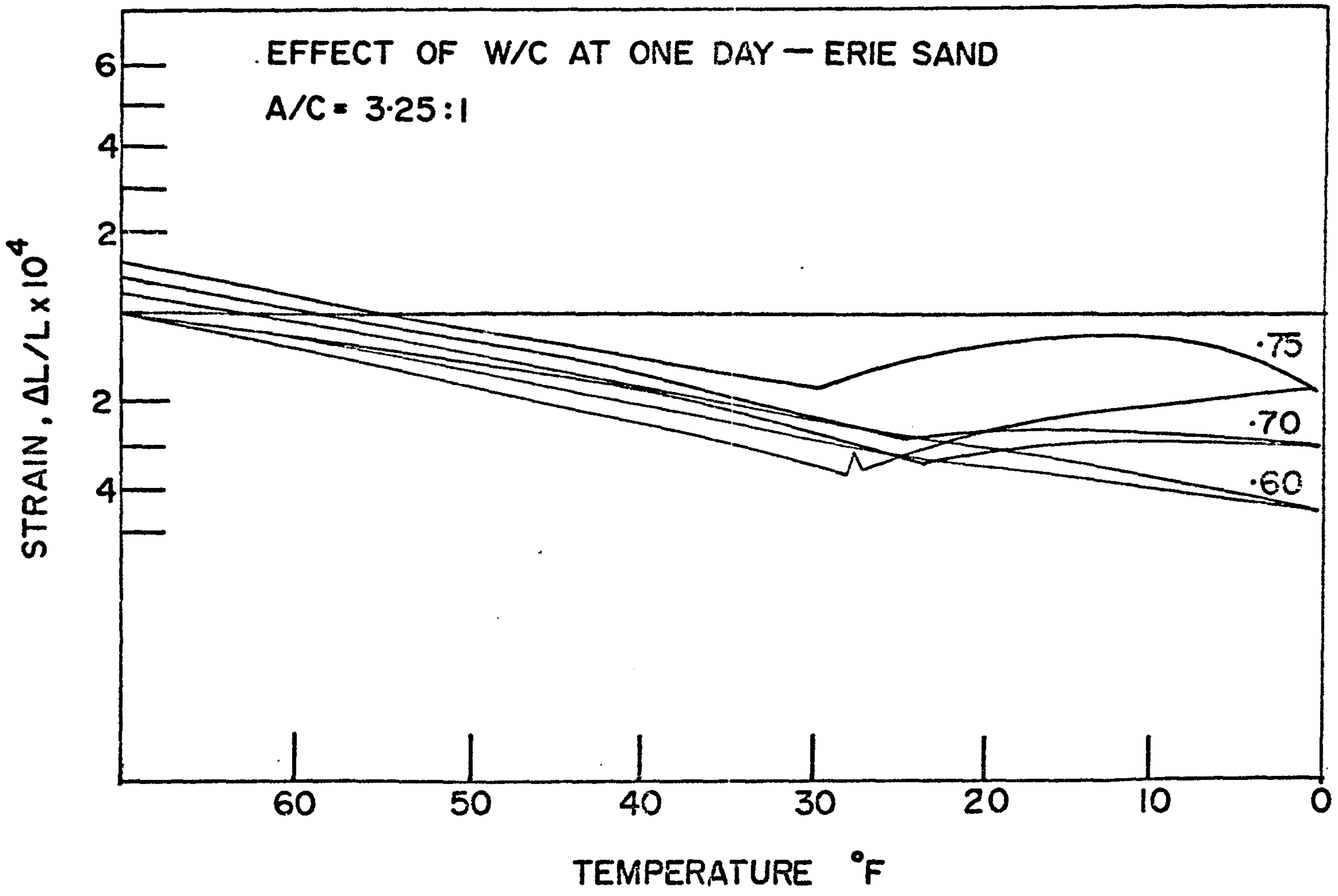


Figure 105 Effect of Water-Cement Ratio on Length Change Patterns-Erie Sand; a/c=3.25:1

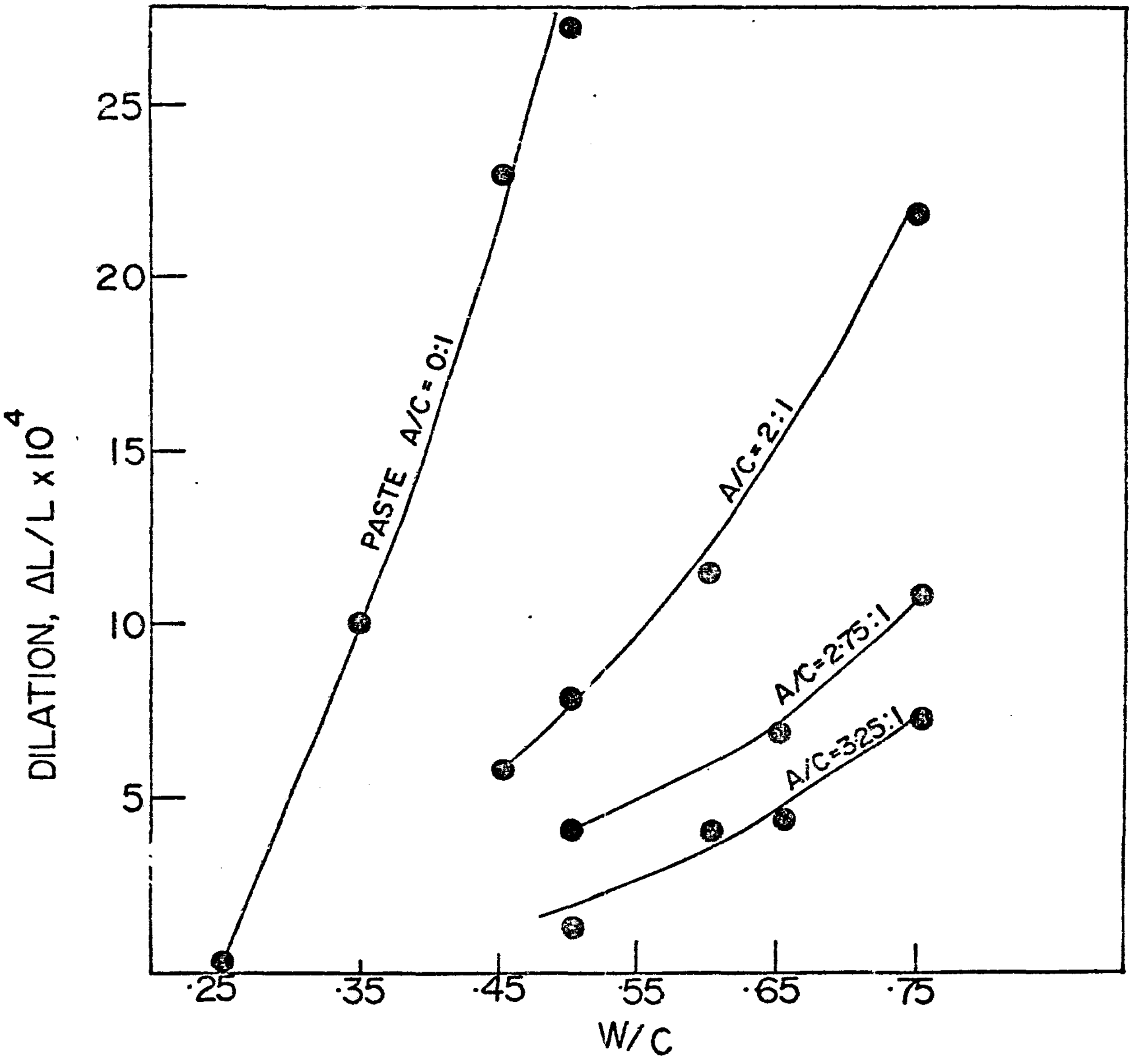


Figure 106 Dilation vs Water-Cement Ratio For Various Aggregate-Cement Ratios-Paris Sand

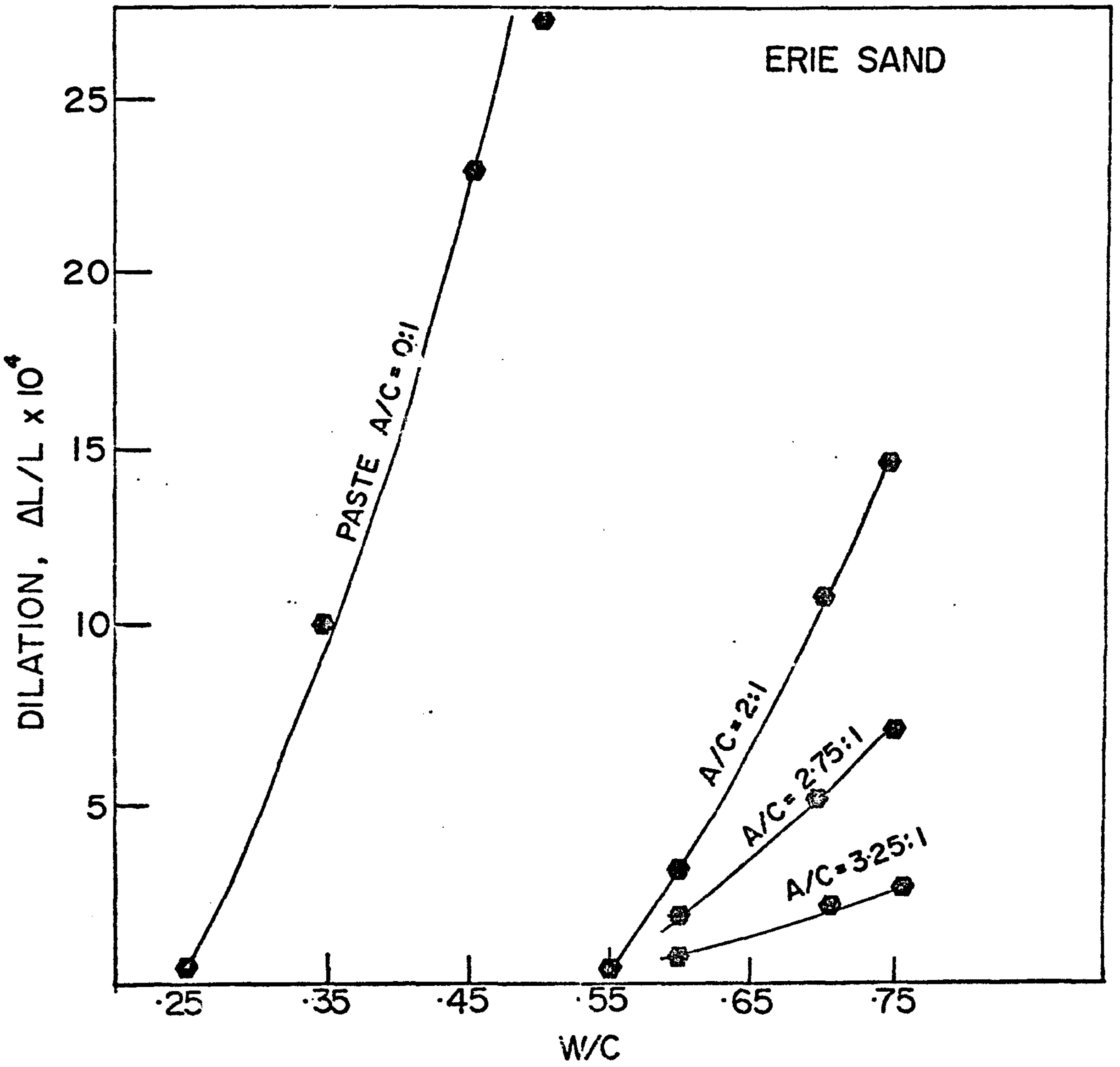


Figure 107 Dilation vs Water-Cement Ratio For Various Aggregate-Cement Ratios-Erie Sand

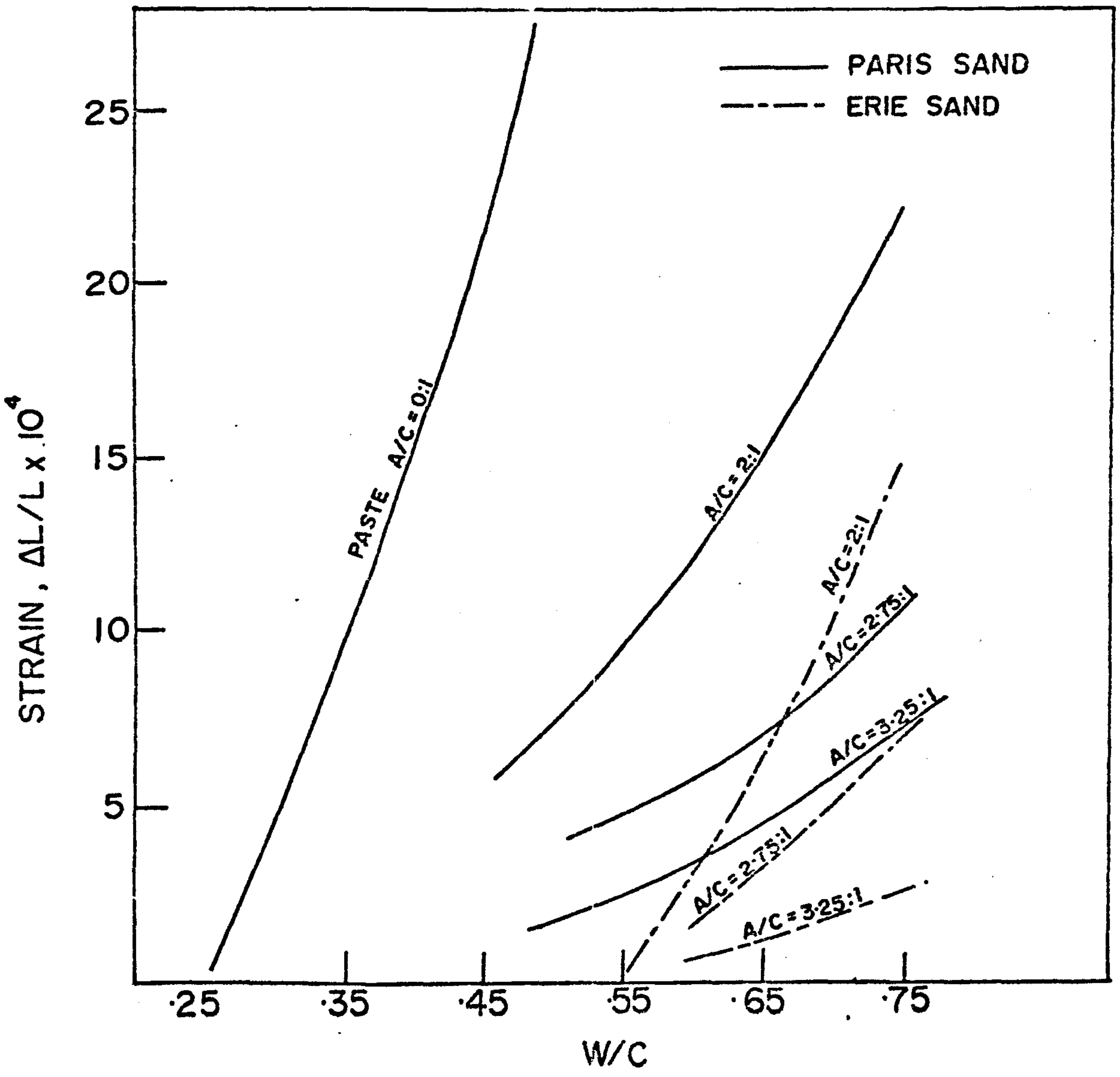


Figure 108 Effect of Aggregate-Cement Ratio on Dilation-Paris And Erie Sand

Figure 109 shows dilation as a function of aggregate-cement ratio for various water-cement ratios (at age one day). The effect of water-cement ratio is clearly demonstrated. That is at a given aggregate-cement ratio dilation increases with water-cement ratio.

Figure 110 is a three dimensional plot of dilation, aggregate-cement ratio and water-cement ratio for Paris Sand. The relative inter-relation of the three parameters is quite clear.

Multiple Cycling

A few mortar specimens were subjected to multiple cycling in the selected slow cooling-warming regime. Figure 111 demonstrates the transient strain response for a mortar mix with water cement ratio 0.60 and aggregate-cement ratio 1.75:1. There is an initial dilational response cycle and large hysteresis on the first cycle followed by a continued collapse of hysteresis resulting in a linear oscillation of volume change on cooling and warming.

Dilation as a Function of $\frac{\Delta w}{w_o}$ and the Aggregate Restraint Factor δ

Dilation was plotted as a function of $\frac{\Delta w}{w_o}$ for Paris Sand (see fig 112). It was apparent that for a given aggregate-cement ratio, the data

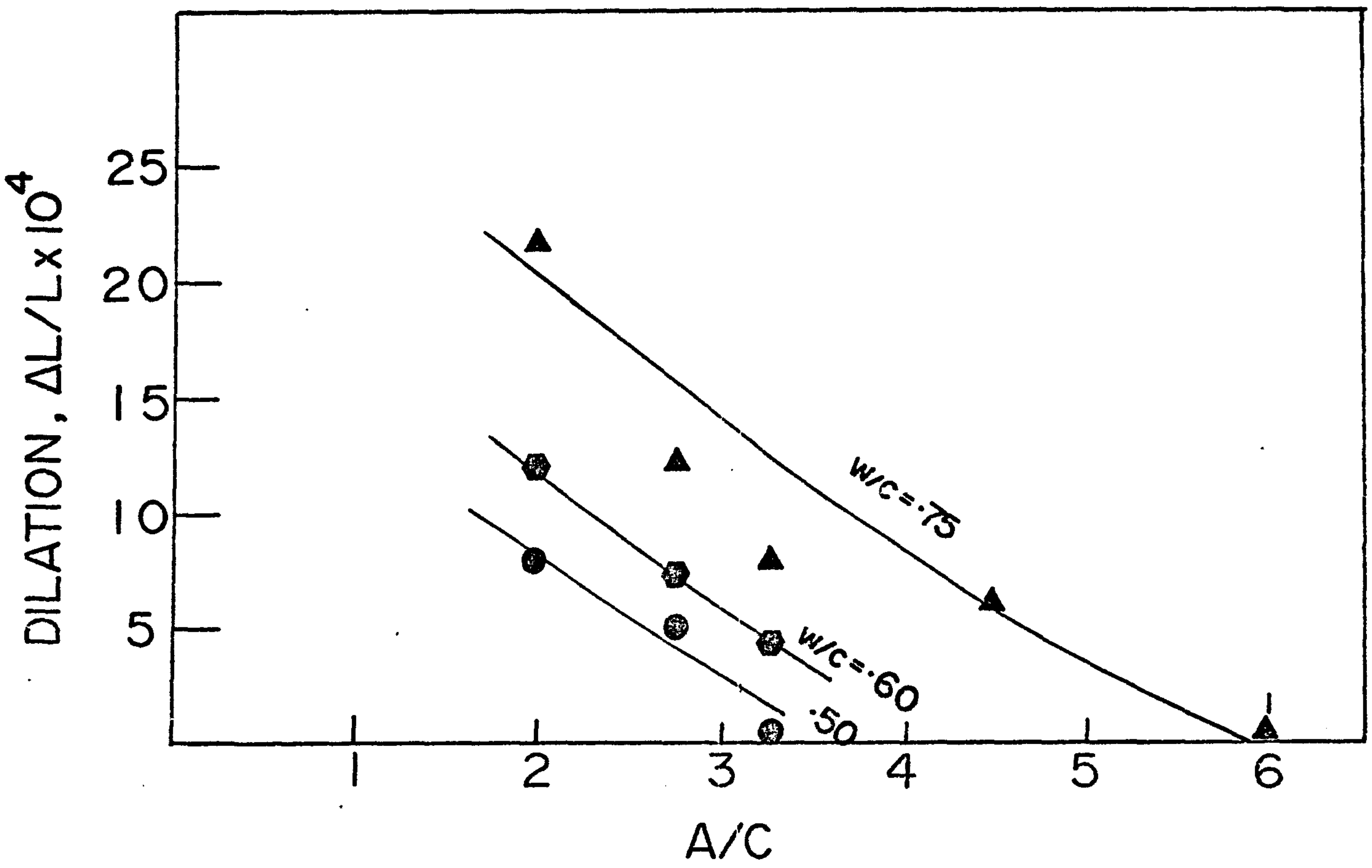


Figure 109 Dilation vs Aggregate-Cement Ratio For Various Water-Cement Ratios-Paris Sand

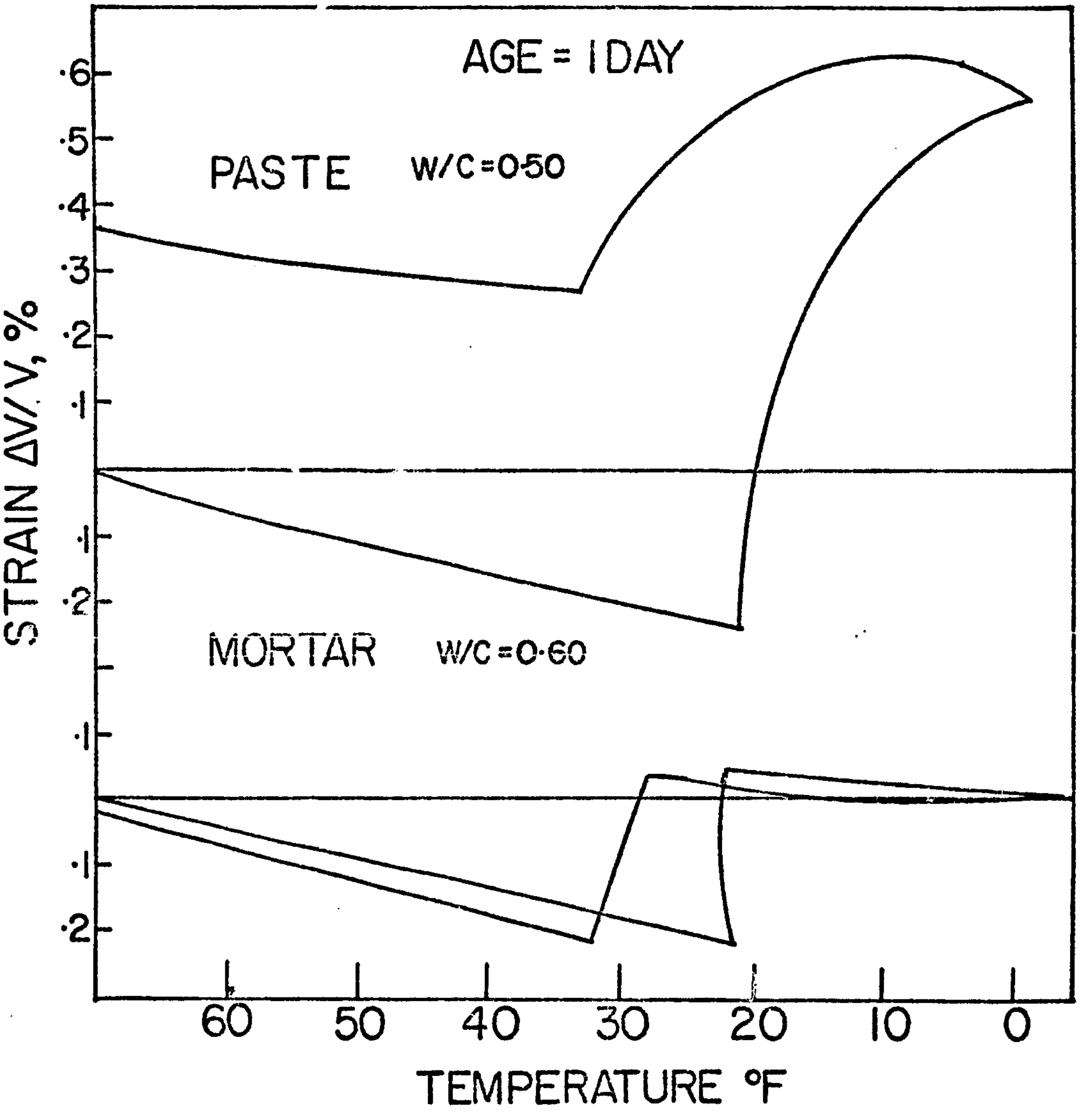


Figure 109-1 Strain-Temperature Plot Comparing Paste And Mortar

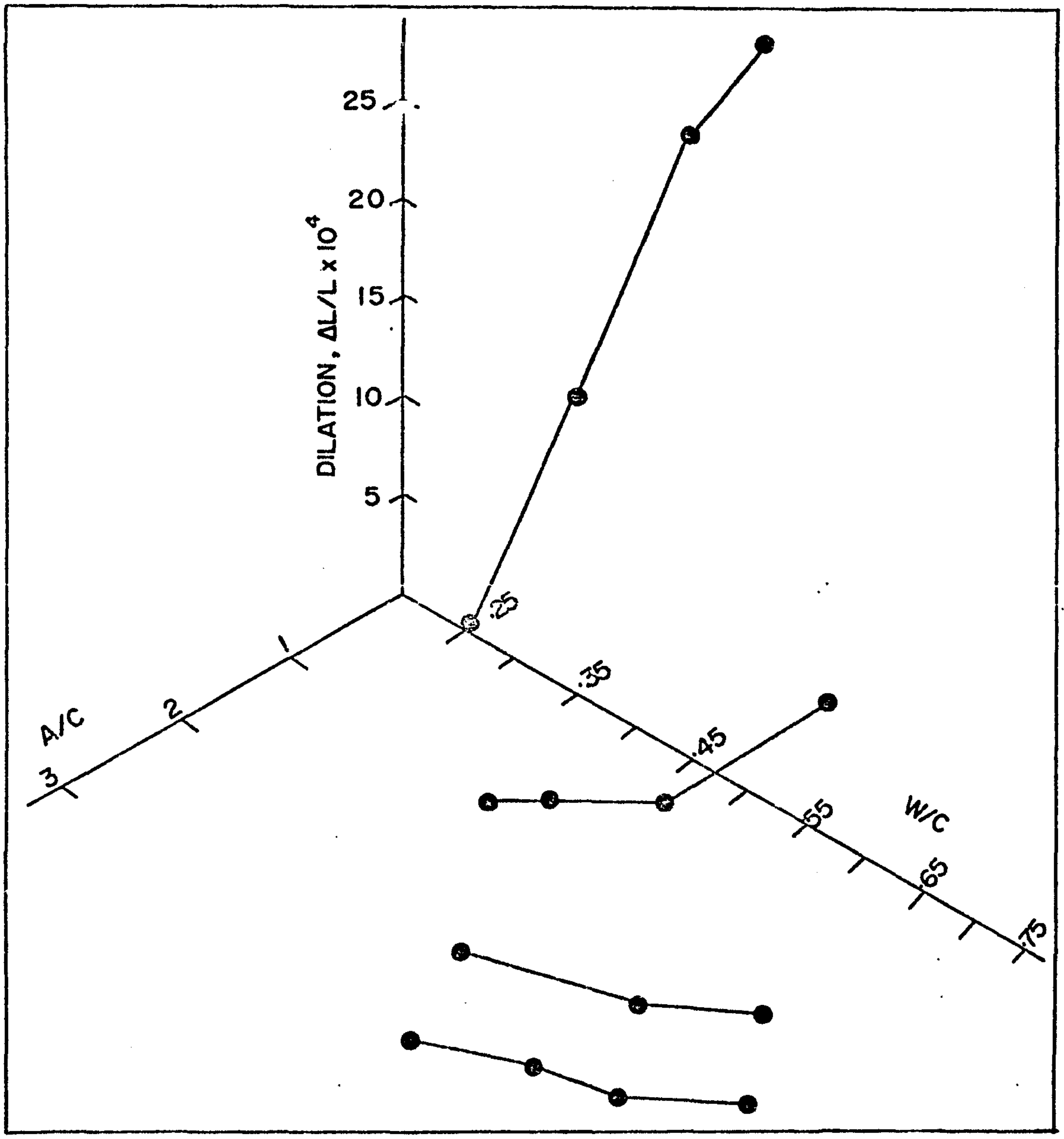


Figure 110 Three Dimensional Plot Showing Dilation As A Function Of Aggregate-Cement Ratio And Water-Cement Ratio

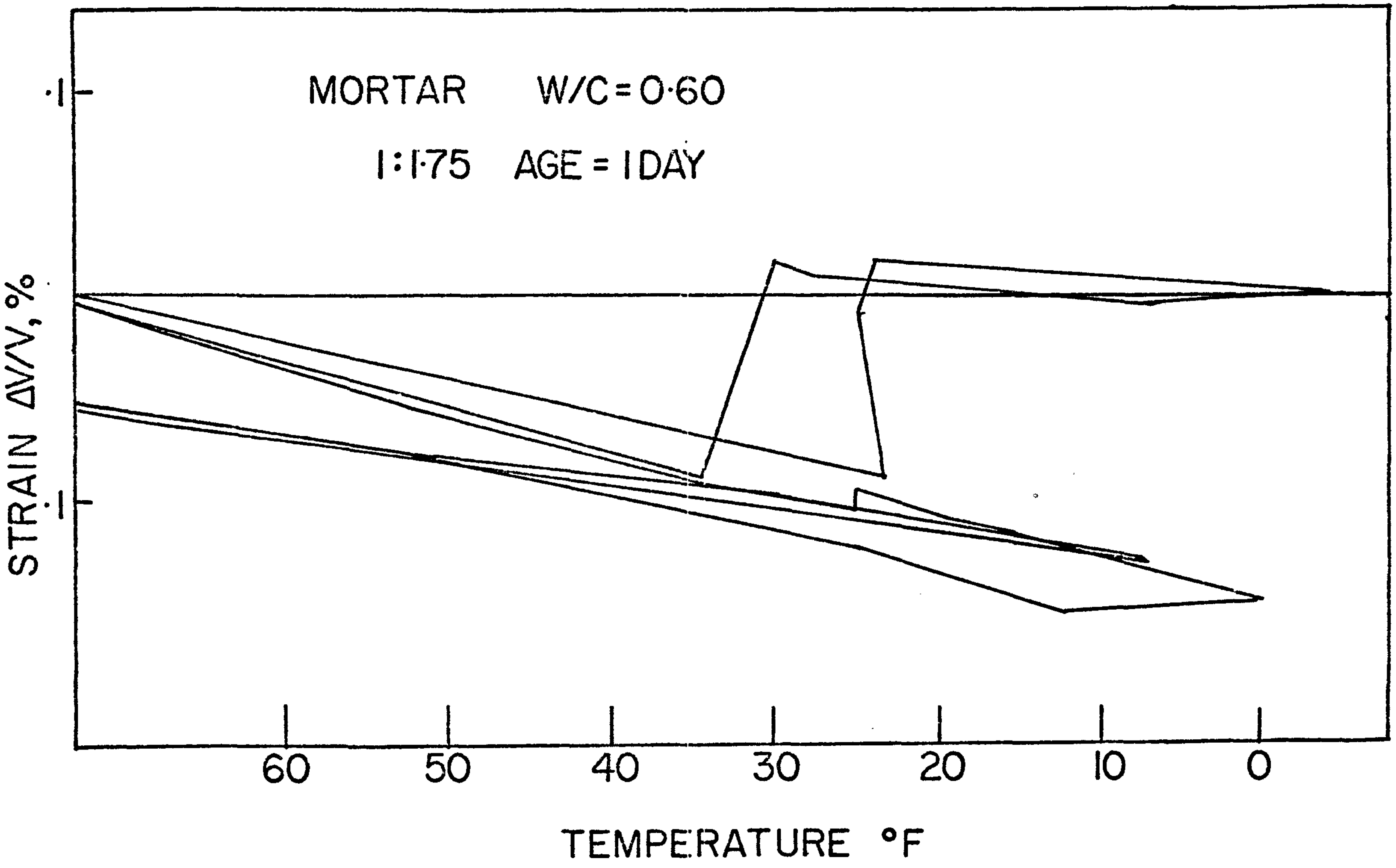


Figure 111 Multiple Cycle Test For Mortar; w/c=0.60; a/c=1.75:1

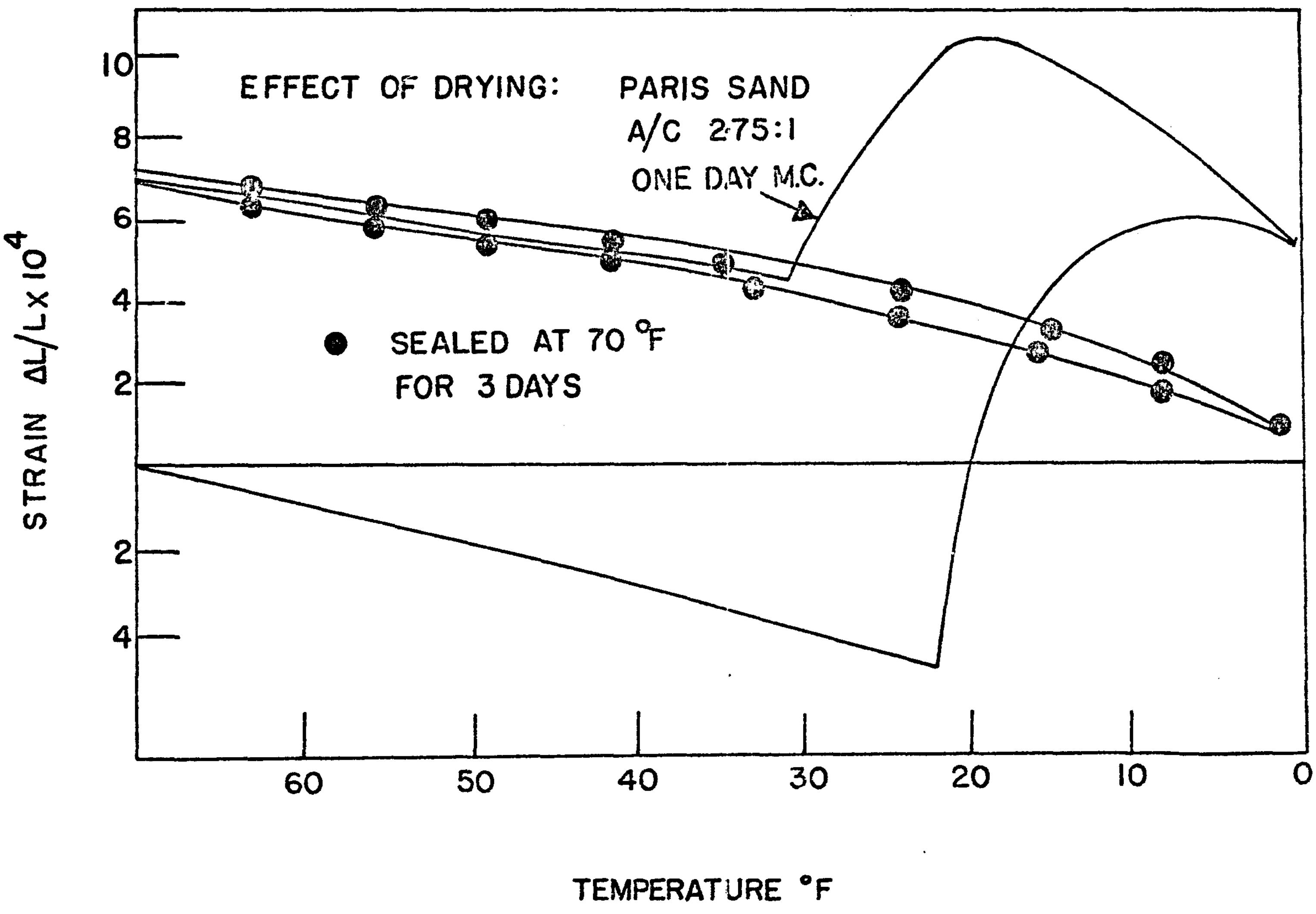


Figure 111-1 Effect of Drying of Mortar on Strain-Temperature Response

was shifted to the left along the abscissa. This trend was also observed for Erie Sand. In other words for a given value of $\frac{\Delta w}{w_o}$ (ie. a given volume concentration of hydrate product) an increased aggregate content (i.e., a/c) provides a stiffness or restraint and correspondingly yields less dilation.

For a given aggregate content the physical restraint due to the aggregate should be constant and this appears to be reflected in a shift of the dilation function. Thus it appears, that for the cement-water-sand system, dilation is a function of $\frac{\Delta w}{w_o}$ and δ (which is a constant for a given aggregate cement ratio). That is to say:

$$D_o^m = \phi\left(\frac{\Delta w}{w_o}, \delta\right) \qquad \text{---------}(57)$$

$\frac{\Delta w}{w_o}$ reflects the progress of the hydration process and δ reflects the degree of aggregate restraint.

It is possible to evaluate the function expressed in equation (57) by the following arguments.

$$\text{When } \underset{\text{mortar phase}}{D_o^m} = \underset{\text{paste phase}}{D_o} \quad \text{then } \left(\frac{\Delta w}{w_o}\right)_{\text{mortar}} = \left(\frac{\Delta w}{w_o}\right)_{\text{paste}} - \delta$$

Therefore from equation-(25)

$$D_{o\ \text{paste}} = 1.081 - 3.75 \left[\frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \right]^{2.6}$$

and

$$D^{m}_{o\ \text{mortar}} = D_{o\ \text{paste}} = 1.081 - b \left[\frac{8.95 \left[\frac{\Delta w}{w_o} - \delta \right]}{4.35 \left[\frac{\Delta w}{w_o} - \delta \right] + 1} \right]^{2.6} \quad \text{------(58)}$$

Equating equations(57)and(25)

and solving for b we obtain

$$b = 3.75 \left[\frac{4.35 \left[\frac{\Delta w}{w_o} - \delta \right] + 1}{4.35 \left[\frac{\Delta w}{w_o} - \delta \right] + 1 - \delta \frac{w_o}{\Delta w}} \right]^{2.6} \quad \text{-----(59)}$$

Substituting for b into equation(57)we obtain:

$$D^{m}_{o} = 1.081 - 3.75 \left[\frac{1 + 4.35 \left[\frac{\Delta w}{w_o} - \delta \right]}{1 + 4.35 \left[\frac{\Delta w}{w_o} - \delta \right] - \frac{w_o}{\Delta w} \delta} \right]^{2.6} \left[\frac{8.95 \frac{\Delta w}{w_o}}{4.35 \frac{\Delta w}{w_o} + 1} \right]^{2.6} \quad \text{------(60)}$$

which is the expression for dilation of mortar as a function of aggregate restraint and volume concentration of hydrate product.

Figure 112 illustrates graphically the general agreement of equation 60) with experimental observation.

Spherical Glass Inclusions

A series of cement paste mixes with spherical glass inclusions (5/8" Ø) were cast in an endeavour to obtain data illustrating certain features of the effect of aggregate restraint on dilation.

In incorporating spherical glass aggregate advantage is taken of the following factors:

1) low coefficient of thermal expansion which allows the glass to maintain full restraint.

2) reduced bond between the smooth glass surface and paste minimizes the contribution of bond at the paste aggregate interface and focuses attention on pure physical restraint.

Mixes were cast in the form of 3" Ø x 6" cylinders and moist cured one day until time of

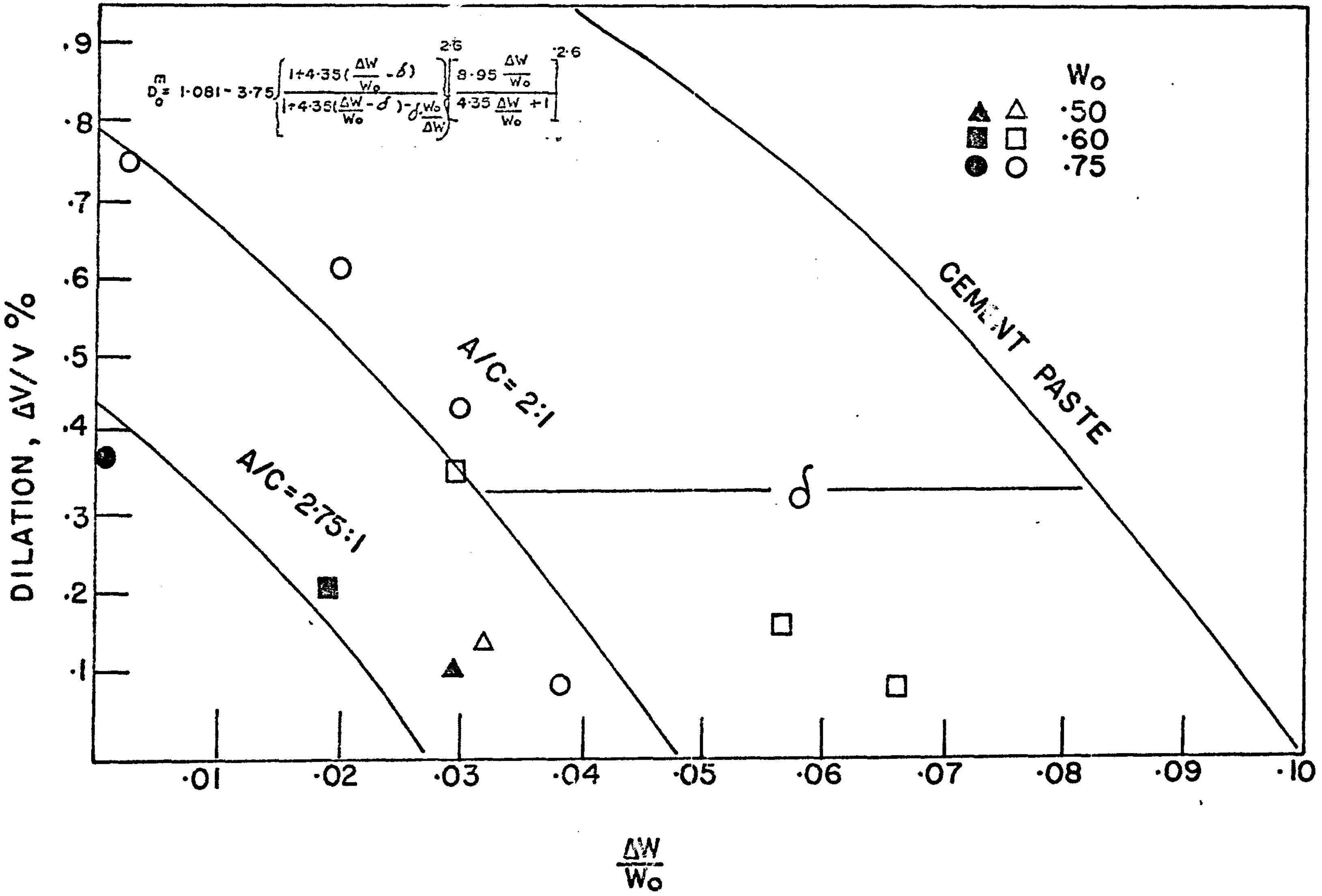


Figure 112 Dilation As A Function Of $\frac{\Delta W}{W_o}$ And Aggregate Restraint

test. Specimens were prepared at three different paste contents (39%, 62.5% and 90%) and at a water cement ratio of 0.50.

All the specimens were subjected to the $\frac{dT}{dt} = 5^{o}F/hr.$ cooling-warming regime and subjected to multiple cycles.

Figure 113 illustrates that the glass sphere-cement paste matrix undergoes a systematic collapse of hysteresis with increased number of cycles. The final collapse produces a linear response for all paste contents.

Figure 114 shows that residual volume change increases exponentially with an increase in paste content. Dilation increases with an increase in paste content except for an anomaly at 90%. It would appear that further study on the effect of coarse aggregate in providing volume change restraints due to cooling may resolve any anomaly in the higher paste content region. The anomaly may be due to the fact that with such a high paste content (and therefore few spherical glass inclusions) it is difficult to obtain a randomly uniform distribution of the aggregate throughout the matrix. That is, a concentration of the aggregate in one region of the specimen may provide an artificial restraint on the system.

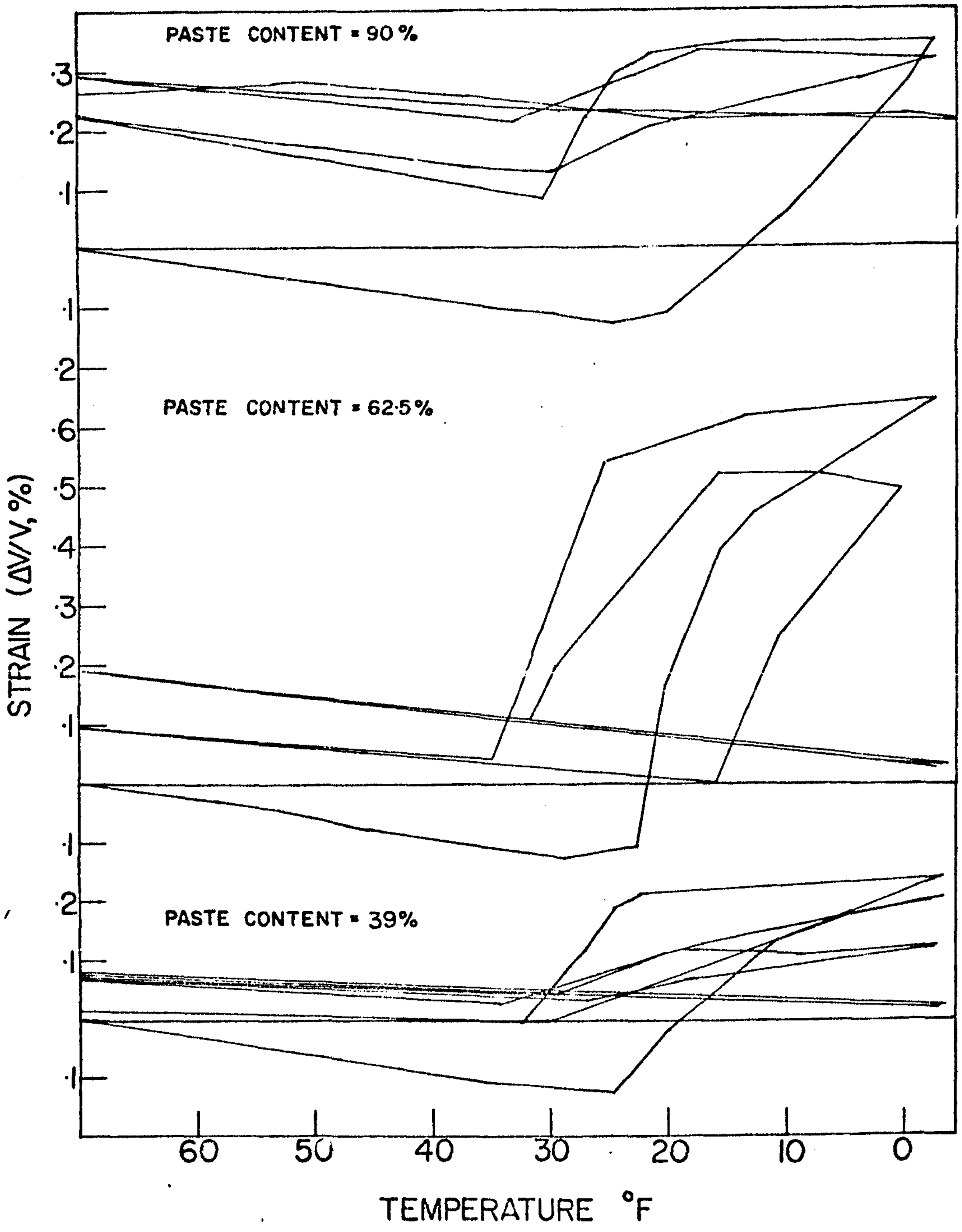


Figure 113 Multiple Cycle Tests For Glass Inclusion Series

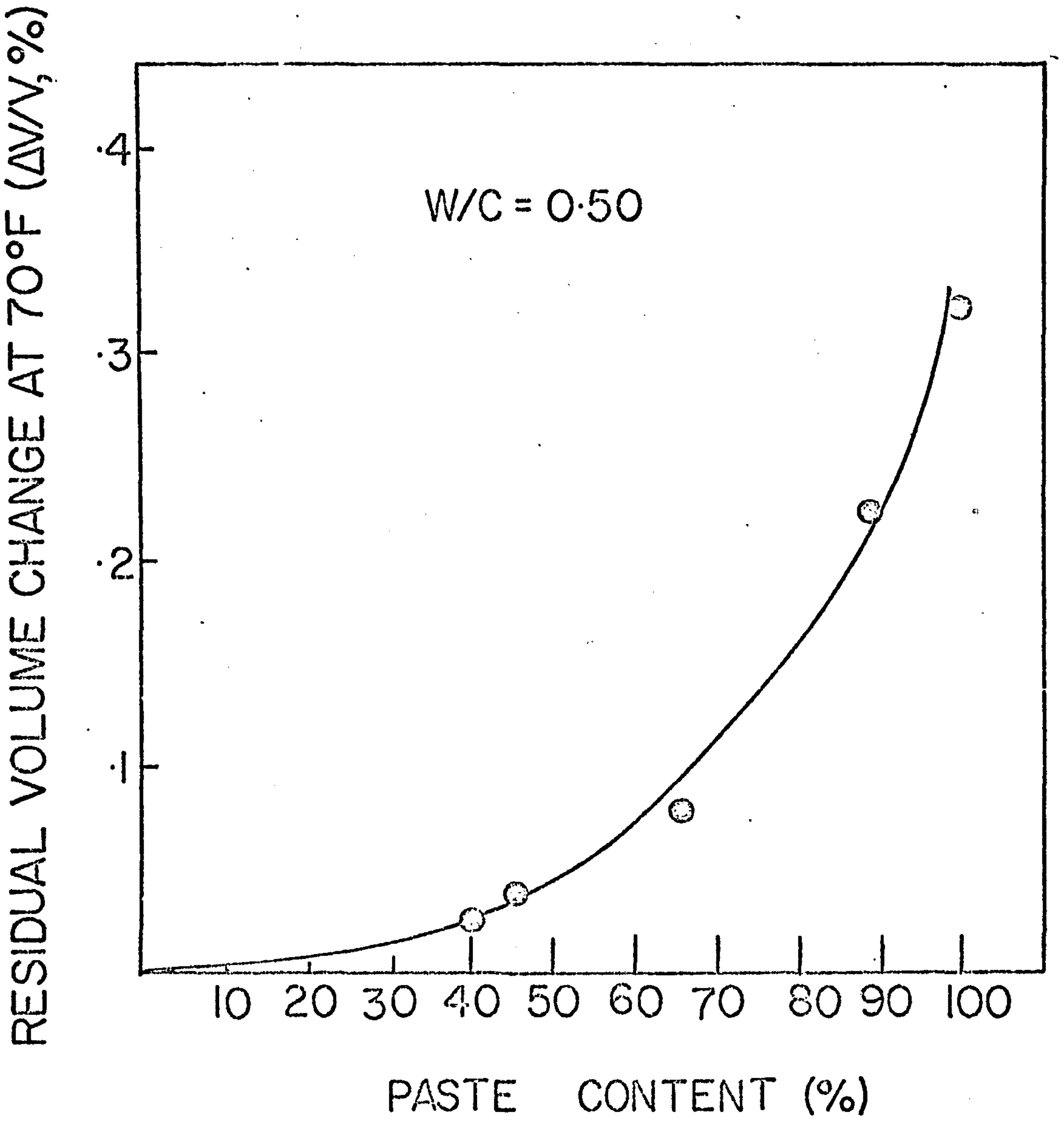


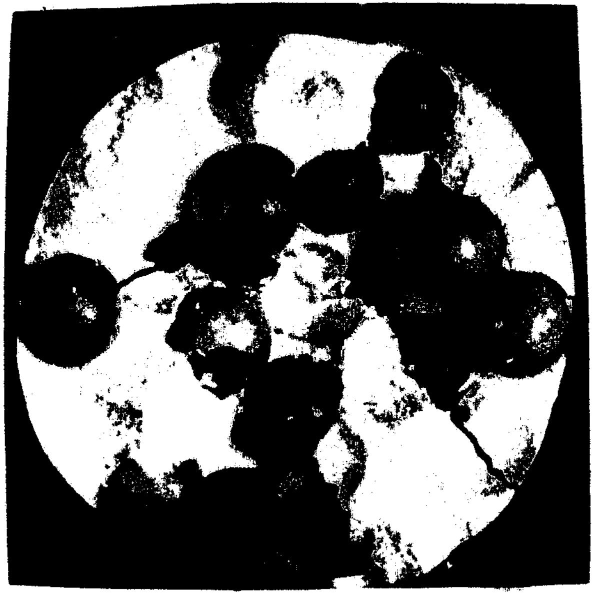
Figure 114 Residual Volume Change vs Paste Content (Glass Inclusions); w/c=0.50

It is of interest to note however that there is no apparent anomaly for the residual volume change as a function of the paste content in the glass-paste system. A few paste samples (62.5 percent paste content) were examined visually for cracks at the paste-aggregate interface. The samples were broken by hand to reveal the aggregate-paste matrix. Fracturing the specimens by hand was quite easy as the specimens were cycled at one day; this was accomplished with greater facility than sawing specimens which is common procedure in crack investigations. Hsu (61) has demonstrated that cracks at the paste-aggregate interface occur normal to the aggregate surface; these cracks are induced by mechanical load.

Photograph 7 illustrates large cracks which are normal to the aggregate, at the paste-aggregate interface. This suggests that slow-cooling and warming can induce tensile stress at the paste-aggregate interface in a similar manner as those induced by mechanical load.

CONCLUSIONS - MORTAR SERIES

1) Mortar undergoes a time dependent collapse of hysteresis when subjected to slow cooling and warming cycles.



P_7 - Cracks At Paste Aggregate Interface

2) The magnitude of strain-temperature hysteresis for mortar is a function of aggregate-cement ratio at a given water-cement ratio and is a function of water-cement ratio at a given aggregate-cement ratio.

3) The magnitude of dilation and residual volume change is decreased by the inclusion of fine aggregate in the matrix.

4) Dilation of mortar can be expressed as a function of the volume concentration of ydrate product and the degree of aggregate restraint.

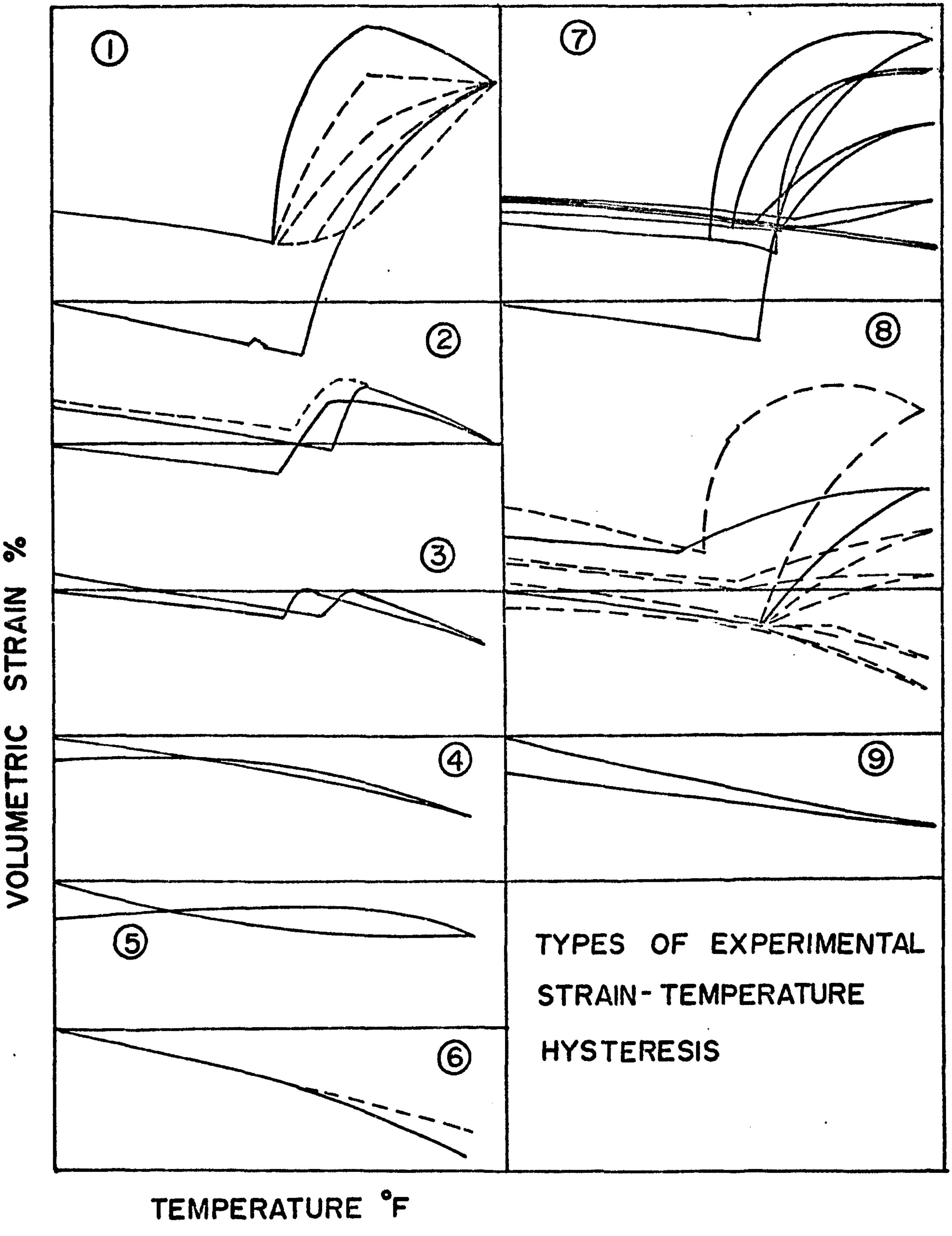
5) It appears that differences in transient strain behaviour of mortar made with sands having similar grading and porosity may be attributed to the rigidity of the aggregate particles themselves.

6) Collapse of hysteresis occurs for a system of pure restraint ie. no bond and low coefficient of thermal expansion.

7) Cracks due to cooling at the paste-aggregate interface appears to be normal to the aggregate surface.

SUMMARY OF HYSTERESIS BEHAVIOUR - CEMENT PASTE AND MORTAR

Figure 115 illustrates the types of strain-temperature hysteresis generally observed in this



TYPES OF EXPERIMENTAL STRAIN-TEMPERATURE HYSTERESIS

Figure 115

programme. Patterns in block 1, depicting large hysteresis, are observed at early stages of the hydration process. Here the hysteresis collapse is dependent on the rate of cooling as well as the degree of hydration.

Patterns in block 2 were generally exhibited by mortar at intermediate stages in the hydration process. The effect of aggregate restraint is observed as $\frac{d(\Delta V/V)}{dT}$ changes sign in the lower region of the cooling cycle.

Patterns in block3 are representative of the strain-temperature response of pastes containing an air-entraining admixture.

Negative residual strains are observed in patterns of types 4,5,9. It appears that perhaps a structural reorientation of hydrate layers may account for this change in sign of the residual strain.

Pattern 6 depicts linear thermal contraction followed by increased linear thermal contraction in the freezing zone. This can be explained by diffusion of hydrate water to ice nucleation sites in capillary pores.

Pattern 7 is an example of collapse in hysteresis due to multiple cycling of cement paste. A combination of self desiccation, continued hydration and structural reorientation due to internal pressure appear to offer plausible explanation for the hysteresis collapse.

Block 8 illustrates a typical set of strain-temperature hysteresis collapse due to progressive hydration.

It is noted that after freezing is initiated and the temperature continually lowered,

$$0 \leqslant \frac{d(\Delta V/V)}{dT} \quad \text{or} \quad 0 \geqslant \frac{d(\Delta V/V)}{dT}$$

Thus, the slope of the strain temperature function in the freezing zone changes sign as the degree of hydration increases.

SUGGESTIONS FOR FURTHER RESEARCH

This dissertation has attempted to interrelate the hydration process variables with length change phenomena due to slow cooling and warming. It was observed that the role water plays in length change phenomena is a complex one. It is the authors opinion that further research should involve experiments directed toward assessing the role of the different states of water in freezing phenomena.

The following are a few suggestions for further research:

1) A detailed and systematic study of the morphological change accompanying length change due to natural cooling may provide valuable information helpful in studying the basic mechanisms of frost action. This work would be carried out with a scanning electron microscope.

2) In conjunction with 1) a study of length change due to slow cooling of pure compounds may provide useful data.

3) Aggregate inclusions in the matrix make the frost action problem even more complex. It is suggested that several sources of fine aggregate be used in an attempt to study further the effect of aggregate restraint. The study might concentrate on such variables as porosity,

grading and aggregate restraint.

4) Investigations concerned with the restraint factor of coarse aggregate may yield promising information.

5) It is suggested that further research on a the slow cooling method is required before the method is adopted as a standard criteria for aggregate acceptance. Many factors regarding the method have yet to be resolved. The contributions and interaction of the various phases that make up the matrix as they pertain to slow cooling phenomena have yet to be resolved.

CHAPTER XI

DISCUSSION OF EXPERIMENTAL ERRORS

Variation in Consistency of Materials

Concrete is perhaps subject to greater behavioural variation than any other building material. Of the constituent phases-cement, water coarse, and fine aggregate-which make up the matrix, cement is the only ingredient which is controlled within limits by the manufacturer. However even cement is subject to considerable variation. As cement is manufactured from naturally occurring raw products it is understandable that any disparity in the consistency of the raw product will be reflected in the consistency of the finished product ie. cement.

In an attempt to avoid variation in our laboratory cement supply the cement was blended on arrival in a systematic fashion and stored in steel drums with air tight lids. This blended supply of cement was used throughout the test series.

Fine aggregate is subject to variation depending on the source of supply. In the mortar test series in this programme two fine aggregates with good service records were employed.

Variation in Batching and Mixing

When a number of batches are made in the laboratory there is a possibility of within batch variation and between batch variation. It is of course desirable to schedule batching of mixes in such manner that as many mix variables as possible be considered during any given period of casting in order to avoid any fluctuations in temperature or humidity that might occur. Scheduling of mixes, where possible, attempted to reduce any random errors inherent in small environmental fluctuations. Ideally to avoid completely within batch and between batch variation one would have to have an extremely large number of batches, each batch having a large number of test specimens. It was attempted to provide as many test specimens from a sufficiently large number of batches as possible.

In the volume change experiments in this programme at least three specimens for each test condition were cycled according to the selected slow cooling-warming regime. Several test cycles involved six or more test specimens for each test condition. Where possible each test specimen for a given test condition was from a separate batch.

Repeatability of Test Data

Figure 116 plots the transient strain behaviour at one day for five cement paste prisms from five separate batches, all having a water-cement ratio 0.50. This figure illustrates well any variation in strain-temperature response as it is a well known fact (62) that the coefficient of variation for the strength property is largest at early ages. The following table tabulates residual volume change and dilation for the five test specimens in figure 116.

Test Specimen	Residual Volume Change ($\Delta L/L \times 10^4$)	Dilation ($\Delta L/L \times 10^4$)
1	8.0	15.2
2	9.7	15.3
3	10.2	15.8
4	10.5	18.0
5	12.2	19.5
Average	10.12	16.76
Standard Deviation	1.51	1.47

Table XIII Repeatability of Test Data From Figure 116

All values of D_o and ΔV_R plotted previously are average values for at least three test specimens for each test condition. Several values of D_o and ΔV_R were averages of as many as six test specimens per test condition.

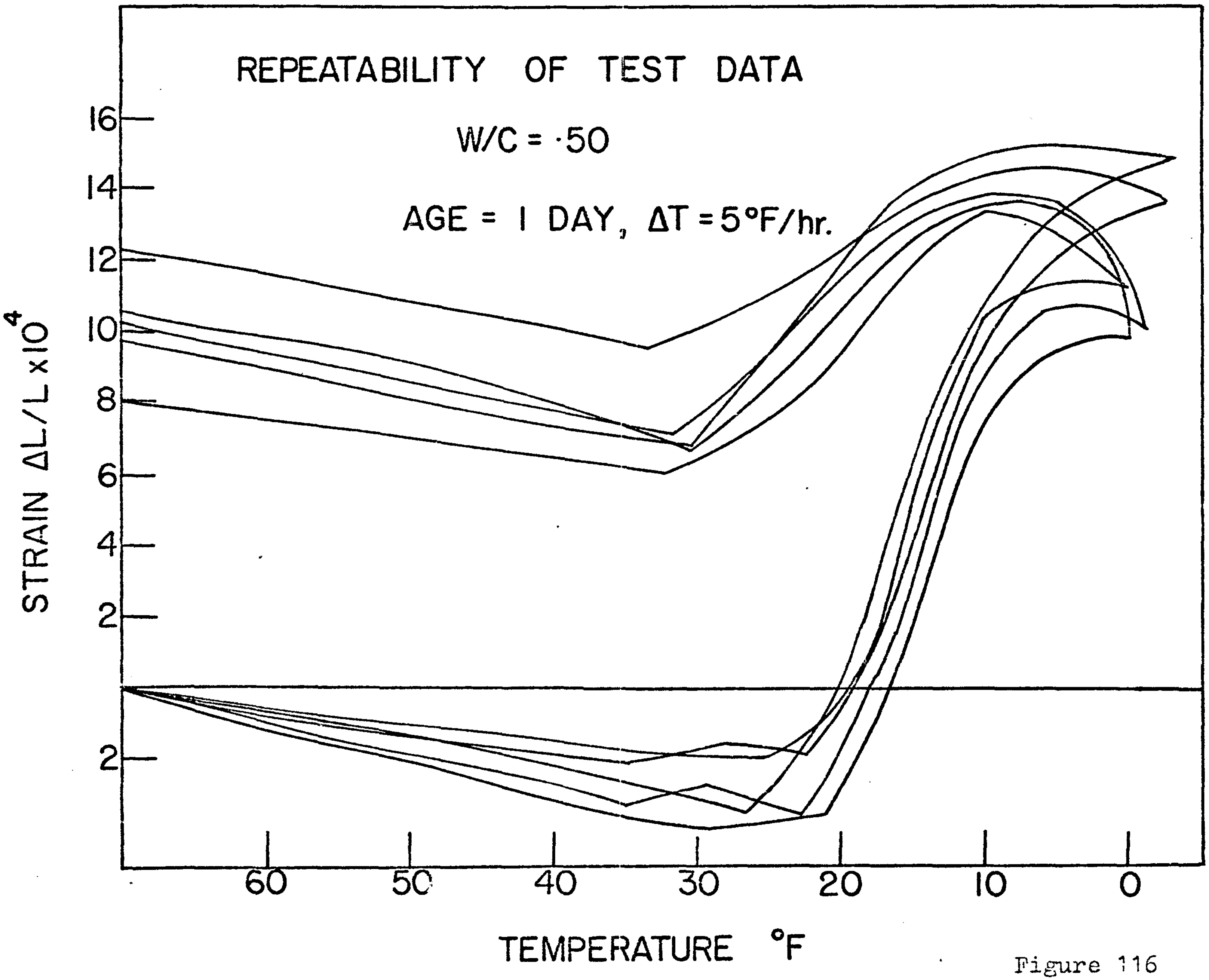

REPEATABILITY OF TEST DATA
W/C = ·50
AGE = 1 DAY, ΔT = 5°F/hr.
STRAIN ΔL/L x10^4
16
14
12
10
8
6
4
2
2
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 116

Volume Change Measurements

Two measuring systems were used to measure volume changes:

1) mercury displacement dilatometry
2) displacement transducers

The mercury displacment dilatometer was calibrated using two reference specimens-a 3" Ø x 6" solid steel (1020) cylinder and a 3" Ø x 6" aluminum (6061-T6) cylinder. Figures 117 and 118 give the calibration curve for both dilatometers. The volumetric coefficient of thermal expansion (see Appendix) was computed for the steel dilatometer chamber itself. The value was within 4 % of the published value for steel.

The dilatometer was read to .01 ml ± .01 ml. Expressed as a percentage of a maximum burette reading of 5 ml. the accuracy is about.25%. This accuracy is quite good for the range and magnitude of the volume changes measured.

The displacment transducers were mounted axially on invar frames, after being calibrated for rated output. The rated outputs agreed well with those observed (figures 119 to 124). The complete measuring system (frames plus transducers) were calibrated with reference samples (steel and

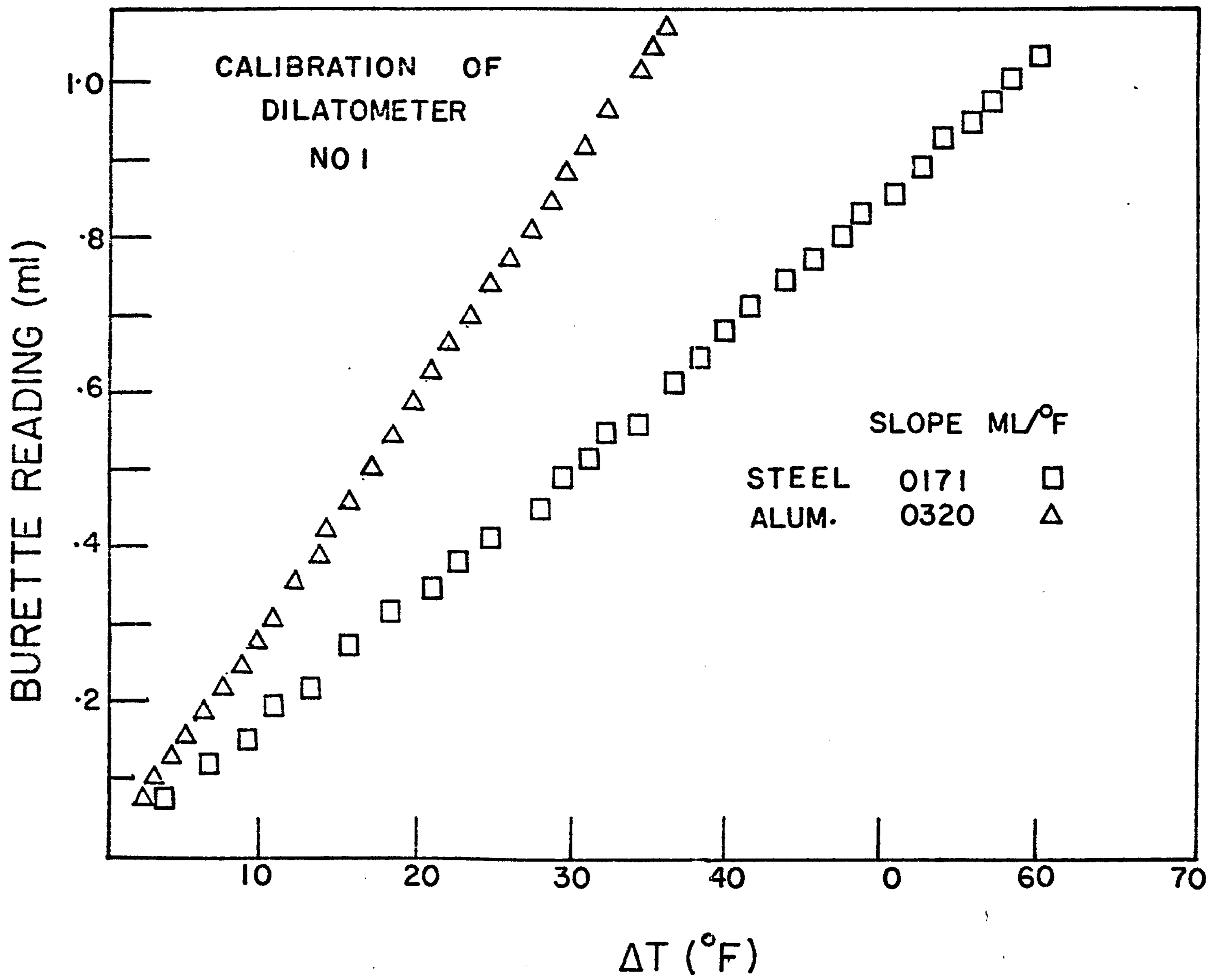

CALIBRATION OF
DILATOMETER
NO I
BURETTE READING (ml)
1·0
·8
·6
·4
·2
10
20
30
40
0
60
70
ΔT (°F)
SLOPE ML/°F
STEEL 0171 □
ALUM. 0320 △

Figure 117

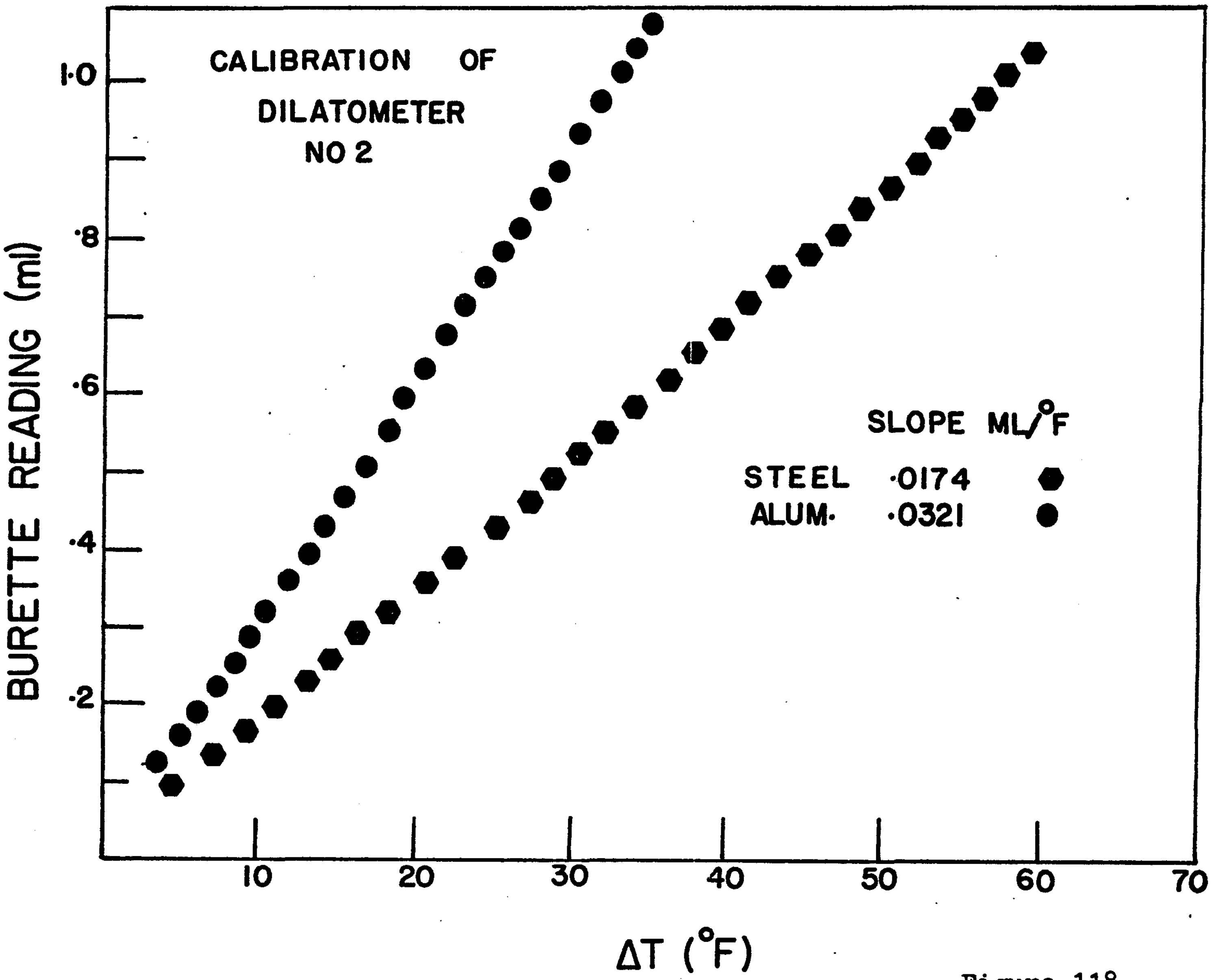

CALIBRATION OF
DILATOMETER
NO 2
SLOPE ML/°F
STEEL ·0174 ⬣
ALUM· ·0321 ●
BURETTE READING (ml)
1·0
·8
·6
·4
·2
10
20
30
40
50
60
70
ΔT (°F)

Figure 118

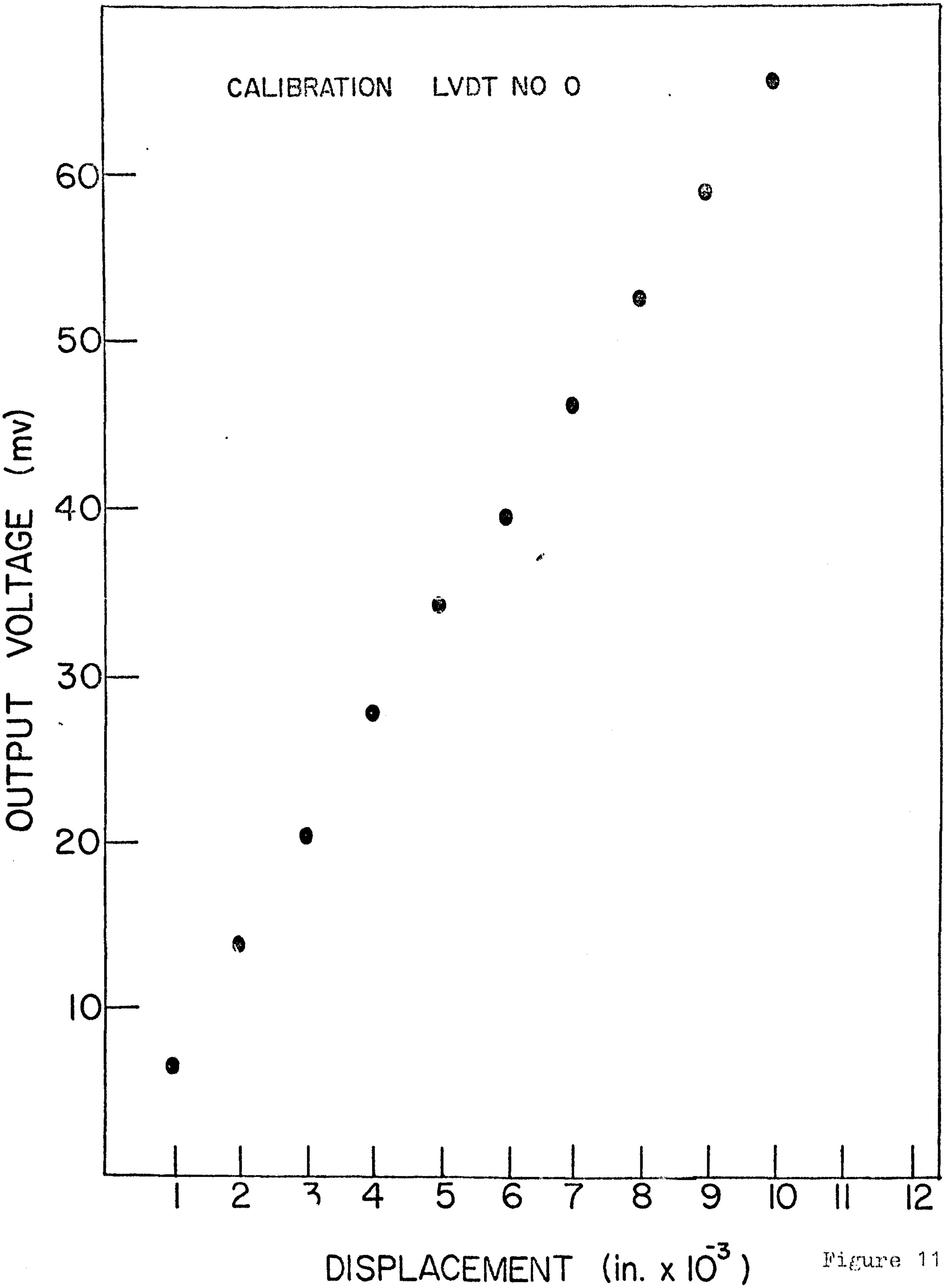

CALIBRATION LVDT NO 0
OUTPUT VOLTAGE (mv)
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
DISPLACEMENT (in. x 10^{-3})

Figure 119

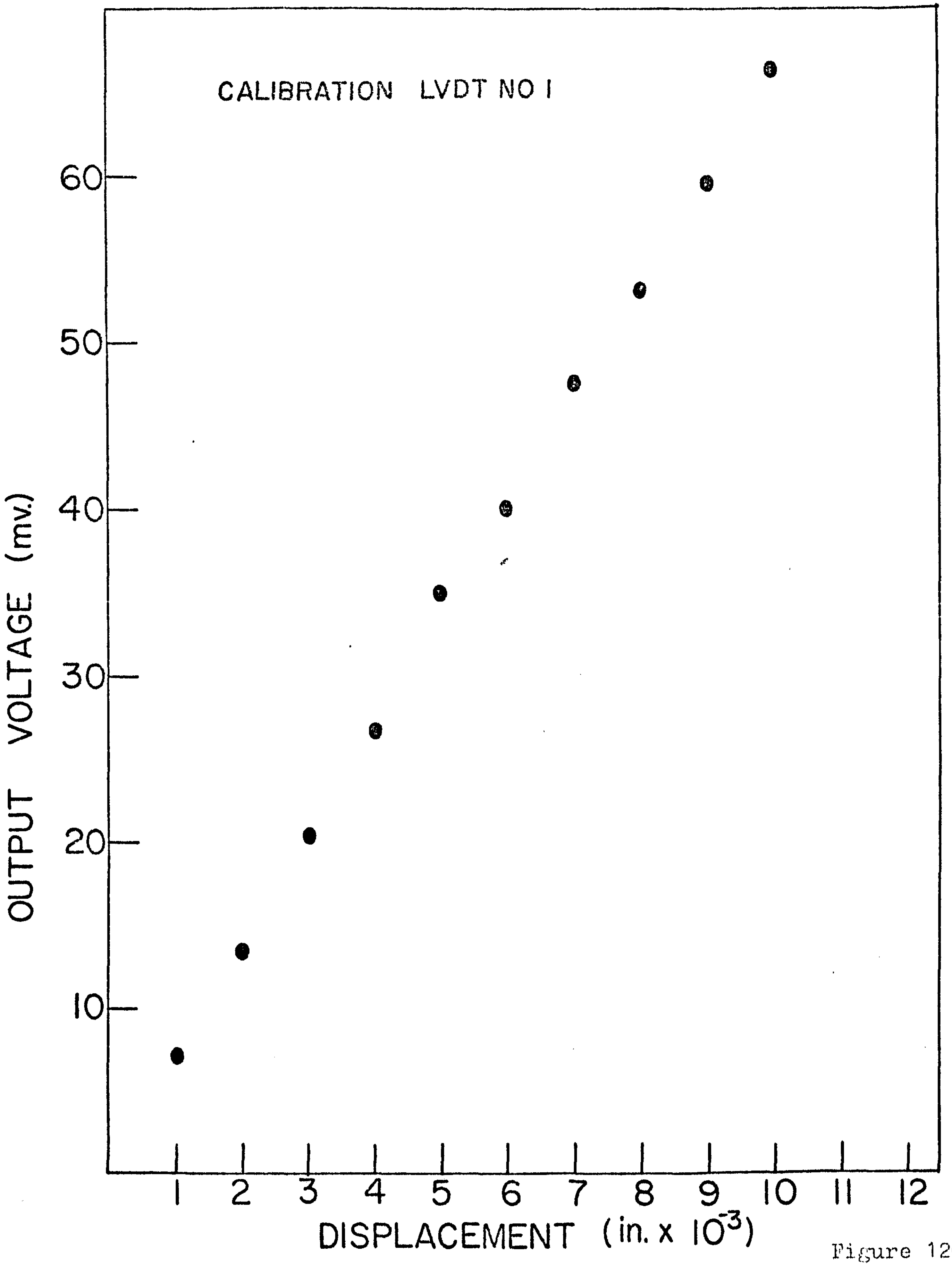

CALIBRATION LVDT NO I
OUTPUT VOLTAGE (mv.)
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
DISPLACEMENT (in. x 10^{-3})

Figure 120

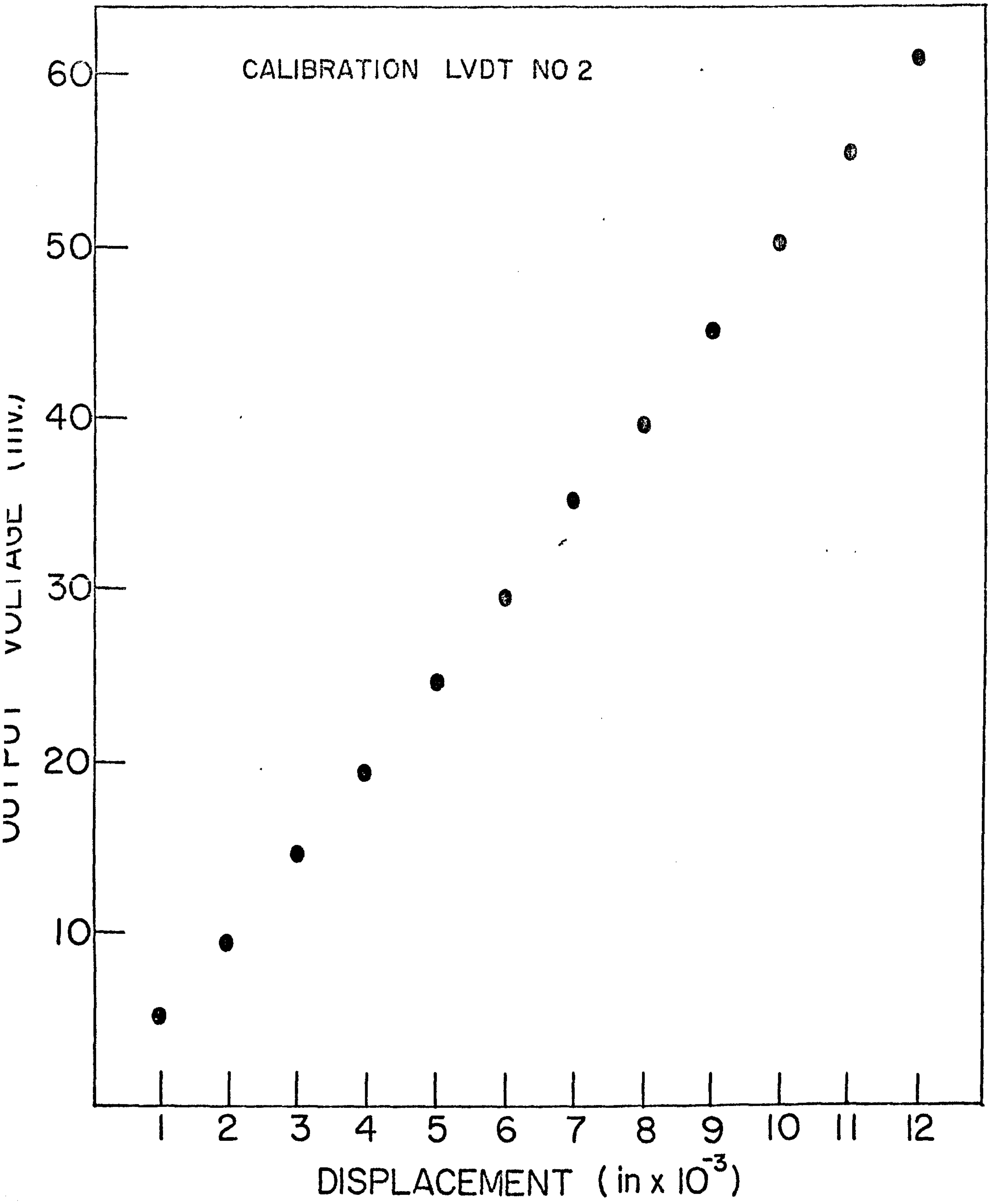

CALIBRATION LVDT NO 2
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
DISPLACEMENT (in x 10^{-3})

Figure 121

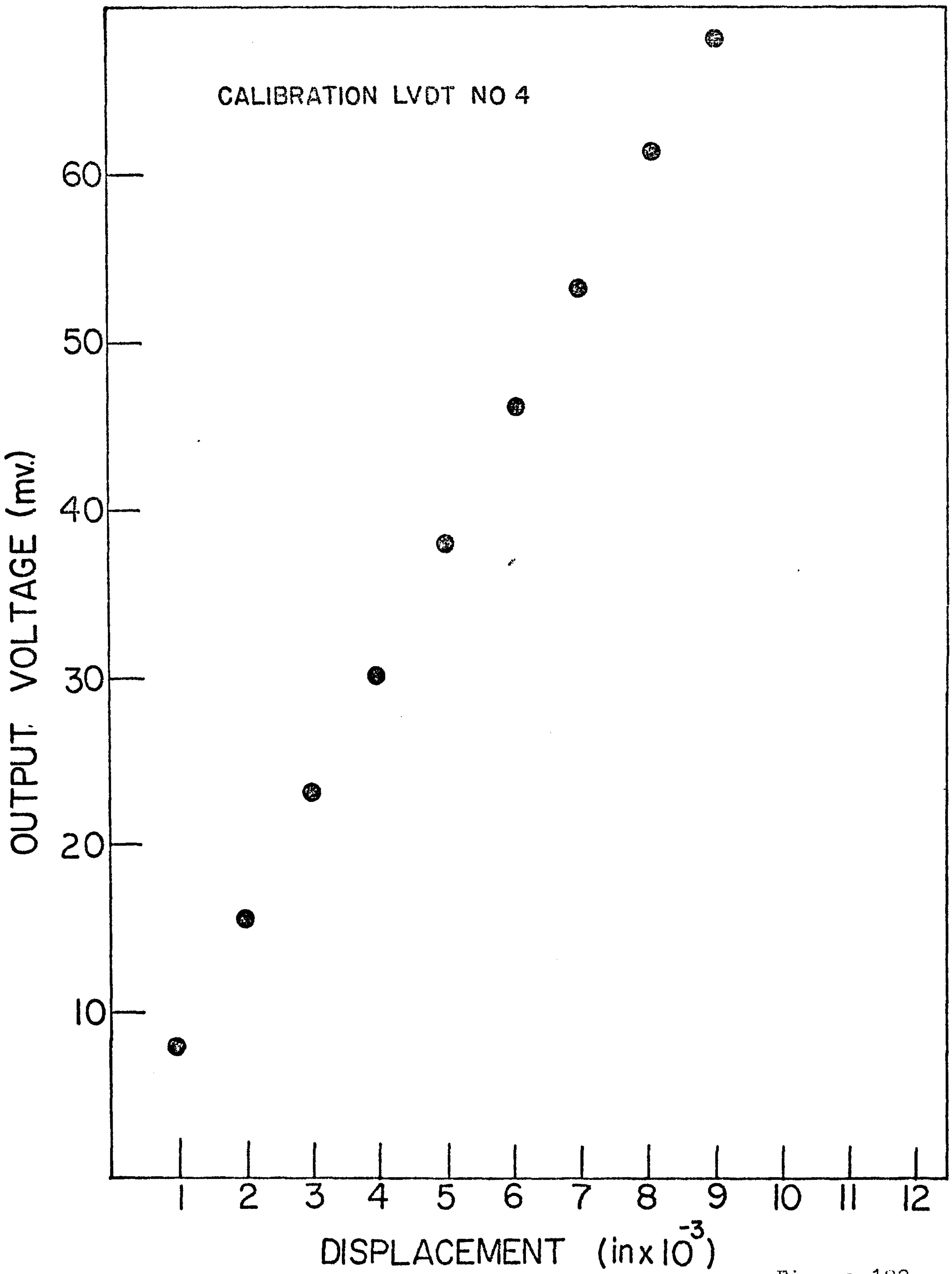

CALIBRATION LVDT NO 4
OUTPUT VOLTAGE (mv.)
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11
12
DISPLACEMENT (in x 10^{-3})

Figure 122

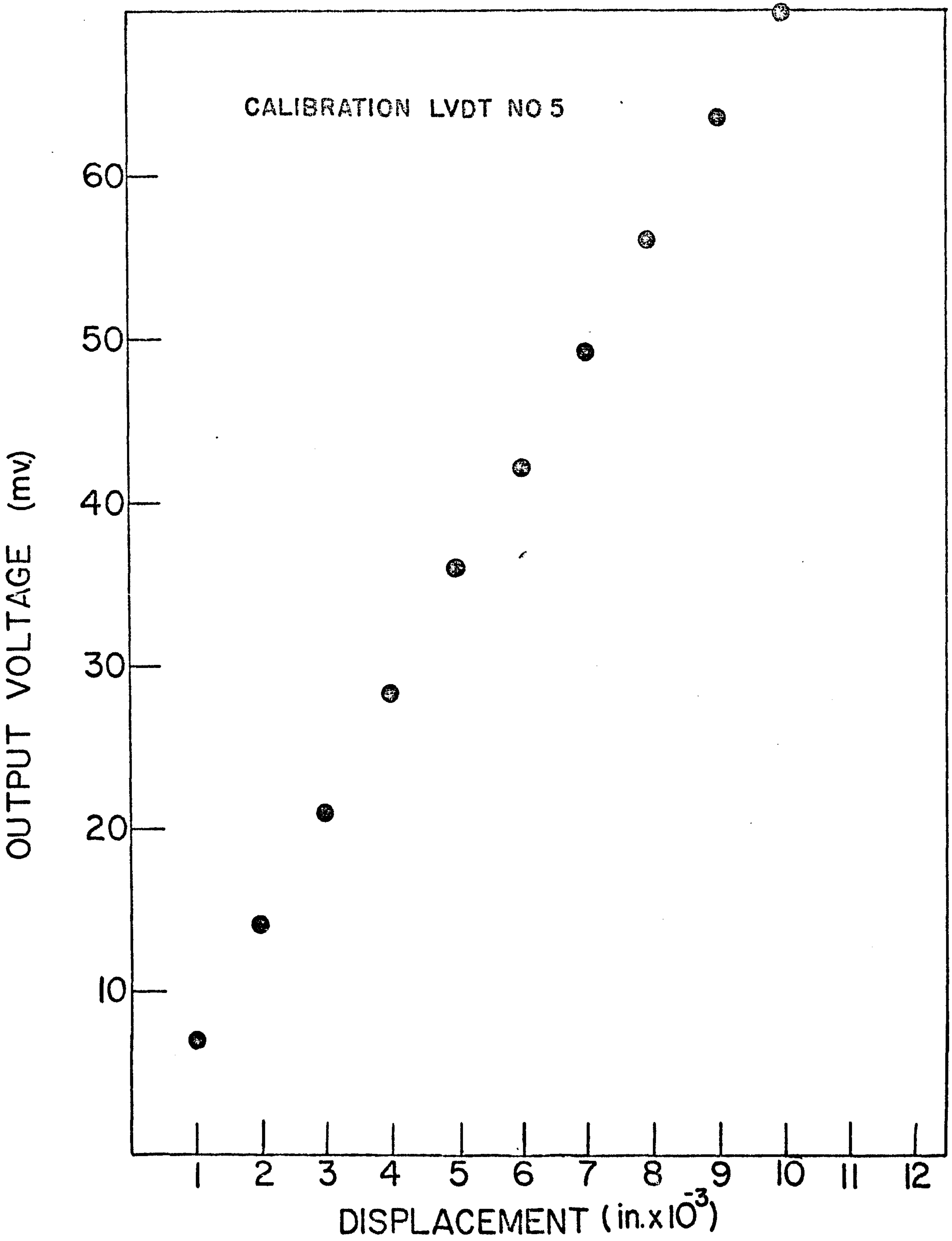

CALIBRATION LVDT NO 5
OUTPUT VOLTAGE (mv)
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11
12
DISPLACEMENT (in.x 10^{-3})

Figure 123

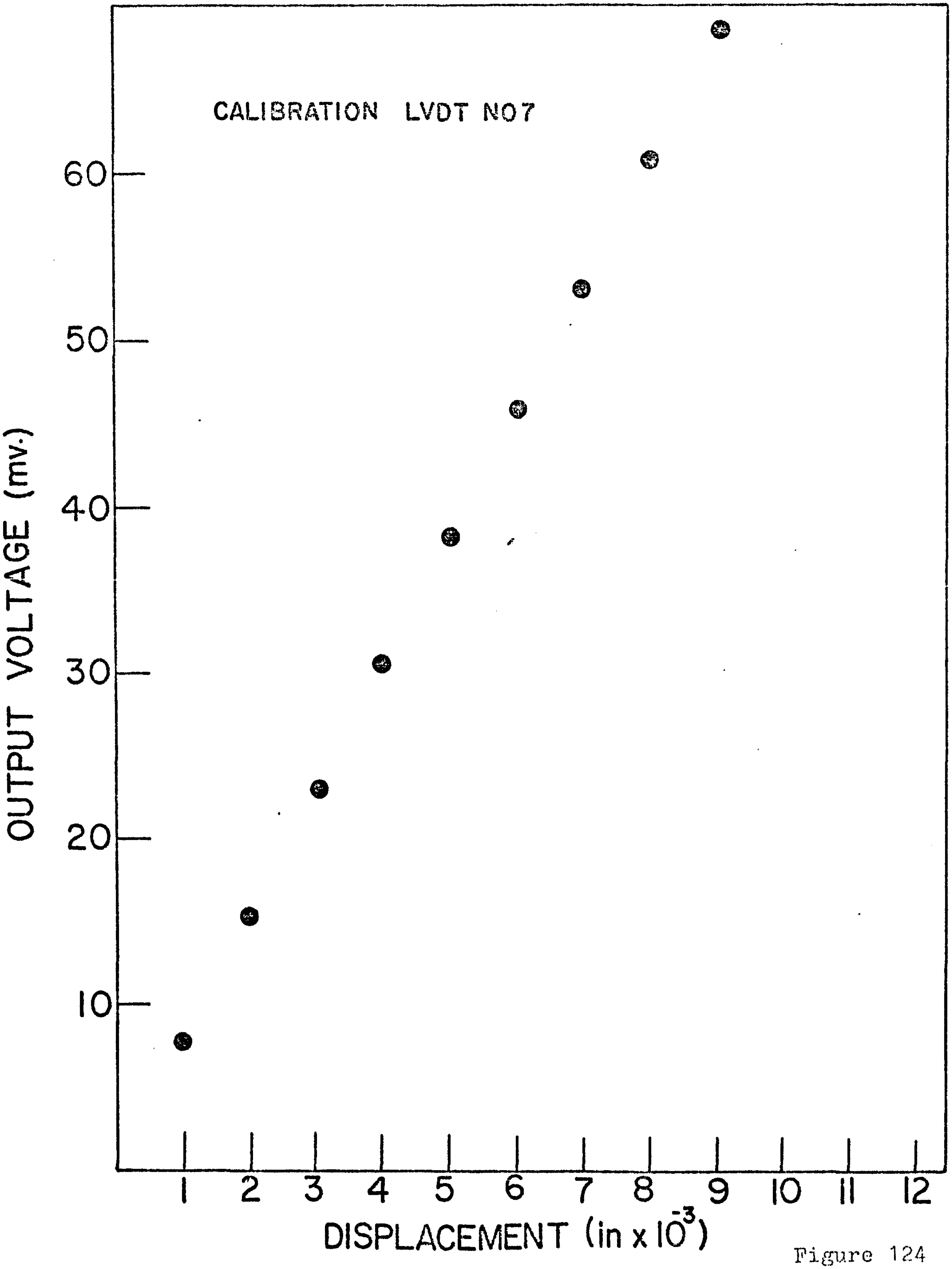

CALIBRATION LVDT NO7
OUTPUT VOLTAGE (mv.)
10
20
30
40
50
60
DISPLACEMENT (in x 10^{-3})
1
2
3
4
5
6
7
8
9
10
11
12

Figure 124

aluminum) by subjecting them to the selected slow cooling-warming regime. The slope of the strain-temperature response (figures 125 to 130) provided a check on the thermal contribution of the measuring system itself. The following table summarizes the frame contributions.

Frame No.	$\alpha_c \times 10^6$ (in/in°F)
1	0.50
2	0.40
3	0.15
4	0.40
5	0.15
6	0.35

Table XIV Thermal Contribution of Invar Frames

Expressed as a percentage of a maximum strain reading of 7.15×10^{-3} in/in., the maximum frame contribution over 70°F ($\alpha_c = .50 \times 10^{-6}$) is 35×10^{-6} in/in. Thus, the maximum frame contribution is 0.49%. This is a negligible contribution over the range of strain and temperature realized in this programme. Other investigators (63) have also neglected thermal contributions of the frame itself.

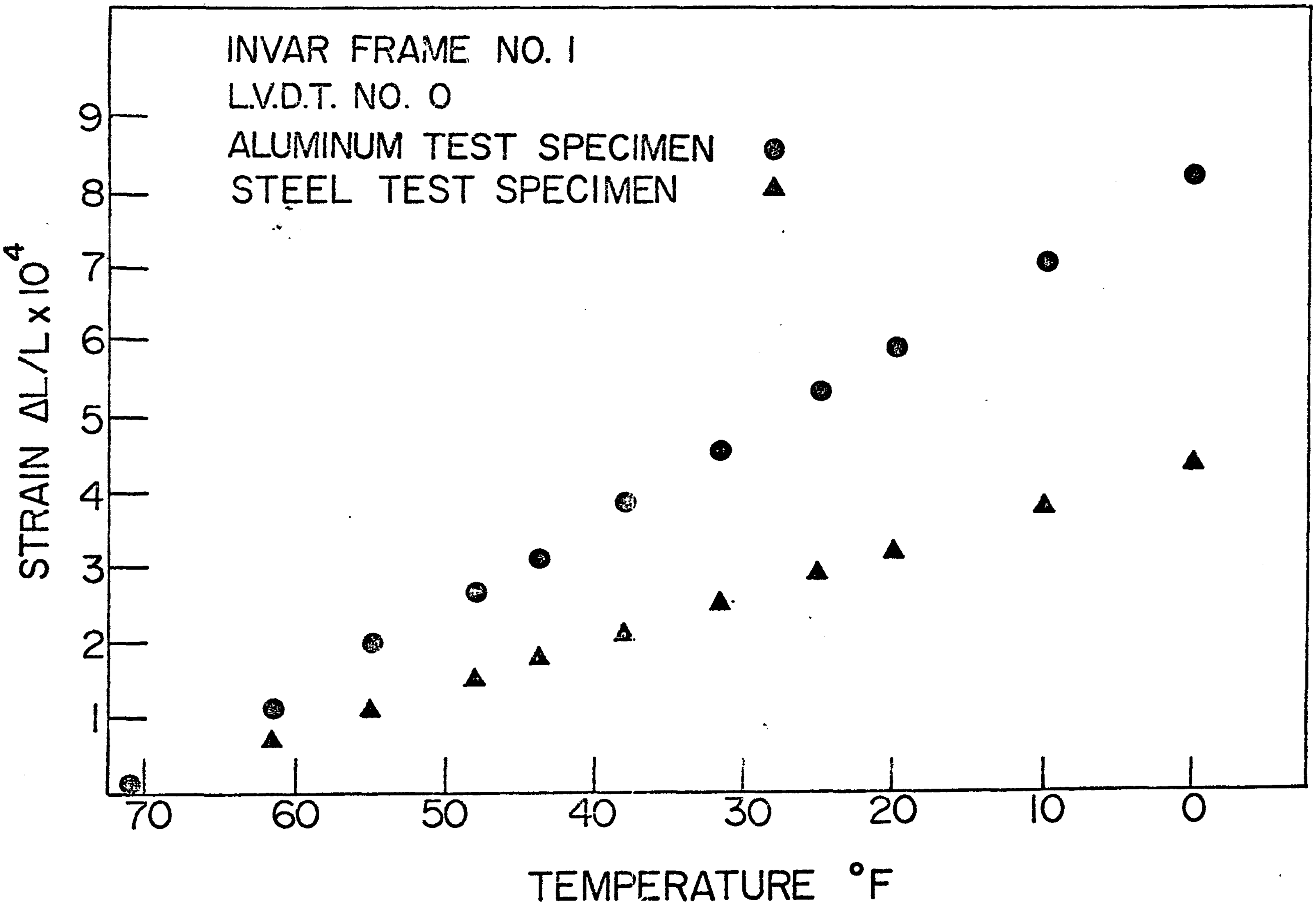

INVAR FRAME NO. I
L.V.D.T. NO. 0
ALUMINUM TEST SPECIMEN ●
STEEL TEST SPECIMEN ▲
STRAIN $\Delta L/L \times 10^4$
9
8
7
6
5
4
3
2
1
70
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 125

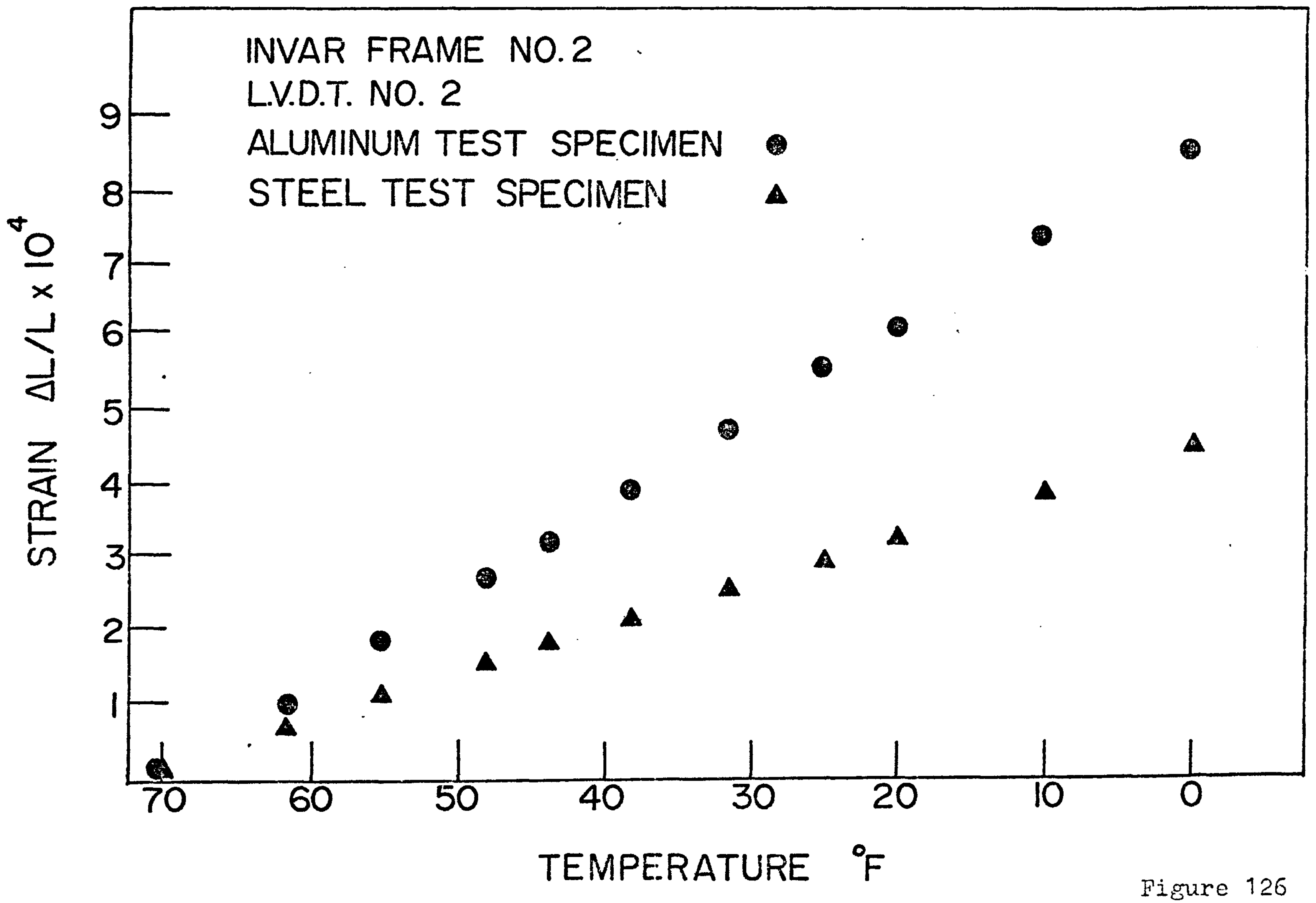

INVAR FRAME NO. 2
L.V.D.T. NO. 2
ALUMINUM TEST SPECIMEN ●
STEEL TEST SPECIMEN ▲
STRAIN $\Delta L/L \times 10^4$
9
8
7
6
5
4
3
2
1
70
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 126

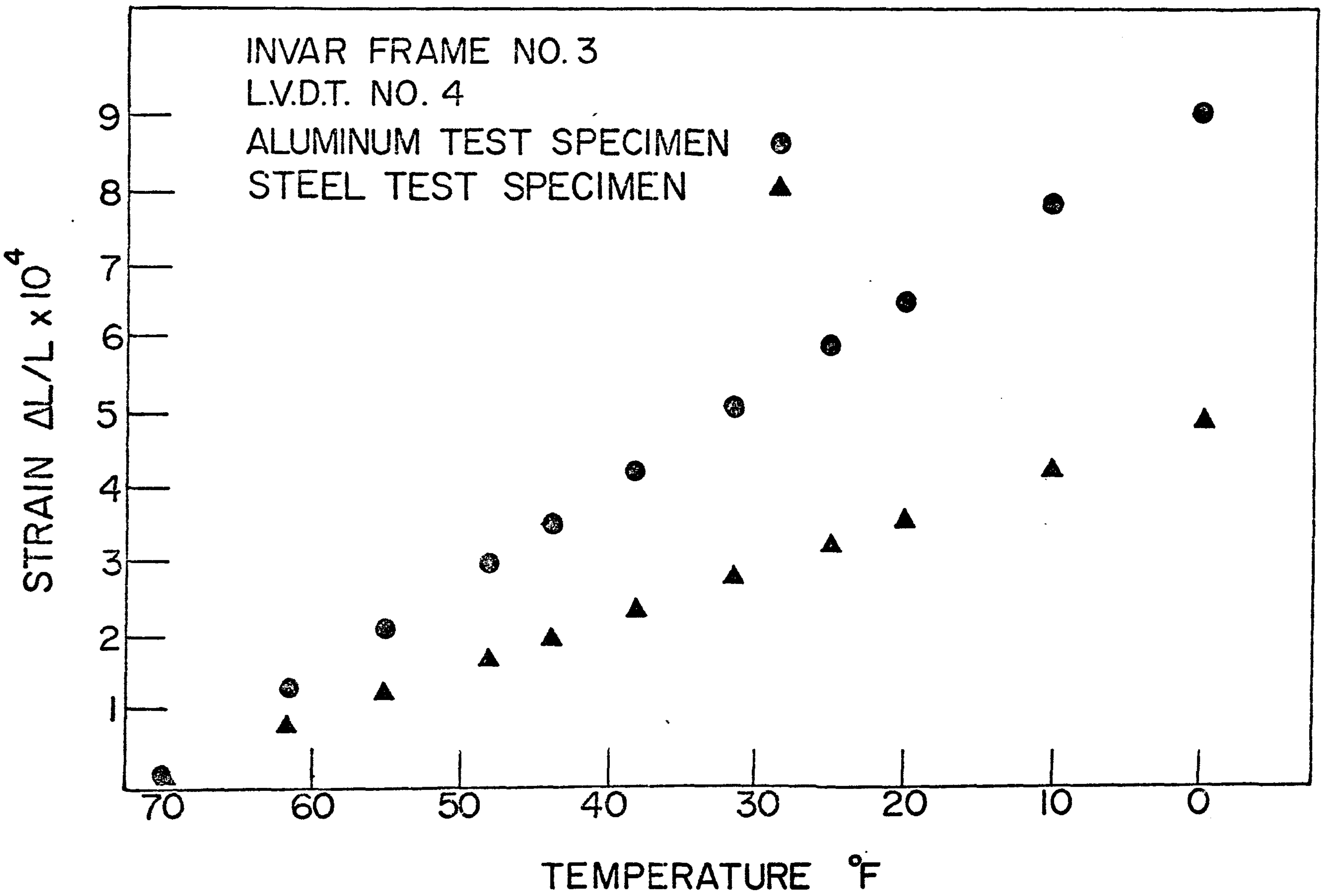

INVAR FRAME NO. 3
L.V.D.T. NO. 4
ALUMINUM TEST SPECIMEN ●
STEEL TEST SPECIMEN ▲
STRAIN ΔL/L x 10⁴
9
8
7
6
5
4
3
2
1
70
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 127

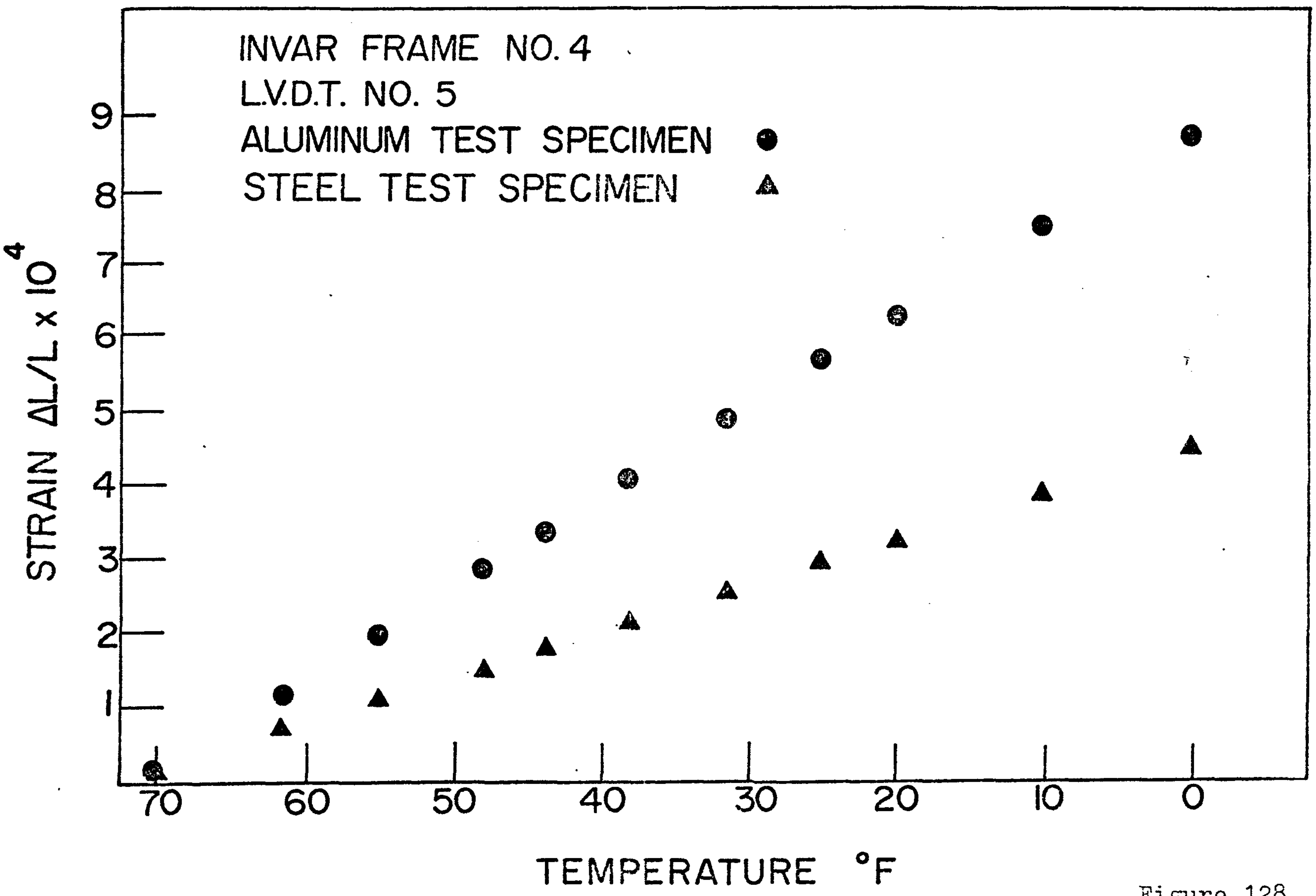

INVAR FRAME NO. 4
L.V.D.T. NO. 5
ALUMINUM TEST SPECIMEN ●
STEEL TEST SPECIMEN ▲
STRAIN ΔL/L x 10⁴
9
8
7
6
5
4
3
2
1
70
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 128

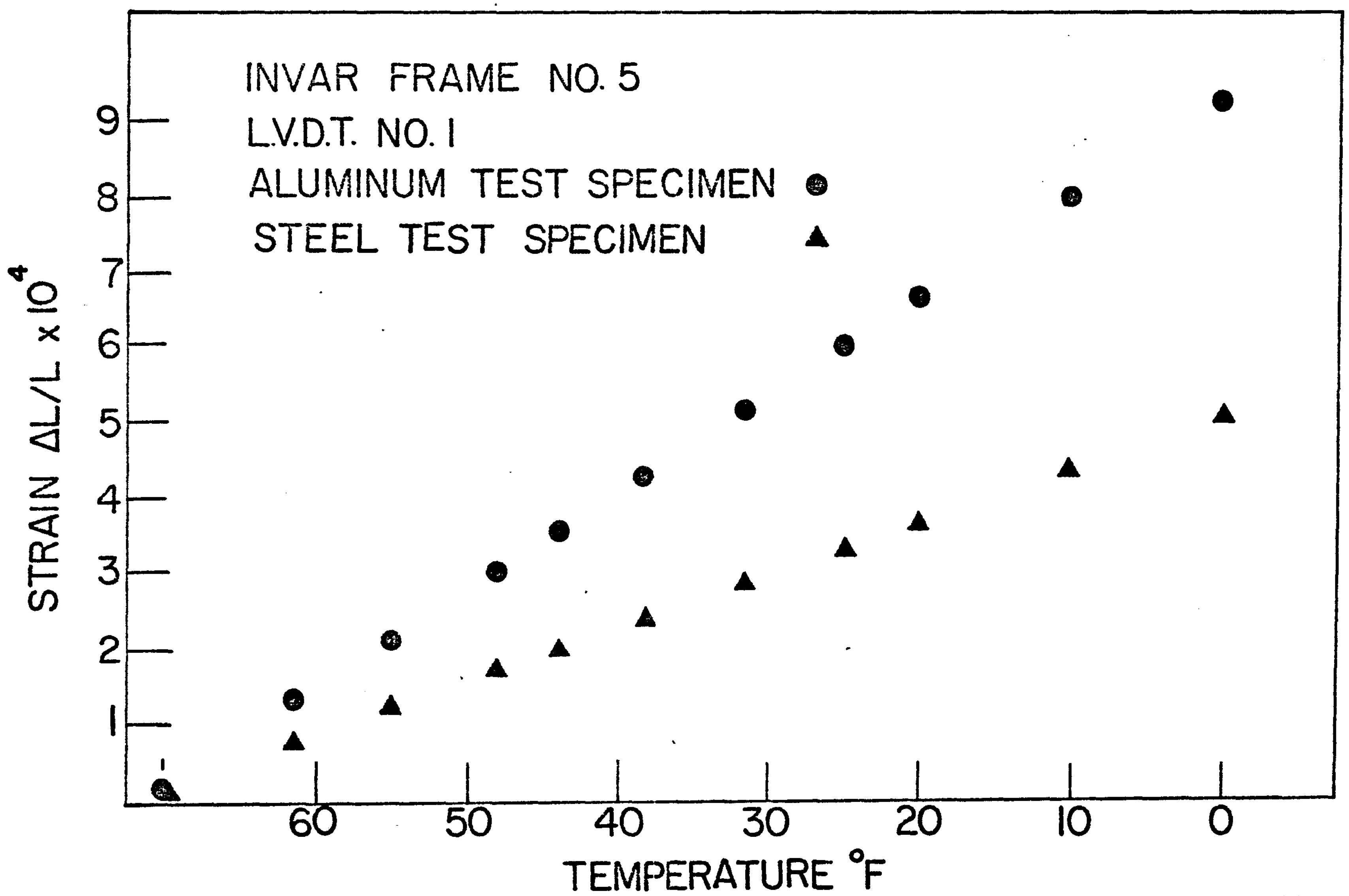

INVAR FRAME NO. 5
L.V.D.T. NO. 1
ALUMINUM TEST SPECIMEN ●
STEEL TEST SPECIMEN ▲
STRAIN ΔL/L x 10^4
9
8
7
6
5
4
3
2
1
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 129

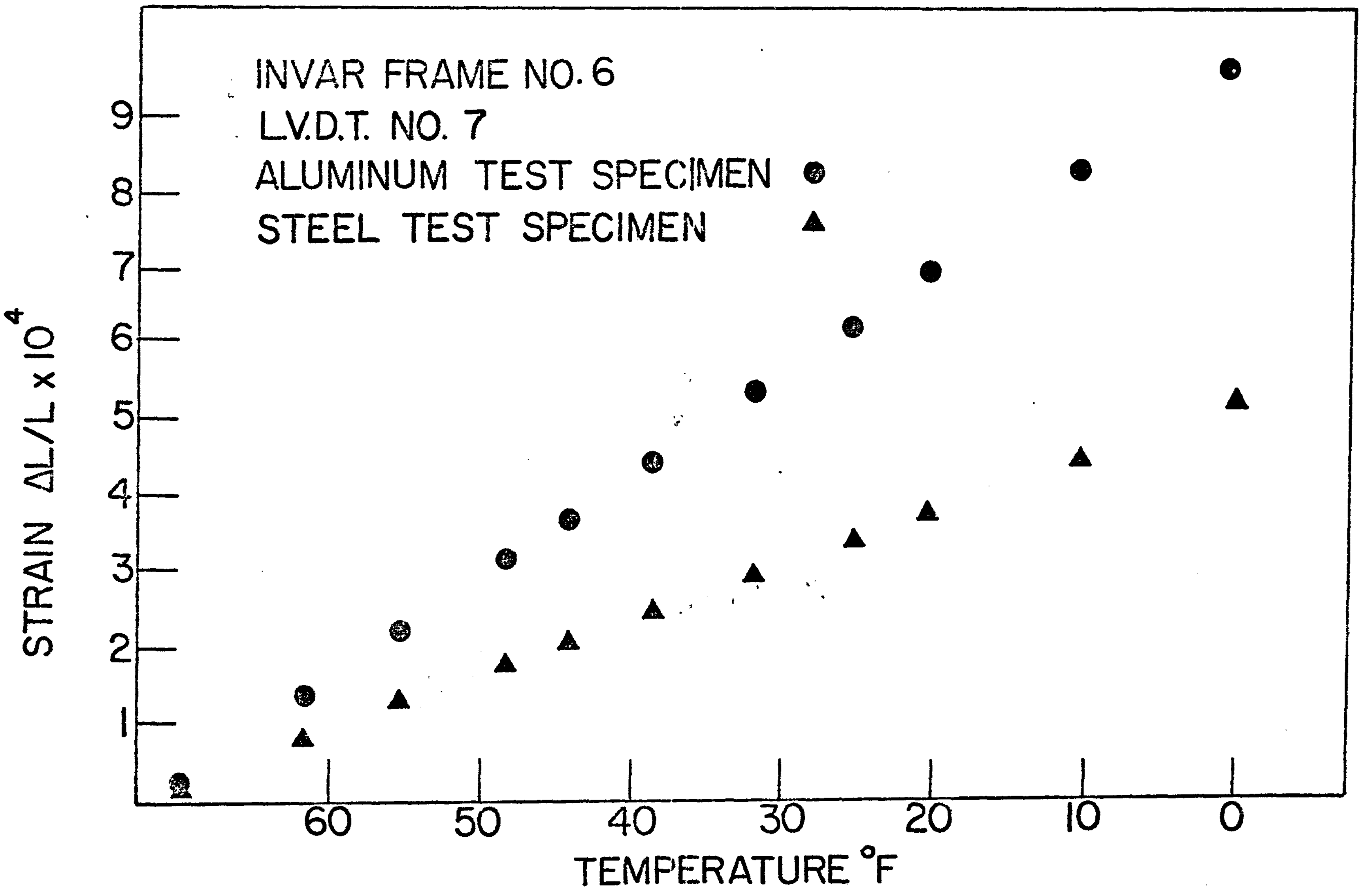

INVAR FRAME NO. 6
L.V.D.T. NO. 7
ALUMINUM TEST SPECIMEN ●
STEEL TEST SPECIMEN ▲
STRAIN $\Delta L/L \times 10^4$
9
8
7
6
5
4
3
2
1
60
50
40
30
20
10
0
TEMPERATURE °F

Figure 130

Regression Analysis

A summary of regression analysis performed on test data is given in the table XV.

The correlation of experimentally observed relationships is excellent especially when one considers the intrinsic variances encountered when dealing with a non homogeneous, non isotropic material of the nature of portland cement paste.

Perhaps it should also be mentioned that admixtures are proprietary products and as such are subject to variation themselves. Because of observed inconsistencies they have defied rigorous chemical analysis.

Relation	Correlation Coefficient (64)
σ vs. D_o (Plain) Eqn	94%
log σ vs. log D_o (all mixes)	
(.10 $< D_o <$ 2.2) Eqn	91%
σ vs. D_o (Plain + Water Red.) Eqn	87%
$\frac{\sigma_r}{\sigma}$ vs. logt (all mixes) Eqn	83%
— 15% ash	84%
— 30% ash	81%
— 45% ash	82%
Plain 0% ash Eqn	90%
ΔV_R vs. D_o (Plain paste) Eqn	97%

Table XV Summary of Regression Analysis

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APPENDIX A

Dilatometer Calibration

DILATOMETER CALIBRATION

Volume of steel cylinder at 70°F=705 ml

Capacity of dilatometer chamber at 70°F=937 ml

Volume of Mercury in dilatometer chamber at 70°F=232 ml

Volume change of steel specimen per °F=705 x 6.3 x 10^{-6}x3
=.0130 ml

Volume change of Mercury per °F=232 x 100.7 x 10^{-6}
=.02325 ml

Total volume change steel specimen and Hg. per deg F
=.01300 + .02325=.03625 ml

Burrette reading change per deg F=.01835 ml

Burrette stem correction neglected.

Volume change of dilatometer per °F
=.03625 - .01835 = .01790

Volume change of dilatometer per °F, per ml capacity

$$=\frac{.01790}{937} = 19.1 \times 10^{-6} \text{ ml/}^{\circ}\text{F/ml}$$

Thermal coeifficient of linear expansion for dilatometer chamber = 6.37 x 10-6 in/in/°F

APPENDIX B

Air Void System Determination

AIR VOID SYSTEM DETERMINATIONS

Only one air entraining agent was used in this programme. However, to obtain more detailed information about the air void system provided by the particular agent used, microscopic examination of selected samples was undertaken according to A.S.T.M. C457-67T (Modified Point Count Method). The results are given in the following table.

Air Content	Specific Surface	$\bar{L}$
10.67%	366	.0169
18.01%	610	.0081

The air contents determined microscopically check with those determined gravimetrically.

APPENDIX C

Strength Determinations

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
I 2	2240	3470	4125	5110	6680
	2095	3800	4450	5910	5275
	2300	3360	4725	5210	6600
				5460	5350
AVG	2210	3540	4430	5420	5975
I 3	3180	4840	4660	6610	7540
	2880	4925	5790	5550	7440
	2740	4625	6010	6730	7800
				5830	6360
AVG	2935	4795	5485	6180	7285
I 4	1245	2610	4230	4440	4360
	1290	2040	3705	5300	5940
	1375	2160	3805	3910	6075
		2750	4170	4600	4300
					5560
AVG	1305	2390	3980	4560	5250
I 5	1500 (2)	1420 (4)	2720	3740	3475
	1425 (2)	2360 (4)	2440	3650	3975
	1480 (2)	2270 (4)	2530	3405	3975
	1250 (2)	2320 (4)	2780	3750	3860
	1480 (2)	2095 (4)	2660	4260	5140
	1410 (2)	2400 (4)	3000	3910	
AVG	1425 (2)	2145 (4)	2690	3785	4085
AVG					

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
I 6	4575 (3)	4950 (5)	3925 *	4010 *	3360 *
	5110 (3)	5410 (5)	4640	7225	2890 *
	5275 (3)	3700 (5) *	4050	6040	7500
I 26	5340	3540 *	5890	6375	6450
	5420	5700	5500	6640	6075
	5085	3750 *	6930	5975	7500
AVG	5135	5320	5400	6450	6880
I 7	2900 (3)	3810 (5)	4575	5590	5690
	2150 (3)	4550 (5)	4260	5610	5000
	3425 (3)	3025 (5)	4850	5000	5490
I 27	2500	3975	5875	5560	6810
	3070	5590 *	6380	6300	6610
	2045	4575	5860	5460	9250 *
AVG	2850	3990	5300	5590	5920
II 8	2940 (3)	3550 (5)	4150	4010	5950
	2790 (3)	4200 (5)	4490	5125	5550
	3090 (3)	4175 (5)	4350	4875	5350
II 28	2925	3830	4540	4960	5660
	2490	3295	4395	4350	6110
	3210	2820 *	3775	5760	5710
AVG	3075	3810	4285	4850	5720
II 9	3360 (3)	4875 (5)	5260	4225 *	6840
	4250 (3)	4425 (5)	5240	5325	7475
	3790 (3)	4375 (5)	5575	4525 *	5740 *
II 29	3295	5110	6260	7440	8575
	4000	4760	5990	7590	7700
	4030	4900	6525	7390	7225
AVG	3790	4740	5810	6940	7565
AVG					

*OUTLIER

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
I 10	2940	4160	4510	6825	5790
	2600	4160	4710	5775	6660
	2760	4010	5510	5410	5390 *
I 30	2580	4730 (5)	5375	6525	6760
	2940	4850 (5)	4930	6725	7450
	3320	3140 (5)	5125	6090	6125
AVG	2855	4175	5025	6060	6565
I 11	2410	3490	3810	5260	6890
	1860	3525	4440	5900	6325
	2060	3860	4350	5175	6360
I 31	1045	3155 (5)	3950	5375	5890
	1625	3145 (5)	3345	5050	6290
	1295	2760 (5)	3995	4290	6975
AVG	1715	3320	3980	5175	6455
II 12	650 *	1310	1750	2275	2180
	1000	1340	1300	1990	2400
	660 *	1405	1560	1460	2410
II 32	1455	2205 (5)	2140	3310	2940
	1200	2100 (5)	2170	3000	3750
	1400	2100 (5)	2440	2975	3475
AVG	1265	1745	1895	2490	2860
II 13	1625	2325	3700	4420	4875
	1790	2630	2490	3900	5170
	1875	2710	3425	3870	4370
II 33	2150	3095 (5)	3355	3760	4775
	2105	3170 (5)	3460	4200	5360
	2130	3440 (5)	3895	4040	4690
AVG	1945	2895	3390	4030	4875
AVG					

* OUTLIER

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
I 14	1845	2805	4460	4700	3810 *
	2110	2890	3300	4510	4530
	2320	3325	3990	4720	5500
I 34	2110	2440	3730	4575	4325 *
	1960	2890	4010	4990	4425
	1760	2750	3710	5720 *	5760
AVG	2020	2850	3865	4700	5055
I 15	1410	2510	3720	4890	3905 *
	1430	2810	3475	3750	5375
	1450	2410	3100	4460	5710
I 35	755	2025	2345	4680	4050 *
	630	1860	2280	4440	3555 *
	850	2150	2840	4560	4560
AVG	1085	2295	2960	4465	5215
II 16	685	875	1225	1175	1650
	640	1080	1140	1790	1925
	505	1075	1090	1420	1690
II 36	520	900	1250	2340	1640
	780	1260	1810	2075	2175
	760	1325	1725	1825	1750
AVG	650	1085	1375	1770	1805
II 17	1260	1790	2500	3000	3430
	1395	1830	2760	3655	4505
	1405	1685	2025	2915	3800
II 37	1220	1790	2500	3225	3655
	1555	2290	2110	3000	3370
	1230	2010	2640	3210	4390
AVG	1345	1900	2420	3170	3860
AVG					

* OUTLIER

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
I 18	1420	2680	3240	4350	4190
	1520	2390	3375	3890	5325
	1575	2445	2950	3775	4875
I 38	2055 (3)	2290	2845	4275	4710
	2550 (3)	2315	3475	3955	5350
	2405 (3)	2590	4375 *	4205	4375
AVG	1920	2460	3180	4075	4805
I 19	755	1200	2290	3450	5125
	820	1380	2670	4075	4775
	630	1395	2950	3760	5240
I 39	2150 (3)	2375	3220	4040	6160
	1925 (3)	2375	2505	3880	6815 *
	2137 (3)	2360	3100	4225	6340
AVG	1400	1850	2790	3920	5530
II 20	440	890	1300	1725	2125
	560	845	1025	1900	1750 *
	580	860	1390	1790	2530
II 40	970 (3)	1310	1870	2195	2075
	590 (3)	1200	1575	2510	2945
	1005 (3)	1175	1790	2340	2575
AVG	690	1045	1490	2075	2450
II 21	830	1175	1200	2475	2050 *
	975	1225	1925	2010	2205
	860	1300	1800	1500 *	2495
II 41	1255 (3)	1550	2290	2545	3925
	1245 (3)	1610	2200	2955	3660
	1030 (3)	1800	2305	3410	3920
AVG	1030	1445	1955	2680	3240
AVG					

* OUTLIER

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
Rockflour 1-19 III	2675	3375	3350	3925	4950
	3100	3050	2638 *	4525	4875
	2925	3075	4075	4875	4438
	2700	3763	4438	3863	6050 *
	2688	3350	5025	3875	4125
	2932	3338	4613	3981	5000
AVG	2836	3308	3584	4182	4678
2-20 III	975	1600	1975	2063	3025
	975	1588	1788	2200	2656 *
	975	1538	1556 *	2575	2700 *
	1225	1694	2288	2500	3850
	1025	1875	2325	2794	3888
	1125	1750	2250	3025	3565
AVG	1050	1674	2150	2543	3565
3-21 III	460	788	875	1675	1688
	375	775	843	1363	1981
	405	675	1025	1575	1743
	538	894	1318	1450	1793
	412	1012	1231	1638	1950
	488	956	1225	1350	1978
AVG	445	850	1253	1508	1854
4-22 III	2956	3575	4988	4613	5025
	2550	3625	4638	4081	5081
	2931	3937	4775	4493	5425
	2510	3513	4225	4225	4813
	3506	3681	4093	3863	5237
	3775	4038	5888 *	3425 *	6287 *
AVG	3040	3728	4544	4255	5116
5-23 III	1138	1843	2706	2288	3625
	975	1862	2606	3012	3388
	950	1743	2488	3038	3788
	1313	1888	2275	3075	2794
	1494	1675	1575	2600	3225
	1275	1675	2706	2650	3250
AVG	1357	1781	2393	2777	3345

*OUTLIER

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
6–24 III	631	1094	1288	1325	2388
	550	998	1888	1781	2219
	588	1100	1880	1450	2281
	400	931	1219	1425	1875
	569	838	1243	1656	1900
	438	963	1257	1631	1900
AVG	546	953	1295	1561	2094
7–25 III	2481	3681	3394	3694	3650
	2187	3062	3388	3756	3100
	2450	3038	3525	3700	3637
	2700	2694	3350	3719	4175
	2488	2841	3250	3025	3925
	2925	3513	3143	3200	3875
AVG	2505	3138	3342	3516	3727
8–26 III	800	1306	1631	1913	2438
	862	1175	1581	2181	2212
	919	1162	1600	2275	2550
	725	1275	1200	1700	2363
	914	1113	1663	1888	1869
	725	1275	1488	2081	1938
AVG	826	1218	1527	1980	2228
9–27 III	713	975	1462	1513	1850
	700	1025	1275	1633	2050
	713	975	1438	1912	1825
	575	1050	1331	1638	2175
	587	925	1312	1344	2163
	575	1144	1356	1488	2263
AVG	644	1016	1362	1586	2054
AVG					

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
Fly Ash 10-28 IV	4425	5175	3900 *	4756 *	7256
	4256	5075	6513	3725 *	8550
	4362	5262	5838	6350	7000
	4000	5888	6469	6775	5789
	4338	5450	5356	6350	6500
	4100	4888	3094 *	6113	5713
AVG	4247	5190	6044	6397	6452
11-29 IV	3538	5925	6200	5982	5246
	3931	5350	5813	6025	5081
	3875	5388	5125	4513	8788
	4138	4138	3500 *	6356	4213
	3975	3725	4538	4450	4800
	2900	3950	6363	6100	4288
AVG	3724	4766	3800	3888	6012
12-30 IV	2038	2888	3800	4600	5375
	2313	2913	3375	3888	6012
	2106	3138	3825	3875	4825
	2400	3062	3550	4894	4075
	2250	3562	4044	3750	6038
	2238	3062	4038	4025	5606
AVG	2224	3104	3772	4171	5322
13-31 IV	2081	3438	4063	4781	5663
	2138	3488	4650	4175	6000
	1956	3050	4638	4300	4162
	2388	3388	4588	4525	5531
	2013	3413	3881	4075	5593
	2338	3588	4932	4288	5212
AVG	2152	3394	4459	4354	5360
14-32 IV	1663	2625	2850	3762	5188
	1700	2588	3425	3488	5481
	1644	2275	3000	3120	5325
	1856	2462	2950	4688	5681
	1825	2344	4138	5500 *	5488
	1968	2644	4288	4288	5015
AVG	1776	2473	3442	4069	5363

*OUTLIER

MIX	STRENGTH PSI				
	DAY	DAY	DAY	DAY	DAY
15-33 IV	1088	1981	2300	2394	2875
	1113	1787	2225	2756	3256
	1075	1912	2313	3169	3594
	1125	1419	2363	2756	3481
	1163	1931	2175	2718	3275
	1131	1866	2413	2780	3178
AVG	1116	1866	2353	2780	3178
16-34 IV	1469	2275	2600	3175	3350
	1613	2444	2475	2488	5469
	1556	2288	2568	3200	5063
	1319	1975	2350	3700	3394
	1319	2050	2025	3350	4350
	1319	1738	2688	2413	4013
AVG	1432	2111	2550	2871	4132
17-35 IV	1194	1756	2038	2450	3238
	1000	2000	2100	2750	3063
	938	1413	2025	2281	3413
	881	1338	1868	2656	3744
	868	1231	2015	2763	3050
	842	1388	1988	2338	3291
AVG	954	1521	2006	2540	3291
18-36 IV	875	1300	2000	2344	2231
	800	1281	1938	2350	2581
	763	1106	1788	1913	2350
	900	1300	1800	2244	2813
	988	1125	1713	2338	2819
	788	1325	1575	1713	2556
AVG	852	1240	1802	2150	2608
AVG					

APPENDIX D

$\frac{\Delta w}{w_o}$ vs Strength

$\frac{\Delta W}{W_o}$ VS STRENGTH

DAY	3 DAYS		5 DAYS		7 DAYS		14 DAYS		28 DAYS	
MIX	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.
3	.0869	4,600	.0943	5.200	.0971	5,600	.1014	6,200	.1043	7,200
2	.0820	3.200	.0913	3,900	.0950	4,200	.0988	5,400	.1063	6,000
4	.0733	2,600	.0833	3,400	.0878	3,800	.0951	4,600	.1000	5,200
5	.0660	1,900	.0760	2,600	.0816	3,000	.0880	3,700	.0920	4,200
6-26	.0871	4,700	.0957	5,400	.1000	5,800	.1086	6,400	.1120	6,800
7-27	.0951	3,200	.1057	4,200	.1100	4,800	.1157	5,600	.1200	5,900
8-28	.1014	3,400	.1086	4,000	.1114	4,300	.1200	5,100	.1257	5,700
9-29	.0920	4,100	.1000	5,200	.1043	5,800	.1120	6,800	.1143	7,600
10-30	.0800	3,400	.0888	4,400	.0913	5,000	.0950	6,000	.1025	6,500
11-31	.0775	2,500	.0925	3,400	.1000	3,900	.1055	5,100	.1150	6,300
12-32	.1250	1,600	.1350	1,900	.1408	2,200	.1500	2,600	.1570	2,800
13-33	.0900	2,400	.0975	3,000	.1025	3,400	.1125	4,100	.1175	4,900
14-34	.0811	2,500	.0911	3,300	.0956	3,800	.1022	4,700	.1089	5,100
15-35	.0778	1,700	.0889	2,500	.0944	3,100	.1022	4,400	.1067	5,200
16-36	.1160	900	.1256	1,200	.1311	1,400	.1433	1,800	.1533	1,900
17-37	.0827	1,700	.0926	2,200	.0978	2,500	.1078	3,200	.1144	3,800
18-38	.0650	2,100	.0760	2,700	.0820	3,100	.0910	4,000	.0960	4,700
19-39	.0640	1,600	.0740	2,300	.0790	2,800	.0850	3,900	.0920	5,500
20-40	.1110	800	.1180	1,300	.1230	1,600	.1310	2,100	.1360	2,400
21-41	.0786	1,200	.0866	1,700	.0920	2,000	.1000	2,700	.1066	3,300

Series I and II

$\frac{\Delta W}{W_o}$ VS STRENGTH

DAY	3 DAYS		5 DAYS		7 DAYS		14 DAYS		28 DAYS	
MIX	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.	$\frac{\Delta W}{W_o}$	STR.
1-19	0.0640	2836	0.0820	3308	0.0910	3584	0.0970	4182	0.1020	4678
2-20	0.0505	1050	0.0617	1674	0.0719	2150	0.0775	2543	0.0876	3565
3-21	0.0380	445	0.0491	850	0.0558	1253	0.0618	1508	0.0657	1854
4-22	0.0670	3040	0.0788	3728	0.0842	4544	0.0884	4255	0.0926	5116
5-23	0.0401	1357	0.0563	1782	0.0644	2393	0.0687	2777	0.0748	3345
6-24	0.0343	546	0.0441	953	0.0506	1295	0.0569	1561	0.0612	2094
7-25	0.0742	2505	0.0836	3138	0.0912	3342	0.0990	3516	0.1078	3727
8-26	0.0655	826	0.0787	1218	0.0868	1527	0.0960	1980	0.0987	2228
9-27	0.0500	644	0.0598	1016	0.0662	1362	0.0723	1586	0.0768	2054
10-28	0.0993	4247	0.1167	5190	0.1240	6044	0.1317	6397	0.1373	6452
11-29	0.1170	3724	0.1370	4766	0.1497	3800	0.1593	3888	0.1667	6012
12-30	0.1297	2224	0.1570	3104	0.1733	3772	0.1893	4171	0.2030	5322
13-31	0.0810	2152	0.0998	3394	0.1095	4459	0.1145	4354	0.1222	5360
14-32	0.0778	1776	0.0990	2473	0.1135	3442	0.1275	4069	0.1450	5363
15-33	0.0752	1116	0.0990	1866	0.1175	2353	0.1370	2780	0.1550	3178
16-34	0.0642	1432	0.0900	2111	0.0926	2550	0.1006	2871	0.1068	4132
17-35	0.0624	954	0.0800	1521	0.0926	2006	0.1042	2540	0.1176	3291
18-36	0.0582	852	0.0780	1240	0.0926	1802	0.1078	2150	0.1264	2608

Series III and IV

APPENDIX E

Δ w Determination

MIX NO: I 2		MIX NO:		MIX NO: I 7	
$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW
0		24.664	.04184	0	0
1.000	.00155	26.155	.04237	1.472	.00130
1.414	.00214	31.309	.04312	2.739	.00337
1.732	.00268			2.901	.00390
2.000	.00348			3.082	.00432
2.236	.00482			3.329	.00520
2.450	.00595			3.686	.00780
2.644	.00696			4.163	.01484
3.354	.01425			5.809	.02477
4.761	.02303			6.164	.02595
4.953	.02357			6.868	.02814
5.186	.02432			7.762	.03056
5.303	.02470			8.251	.03151
5.492	.02512			8.949	.03269
6.652	.02850			9.815	.03381
7.059	.02962			10.376	.03423
7.692	.03102			11.435	.03511
8.396	.03278			12.400	.03594
9.142	.03418			13.832	.03683
9.734	.03493			14.483	.03772
10.836	.03621			16.525	.03866
12.390	.03707			18.520	.03925
13.478	.03782			20.372	.03984
14.629	.03862			22.692	.04032
17.103	.04002			24.968	.04138
18.319	.04023			27.696	.04197
20.213	.04098				
21.983	.04120				

MIX NO: I 2 A		MIX NO: I 27		MIX NO: II 8	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.0	.00107	1.225	.00358	1.258	.00423
1.424	.00203	2.432	.00907	2.630	.00856
1.732	.00268	2.646	.00950	2.784	.01027
2.000	.00364	3.069	.01022	2.972	.01136
2.237	.00444	3.428	.01103	3.228	.01295
3.110	.01124	3.582	.01146	3.594	.01735
4.590	.02210	3.730	.01232	4.083	.02152
4.788	.02301	3.873	.01313	5.759	.02816
5.024	.02392	4.491	.01595	6.110	.02904
5.140	.02414	4.708	.01800	6.819	.03101
5.331	.02467	4.967	.01991	7.719	.03277
6.595	.02831	5.196	.02182	8.211	.03370
6.934	.02917	5.568	.02445	8.916	.03453
7.577	.03018	5.845	.02584	9.785	.03552
8.287	.03104	6.481	.02851	10.344	.03596
9.060	.03211	7.129	.03047	11.405	.03672
9.644	.03270	7.427	.03185	12.373	.03755
10.755	.03356	7.599	.03252	13.808	.03826
12.319	.03479	7.821	.03300	14.357	.03919
14.572	.03543	8.241	.03405	16.505	.03996
17.051	.03650	9.005	.03530	18.502	.04051
18.271	.03682	9.742	.03648	20.355	.04155
20.170	.03746	11.295	.03830	22.677	.04254
21.943	.03752	11.941	.03878	24.955	.04370
24.629	.03805	12.845	.03949	27.684	.04452
26.123	.03853	14.933	.04073		
31.281	.03896	18.248	.04072		
		21.399	.04288		
		25.966	.04413		

MIX NO: I 3B		MIX NO: II 28		MIX NO: II 9	
$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW
0	0	0	0	0	0
1.000	.00154	2.345	.00799	1.041	.00151
1.500	.00218	2.533	.01065	2.533	.00523
1.803	.00295	2.986	.01166	2.708	.00739
2.061	.00402	3.366	.01326	2.887	.00855
2.958	.01266	3.512	.01448	3.149	.01187
4.488	.02121	3.663	.01608	3.535	.01599
4.699	.02202	3.819	.01757	4.031	.01936
4.942	.02279	4.425	.02241	5.708	.02544
5.056	.02326	4.646	.02396	6.069	.02670
5.252	.02369	4.916	.02502	6.782	.02826
6.455	.02639	5.156	.02598	7.687	.03017
6.874	.02703	5.523	.02768	8.185	.03082
7.522	.02758	5.802	.02896	8.888	.03168
8.236	.02848	6.442	.03200	9.759	.03263
9.018	.02917	7.100	.03322	10.320	.03288
9.600	.02968	7.394	.03429	11.383	.03364
10.716	.03019	7.566	.03477	12.352	.03424
12.285	.03083	7.789	.03551	13.793	.03484
13.385	.03113	8.216	.03572	14.439	.03540
14.543	.03160	8.977	.03705	16.490	.03625
17.029	.03237	9.717	.03785	18.489	.03721
18.248	.03242	11.273	.03881	20.343	.03781
20.152	.03306	11.920	.03908	22.666	.03841
21.924	.03319	12.829	.03961	24.947	.03932
24.612	.03366	14.914	.04062	27.677	.03997
26.107	.03404	18.235	.04163		
31.269	.03430	21.399	.04260		
		25.958	.04419		

MIX NO: I 4A		MIX NO: II 29		MIX NO: I 10	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.324	.00135	2.273	.00513	1.190	.00149
1.958	.00227	2.432	.00646	3.028	.00762
2.750	.00706	2.915	.00908	3.149	.00871
2.930	.00817	3.291	.01138	3.304	.01051
4.143	.01947	3.440	.01261	3.464	.01240
4.253	.02057	3.606	.01389	3.606	.01399
4.369	.02137	3.753	.01528	3.775	.01588
4.490	.02199	4.368	.02020	4.031	.01782
4.726	.02309	4.592	.02185	4.453	.01962
5.307	.02487	4.865	.02292	4.848	.02136
5.701	.02598	5.107	.02399	6.007	.02504
6.595	.02831	5.477	.02602	6.788	.02758
7.422	.03052	5.759	.02720	7.681	.03042
8.134	.03237	6.403	.03008	8.031	.03097
8.855	.03378	7.065	.03174	8.539	.03246
10.108	.03599	7.365	.03323	9.110	.03341
10.797	.03703	7.533	.03323	9.832	.03440
11.420	.03752	7.757	.03409	10.500	.03525
12.757	.03906	8.185	.03430	11.507	.03635
14.083	.03986	8.944	.03521	13.360	.03744
15.532	.04127	9.691	.03590	15.764	.03878
16.860	.04164	11.251	.03724	17.903	.03953
18.903	.04287	11.902	.03745	20.504	.04033
20.785	.04330	12.809	.03799	22.998	.04132
23.603	.04428	14.897	.03890	25.934	.04197
25.156	.04471	18.221	.03964		
26.342	.04483	21.387	.04050		
30.480	.04569	25.949	.04232		

MIX NO: I 4B		MIX NO: I 30		MIX NO: I 11	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.292	.00126	1.658	.00161	2.915	.00363
1.938	.00299	2.828	.00474	3.069	.00466
2.750	.00713	3.149	.00697	3.228	.00488
2.930	.00839	3.524	.00999	3.391	.00573
4.133	.01929	3.841	.01316	3.536	.00704
4.243	.02037	4.330	.01764	3.719	.00829
4.359	.02114	4.655	.01946	3.969	.01158
4.481	.02156	5.454	.02352	4.397	.01743
4.708	.02288	5.686	.02425	4.796	.02015
5.299	.02468	6.076	.02550	5.965	.02458
5.694	.02623	6.212	.02586	6.752	.02725
6.589	.02857	6.532	.02727	7.654	.02975
7.416	.03085	6.727	.02784	8.005	.03060
8.124	.03288	6.993	.02914	8.510	.03253
8.850	.03426	7.461	.02971	9.083	.03361
10.104	.03672	7.757	.03049	9.806	.03486
10.794	.03780	8.292	.03127	10.476	.03599
11.420	.03833	9.087	.03237	11.486	.03718
12.757	.03971	10.735	.03408	13.345	.03866
14.080	.04085	11.416	.03471	15.748	.03991
15.532	.04205	11.864	.03549	17.889	.04082
16.860	.04253	14.511	.03679	20.492	.04173
18.901	.04372	16.641	.03762	22.989	.04280
20.783	.04414	21.113	.03882	25.925	.04377
23.601	.04510	25.912	.04038		
25.156	.04558				
26.341	.04558				
30.478	.04630				

MIX NO: I 5A		MIX NO: I 31		MIX NO: II 12	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.554	.00235	1.581	.00411	2.814	.01537
2.532	.00667	2.799	.00591	2.972	.02488
2.723	.00813	3.096	.00675	3.136	.02853
3.969	.01989	3.476	.00737	3.304	.03074
4.093	.02123	3.808	.00900	3.464	.03410
4.213	.02180	4.292	.01373	3.640	.03568
4.340	.02256	4.646	.01682	3.894	.03761
4.583	.02326	5.431	.01778	4.330	.04140
5.180	.02523	5.664	.01896	4.735	.04290
5.583	.02631	6.057	.01952	5.916	.04733
6.494	.02854	6.212	.02009	6.708	.04948
7.331	.03076	6.513	.02178	7.616	.05148
8.047	.03260	6.708	.02245	7.969	.05277
8.780	.03413	6.976	.02318	8.475	.05505
10.042	.03673	7.444	.02470	9.051	.05663
10.735	.03794	7.741	.02566	9.781	.05798
11.365	.03864	8.276	.02695	10.448	.05934
12.708	.04048	9.060	.02920	11.460	.06084
14.036	.04175	10.720	.03821	13.323	.06276
15.492	.04309	11.405	.03939	15.732	.06449
17.117	.04360	11.857	.03967	17.875	.06578
18.866	.04506	12.352	.04029	20.480	.06706
20.755	.04557	14.500	.04243	22.976	.06892
23.576	.04684	16.636	.04355	25.915	.07007
25.131	.04741	21.107	.04596		
26.506	.04747	25.910	.04721		
30.459	.04830				

MIX NO: I 5B		MIX NO: I 32		MIX NO: II 13	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1,444	.00151	1.443	.00954	2.784	.01191
2.467	.00648	2.739	.01848	2.944	.01504
2.661	.00822	3.028	.02092	3.082	.01680
3.926	.01984	3.416	.02659	3.253	.01811
4.052	.02096	3.742	.02742	3.416	.01943
4.173	.02157	4.243	.03004	3.594	.02175
4.301	.02213	4.583	.03440	3.851	.02325
4.546	.02330	5.385	.03702	4.292	.02651
5.148	.02487	5.620	.03940	4.699	.02651
5.553	.02599	6.021	.03952	5.888	.02908
6.474	.02833	6.171	.03970	6.683	.03065
7.310	.03062	6.481	.04119	7.594	.03328
8.031	.03264	6.671	.04250	7.948	.03366
8.761	.03448	6.940	.04417	8.461	.03529
10.025	.03683	7.411	.04453	9.032	.03629
10.720	.03789	7.708	.04495	9.764	.03748
11.350	.03845	8.236	.04548	10.428	.03836
12.695	.03996	9.032	.04835	11.445	.03899
14.024	.04085	10.693	.04852	13.310	.04099
15.481	.04197	11.383	.04894	15.722	.04256
16.810	.04253	12.329	.04966	17.865	.04381
18.859	.04359	14.480	.05073	20.472	.04507
20.748	.04404	16.616	.05174	22.969	.04664
23.569	.04510	17.889	.05204	25.908	.04845
25.125	.04543	21.091	.05317		
26.500	.04555	25.897	.05568		
30.454	.04622				

MIX NO: II 6		MIX NO: II 33		MIX NO: I 14	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.118	.00140	1.323	.00381	3.028	.01050
1.633	.00219	2.662	.01053	3.329	.01462
2.828	.00708	2.958	.01271	3.582	.01869
2.986	.00864	3.354	.01592	4.052	.02087
3.162	.01050	3.686	.01859	4.463	.02378
3.391	.01348	4.193	.02192	4.655	.02487
3.742	.01673	4.537	.02385	4.992	.02845
4.223	.02235	5.354	.02797	5.759	.02845
5.852	.02527	5.583	.02894	5.916	.02918
6.205	.02650	5.986	.03015	6.589	.03294
6.904	.02875	6.137	.03100	6.988	.03343
7.800	.03116	6.449	.03239	7.895	.03792
8.281	.03229	6.640	.03300	8.196	.03889
8.977	.03335	6.916	.03403	9.197	.04150
9.840	.03453	7.382	.03536	9.738	.04247
10.400	.03498	7.681	.03596	10.468	.04392
11.456	.03577	8.211	.03669	12.606	.04429
12.420	.03667	9.009	.03814	14.172	.04562
13.850	.03751	10.673	.03996	16.518	.04726
14.497	.03813	11.369	.04050	19.307	.04787
16.540	.03942	12.312	.04105	21.936	.05054
18.534	.04009	14.465	.04202	25.902	.05242
20.384	.04071	16.606	.04317		
22.703	.04127	21.081	.04498		
24.978	.04228	25.888	.04795		
27.705	.04296				

MIX NO: I 26		MIX NO: I 26		MIX NO: I 34	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	13.916	.03231	0	0
1.414	.00156	14.950	.03285	1.354	.00166
2.516	.00361	17.020	.03350	2.466	.00332
2.739	.00453	18.262	.03393	2.887	.00421
3.149	.00798	21.410	.03452	3.082	.00534
3.500	.01181	25.976	.03603	3.452	.00937
3.651	.01311			3.594	.01044
3.797	.01456			3.797	.01186
3.937	.01596			4.062	.01424
4.546	.02023			4.193	.01525
4.655	.02050			4.292	.01620
4.761	.02130			5.008	.02142
5.008	.02195			5.212	.02249
5.244	.02260			5.447	.02320
5.605	.02390			5.620	.02380
5.888	.02432			5.909	.02480
6.513	.02605			6.158	.02581
6.714	.02637			7.182	.02884
7.165	.02702			9.183	.03430
7.461	.02772			9.992	.03572
7.632	.02783			10.480	.03655
7.853	.02832			11.057	.03726
8.272	.02880			12.254	.03880
9.037	.02918			13.401	.03987
9.764	.02993			14.922	.04094
11.317	.03101			17.029	.04230
11.962	.03134			20.372	.04355
12.865	.03182			25.987	.04569

MIX NO: I 15		MIX NO: II 16		MIX NO: II 36	
$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW
0	0	0	0	0	0
2.958	.00360	2.872	.01230	2.273	.01334
3.266	.00412	3.202	.01609	2.723	.02031
3.536	.00629	3.464	.02032	2.915	.0225
4.021	.01156	3.947	.02484	3.317	.02708
4.416	.01585	4.359	.02858	3.464	.03063
4.619	.01814	4.555	.03298	3.674	.03418
4.958	.01871	4.907	.03519	3.948	.03814
5.723	.02094	5.679	.03819	4.072	.03961
5.888	.02157	5.853	.04057	4.183	.04062
6.551	.02477	6.513	.04363	4.924	.04370
6.952	.02855	6.910	.04590	5.123	.04631
7.869	.02935	7.831	.04810	5.362	.04745
8.170	.03061	8.139	.04981	5.530	.04860
9.170	.03290	8.456	.05165	5.831	.04966
9.717	.03479	9.687	.05275	6.076	.05074
10.440	.03582	10.416	.05348	7.118	.05208
11.424	.03656	11.398	.05403	9.133	.05637
12.590	.03662	12.573	.05477	9.946	.05777
14.157	.03913	14.142	.05611	10.432	.05932
16.505	.03936	16.492	.05783	11.015	.06012
19.294	.04051	19.279	.05973	12.213	.06099
21.926	.04171	21.917	.06168	13.366	.06173
25.896	.04325	25.886	.06419	14.888	.06294
				17.000	.06421
				20.347	.06883
				25.970	.07360

MIX NO: II 37		MIX NO: I 18A		MIX NO: I 38	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
2.179	.00579	1.323	.00142	1.581	.00242
2.646	.00824	3.055	.00791	3.055	.00598
2.843	.00956	3.214	.00940	3.202	.00702
3.241	.01302	3.379	.01096	3.354	.00823
3.391	.01678	3.524	.01292	3.685	.01064
3.606	.01893	3.884	.01657	3.926	.01254
3.884	.02222	4.203	.01867	4.072	.01398
4.021	.02467	4.628	.02070	4.213	.01519
4.123	.02580	4.787	.02110	4.340	.01611
4.873	.02783	6.000	.02529	4.673	.01864
5.074	.02962	6.788	.02780	5.958	.02542
5.315	.03499	6.892	.02814	6.097	.02594
5.492	.03536	7.539	.03037	8.261	.03256
5.788	.03571	8.036	.03179	8.510	.03307
6.035	.03619	8.471	.03341	9.170	.03451
7.083	.03715	9.206	.03530	9.691	.03566
9.106	.04479	9.704	.03639	10.312	.03687
9.992	.04605	10.412	.03801	11.587	.03906
10.412	.04670	11.347	.03929	12.793	.04067
10.992	.04724	12.516	.04078	14.373	.04193
12.193	.04844	13.367	.04193	16.553	.04360
13.348	.04969	14.306	.04335	19.975	.04360
14.872	.05076	17.708	.04579	25.976	.04711
16.985	.05214	20.170	.04694		
20.3[illegible]	.05351	22.964	.04795		
25.960	.05626	25.905	.04917		

MIX NO: I 19A		MIX NO: I 39		MIX NO: II 20A	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.118	.00071	1.414	.00181	0.913	.00999
2.986	.00336	2.972	.00501	2.915	.02292
3.149	.00432	3.122	.00603	3.069	.02538
3.304	.00452	3.279	.00688	3.228	.02625
3.452	.00529	3.617	.00893	3.379	.02997
3.819	.00768	3.862	.01086	3.764	.03473
4.143	.01162	4.010	.01206	4.093	.03822
4.574	.01684	4.163	.01333	4.528	.04131
4.735	.01801	4.282	.01435	4.682	.04354
5.965	.02349	4.619	.01695	5.923	.04718
6.751	.02627	5.916	.02419	6.714	.04988
6.855	.02646	6.055	.02473	6.819	.05131
7.506	.02859	8.231	.03112	7.472	.05305
8.005	.03014	8.483	.03185	7.974	.05456
8.441	.03156	8.142	.03317	8.441	.05511
9.179	.03395	9.665	.03438	9.174	.05606
9.678	.03435	10.286	.03552	9.652	.05717
10.392	.03621	11.565	.03770	10.368	.05781
11.325	.03782	12.777	.03920	11.306	.05900
12.497	.03885	14.355	.04041	12.477	.06002
13.348	.04001	16.538	.04210	13.329	.06098
14.289	.04130	19.965	.04306	14.274	.06232
17.694	.04324	25.966	.04524	17.680	.06415
20.156	.04460			20.143	.06566
22.953	.04576			22.944	.06709
25.896	.04673			25.886	.06883

MIX NO: II 40		MIX NO: II 21A		MIX NO: II 41	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
2.614	.01387	0.577	.00351	2.614	.00738
2.799	.01650	2.828	.01325	2.784	.00956
2.972	.01862	2.986	.01572	2.958	.01130
3.342	.02385	3.069	.01806	3.329	.01457
3.594	.02813	3.228	.02014	3.583	.01714
3.753	.03050	3.697	.02397	3.742	.01919
3.916	.03288	4.031	.02755	3.905	.02054
4.042	.03630	4.472	.03060	4.042	.02195
4.396	.03782	4.628	.03261	4.387	.02350
5.752	.04181	5.881	.03593	5.744	.02792
5.888	.05112	6.677	.03892	5.888	.02882
8.108	.05236	6.782	.04002	8.108	.03453
8.367	.05397	7.439	.04178	8.362	.03524
9.032	.05606	7.942	.04327	9.028	.03685
9.561	.05749	8.382	.04431	9.557	.03774
10.190	.05863	9.129	.04535	10.186	.03890
11.477	.06130	9.626	.04613	11.474	.04076
12,698	.06300	10.344	.04691	12.695	.04204
14.286	.06509	11.284	.04788	14.283	.04384
16.477	.06747	12.460	.04892	16.475	.04461
19.914	.06918	13.314	.05009	19.912	.04551
25.923	.07754	14.257	.05133	25.965	.05000
		17.658	.05334		
		20.131	.05444		
		22.933	.05555		
		25.876	.05769		

MIX NO: III 1		MIX NO: III 26		MIX NO: III 2	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.41	0.0004	1.41	0.0063	1.41	0.0023
2.00	0.0013	1.87	0.0062	2.00	0.0055
2.45	0.0020	4.59	0.0265	3.08	0.0101
3.46	0.0107	5.52	0.0316	4.36	0.0215
4.64	0.0216	6.78	0.0355	4.58	0.0239
4.80	0.0220	7.18	0.0367	4.80	0.0250
5.05	0.0230	7.31	0.0371	5.00	0.0268
5.24	0.0238	7.75	0.0388	5.43	0.0283
5.66	0.0254	8.40	0.0405	5.70	0.0305
5.92	0.0266	8.97	0.0424	6.60	0.0340
6.78	0.0238	11.00	0.0456	7.31	0.0365
7.48	0.0317	12.08	0.0464	8.57	0.0403
8.72	0.0347	12.92	0.0478	10.79	0.0474
10.91	0.0382	14.56	0.0488	12.16	0.0495
12.29	0.0394	17.13	0.0499	14.83	0.0533
14.93	0.0422	18.28	0.0511	17.58	0.0557
17.65	0.0431	20.33	0.0514	18.89	0.0569
19.96	0.0439	21.63	0.0520	20.05	0.0575
20.11	0.0440	24.70	0.0532	21.99	0.0581
22.04	0.0449	25.48	0.0541	23.00	0.0593
22.94	0.0457	25.95	0.0541	24.66	0.0593
24.61	0.0453			27.07	0.0605
27.03	0.0470				

MIX NO:III 20		MIX NO: III 3		MIX NO: III 21	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.87	0.0046	1.41	0.0069	1.73	0.0069
2.45	0.0104	1.73	0.0100	2.34	0.0106
2.92	0.0135	2.32	0.0130	2.83	0.0147
3.54	0.0188	4.24	0.0239	3.46	0.0193
4.80	0.0304	4.47	0.0262	4.74	0.0305
5.70	0.0354	4.69	0.0275	5.66	0.0343
6.12	0.0375	4.90	0.0289	6.08	0.0381
6.89	0.0403	5.34	0.0318	6.86	0.0407
7.48	0.0424	5.61	0.0337	7.45	0.0428
7.90	0.0437	6.52	0.0377	7.90	0.0447
9.27	0.0475	7.25	0.0400	9.25	0.0486
9.80	0.0491	8.51	0.0442	9.77	0.0500
10.51	0.0504	10.75	0.0506	10.49	0.0512
12.08	0.0534	12.14	0.0532	11.04	0.0537
14.35	0.0561	14.82	0.0586	12.06	0.0553
15.64	0.0569	17.55	0.0600	14.34	0.0584
16.43	0.0576	18.87	0.0618	15.62	0.0592
17.72	0.0586	20.02	0.0625	16.42	0.0604
20.25	0.0589	21.96	0.0636	17.71	0.0618
21.98	0.0604	22.98	0.0644	20.24	0.0622
26.04	0.0613	24.64	0.0648	21.94	0.0650
		27.06	0.0651	26.01	0.0668

MIX NO: III 4		MIX NO: III 22		MIX NO: III 5	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.87	0.0028	1.73	0	1.73	0.0015
2.55	0.0078	2.74	0.0062	2.45	0.0032
3.00	0.0114	3.67	0.0156	2.92	0.0056
3.67	0.0183	5.05	0.0253	3.60	0.0118
4.85	0.0275	6.08	0.0298	4.80	0.0220
5.66	0.0314	7.00	0.0329	5.61	0.0273
6.24	0.0336	7.55	0.0342	6.20	0.0302
7.04	0.0364	8.51	0.0364	7.00	0.0334
7.38	0.0371	10.44	0.0388	7.35	0.0344
7.87	0.0378	12.14	0.0401	7.84	0.0349
8.48	0.0393	13.15	0.0408	8.46	0.0371
9.30	0.0402	14.71	0.0418	9.27	0.0389
9.92	0.0412	17.71	0.0423	9.90	0.0414
10.49	0.0421	19.62	0.0441	10.46	0.0427
11.04	0.0430	22.07	0.0436	11.02	0.0441
13.43	0.0441	23.50	0.0450	13.47	0.0489
14.85	0.0447	25.92	0.0456	14.83	0.0501
15.68	0.0453			15.67	0.0503
17.03	0.0459			17.01	0.0520
19.66	0.0464			19.65	0.0530
21.39	0.0476			21.38	0.0550
23.67	0.0472			23.66	0.0541
25.01	0.0481			25.00	0.0553
25.35	0.0485			25.94	0.0561

MIX NO: III 23		MIX NO: III 6		MIX NO: III 24	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.58	0.0016	1.58	0.0041	1.73	0.0045
2.64	0.0047	2.12	0.0065	2.55	0.0065
3.60	0.0129	2.83	0.0034	2.92	0.0089
5.00	0.0258	3.87	0.0186	3.81	0.0166
6.04	0.0323	5.05	0.0290	5.00	0.0255
6.96	0.0355	5.52	0.0310	5.70	0.0293
7.52	0.0372	6.16	0.0333	5.96	0.0306
8.48	0.0400	6.93	0.0365	7.21	0.0357
10.44	0.0452	7.90	0.0386	7.52	0.0369
12.12	0.0474	8.63	0.0419	8.83	0.0408
13.13	0.0494	9.27	0.0439	11.02	0.0472
14.70	0.0516	9.90	0.0453	12.14	0.0485
17.70	0.0521	12.57	0.0517	13.02	0.0496
19.61	0.0549	14.02	0.0531	13.96	0.0510
22.06	0.0549	14.90	0.0544	14.76	0.0515
23.49	0.0560	16.31	0.0559	17.00	0.0555
25.92	0.0567	17.68	0.0568	17.75	0.0556
		20.82	0.0599	18.55	0.0556
		23.16	0.0592	20.26	0.0579
		24.52	0.0612	21.41	0.0587
		26.40	0.0626	22.49	0.0588
				25.32	0.0600

MIX NO: III 7		MIX NO: III 25		MIX NO: III 8	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.87	0.0036	1.58	0.0029	1.22	0.0096
2.92	0.0151	2.83	0.0037	2.45	0.0154
3.67	0.0270	3.60	0.0176	3.46	0.0285
4.80	0.0343	4.74	0.0292	4.90	0.0417
6.16	0.0382	6.12	0.0333	5.96	0.0473
8.72	0.0422	8.69	0.0381	6.89	0.0508
10.10	0.0443	10.07	0.0402	7.45	0.0531
12.06	0.0466	12.04	0.0437	8.43	0.0564
13.08	0.0468	13.06	0.0443	10.39	0.0618
13.89	0.0476	13.86	0.0450	12.08	0.0645
14.82	0.0483	14.80	0.0454	13.10	0.0662
15.56	0.0488	15.54	0.0458	14.66	0.0683
17.70	0.0509	17.69	0.0485	17.66	0.0693
20.40	0.0518	20.37	0.0489	19.58	0.0718
21.94	0.0533	21.93	0.0506	22.03	0.0721
24.03	0.0548	24.02	0.0521	23.47	0.0738
25.92	0.0553	25.92	0.0526	25.92	0.0748

MIX NO: III 26		MIX NO: III 9		MIX NO: III 27	
$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW	$\sqrt{TIME}$	ΔW
0	0	0	0	0	0
2.00	0.0126	1.41	0.0038	1.58	0.0129
3.00	0.0211	2.55	0.0077	2.74	0.0219
3.74	0.0278	3.54	0.0161	3.54	0.0291
4.85	0.0352	4.95	0.0297	4.69	0.0402
6.20	0.0455	6.00	0.0346	6.08	0.0477
8.75	0.0545	6.93	0.0378	8.66	0.0558
10.10	0.0584	7.48	0.0400	10.05	0.0601
12.08	0.0635	8.46	0.0428	12.02	0.0657
13.08	0.0643	10.42	0.0484	13.04	0.0667
13.91	0.0649	12.10	0.0513	13.86	0.0673
14.83	0.0662	13.11	0.0540	14.78	0.0687
15.57	0.0662	14.68	0.0566	15.52	0.0687
17.72	0.0696	17.68	0.0575	17.68	0.0730
20.41	0.0699	19.60	0.0617	20.37	0.0730
21.95	0.0717	22.04	0.0611	21.92	0.0753
24.04	0.0729	23.48	0.0632	24.01	0.0753
25.92	0.0739	25.92	0.0645	25.92	0.0766

MIX NO: IV 10		MIX NO: IV 28		MIX NO: IV 11	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.41	0.0026	2.00	0.0036	1.41	0.0043
2.83	0.0093	2.45	0.0053	2.64	0.0102
4.24	0.0217	2.74	0.0071	4.12	0.0244
4.53	0.0233	3.54	0.0135	4.36	0.0263
4.74	0.0240	4.80	0.0234	4.64	0.0274
4.95	0.0254	5.10	0.0251	4.85	0.0288
5.24	0.0265	5.79	0.0280	5.15	0.0299
5.52	0.0267	6.82	0.0313	5.34	0.0314
6.48	0.0309	7.38	0.0324	6.40	0.0354
8.12	0.0338	8.46	0.0340	8.06	0.0392
8.69	0.0344	9.70	0.0362	8.63	0.0411
9.51	0.0353	10.93	0.0362	9.49	0.0420
9.82	0.0355	12.14	0.0366	9.77	0.0424
10.22	0.0359	12.84	0.0373	10.20	0.0432
11.20	0.0368	15.00	0.0388	11.18	0.0449
12.81	0.0378	15.68	0.0383	12.77	0.0457
13.67	0.0381	16.93	0.0392	13.64	0.0459
14.56	0.0386	18.33	0.0396	14.52	0.0467
16.03	0.0391	20.51	0.0399	16.00	0.0476
18.40	0.0397	23.73	0.0409	18.37	0.0485
19.47	0.0403	24.49	0.0412	19.46	0.0493
21.40	0.0409	25.99	0.0412	21.39	0.0500
22.64	0.0409			22.63	0.0504
25.58	0.0416			25.58	0.0514
26.34	0.0416			26.32	0.0517

MIX NO: IV 29		MIX NO: IV 12		MIX NO: IV 30	
√TIME	ΔW	√TIME	ΔW	√TIME	ΔW
0	0	0	0	0	0
1.73	0.0031	1.41	0.0037	1.58	0.0028
2.65	0.0063	2.55	0.0079	2.55	0.0081
3.39	0.0134	4.06	0.0240	3.32	0.0149
4.69	0.0249	4.30	0.0260	4.64	0.0284
5.00	0.0271	4.58	0.0273	4.35	0.0304
5.70	0.0301	4.80	0.0283	5.66	0.0342
6.74	0.0342	5.10	0.0304	6.71	0.0382
7.34	0.0362	5.38	0.0316	7.31	0.0405
8.43	0.0383	6.36	0.0367	8.40	0.0436
9.67	0.0402	8.03	0.0425	9.64	0.0468
10.88	0.0417	8.60	0.0440	10.86	0.0494
12.12	0.0424	9.43	0.0464	12.10	0.0504
12.82	0.0432	10.15	0.0475	12.81	0.0513
14.97	0.0450	11.14	0.0499	14.95	0.0540
15.65	0.0456	12.77	0.0525	15.64	0.0540
16.90	0.0457	13.64	0.0533	16.88	0.0553
19.10	0.0465	14.51	0.0550	19.09	0.0567
20.48	0.0472	15.98	0.0556	20.47	0.0573
23.68	0.0480	18.36	0.0577	23.70	0.0591
24.52	0.0485	19.43	0.0584	24.52	0.0595
26.02	0.0488	21.36	0.0596	26.00	0.0602
		22.60	0.0603		
		25.55	0.0618		
		26.32	0.0619		

MIX NO: IV 13		MIX NO: IV 31		MIX NO: IV 14	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.00	0.0017	1.41	0.0023	1.41	0.0017
2.34	0.0048	2.45	0.0044	2.00	0.0021
3.94	0.0157	3.24	0.0091	2.65	0.0038
4.18	0.0170	4.58	0.0200	3.00	0.0068
4.47	0.0201	4.90	0.0229	4.64	0.0213
4.69	0.0221	5.61	0.0272	5.29	0.0263
5.00	0.0246	6.67	0.0312	6.74	0.0320
5.29	0.0258	7.28	0.0335	7.42	0.0342
6.28	0.0304	8.37	0.0368	8.40	0.0369
7.97	0.0361	9.62	0.0394	8.72	0.0379
8.54	0.0375	10.84	0.0412	8.83	0.0384
9.38	0.0394	12.08	0.0423	9.19	0.0401
10.10	0.0406	12.79	0.0429	10.17	0.0432
11.09	0.0418	14.93	0.0446	11.98	0.0449
12.73	0.0434	15.62	0.0446	12.90	0.0461
13.60	0.0441	16.87	0.0452	13.84	0.0478
14.47	0.0450	19.08	0.0459	15.38	0.0491
15.95	0.0457	20.46	0.0465	17.83	0.0508
18.33	0.0471	23.68	0.0476	18.93	0.0521
19.40	0.0475	24.50	0.0477	20.93	0.0531
21.34	0.0482	26.00	0.0482	22.19	0.0538
22.58	0.0486			25.19	0.0555
25.53	0.0493			25.96	0.0557
26.30	0.0497				

MIX NO: IV 32		MIX NO: IV 15		MIX NO: IV 33	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.87	0.0008	1.58	0.0011	1.73	0
2.45	0.0019	2.34	0.0024	2.34	0.0002
3.08	0.0054	3.00	0.0035	3.00	0.0025
3.54	0.0091	4.53	0.0189	3.46	0.0063
4.90	0.0216	5.20	0.0226	4.85	0.0136
5.29	0.0246	6.63	0.0294	5.24	0.0225
5.52	0.0260	7.35	0.0318	5.48	0.0236
6.93	0.0318	8.31	0.0353	6.89	0.0300
7.58	0.0338	8.11	0.0377	7.55	0.0322
8.43	0.0360	10.20	0.0413	8.40	0.0343
8.86	0.0368	11.96	0.0452	8.83	0.0353
9.85	0.0399	12.88	0.0471	9.82	0.0391
10.07	0.0403	13.80	0.0495	10.05	0.0397
10.93	0.0422	15.35	0.0518	10.93	0.0426
12.08	0.0442	17.80	0.0548	12.06	0.0451
13.23	0.0453	18.91	0.0566	13.21	0.0468
14.09	0.0462	20.89	0.0589	14.07	0.0482
15.08	0.0468	22.16	0.0595	15.07	0.0494
15.89	0.0476	25.16	0.0625	15.89	0.0512
17.33	0.0484	25.93	0.0630	17.32	0.0525
19.90	0.0502			19.89	0.0556
20.86	0.0507			20.84	0.0568
24.50	0.0522			24.49	0.0588
25.92	0.0538			25.92	0.0612

MIX NO: IV 16		MIX NO: IV 34		MIX NO: IV 17	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.41	0.0025	1.58	0.0029	1.00	0.0009
2.24	0.0045	2.24	0.0036	2.00	0.0022
2.91	0.0064	2.92	0.0061	2.74	0.0039
4.42	0.0195	3.39	0.0092	4.31	0.0161
5.15	0.0254	4.80	0.0206	5.00	0.0234
6.60	0.0316	5.20	0.0238	6.52	0.0301
7.31	0.0345	5.43	0.0254	7.24	0.0334
8.28	0.0374	6.86	0.0324	8.22	0.0358
9.08	0.0394	7.52	0.0337	9.03	0.0386
10.17	0.0419	8.37	0.0359	10.12	0.0419
11.92	0.0450	8.80	0.0366	11.87	0.0452
12.84	0.0462	9.80	0.0397	12.81	0.0466
13.77	0.0476	10.02	0.0398	13.73	0.0483
15.31	0.0491	10.88	0.0422	15.28	0.0507
17.78	0.0505	12.04	0.0438	17.75	0.0528
18.89	0.0514	13.19	0.0451	18.87	0.0542
20.88	0.0520	14.05	0.0455	20.86	0.0555
22.15	0.0527	15.05	0.0467	22.12	0.0561
25.15	0.0542	15.87	0.0475	25.13	0.0584
25.92	0.0542	17.31	0.0483	25.90	0.0589
		19.87	0.0498		
		20.83	0.0498		
			0.0507		
		25.92	0.0526		

MIX NO: IV 35		MIX NO: IV 18		MIX NO: IV 36	
$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW	$\sqrt{\text{TIME}}$	ΔW
0	0	0	0	0	0
1.41	0.0010	1.73	0.0041	1.41	0.0005
2.12	0.0013	2.12	0.0031	2.00	0.0005
2.83	0.0043	4.64	0.0220	2.92	0.0030
3.32	0.0073	5.61	0.0242	3.39	0.0056
4.74	0.0198	6.82	0.0276	4.69	0.0183
5.15	0.0236	7.78	0.0310	5.00	0.0214
5.39	0.0249	8.43	0.0334	5.24	0.0226
6.82	0.0322	9.03	0.0349	5.87	0.0260
7.48	0.0335	10.98	0.0407	7.78	0.0305
8.34	0.0359	11.98	0.0424	8.43	0.0350
8.78	0.0367	12.96	0.0444	8.80	0.0360
9.77	0.0398	14.59	0.0469	9.59	0.0387
10.00	0.0400	17.16	0.0514	10.05	0.0398
10.86	0.0425	18.30	0.0536	11.40	0.0438
12.02	0.0452	20.35	0.0558	12.47	0.0463
13.17	0.0470	21.65	0.0573	13.36	0.0480
14.04	0.0480	24.72	0.0611	14.66	0.0505
15.03	0.0491	25.50	0.0620	17.28	0.0547
15.86	0.0500	25.96	0.0620	18.37	0.0564
17.29	0.0508			22.42	0.0603
19.86	0.0534			23.97	0.0641
20.82	0.0543			26.02	0.0641
24.47	0.0559				
25.92	0.0579				

APPENDIX F

Volume Change Data (Dilatometry)

W/C .50 AGE 2 days
AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$, %
1.14	38.0	35.5	.701	.825	1.016	.146
1.18	34.0	39.5	.780	.918	1.042	.150
1.30	27.5	46.0	.909	1.070	1.139	.164
1.40	21.0	52.5	1.037	1.221	1.216	.175
0.30	18.5	55.0	1.086	1.279	.107	.154
-1.30	11.0	62.5	1.234	1.453	-1.552	-.223
-2.50	1.5	72.0	1.422	1.674	-2.752	-.396
-2.80	2.5	71.0	1.402	1.651	-3.049	-.439
-2.70	9.5	64.0	1.264	1.488	-2.924	-.421
-2.75	16.0	57.5	1.136	1.337	-2.951	-.425
-2.65	22.0	51.5	1.017	1.197	-2.830	-.407
-1.95	27.5	46.0	.909	1.070	-2.111	-.304
-. 63	38.5	35.0	.691	.814	- .753	-.108
-. 77	45.5	28.0	.553	.651	- .858	-.123
-1.00	57.5	16.0	.316	.372	-1.056	-.152

W/C .50 AGE 4 days

AIR ____ ADMIXTURE ____

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.18	33.5	37.5	.741	.872	1.049	.151
1.27	29.0	42.0	.830	.977	1.123	.162
1.32	25.5	45.5	.899	1.058	1.161	.167
1.39	21.5	49.5	.978	1.151	1.217	.175
0.37	18.5	52.0	1.027	1.209	.188	.027
-0.86	9.5	61.0	1.205	1.418	-1.073	-.154
-1.20	6.0	64.5	1.274	1.500	-1.426	-.205
-1.68	0.0	70.5	1.392	1.639	-1.927	-.277
-1.98	5	65.5	1.294	1.523	-2.209	-.318
-1.88	9.5	61.0	1.205	1.418	-2.093	-.301
-1.78	18.0	52.5	1.057	1.221	-1.964	-.282
-1.36	25.5	45.0	.889	1.046	-1.517	-.218
-1.00	32.5	38.0	.751	.884	- .223	-.032
-. 230	37.0	33.0	.662	.779	- .308	-.044
-. 780	71.0	0.0	0	0	- .780	-.112

W/C .50 AGE 9 days
AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.88	34.5	26.0	.514	.605	.789	.114
1.04	28.0	32.5	.642	.756	.926	.133
0.87	18.5	42.0	.830	.976	.724	.104
0.83	15.0	45.5	.899	1.058	.671	.096
0.42	7.0	53.5	1.057	1.244	.233	.034
-0.03	2.0	58.0	1.146	1.349	-.233	-.034
- .30	1.5	58.5	1.155	1.360	-.505	-.073
- .23	22.5	37.5	.741	.872	-.361	-.052
- .32	31.0	29.0	.573	.674	-.421	-.061
.07	46.0	14.0	.277	.326	.021	.003
.02	54.0	6.0	.119	.140	-.001	-.0001

W/C .50 AGE 14 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.17	32	39.5	.780	.918	1.032	.148
1.50	29	42.5	.839	.988	1.351	.194
1.52	21	50.5	.997	1.174	1.343	.193
1.52	14	57.5	1.136	1.337	1.319	.190
1.52	11	60.5	1.195	1.407	1.308	.188
1.02	0	71.5	1.412	1.662	.770	.111
.97	8	63.5	1.254	1.476	.748	.108
.87	15	58.5	1.155	1.366	.665	.096
.88	25	48.5	.958	1.128	.710	.102
1.13	32	41.5	.820	.965	.985	.142
1.07	40	33.5	.662	.779	.953	.137
0.41	73.5	0.0	0	0	.410	.059

W/C .50 AGE 14 days
AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.20	32	39.5	.780	.918	1.062	.153
0.90	29	42.5	.839	.988	.751	.108
0.95	21	50.5	.997	1.174	.773	.111
0.85	14	57.5	1.136	1.337	.649	.093
0.70	11	60.5	1.195	1.407	.488	.070
-0.60	0	71.5	1.412	1.662	-.850	-.122
-0.60	8	63.5	1.254	1.476	-.822	-.118
-0.70	15	58.5	1.153	1.360	-.905	-.130
-0.55	25	48.5	.958	1.120	-.720	-.104
0.20	32	41.5	.820	.965	.055	.008
0.08	40	33.5	.662	.772	-.037	-.005
-0.50	73.5	0	0	-.50	-.072	0

W/C .50 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.45	60.5	13.5	.267	.314	.403	.058
1.10	41.5	32.5	.642	.756	.986	.142
1.30	23.0	51.0	1.007	1.186	1.121	.162
0.4	21.5	52.5	1.037	1.221	.266	.038
-1.85	13.5	60.5	1.195	1.407	-2.062	-.298
-3.30	-2.5	76.5	1.511	1.779	-3.568	-.513
-3.30	6.5	67.5	1.333	1.569	-3.536	-.509
-3.30	18.0	56.0	1.105	1.302	-3.497	-.503
-2.50	21.5	52.0	1.027	1.209	-2.682	-.386
-1.25	31.5	42.5	.839	.988	-1.359	-.196
-.65	37.5	36.5	.721	.849	-.778	-.112
-.70	41.5	32.5	.642	.756	-.814	-.117
-1.25	61.5	12.5	.247	.291	-1.294	-.186

W/C 0.50 AGE 4 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.40	59.5	12.5	.247	.291	.356	.051
.85	44.5	27.5	.543	.639	.754	.108
1.25	32.5	39.5	.780	.918	1.112	.160
1.50	22.0	50.0	.988	1.163	1.325	.191
0.75	19.0	53.0	1.047	1.232	.565	.083
-0.10	15.0	57.0	1.126	1.325	-.299	-.043
-1.30	4.5	67.5	1.333	1.569	-1.536	-.221
-1.75	-0.5	72.5	1.432	1.686	-2.004	-.288
-1.90	7.0	65.0	1.284	1.511	-2.127	-.306
-1.75	14.5	57.5	1.136	1.337	-1.951	-.281
-1.40	24.0	48.0	.948	1.116	-1.569	-.226
-0.60	29.5	42.5	.839	.988	- .749	-.108
0.0	33.0	39.0	.770	.907	- .137	-.019
-0.30	47.0	25.0	.494	.581	- .117	-.017
-0.55	66.0	6.00	.119	.140	- .571	-.082

W/C 0.50 AGE 9 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.90	47	25	.494	.581	.813	.117
1.05	39	33	.652	.767	.935	.135
0.60	32	40	.790	.930	.460	.066
0.10	20	52	1.027	1.209	-.082	-.012
-0.30	13	59	1.165	1.372	-.507	-.073
-0.32	19.5	52.5	1.037	1.221	-.504	-.073
-0.31	35.5	36.5	.721	.849	-.438	-.053
0.40	44.0	28.0	.553	.651	.302	+.043
-0.10	63.5	8.5	.168	.198	-.130	-.019

W/C 0.50 AGE 21 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.45	57	15	.296	.349	.397	.057
.75	46	26	.514	.605	.659	.095
1.05	34.5	37.5	.741	.872	.919	.132
1.20	22.5	49.5	.978	1.151	1.027	.148
1.50	4.5	67.5	1.333	1.569	1.264	.185
1.51	7.5	64.5	1.274	1.500	1.284	.185
1.45	15.0	57.0	1.126	1.325	1.251	.180
1.30	23.0	49.0	.968	1.139	1.129	.162
1.25	34.0	38.0	.751	.884	1.117	.161
1.05	45.0	27.0	.533	.628	.955	.137
0.85	56.0	16.0	.316	.372	.794	.114
0.70	64.5	7.50	.148	.174	.674	.097
0.55	71.0	1.00	.020	.023	.547	.079

W/C 0.50 AGE 21 days

AIR ____ ADMIXTURE ____

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	57.5	14.5	.286	.337	.349	.050
0.80	41.5	30.5	.602	.709	.693	.100
1.20	25.5	46.5	.918	1.081	1.037	.149
1.45	13.5	58.5	1.155	1.360	1.245	.179
1.60	1.0	71.0	1.402	1.651	1.351	.194
1.60	16.0	56.0	1.106	1.302	1.404	.202
1.40	31.0	41.0	.810	.953	1.257	.181
1.10	42.5	26.5	.523	.616	1.007	.145
0.70	61.0	11.0	.217	.256	.661	.095

W/C 0.50 AGE 28 days
AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.50	58	14	.277	.326	.401	.058
0.80	41	29	.573	.674	.706	.102
1.05	32.5	39.5	.780	.918	.912	.131
1.15	30.5	41.5	.820	.965	1.005	.145
1.50	16.0	56.0	1.106	1.302	1.304	.188
1.85	2.50	69.5	1.373	1.616	1.607	.231
1.55	14.00	58.0	1.146	1.349	1.347	.194
1.20	27.00	45.0	.889	1.046	1.043	.150
0.90	39.00	33.0	.652	.767	.785	.113
0.65	51.50	20.5	.405	.477	.578	.083

W/C 0.50 AGE 28 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	61.0	9	.178	.209	.269	.039
0.75	45.0	27	.533	.628	.655	.094
0.95	38.0	34	.672	.791	.831	.120
1.25	23.5	48.5	.958	1.128	1.080	.155
1.70	8.0	64.0	1.264	1.488	1.476	.212
1.80	1.0	71.0	1.402	1.651	1.551	.223
1.45	15.5	56.5	1.116	1.314	1.252	.180
1.05	33.0	39.0	.770	.907	.913	.131
0.65	50.0	22.0	.435	.512	.573	.082
0.40	60.50	11.5	.227	.267	.360	.052

W/C 0.50 AGE 1 day

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$, %
1.00	42	30	.593	.698	.895	.129
1.15	37	35	.691	.814	1.027	.148
1.40	20	52	1.027	1.209	1.218	.170
0.40	16	56	1.106	1.302	.204	.029
-1.15	10.5	61.5	1.215	1.430	-1.365	-.196
-3.10	-1.0	73.0	1.442	1.697	-3.355	-.483
-3.10	9.5	62.5	1.234	1.453	-3.319	-.478
-3.10	18.0	54.0	1.067	1.256	-3.289	-.473
-2.40	24.0	48.0	1.948	1.116	-2.568	-.369
-0.70	34.0	38.0	.751	.884	- .833	-.120
-1.10	55.5	16.5	.326	.384	-1.158	-.167
-1.45	69.0	3.0	.059	.070	-1.461	-.210

W/C 0.50 AGE 4 days

AIR ______ ADMIXTURE ____________

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.70	56	16.0	.316	.372	.644	.093
1.20	43	29.0	.573	.674	1.099	.158
1.55	28	44.0	.859	1.023	1.386	.199
1.15	27.5	44.5	.879	1.035	.994	.143
0.10	20.0	52.0	1.027	1.209	-.082	-.012
-1.20	8.5	63.5	1.254	1.476	-1.422	-.205
-2.00	3.5	68.5	1.353	1.593	-2.240	-.322
-2.00	16.0	56.0	1.106	1.302	-2.195	-.316
-1.45	26.0	46.0	.909	1.070	-1.611	-.232
-0.25	33.0	39.0	.770	.907	- .387	-.056
0.10	37.0	35.0	.691	.814	- .023	-.003
-0.30	49.5	22.5	.444	.523	- .379	-.055
-0.60	64.5	7.5	.148	.174	- .626	-.090

W/C 0.50 AGE 8 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	58.5	13.5	.267	.314	.353	.051
0.80	44.0	28.0	.553	.651	.702	.101
1.15	33.0	39.0	.770	.907	1.013	.146
1.30	24.5	47.5	.938	1.104	1.134	.163
1.60	16.0	56.0	1.106	1.307	1.404	.202
2.00	-3.0	75.0	1.481	1.743	1.7[illegible]8	.250
1.50	21.0	51.0	1.007	1.186	1.321	.190
1.10	37.5	34.5	.681	.802	.979	.141
0.70	50.5	21.5	.425	.500	.625	.090
0.35	62.5	9.5	.188	.221	.317	.046

W/C 0.50 AGE 9 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.35	63.5	8.5	.168	.198	.320	.046
0.70	52.5	19.5	.385	.453	.632	.091
1.10	40.0	32.0	.632	.744	.988	.142
0.80	36.0	36.0	.711	.837	.674	.097
0.40	32.0	40.0	.790	.930	.260	.037
-0.15	22.5	49.5	.978	1.151	-.323	-.046
-0.50	10.0	62.0	1.225	1.442	-.717	-.103
-0.50	25.5	46.5	.918	1.081	-.663	-.095
-0.40	36.5	35.5	.701	.825	-.524	-.075
0.20	41.0	31.0	.612	.721	-.433	-.052
0.45	44.5	27.5	.543	.639	.354	.051
0.05	56.5	15.5	.306	.360	-.004	-.001
-.030	70.5	1.5	.030	.035	-.305	-.044

W/C 0.50 AGE 14 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.15	32.5	39.5	.780	.918	1.012	.146
1.50	29.5	42.5	.839	.988	1.351	.194
1.55	21.5	50.5	.997	1.174	1.373	.198
1.55	14.5	57.5	1.136	1.337	1.349	.194
1.55	11.5	60.5	1.195	1.407	1.338	.193
1.00	0.5	71.5	1.412	1.662	.750	.108
0.95	8.5	63.5	1.254	1.476	.728	.105
0.90	14.0	58.0	1.146	1.349	.697	.100
0.90	23.5	48.5	.958	1.128	.730	.105
1.10	30.5	41.5	.820	.965	.955	.137
1.05	38.5	33.5	.662	.779	.933	.135
0.45	72.0	0	0	0	.450	.065

W/C 0.50 AGE 21 days

AIR _____ ADMIXTURE _____

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.65	57.5	14.5	.286	.337	.599	.086
1.15	41.5	30.5	.602	.709	1.043	.150
1.40	28.0	44.0	.859	1.023	1.236	.178
1.50	18.0	54.0	1.067	1.256	1.007	.145
1.65	-1.5	73.5	1.452	1.710	1.392	.200
1.55	16.5	55.5	1.096	1.290	1.356	.195
1.25	39.5	32.5	.642	.756	1.136	.163
0.95	59.5	12.5	.247	.291	.906	.130
0.75	70.5	1.5	.030	.035	.745	.107

W/C 0.50 AGE 28 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.35	60	12.0	.237	.279	.308	.044
0.80	41.50	30.5	.602	.709	.693	.100
1.15	26.00	46.0	.909	1.070	.989	.142
1.50	12.00	60.0	1.185	1.395	1.290	.186
1.75	1.50	70.5	1.392	1.639	1.503	.216
1.60	5.50	66.5	1.313	1.546	1.367	.197
1.25	19.50	52.5	1.037	1.221	1.066	.153
0.95	34.5	37.5	.741	.872	.819	.118
0.50	52.5	19.5	.385	.453	.432	.062
0.20	66.0	6.0	.119	.140	.179	.026

W/C .45 AGE 1 day
AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.12	39.5	42	0.830	0.975	0.975	0.140
1.16	38.0	43.5	0.860	1.020	1.000	0.145
1.23	33.5	48.0	0.950	1.115	1.065	0.154
1.30	29.5	52.0	1.030	1.210	1.120	0.162
1.36	28.5	53.0	1.050	1.230	1.180	0.171
1.04	27.0	54.5	1.080	1.270	0.850	0.123
0.65	22.5	59.0	1.170	1.370	0.450	0.065
0.55	22.0	59.5	1.185	1.390	0.345	0.050
0.45	21.0	60.5	1.200	1.410	0.240	0.035
0.14	20.0	61.5	1.220	1.430	-0.070	-.010
-.15	19.0	62.5	1.245	1.465	- .375	-.055
-.33	17.5	64.0	1.275	1.500	- .560	-.081
-.85	16.0	65.5	1.295	1.520	-1.070	-.155
-.93	15.5	66.0	1.315	1.550	-1.160	-.168
-2.10	8.5	73.0	1.455	1.710	-2.350	-.340
-2.45	4.5	77.0	1.535	1.800	-2.720	-.392
-3.05	0	81.5	1.630	1.860	-3.290	-.473

W/C .45 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-3.12	2.5	79	1.560	1.840	-3.40	-.490
-3.09	15.0	66.5	1.315	1.555	-3.33	-.480
-3.05	20.5	61.0	1.205	1.420	-3.26	-.470
-1.63	30.0	51.5	1.020	1.200	-1.81	-.260
- .53	35.5	46.0	.910	1.075	- .69	-.100
- .85	55.5	26.0	.513	.605	- .95	-.130
- .88	56.0	25.5	.506	.595	- .97	-.140
- .96	60.0	21.5	.425	.502	-1.04	-.150
-1.20	75.0	6.5	.129	.151	-1.22	-.175

W/C .45 AGE 3 days
AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.36	33.5	43.5	.860	1.011	1.211	.174
1.46	24.5	52.5	1.035	1.220	1.275	.184
1.56	18.5	58.5	1.145	1.360	1.345	.194
1.60	16.0	61.0	1.205	1.418	1.387	.200
1.10	11.0	66.0	1.304	1.535	.869	.126
1.05	8.0	69.0	1.353	1.604	.799	.115
.99	4.0	73.0	1.442	1.697	.735	.106
.05	-4.0	81.0	1.600	1.883	-.233	-.034
-.05	-4.5	81.5	1.610	1.895	-.335	-.049
-.35	-5.5	87	1.718	2.023	-.655	-.095
-2 .25	-10.0	91.5	1.807	2.127	-2.570	-.370
-2. 25	2.0	79.5	1.570	1.848	-2.528	-.363
-2. 03	10.0	71.5	1.415	1.666	-2.290	-.33
- . 76	21.0	60.5	1.200	1.410	- .972	-.14
- . 29	25	56.5	1.120	1.315	- .485	-.07
- . 35	42	39.5	.780	.918	- .488	-.069
- . 25	46	35.5	.700	.825	- .375	-.054

W/C .45 AGE 3 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-.63	64	17.5	.35	.407	-.687	-.100

W/C .45 **AGE** 1 day

AIR ______ **ADMIXTURE** ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
.75	46	26.0	.514	.605	.659	.095
1.10	37.5	34.5	.681	.802	.979	.141
1.15	27.5	44.5	.879	1.035	.994	.143
1.30	20.5	51.5	1.017	1.197	1.120	.161
0.85	16.0	56.0	1.105	1.302	.653	.094
0.100	9.5	62.5	1.234	1.453	-.119	-.017
-1.00	4.0	68.0	1.343	1.581	-1.238	-.178
-2.70	-7.0	79.0	1.560	1.837	-2.977	-.428
-3.20	-10.5	82.5	1.629	1.918	-3.489	-.502
-3.25	- .50	72.5	1.432	1.686	-3.504	-.504
-3.25	8.5	63.5	1.254	1.476	-3.472	-.500
-3.20	15.5	56.5	1.116	1.314	-3.398	-.490
-2.25	20.0	52.0	1.027	1.209	-2.432	-.350
-.55	28.0	44.0	.869	1.023	-.704	-.101
-.50	28.5	43.5	.859	1.011	-.652	-.094
-.75	40.5	31.5	.622	.732	-.86	-.124
-.90	52.0	20.0	.395	.465	-.97	-.140

W/C .45 AGE 1 day

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-1.15	68.0	4.0	.079	.093	-1.071	-.154
-1.20	69.0	3.0	.059	.070	-1.211	-.174

W/C .45 AGE 3 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.25	65.0	6	.119	.140	.229	.033
.50	59.0	12	.237	.279	.458	.066
.51	58.0	13	.257	.302	.820	.118
1.15	42.0	29	.573	.674	1.049	.151
1.35	32.0	39	.770	.907	1.213	.175
1.60	19.0	52	1.027	1.209	1.418	.204
.85	11.0	60	1.185	1.395	.640	.092
.40	4.0	67	1.323	1.558	.165	.024
-.15	-1.0	72	1.422	1.674	-.402	-.058
-1.55	-6.0	77	1.521	1.790	-1.819	-.262
-2.35	-6.5	77.5	1.531	1.802	-2.621	-.377
-2.40	3.0	68.0	1.343	1.581	-2.638	-.380
-2.30	13.0	58.0	1.146	1.349	-2.503	-.360
-1.70	20.0	51.0	1.007	1.186	-1.879	-.270
-0.90	26.0	45.0	.889	1.045	-1.056	-.152
-0.20	31.5	39.5	.780	.918	- .338	-.049
- .35	44.5	26.5	.523	.616	- .443	-.064

W/C .45 AGE 3 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-.60	58.5	12.5	.247	.291	-.644	-.093
-.75	66.5	4.5	.039	.105	-.766	-.110
-.80	69.5	1.5	.030	.035	-.805	-.116

W/C .45 AGE 5 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	67	6	.119	.140	.279	.040
0.90	50.5	22.5	.444	.523	.821	.118
1.35	33.5	39.5	.780	.918	1.212	.174
1.65	30.5	42.5	.839	.988	1.501	.216
1.00	16.5	56.5	1.116	1.314	.802	.115
-.25	5.0	68.0	1.343	1.581	-.488	-.070
-1.25	.5	72.5	1.432	1.686	-1.504	-.216
-1.45	10.0	63.0	1.244	1.465	-1.671	-.240
-1.20	17.5	55.5	1.096	1.290	-1.394	-.201
- .30	26.5	46.5	.918	1.081	-.463	-.056
.25	33.0	40.0	.790	.930	.110	.016
-.10	40.5	32.5	.642	.756	-.214	-.031
-.35	58.5	14.5	.286	.337	-.401	-.058
-.55	66.5	6.5	.128	.151	-.573	-.092

W/C .45 AGE 9 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.94	59.0	16.0	.316	.373	.883	.128
0.82	60.5	14.5	.286	.338	.768	.111
0.79	64.5	10.5	.207	.245	.752	.109
0.64	74.0	0.5	.010	.017	.632	.092
1.32	40.5	34.0	.670	.792	1.198	.174
1.47	17.5	57.0	1.125	1.325	1.270	.184
1.60	15.0	59.5	1.175	1.385	1.390	.202
1.54	22.5	52.0	1.025	1.210	1.355	.196
0.49	70.0	4.5	.089	.105	.074	.107

W/C .45 AGE 5 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.43	34.5	43	.849	1.000	1.279	.184
1.46	32.0	45.5	.898	1.058	1.300	.187
1.61	23.5	54.0	1.057	1.256	1.411	.203
1.24	18.5	59.0	1.145	1.372	1.013	.146
0.95	11.0	63.5	1.254	1.476	.728	.105
0.64	7.5	67.0	1.323	1.558	.363	.052
0.53	7.0	72.0	1.422	1.674	.278	.040
-1.17	-6.8	85.8	1.694	1.995	-1.471	-.212
-1.15	0	79.0	1.550	1.837	-1.437	-.207
-0.85	24.5	54.5	1.066	1.267	-1.051	-.151
-0.72	25.5	53.5	1.047	1.144	- .817	-.118
0.15	40.5	38.5	.760	.895	.015	.002
-.05	50.5	28.5	.563	.663	-.150	-.022
-.35	70.5	8.5	.168	.198	-.380	-.055
.16	35.5	43	.849	1.000	.009	.001
.26	28.5	50	.978	1.163	.075	.011
.31	25.0	53.5	1.047	1.224	.133	.019

W/C .45 AGE 5 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
37	22.5	56	1.096	1.302	.164	.024
-.63	6.0	72.5	1.432	1.686	-.884	-.127

W/C .45 AGE 3 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
.75	56	16	.316	.372	.694	.100
1.25	37	35	.691	.814	1.127	.162
1.55	20.5	51.5	1.017	1.197	1.370	.197
1.10	9.5	62.5	1.234	1.453	.881	.127
0.00	0.0	72.0	1.422	1.674	.629	.091
-2.50	-3.0	75.0	1.481	1.744	-2.763	-.398
-2.55	8.0	64.0	1.264	1.488	-2.774	-.399
-2.50	17.0	55.0	1.086	1.279	-2.693	-.387
-1.60	26.0	46.0	.909	1.070	-1.761	-.253
-0.70	32.5	39.5	.780	.918	-.838	-.121
-0.15	37.5	34.5	.681	.802	-.271	-.039
-0.40	50.5	21.5	.425	.500	-.475	-.058
-0.75	61.5	10.5	.207	.244	-.787	-.113

W/C .45 AGE 5 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.60	58	14	.277	.326	.551	.079
1.10	40	32	.632	.744	.988	.142
1.50	22	50	.988	1.163	1.325	.191
1.05	13.5	58.5	1.155	1.360	.845	.122
-.15	2.0	70.0	1.383	1.628	-.395	-.057
-1.00	-4.0	76.0	1.501	1.767	-1.266	-.182
-1.20	3.0	69.0	1.363	1.604	-1.441	-.207
-1.15	9.5	62.5	1.234	1.453	-1.369	-.197
-1.00	18.0	54.0	1.067	1.256	-1.189	-.171
- .30	25.0	47.0	.928	1.093	- .465	-.067
0.20	31.0	41.0	.810	.953	.057	.008
-.05	43.0	29.0	.573	.674	- .151	-.022
-.30	57.5	13.5	.267	.314	- .347	-.050
-.40	62.5	9.5	.188	.221	- .433	-.062

W/C .45 AGE 9 days

AIR – ADMIXTURE –

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	67.0	8	.158	.186	.272	.039
0.90	49.5	25.5	.505	.595	.810	.117
0.98	47.5	27.5	.545	.641	.884	.127
1.22	38.0	37.0	.732	.862	1.090	.157
1.47	27.0	48.0	.950	1.116	1.304	.188
1.49	25.8	49.2	.975	1.145	1.320	.190
1.49	24.0	51.0	1.005	1.186	1.309	.188
1.54	23.0	52.0	1.025	1.210	1.355	.195
1.45	21.2	53.8	1.060	1.255	1.255	.181
1.49	18.5	56.5	1.115	1.315	1.290	.186
1.49	17.8	57.2	1.130	1.332	1.288	.185
1.34	-1.5	76.5	1.510	1.781	1.069	.154
1.44	4	71.0	1.400	1.651	1.189	.171
1.35	15	60.0	1.185	1.400	1.135	.164
1.49	24	51.0	1.005	1.119	1.376	.199
1.36	29.2	45.8	.906	1.065	1.201	.174
1.27	38.5	36.5	.720	.853	1.137	.163

W/C .45 AGE 16 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$, %
.19	65.5	7.0	.138	.163	.165	.024
.54	55.5	17.0	.336	.396	.480	.069
.99	40.5	32.0	.632	.745	.877	.126
1.09	37.0	35.5	.702	.826	.966	.139
1.24	31.0	41.5	.820	.966	1.094	.157
1.59	15.0	57.5	1.135	1.340	1.385	.199
1.60	11.9	60.6	1.195	1.411	1.384	.199
1.60	5.0	67.5	1.332	1.575	1.357	.195
1.70	11.0	61.5	1.215	1.435	1.480	.213
1.50	22.5	50.0	.988	1.165	1.323	.190
1.25	32.5	40.0	.791	.932	1.109	.160
0.84	50.0	22.5	.443	.523	.760	.109
0.45	71.0	1.5	.030	.035	.445	.064

W/C .45 AGE 28 days

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.25	68	10	.197	.233	.448	.064
.65	59	19	.376	.443	.583	.085
.90	47.5	30.5	.604	.711	.793	.114
1.20	38.0	40.0	.792	.932	1.060	.153
1.40	31.5	46.5	.920	1.085	1.235	.178
1.75	24.0	54.0	1.065	1.260	1.555	.224
1.95	15.5	62.5	1.235	1.460	1.725	.248
2.20	8.0	70.0	1.380	1.635	1.945	.280
2.50	0.0	78.0	1.540	1.820	2.220	.319
2.10	13.0	65.0	1.281	1.520	1.851	.266
1.75	21.5	57.5	1.135	1.345	1.540	.222
1.60	29.5	49.5	.980	1.155	1.425	.205
1.35	36.5	42.5	.840	.992	1.198	.172
1.15	44.0	35.0	.693	.816	1.027	.148
0.75	54.0	25.0	.495	.583	.662	.095
0.50	62.5	16.5	.326	.385	.441	.063
0.20	73.0	6.0	.119	.140	.179	.026

W/C 0.35 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.19	38	37	0.731	0.860	1.061	.152
1.28	31.5	42.5	0.839	0.986	1.133	.163
1.33	28.5	45.5	0.899	1.060	1.169	.168
1.43	23.1	50.9	1.004	1.118	1.316	.189
1.43	21.0	53.0	1.047	1.230	1.247	.179
1.39	13.5	61.5	1.215	1.430	1.175	.169
0.00	-5.0	80.0	1.580	1.860	-.280	-.042
-0.37	-3.5	78.5	1.550	1.825	-.645	-.093
-0.37	3.5	71.5	1.412	1.660	-.618	-.088
-0.44	6.5	68.5	1.353	1.590	-.677	-.097
-0.44	25.0	50.0	0.988	1.161	-.613	-.088
0.42	37.5	37.5	0.740	0.871	.289	.042
0.170	47.0	28.0	0.553	0.650	.073	.011
-0.040	60.0	15.0	0.296	0.348	-.092	-.013
-0.190	72.5	2.5	0.049	0.058	-.198	-.028

W/C .35 AGE 4 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.22	68	8	.158	.187	.191	0.028
1.28	39	37	.732	.864	1.148	.165
1.42	32.5	43.5	.861	1.015	1.266	.182
1.50	29.0	47.0	.930	1.095	1.335	.192
1.62	19.0	57.0	1.125	1.330	1.415	.204
1.78	10.0	66.0	1.300	1.540	1.540	.221
1.95	-7.0	83.0	1.640	1.935	1.655	.238
1.82	3.0	73.0	1.440	1.705	1.555	.223
1.80	9.0	67.0	1.320	1.565	1.555	.223
1.45	28.5	47.5	0.940	1.110	1.280	.184
0.95	50.0	21.5	0.425	0.502	0.873	.127
0.65	65.0	6.5	0.128	0.152	0.625	.091
0.50	74.0	-2.5	-0.049	-0.058	0.509	.074

W/C 0.35 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.265	37	37.0	.731	.895	1.37	.197
.285	29.5	44.5	.879	1.035	1.29	.186
.295	26.0	48.0	.948	1.116	1.27	.183
.315	21.0	53.0	1.047	1.232	3.32	.477
.035	15.5	57.5	1.136	1.337	-.166	-.024
.015	8.0	65.0	1.283	1.511	-.213	-.031
.015	-8.0	81.0	1.600	1.883	-268	-.039
.035	-3.5	76.5	1.511	1.779	-.235	-.034
.055	4.5	68.5	1.353	1.583	-.183	-.026
.055	8.5	64.5	1.274	1.490	-.172	-.025
.055	23.0	50.0	.988	.233	.810	.117
0.270	41.5	31.5	.622	.723	.179	.026
.255	51.0	22.0	.435	.512	.178	.112
.255	62.0	11.0	.217	.256	.186	.027
.185	74.5	0.0	0	0	0	0

W/C 0.35 AGE 4 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	68	8	.158	.187	.270	.039
1.50	39	37	.732	.864	1.368	.197
1.66	32.5	43.5	.861	1.015	1.506	.217
1.77	29.0	47.0	.930	1.095	1.605	.231
1.86	19.0	57.0	1.125	1.330	1.655	.238
2.01	10.0	66.0	1.300	1.540	1.770	.255
2.18	-7.0	83.0	1.640	1.935	1.885	.271
2.06	3.0	73.0	1.440	1.705	1.795	.258
2.05	9.0	67.0	1.320	1.565	1.805	.260
1.69	28.5	47.5	0.940	1.110	1.520	.219
1.30	50.0	21.5	0.425	0.502	1.223	.176
1.10	65.0	6.5	0.128	.152	1.076	.155
0.90	74.0	-2.5	-0.049	-.058	0.793	.144

W/C 0.35 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.15	40	33	.652	.767	1.035	.149
1.40	32	41	.810	.953	1.257	.181
1.50	23	50	.988	1.163	1.325	.191
1.25	13	60	1.185	1.395	1.040	.150
0.60	03	70	1.383	1.628	.355	.051
-.10	-7.0	80	1.580	1.860	-.380	-.055
-.30	2.5	70.5	1.392	1.639	-.547	-.079
-.30	15	58.0	1.146	1.349	-.503	-.072
-.15	24	49.0	.968	1.139	-.321	-.046
0.50	28	45.0	.889	1.046	.343	.049
0.40	35.5	37.5	.741	.872	.269	.039
0.30	42.5	30.5	.602	.709	.193	.028
-.10	66.0	7.0	.138	.163	-.125	-.018

W/C 0.35 AGE 4 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	68	8	.158	.186	.272	.039
1.50	39	37	.731	.860	1.371	.197
1.66	32.5	43.5	.859	1.011	1.508	.217
1.77	29.0	47.0	.928	1.093	1.605	.231
1.86	19.0	57.0	1.126	1.325	1.661	.239
2.01	10.0	66.0	1.304	1.535	1.779	.256
2.18	-7.0	83.0	1.639	1.930	1.889	.272
2.06	3.0	73.0	1.442	1.697	1.805	.260
2.05	9.0	67.0	1.323	1.558	1.815	.261
1.69	28.5	47.5	.938	1.104	1.524	.219
1.30	50.0	21.5	.425	.500	1.225	.176
1.10	65.0	6.5	.128	.151	1.077	.155
0.90	74.0	-2.5	-.049	-.058	.793	.114

W/C .35 AGE 1 day
AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.50	59	13	.267	.302	.465	.067
0.85	49	23	.454	.535	.769	.111
1.20	37	35	.691	.814	1.077	.155
1.50	29	43	.849	1.000	1.349	.194
1.55	22	50	.988	1.163	1.375	.198
1.50	14.5	57.5	1.136	1.337	1.299	.187
1.15	11.5	60.5	1.195	1.407	.938	.135
0.75	6.0	66.0	1.304	1.535	.519	.075
0.10	-2.5	74.5	1.471	1.732	-.161	-.023
-0.30	-7.0	79.5	1.570	1.848	-.578	-.083
-0.45	-1.5	73.5	1.452	1.709	-.707	-.102
-0.40	6.0	66.0	1.304	1.535	-.631	-.091
-0.25	19.0	53.0	1.047	1.232	-.435	-.063
0.15	23.0	49.0	.968	1.139	-.210	-.030
0.50	27.0	45.0	.889	1.046	.343	.049
0.30	40.5	31.5	.622	.732	.190	.027
-0.20	68.0	4.0	.079	.002	-.123	-.018

W/C 0.35 AGE 4 days
AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	68	8	.158	.186	.272	.039
1.50	39	37	.731	.860	1.371	.197
1.66	32.5	43.5	.859	1.011	1.508	.217
1.77	29.0	47.0	.928	1.093	1.605	.231
1.86	19.0	57.0	1.126	1.325	1.661	.239
2.01	10.0	66.0	1.304	1.535	1.779	.256
2.18	-7.0	83.0	1.639	1.930	1.889	.272
2.06	3.0	73.0	1.442	1.697	1.805	.260
2.05	9.0	67.0	1.323	1.558	1.815	.261
1.69	28.5	47.5	.938	1.104	1.524	.219
1.30	50.0	21.5	.425	.500	1.225	.176
1.10	65.0	6.5	.128	.151	1.077	.155
0.90	74.0	-2.5	-.049	-.058	.793	.114

W/C .35 AGE 4 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.75	54.5	17.5	.346	.407	.689	.099
1.50	35.5	36.5	.721	.849	1.372	.197
1.95	14.0	58.0	1.146	1.349	1.747	.251
2.10	-3.0	75.0	1.481	1.744	1.837	.264
2.05	10.0	62.0	1.225	1.442	1.833	.264
1.80	30.5	41.5	.820	.965	1.655	.238
1.50	49.0	23.0	.454	.535	1.419	.204
1.20	62.5	9.5	.188	.221	1.167	.168
1.00	71.0	1.0	.193	.233	.965	.139

W/C .35 AGE 14 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.80	54.0	18	.356	.419	.737	.106
1.30	41.5	30.5	.602	.709	1.193	.172
1.80	29.0	43.0	.849	1.000	1.649	.237
2.15	10.0	62.0	1.225	1.442	1.933	.278
2.50	-3.0	75.0	1.481	1.744	2.237	.322
2.30	9.0	63.0	1.244	1.465	2.079	.299
1.95	25.0	47.0	.928	1.093	1.785	.251
1.65	36.5	35.5	.701	.825	1.526	.220
1.35	42.5	29.5	.583	.686	1.247	.179
0.95	54.5	17.5	.346	.407	.890	.128

W/C .35 AGE 28 days

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	67.0	5.0	.099	.116	.283	.041
0.65	58.5	13.5	.267	.314	.603	.087
1.15	46.5	25.5	.504	.593	1.061	.153
1.75	30.5	41.5	.820	.965	1.605	.231
2.20	17.0	55.0	1.086	1.279	2.007	.289
2.65	3.5	68.5	1.353	1.593	2.410	.347
2.60	5.0	67.0	1.323	1.558	2.365	.340
2.40	12.0	60.0	1.185	1.395	2.190	.315
2.15	19.5	52.5	1.037	1.221	1.966	.283
1.45	39.5	32.5	.642	.756	1.336	.192
1.00	51.0	21.0	.415	.488	.927	.133
0.50	59.5	12.5	.247	.291	.456	.066
0.35	65.5	6.5	.128	.151	.327	.047

W/C 0.25 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.35	38	34	0.672	0.791	1.231	0.177
1.55	31.5	40.5	0.800	0.942	1.408	0.203
1.75	22.5	49.5	0.978	1.151	1.577	0.227
1.90	17.0	55.0	1.086	1.279	1.707	0.246
2.00	12.0	60.0	1.135	1.395	1.790	0.258
2.05	5.5	66.5	1.313	1.546	1.817	0.261
2.20	0.5	71.5	1.412	1.662	1.950	0.281
2.25	-4.0	76.0	1.501	1.767	1.984	0.285
1.65	30.0	42.0	0.803	0.977	1.503	0.216
1.60	37.0	35.0	0.691	0.814	1.477	0.213
1.10	72.0	0.0	0	0	1.100	0.158

W/C 0.25 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.36	41	34	0.672	0.791	1.241	0.179
1.55	34.5	40.5	0.800	0.942	1.408	0.203
1.77	26.5	48.5	0.958	1.128	1.600	0.230
1.87	20.0	55.0	1.086	1.279	1.677	0.241
1.98	15.0	60.0	1.185	1.395	1.770	0.255
2.06	9.0	66.0	1.304	1.535	1.829	0.263
2.16	3.5	71.5	1.412	1.662	1.910	0.275
2.29	-1.0	76.0	1.501	1.767	2.024	0.291
1.65	33	42.0	0.830	0.977	1.503	0.216
1.62	40	35.0	0.691	0.814	1.497	0.215
1.11	75	0.0	0	0	1.110	0.159

W/C 0.25 AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.38	41	34	0.672	0.7905	1.261	.181
1.58	34.5	40.5	0.800	0.942	1.438	.207
1.78	26.5	48.5	0.958	1.128	1.610	.232
1.88	20.0	55.0	1.086	1.279	1.687	.243
1.98	15.0	60.0	1.185	1.395	1.770	.255
2.08	9.0	66.0	1.304	1.535	1.849	.266
2.18	3.5	71.5	1.412	1.662	1.930	.278
2.28	-1.0	76.0	1.501	1.767	2.014	.290
1.68	33	42.0	0.830	0.977	1.533	.221
1.63	40	35.0	0.691	0.976	1.345	.194
1.13	75	0.0	0	0	1.130	.162

W/C 0.25 **AGE** 7 days
AIR - **ADMIXTURE** -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.80	52.0	20.0	0.395	0.465	0.730	0.105
1.30	38.0	34.0	0.672	0.791	1.181	0.170
1.95	21.0	51.0	1.007	1.186	1.771	0.255
2.35	6.0	66.0	1.304	1.535	2.119	0.305
2.10	19.5	52.5	1.037	1.221	1.916	0.276
1.55	37.0	35.0	0.691	0.814	1.427	0.205
0.95	55.0	17.0	0.336	0.395	0.891	0.128
0.50	69.5	2.5	0.049	0.058	0.491	0.071

W/C 0.25 **AGE** 7 days

AIR - **ADMIXTURE** -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.80	52.0	20.0	0.395	0.465	0.730	0.105
1.30	38.0	34.0	0.672	0.791	1.181	0.170
1.95	21.0	51.0	1.007	1.186	1.771	0.255
2.35	6.0	66.0	1.304	1.535	2.119	0.305
2.10	19.5	52.5	1.037	1.221	1.916	0.276
1.55	37.0	35.0	0.691	0.814	1.427	0.205
0.95	55.0	17.0	0.336	0.395	0.891	0.128
0.50	69.5	2.5	0.049	0.058	0.491	0.071

W/C 0.25 AGE 28 days
AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.55	59	13.0	.257	0.302	0.505	0.072
0.90	50	22.0	.435	0.512	0.823	0.118
1.25	40	32.0	.632	0.744	1.138	0.164
1.75	25	47.0	.928	1.093	1.585	0.228
2.40	7.0	65.0	1.284	1.511	2.173	0.313
1.95	19.5	52.5	1.037	1.221	1.766	0.254
1.48	34.5	37.5	0.741	0.872	1.349	0.194
1.20	46.5	25.5	0.504	0.593	1.111	0.160
0.35	66.0	6.0	0.119	0.140	0.329	0.047

W/C 0.50 AGE 1 day

AIR 16.30% ADMIXTURE ____

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.60	37	35	.691	.814	.477	.061
0.70	34.5	37.5	.741	.872	.569	.082
0.75	29.5	42.5	.839	.988	.601	.096
0.80	28.0	44.0	.869	1.023	.645	.093
0.55	27.0	45.0	.889	1.046	.393	.657
0.65	23.0	49.0	.968	1.139	.479	.059
0.75	10	62.5	1.234	1.453	.531	.076
1.30	-12	84.0	1.659	1.953	1.00	.146
0.95	11	61.0	1.205	1.418	.737	.106
0.60	29.5	42.5	.839	.988	.451	.065
1.05	31.5	40.5	.800	.942	.908	.131
0.90	40.5	31.5	.622	.732	.790	.114
0.60	54.5	17.5	.346	.407	.539	.078
0.35	68.0	4.0	.079	.093	.336	.048

W/C 0.50 **AGE** 3 days

AIR 16.30% **ADMIXTURE** ____

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.20	59	13	.257	.302	.155	.022
0.45	45	27	.533	.628	.355	.051
0.55	36.5	35.5	.701	.825	.426	.061
0.55	29.5	42.5	.839	.988	.401	.058
0.60	23.5	48.5	.958	1.128	.430	.062
0.90	17.5	54.5	1.076	1.267	.709	.102
1.00	10	62.0	1.225	1.442	.783	.113
1.25	-8	80.0	1.580	1.860	.970	.140
1.30	-4	76.0	1.501	1.767	1.034	.149
1.15	12.5	59.5	1.175	1.383	.942	.136
0.75	26.0	46.0	.909	1.070	.589	.085
0.70	33.5	38.5	.760	.895	.565	.081
0.65	44.0	28.0	.553	.651	.552	.079
0.45	59.5	12.5	.247	.291	.406	.058

W/C 0.50 AGE 7 days

AIR 16.3% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$, %
0.30	54.5	17.5	.346	.407	.239	.034
0.65	36.5	35.5	.701	.825	.526	.076
0.80	22.5	49.5	.978	1.151	.627	.090
1.00	13.0	59.0	1.165	1.372	.793	.114
1.45	-7.5	79.5	1.570	1.848	1.172	.169
1.25	9.0	63.0	1.244	1.465	1.029	.148
0.95	26.0	46.0	.909	1.070	.789	.114
0.75	39.5	32.5	.642	.756	.636	.092
0.40	57.5	14.5	.296	.337	.359	.052

W/C 0.50 AGE 14 days

AIR 16.3% ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.50	52	20	.395	.465	.430	.052
0.90	36	36	.711	.837	.774	.111
1.25	20.5	51.5	1.017	1.197	1.070	.154
1.70	5.0	67.0	1.323	1.558	1.465	.211
1.85	-3.0	75.0	1.481	1.744	1.587	.228
1.45	15	57.0	1.126	1.325	1.251	.180
1.10	29.5	42.5	.839	.988	.951	.137
0.75	47.0	25.0	.494	.581	.663	.095
0.35	62.0	10.0	.198	.233	.315	.045

W/C 0.50 AGE 28 days
AIR 16.3% ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.10	69.5	2.5	.049	.058	.091	.013
0.65	47.5	24.5	.484	.600	.534	.077
0.85	39.0	33.0	.652	.767	.735	.106
1.15	27.0	45.0	.889	1.046	.993	.143
1.50	14.5	57.5	1.136	1.337	1.299	.187
1.80	-2.5	74.5	1.471	1.732	1.539	.221
1.85	-5.0	77.0	1.521	1.790	1.581	.227
1.75	0.0	72.0	1.422	1.674	1.498	.216
1.40	16.0	56.0	1.106	1.302	1.204	.173
0.90	36.5	35.5	.701	.825	.776	.112
0.70	46.5	25.5	.504	.593	.611	.098
0.30	61.0	11.0	.217	.256	.261	.038

W/C 0.50 AGE 1 day

AIR 8% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.80	36	36	.711	.837	.674	.097
0.85	33	39	.770	.907	.713	.103
1.00	27	45	.889	1.046	.843	.121
1.05	25.5	46.5	.918	1.0811	.887	.128
0.75	24.5	47.5	.938	1.104	.584	.084
0.80	20.5	51.5	1.017	1.197	.620	.089
1.00	7.0	65.0	1.284	1.511	.773	.111
1.50	-14.5	86.5	1.708	2.011	1.197	.172
1.10	9.5	62.5	1.234	1.453	.881	.127
0.80	27.0	45.0	.889	1.046	.643	.093
1.10	29.5	42.5	.839	.988	.951	.137
1.35	31.5	40.5	.800	.942	1.208	.174
1.15	40.0	32.0	.632	.744	1.038	.149
0.75	54.5	17.5	.346	.407	.689	.099
0.50	65.5	6.5	.128	.151	.477	.069

W/C 0.50 AGE 7 days

AIR 9.8% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.25	62	10	.198	.233	.215	.031
0.65	46.5	25.5	.504	.593	.561	.081
1.05	35.0	37.0	.731	.860	.921	.133
1.05	30.0	42.0	.830	.977	.903	.130
1.15	20.5	51.5	1.017	1.197	.970	.140
1.35	14.5	57.5	1.136	1.337	1.149	.165
1.65	11.5	60.5	1.195	1.407	1.438	.207
1.75	7.0	65.0	1.293	1.511	1.532	.220
2.00	-3.0	75.0	1.481	1.743	1.738	.250
1.50	24.0	48.0	.948	1.116	1.332	.192
1.25	35.5	36.5	.721	.849	1.122	.161
0.90	53.0	19.0	.375	.442	.833	.120
0.65	67.0	5.0	.099	.116	.633	.091

W/C 0.50 AGE 14 days
AIR 10% ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.50	54	18	.356	.419	.437	.063
0.85	38.5	33.5	.662	.779	.733	.105
1.35	21.0	51.0	1.007	1.180	1.177	.169
2.05	-1.0	73.0	1.442	1.697	1.795	.259
1.60	15.5	56.5	1.116	1.314	1.402	.202
1.10	33.5	38.5	.760	.895	.965	.139
0.65	49.0	22.5	.444	.523	.571	.082
0.25	67.0	5.0	.099	.116	.233	.034

W/C 0.50 AGE 28 days
AIR 10% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.55	54	18.0	.356	.419	.487	.070
1.00	38	34.0	.672	.791	.881	.127
1.40	22.5	49.5	.978	1.151	1.227	.177
2.00	0.5	71.5	1.412	1.662	1.750	.252
1.50	19.5	52.5	1.037	1.221	1.416	.204
1.05	37.0	35.0	.691	.814	.927	.133
0.75	48.0	24.0	.474	.558	.666	.096
0.35	63.0	9.0	.178	.209	.319	.046

W/C .50 AGE 1 day

AIR 16% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.63	35	35	.691	.814	.507	.073
.68	32.5	37.5	.741	.872	.549	.079
.78	26.5	42.5	.839	.988	.631	.091
.83	25.0	44.0	.869	1.023	.676	.097
.68	24.0	45.0	.889	1.046	.523	.075
.58	24.0	45.0	.889	1.046	.423	.061
.63	20.0	49.0	.958	1.139	.449	.065
.78	6.5	62.5	1.234	1.453	.561	.081
1.33	-15.0	84.0	1.659	1.953	1.036	.149
.95	8.0	61.0	1.205	1.418	.737	.107
.60	26.5	42.5	.839	.988	.451	.065
1.05	28.5	40.5	.800	.942	.908	.131
.90	37.0	32.0	.632	.744	.788	.113
.60	51.5	17.50	.346	.407	.539	.078
.33	65.0	4.00	.079	.093	.316	.045

W/C 0.5 AGE 3 days

AIR 16% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.25	55	17.0	.336	.395	.191	.027
0.60	35	37.0	.731	.850	.481	.069
0.60	27	45.0	.889	1.046	.443	.064
0.60	18.5	53.5	1.057	1.244	.413	.059
0.60	12.0	60.0	1.185	1.395	.390	.056
1.00	0.5	71.5	1.412	1.662	.750	.108
1.25	-10.0	82.0	1.620	1.907	.963	.159
1.20	- 5.0	77.0	1.521	1.790	.931	.134
0.80	12.0	60.0	1.185	1.395	.590	.085
0.55	20.0	52.0	1.027	1.209	.368	.053
0.55	28.5	43.5	.859	1.011	.398	.057
0.70	40.5	31.5	.622	.732	.590	.085
0.40	55.5	16.5	.326	.384	.342	.049
0.25	68.5	3.5	.069	.081	.238	.034

W/C 0.50 **AGE** 7 days

AIR 16% **ADMIXTURE** ________

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	58	14	.277	.326	.351	.051
0.80	42	30	.593	.698	.695	.100
1.10	26	46	.910	1.070	.940	.135
1.30	14.5	57.5	1.136	1.337	1.099	.158
1.55	-1.5	73.5	1.452	1.709	1.293	.186
1.40	14.0	58.0	1.146	1.349	1.197	.172
1.25	22.0	50.0	.988	1.163	1.075	.155
0.95	37.0	35.0	.691	.814	.827	.119
0.65	52.5	19.5	.385	.453	.582	.084

W/C 0.50 **AGE** 1 day

AIR 10% **ADMIXTURE**

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.50	48.5	23.5	.464	.546	.418	.050
0.80	37.0	35.0	.691	.814	.677	.097
0.95	28.5	43.5	.859	1.011	.798	.115
0.80	23.5	48.5	.958	1.128	.630	.091
0.65	21.5	50.5	.997	1.174	.473	.058
0.85	16.0	55.0	1.086	1.278	.658	.095
0.90	11.0	60.0	1.185	1.395	.690	.099
1.20	3.0	68.0	1.343	1.581	.962	.139
1.40	-9.0	80.0	1.580	1.850	1.130	.163
1.20	8.5	62.5	1.234	1.453	.981	.141
1.00	22.5	48.5	.958	1.128	.830	.119
.75	31.5	39.5	.780	.918	.612	.0883
1.10	33.5	37.5	.741	.872	.869	.123
1.20	38.0	33.0	.652	.767	1.085	.156
1.00	48.0	23.0	.454	.535	.919	.132
0.70	62.0	9.0	.178	.209	.669	.096

W/C 0.50 AGE 7 days

AIR 10.8% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	54	18	.356	.419	.337	.0485
0.75	39.5	32.5	.641	.756	.635	.091
1.00	27.0	45.0	.889	1.046	.843	.121
1.00	22.5	49.5	.978	1.151	.827	.119
1.00	19.0	53.0	1.046	1.232	.814	.117
1.40	11.0	61.0	1.205	1.418	1.187	.171
1.95	-3.5	75.5	1.491	1.755	1.686	.243
1.70	7.0	65.0	1.284	1.511	1.473	.212
1.25	19.5	52.5	1.037	1.221	1.066	.153
1.15	24.5	47.5	.938	1.104	.984	.142
1.05	30.5	41.5	.820	.965	.905	.130
1.00	37.0	35.0	.691	.814	.877	.126
0.90	47.0	25.0	.494	.581	.813	.117
0.60	66.0	6.0	.119	.140	.579	.083

W/C 0.50 AGE 1 day

AIR 9.8% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	53.5	18.5	.365	.430	.335	.048
0.85	35.0	37.0	.731	.860	.721	.104
1.00	26.5	45.5	.899	1.058	.841	.121
0.60	24.0	48.0	.948	1.116	.432	.062
0.60	20.0	52.0	1.027	1.209	.418	.060
0.80	15.5	56.5	1.116	1.314	.602	.097
1.05	12.0	60.0	1.185	1.395	.840	.121
1.25	7.0	65.0	1.284	1.511	1.023	.147
1.40	-7.5	79.5	1.570	1.848	1.122	.161
1.30	8.0	64.0	1.264	1.488	1.076	.155
1.20	16.5	55.5	1.096	1.290	1.006	.145
0.95	23.0	49.0	.968	1.139	.779	.112
0.65	29.0	43.0	.849	1.000	.499	.072
1.05	34.5	37.5	.741	.872	.919	.132
0.95	40.5	31.5	.622	.732	.840	.121
0.75	50.0	22.0	.435	.512	.673	.097
0.51	66.0	6.0	.119	.140	.489	.070

W/C 0.50 AGE 7 days

AIR 10% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	60.5	11.5	.227	.267	.260	.037
0.65	44.0	28.0	.553	.651	.552	.079
0.95	31.0	41.0	.810	.953	.807	.116
1.10	24.5	47.5	.938	1.110	.928	.134
1.10	20.5	51.5	1.017	1.197	.920	.132
1.10	17.0	55.0	1.086	1.279	.907	.130
1.25	14.0	58.0	1.146	1.349	1.047	.151
1.55	8.0	64.0	1.264	1.488	1.326	.191
2.10	-5.5	77.5	1.531	1.802	1.829	.263
1.85	4.0	68.0	1.343	1.581	1.612	.232
1.60	14.0	58.0	1.146	1.349	1.397	.201
1.30	20.5	51.5	1.017	1.197	1.120	.161
1.20	27.5	44.5	.879	1.035	1.044	.150
1.10	36.5	35.0	.691	.814	.977	.141
0.80	49.0	22.5	.444	.523	.769	.111
0.50	63.0	9.0	.178	.209	.469	.067

W/C 0.50 AGE 1 day

AIR 16.9% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.30	56	16.0	.316	.372	.244	.035
0.55	44.5	27.5	.543	.639	.454	.065
0.90	27.0	45.0	.889	1.046	.743	.107
0.45	25.0	47.0	.928	1.093	.285	.041
0.40	23.5	48.5	.958	1.128	.230	.033
0.60	17.0	55.0	1.086	1.279	.407	.059
1.30	-6.5	78.5	1.550	1.825	1.025	.147
1.05	5.0	67.0	1.323	1.550	.815	.117
0.55	22.5	49.5	.978	1.151	.377	.054
0.40	28.0	44.0	.869	1.023	.246	.035
0.95	32.5	39.5	.780	.918	.812	.117
0.70	46.0	26.0	.514	.605	.609	.088
0.55	58.0	14.0	.277	.326	.501	.072
0.35	69.5	2.5	.494	.658	.186	.027

W/C 0.50 AGE 7 days

AIR 16.9% ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.25	61.5	10.5	.207	.244	.213	.031
0.50	48.0	24.0	.474	.558	.416	.060
0.85	33.0	39.0	.770	.907	.713	.103
1.10	16.0	56.0	1.105	1.302	.903	.130
1.50	-7.5	79.5	1.570	1.848	1.222	.176
1.20	15.5	56.5	1.116	1.314	1.002	.144
0.90	33.0	39.0	.770	.907	.763	.110
0.45	52.0	20.0	.395	.465	.380	.055
0.20	66.5	5.5	.109	.128	.181	.026

W/C .50 AGE 1 day

AIR 10% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$, %
.83	35	36.5	.721	.849	.702	.101
.86	32.5	39.0	.770	.907	.723	.104
.98	26.5	45.0	.889	1.046	.823	.118
1.06	25.0	46.5	.918	1.081	.897	.129
.78	24.0	47.5	.938	1.104	.614	.088
.78	24.0	47.5	.938	1.104	.614	.038
.83	20.0	51.5	1.017	1.197	.650	.094
1.00	6.5	65.0	1.284	1.511	.773	.111
1.48	-15	86.5	1.708	2.011	1.177	.169
1.10	9.0	62.5	1.234	1.453	.881	.127
.80	26.5	45.0	.889	1.046	.643	.093
1.15	28.5	43.0	.849	1.000	.999	.144
1.35	30.5	41.0	.810	.953	1.207	.174
1.15	39.0	32.5	.642	.756	1.036	.149
.75	54	17.5	.346	.756	.340	.049
.48	65	6.5	.128	.151	.457	.061

W/C .50 AGE 8 days

AIR 10% ADMIXTURE A.E.A.

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.88	42	33	.651	.767	.764	.110
1.03	39	36	.711	.837	.904	.130
1.09	34	41	.810	.953	.947	.136
1.58	11.5	63.5	1.254	1.476	1.358	.195
1.98	2.0	73.0	1.442	1.697	1.725	.248
1.75	12.5	62.5	1.234	1.453	1.531	.220
1.25	30.0	45.0	.889	1.046	1.093	.157
.63	55.0	20.0	.395	.465	.560	.081
.25	70.0	5	.099	.116	.233	.034

W/C .45 AGE 1 day

AIR 15.3% ADMIXTURE AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
.45	60.5	11.5	.227	.267	.410	.059
.80	50.0	22.0	.435	.512	.723	.104
1.35	33.5	38.5	.760	.895	1.215	.175
1.45	27.0	45.0	.889	1.046	1.293	.186
1.20	24.5	47.5	.938	1.104	1.034	.149
1.35	18.5	53.5	1.057	1.244	1.163	.167
1.80	2.0	70.0	1.383	1.628	1.555	.224
1.55	13.0	59.0	1.165	1.372	1.343	.193
1.15	27.0	45.0	.889	1.046	.993	.143
1.50	31.5	40.5	.800	.942	1.358	.195
.95	48.0	24.0	.474	.558	.866	.125
.35	66.5	5.50	.109	.128	.331	.048

W/C .45 AGE 7 days

AIR 15.3% ADMIXTURE AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.55	59.5	12.5	.247	.291	.506	.073
1.20	40.0	32.0	.632	.744	1.088	.157
1.60	27.5	44.5	.879	1.035	1.444	.208
2.10	7.0	65.0	1.284	1.511	1.873	.209
2.20	8.0	64.0	1.264	1.488	1.976	.284
2.15	16.0	56.0	1.106	1.302	1.954	.291
1.50	42.0	30.0	.593	.698	1.395	.201
.75	70.5	1.5	.296	.035	1.011	.145

W/C .45 AGE 28 days

AIR 15.3% ADMIXTURE AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.55	60	12	.237	.279	.508	.073
1.15	43	29	.573	.674	1.049	.151
1.55	30.5	41.5	.820	.965	1.405	.202
1.95	14.5	57.5	1.136	1.337	1.749	.252
2.25	5.0	67.0	1.323	1.558	2.015	.290
2.20	7.0	65.0	1.284	1.511	1.973	.284
1.90	16.5	55.5	1.096	1.290	1.706	.245
1.60	28.5	43.5	.859	1.011	1.448	.208
1.00	47.5	24.5	.484	.570	.914	.132
0.40	63.5	8.5	.168	.198	.370	.053

W/C .35 AGE 1 day
AIR 8% ADMIXTURE AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.35	60.5	11.5	.227	.267	.310	.045
0.65	52.0	20.0	.395	.465	.580	.083
0.90	42.0	30.0	.593	.698	.795	.114
1.20	31.0	41.0	.810	.953	1.057	.152
1.30	20.5	51.5	1.017	1.197	1.120	.161
1.30	16.0	56.0	1.106	1.302	1.104	.159
1.40	9.0	63.0	1.244	1.465	1.179	.170
1.50	3.5	68.5	1.353	1.592	1.261	.181
1.55	-1.5	73.5	1.452	1.709	1.293	.186
1.55	13.5	58.5	1.155	1.360	1.345	.194
1.45	28.0	44.0	.869	1.023	1.296	.186
1.05	44.5	27.5	.543	.639	.954	.137
0.55	60.0	12.0	.237	.279	.508	.073

W/C 0.50 AGE 8 days
AIR 10% ADMIXTURE

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.85	39	33.0	.652	.767	.735	.106
1.05	36	36.0	.711	.837	.924	.133
1.10	31	41.0	.810	.953	.957	.138
1.60	8.5	63.5	1.254	1.476	1.378	.198
2.00	-1.0	73.0	1.442	1.697	1.745	.251
1.70	9.5	62.5	1.234	1.453	1.481	.213
1.25	27.0	45.0	.889	1.046	1.093	.157
0.65	52.0	20.0	.395	.465	.580	.083
0.25	67.0	5.0	.099	.116	.233	.034

W/C 0.35 AGE 14 days

AIR 8% ADMIXTURE AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	58.5	13.5	.267	.314	.353	.051
0.80	44.0	28.0	.553	.651	.843	.121
1.15	32.0	40.0	.790	.930	1.010	.145
1.45	22.5	49.5	.968	1.151	1.267	.182
1.55	11.0	61.0	1.205	1.418	1.337	.193
2.05	2.0	70.0	1.383	1.628	1.805	.260
2.00	4.0	68.0	1.343	1.581	1.762	.254
1.60	17.0	55.0	1.085	1.279	1.406	.202
1.30	28.0	44.0	.869	1.023	1.146	.165
0.95	38.5	33.5	.662	.779	.833	.120
0.60	51.5	20.5	.405	.477	.520	.750
0.20	66.0	6.0	.119	.140	.179	.026

W/C .35 AGE 28 days

AIR 8% ADMIXTURE AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.40	60.0	12.0	.237	.279	.358	.052
0.80	46.5	25.5	.514	.593	.711	.102
1.15	35.0	37.0	.731	.860	1.021	.147
1.55	20.0	52.0	1.027	1.209	1.368	.197
1.95	9.5	62.5	1.234	1.453	1.731	.249
2.15	1.0	71.0	1.402	1.651	1.901	.274
2.20	-2.5	74.5	1.471	1.732	1.030	.279
2.05	3.5	67.5	1.333	1.569	1.814	.261
1.80	13.5	58.5	1.155	1.360	1.595	.229
1.40	26.5	45.5	.899	1.058	1.241	.179
0.55	54.0	18.0	.356	.419	.487	.070
0.20	66.0	6.0	.119	.140	.179	.026

W/C 0.50 AGE 1 day
AIR ______ ADMIXTURE Glass incl. p=90%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-1.98	0	70.0	1.385	1.635	-2.230	-.320
-2.18	20	50.0	0.990	1.170	-2.360	-.330
-1.36	36.5	33.5	0.663	0.781	-1.478	-.215
-1.96	63.0	7.0	.1381	0.164	-1.985	-.285
-1.66	39.0	31.0	.612	0.725	-1.773	-.254
-1.48	30	40	.790	.935	-1.625	-.234
-1.30	23.5	46.5	.920	1.080	-1.460	-.211
-1.33	8.0	62.0	1.222	1.445	-1.553	-.221
-1.36	3.0	67.0	1.333	1.560	-1.587	-.229
-1.22	-4.5	74.5	1.470	1.731	-1.481	-.214
-1.38	12.5	57.5	1.138	1.340	-1.582	-.228
-1.56	22.0	48.0	.950	1.118	-1.728	-.249
-1.47	29.5	40.5	.800	.945	-1.615	-.223
-1.47	32.0	38.0	.750	.888	-1.608	-.231
-1.72	48.0	22.0	.435	.515	-1.800	-.260
-1.87	54.0	16.0	.316	.374	-1.928	-.278
-1.58	65.0	5.0	.098	.116	-1.598	-.230

W/C 0.50 AGE 1 day

AIR ______ ADMIXTURE Glass incl. p=90%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch}\cdot\Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
.82	37.5	32.5	.644	.760	.704	.101
.90	33.0	37.0	.732	.865	.767	.110
1.03	27.0	43.0	.851	1.005	.876	.126
1.00	23.0	47.0	.930	1.100	.830	.119
-.23	13.0	57.0	1.130	1.330	-.430	-.061
-1.68	2.50	67.5	1.335	1.575	-1.920	-.276
-2.18	0	70.0	1.385	1.640	-2.435	-.350
-2.22	17.0	53.0	1.050	1.240	-2.410	-.345
-2.10	24.5	45.5	.900	1.065	-2.265	-.325
-1.90	26.5	43.5	.861	1.015	-2.054	-.294
-1.43	29.0	41.0	.811	0.955	-1.574	-.225
- .88	48.5	21.5	.426	0.502	- .936	-.135
-1.03	55.0	15.0	.296	0.350	-1.084	-.156
- .90	39.0	31.0	.614	0.725	-1.011	-.145
- .82	32.5	37.5	.742	0.875	- .953	-.137
- .57	24.0	46.0	.910	1.075	-1.415	-.203
-1.68	6.0	64.0	1.265	1.495	-1.910	-.274

W/C 0.50 **AGE** 1 day

AIR ______ **ADMIXTURE** Glass incl. p=39%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-1.250	0	70.0	1.385	1.635	-1.500	-.216
-1.300	20	50.0	.990	1.170	- .860	-.124
- .100	36.5	33.5	.663	.781	- .218	-.031
- .440	63.0	7.0	.1381	.1635	- .466	-.067
- .200	39.0	31.0	.612	.725	- .313	-.045
- .050	30	40	.790	.935	- .195	-.028
- .250	23.5	46.5	.920	1.080	- .410	-.059
- .650	8.0	62.0	1.222	1.445	- .873	-.126
- .650	3.0	67.0	1.333	1.560	- .877	-.127
- .600	-4.5	74.5	1.470	1.731	- .861	-.124
- .650	12.5	57.5	1.138	1.340	- .852	-.123
- .750	22.0	48.0	.950	1.118	- .918	-.133
- .290	29.5	40.5	.800	.945	- .435	-.063
- .140	32.0	38.0	.750	.888	- .278	-.041
- .250	48.0	22.0	.435	.515	- .330	-.047
- .300	54.0	16.0	.316	.374	- .358	-.052
- .850	65.0	5.0	.098	.116	.636	.092

W/C 0.50 AGE 1 day

AIR ______ ADMIXTURE Glass incl. p=39%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.82	37.5	32.5	.644	.760	.704	.101
.88	33.0	37.0	.732	.865	.747	.107
.95	27.0	43.0	.851	1.005	.796	+.115
.30	23.0	47.0	.930	1.100	.130	.018
−.75	13.0	57.0	1.130	1.330	−.950	−.137
−1.20	2.50	67.5	1.335	1.575	−1.440	−.207
−1.40	0	70.0	1.385	1.640	−1.655	−.238
−1.40	17.0	53.0	1.050	1.240	−1.590	−.229
−1.35	24.5	45.5	.900	1.065	−1.515	−.218
−1.10	26.5	43.5	.861	1.015	−1.254	−.181
−.650	29.0	41.0	.811	.955	− .794	−.114
.030	48.5	21.5	.426	.502	− .046	−.006
−.050	55.0	15.0	.296	.350	− .104	−.015
.080	39.0	31.0	.614	.725	−.031	−.004
.150	32.5	37.5	.742	.875	.017	−.002
−.150	24.0	46.0	.910	1.075	−.315	−.045
−.150	6.0	64.0	1.265	1.495	−1.380	−.198

W/C 0.50 AGE 1 day

AIR ______ ADMIXTURE Glass incl. p=62.5%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.08	22.0	46.5	.920	1.085	- .085	-.013
0.13	18.5	50.0	.987	1.165	- .048	-.007
-3.32	2.5	66.0	1.305	1.540	-3.555	-.510
-3.37	3.0	65.5	1.292	1.530	-3.608	-.520
-3.42	9.5	59.0	1.169	1.375	-3.626	-.522
-3.47	18.0	51.5	1.020	1.200	-3.650	-.526
-1.21	32.0	37.5	.742	.875	-1.343	-.194
-1.12	57.5	12.0	.237	.280	-1.163	-.167
-1.28	66.0	3.5	.069	.082	-1.293	-.186
-1.04	59.5	10	.1975	.232	-1.072	-.155
-.59	30.5	39	.770	.906	- .726	-.105
-.52	28.0	41.5	.820	.966	- .666	-.096
-.46	22.0	47.5	.937	1.100	-.623	-.089
-.02	5.0	64.0	1.265	1.490	-.225	-.032
-.19	0.0	69.0	1.365	1.610	-.055	-.008

W/C 0.50 AGE 1 day

AIR ______ ADMIXTURE Glass incl. p=62.5%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
0.34	56	12.5	.247	.291	.291	.043
0.62	48	20.5	.405	.477	.548	.079
0.94	35.5	33.0	.652	.769	.823	.119
1.01	31.5	37.0	.731	.861	.880	.126
0.91	25.5	43.0	.850	1.000	.760	.109
0.58	25.0	43.5	.860	1.010	.430	.062
-1.02	22.5	46.0	.910	1.070	-1.180	-.170
-2.62	18.0	50.5	.988	1.170	-2.802	-.402
-3.02	16	52.5	1.040	1.222	-3.202	-.462
-4.32	0	68.5	1.355	1.595	-4.5[illegible]0	-.656
-3.62	27	41.5	.819	.970	-3.771	-.542
-0.80	36	32.5	.642	.757	- .915	-.132
-0.35	51.5	17.0	.336	.396	- .410	-.059
-0.47	59.0	8.5	.168	.198	- .500	-.072
-0.52	64.0	3.5	.069	.082	- .533	-.077
-0.05	31.0	36.5	.721	.851	- .180	-.026
0.02	25.5	43.0	.850	1.000	- .130	-.018

W/C .60 AGE 1 day
AIR ______ ADMIXTURE Mortar 1:1.75

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.28	1.0	66.0	1.310	1.540	1.050	.151
1.28	12.5	54.5	1.080	1.270	1.090	.157
1.00	25.0	42.0	.833	.981	.852	.123
.95	29.0	48.0	.952	1.120	.782	.1125
.60	53.0	14.0	.278	.328	.542	.078
.59	55.0	12.0	.238	.281	.546	.079
.55	57.5	9.5	.188	.222	.516	.074
.68	37.0	30.0	.595	.701	.574	.083
.78	31.0	36.0	.715	.842	.653	.094
.81	28.5	38.5	.765	.900	.675	.097
1.01	14.0	53.0	1.050	1.235	.825	.1190
1.09	11.0	56.0	1.110	1.310	.890	.1280
1.12	9.0	58.0	1.150	1.355	.915	.1315
.50	60.0	7.0	.139	.163	.476	.068
.48	63.0	4.0	.079	.093	.466	.067
.43	65.0	2.0	.040	.046	.424	.061
.84	24.0	43.0	.855	1.000	.695	.1000
.33	61.0	6.0	.119	.140	.309	.045

W/C .60 AGE 1 day

AIR ______ ADMIXTURE Mortar 1:1.75

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.23	56.5	10.5	.207	.245	.192	.028
.33	51.0	16.0	.316	.373	.273	.039
.80	23.5	43.5	.860	1.010	.650	.093
.18	25.0	42.0	.830	.980	.030	.004
.04	24.0	41.0	.810	.955	-.105	-.015
.23	-3.0	70.0	1.380	1.630	-.020	-.003
.23	7.5	59.5	1.170	1.390	.010	.001
.04	27.5	39.5	.792	.921	-.089	-.013
.01	30.0	37.0	.731	.863	-.122	-.018
.73	34.5	32.5	.642	.753	.619	+.090
.33	65.0	2.0	.039	.467	.098	+.014
.43	53.5	13.5	.267	.315	.382	+.055
.68	37.5	29.5	.584	.687	.577	+.083
.88	24.0	43.0	.850	1.000	.730	.105
.83	26.0	41.0	.811	.956	.685	.099
.93	20.5	46.5	.921	1.085	.766	.110
.99	16.0	51.0	1.010	1.190	.810	.117

W/C .50* AGE 1 day

AIR - ADMIXTURE -

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.230	67.5	5.0	.099	.116	.213	.031
1.580	35.5	37.0	.731	.860	1.451	.208
1.650	31.5	41.0	.810	.953	1.507	.217
1.700	29.0	43.5	.859	1.011	1.548	.223
1.830	22.0	49.5	.978	1.151	1.657	.238
1.620	22.5	50.0	.988	1.163	1.445	.208
1.510	22.5	50.0	.988	1.163	1.335	.192
1.430	22.5	50.0	.988	1.163	1.255	.181
1.330	22.5	50.0	.988	1.163	1.155	.166
-2.670	12.0	60.5	1.195	1.407	-2.882	-.415
-3.57	0.0	72.5	1.432	1.686	-3.824	-.550
-3.97	4.5	68.0	1.343	1.581	-4.208	-.605
-3.97	9.0	63.5	1.254	1.476	-4.198	-.604
-3.97	10.5	62.0	1.225	1.442	-4.187	-.602
-3.97	16.5	56.0	1.106	1.302	-4.166	-.599
-3.27	26.5	46.0	.909	1.070	-3.431	-.494
-1.77	32	40.5	.800	.942	-1.912	-.275

* MULTL-CYCLE

W/C .50* AGE 1 day
AIR – ADMIXTURE –

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-1.67	35.0	37.5	.741	.872	-1.801	-.259
-1.92	50.0	22.5	.444	.523	-2.003	-.288
-2.17	63.0	9.5	.188	.221	-2.203	-.317
-2.27	69.0	3.5	.069	.081	-2.282	-.328
-1.67	40.0	32.5	.642	.756	-1.784	-.257
-1.62	35.5	37.0	.731	.860	-1.749	.252
-1.57	32.0	40.5	.800	.942	-1.712	-.246
-1.45	25.0	47.5	.938	1.104	-1.616	-.233
-1.57	23.0	49.5	.978	1.151	-1.743	-.251
-3.97	12.0	60.5	1.195	1.407	-4.282	-.616
-5.17	-3.0	75.5	1.491	1.756	-5.435	-.782
-5.37	9.5	63	1.245	1.465	-5.59	-.895
-5.07	14.5	58	1.145	1.350	-5.28	-.761
-3.12	29.0	43.5	.861	1.012	-3.27	-.470
-2.62	36.0	36.5	.725	.851	-2.75	-.396
-3.07	52.5	20.0	.396	.467	-3.14	-.452
-3.17	56	16	.316	.372	-3.226	-.465

* MULTI-CYCLE

W/C .50* AGE 1 day

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-3.22	58.5	13.5	.267	.312	-3.265	-.470
-3.47	66.0	6.0	.118	.140	-3.492	-.502
-2.77	35.0	37.0	.730	.861	-2.901	-.416
-2.67	30.0	42.0	.830	.980	-2.820	-.406
-2.67	24.0	48.0	.950	1.120	-2.840	-.410
-2.87	23.0	49.0	.970	1.140	-3.040	-.437
-4.17	18.0	53.0	1.050	1.235	-4.355	-.623
-4.92	4.5	66.5	1.315	1.550	-5.155	-.743
-5.17	7.0	64.0	1.265	1.490	-5.395	-.780
-4.97	25.5	38.5	.761	.897	-5.106	-.734
-3.32	31.0	31.5	.622	.735	-3.433	-.495
-3.12	37.5	25.0	.493	.582	-3.209	-.464
-3.22	46.5	16.0	.316	.372	-3.276	-.472
-.357	68.0	4.5	.089	.105	-3.586	-.519
-3.02	41.0	31.5	.622	.735	-3.133	-.452
-3.02	34.0	38.5	.760	.895	-3.155	-.456
-2.82	26.5	46.0	.910	1.070	-2.980	-.430

* MULTI-CYCLE

W/C .50* AGE 1 day

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-2.77	21.1	51.4	1.010	1.190	-2.950	-.426
-2.87	21.1	51.4	1.010	1.190	-3.050	-.441
-3.17	19.0	53.4	1.061	1.240	-3.349	-.484
-3.77	1.0	71.0	1.405	1.650	-4.015	-.580
-4.22	8.50	63.5	1.255	1.480	-4.45	-.644
-4.27	14.00	58.0	1.145	1.350	-4.48	-.650
-4.32	22.00	50.0	.987	1.165	-4.50	-.651
-3.57	28.00	44.0	.870	1.025	-3.73	-.540
-3.32	40.00	32.0	.632	.745	-3.43	-.495
-3.47	46.0	26.0	.515	.605	-3.55	-.511
-3.67	57.5	14.5	.288	.338	-3.72	-.536
-3.77	61.0	10.5	.207	.244	-3.81	-.548
-3.42	40.0	31.5	.624	.735	-3.53	-.510
-3.38	38.5	33.0	.653	.770	-3.50	-.506
-3.23	33.0	38.5	.761	.900	-3.37	-.486
-3.08	22.5	46.0	.910	1.075	-3.25	-.469
-3.33	18.5	50.0	.990	1.165	-3.51	-.506

* MULTI-CYCLE

W/C .50 * AGE 1 day

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-3.43	4.5	64.0	1.265	1.491	-3.66	-.529
-3.43	3.0	65.5	1.295	1.520	-3.66	-.529
-3.33	0	68.5	1.350	1.590	-3.57	-.515
-3.48	9	59.5	1.175	1.381	-3.686	-.531
-3.53	20.5	48.0	.950	1.115	-3.695	-.532
-3.33	30.5	38.0	.750	.883	-3.463	-.497
-3.38	34.0	34.5	.682	.801	-3.499	-.504
-3.43	40.5	28.0	.552	.651	-3.529	-.511
-3.50	45.0	23.5	.464	.546	-3.582	-.516
-3.78	54.0	14.5	.286	.337	-3.831	-.552
-4.28	62.5	6.0	.118	.139	-4.301	-.620
-3.48	36.5	32	.634	.745	-3.591	-.518
-3.38	33.0	35.5	.702	.830	-3.508	-.506
-3.28	28.0	40.5	.800	.945	-3.325	-.478
-3.20	20.0	48.5	.960	1.130	-3.370	-.485
-3.18	13.0	55.5	1.100	1.295	-3.375	-.486
-3.18	8.0	60.5	1.195	1.410	-3.395	-.489

* MULTI-CYCLE

W/C .50 * AGE 1 day

AIR ______ ADMIXTURE ______

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-3.13	3.0	65.5	1.292	1.530	-3.368	-.485
-3.68	45.0	23.5	.465	.550	-3.765	-.542
-4.28	60.0	8.5	.168	.199	-4.311	-.621
-4.38	65.0	3.5	.069	.082	-4.393	-.634
-3.68	40.0	28.5	.552	.665	-3.793	-.547
-3.43	29.2	39.5	.781	.921	-3.570	-.515

* MULTI-CYCLE

W/C .70* AGE 1 day
AIR 15% ADMIXTURE AEA; RF

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.64	63	15	.296	.349	.587	.084
.77	60	18	.356	.419	.707	.102
1.20	48	30	.593	.698	1.095	.158
1.77	41	37	.731	.860	1.641	.236
1.88	36.5	41.5	.820	.965	1.735	.250
2.03	28.9	49.1	.970	1.142	1.858	.267
2.07	26.1	51.9	1.025	1.207	1.888	.272
1.12	23.5	54.5	1.076	1.267	.929	.134
1.14	21.7	56.8	1.122	1.321	.941	.135
1.26	15.0	63.5	1.254	1.477	1.037	.149
1.34	11.0	67.5	1.333	1.569	1.104	.159
1.60	.80	77.7	1.535	1.807	1.328	.191
1.43	16.5	62	1.225	1.442	1.213	.175
1.28	22.0	56.5	1.116	1.314	1.082	.156
1.26	33.0	45.5	.899	1.058	1.091	.157
1.60	34.5	44.0	.859	1.023	1.436	.207
2.06	38.5	40.0	.790	.930	1.920	.276

* MULTI-CYCLE

W/C .70 * AGE 1 day
AIR 15% ADMIXTURE AEA; RF

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
2.84	44.8	33.7	.666	.784	2.722	.392
2.94	49.5	29.0	.573	.674	2.773	.399
3.07	52.5	26.0	.514	.605	2.979	.429
3.34	66.0	18.5	.365	.430	3.275	.471
3.33	70.0	14.5	.286	.337	3.279	.472
4.07	37.2	47.3	.934	1.100	3.904	.562
4.07	31.5	53.0	1.047	1.232	3.885	.559
4.22	25.5	59.0	1.165	1.372	4.013	.577
3.45	21.2	63.3	1.250	1.472	3.228	.464
3.43	20.6	63.9	1.262	1.486	3.206	.461
3.82	-9.0	93.5	1.847	2.174	3.493	.503
3.75	-3.0	87.5	1.728	2.034	3.444	.496
3.60	8	76.5	1.511	1.779	3.332	.479
3.50	16	68.5	1.353	1.592	3.261	.469
3.32	27	57.0	1.126	1.325	3.121	.449
3.25	32.5	51.5	1.017	1.197	3.070	.442
3.75	35.5	48.5	.958	1.128	3.580	.515

* MULTI-CYCLE

W/C .70 * AGE 1 day

AIR 15% ADMIXTURE AEA; RF

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
4.07	38.0	46.5	.918	1.081	3.907	.562
3.60	69.5	14.0	.277	.326	3.551	.511
4.22	35.0	49.0	.968	1.139	4.049	.583
4.42	29.0	54.0	1.067	1.256	4.231	.609
4.45	21.0	62.0	1.225	1.442	4.233	.609
3.55	16.5	66.5	1.313	1.546	3.317	.477
3.62	11.0	72.0	1.422	1.674	3.368	.485
3.72	10.0	73.0	1.442	1.697	3.465	.499
3.82	5.0	78.0	1.541	1.814	3.547	.510

* MULTI-CYCLE

W/C .50* AGE 1 day
AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.28	32.5	41.5	.810	.968	1.122	.162
0.42	28.0	46.0	.910	1.070	.260	.038
-5.40	21.0	53.0	1.045	1.230	-5.585	-.807
-8.70	19.0	55.0	1.085	1.280	-8.895	-1.285
-11.0	15.0	59.0	1.165	1.370	-11.205	-1.620
-12.45	0	4.0	1.460	1.720	-12.710	-1.835
-12.10	17.5	56.5	1.115	1.310	-12.295	-1.777
-11.70	23.5	50.5	1.000	1.175	-11.875	-1.720
-10.80	29.0	45.0	.890	1.045	-10.955	-1.585
- 9.70	31.0	43.0	.850	1.000	- 9.850	-1.425
- 5.20	33.0	41.0	.810	.951	- 5.341	- .775
- 3.05	36.0	38.0	.750	.882	- 3.182	- .461
- 2.35	37.2	36.8	.725	.855	- 2.480	- .359
- 1.29	48.0	26.0	.512	.602	- 1.380	- .200
- 1.45	56.5	17.5	.346	.406	- 1.510	- .219
- 1.52	60.5	13.5	.267	.313	- 1.566	- .226
- 1.55	62.5	11.5	.227	.267	- 1.590	- .230

* MULTI-CYCLE

W/C .50 * AGE 1 day

AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
- 0.94	32	42	.830	.975	-1.085	- .157
- 0.95	30	44	.870	1.025	-1.105	- .160
- 1.01	27	47	.930	1.095	-1.175	- .170
- 1.96	26	48	.950	1.115	-2.125	- .305
- 6.66	20	54	1.065	1.255	-6.850	- .990
- 8.36	17	57	1.125	1.325	-8.560	-1.245
- 9.96	2.5	71.5	1.410	1.665	-10.215	-1.480
-10.60	-10	84	1.660	1.955	-10.895	-1.570
-10.65	5	69	1.360	1.605	-10.895	-1.570
-10.50	16	58	1.145	1.350	-10.705	-1.550
- 8.90	29	45	.887	1.045	- 9.058	-1.320
- 8.20	30	44	.868	1.025	- 8.357	-1.215
- 2.95	36.5	37.5	.742	.874	- 3.082	- .444
- 2.55	41.5	32.5	.640	.760	- 2.670	- .386
- 2.59	44.5	29.5	.582	.687	-2.695	- .389
- 2.65	48.0	26.0	.514	.605	-2.741	- .395
- 2.85	58.5	15.5	.306	.361	-2.905	- .420

W/C .50 * AGE 1 day

AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-2.40	31.5	42.5	.840	.990	-2.550	-.368
-2.35	29.0	45	.890	1.050	-2.510	-.362
-2.35	28.0	46	.910	1.070	-2.510	-.362
-2.90	26.0	48	.950	1.115	-3.065	-.441
-3.90	22.1	52	1.030	1.210	-4.080	-.588
-5.50	19.0	55	1.085	1.280	-5.695	-.822
-8.75	9.0	65	1.285	1.515	-8.980	-1.295
-9.20	-11.0	84	1.660	1.960	-9.500	-1.370
-9.50	5	68	1.340	1.580	-9.740	-1.395
-9.30	11	62	1.225	1.440	-9.515	-1.369
-8.60	28	45	.890	1.045	-8.755	-1.260
-7.10	30	43	.850	1.000	-7.250	-1.045
-4.10	33	40	.790	.931	-4.241	- .606
-3.10	36	37	.730	.860	-3.230	- .465
-3.05	59	17	.336	.396	-3.110	- .448
-3.10	58.5	15.5	.306	.360	-3.154	- .455
-3.15	62	12.0	.237	.280	-3.193	- .460

* MULTI-CYCLE

W/C .50 * AGE 1 day

AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-2.70	35	39	.770	.910	- .284	-.410
-2.55	29	45	.890	1.045	-2.705	-.390
-2.45	23	51	1.010	1.185	-2.625	-.378
-3.30	24	50	.985	1.160	-3.475	-.500
-7.20	13	61	1.210	1.415	-7.505	-1.090
-7.60	0	74	1.460	1.725	-7.865	-1.130
-7.65	5	69	1.360	1.610	-7.900	-1.140
-5.20	31.5	42.5	.840	.991	-5.351	- .771
-3.50	59.0	13	.257	.303	-3.546	- .512
-3.05	33.5	40.5	.800	.945	-3.195	- .461
-3.05	31.5	42.5	.840	.992	-3.202	- .462
-2.80	22.0	52.0	1,030	1.215	-2.985	- .430
-3.20	26.0	48.0	.950	1.120	-3.370	- .487
-3.77	23.0	51.0	1.010	1.190	-3.950	- .570
-6.30	13.0	61.0	1.205	1.425	-6.520	- .940
-6.40	10.0	64.0	1,265	1.495	-6.620	- .955
-6.80	-2.0	76.0	1.505	1.775	-7.070	-1.02

* MULTI-CYCLE

W/C .50 * AGE 1 day

AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$, %
-7.05	3	71	1.405	1.660	-7.305	-1.05
-7.00	10	64	1.265	1.495	-7.230	-1.04
-7.03	19.5	54.5	1.075	1.275	-7.230	-1.04
-6.90	23.0	51.0	1.010	1.190	-7.080	-1.02
-5.05	31.0	43.0	.850	1.000	-5.200	- .750
-4.45	32.0	42.0	.830	.980	-4.600	- .662
-3.30	38.0	36.0	.710	.840	-3.430	- .494
-3.50	59	15	.296	.350	-3.554	- .512
-2.98	33	41	.810	.955	-3.125	- .450
-2.98	31	43	.850	1.000	-3.130	- .452
-2.88	23	51	1.010	1.190	-3.060	- .440
-3.16	26	48	.950	1.120	-3.330	- .475
-3.76	21	53	1.050	1.235	-3.945	- .568
-6.18	9	65	1.285	1.515	-6.410	- .921
-6.28	2	72	1.425	1.680	-6.535	- .940
-6.33	0	74	1.465	1.725	-6.590	- .950
-6.03	26	48	.950	1.120	-6.200	- .892

* MULTI-CYCLE

W/C .50* AGE 1 day
AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-4.76	31	43	.850	1.000	-4.910	-.706
-3.93	33.5	40.5	.800	.944	-4.074	-.586
-3.53	62.0	12.0	.238	.279	-3.571	-.514
-3.01	33.5	40.5	.800	.944	-3.154	-.454
-2.93	28.5	45.5	.900	1.060	-3.090	-.445
-3.08	27.0	47.0	.930	1.095	-3.245	-.467
-3.33	24.0	50	.990	1.165	-3.55	-.512
-5.58	-4.0	78	1.540	1.815	-5.855	-.844
-5.73	3	71	1.405	1.655	-5.990	-.865
-5.73	10	64.0	1.265	1.490	-5.955	-.756

* MULTI-CYCLE

W/C .50 * AGE 19 days
AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.28	33.5	40.5	.800	.945	1.135	.164
1.40	26.0	48.0	.946	1.115	1.231	.175
1.54	23	51.0	1.005	1.185	1.360	.196
-.63	15.5	58.5	1.155	1.360	-.835	-.120
-1.08	13.0	61.0	1.205	1.420	-1.295	-.186
-1.[illegible]3	7.5	66.5	1.315	1.550	-1.865	-.268
-2.03	5.0	69.0	1.365	1.610	-2.275	-.328
-2.46	3.5	70.5	1.391	1.640	-2.709	-.390
-2.93	0	74.0	1.460	1.720	-3.190	-.455
-3.73	-2.5	76.5	1.510	1.780	-4.000	-.575
-3.98	-2.0	76.0	1.500	1.770	-4.250	-.615
-3.78	11.50	62.5	1.235	1.455	-4.000	-.575
-3.63	27.0	47.0	.926	1.095	-3.799	-.548
-1.73	32.0	42	.829	.980	-1.881	-.272
- .83	34	40	.790	.934	-.974	-.141
- .78	38.5	35.5	.700	.828	-.908	-.131
-1.28	67.5	6.5	.119	.152	-1.313	-.189

* MULTI-CYCLE

W/C .50 * AGE 19 days

AIR – ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-.73	33.0	41	.810	.955	- .875	-.127
-.73	31.5	42.5	.840	.990	- .880	-.127
-.73	25.0	39.0	.770	.910	- .870	-.126
-1.11	20.5	53.5	1.055	1.245	-1.300	-.188
-1.28	19.5	54.5	1.075	1.270	-1.475	-.214
-1.88	15.5	58.5	1.155	1.365	-2.090	-.302
-2.30	12.5	61.5	1.215	1.431	-2.516	-.363
-3.23	6.0	68.0	1.345	1.585	-3.470	-.502
-4.36	-1.5	75.5	1.490	1.760	-4.630	-.670
-4.48	0	74.0	1.465	1.720	-4.735	-.682
-4.23	3	71.0	1.405	1.655	-4.480	-.645
-4.18	13	61	1.205	1.420	-4.395	-.633
-4.03	22	52	1.030	1.210	-4.210	-.606
-3.98	26.5	47.5	.940	1.105	-4.145	-.597
-1.68	53.0	21.0	.415	.490	-1.755	-.252
-1.78	58.2	16.0	.316	.373	-1.837	-.265
-1.38	34.0	40.0	.792	.932	-1.520	-.219

* MULT-CYCLE

W/C .50* AGE 19 days

AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$, %
-1.45	29.5	40.5	.801	.945	-1.594	-.229
-3.97	0	74.0	1.465	1.725	-4.230	-.610
-4.82	-4.5	78.5	1.550	1.830	-5.100	-.735
-4.67	6	68.0	1.345	1.585	-4.910	-.706
-4.67	16	58.0	1.145	1.350	-4.875	-.702
-3.72	29.5	44.5	.880	1.040	-3.880	-.558
-2.22	56.0	18.0	.356	.420	-2.284	-.328
-2.37	60.0	14.0	.276	.327	-2.421	-.348
-1.89	32.5	41.5	.820	.969	-2.039	-.293
-1.84	28.0	46.0	.910	1.075	-2.005	-.288
-1.74	24.0	5.0	.987	1.165	-1.918	-.276
-1.94	18.0	56	1.105	1.308	-2.143	-.308
-2.84	9.0	65	1.282	1.518	-3.076	-.442
-4.64	-4.0	78	1.540	1.820	-4.920	-.706
-4.69	1	73	1.440	1.705	-4.955	-.712
-4.49	11	63	1.245	1.470	-4.715	-.677
-4.14	21.5	52.5	1.035	1.225	-4.330	-.621

* MULTI-CYCLE

W/C .50 * AGE 19 days

AIR - ADMIXTURE FA - 30%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-3.34	30	44.0	.870	1.028	-3.498	-.502
-2.24	40.5	33.5	.651	.782	-2.361	-.340
-2.64	59.5	14.5	.286	.338	-2.692	-.387
-2.67	62	12	.237	.280	-2.713	-.390

* MULTI-CYCLE

W/C .50 * AGE 1 day
AIR - ADMIXTURE FA - 45%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.57	55	21	.412	.489	.492	.072
1.27	32.5	43.5	.860	1.015	1.115	.160
-7.78	23.5	52.5	1.035	1.220	-7.965	-1.145
-10.28	15.0	61.0	1.201	1.420	-11.501	-1.650
-12.37	10.0	66.0	1.301	1.531	-12.60	-1.810
-12.94	5.0	71.0	1.400	1.651	-13.20	-1.900
-13.77	0.0	76.0	1.500	1.770	-13.90	-2.00
-13.32	10.0	66.0	1.301	1.531	-13.55	-1.950
-13.34	20.0	56.0	1.101	1.310	-13.55	-1.950
-13.03	28.0	48.0	.950	1.120	-13.20	-1.900
-11.65	30	46.0	.910	1.075	-11.80	-1.700
-2.38	32	44	.870	1.022	-2.022	- .365
1.06	32	44	.870	1.022	.908	-1.31
3.20	36	40	.790	.935	3.055	- .440

* Large Horizontal and Vertical Cracks After Cycling

W/C .50 AGE 5 days

AIR - ADMIXTURE FA - 45%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.21	33	41	.810	.955	1.065	.153
1.31	26	48	.950	1.118	1.142	.164
-1.17	24	50	.990	1.117	-1.297	-.187
-2.10	23	51	1.010	1.119	-2.209	-.318
-2.40	23	51	1.010	1.119	-2.509	-.361
-2.72	22.5	51.5	1.020	1.200	-2.900	-.417
-3.42	22.5	51.5	1.020	1.200	-3.600	-.518
-8.72	17.5	56.5	1.115	1.315	-8.920	-1.285
-8.87	9.0	65.0	1.285	1.515	-9.100	-1.310
-8.92	-2.0	76.0	1.500	1.770	-9.190	-1.325
-9.02	9.0	65.0	1.285	1.515	-9.450	-1.360
-8.82	13.0	61.0	1.200	1.420	-9.040	-1.300
-8.82	17.5	56.5	1.115	1.315	-9.020	-1.290
-8.22	25.0	49.0	.970	1.140	-8.390	-1.210
-7.82	29.0	45.0	.890	1.050	-7.980	-1.150
-2.12	35.5	38.5	.760	.896	-2.256	-.325
1.58	44.5	29.5	.582	.687	1.475	.212
1.38	56.0	18.0	.356	.420	1.316	.189

W/C .50 * AGE 1 day
AIR - ADMIXTURE FA - 45%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.13	59.5	15.0	.297	.348	.08	.012
.34	39.0	35.5	.707	.825	.223	.032
-.18	34.0	40.5	.800	.945	- .325	-.047
.07	25.5	49.0	.966	1.140	-.104	-.015
.37	17.0	57.5	1.135	1.340	.165	.023
.57	10.0	64.5	1.275	1.500	.345	.050
.72	6.0	68.5	1.355	1.600	.475	.059
.92	0	74.5	1.470	1.740	.650	.094
1.07	-3	77.5	1.530	1.805	.795	.115
.12	24	50.5	1.000	1.175	-.055	-.008
-.23	37.5	37.0	.730	.861	-.361	-.052
.32	43	31.5	.622	.735	.207	.030
.20	57	17.5	.346	.408	.138	.020
.09	68	6.5	.129	.148	.069	.010

* Benzene Saturated

W/C .50 AGE 1 day

AIR 15% ADMIXTURE FA - 45%; AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.00	33.5	40.5	.800	.940	.860	.124
1.07	27.5	46.5	.920	1.080	.910	.131
1.02	26.0	48.0	.950	1.120	.850	.122
1.10	17.5	56.5	1.115	1.315	.900	.129
1.22	11.5	62.5	1.230	1.455	.995	.143
1.32	6.5	68.0	1.340	1.585	1.075	.155
1.52	0	74.0	1.460	1.725	1.255	.180
1.72	-5	79.0	1.560	1.840	1.440	.207
1.52	3	71.0	1.400	1.655	1.265	.182
1.12	24	50.0	.990	1.165	.945	.136
1.02	30	44.0	.870	1.025	.865	.125
0.59	67	7.0	.138	.163	.565	.081

W/C .50 AGE 1 day

AIR - ADMIXTURE FA - 15%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.07	33	43	.850	1.000	.920	.133
1.14	25	51	1.005	1.190	.955	.138
-4.81	15.5	60.5	1.410	1.410	-5.025	-.721
-7.36	12.0	64.0	1.265	1.490	-8.585	-1.24
-8.91	2.5	73.5	1.450	1.715	-9.175	-1.32
-9.11	-1.0	77	1.520	1.795	-9.385	-1.36

W/C .50 * AGE 1 day
AIR - ADMIXTURE FA - 15%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.07	33	43	.850	1.000	.920	.132
1.14	25	51	1.010	1.190	.960	.138
-4.81	15.5	60.5	1.200	1.410	-5.020	-.721
-7.36	12.0	64.0	1.270	1.490	-7.580	-1.090
-8.91	2.5	73.5	1.455	1.710	-9.165	-1.320
-9.10	-1.0	77.0	1.525	1.795	-9.270	-1.340
-8.86	11.5	64.5	1.278	1.500	-9.082	-1.30
-8.86	16.0	60.0	1.190	1.400	-9.070	-1.28
-8.16	23.5	52.5	1.040	1.222	-8.342	-1.20
-7.46	26.5	49.5	.970	1.155	-7.645	-1.10
-5.56	31.5	44.5	.880	1.035	-5.715	-.821
-5.06	34.0	42.0	.830	.977	-5.207	-.748
-1.81	57.5	18.5	.366	.430	-1.874	-.268
-1.93	65.5	10.5	.208	.244	-1.966	-.282
-1.35	33.0	43.0	.850	1.000	-1.500	-.216
-1.45	27	49.0	.970	1.140	-1.620	-.232
-1.96	24	52.0	1.030	1.210	-2.140	-.308

* MULTI-CYCLE

W/C .50 * AGE 1 day
AIR - ADMIXTURE FA - 15%

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
-4.05	20	56	1.110	1.305	-4.245	-.611
-7.08	9.5	66.5	1.315	1.550	-7.315	-1.05
-7.53	-4.0	80	1.580	1.860	-7.810	-1.12
-3.25	34	42	.830	.977	-3.397	-.487
-3.18	29.5	46.5	.920	1.070	-3.330	-.475
-3.08	21.5	54.5	1.078	1.265	-3.267	-.470
-3.33	24.0	52.0	1.030	1.210	-3.513	-.510
-6.43	16.0	60.0	1.185	1.395	-6.640	-.955
-7.33	10.0	66.0	1.310	1.535	-7.555	-1.085
-7.73	1.5	74.5	1.460	1.730	-8.000	-1.150
-7.83	-4.0	80	1.580	1.860	-8.110	-1.170
-7.73	-1.15	80	1.580	1.860	-8.010	-1.150
-7.73	5	71	1.405	1.650	-7.975	-1.150
-4.18	75	1	.019	.023	-4.188	- .600

* MULTI-CYCLE

W/C 1.0 AGE 1 day

AIR ______ ADMIXTURE RF

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
2.01	41	37	.731	.861	1.871	.268
2.18	36.2	41.8	.825	.966	2.039	.292
2.29	30.0	48.0	.950	1.120	2.120	.304
1.11	28.5	49.5	.980	1.150	0.940	.135
0.23	25.9	52.1	1.030	1.210	0.050	.007
-1.56	23.5	54.5	1.075	1.270	-1.765	-.252
-2.06	22.4	55.6	1.100	1.292	-2.252	-.323
-2.36	22.0	56.0	1.110	1.301	-2.55	-.366
-2.86	21.9	56.1	1.111	1.303	-3.05	-.437
-4.06	18.5	59.5	1.1175	1.385	-4.328	-.621
-4.36	18.0	60.0	1.1185	1.395	-4.637	-.666
-6.16	14.0	64.0	1.265	1.490	-6.385	-.912
-6.86	10.0	68.0	1.341	1.580	-7.100	-1.04
-5.00	11.8	66.2	1.310	1.540	-5.230	-.750
-4.00	29.2	48.8	.966	1.120	-4.154	-.595
2.20	40.0	38.0	.750	.884	2.066	-.296
3.40	48.5	29.5	.582	.687	3.293	-.472

W/C 1.0 AGE 1 day

AIR ______ ADMIXTURE RF

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
3.37	52.5	25.5	.502	.592	2.276	-.326
3.30	56.5	21.5	.425	.500	3.225	-.463
3.22	61.5	16.5	.326	.384	3.162	-.455
3.10	73.5	4.0	.079	.093	3.086	-.442

W/C 1.0 AGE 1 day

AIR - ADMIXTURE R.F.

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
2.01	41	37	.731	.860	1.871	.269
2.18	36.2	41.8	.826	.972	2.034	.293
2.29	30.0	48.0	.948	1.116	2.122	.305
1.11	28.5	49.5	.978	1.151	.937	.135
.23	25.9	52.1	1.029	1.211	.048	.007
-1.56	23.5	54.5	1.076	1.267	-1.751	-.252
-2.06	22.4	55.6	1.098	1.293	-2.255	-.324
-2.36	22.0	56.0	1.106	1.302	-2.556	-.368
-2.86	21.9	56.1	1.108	1.304	-3.056	-.440
-4.06	18.5	59.5	1.175	1.383	-4.268	-.614
-4.36	18.0	60.0	1.185	1.395	-4.570	-.658
-6.16	14.0	64.0	1.264	1.488	-6.384	-.919
-6.86	10.0	68.0	1.343	1.581	-7.098	-1.021
-6.86	11.8	66.2	1.307	1.539	-7.092	-1.020
-5.86	29.2	48.8	.964	1.135	-6.031	-.858
.34	40.0	38.0	.751	.884	.207	.030
1.54	48.5	29.5	.583	.686	1.437	.206

W/C 1.0 AGE 1 day

AIR - ADMIXTURE R.F.

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.51	52.5	25.5	.504	.593	1.421	-.204
1.44	56.5	21.5	.425	.500	1.365	.196
1.36	61.5	16.5	.326	.384	1.302	.187
1.24	73.5	4.0	.079	.093	1.226	.176

W/C 1.0 AGE 1 day

AIR - ADMIXTURE R.F.

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.35	57.0	19	.375	.442	1.283	.185
2.20	39.5	36.5	.721	.849	2.072	.298
2.28	36.5	39.5	.780	.918	2.142	.308
2.40	31.5	44.5	.879	1.035	2.244	.323
-2.20	27.0	49.0	.958	1.139	-2.381	-.343
-2.50	25.0	51.0	1.007	1.186	-2.679	-.385
-3.50	16.0	60	1.135	1.395	-3.710	-.534

W/C 1.0 AGE 1 day
AIR 10% ADMIXTURE RF: AEA

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch}\cdot\Delta T$	ΔHg · ΔT	ΔV(ml)	$\frac{\Delta V}{V}$,%
.840	37	35	.692	.816	.716	.103
.900	32.5	39.5	.780	.921	.759	.109
1.08	23.5	48.5	.959	1.131	.908	.131
.899	26.5	45.5	.900	1.061	.738	.106
.520	21.0	51.0	1.010	1.190	.340	.049
-.830	12.0	60.0	1.185	1.400	-1.045	-.150
-.980	2.0	70.0	1.381	1.631	-1.231	-.177
-.660	28.5	43.5	.860	1.015	- .815	-.117
-.430	44.0	28.0	.552	.653	- .531	-.076
-.780	70.0	2.0	.0395	.0466	- .788	-.113

W/C .60 AGE 1 day

AIR ____ ADMIXTURE Mortar 1:1.75

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
1.30	1.0	66.0	1.310	1.540	1.070	.154
1.22	12.5	54.5	1.080	1.270	1.030	.148
.97	25.0	42.0	.833	.981	.822	.1185
.90	29.0	48.0	.952	1.120	.732	.1055
.59	53.0	14.0	.278	.328	.532	.076
.55	55.0	12.0	.238	.281	.506	.073
.51	57.5	9.5	.188	.222	.476	.068
.70	37.0	30.0	.595	.701	.594	.085
.78	31.0	36.0	.715	.842	.653	.094
.81	28.5	38.5	.765	.900	.675	.097
1.05	14.0	53.0	1.050	1.235	.865	.124
1.11	11.0	56.0	1.110	1.310	.910	.131
1.17	9.0	58.0	1.150	1.355	.965	.139
.43	60.0	7.0	.139	.163	.406	.058
.40	63.0	4.0	.079	.093	.386	.056
.37	65.0	2.0	.040	.046	.364	.052
.72	24.0	43.0	.855	1.000	.575	.083
.50	61.0	6.0	.119	.140	.479	.069

W/C .60 AGE 1 day

AIR ______ ADMIXTURE Mortar 1:1.75

ΔR(ml)	T(°F)	ΔT	$\Delta_{ch} \cdot \Delta T$	$\Delta Hg \cdot \Delta T$	ΔV(ml)	$\frac{\Delta V}{V}$,%
.30	56.5	10.5	.207	.245	.262	.038
.40	51.0	16.00	.316	.373	.343	.049
.82	23.5	43.5	.860	1.010	.670	.096
.40	25.0	42.0	.830	.980	.250	.036
.28	24.0	41.0	.810	.955	.135	.019
.41	-3.0	70.0	1.380	1.630	.160	.023
.40	7.5	59.5	1.170	1.390	.180	.026
.22	27.5	39.5	.792	.921	.091	.013
.20	30.0	37.0	.731	.863	.068	.010
.72	34.5	32.5	.642	.753	.609	.088
.36	65.0	2.0	.039	.467	.068	.010
.50	53.5	13.5	.267	.315	.452	.065
.71	37.5	29.5	.584	.687	.607	.087
.96	24.0	43.0	.850	1.000	.810	.117
.81	26.0	41.0	.811	.956	.665	.0956
.90	20.5	46.5	.921	1.085	.736	.106
.95	16.0	51.0	1.010	1.190	.770	.111

APPENDIX G

Length Change Data (Position Transducers)

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
48	1.55	.046
33	2.02	.061
31.5	2.38	.072
27.0	2.97	.089
19	−1.78	−.054
9	−9.72	−.292
0	−12.10	−.361
1	−12.70	−.382
3	−12.70	−.382
5	−12.30	−.368
9	−11.90	−.357
11	−9.96	−.298
14	−8.90	−.268
32	−4.50	−.135
48	−5.57	−.171
55	−5.82	−.176

W/C .50 AIR – AD. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
48	.83	.025
33	1.33	.040
31.5	1.33	.040
27.0	−.67	−.02
19	−3.33	−.100
9	−10.30	−.308
0	−13.00	−.390
1	−12.00	−.360
3	−12.00	−.360
5	−11.50	−.345
9	−10.70	−.321
11	− 8.17	−.245
14	− 6.32	−.190
32	− 2.67	−.081
48	− 3.83	−.116
55	− 4.00	−.120

W/C .50 AIR – AD. –
AGE A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
48	2.41	.072
33	3.83	.116
31.5	4.60	.138
27.0	4.93	.148
19	2.08	.062
9	–4.05	–.122
0	–5.80	–.174
1	–8.20	–.246
3	–9.75	–.295
5	–10.85	–.325
9	–10.70	–.320
11	– 8.40	–.252
14	– 6.77	–.202
32	– 2.84	–.085
48	– 4.26	–.127
55	– 4.59	–.138

W/C .50 AIR – , AD. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
48	.72	.021
33	1.19	.036
3.15	1.19	.036
27.0	.59	.018
19	–3.21	.096
9	–12.10	–.362
0	–14.70	–.440
1	–14.70	–.440
3	–14.40	–.432
5	–14.10	–.418
9	–13.50	–.402
11	–11.10	–.333
14	– 9.15	–.272
32	– 4.15	–.123
48	– 4.98	–.148
55	– 5.25	–.156

W/C .50 AIR – AD. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
48	3.74	.113
33	3.84	.116
31.5	4.83	.146
27.0	5.16	.156
19.0	1.76	.052
9.0	-4.17	-.126
0	-5.27	-.158
1	-7.70	-.232
3	-9.00	-.270
5	-10.40	-.314
9	-10.00	-.300
11	-7.15	-.215
14	-5.72	-.173
32	-2.97	-.089
48	-4.72	-.142
55	-5.17	-.155

W/C .50 AIR - AD. -

AGE 1d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
48	4.00	.120
33	4.95	.148
31.5	5.96	.179
27.0	6.42	.193
19.0	2.82	.085
9	-2.59	-.078
0	-3.49	-.104
1	-7.55	-.225
3	-8.66	-.260
5	-9.57	-.287
9	-9.57	-.287
11	-7.77	-.231
14	-6.20	-.186
32	-3.45	-.103
48	-5.07	-.152
55	-5.40	-.162

W/C .50 AIR - AD. -

AGE 1d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	-	-
65	.59	.018
55	1.25	.038
45	1.67	.050
32	1.68	.051
30	1.79	.054
25	1.79	.054
19	.72	.022
13	-7.50	-.225
10	-10.25	-.306
2	-11.10	-.332
0	-11.10	-.332
1	-11.10	-.332
6	-11.10	-.332
11	-11.10	-.332
18.5	-11.10	-.332

W/C .50 AIR - ADM. -
AGE 1d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
25	-7.85	-.235
33	-6.30	-.188
40	-6.42	-.192
46	-6.90	-.205
55	-7.26	-.217
60	-7.39	-.221

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
55	3.57	.108
45	4.17	.125
35	4.82	.145
19	4.75	.141
13	-2.86	-.086
10	-6.42	-.193
2	-9.75	-.293
0	-9.65	-.290
1	-11.65	-.350
6	-13.00	-.390
11	-13.45	-.403
18.5	-11.80	-.354
25.0	- 8.22	-.246
33	- 7.03	-.210
40	- 7.85	-.235

W/C .50 AIR – ADM. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
46	-8.59	-.257
55	-9.53	-.285
60	-9.90	-.297

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
65	2.14	.064
60	3.73	.112
55	3.84	.115
50	3.95	.119
45	3.95	.119
40	4.06	.121
35	4.06	.121
30	3.95	.118
25	4.87	.146
19	3.40	.102
13	−3.84	−.115
10	−7.57	−.227
2	−10.85	−.325
0	−10.75	−.323
1	−12.40	−.372

W/C .50 AIR – ADM. –

AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
6	−13.33	−.398
11	−13.60	−.407
18.5	−12.00	−.360
25	− 8.45	−.254
33	− 7.15	−.214
40	− 7.90	−.237
46	− 8.45	−.253
55	− 9.12	−.272
60	− 9.25	−.278

W/C ____ AIR ____ ADM. ____

AGE ____ A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
50	2.16	.065
45	2.50	.075
35	2.66	.079
30	2.82	.085
25	3.00	.100
19	-1.33	-.039
13	-12.60	-.372
10	-16.6	-.497
2	-17.5	-.525
0	-17.7	-.532
1	-17.9	-.538
6	-17.2	-.517
18.5	-16.6	-.496
25	-16.6	-.496
33	-12.8	-.383

W/C .50 AIR – ADM. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
40	-13.6	-.407
46	-14.3	-.428
55	-15.1	-.450
60	-15.3	-.461

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
55	1.29	.039
45	1.85	.055
35	2.67	.080
30	2.67	.080
25	3.03	.100
19	−.65	−.019
13	−9.90	−.298
10	−12.35	−.372
2	−13.00	−.390
0	−13.75	−.413
1	−13.85	−.417
6	−14.00	−.420
11	−14.20	−.427
18.5	−12.35	−.371
25	−11.10	−.333

W/C .50 AIR – ADM. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
33	−10.45	−.315
40	−10.75	−.338
46	−11.25	−.352
55	−11.75	−.352
60	−11.95	−.358

W/C____AIR____ADM.____
AGE____A/C____SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
55	1.47	.044
45	2.60	.078
33	3.95	.118
30	4.27	.127
25	4.27	.127
19	-2.40	-.072
13	-9.45	-.283
10	-12.60	-.372
2	-14.70	-.440
0	-14.30	-.427
1	-14.70	-.440
6	-14.70	-.440
11	-14.70	-.440
18.5	-12.40	-.370
25	- 8.65	-.259

W/C .50 AIR – ADM. –
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
33	-7.20	-.216
40	-7.50	-.225
46	-8.02	-.241
55	-8.95	-.268
60	-9.16	-.274

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	–	–
56	3.56	.103
43	3.91	.117
33	4.27	.128
25	6.42	.193
16	2.02	.061
9	.238	.007
7	.119	.004
15	–.59	–.018
0	–.77	–.023
15	–2.98	–.089
3	–3.69	–.111
12	–5.00	–.150
22	–4.64	–.139
30	–3.33	–.100
40	–2.85	–.086

W/C .50 AIR____ ADM.____
AGE 7d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
45	–3.92	–.117
52	–4.40	–.732

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
56	.74	.022
43	1.13	.034
33	1.78	.053
25	2.26	.068
16	-.47	-.0014
9	-3.10	-.093
7	-3.81	-.114
15	-4.76	-.142
0	-5.12	-.154
15	-5.24	-.157
3	-5.12	-.153
12	-4.52	-.135
22	-3.33	-.100
30	-2.50	-.075
40	-2.74	-.082

W/C .50 AIR____ ADM.____

AGE 7d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
45	-3.45	-.103
52	-3.69	-.111

W/C____ AIR____ ADM.____

AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
56	.27	.008
43	.50	.015
33	.77	.020
25	.88	.030
16	-1.43	-.043
9	-3.41	-.103
7	-3.85	-.116
15	-4.62	-.138
0	-4.72	-.141
15	-4.40	-.132
3	-4.27	-.128
12	-3.85	-.116
22	-2.53	-.076
30	-1.98	-.059
40	-2.09	-.062

W/C .50 AIR____ ADM.____
AGE 7d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
45	-2.64	-.079
52	-2.86	-.085

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
56	.42	.012
43	.67	.021
33	1.00	.030
25	1.50	.045
16	-.06	-.002
9	- 2.67	-.080
7	- 3.50	-.105
15	- 5.17	-.155
0	- 5.67	-.170
15	- 5.50	-.165
3	- 5.50	-.165
12	- 4.67	-.140
22	- 3.18	-.095
30	- 2.34	-.070
40	- 2.68	-.085

W/C .50 AIR____ ADM.____
AGE 7d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
45	-3.33	-.100
52	-3.33	-.100

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
56	2.27	.068
43	3.66	.109
33	4.90	.147
25	6.50	.195
16	6.36	.191
9	5.80	.174
7	5.68	.171
15	4.77	.143
0	4.66	.139
15	2.73	.082
3	2.16	.065
12	1.03	.031
22	1.14	.034
30	.910	.027
40	-.22	-.006

W/C .50 AIR____ ADM.____
AGE 7d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
45	-1.25	-.038
52	-1.82	-.055

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	4.31	.130
42	4.77	.143
36	5.00	.150
32.5	5.00	.150
25	6.70	.201
21.5	2.96	.088
17.0	-5.12	-.155
13.0	-8.86	-.266
8.0	-12.60	-.378
0	-13.30	-.400
9	-13.30	-.400
20	-13.30	-.400
30	-8.28	-.250
51.5	-10.30	-.310
61.5	-11.20	-.337

W/C .50 AIR____ AD. lignin
AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.26	.068
42	2.62	.079
36	2.62	.079
32.5	2.74	.082
25.0	3.57	.108
21.5	-.357	-.108
17.0	-7.48	-.224
13.0	-11.75	-.354
8.0	-14.5	-.436
0	-14.5	-.436
9	-14.5	-.436
20	-13.65	-.411
30	-8.55	-.255
51.5	-10.00	-.300
61.5	-10.35	-.312

W/C .50 AIR____ AD. lignin
AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	1.43	.043
42	1.67	.050
36	1.67	.050
32.5	1.67	.051
25	2.38	.072
21.5	1.55	.047
17.0	-5.70	-.171
13.0	-9.30	-.278
8.0	-12.60	-.378
0.0	-13.80	-.415
9.0	-13.80	-.415
20	-9.80	-.296
30	-5.85	-.176
51.5	-7.30	-.219
61.5	-7.50	-.225

W/C .50 AIR ____ AD. lignin
AGE 5d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.42	.073
42	2.96	.089
36	3.16	.095
32.5	3.29	.099
25	4.61	.139
21.5	1.53	-.046
17.0	-4.95	-.149
13.0	-8.55	-.267
8.0	-12.20	-.362
0.0	-12.70	-.381
9.0	-12.70	-.381
20	-12.70	-.381
30	-8.0	-.240
51.5	-9.65	-.290
61.5	-9.75	-.293

W/C .50 AIR ____ AD. lignin
AGE 5d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.96	.089
42	3.62	.109
36	3.84	.116
32.5	3.92	.117
25.0	4.50	.135
21.5	-1.42	-.043
17.0	-8.57	-.256
13.0	-12.50	-.374
8	-13.20	-.394
0	-13.20	-.394
9	-13.20	-.394
20	-13.20	-.394
30	-9.65	-.290
51.5	-11.40	-.364
61.5	-11.90	-.358

W/C .50 AIR____ AD. lignin
AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %

W/C____ AIR____ AD.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60.5	2.64	.079
50.5	3.84	.115
44.5	4.27	.129
38.0	4.74	.143
33.0	5.05	.152
24.5	4.07	.122
21.5	3.08	.092
19.0	1.85	.055
9.5	-.77	-.023
-3.5	-2.08	-.062
2.0	-6.57	-.197
25.0	-4.28	-.123
37.0	-3.51	-.106
45.0	-4.61	-.138
60.5	-5.27	-.157

W/C .50 AIR ____ AD. lignin
AGE 12d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60.5	1.33	.040
50.5	1.83	.055
44.5	2.00	.060
38.0	2.33	.070
33.0	2.33	.070
24.5	2.83	.085
21.5	-2.00	-.060
19.0	-4.00	-.120
9.5	-9.85	-.295
-3.5	-12.70	-.380
2.0	-11.30	-.338
25.0	-7.17	-.215
37.0	-6.32	-.190
45.0	-7.32	-.220
60.5	-7.85	-.236

W/C .50 AIR ____ AD. lignin
AGE 12d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60.5	.72	.022
50.5	.96	.029
44.5	1.19	.036
38.0	1.19	.036
33.0	1.31	.040
24.5	.48	.014
21.5	-.48	-.014
19.0	-1.43	-.043
9.5	-4.62	-.139
-3.5	-6.78	-.204
2.0	-6.19	-.186
25	-3.57	-.107
37	-2.98	-.089
45	-3.57	-.107
60.5	-3.81	-.115

W/C .50 AIR ____ AD. lignin
AGE 12d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60.5	1.97	.059
50.5	2.41	.072
44.5	2.73	.082
38.0	3.06	.092
33.0	3.39	.102
24.5	1.97	.059
21.5	.55	.017
19.0	-.55	-.017
9.5	-3.28	-.099
-3.5	-4.37	-.132
2.0	-8.10	-2.42
25	-4.92	-.147
37	-4.72	-.142
45	-5.25	-.157
60.5	-5.70	-.171

W/C .50 AIR ____ AD. lignin
AGE 12d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60.5	1.43	.043
50.5	2.03	.061
44.5	2.14	.064
38.0	2.38	.071
33.0	2.50	.075
24.5	2.97	.074
21.5	-.59	-.018
19.0	-1.78	-.054
9.5	-5.36	-.161
-3.5	-6.52	-.196
2.0	-6.78	-.202
25	-4.75	-.142
37	-4.40	-.132
45	-5.00	-.150
60.5	-5.35	-.161

W/C .50 AIR ______ AD. lignin
AGE 12d A/C ______ SAND ______

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60.5	1.82	.055
50.5	2.73	.082
44.5	3.52	.106
38.0	3.86	.116
33.0	4.07	.122
24.5	5.90	.177
21.5	2.04	.061
19.0	0	0
9.5	-4.54	-.136
-3.5	-5.22	-.157
2.0	-10.20	-.305
25	-5.10	-.153
37	-7.02	-.211
45	-7.95	-.238
60.5	-8.40	-.260

W/C .50 AIR ______ AD. lignin
AGE 12d A/C ______ SAND ______

T(°F)	$\frac{\Delta L}{L} x 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	3.25	.098
42	4.72	.142
33	5.07	.152
27	6.41	.193
26	6.41	.193
25	6.51	.196
15	4.72	.142
5	5.29	.158
0	6.30	.189
5	2.25	.067
17	-3.37	-.103
34	-6.75	-.203
52	-2.14	-.064
62	-2.36	-.071
65	-2.69	-.081
70	-3.22	-.097

W/C .50 **AIR** - **AD.** lignin
AGE 22d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} x 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	2.85	.086
42	3.94	.118
33	3.83	.115
27	5.25	.158
26	5.25	.158
25	5.46	.164
15	2.19	.065
5	2.52	.076
0	3.50	.105
5	2.63	.079
17	-1.75	-.052
34	-1.31	-.029
52	-2.74	-.082
62	-3.06	-.092
65	-3.28	-.099
70	-3.72	-.112

W/C .50 **AIR** - **AD.** lignin
AGE 22d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	1.60	.048
42	2.00	.060
33	2.00	.060
27	2.30	.069
26	2.30	.069
25	.17	.051
15	4.0	.120
5	3.0	.090
0	-4.0	-.120
5	-3.8	-.110
17	-2.5	-.080
34	-1.5	-.050
52	-2.5	-.080
62	-2.8	-.084
65	-3.0	-.090
70	-3.15	-.095

W/C .50 **AIR** - **AD.** lignin
AGE 22d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	1.67	-.050
42	2.03	-.061
33	2.15	-.065
27	2.03	-.061
26	2.03	-.061
25	.24	-.072
15	-5.85	-.170
5	-7.15	-.214
0	-7.71	-.229
5	-6.20	-.186
17	-5.71	-.172
34	-3.56	-.107
52	-5.71	-.171
62	-6.66	-.200
65	-7.14	-.215
70	-7.50	-.225

W/C .50 **AIR** - **AD.** lignin
AGE 22d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	2.15	.065
42	3.01	.091
33	3.12	.093
27	4.07	.122
26	4.07	.122
25	4.19	.126
15	-2.69	-.081
5	-3.01	-.091
0	-2.90	-.087
5	-6.12	-.186
17	-5.91	-.177
34	-3.33	-.100
52	-4.19	-.126
62	-4.40	-.132
65	-4.61	-.138
70	-4.94	-.148

W/C .50 AIR – AD. lignin
AGE 22d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	3.18	.095
42	2.86	.085
33	3.02	.090
27	3.26	.097
26	1.43	.043
25	1.59	.048
15	-2.06	-.062
5	-4.12	-.124
0	-4.92	-.147
5	-4.28	-.129
17	-3.34	-.101
34	-3.02	-.091
52	-4.45	-.134
62	-4.77	-.143
65	-4.92	-.148
70	-5.25	-.158

W/C .50 AIR – AD. lignin
AGE 22d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	3.11	.094
42	4.28	.128
34	4.45	.133
33	4.51	.136
33	4.51	.136
33	5.27	.158
25	4.90	.147
17.5	4.29	.128
11.0	4.29	.128
2	5.06	.152
0	6.21	.186
5	2.58	.077
17	.22	.007
34	-.74	-.022
52	-1.72	-.052
70	-2.85	-.086

W/C .50 AIR - AD. lignin
AGE 30d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.03	.061
42	2.50	.075
34	2.50	.075
33	2.50	.075
33	2.26	.067
33	2.26	.067
25	2.38	.072
17.5	-1.55	-.047
11.0	-3.09	-.093
2	-3.93	-.119
0	-3.80	-.114
5	-3.33	-.100
17	-2.62	-.078
34	-1.67	-.050
52	-2.38	-.072
70	-2.86	-.086

W/C .50 AIR - AD. lignin
AGE 30d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.31	.069
42	3.18	.096
34	3.73	.113
33	3.73	.113
33	3.73	.113
33	3.73	.113
25	4.06	.122
17.5	2.09	.062
11.0	.77	.023
2	.44	.013
0	.55	.016
5	-2.41	-.072
17	-2.96	-.089
34	-3.07	-.092
52	-3.95	-.119
72	-5.04	-.152

W/C .50 **AIR** - **AD.** lignin
AGE 30d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	1.67	.050
42	2.00	.060
34	2.00	.060
33	1.83	.055
33	1.83	.055
33	1.83	.055
25	.50	.015
17.5	-1.00	-.030
11.0	-2.66	-.079
2	-4.00	-.120
0	-4.50	-.135
5	-4.00	-.120
17	-3.16	-.095
34	-2.33	-.070
52	-3.00	-.090
70	-3.33	-.100

W/C .50 **AIR** - **AD.** lignin
AGE 30d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.39	.072
42	2.98	.090
34	2.98	.090
33	2.98	.090
33	2.98	.090
33	2.86	.086
25	3.10	.093
17.5	.78	.023
11.0	-.47	-.014
2	-1.31	-.029
0	-1.19	-.036
5	-1.55	-.047
17	-1.19	-.036
34	-1.67	-.050
52	-2.26	-.068
70	-2.86	-.086

W/C .50 AIR - AD. lignin
AGE 30 d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	3.82	.115
42	5.16	.155
34	5.34	.161
33	5.34	.161
33	5.34	.161
33	6.06	.182
25	5.30	.159
17.5	4.03	.121
11.0	3.25	.098
2	3.60	.108
0	3.93	.118
5	0	0
17	-1.80	-.054
34	-1.01	-.031
52	-2.03	-.061
70	-3.37	-.102

W/C .50 AIR - AD. lignin
AGE 30d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	1.43	.043
42	1.29	.054
36	1.79	.054
33	1.91	.057
28	2.14	.064
20	-3.45	-.104
18.5	-8.95	-.268
16.0	-12.5	-.376
15	-12.5	-.376
13	-12.5	-.376
5	-12.5	-.376
0	-12.5	-.376
11	-12.5	-.376
20	-10.6	-.318
48.5	-11.9	-.358
67.0	-12.4	-.372

W/C .35 AIR____ AD. lignin

AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	3.82	.115
42	4.72	.141
36	4.95	.148
33	5.07	.152
28	6.22	.186
20	2.02	.061
18.5	-2.25	-.068
16.0	-5.50	-.165
15.0	-7.75	-.234
13.0	-9.45	-.284
5.0	-12.40	-.372
0	-12.40	-.372
11	-12.40	-.372
20	- 9.70	-.292
48.5	-10.70	-.322
67.0	-11.90	-.358

W/C .35 AIR____ AD. lignin

AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	2.38	.071
42	2.62	.078
36	2.50	.075
33	2.50	.075
28	3.22	.097
20	-3.34	-.100
18.5	-7.05	-.212
16.0	-8.80	-.264
15.0	-10.60	-.318
13	-12.00	-.360
5	-13.20	-.396
6	-13.20	-.396
11	-13.00	-.390
20	-8.35	-.250
48.5	-9.65	-.288
67.0	-10.40	-.312

W/C .35 AIR____ AD. lignin

AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	2.74	.082
42	3.30	.099
36	3.40	.102
33	3.51	.106
28	4.50	.136
20	2.41	.073
18.5	-1.43	-.043
16.0	-4.55	-.136
15.0	-6.75	-.202
13.0	-8.46	-.254
5.0	-10.70	-.321
0	-11.10	-.332
11	-11.10	-.332
20	-7.49	-.225
48.5	-8.75	-.262
67.0	-9.57	-.287

W/C .35 AIR____ AD. lignin

AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	3.74	.112
42	4.27	.128
36	4.52	.136
33	4.52	.136
28	5.71	.171
20	-5.27	-.158
18.5	-8.25	-.248
16.0	-10.00	-.300
15.0	-11.20	-.334
13.0	-11.20	-.334
5	-11.20	-.334
0	-11.20	-.334
11	-11.20	-.334
20	-11.20	-.334
48.5	-10.20	-.306
67.0	-10.90	-.328

W/C .35 AIR ____ AD. lignin
AGE 1d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	1.50	.045
42	1.83	.055
36	1.99	.059
33	2.82	.084
28	3.33	.100
20	-2.98	-.088
18.5	-6.47	-.194
16.0	-9.15	-.278
15.0	-11.50	-.345
13.0	-12.95	-.390
5	-16.30	-.490
0	-17.00	-.510
11	-13.00	-.390
20	- 7.50	-.225
48.5	- 8.50	-.255
67.0	- 8.99	-.270

W/C ____ AIR ____ AD. ____
AGE ____ A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	-	-
62	1.91	.057
40.5	2.74	.082
33.0	2.50	.075
26.5	3.10	.093
22.0	3.33	.099
15.0	2.38	.072
10.0	-.48	-.014
5.0	-.83	-.025
0.0	-.83	-.025
1.0	-.48	-.014
2.0	0.0	0.0
16.0	.95	.028
28.5	-.24	-.072
44.5	-1.19	-.036
53.0	-1.43	-.043
63.5	-1.67	-.050

W/C .35 AIR - AD. lignin
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	-	-
62	3.30	.099
40.5	5.90	.177
33.0	6.11	.184
26.5	7.60	.228
22.0	8.50	.255
15.0	9.07	.273
10.0	8.75	.263
5.0	8.85	.266
0.0	8.85	.266
1.0	9.30	.279
2.0	3.06	.092
16.0	2.73	.082
28.5	1.02	.031
44.5	-.34	-.012
53.0	-.57	-.017
63.5	-1.25	-.375

W/C .35 AIR - AD. lignin
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
62	2.85	.052
40.5	5.16	.150
33.0	5.25	.157
26.5	6.57	.197
22.0	7.55	.227
15.0	7.90	.237
10.0	7.45	.223
5.0	7.00	.210
0.0	7.55	.228
1.0	7.90	.238
2.0	2.41	.072
16.0	1.54	.046
28.5	0.55	.016
44.5	-.44	-.013
53.0	-1.32	-.039
63.5	-1.57	-.047

W/C .35 AIR – AD. lignin
AGE 7d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
62	2.15	.064
40.5	3.10	.093
33.0	2.86	.085
26.5	3.58	.107
22.0	3.82	.114
15.0	3.22	.097
10.0	1.07	.032
5.0	.83	.025
0.0	.83	.025
1.0	1.07	.032
2.0	4.77	.143
16.0	1.55	.047
28.5	0	0
44.5	-1.07	-.032
53.0	-1.31	-.039
63.5	-1.55	-.047

W/C .35 AIR – AD. lignin
AGE 7d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
	-	
62	2.38	.072
40.5	4.17	.125
33	4.41	.132
26.5	5.62	.168
22.0	6.20	.186
15.0	6.60	.198
10.0	6.68	.201
5.0	7.62	.229
0.0	7.30	.219
1.0	2.72	.082
2.0	2.50	.075
16.0	.83	.025
28.5	-.59	-.017
44.5	-.95	-.028
53.0	-1.19	-.036
63.5	-1.43	-.043

W/C .35 **AIR** - **AD.** lignin
AGE 7d **A/C** - **SAND** -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
	-	
62	2.17	.065
40.5	2.84	.085
33.0	2.84	.085
26.5	3.00	.090
22.0	3.50	.105
15.0	3.00	.090
10.0	.33	.010
5.00	0.00	0.0
0.0	-.33	-.100
1.0	.17	.005
2.0	1.33	.040
16.0	.83	.025
28.5	-.50	-.015
44.5	-.83	-.025
53.0	-1.00	-.030
63.5	-1.39	-.042

W/C .35 **AIR** - **AD.** lignin
AGE 7d **A/C** - **SAND** -

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71.0	-	-
56.0	2.30	.069
41.0	3.26	.098
33.5	3.38	.102
29.0	4.70	.141
24.0	5.00	.151
20.5	5.47	.164
12.0	5.25	.157
8.5	5.37	.161
2.0	5.37	.161
0	5.57	.167
3	4.27	.128
12.5	2.41	.072
21.0	2.52	.076
30.0	1.53	.046
39.0	.55	.017

W/C .35 AIR____ ADM.____
AGE 1d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
42	.32	.010
45.5	-.109	-.003
48.5	-.27	-.008
70.0	-.43	-.013

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71.0	–	–
56.0	.35	.011
41.0	.80	.024
33.5	1.19	.036
29.0	1.31	.039
24.0	.95	.029
20.5	.24	.007
12.0	-1.43	-.043
8.5	-1.90	-.057
5	-2.62	-.078
2	-2.86	-.086
0	-2.86	-.086
3	-2.62	-.078
12.5	-2.14	-.064
21.0	- .59	-.017
30.0	- .48	-.014

W/C .35 AIR____ ADM.____
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
39	-1.07	-.032
42.0	-1.31	-.039
45.5	-1.43	-.043
48.5	-1.55	-.047
70.0	-1.67	-.050

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
56	1.33	.034
41	2.80	.084
33.5	3.33	.100
29.0	3.07	.093
24	2.71	.082
20.5	1.30	.039
12.0	-2.54	-.076
8.5	-6.96	-.088
5	-3.75	-.112
2	-4.00	-.120
0	-4.17	-.126
3	-6.25	-.187
12.5	.31	.009
21	2.29	.069
30	1.61	.048

W/C .35 AIR____ ADM.____
AGE 1d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
39	.940	.028
42	.63	.019
45.5	.42	.013
48.5	.21	.006
70.0	0	0

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
56	1.55	.047
41	3.75	.113
33.5	4.55	.137
29	4.70	.141
24.0	2.30	.069
20.5	1.19	.036
12.0	-4.00	-.120
8.5	-4.53	-.136
5	-4.75	-.143
2	-4.80	-.144
0	-4.90	-.147
3	-4.10	-.123
12.5	-3.30	-.100
21	-2.80	-.084
30	-1.29	-.039

W/C .35 AIR____ ADM.____
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
39	-1.13	.034
42	.80	.024
45.5	.45	.014
48.5	.11	.003
70.0	-.11	-.003

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
56	1.00	.030
41	1.50	.045
33.5	1.80	.054
29.0	1.83	.055
24.0	2.16	.065
20.5	1.83	.054
12.0	.33	.010
8.5	.17	.005
5	–.33	–.010
2	–.50	–.015
0	–.50	–.015
3	–.33	–.010
12.5	–.17	–.005
21	–1.17	–.350
30	–.50	–.015

W/C .35 AIR____ ADM.____
AGE 1d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
39	–.17	–.005
42	–.33	–.010
45.5	–.50	–.015
48.5	–.67	–.021
70.0	–.67	–.021

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
56	1.66	.050
41	1.83	.055
33.5	1.90	.057
29	2.38	.072
24	2.62	.079
20.5	2.14	.064
12.0	1.19	.036
8.5	.59	.018
5	-.24	-.007
2	-.59	-.018
0	-.72	-.022
3	-.72	-.022
12.5	-.59	-.018
21.0	-.72	-.022
30.0	-.48	-.014

W/C .35 AIR____ ADM.____
AGE 1d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
39	-.24	-.007
42	-.48	-.014
45.5	-.60	-.018
48.5	-.72	-.016
70.0	-.84	-.025

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
57	1.56	.052
43	3.24	.108
33	5.40	.162
30	6.75	.202
22.5	8.10	.242
19.0	9.10	.212
16.5	9.33	.278
11.0	10.0	.300
9.0	10.1	.302
6.5	11.1	.332
0	11.2	.334
7	7.85	.236
15	6.36	.191
29	4.67	.141
34	3.75	.112

W/C .35 AIR____ ADM.____
AGE 7d A/C____ SAND____

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
49	1.70	.051
72	-.22	-.066

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
57	.60	.018
43	1.23	.037
33	1.78	.053
30	2.14	.064
22.5	2.61	.078
19.0	2.86	.085
16.5	2.98	.089
11.0	3.21	.096
9.0	3.33	.100
6.5	3.21	.096
0	2.74	.082
7	2.62	.078
15	2.62	.078
29	2.26	.067
34	1.67	.050

W/C .35 AIR – ADM. –
AGE 7d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
49	2.85	.085
72	.35	.105

W/C .35 AIR – ADM. –
AGE 7d A/C – SAND –

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
57	.67	.020
43	1.70	.051
33	2.33	.071
30	2.33	.071
22.5	2.84	.085
19.0	3.50	.106
16.5	3.67	.111
11.0	4.00	.120
9.0	4.34	.131
6.5	4.34	.131
0	4.50	.135
7	4.17	.126
15	3.67	.111
29	3.33	.100
34	2.67	.081

W/C .35 AIR - ADM. -
AGE 7d A/C - SAND -

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
49	1.00	.030
72	0.67	.021

W/C .35 AIR - ADM. -
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
57	.70	.021
43	1.38	.042
33	2.28	.069
30	2.69	.081
22.5	3.31	.100
19.0	3.62	.109
16.5	3.83	.116
11.0	4.03	.121
9.0	4.03	.121
6.5	4.03	.121
0	3.83	.115
7	3.20	.096
15	2.79	.083
29	2.48	.075
34	1.87	.056

W/C .35 AIR - ADM. -
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
49	2.79	.084
72	.10	.003

W/C .35 AIR - ADM. -
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
57	1.56	.470
43	3.50	.106
33	4.82	.144
30	6.47	.194
22.5	7.67	.230
19.0	8.65	.260
16.5	8.90	.268
11.0	9.65	.290
9.0	10.40	.312
6.5	10.50	.316
0	7.66	.230
7	6.25	.188
15	4.37	.132
29	3.50	.105
34	3.50	.105
49	1.86	.056

W/C .35 AIR - AD. -
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	.33	.100

W/C .35 AIR - AD. -
AGE 7d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
55	.72	.021
42	1.43	.043
36	1.57	.050
34.5	1.91	.057
29.5	1.91	.057
23.0	2.15	.065
19.0	2.15	.065
16.0	2.15	.065
13.0	2.15	.065
8.0	1.91	.057
3.0	.72	.021
0	-.24	-.007
4	-.36	-.012
12	.12	.004
24	1.43	.043
33	1.31	.039

W/C .35 AIR_____ AD._____

AGE 1d A/C_____ SAND_____

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
61	.72	.021

W/C_____ AIR_____ AD._____

AGE_____ A/C_____ SAND_____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
55	1.17	.035
42	1.67	.050
36	2.17	.066
34.5	2.33	.070
29.5	3.00	.090
23.0	3.17	.095
19.0	3.00	.090
16.0	3.00	.090
13.0	2.83	.085
8.0	2.00	.060
3.0	0	.000
0	-.67	-.020
4	-.17	-.005
12	.33	.010
24	1.67	.050
33	1.83	.055

W/C.35 AIR____ AD.____
AGE 1d A/C____ SAND____

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
61	-.33	-.010

W/C____ AIR____ AD.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	3.40	.102
42	4.77	.143
36	5.22	.108
34.5	5.67	.171
29.5	6.71	.201
23.0	7.70	.231
19.0	8.17	.245
16.0	8.40	.252
13.0	8.50	.255
8.0	7.26	.218
3.0	5.80	.174
0	5.22	.157
4	1.58	.047
12	-.113	-.003
24	1.36	.041
33	1.58	.048

W/C .35 AIR ______ AD. ______
AGE 1d A/C ______ SAND ______

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
61	1.36	.041

W/C ______ AIR ______ AD. ______
AGE ______ A/C ______ SAND ______

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	1.43	.043
42	2.15	.065
36	2.50	.075
34.5	2.73	.082
29.5	2.97	.088
23.0	3.32	.100
19.0	3.56	.107
16.0	3.56	.107
13.0	3.80	.114
8.0	3.44	.103
3.0	2.38	.072
0	1.67	.050
4	.95	.029
12	1.19	.036
24	2.03	.061
33	1.91	.057

W/C .35 AIR ____ AD. ____
AGE 1d A/C ____ SAND ____

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
61	-.347	-.011

W/C ____ AIR ____ AD. ____
AGE ____ A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	1.21	.036
42	2.30	.069
36	2.73	.082
34.5	2.62	.079
29.5	3.39	.113
23.0	4.26	.142
19.0	4.70	.156
16.0	5.12	.171
13.0	5.35	.178
8.0	5.68	.190
3.0	5.12	.171
0	4.47	.149
4	1.42	.042
12	.55	.017
24	1.53	.046
33	1.10	.033

W/C .35 AIR____ AD.____

AGE 1d A/C____ SAND____

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
61	0	0

W/C____ AIR____ AD.____

AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	2.20	.066
42	3.62	.108
36	4.27	.128
34.5	5.37	.161
29.5	5.37	.161
23.0	6.47	.195
19.0	7.14	.212
16.0	7.57	.228
13.0	7.70	.231
8.0	7.14	.214
3.0	5.71	.172
0	5.15	.155
4	1.54	.046
12	-.11	-.033
24	1.21	.036
33	.98	.029

W/C .35 AIR ______ AD. ______
AGE 1d A/C ______ SAND ______

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
61	-1.65	-.050

W/C .35 AIR ______ AD. ______
AGE 1d A/C ______ SAND ______

1" x 6" x 6" slab

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	.60	.018
42.5	1.50	.045
36.0	2.33	.070
33.0	2.50	.075
24.0	2.67	.080
20.0	2.67	.080
17.0	2.50	.075
15.0	1.17	.035
5.0	-10.81	-.322
0	-12.10	-.362
-2.5	-13.65	-.410
1.0	-13.15	-.392
22.5	-9.50	-.285
26.0	-4.82	-.145
45	-5.16	-.155
60	-5.52	-.166

W/C.50 **AIR**____ **AD.**____
AGE 1d **A/C**____ **SAND**____

1" x 6" x6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	1.31	.039
42.5	2.97	.089
36.0	4.07	.122
33.0	4.51	.135
24.0	5.93	.178
20.0	5.93	.178
17.0	6.37	.192
15.0	6.05	.182
5.0	1.58	.048
0	-2.96	-.089
-2.5	-4.38	-.132
1.0	-8.00	-.240
22.5	-5.81	-.175
26.0	-3.07	-.092
45.0	-3.95	-.118
60.0	-4.43	.133

W/C.50 **AIR**____ **AD.**____
AGE 1d **A/C**____ **SAND**____

1" x 6" x6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	.55	.017
42.5	1.65	.050
36.0	2.75	.083
33.0	3.18	.095
24.0	4.28	.128
20.0	4.40	.132
17.0	4.51	.136
15.0	3.84	.115
5.0	-1.87	-.056
0	-7.14	-.215
-2.5	-9.11	-.273
1.0	-12.22	-.368
22.5	-9.66	-.290
26.0	-5.50	-.165
45.0	-6.36	-.191
60.0	-7.23	-.217

W/C .50 AIR_____ AD._____
AGE 1d A/C_____ SAND_____

1" x 6" x 6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	.83	.025
42.5	1.43	.043
36.0	2.02	.061
33.0	2.26	.068
24.0	2.62	.078
20.0	2.02	.061
17.0	1.67	.050
15.0	0.71	.021
5.0	-7.03	-.212
0	-12.00	-.360
-2.5	-13.40	-.402
1.0	-13.10	-.394
22.5	-8.55	-.256
26.0	-4.75	-.143
45.0	-5.25	-.158
60.0	-5.76	-.173

W/C .50 AIR_____ AD._____
AGE 1d A/C_____ SAND_____

1" x 6" x 6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
55	1.31	.039
42.5	1.57	.047
36.0	2.98	.089
33.0	3.09	.093
24	3.51	.105
20	2.98	.090
17	2.86	.086
15	1.79	.054
5	-5.72	-.172
0	-10.00	-.300
-2.5	-11.20	-.334
1.0	-11.30	-.340
22.5	-6.80	-.204
26	-4.30	-.129
45	-5.48	-.165
60	-6.40	-.192

W/C .50 AIR_____ AD._____
AGE 1d A/C_____ SAND_____

1" x 6" x 6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
55	2.27	.068
42.5	4.32	.130
36.0	5.54	.160
33.0	5.80	.174
24.0	7.34	.220
20.0	7.61	.228
17.0	7.95	.238
15.0	7.95	.238
5.0	1.48	.044
0	-4.21	-.126
-2.5	-5.91	-.177
1.0	-10.90	-.328
22.5	-8.63	-.260
26	-5.00	-.150
45	-5.75	-.172
60	-6.68	-.200

W/C .50 AIR_____ AD._____
AGE 1d A/C_____ SAND_____

1" x 6" x 6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	-	-
41	1.78	.054
35	.24	.007
31	-.96	-.028
25	-1.91	-.057
15	-2.27	-.068
11	-2.38	-.071
5	-2.73	-.082
0	-2.27	-.068
6	-1.67	-.050
10	-1.43	-.043
20	-1.14	-.034
26	-1.31	-.039
32	-1.31	-.039
40	-1.37	-.041
50	-1.55	-.046
60	-1.79	-.053

W/C .50 AIR - AD. -
AGE 1d A/C - SAND -

* 1" x 1" x 6"

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %

W/C____ AIR____ AD.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	1.31	.039
42	1.67	.050
36	1.79	.054
33	1.79	.054
29	2.28	.069
27	2.38	.072
24	-.12	-.004
20	-13.35	-.400
18	-13.35	-.400
5	-13.60	-.410
0	-13.80	-.415

W/C .50 AIR____ AD. FA-45%
AGE 2d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	3.26	.098
42	4.62	.138
36	5.06	.151
33	5.06	.151
29	6.20	.186
27	6.52	.196
24	6.07	.182
20	-5.51	-.165
18	-12.10	-.360
5	-12.30	-.370
0	-12.50	-.375

W/C .50 AIR____ AD. FA-45%
AGE 2d A/C____ SAND____

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	1.53	.046
42	2.31	.069
36	2.64	.079
33	2.64	.079
29	3.19	.096
27	3.19	.096
24	3.19	.096
20	-2.96	-.089
18	-12.40	-.370
5	-12.60	-.376
0	-12.80	-.384

W/C•50 AIR____ AD. FA-45%

AGE 2d A/C____ SAND____

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	1.07	.032
42	1.07	.032
36	1.19	.036
33	1.19	.036
29	1.43	.043
27	1.43	.043
24	.72	.026
20	- 6.17	-.185
18	-11.90	-.358
5	-12.20	-.366
0	-12.30	-.368

W/C•50 AIR____ AD. FA-45%

AGE 2d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	.67	.020
42	1.00	.030
36	1.17	.035
33	1.33	.040
29	1.50	.045
27	1.50	.045
24	.83	.025
20	-3.16	-.095
18	-18.30	-.550
5	-18.60	-.560
0	-18.80	-.565

W/C .50 AIR ____ AD. FA-45%
AGE 2d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	2.08	.062
42	3.07	.092
36	3.40	.102
33	3.51	.105
29	4.61	.138
27	4.27	.128
24	4.50	.135
20	-.66	-.019
18	-11.40	-.352
5	-12.60	-.378
0	-12.80	-.384

W/C .50 AIR ____ AD. FA-45%
AGE 2d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	3.19	.096
42	3.63	.109
36	3.63	.109
33	3.63	.109
20.5	2.75	.083
16.0	2.09	.063
9.0	2.09	.063
3.0	2.75	.083
0	3.53	.106
6	-1.66	-.050
10	-1.77	-.053
13.5	-1.55	-.047
17.5	-.99	-.029
43.0	-1.98	-.060
51.0	-2.05	-.062

W/C .50 AIR____ AD. FA-15%
AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	1.19	.036
42	1.43	.043
36	1.43	.043
33	1.55	.047
20.5	-2.32	-.069
16.0	-5.61	-.168
9.0	-7.94	-.238
3.0	-8.50	-.254
0	-8.90	-.268
6	-9.00	-.270
10	-8.12	-.243
13.5	-7.25	-.217
17.5	-5.02	-.151
43.0	-5.61	-.168
51.0	-5.80	-.174

W/C .35 AIR____ AD. FA-45%
AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
54	.83	.025
45	1.17	.035
37	1.33	.040
36	1.33	.040
35	1.33	.040
33	1.50	.045
30	1.67	.050
25	1.17	.035
21.5	-3.17	-.095
18.0	-7.84	-.233
11.5	-16.50	-.495
3.0	-20.50	-.616
0	-21.81	-.635
3.0	-19.50	-.583
8	-16.50	-.493

W/C .50 AIR____ ADM. FA-15%
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
12.5	-12.83	-.383
19.0	- 9.50	-.285
24.0	- 7.84	-.235
33	- 6.67	-.200
35.5	- 6.84	-.205
66.5	- 8.00	-.240

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
54	2.96	.088
45	3.51	.105
37	3.73	.113
36	3.73	.113
35	3.73	.113
33	3.95	.118
30	5.04	.151
25	5.71	.171
21.5	2.63	.078
18.0	-.44	-.013
11.5	-6.69	-.202
3	-8.77	-.263
0	-8.77	-.263
3	-12.71	-.381
8	-12.06	-.361

W/C .50 AIR ____ ADM. FA-15%
AGE 1d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
12.5	-8.98	-.269
19.0	-6.37	-.192
24.0	-5.16	-.155
33.0	-4.28	-.129
35.5	-4.49	-.134
66.5	-6.47	-.194

W/C ____ AIR ____ ADM. ____
AGE ____ A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
54	0.83	.025
45	1.19	.036
37	1.31	.039
33	1.43	.042
30	1.31	.039
25	0.00	.000
21.5	-6.43	-.193
18.0	-10.95	-.329
11.5	-12.85	-.384
3	-12.85	-.384
0	-12.85	-.384
3	-12.85	-.384
8	-12.85	-.384
12.5	-12.62	-.375
19	-10.46	-.315

W/C .50 AIR____ ADM. FA-15%
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
24	-8.69	-.261
33	-7.14	-.214
35.5	-7.38	-.222
66.5	-8.34	-.251

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	1.00	.030
42	1.17	.033
36	1.17	.033
33	1.17	.033
20.5	-1.67	-.048
16.0	-2.50	-.072
9.0	-3.50	-.100
3.0	-3.50	-.100
0	-3.54	-.115
+6	-3.66	-.110
10	-2.16	-.064
13.5	-1.50	-.045
17.5	- .496	-.013
43	-1.50	-.045
51	-1.67	-.050

W/C .50 AIR ___ AD. FA-15%
AGE 5d A/C ___ SAND ___

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
55	3.15	-.080
42	3.72	-.111
36	3.72	-.112
33	3.82	-.115
20.5	3.60	-.108
16.0	2.59	-.078
9.0	2.25	-.068
3.0	2.59	-.078
0	3.15	-.095
6	-2.29	-.069
10	-2.14	-.064
13.5	-1.85	-.055
17.5	-1.01	-.031
43.0	-2.03	-.061
51.0	-2.37	-.072

W/C .50 AIR ___ AD. FA-15%
AGE 5d A/C ___ SAND ___

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.70	.051
50	3.36	.101
40	4.33	.130
30	5.00	.150
25	6.00	.180
10	1.10	.040
0	-6.66	-.200
10	-8.33	-.250
15	-10.33	-.310
20	-7.66	-.230
25	-3.33	-.100
30	-2.00	-.06
45	0	0
55	-.33	-.01
65	-2.66	-.08

W/C .50 AIR ____ AD. FA-15%
AGE 7d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.76	.053
50	3.66	.110
40	4.50	.135
30	5.10	.153
25	6.03	.181
10	6.66	.200
0	7.00	.210
10	6.50	.195
15	6.00	.180
20	5.50	.175
25	5.00	.150
30	4.00	.120
45	3.00	.09
55	1.66	.05
65	.33	.01

W/C .50 AIR ____ AD. FA-15%
AGE 14d A/C ____ SAND ____

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.66	.050
50	2.33	.070
40	2.66	.080
30	3.00	.090
25	3.33	.100
10	-26.60	-.800
0	-33.30	-1.00
10	-31.60	- .950
15	-30.00	- .900
20	-28.30	- .850
25	-26.60	- .800
30	-3.33	- .100
45	-5.33	- .160
55	-5.66	- .170
65	-6.16	- .185

W/C .50 AIR ____ AD. FA-45%
AGE 14d A/C ____ SAND ____

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	2.00	.060
50	2.50	.075
40	2.80	.084
30	3.16	.095
25	3.66	.110
10	-2.66	-.080
0	-9.00	-.270
10	-7.33	-.220
15	-6.83	-.205
20	-5.33	-.160
25	-1.70	-.051
30	0	0
45	-1.36	-.041
55	-1.66	-.050
65	-3.26	-.098

W/C .50 AIR ____ AD. FA-45%
AGE 28d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.70	.051
50	3.36	.101
40	4.33	.130
30	5.00	.150
25	6.00	.180
10	-4.00	-1.20
0	-46.0	-1.38
10	-46.33	-1.39
15	-46.0	-1.38
20	-42.0	-1.28
25	-38.0	-1.15
30	-29.0	- .87
45	-8.30	- .25
55	-9.00	- .27
65	-9.66	- .29

W/C .50 AIR____ AD. FA-15%
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.33	.040
50	2.33	.070
40	5.00	.150
30	6.66	.200
25	7.00	.210
10	-1.00	-.03
0	-2.00	-.06
10	-2.66	-.08
15	-2.33	-.07
20	-1.66	-.05
25	- .67	-.02
30	0	0
45	.67	.02
55	-.33	-.01
65	-1.66	-.05

W/C .45 AIR____ AD. FA-45%
AGE 28d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.36	.041
50	2.43	.073
40	4.96	.149
30	6.76	.203
25	7.06	.212
10	-11.60	-.350
0	-14.60	-.440
10	-13.30	-.400
15	-11.30	-.340
20	-10.00	-.300
25	-7.00	-.210
30	-2.00	-.060
45	-1.33	-.040
55	-3.60	-1.10
65	-5.00	-1.50

W/C .45 AIR____ AD. FA-45%
AGE 14d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.43	.043
50	2.63	.079
40	5.10	.153
30	6.30	.207
25	7.30	.219
10	-19.60	-.590
0	-26.6	-.800
10	-27.3	-.820
15	-27.6	-.830
20	-25.3	-.760
25	-19.6	-.590
30	-1.33	-.040
45	-.33	-.010
55	-1.65	-.05
65	-4.66	-.140

W/C .45 AIR____ AD. FA-45%
AGE 7d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	2.00	.06
50	3.66	.11
40	5.00	.15
30	6.00	.18
25	7.00	.21
10	−15.0	−.45
0	−20.3	−.61
10	−21.6	−.65
15	−20.0	−.60
20	−19.0	−.57
25	−14.0	−.42
30	−6.6	−.20
45	0	0
55	−.67	−.02
65	−1.00	−.03

W/C .45 **AIR**____ **AD.** FA-30%
AGE 14d **A/C**____ **SAND**____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	2.00	.06
50	3.66	.11
40	5.00	.15
30	6.00	.18
25	7.00	.21
10	7.66	.23
0	8.66	.26
10	7.33	.22
15	6.66	.20
20	6.00	.18
25	5.33	.16
30	4.33	.13
45	4.00	.12
55	3.33	.10
65	1.00	.03

W/C .45 **AIR**____ **AD.** FA-30%
AGE 28d **A/C**____ **SAND**____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.33	.040
50	2.66	.080
40	4.00	.120
30	6.00	.180
25	6.66	.200
10	-17.60	-.590
0	-27.30	-.820
10	-27.00	-.810
15	-25.0	-.750
20	-20.66	-.620
25	-17.3	-.520
30	-8.30	-.250
45	-3.30	-.100
55	-5.00	-.150
65	-7.33	-.220

W/C .45 AIR____ AD. FA-15%
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.66	.050
50	2.83	.085
40	4.10	.123
30	5.90	.177
25	6.53	.196
10	-4.33	-.130
0	-8.33	-.260
10	-12.33	-.370
15	-13.33	-.400
20	-12.66	-.380
25	-10.00	-.300
30	3.33	.100
45	1.66	.05
55	.33	.01
65	-.66	-.02

W/C .45 AIR____ AD. FA-15%
AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
60	1.3	.040
50	2.7	.080
40	3.7	.110
30	5.7	.170
25	6.3	.190
10	5.3	.160
0	3.7	.110
10	3.0	.100
15	4.0	.120
20	5.7	.170
25	6.7	.200
30	6.3	.190
45	5.7	.170
55	3.7	.110
65	2.7	.080

W/C .45 AIR____ AD. FA-15%
AGE 14d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
60	.67	.02
50	1.33	.04
40	2.00	.06
30	2.66	.08
25	1.33	.04
10	-8.00	-.24
0	-10.6	-.32
10	-13.3	-.40
15	-10.0	-.30
20	-7.3	-.22
25	-6.7	-.20
30	-6.3	-.19
45	-6.7	-.20
55	-7.0	-.21
65	-7.7	-.23

W/C .35 AIR____ AD. FA-45%
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60	1.30	.040
50	2.00	.060
40	4.00	.120
30	5.30	.160
25	6.50	.195
10	-10.00	-.300
0	-16.60	-.500
10	-17.70	-.530
15	-18.30	-.550
20	-18.60	-.560
25	-10.00	-.300
30	-6.66	-.200
45	-6.33	-.190
55	-6.66	-.200
65	-6.66	-.200

W/C .50 AIR____ AD. FA-30%
AGE 19d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60	1.26	.038
50	1.96	.059
40	4.06	.122
30	5.50	.165
25	6.65	.197
10	3.76	.110
0	-1.00	-.030
10	.67	.020
15	1.33	.040
20	2.33	.070
25	3.76	.110
30	2.33	.070
45	.67	.020
55	-.67	-.020
65	-1.66	-.050

W/C .50 AIR____ AD. FA-30%
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60	1.33	.04
50	2.66	.08
40	3.33	.10
30	4.00	.12
25	2.66	.08
10	-3.33	-.10
0	-5.00	-.15
10	-5.67	-.17
15	-5.00	-.15
20	-4.00	-.12
25	-2.67	-.08
30	-.67	-.02
45	-1.00	-.03
55	-2.00	-.06
65	-2.66	-.08

W/C.35 AIR____ AD. FA-30%
AGE 1d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60	1.00	.03
50	1.67	.05
40	2.67	.08
30	3.33	.10
25	.67	.02
10	-3.33	-.10
0	-6.67	-.20
10	-5.67	-.17
15	-5.00	-.15
20	-4.33	-.13
25	-3.00	-.09
30	-1.67	-.05
45	0	0
55	-.67	-.02
65	-1.00	-.03

W/C.35 AIR____ AD. FA-15%
AGE 1d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
46	3.07	.092
39	3.18	.095
33	3.29	.099
30	4.28	.127
25	4.17	.125
21.5	3.73	.112
18	0.44	.132
11.5	-6.48	-.194
3.0	-9.42	-.283
0	-9.65	-.290
3.0	-13.38	-.402
8.0	-12.72	-.382
12.5	- 9.87	-.296
19.0	- 7.24	-.218
24.0	- 6.04	-.181

W/C .35 AIR____ ADM. FA-45%
AGE 1d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
33.0	-5.70	-.171
35.5	-5.92	-.177
66.5	-7.46	-.225

W/C____ AIR____ ADM.____
AGE____ A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
59	1.31	.039
46	1.66	.049
39	1.79	.054
33	1.91	.057
30	2.02	.061
25	1.91	.057
21.5	.12	.003
18.0	-3.33	-.101
11.5	-9.42	-.282
3.0	-12.26	-.362
0	-12.97	-.389
3.0	-13.57	-.410
8.0	-11.42	-.342
12.5	- 8.69	-.261
19.0	- 5.95	-.178

W/C .35 AIR ____ ADM. FA-45%
AGE 1d A/C ____ SAND ____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
24.0	-4.89	-.147
33.0	-4.64	-.140
66.5	-6.19	-.186

W/C ____ AIR ____ ADM. ____
AGE ____ A/C ____ SAND ____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
46	4.05	.125
39	4.28	.128
33	4.39	.132
30	5.41	.163
25	5.52	.166
21.5	4.73	.142
18.0	2.03	.061
11.5	-3.27	-.098
3.0	-5.41	-.162
0	-5.30	-.159
3.0	-10.59	-.318
8.0	- 7.78	-.234
12.5	- 5.64	-.169
19.0	- 4.39	-.132
24.0	- 3.72	-.111

W/C .35 AIR ____ ADM. FA-45%

AGE 1d A/C ____ SAND ____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
33.0	-4.06	-.121
35.5	-4.39	-.132
66.5	-5.96	-.178

W/C ____ AIR ____ ADM. ____

AGE ____ A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	3.41	.102
42	3.98	.119
36	4.07	.122
33	4.20	.126
20.5	4.77	.143
16.0	4.31	.129
9.0	4.09	.123
3.0	4.32	.130
0	5.11	.153
6	-.12	-.004
10	-.23	-.008
13.5	0	0
17.5	-.80	-.024
43.0	-1.82	-.055
51.0	-2.16	-.065

W/C .35 AIR____ AD. FA-45%

AGE 5d A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
55	.24	.008
42	.36	.012
36	.36	.012
33	.48	.016
20.5	-1.30	-.038
16.0	-2.84	-.085
9.0	-4.14	-.124
3.0	-4.14	-.124
0	-4.25	-.127
6.0	-3.07	-.092
10.0	-2.60	-.078
13.5	-1.89	-.057
17.5	-1.66	-.050
43.0	-7.13	-.064
51.0	-2.38	-.072

W/C .35 AIR____ AD. FA-45%

AGE 5d A/C____ SAND____

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
61	.50	.015
52	1.02	.030
41.5	.91	.027
39	1.02	.030
37	1.36	.041
33	2.27	.068
27.5	3.40	.102
21.0	3.96	.118
19.0	4.07	.123
10.0	5.45	.164
6.0	5.67	.171
-5.0	5.34	.162
-2.0	4.66	.141
3.5	3.18	.096
13.5	1.59	.048

W/C .50 AIR - ADM. FA-45%
AGE 1d A/C - SAND -

Benzene Saturated

$T(^\circ F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
44	1.48	.045
59	.68	.021
66	.45	.014
31.0	1.36	.041

W/C .50 AIR - ADM. FA-45%
AGE 1d A/C - SAND -

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
61	.67	.020
52	.83	.025
41.5	.83	.025
39	.67	.020
37	.83	.025
33	1.66	.050
27.5	3.49	.105
21.0	4.32	.131
19	4.47	.135
10.0	6.31	.190
6.0	6.31	.190
-5.0	6.15	.185
-2.0	5.47	.164
3.5	3.49	.105
13.5	1.49	.045

W/C .50 AIR – ADM. FA-45%
AGE 1d A/C – SAND –
Benzene Saturated

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
44.0	1.49	.045
59.0	.67	.020
66.0	.50	.015
31.0	1.00	.030

W/C .50 AIR – ADM. FA-45%
AGE 1d A/C – SAND –

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
30	2.50	.075
26	2.84	.085
24	2.66	.079
20	1.50	.045
16	-4.15	-.120
10	-8.95	-.270
5	-11.80	-.350
0	-13.60	-.410
6	-13.40	-.400
10	-12.60	-.380
20	-8.85	-.270
30	-7.30	-.219
36	-7.45	-.224
50	-8.00	-.240
60	-8.50	-.257

W/C .50 AIR ____ AD. FA-45%
AGE 1d A/C ____ SAND ____

* 2°F/hr

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
30	2.26	.068
26	2.26	.068
24	1.90	.057
20	2.02	.061
16	2.02	.061
10	-4.50	-.135
5	-6.17	-.185
0	-7.36	-.221
6	-6.20	-.186
10	-5.35	-.161
20	-4.40	-.132
30	-4.87	-.146
36	-5.00	-.150
50	-5.95	-.178
60	-6.50	-.195

W/C .50 AIR ____ AD. FA-45%
AGE 1d A/C ____ SAND ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
54	.67	.020
46	1.00	.030
30	1.33	.039
22	1.67	.050
20	1.33	.039
18	.67	.020
14	-3.33	-.100
10	-4.17	-.126
0	-6.00	-.180
4	-5.81	-.175
10	-4.00	-.120
14	-3.17	-.095
28	-2.17	-.065
40	-2.00	-.060
50	-1.83	-.055
66	-1.62	-.049

W/C .50 AIR____ AD. FA-30%
AGE 1d A/C____ SAND____
* 2°F/hr

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
70	–	–
54	1.19	.036
46	2.02	.061
30	2.62	.079
22	2.38	.071
20	2.74	.023
18	-1.07	-.032
14	-3.80	-.114
10	-4.65	-.139
0	-6.06	-.181
4	-6.30	-.189
10	-4.64	-.139
14	-3.92	-.118
28	-3.69	-.111
40	-3.21	-.097
50	-3.57	-.109
66	-3.92	-.118

W/C .50 AIR____ AD. FA-30%
AGE 1d A/C____ SAND____
2°F/hr

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
70		
54	.60	.018
46	.83	.025
30	1.67	.050
22	1.67	.050
2[illegible]	-1.43	-.043
18	-2.02	-.065
14	-3.81	-.114
10	-4.29	-.129
0	-5.35	-.161
4	-5.60	-.168
10	-4.64	-.139
14	-4.16	-.124
28	-4.29	-.129
40	-3.69	-.111
50	-3.92	-.117
66	-4.17	-.125

W/C.50 **AIR**____ **AD.** FA-30%
AGE 1d **A/C**____ **SAND**____

* 2°F/hr

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
36	1.31	.039
30	1.43	.043
24	1.31	.039
20	.72	.021
19	-1.90	-.057
16	-4.27	-.128
11	-5.35	-.161
0	-5.82	-.175
8	-5.95	-.179
20	-3.68	-.111
35	-2.98	-.090
50	-2.86	-.086
55	-2.73	-.082
60	-2.86	-.086
64	-2.74	-.082
66	-2.62	-.079

W/C.50 **AIR**____ **AD.** FA-45%
AGE 5d **A/C**____ **SAND**____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60	2.10	.063
50	3.75	.113
40	5.00	.150
30	6.50	.195
25	1.50	.045
20	-4.00	-.120
15	-8.10	-.243
10	-13.20	-.395
5	-16.00	-.480
0	-18.00	-.540
10	-17.75	-.535
20	-15.90	-.477
30	-11.75	-.354
35	-9.80	-.295
45	-11.10	-.330
65	-12.50	-.375

W/C .75 **AIR**____ **AD.**____
AGE 1d **A/C** 2:1 **SAND** Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	-	-
60	1.10	.033
50	2.03	.061
40	3.15	.095
30	4.06	.122
25	3.80	.114
20	3.70	.111
10	3.65	.110
0	3.65	.110
10	1.98	.060
15	1.40	.042
20	1.60	.048
25	1.70	.051
30	2.00	.060
45	.50	.015
55	-.55	-.016
65	-1.10	-.330

W/C .75 **AIR**____ **AD.**____
AGE 11d **A/C** 3.25 **SAND**____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.17	.035
50	2.09	.063
40	2.63	.079
30	3.31	.100
25	3.47	.105
20	-1.10	-.033
15	-3.30	-.099
10	-5.30	-.159
5	-5.75	-.173
0	-7.50	-.226
10	-7.40	-.223
20	-5.60	-.168
25	-4.20	-.126
30	-4.40	-.132
45	-5.90	-.177
65	-7.10	-.213

W/C .75 **AIR** ____ **AD.** ____
AGE 7d **A/C** 2:1 **SAND** Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.12	.034
50	2.13	.064
40	2.57	.077
30	3.48	.105
25	3.53	.107
20	-3.80	-.114
15	-8.80	-.265
10	-12.60	-.375
5	-15.00	-.450
0	-16.00	-.480
10	-15.20	-.457
20	-13.10	-.392
25	-10.50	-.315
30	-8.50	-.255
45	-9.00	-.270
65	-10.50	-.315

W/C .75 **AIR** ____ **AD.** ____
AGE 4d **A/C** ____ **SAND** Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.00	.030
50	2.01	.063
40	2.40	.072
30	3.10	.093
20	4.00	.120
10	5.10	.153
0	5.90	.177
10	4.40	.132
20	3.10	.093
30	2.00	.060
40	1.10	.033
50	.02	.001
60	−.07	−.002
65	−.08	−.002

W/C .75 AIR ____ AD. ____

AGE 28d A/C 2.1 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.10	.033
50	2.12	.064
40	2.51	.075
30	3.23	.097
25	3.50	.105
20	−.20	−.006
15	1.00	.030
10	2.10	.063
0	3.10	.093
10	1.80	.054
20	−.60	−.018
25	−1.80	−.054
30	.70	.021
40	−.90	−.027
50	1.50	.045
65	2.40	.072

W/C .75 AIR ____ AD. ____

AGE 14d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
71	–	–
60	.50	.015
50	1.10	.033
40	1.80	.054
30	1.20	.036
25	1.10	.033
20	.90	.027
10	–.10	–.003
0	–1.00	–.030
10	–.90	–.027
15	–.80	–.024
20	–.70	–.021
25	–.50	–.015
30	0.0	0.0
45	–.10	–.003
55	–.90	–.027
65	–1.50	–.045

W/C .75 **AIR** ____ **AD.** ____
AGE 8d **A/C** 3.25 **SAND** Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
71	–	–
60	1.10	.033
50	2.10	.063
40	4.00	.120
30	6.10	.183
25	6.50	.195
20	7.20	.216
10	2.50	.075
0	1.80	.054
10	–2.20	–.066
15	–3.80	–.114
20	–2.00	–.060
25	–1.90	–.057
30	–3.00	–.090
45	–4.00	–.120
55	–5.20	–.156
65	–6.10	–.183

W/C .75 **AIR** ____ **AD.** ____
AGE 1d **A/C** 3.25 **SAND** Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
60	.90	.027
50	1.90	.048
40	2.00	.060
30	3.40	.102
25	3.80	.114
20	2.20	.066
10	1.75	.052
0	1.20	.036
10	0	0
15	.50	.015
20	1.10	.033
25	1.90	.057
30	1.60	.048
45	-.40	-.012
55	-1.35	-.041
65	-2.30	-.069

W/C .60 AIR_____ AD._____

AGE 7d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	-	-
60	.75	.023
50	1.10	.033
40	1.60	.048
30	1.90	.057
25	2.20	.066
20	2.70	.081
10	3.20	.096
0	5.00	.150
10	4.00	.120
15	2.80	.084
20	2.10	.063
25	1.80	.054
30	1.40	.042
45	0.0	0
55	-.50	-.015
65	-1.50	-.045

W/C .60 AIR_____ AD._____

AGE 14d A/C 2:1 SAND_____

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.10	.033
50	1.80	.054
40	2.20	.066
30	3.80	.114
25	4.20	.126
20	4.80	.144
10	-5.00	-.150
0	-5.50	-.165
10	-7.00	-.213
15	-8.20	-.253
20	-7.90	-.253
25	-7.10	-.219
30	-6.00	-.185
45	-6.80	-.209
55	-8.00	-.245
65	-8.20	-.253

W/C .60 AIR____ AD.____

AGE 1d A/C 2:1 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
71	–	–
60	1.20	.036
50	2.20	.066
40	3.60	.111
30	5.20	.156
25	5.75	.173
20	3.90	.117
10	-.50	-.015
0	.20	.006
10	-4.00	-.120
15	-4.50	-.135
20	-4.20	-.126
25	-3.10	-.093
30	-3.25	-.098
45	-4.50	-.135
55	-5.20	-.156
65	-6.00	-.180

W/C .60 AIR____ AD.____

AGE 4d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
54	2.5	.075
42	3.86	.116
33	5.92	.177
28.5	6.81	.202
19.0	7.96	.238
7.0	.80	.024
0.0	1.02	.031
4.5	-.83	-.028
7.0	-2.14	-.064
16.0	-3.68	-.111
22.0	-2.73	-.082
33.5	-1.79	-.054
51.0	-4.16	-.125

W/C .75 AIR - AD. -

AGE 1d A/C 3.25 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
54	1.59	.048
42	2.38	.072
33	3.87	.116
28.5	4.65	.139
19.0	5.22	.157
7.0	5.67	.171
0.0	6.14	.184
4.5	5.06	.152
7.0	4.28	.128
16.0	3.19	.096
22.0	3.19	.096
33.5	2.64	.079
51.0	.67	.020

W/C .50 AIR - AD. -

AGE 1d A/C 3.25 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	–	–
54	1.07	.032
42	2.02	.061
33	2.87	.086
28.5	3.46	.104
19.0	3.32	.101
7.0	–.72	–.021
0.0	–.36	–.011
4.5	–.95	–.029
7.0	–1.43	–.043
16.0	–1.55	–.047
22.0	–2.62	–.078
33.5	.48	.0014
51.0	–.36	–.0011

W/C.60 AIR____ AD.____
AGE 1d A/C 3.25 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	–	–
54	1.71	.051
42	3.08	.092
33	5.22	.157
28.5	6.26	.187
19.0	7.06	.212
7.0	4.44	.133
0.0	5.25	.157
4.5	3.17	.096
7.0	2.30	.069
16.0	.66	.020
22.0	.22	.007
33.5	–.22	–.007
51.0	–.77	–.023

W/C____ AIR____ AD.____
AGE____ A/C____ SAND____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73		
54	1.07	.032
42	2.02	.061
33	2.87	.086
28.5	3.46	.104
19.0	3.32	.100
7.0	-.72	-.022
0.0	-.36	-.011
4.5	-.92	-.028
7.0	-1.38	-.042
16.0	-1.49	-.045
22.0	-2.53	-.076
33.5	.24	.007
51.0	-1.73	-.052

W/C .50 **AIR** ____ **AD.** ____
AGE 1d **A/C** 2.75 **SAND** Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %

W/C ____ **AIR** ____ **AD.** ____
AGE ____ **A/C** ____ **SAND** ____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	3.84	.115
35.5	5.05	.151
26.0	5.61	.168
15.0	5.82	.174
8.0	6.57	.196
0.0	7.90	.236
1	5.05	.151
6	3.29	.099
14	1.86	.056
20.5	2.08	.062
30.0	1.97	.059
57.5	1.09	.053

W/C .75 **AIR** - **AD.** -
AGE 4d **A/C** 4.5 **SAND** Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	1.55	.047
35.5	2.14	.064
26.0	1.55	.047
15.0	.60	.018
8.0	-.12	-.004
0.0	-.71	-.021
1	-1.09	-.033
6	-1.19	-.036
14	-.95	-.028
20.5	-.72	-.022
30.0	-.48	-.014
57.5	-.95	-.028

W/C .75 **AIR** - **AD.** -
AGE 8d **A/C** 3.25 **SAND** Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	2.47	.074
35.5	3.14	.094
26.0	4.37	.131
15.0	6.20	.186
8.0	7.55	.226
0.0	9.00	.270
1	7.10	.213
6	5.83	.174
14	4.65	.139
20.5	3.59	.107
30.5	2.81	.084
57.5	.67	.021

W/C .50 **AIR** – **AD.** –
AGE 8d **A/C** 3.25 **SAND** paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	2.50	.075
35.5	3.30	.090
26.0	2.97	.088
15.0	-.67	-.020
8.0	-1.65	-.049
0.0	-1.54	-.046
1	-3.52	-.105
6	-4.61	-.138
14	-5.04	-.151
20.5	-3.72	-.111
30.5	-1.98	-.059
57.5	-4.18	-.126

W/C .50 **AIR** ____ **AD.** ____
AGE 4d **A/C** 2:1 **SAND** Paris

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	3.61	.109
35.5	4.81	.144
26.0	5.80	.174
15.0	1.64	.049
8.0	-.33	-.010
0.0	0	0
1	-3.30	-.100
6	-4.70	-.141
14	-5.60	-.168
20.5	-4.50	-.135
30.5	-2.51	-.075
57.5	-5.17	-.156

W/C .60 **AIR**_____ **AD.**______
AGE 4d **A/C** 2:1 **SAND** Paris

Mortar

$T(°F)$	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	1.16	.035
35.5	1.33	.040
26.0	1.83	.056
15.0	-6.5	-.195
8.0	-13.30	-.399
0.0	-15.70	-.471
1	-15.70	-.471
6	-15.70	-.471
14	-15.70	-.471
20.5	-14.60	-.438
30.5	-12.10	-.361
57.5	-8.90	-.267
	-9.50	-.285

W/C .75 **AIR**_____ **AD.**______
AGE 4d **A/C** 2:1 **SAND** Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	–	–
55	2.20	.066
33	5.16	.155
26	6.72	.201
20	7.00	.210
17	7.81	.234
0	7.88	.237
6	7.81	.235
13	5.60	.168
16	5.16	.154
22	4.37	.131
33	3.28	.99
40	2.30	.69
53	.98	.29

W/C .75 AIR ____ AD. ____
AGE 1d A/C 6:1 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	–	–
55	1.97	.059
33	4.06	.121
26	5.27	.158
20	4.95	.149
17	1.32	.039
0	.77	.023
6	-1.2	-.036
13	-2.53	-.076
16	-2.31	-.069
22	-.77	-.023
33	-.88	-.026
40	-1.86	-.057
53	-2.96	-.089

W/C .45 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73		
55	.87	.026
33	1.83	.055
26	2.16	.065
20	1.50	.045
17	-7.65	-.228
0	-18.00	-.538
6	-18.00	-.538
13	-17.80	-.532
16	-17.30	-.517
22	-14.60	-.437
33	-11.00	-.329
40	-10.60	-.317
53	-11.70	-.350

W/C .75 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73		
55	3.10	.092
33	6.22	.186
26	7.80	.234
20	7.90	.237
17	1.31	.039
0	1.09	.033
6	-1.53	-.046
13	-3.61	-.108
16	-3.61	-.108
22	-1.97	-.039
33	-1.53	-.046
40	-2.75	-.082
53	-4.16	-.124

W/C .50 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73		
55	1.22	.037
33	2.62	.078
26	2.98	.089
20	1.79	.054
17	-2.26	-.068
0	-2.26	-.068
6	-2.74	-.082
13	-2.74	-.082
16	-2.62	-.078
22	-1.31	-.039
33	-.72	-.022
40	-1.07	-.032
53	-1.90	-.057

W/C .75 AIR ______ AD. ______
AGE 1d A/C 45 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	1.72	.052
33	3.67	.111
26	5.05	.152
20	4.82	.145
17	-4.60	-.138
0	-5.71	-.171
6	-7.12	-.214
13	-8.50	-.254
16	-8.50	-.254
22	-6.80	-.204
33	-5.40	-.162
40	-5.85	-.176
53	-7.50	-.225

W/C .60 AIR ______ AD. ______
AGE 1d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73		
55	1.22	.037
33	2.62	.078
26	2.98	.089
20	1.79	.054
17	-2.26	-.068
0	-2.26	-.068
6	-2.74	-.082
13	-2.74	-.082
16	-2.62	-.078
22	-1.31	-.039
33	-.72	-.022
40	-1.07	-.032
53	-1.90	-.057

W/C .75 AIR ______ AD. ______
AGE 1d A/C 4.5 SAND Paris

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
55	1.72	.052
33	3.67	.111
26	5.05	.152
20	4.82	.145
17	-.460	-.138
0	-5.71	-.171
6	-7.12	-.214
13	-8.50	-.254
16	-8.50	-.254
22	-6.80	-.204
33	-5.40	-.162
40	-5.85	-.176
53	-7.50	-.225

W/C .60 AIR ______ AD. ______
AGE 1d A/C 2:1 SAND Paris

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	1.76	.053
42	2.64	.079
33	3.85	.116
30	4.54	.136
27	5.06	.152
19.5	2.64	.079
10	1.32	.040
0	1.54	.046
9	-.99	.029
21	-.11	-.003
38	.77	.023
57	0	0.0
66	-.77	-.023
70	-1.43	-.043
72	-1.65	-.049

W/C .65 **AIR**____ **AD.**____
AGE 7d **A/C** 2.95 **SAND** Paris Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
73	-	-
55	1.43	.043
42	2.42	.073
35	3.07	.092
34	3.29	.098
29.5	4.72	.143
26	5.50	.165
21	3.50	.105
17	-2.09	-.62
15.5	-3.19	-.96
12.0	-3.74	-.112
8	-2.42	-.73
0	-2.64	-.79

W/C .65 **AIR**____ **AD.**____
AGE 1d **A/C** 2.75 **SAND**____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
49	2.31	.070
36	3.41	.103
26	5.16	.155
23	5.04	.151
19	-.21	.006
12	-5.77	-.173
7	-6.20	-.186
0	-5.15	-.154
9	-5.36	-.161
21	-9.90	-.299
28	-7.15	-.214
32	-4.30	-.129
40	-5.25	-.157
50	-5.77	-.173
58	-6.30	-.189
65	-6.51	-.196

W/C .75 **AIR**_____ **AD.**_____
AGE 1d **A/C** 7.75 **SAND**_____

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
48	2.74	.082
34	4.31	.130
30	5.05	.152
19	2.10	.063
15.0	-3.36	-.101
5	-2.52	-.075
0	-2.10	-.063
10	-4.20	-.126
22	-6.40	-.192
25	-3.37	-.101
35	-3.78	-.113
51	-4.72	-.142
57	-5.05	-.151
59	-5.26	-.157
70	-5.90	-.177

W/C 1.00 **AIR**_____ **AD.**_____
AGE 1d **A/C** 3.43 **SAND** Ottawa

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	–	–
60	1.00	.030
50	2.10	.063
40	3.00	.090
30	5.10	.153
25	4.86	.144
20	3.80	.104
15	-6.0	-.180
10	-8.30	-.249
5	-8.00	-.240
0	-7.50	-.225
10	-11.80	-.354
20	-11.00	-.330
30	-9.60	-.288
40	-9.60	-.288
50	-10.50	-.315
65	-12.0	-.360

W/C .75 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	–	–
60	1.03	.031
50	2.13	.064
40	3.12	.094
30	5.17	.155
25	4.73	.142
20	2.00	.060
15	-1.50	-.045
10	-3.10	-.093
5	-4.50	-.135
0	-5.50	-.165
10	-6.90	-.197
20	-6.10	-.183
30	-3.70	-.111
40	-4.50	-.135
50	-5.50	-.165
65	-7.50	-.225

W/C .70 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72		
60	.48	.014
50	1.10	.033
40	1.25	.038
30	1.82	.054
25	1.52	.045
10	-2.80	-.084
0	-2.30	-.069
10	-3.50	-.105
15	-3.75	-.112
20	-3.70	-.111
25	-2.50	-.075
30	- .050	-.001
45	-2.20	-.066
55	-3.50	-.105
65	-4.20	-.126

W/C .70 AIR_____ AD._____
AGE 4d A/C 2:1 SAND Erie Sand
Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %

W/C_____ AIR_____ AD._____
AGE_____ A/C_____ SAND_____

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60	.88	.026
50	1.70	.051
40	2.01	.060
30	2.75	.082
25	2.75	.082
10	2.80	.084
0	4.40	.132
10	2.50	.075
15	1.75	.052
20	1.20	.036
25	1.75	.052
30	2.00	.060
45	0.80	.024
55	-.20	-.006
65	-.90	-.027

W/C .75 AIR____ AD.____
AGE 5d A/C 2.75 SAND Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60	.50	.015
50	1.00	.030
40	1.20	.036
30	1.80	.054
25	1.50	.045
10	1.50	.045
0	1.80	.054
10	1.20	.036
15	1.00	.030
20	.90	.027
25	1.00	.030
30	1.20	.036
45	0.50	.015
55	-.50	-.015
65	-1.00	-.030

W/C .70 AIR____ AD.____
AGE 7d A/C 2:1 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	.88	.026
50	1.70	.051
40	2.01	.060
30	2.75	.082
25	2.75	.082
10	2.75	.082
0	3.25	.098
10	1.75	.052
15	1.75	.052
20	1.75	.052
25	1.75	.052
30	1.75	.052
45	.90	.027
55	–.10	–.003
65	–1.00	–.030

W/C .75 **AIR** ____ **AD.** ____

AGE 9d **A/C** 2:1 **SAND** Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	.60	.018
50	1.10	.033
40	1.90	.057
30	2.80	.084
25	3.10	.093
16	–1.10	–.033
0	.40	.012
10	–1.50	–.045
15	–2.10	–.063
20	–2.00	–.060
25	–1.00	–.030
30	1.00	.030
45	–1.20	–.036
55	–2.70	–.081
65	–3.50	–.105

W/C .75 **AIR** ____ **AD.** ____

AGE 3d **A/C** 2.75 **SAND** Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60	0.90	.027
50	1.75	.052
40	2.00	.060
30	3.20	.096
25	3.50	.105
10	-3.30	-.099
0	-5.60	-.168
10	-5.80	-.174
15	-6.10	-.183
20	-5.80	-.174
25	-5.50	-.165
30	-1.90	-.057
45	-3.60	-.108
55	-4.50	-.135
65	-5.70	-.171

W/C .75 AIR ____ AD. ____
AGE 4d A/C 2:1 SAND Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	-	-
60	1.00	.030
50	1.85	.055
40	2.10	.063
30	3.30	.099
25	3.72	.102
10	-.20	-.006
0	1.00	.030
10	-2.00	-.060
15	-2.80	-.084
20	-2.60	-.078
25	-1.20	-.036
30	. 50	.015
45	-1.00	-.030
55	-2.00	-.060
65	-2.70	-.081

W/C .75 AIR ____ AD. ____
AGE 7d A/C 2:1 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	–	–
50	1.60	.048
40	2.00	.060
35	2.50	.075
30	3.00	.090
25	3.50	.105
14	4.00	.120
10	4.20	.126
0	4.50	.135
10	3.50	.105
15	3.20	.096
20	2.75	.083
30	2.20	.066
35	1.90	.057
40	1.60	.048
50	0.40	.012
65	.05	.001

W/C .60 AIR_____ AD._____
AGE 1d A/C 3.25 SAND Erie
Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$,%
72	–	–
50	1.40	.042
40	2.20	.066
35	2.65	.070
30	3.25	.098
25	3.61	.108
14	2.60	.078
10	2.55	.076
0	2.55	.076
10	2.40	.072
15	2.40	.072
20	2.30	.069
30	2.00	.060
35	1.90	.057
40	1.60	.048
50	.05	.001
65	.08	.002

W/C .70 AIR_____ AD._____
AGE 1d A/C 3.25 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.07	.032
50	1.92	.056
40	2.07	.062
30	2.95	.088
25	3.00	.090
20	2.00	.060
15	1.70	.051
10	1.10	.033
5	0.70	.021
0	0.20	.006
14	–.20	–.006
20	.20	.006
30	.90	.027
40	.10	.003
55	–.80	–.024
65	–1.10	–.033

W/C .70 AIR ____ AD. ____

AGE 1d A/C 2.75 SAND Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	.90	.027
50	1.70	.051
40	2.00	.060
30	2.65	.069
25	2.80	.084
20	2.50	.075
15	2.40	.072
10	2.38	.071
5	2.50	.075
0	2.50	.075
14	1.80	.054
20	1.60	.048
30	1.60	.048
40	1.10	.033
55	.20	.006
65	–.30	–.009

W/C .60 AIR ____ AD. ____

AGE 1d A/C 2.75 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
50	1.65	.050
40	2.05	.065
35	2.555	.076
30	3.21	.096
25	2.80	.084
14	1.95	.058
10	1.90	.057
0	1.70	.051
10	.05	.001
15	.05	.001
20	.06	.002
30	1.40	.043
40	1.10	.033
50	.03	.001
60	–.06	–.001
65	–1.00	–.030

W/C .75 **AIR** ____ **AD.** ____
AGE 1d **A/C** 3.25 **SAND** Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
72	–	–
60	1.00	.030
50	1.80	.054
40	2.00	.060
30	2.80	.084
24	3.40	.102
20	2.00	.060
15	.90	.027
10	– .05	–.002
5	–1.20	–.036
0	–2.20	–.066
14	–2.80	–.084
20	–1.90	–.057
25	–.04	–.001
28	.050	.001
45	1.10	.033
65	2.70	.081

W/C .75 **AIR** ____ **AD.** ____
AGE 1d **A/C** 2.75 **SAND** Erie

T(°F)	$\frac{\Delta L}{L} x 10^4$	$\frac{\Delta V}{V}$, %
68.5	.88	.026
32	4.54	.132
30	5.20	.156
27	5.65	.170
18	6.05	.182
13	6.05	.182
10	6.92	.208
0	9.00	.271
5	5.70	.172
10	4.75	.143
22.5	2.65	.080
37.0	1.88	.057
45.0	1.43	.043
65.0	.98	.030

W/C .60 AIR _____ AD. _____
AGE 1d A/C 2:1 SAND Erie

Mortar

T(°F)	$\frac{\Delta L}{L} x 10^4$	$\frac{\Delta V}{V}$, %
68.5	.90	.027
32.0	3.25	.098
30.0	3.60	.108
27.0	3.93	.118
18.0	4.27	.128
13.0	4.50	.135
10	5.10	.153
0	6.45	.194
5	5.30	.159
10	4.06	.122
22.5	2.70	.081
37.0	2.25	.068
45.0	1.58	.048
65.0	1.24	.037

W/C .55 AIR _____ AD. _____
AGE 1d A/C 2:1 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
68.5	.50	.015
32	1.00	.030
30	1.10	.033
27	1.25	.038
18	.33	.010
13	.20	.006
10	.16	.005
0	.16	.005
5	.33	.010
10	.33	.010
22.5	.84	.025
37	1.10	.033
45.0	.63	.019
65.0	.50	.015

W/C .45 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Erie
Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
68.5	.48	.014
32.0	1.67	.051
30.0	1.91	.057
27.0	1.91	.057
18.0	1.55	.047
13.0	1.91	.057
10.0	2.15	.065
0	2.50	.075
5	1.91	.057
10	1.79	.054
22.5	1.43	.043
37.0	1.43	.043
45.0	.84	.025
65.0	.60	.018

W/C .50 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
54	1.64	.049
42	3.18	.096
35	3.95	.118
33	4.27	.129
27.5	5.61	.168
24	5.47	.164
19	3.18	.095
14	-6.50	-.195
8	-8.00	-.240
0	-6.75	-.203
3	-9.10	-.273
8	-11.25	-.338
16	-11.50	-.345
27.5	-9.40	-.283
33.5	-9.38	-.281
58.0	-11.20	-.336

W/C .75 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
54	1.36	.040
42	2.38	.071
35	2.83	.085
33	3.40	.102
27.5	4.53	.136
24	4.30	.129
19	2.26	.068
14	-7.70	-.231
8.0	-9.85	-.296
0	-8.80	-.264
3	-11.10	-.333
8	-12.10	-.363
16	-12.10	-.363
27.5	-10.40	-.312
33.5	-10.20	-.306
58.0	-11.80	-.354

W/C .75 AIR ____ AD. ____
AGE 1d A/C 2:1 SAND Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
54	.67	.020
42	1.23	.037
35	1.23	.037
33	1.23	.037
27.5	1.00	.030
24.0	.83	.025
19.0	-12.80	-.367
14.0	-14.80	-.445
8.0	-15.00	-.450
0.0	-15.20	-.457
3.0	-14.10	-.422
8.0	-10.80	-.324
16.0	-10.20	-.306
27.5	-9.80	-.294
33.5	-9.70	-.291
58.0	-11.20	-.336

W/C .75 **AIR** ____ **AD.** ____
AGE 1d **A/C** 2:1 **SAND** Erie

Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
54	1.07	.032
42	1.56	.047
35	1.56	.047
33	1.68	.051
27.5	2.16	.065
24.0	1.68	.050
19.0	-1.56	-.047
14.0	-11.30	-.337
8.0	-13.30	-.398
0.0	-13.30	-.398
3.0	-13.30	-.398
8.0	-13.30	-.398
16.0	-13.30	-.398
27.5	-11.30	-.338
33.5	-10.70	-.321
58.0	-11.60	-.345

W/C .75 **AIR** ____ **AD.** ____
AGE 1d **A/C** 2:1 **SAND** Erie

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
68.5	.88	.026
32	4.51	.131
30	4.95	.148
27	4.75	.142
18	4.65	.140
13	4.65	.140
10	4.65	.140
0	4.52	.136
5	2.09	·.063
10	1.54	.046
22.5	1.87	.056
37	1.54	.046
45	.55	.017
65	.20	.006

W/C .75 **AIR** ______ **AD.** ______
AGE 11d **A/C** 3.25 **SAND** Erie
Mortar

T(°F)	$\frac{\Delta L}{L} \times 10^4$	$\frac{\Delta V}{V}$, %
68.5	.78	.024
32.0	5.52	.166
30.0	5.85	.176
27.0	6.51	.196
18.0	3.87	.116
13	-2.32	-.069
10	-3.42	-.103
0	-4.07	-.123
5	-7.65	-.230
10	-8.52	-.257
22.5	-7.18	-.216
37.0	-4.61	-.139
45.0	-5.16	-.155
65.0	-5.72	-.171

W/C .75 **AIR** ______ **AD.** ______
AGE 7d **A/C** 2:1 **SAND** Erie

APPENDIX H

Cement Tests

CHEMICAL AND PHYSICAL TEST RESULTS OF ST. MARY'S NORMAL PORTLAND CEMENT

Chemical analysis	
C_3S	48%
C_2S	25%
C_3A	9.9%
C_4AF	9.0%
Physical Tests	
Blaine Fineness	
Fineness, sq. cm./gram	3622
Soundness	
Autoclave Expansion percent	0.09
Time of Set, Gillmore Needle	
Initial, hr. : min.	1.52
Initial, hr. : min.	3.55
Compressive Strength, psi	
1 Day	1428
7 Days	3088
14 Days	3553
28 Days	4556
Normal Consistency, percent	23.5

VITA AUCTORIS

1943	James Joseph Beaudoin was born in Windsor, Ontario, on December 14,1943.
1949	In September, 1949, he entered St. Anthony grade school, Windsor, Ontario, where he obtained his elementary education.
1956	In September, 1956, he enrolled at Assumption High School, where he obtained his secondary education.
1961	In September, 1961 he entered first year engineering at the University of Windsor, Windsor Ontario.
1965	In May, 1965, he was graduated from the University of Windsor with a Bachelor of Applied Science Degree in Civil Engineering. In September, 1965, he continued studies at the University of Windsor in order to obtain the degree of Master of Applied Science in Civil Engineering.
1966	In October, 1966, he was graduated from the University of Windsor with a Master of Applied Science degree in Civil Engineering.
1967	In September 1967 he continued studies at the University of Windsor in order to obtain the degree of Doctor of Philosophy in Civil Engineering.