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LIMITING WATER-CEMENT RATIOS FOR CONCRETE UNDER VARIOUS EXPOSURE CONDITIONS

A THESIS

Submitted to the Faculty of Graduate Studies through the
Department of Civil Engineering in Partial Fulfilment
of the Requirements for the Degree of
Master of Applied Science at The
University of Windsor.

by

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ABSTRACT

The Powers Test is used to establish limiting water-cement ratios for concrete under various exposure conditions.

Mortar prisms were cast from a series of mixes, (both air-entrained and non air-entrained) covering a range of water-cement ratios from 0.40 to 0.70. After being moist cured for one month the prisms were then conditioned at various degrees of saturation, (to simulate exposure conditions) and subjected to the Powers Test - a cooling procedure which involves cooling at the rate of approximately -5°F per hour in the freezing zone. Using data established from the Powers Test length change vs. temperature plots were used to evaluate the frost susceptability of the mixes and accordingly to limit the water-cement ratio for frost resistant concrete.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. C. MacInnis for his guidance and suggestions in the preparation of this work and for his generous aid and constructive criticism throughout its development.

The author is also indebted to Mr. George Michalczuk, laboratory technician, and Mr. Norman Becker for their services.

The financial assistance offered by the National Research Council is greatly appreciated.

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CHAPTER I

INTRODUCTION

Before 1900 most of the work on the behaviour of concrete exposed to freezing and thawing was primarily concerned with the degradation of building stone and concrete aggregates, and the behaviour of concrete placed in freezing weather. Apparently the effect of the repetition of freezing and thawing cycles was not considered until after the turn of the century. From that time until 1939 compressive strength was considered the criterion for durability. However, in the late 1920's and early 1930's there was considerable research in the field of concrete durability. All these researches resulted in recommendations for producing durable concrete published in the Joint Committee Report on concrete and reinforced concrete, (June 1940) where the idea of specifying limiting water-cement ratios for exterior concrete was introduced. Maximum water-cement ratios were established for different types of construction and exposure conditions. In 1942 Codes of practice were established. These recommendations are found in many publications and are still accepted as criteria for producing durable concrete. In 1946 with the advent of air-entrainment the recommended water-cement requirements for different exposure conditions were lowered rather than raised - a strange approach considering the enormous beneficial effect of air-entrainment on durability. These recommendations remained virtually unchanged in the 1945, '53 and '54, A.C.I. Codes of Practice. It is felt that the basis of these limiting water-cement ratios is not too scientific and it is the purpose of this research project to develop data using a one-cycle freezing test which will form a more rational basis on which to establish limiting water-cement ratios for different exposure conditions.

CHAPTER II

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 (1955) gives a detailed description of the void systems in cement pastes.

"While cement is hydrating cement grains in the paste become replaced by other physically and chemically different materials. Being granular it has a characteristic porosity, 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 w/c 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. Figure 1 is a simplified diagram of the pore structure of portland cement paste.

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." Powers (1955)

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.

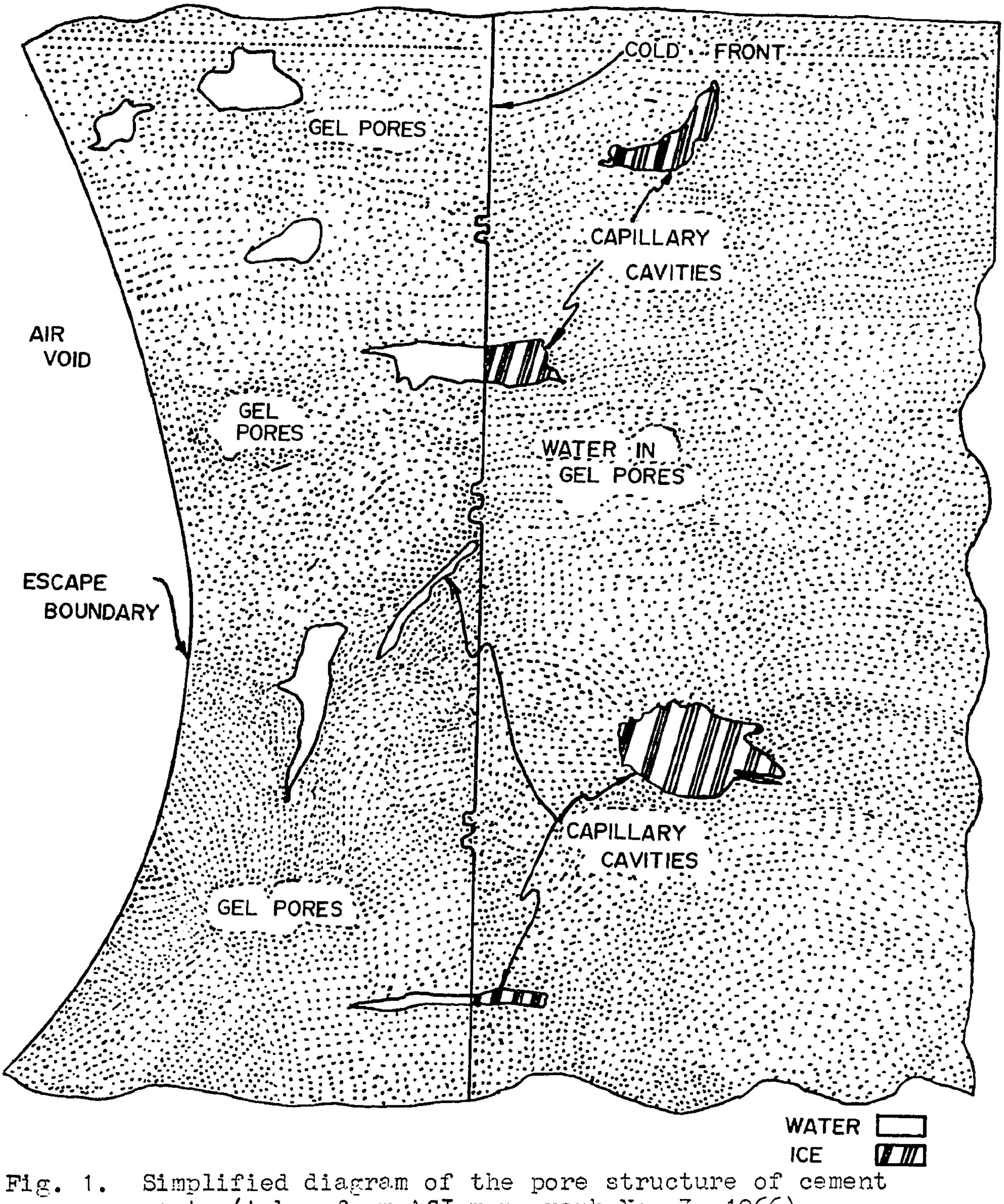

Fig. 1. Simplified diagram of the pore structure of cement paste (taken from ACI monograph No. 3, 1966)

(1) 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 froces 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 1955)

Powers 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 coeifficient 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.

We 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, we 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 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 pressure 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, we can prevent the generation of disruptive hydraulic pressures during the freezing of water in the capillaries.

The following table (T. C. Powers, 1955) 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
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----	---
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.

(ii) 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.

(iii) 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 laboratory experiments to confirm the field observations.

(iv) Microscopic Segregation of Ice Lenses

" 'Frozen capillary water tends to grow by drawing water from the gel'. This extends Collins' (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.

(v) 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 three 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.

The other two, hydraulic pressure and the microscopic growth of ice crystals are the mechanisms most likely to cause damage to hardened cement pastes. Powers (1953-55) 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.

However it is felt that in mature concrete, the hydraulic pressure mechanism is the most important factor responsible for frost damage; Powers has published data which seems to verify this point. (1954)

CHAPTER III

DISCUSSION OF FREEZING TEST METHODS

The several freezing mechanisms which cause deterioration in concrete do not operate under the same climatic conditions. For example rapid freezing is unusually severe in developing hydraulic pressure in the gel structure, but is too rapid to permit the build up of ice crystals. Moreover laboratory specimens which are tested submerged in water are more likely to reach critical saturation than exposed structures in the field. It is difficult therefore to establish standard testing procedures which properly evaluate freezing and thawing resistance for all field conditions.

The four A.S.T.M. methods require that freezing and thawing tests be started after 24 hours of moist curing in the fog room followed by immersion in water saturated with lime to the age of test. The Corps of Engineers Method has a similar requirement except that storage is in the fog room until 48 ± 4 hours prior to test, when they are stored in saturated lime water. A.S.T.M. C290, rapid freezing and thawing in water, is used more extensively than any other method. This method is severe and in a comparatively short time will indicate the relative quality of Portland cement pastes. Table I indicates the methods used to assess damage produced by freeze-thaw tests.

TABLE I

*TESTS USED TO ASSESS FROST DAMAGE

TEST METHOD	TYPE OF SPECIMEN	MEASURE OF DETERIORATION	TYPE OF EXPOSURE
A.S.T.M. C290	3x3x15 in. Prism	Loss in Dynamic E	Rapid freezing and thawing in water
A.S.T.M. C291	3x3x15 in. Prism	Loss in Dynamic E	Rapid freezing in air and thawing in water
A.S.T.M. C292	3x3x15 in. Prism	Loss in Dynamic E	Slow freezing and thawing in water or brine
A.S.T.M. C310	3x3x15 in. Prism	Loss in Dynamic E	Slow freezing in air and thawing in water
Corps of Engs. C-10-54	3½x4½x16 in. Prism	Loss in Dynamic E	Rapid freezing and thawing in air and in water
U.S.B.R. Method	3x6 in. Cylinder	Expansion and Weight loss	Rapid freezing and thawing in water
Powers Method	4½x9 in. Cylinder	Expansion	Controlled freezing

*Taken from ACI Monograph No. 3 (1966)

The U.S.B.R. method of determining weight loss has been correlated successfully with service records on numerous projects in conjunction with all the A.S.T.M. methods.

"The practice of evaluating frost resistance in terms of the number of cycles required to destroy it-no matter how long and severe the "laboratory winter" must be is open to question. Perhaps the freezing-and-thawing test should be expected to tell whether or not a specimen is initially immune to frost damage and, if so, whether or not it would remain that way under the bind of natural exposure it will actually encounter. The behaviour of water-soaked concrete while it is being cooled to temperatures below the normal freezing point is fundamentally the point of concern. The most useful test might be one which would tell whether or not concrete is in a condition to behave properly on cooling and, if it is, to tell how long it will remain in that condition while exposed to water and periodic freezings. Such information cannot be obtained by using a method that forces disintegration (freeze-thaw cycles) and then produces only a measure of the rate of disintegration. It might be obtained by suitable measurements of length change while concrete is being cooled." Powers (1955). Thus, 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 it shrinks normally in the freezing range it is immune; if it dilates it is not immune-the process that eventually causes disintegration has begun.

From investigations by the U.S.B.R., (1948), it was felt that length change or expansion of the concrete gave a more reliable early indication of failure than any other method used in the Dewer 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 length change (residual) was the more effective criteria for durability judgements.

The proposed test (Powers test) was anticipated by Rudolph C. Valore in 1950; he studied volume changes in small concrete cylinders. The study provided test data which enabled Valore to determine residual length change. Referring to various indications of his data Valore said, "should further experimentation verify these implications, the possibility of predicting durability on the basis of measurement of transient or residual strain for one or two cycles of freezing and thawing suggests itself."

CHAPTER IV

PREVIOUS APPLICATION OF THE POWERS TEST

Bailey Tremper (1959) while working for the Highway Department in California utilized the Powers test for the evaluation of frost resistant aggregates. In his test programme he adopted a cooling rate of -5°F per hour, as was suggested by Powers. Each specimen contained a thermocouple, but it soon became evident that all specimens cooled at the same rate; thus a single dummy specimen with a thermocouple was used for temperature measurement. Tremper's results indicate that, "simple soaking of a dry aggregate does not definitely bring it to the ultimate saturation it may have in service and which is necessary in testing to disclose its potentiality for poor performance." As a result of his work in applying the Powers test, 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. In his work in California, Tremper adopted as the criterion of unsatisfactory dilation a measured elongation of 50 millionths ("/„) above the length at the apparent freezing point.

The results of tests on certain aggregates by Powers and Helmuth (1953) are noteworthy. They give Powers the basis for an account of contraction over and above normal thermal contraction.

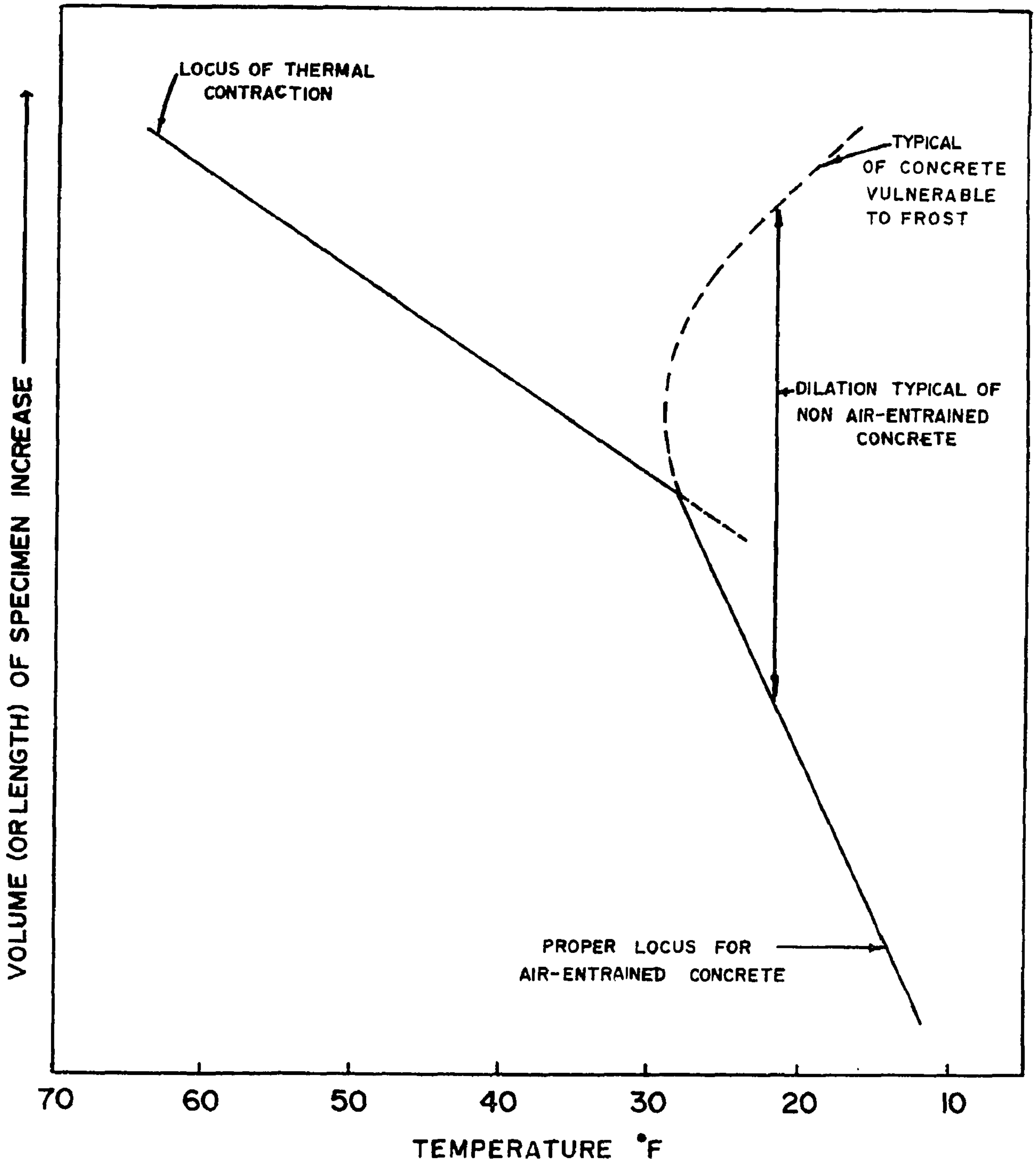


Fig. 2. Diagram illustrating loci for typical frost resistant and frost vulnerable concrete. (taken from Powers 1955)

"The principal phenomena may be summarized 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 temperature 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." Powers and Helmuth (1953)

Powers' description of the effects of cooling in frost resistant and frost vulnerable concretes is best illustrated as in figure 2. Sudden expansion after freezing is shown to be typical of concrete vulnerable to frost, and a locus illustrating contraction over the entire range is shown to be typical of frost resistant concrete.

MacInnis (1962) applied the Powers test as a research tool to evaluate the frost resistance of cement grout mixtures for pre-stressed concrete. He obtained several patterns (see figure 3) which enabled him to select frost resistant grouts. Patterns ranging from distinct expansions, to linear contractions were observed. The distinct expansions obviously represented a great vulnerability to frost damage in direct contrast to the linear contractions representing dur-

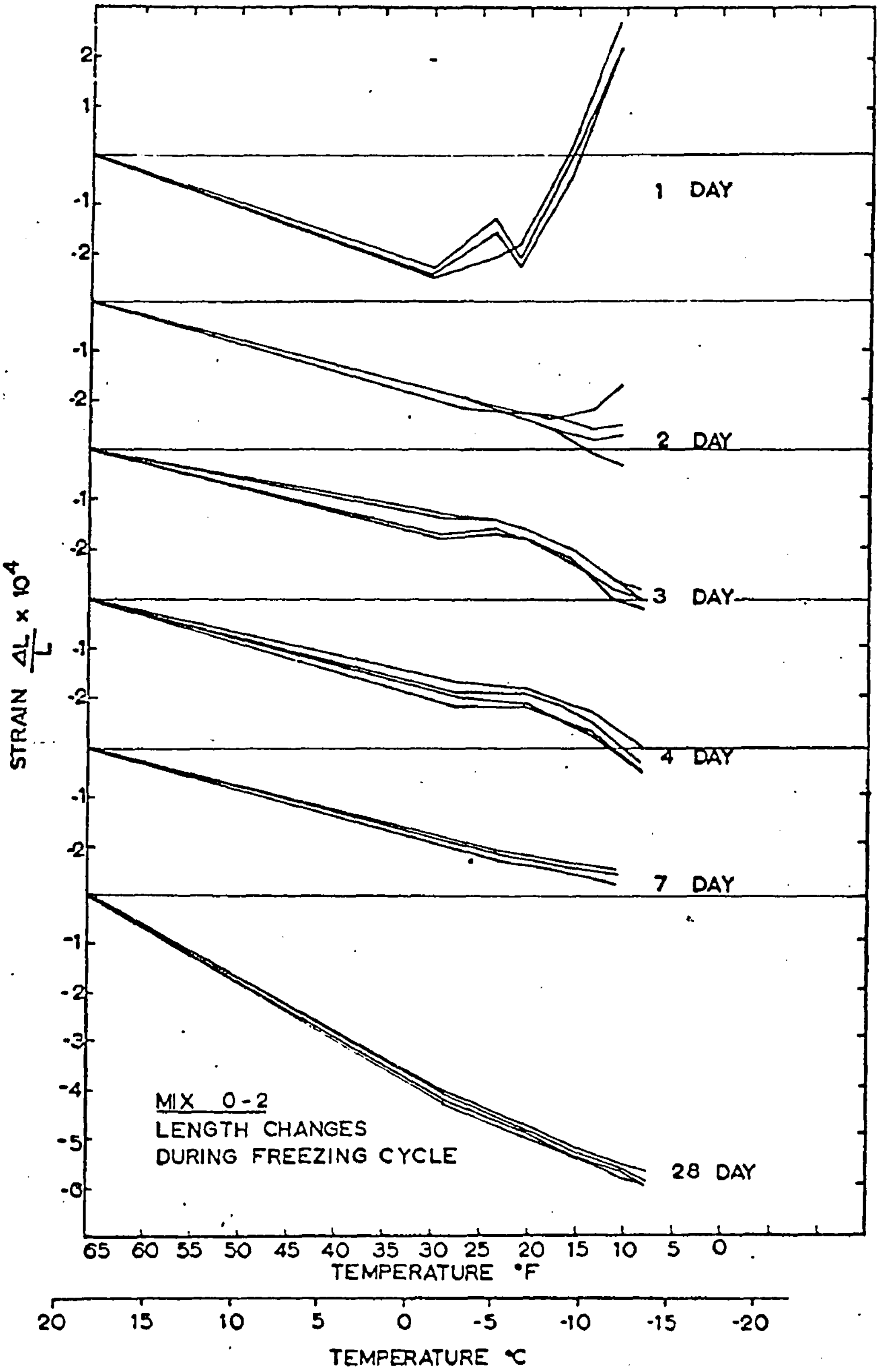


Fig. 3. Typical length change patterns showing effect of maturity on frost resistance (taken from Phd. thesis by C. MacInnis, 1962)

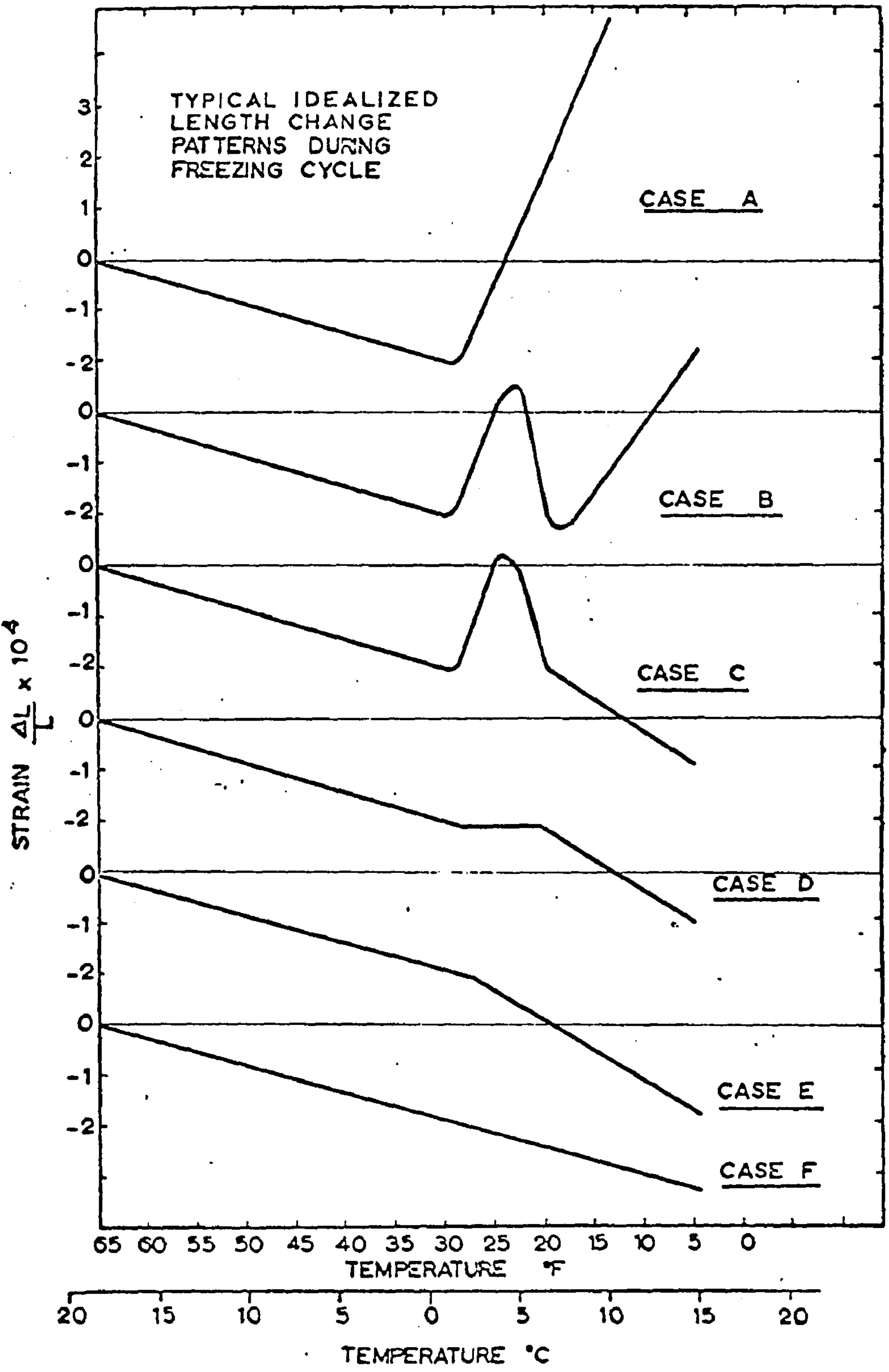


Fig. 4. Idealized length change patterns illustrating ideal frost resistant and frost vulnerable length change patterns (taken from Phd. thesis by C. MacInnis 1962)

able mixes. Periods of no expansion were explained as a cancelling out of opposite effects, that is the tendency to expand from the freezing water in the capillaries is about equal to the thermal contraction plus the tendency to contract due to the diffusion of water from gel pores to the ice bodies. Increased rates of contraction after periods of constant temperature is claimed to occur after ice-crystals begin to form in the air voids of the paste, which tend to attract water from the cement gel pores, and on further cooling cause the gel to shrink. As long as the ice crystals have space available for expansion in the air voids, the net result is a contraction at a rate greater than that due to the thermal coefficient alone. Patterns of this type represent a frost resistant condition. Normal temperature contraction followed by increased contraction after freezing starts is explained similarly. Constant contraction throughout the thermal range also represents a frost resistant condition. Figure 4 illustrates the ideal patterns MacInnis obtained.

The results obtained in MacInnis' work provided a good comparative picture of the frost resistance of various grouts and served to clarify the relative importance of the various factors affecting frost resistance through the use of the Powers test. Air entrainment was found to be the most effective method of preventing expansion and cracking caused by freezing temperatures. The introduction of entrained air, even at a low percentage (5%) in a mix of high water-cement ratio was effective in eliminating all but transitory expansions at all maturities tested. He concluded that water-cement ratio is next in importance to air-entrainment in providing frost protection for grouts. Provided a mix contained at least 5% entrained air a lower water-cement ratio seemed more effective than additional air in increasing frost resistance. MacInnis was also able to establish curing periods which would give frost resistance to grouts at various water-cement ratios; he also concluded that the type of cement used was of minor importance compared with air entrainment or water-cement ratio in the achievement of frost-resistant grouts.

CHAPTER V

FORMULATION OF EXPERIMENTAL PROGRAMME

It was felt that the Powers test could be conveniently utilized to establish limiting water-cement ratio requirements for concrete under various exposure conditions. It was therefore decided to apply this test to a series of mortar prisms, (1"x1"x10"), representing a range of water-cement ratios and exposure conditions. The various factors to be considered in formulating the experimental programme were dealt with as follows:

Range of Water-Cement Ratios

Mixes of the following water-cement ratios were included in the programme: 0.40, 0.45, 0.48, 0.50, 0.55, 0.58, 0.59, 0.60, 0.65, and 0.70. Air-entrained mixes (containing nominal 9% air) were prepared at each of these water-cement ratios while plain mixes were prepared at water-cement ratios of 0.40, 0.50, and 0.60. Twenty-four specimens (4 batches of 6 each) were prepared for each mix.

Simulation of Different Exposure conditions

Since the severity of an exposure condition is largely a function of the degree of saturation of the concrete it was felt that the best way to simulate different degrees of severity of exposure conditions in the laboratory would be to condition specimens to various degrees of saturation which in turn could be related to typical field exposure conditions. All mixes were therefore tested at 100% saturation and at successively smaller degrees of saturation until the length change pattern produced for that mix by the Powers test indicated that expansive tendencies no longer existed. In this way it would be possible to establish the degree of saturation that would produce a critical length change pattern for a mix of a given water-cement ratio.

Choice of Mixes

Mortar mixes having a cement-aggregate ratio of 1:2.75 were used for the entire programme, water being gauged to produce the desired w/c ratios. The choice of mortar mixes rather than concrete was based on the idea that the fines would have little influence on the behaviour of the cement paste. However if coarse aggregate were introduced the results would not be representative, since they would change for every coarse aggregate used, as well as for different sizes of coarse aggregate. However it was felt that by using mortars, limiting water-cement ratios could be established which would hold true for the paste, and indeed for concrete provided that aggregate with a good durability history were used.

Maturity of The Test Specimens

It has been well established that maturity of concrete has a significant affect on its frost resistance. It was decided therefore that all prisms tested in this programme would be subjected to a minimum of one month's standard laboratory curing before being subjected to the Powers test. This was desirable because the aim of the programme was to establish limiting w/c ratios for concrete that has been subjected to a satisfactory regime of curing before being subjected to freezing and thawing conditions.

CHAPTER VI

EQUIPMENT AND MATERIALS

Mixing Apparatus

Two mixers were used, one small one for use in preliminary studies and one for the main programme. The smaller mixer was a Hobart model N-50 in accordance with A.S.T.M. C305 and A.A.S.H.O. T-162, which is widely used for mixing small (1/6 cu. ft.) batches in cement laboratories, (see figure E1). It is furnished with a 5 quart stainless steel bowl, stainless steel flat beater and 1/6 H. P. single phase motor. The second mixer was manufactured by Reynolds Co. It is a 12 quart mixer, and has 1/3 cubic foot mixing capacity. It has a tinned steel bowl with planetary mixing action by means of a flat type beater. It has a 1/3 H. P., 115 volt and 60 cycle motor.

Specimen Moulds

The 1"x1"x10" mortar prisms were formed using two gang moulds, (see figure E2), made of steel, with base plate, removable partitions, and end plates. The end plates of the moulds have provisions for casting contact points into the ends of the specimens so that the effective gauge length is 10" between the inner ends of the embedded gauge points. The reference points are made of stainless steel, knurled and threaded for use with cement prism moulds.

Vacuum Saturation Equipment

Equipment used for vacuum saturating specimens

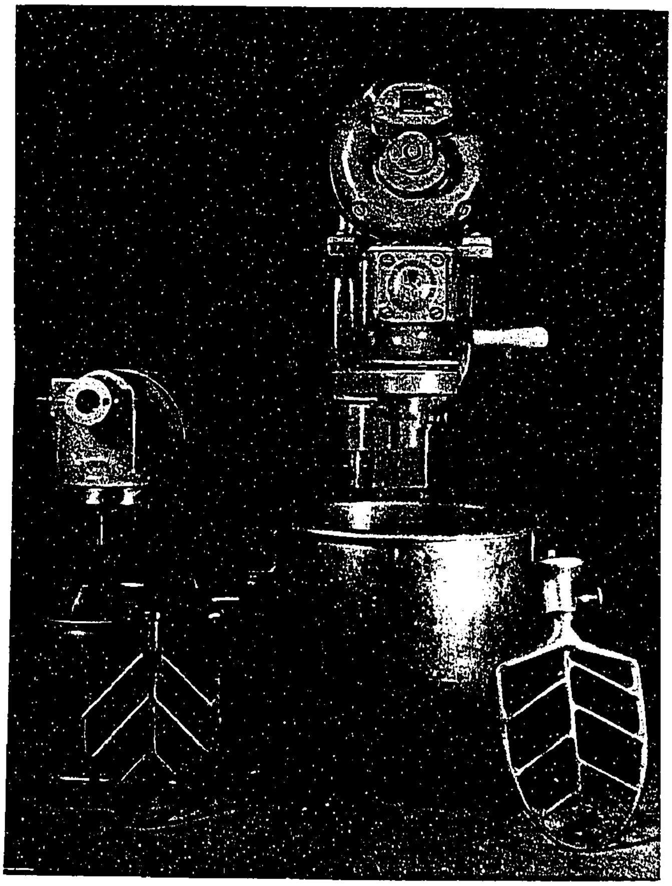


fig.E1 1/6 cu. ft. and 1/3 cu. ft. mixers

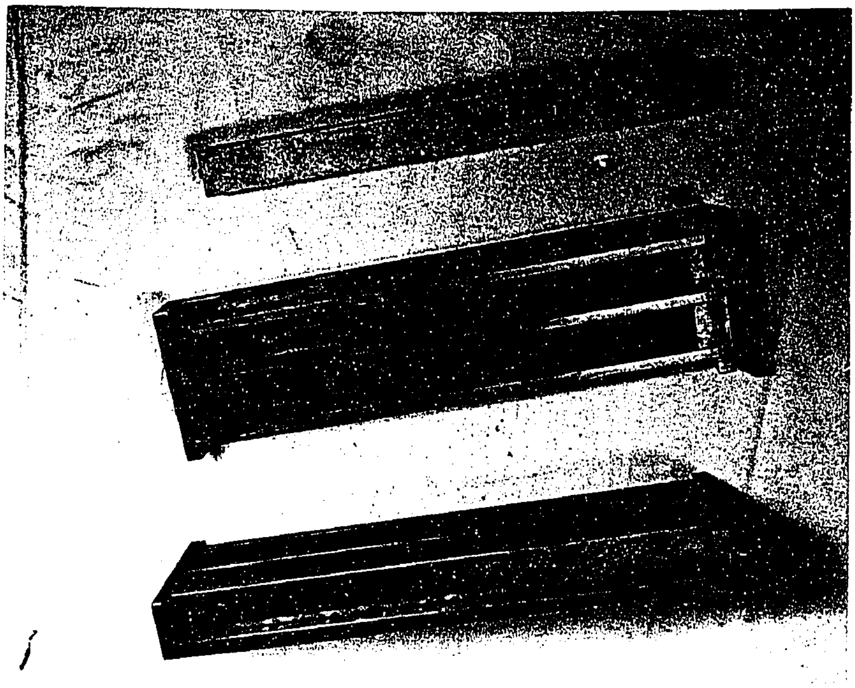


fig.E2 Two gang moulds for moulding 1"x1"x10" prisms

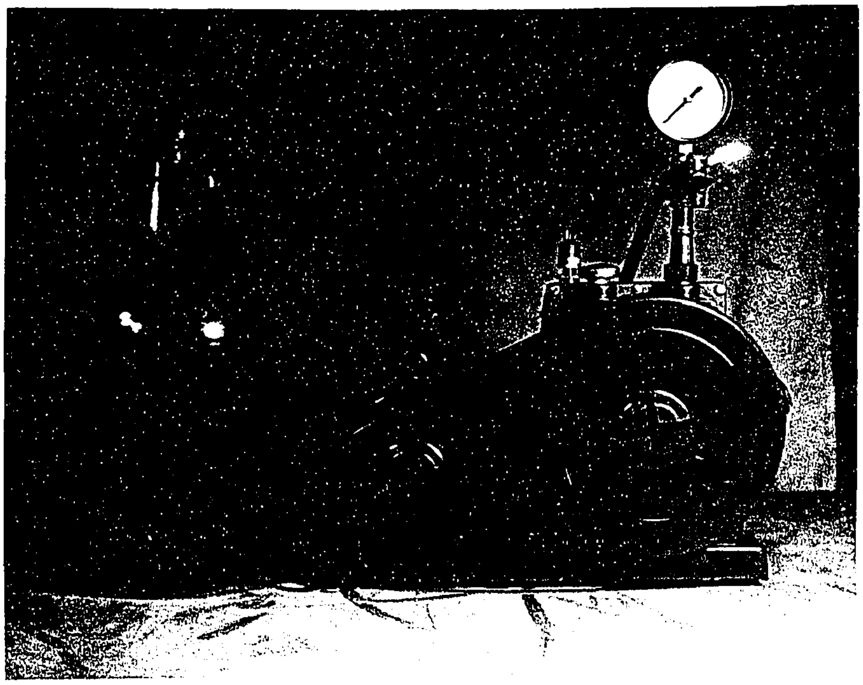


fig.E3 Mechanical vacuum pump connected to 5 gallon carbuoy

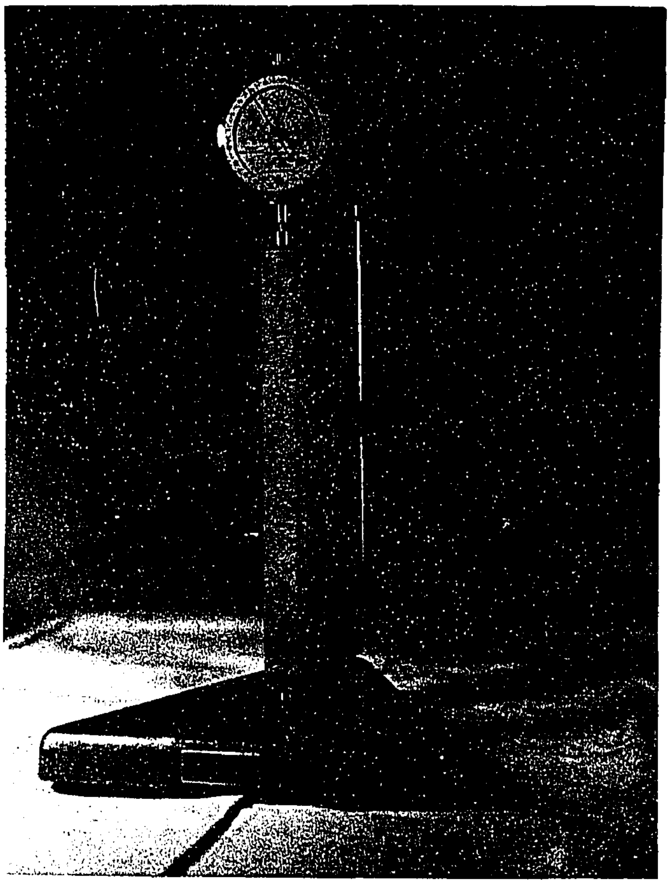


fig.E4 Length Comparator

was quite simple, (see figure E3). A 5 gallon capacity carbuoy equipped with a rubber stopper, through which a 6'-0" long, $\frac{1}{4}$" diameter, rubber vacuum tube connected to a mechanical vacuum pump was inserted provided means for saturating specimens.

Freezing Equipment

The freezer used was manufactured by Lab-line Instruments Inc., and has a five and one-half cubic foot capacity; it is equipped with a 115 volt, 60 cycle, 1 H.P. motor. A Leeds and Northrup temperature potentiometer calibrated to read directly in °F was used to measure the temperature in the freezing chamber.

Length Comparator

The length comparator used for measuring length changes of the mortar specimens consists essentially of an extensometer mounted on a metal stand, (see figure E4). It is adapted to measure length changes over an effective gauge length of 10 in. The dial gauge reads to 0.0001 in. and has a range of 0.4000 in. The comparator is furnished with a standard invar test bar for checking dial readings.

Materials

The following materials were used for the test programme:

(a) cement: The cement used for the mortar mixes was Lake Ontario Type I Portland cement. Properties of the cement are given in table II.

(b) sand: Paris sand meeting the A.S.T.M. requirements for concrete sand was employed as the test sand. This sand is used by the Ontario Hydro as a standard reference sand, and is known to be non reactive. Choice of sand was made after tests on a standard Ottawa Silica Sand indicated the sand possessed inherent air-entraining properties and tests on a lakehead sand indicated it to be of poor gradation; it was also cherty.

(c) water: Distilled water was used for all mixes to insure against any impurities.

(d) air-entraining agent: Darex air-entraining agent produced by Sika Chemical Co. was used in all air-entrained mixes.

CHAPTER VII

EXPERIMENTAL PROCEDURES

Mixing Procedures

The mortar prisms were prepared using a cement aggregate ratio of 1:2.75 by weight with water gauged to produce the desired water-cement ratio. The mixing technique was basically as follows. Cement was placed in the 12 quart mixing bowl. Water was added and the resulting paste was mixed for 1 minute, the water having previously been prepared with the proper amount of darex, (air-entraining agent). Fine aggregate (Paris Sand) was added and the resulting mortar was then mixed for a three minute period.

Air Content Measurement

Air content measurements were made on all mixes. The gravimetric method of measuring air content was felt to be the most accurate and was employed in this project. A copper cylindrical tube, closed at one end was the measuring device. It was calibrated by filling it to the brim with water, the surface being checked for uniformity by placing a smooth glass plate over the surface. The volume of the container was calibrated by using the specific gravity of water at 70°F ± 1°F. The first step is to determine the absolute unit weight of the mix ($W(t)$) by considering the specific gravity of each of its constituents. Then the actual unit weight (W(a)) is obtained by weighing the calibrated cylinder. The difference between the two unit weights expressed as a percentage of the absolute unit weight is a measure of the air content.

Curing

Immediately after the mortar was cast in the moulds, the moulds were covered with damp burlap bags for 24 hours. Stripping of the moulds took place after 24 hours; the specimens were then transferred to the curing chamber, where they were subjected to standard concrete laboratory curing conditions, (70°F(±6°F) and 100% R.H.), for the remaining of the 28 day curing period.

Preparation of Specimens for Powers Test

The second portion of the experimental phase involved the preparation of the specimens for the Powers test. After 28 days specimens were removed from the curing chamber. Specimens were oven dried at 200°F to obtain their respective dry weights, it being felt that since at 28 days hydration would be largely completed, the effect of oven drying would be negligible. To achieve degree of saturation two methods were employed: (i) Specimens were simply soaked for different intervals of time, and their wet weights recorded, giving accurate determination of free water absorbed. (ii) Specimens were vacuum saturated by use of a mechanical vacuum pump connected to a 5 gallon pyrex carbuoy, in which the specimens were inserted.

To achieve 100% saturation the vacuum pump was run for 1 hour and then shut off; the specimens were then allowed to soak 24 hours before removal. This allowed any vapour in the pores to condense and allowed maximum amount of water to be absorbed.

The simple soaking procedure was used mainly to obtain 0% to 50% saturation of the specimens, different degrees of saturation being obtained by varying the length of the simple soaking period.

The vacuum saturation technique was employed for the range of 50%-100% saturation, saturation below 100% being achieved by varying the soaking time after the pump was shut off. The purpose of the vacuum technique was to remove as much air from the specimens as possible and to replace this with water.

To ensure against escape of moisture, immediately after conditioning to desired degree of saturation, the specimens were wrapped in 2mil. polyethelene and fastened with elastic bands. The ends were separately wrapped to facilitate length change measurements.

Freezing Procedures

According to Powers (1955) high rates of cooling give a distorted picture of frost resistance, because it gives an overload test rather than an accelerated natural process. "If in a given cement paste, the principal cause of stress is hydraulic pressure, a high freezing rate will lead to an overestimate of vulnerability." Thus it was decided to employ a cooling rate of approximately 5°F per hour in the freezing zone.

Twelve specimens at a time were placed in the freezing chamber. Temperature was lowered from room temperature to zero degrees. Temperatures were measured by using a thermocouple inserted in the freezer at the same level as the specimens. The thermocouple was connected to a potentiometer which was calibrated to read directly in degrees farenheit. The freezer temperature guage was calibrated against the thermocouple system. This was necessary as the freezer was not designed for lowering temperatures at short and constant intervals of time. This calibration made it possible to set an approximate temperature that would be expected in the freezing chamber; exact temperatures were always measured by potentiometer. After each temperature drop the specimens remained in the freezer for 1 hour, after which they were removed four at a time, and length changes were measured by the length comparator. The ends were then rewrapped and the specimens subjected to a further temperature drop. Data was recorded for the length change of each specimen at each particular temperature. Each cycle took approximately 12 to 13 hours of laboratory time. The recorded data was then plotted-temperature vs. strain.

As a means of measuring temperature lag between the freezing chamber and the specimens two dummy specimens were made each having a thermocouple inserted in it; this provided assurance that the specimens were taken substantially below the freezing point.

CHAPTER VIII

DISCUSSION OF EXPERIMENTAL RESULTS

The experimental results are presented in figures 5 to 14. Basically only two distinctive length-change patterns were produced, ie. the specimens either exhibited a continuous contraction during the freezing cycle or else exhibited an expansion at some stage of the freezing cycle in which case the expansion increased as the temperature was lowered further. The expansion patterns exhibited would suggest that hydraulic pressure is the main mechanism causing expansion in these specimens.

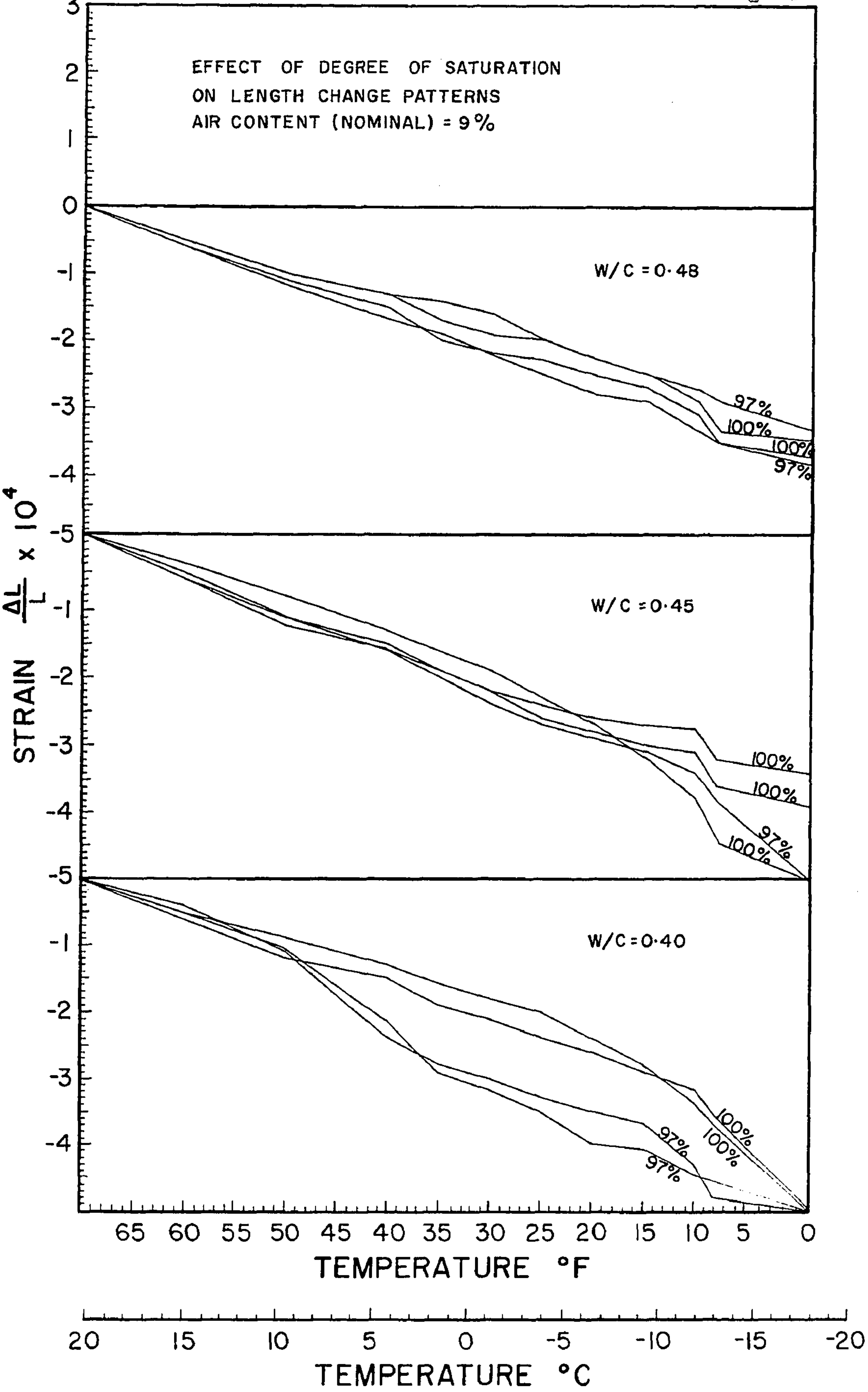
From figures 5, 6, and 7 it can be seen that the air-entrained mixes at water-cement ratios of 0.40, 0.45, 0.48, 0.50 and 0.55 exhibited no expansive tendencies even at 100% saturation.

From figures 8, 9 and 10 it can be seen that for air-entrained mixes at water-cement ratios of 0.60, 0.65 and 0.70, when the degree of saturation was over 90%, expansions were produced in the freezing test and the higher the degree of saturation the greater the expansion. Also the higher the water-cement ratio the greater is the expansion. This is also shown very dramatically in figure 11 where the expansive tendencies of air-entrained mixes of water-cement ratios ranging from 0.58 to 0.70 are compared. All test results in figure 11 were from 100% saturated specimens.

It is interesting to compare the results for the plain and air-entrained mixes, figures 12, 13, and 14. It can be seen from figure 12 that a plain mix of a water-cement ratio as low as 0.40 exhibits expansive tendencies when the degree of saturation is 90% or higher. As the water-cement ratio is increased to 0.50 the expansions exhibited by the plain mixes are considerably higher, figure 13, and higher still at a water-cement ratio of 0.60, figure 14.

In 1942 for water line structures where complete saturation was possible, the ACI code of recommended practice specified a w/c ratio of 0.50 for moderate and heavy sections. In 1954 with the advent of air-entrainment in concrete practice, the water requirements for exposure conditions were reduced. For example, water line structures with moderate section, the water-cement ratio was reduced from 0.58 to 0.47. This seems directly opposed to the argument-if durability is increased one would expect the allowable water requirement to increase, or at least remain the same. Indeed the water-cement ratios recommended by the 1954 code seem quite conservative, although it is probably judicious to be conservative because of other factors which could contribute to deterioration, for example, leaching or moisture movement.

Fig. 5


EFFECT OF DEGREE OF SATURATION
ON LENGTH CHANGE PATTERNS
AIR CONTENT (NOMINAL) = 9%
W/C = 0·48
97%
100%
100%
97%
W/C = 0·45
100%
100%
97%
100%
W/C = 0·40
100%
100%
97%
97%
STRAIN $\frac{\Delta L}{L} \times 10^4$
3
2
1
0
-1
-2
-3
-4
-5
-1
-2
-3
-4
-5
-1
-2
-3
-4
65
60
55
50
45
40
35
30
25
20
15
10
5
0
TEMPERATURE °F
20
15
10
5
0
-5
-10
-15
-20
TEMPERATURE °C

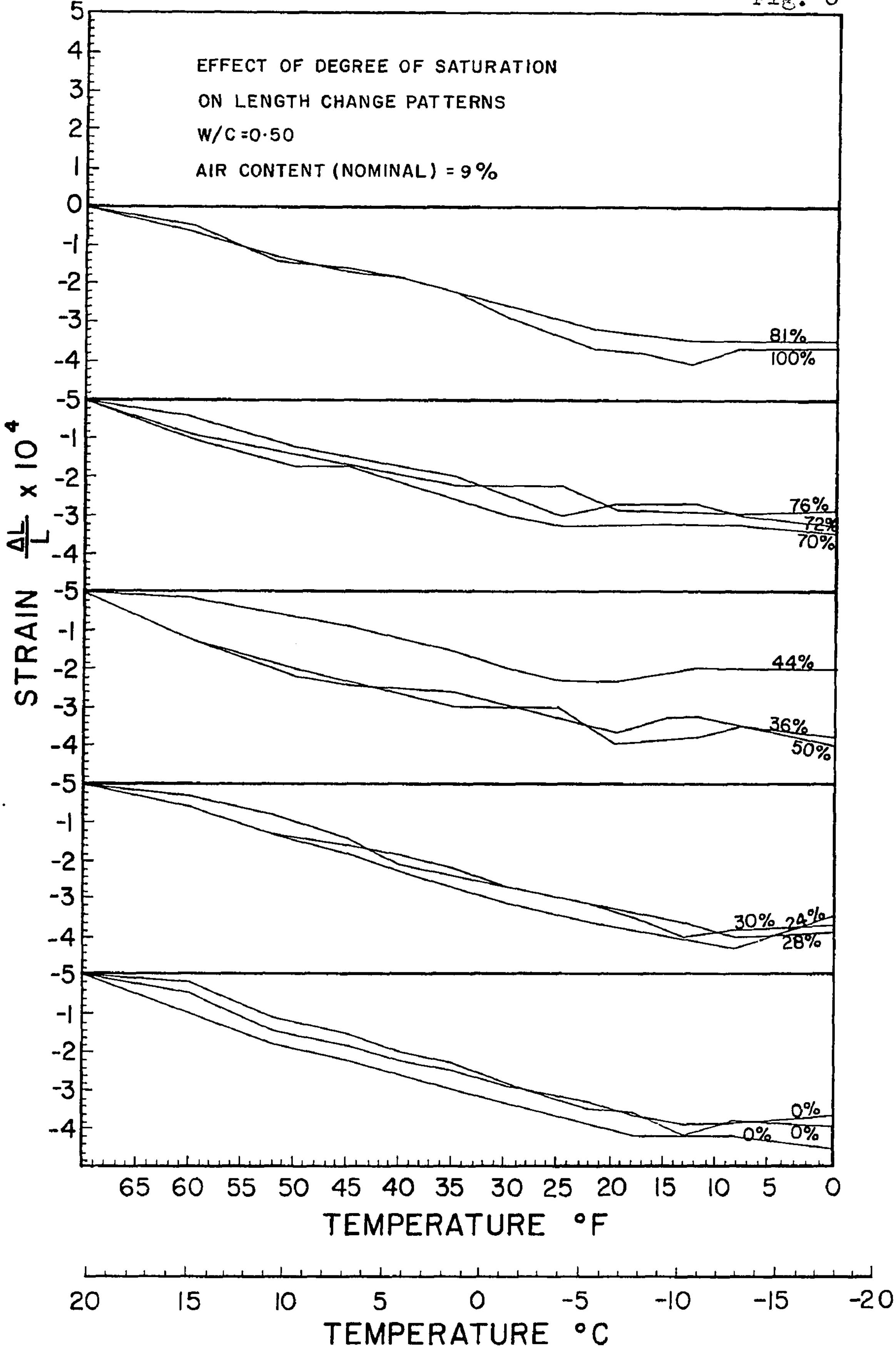
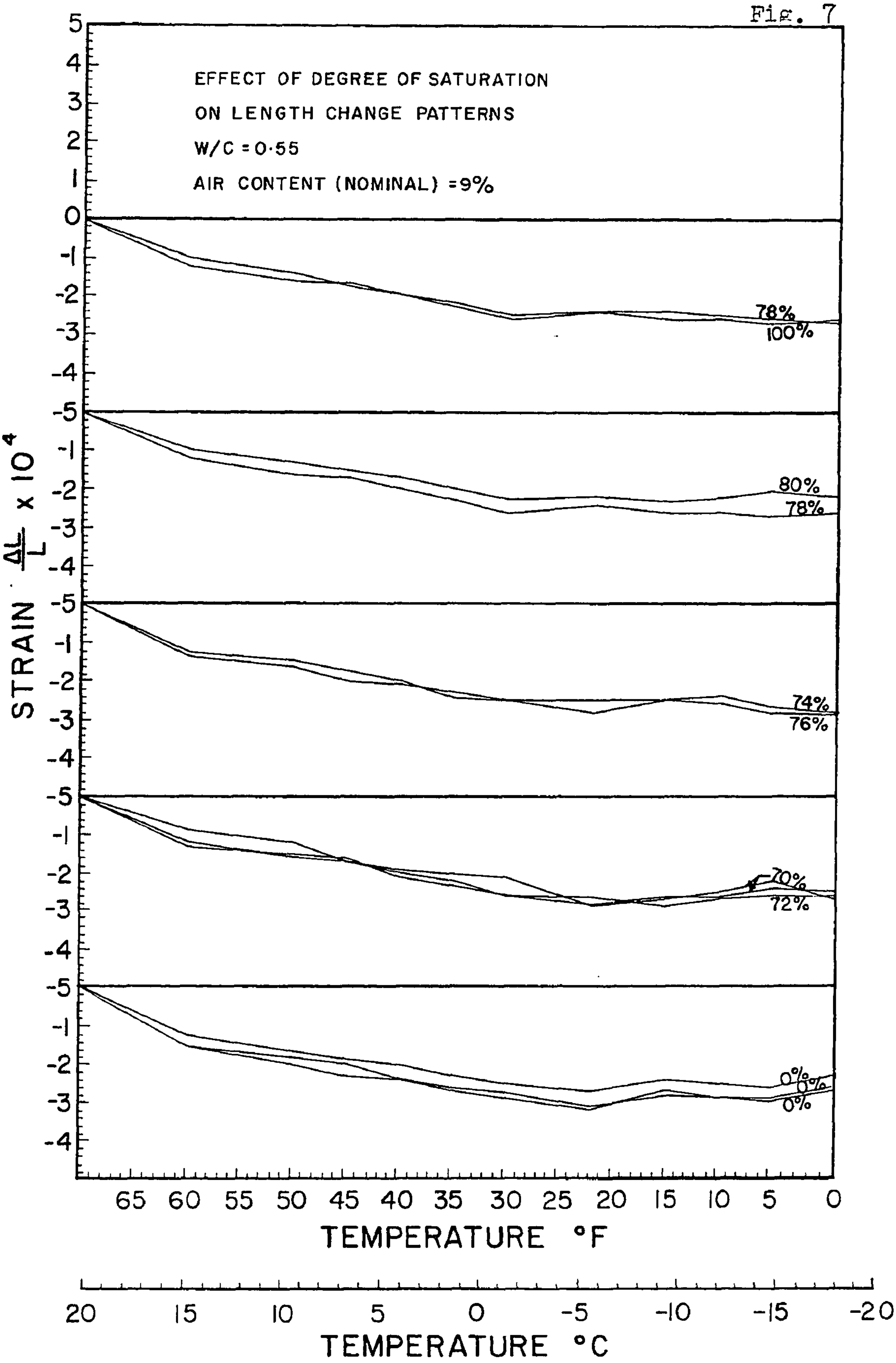

EFFECT OF DEGREE OF SATURATION
ON LENGTH CHANGE PATTERNS
W/C = 0·50
AIR CONTENT (NOMINAL) = 9%
STRAIN $\frac{\Delta L}{L} \times 10^4$
5
4
3
2
1
0
-1
-2
-3
-4
-5
81%
100%
76%
72%
70%
44%
36%
50%
30%
24%
28%
0%
0%
0%
65 60 55 50 45 40 35 30 25 20 15 10 5 0
TEMPERATURE °F
20 15 10 5 0 -5 -10 -15 -20
TEMPERATURE °C

Fig. 7



EFFECT OF DEGREE OF SATURATION ON LENGTH CHANGE PATTERNS

W/C = 0·55

AIR CONTENT (NOMINAL) = 9%

Fig. 8

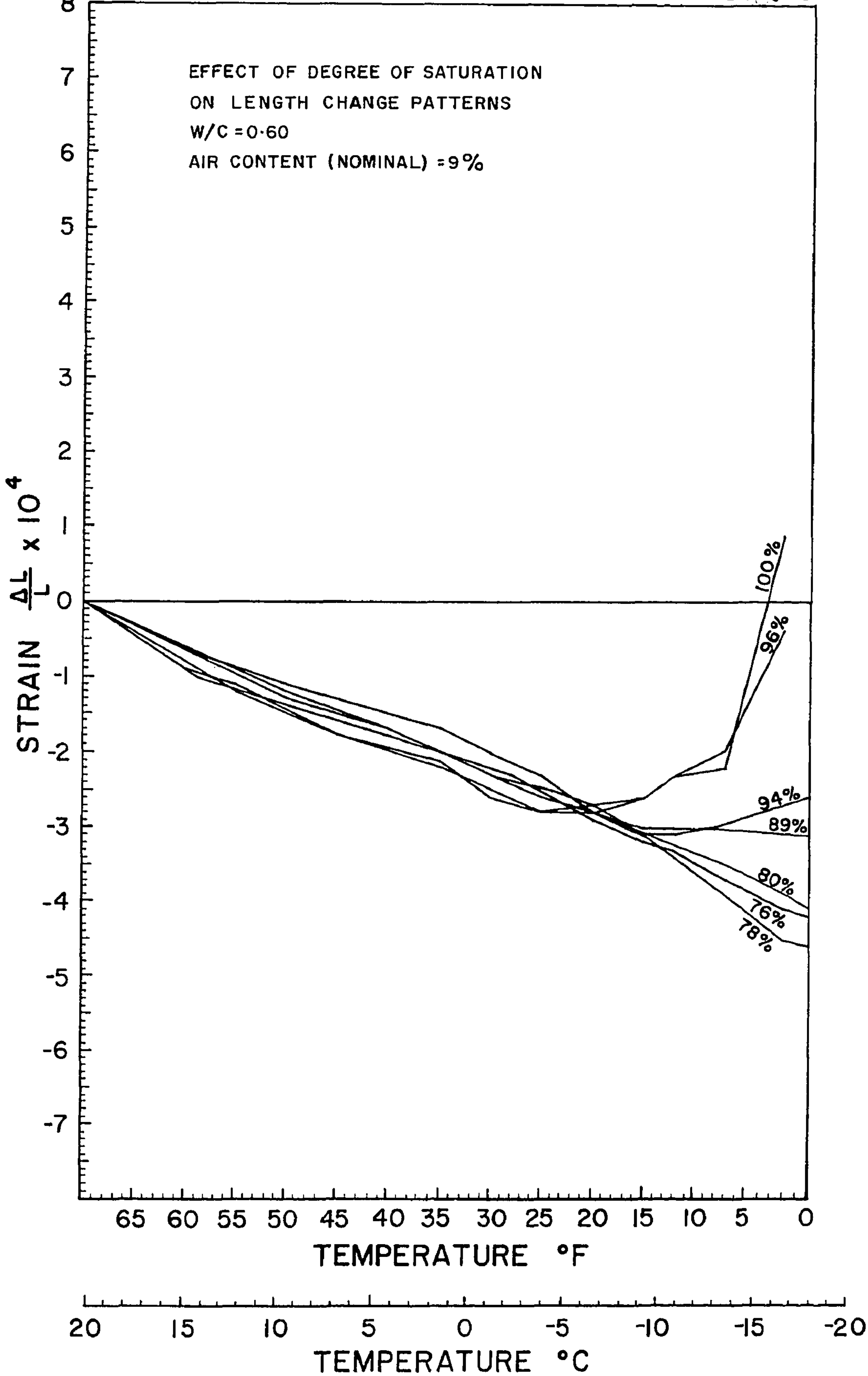

EFFECT OF DEGREE OF SATURATION
ON LENGTH CHANGE PATTERNS
W/C = 0·60
AIR CONTENT (NOMINAL) = 9%
STRAIN $\frac{\Delta L}{L} \times 10^4$
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
100%
96%
94%
89%
80%
76%
78%
65 60 55 50 45 40 35 30 25 20 15 10 5 0
TEMPERATURE °F
20 15 10 5 0 -5 -10 -15 -20
TEMPERATURE °C

Fig. 9

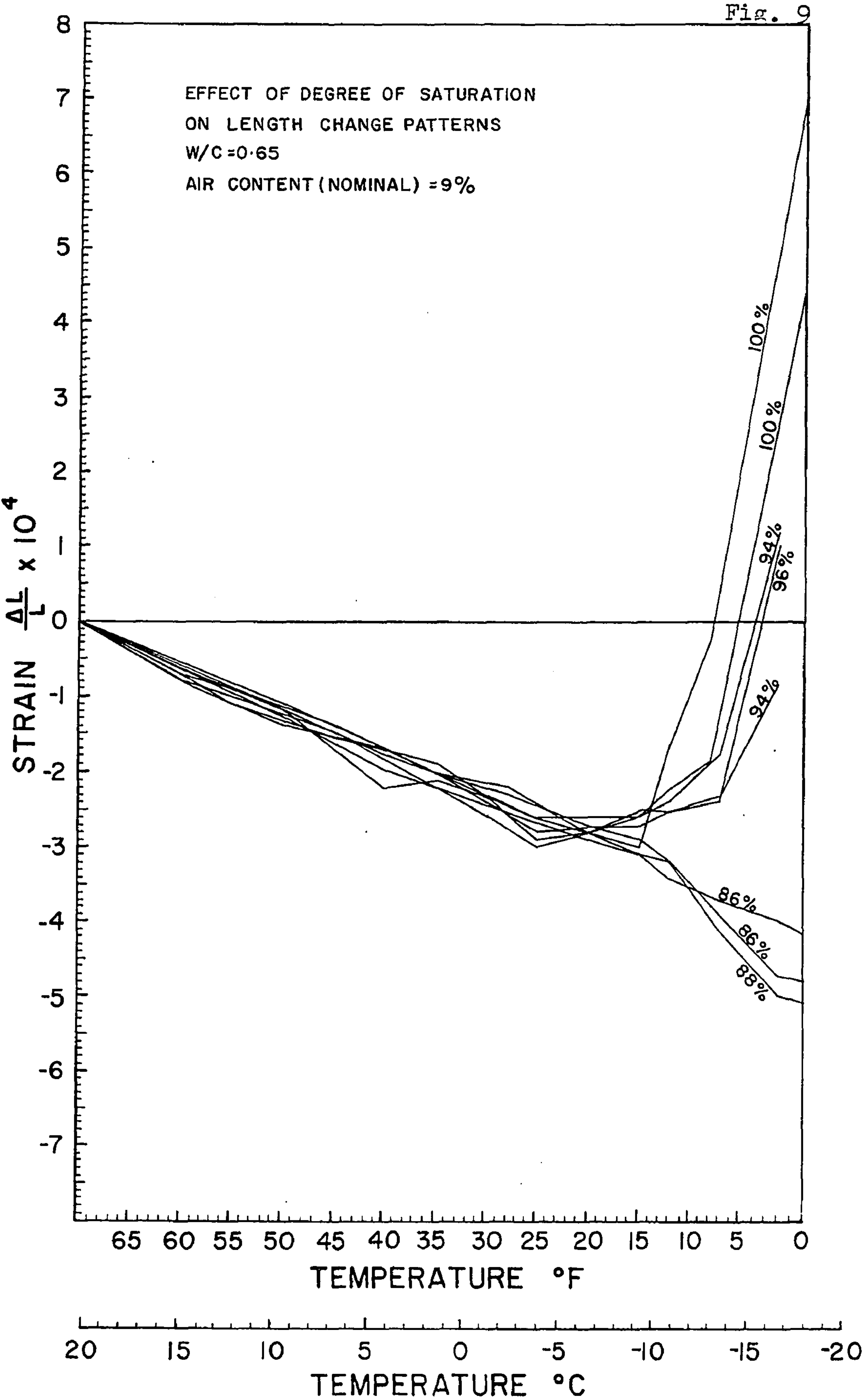

EFFECT OF DEGREE OF SATURATION
ON LENGTH CHANGE PATTERNS
W/C =0·65
AIR CONTENT (NOMINAL) =9%
STRAIN $\frac{\Delta L}{L} \times 10^4$
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
100%
100%
94%
96%
94%
86%
86%
88%
65 60 55 50 45 40 35 30 25 20 15 10 5 0
TEMPERATURE °F
20 15 10 5 0 -5 -10 -15 -20
TEMPERATURE °C

Fig. 10

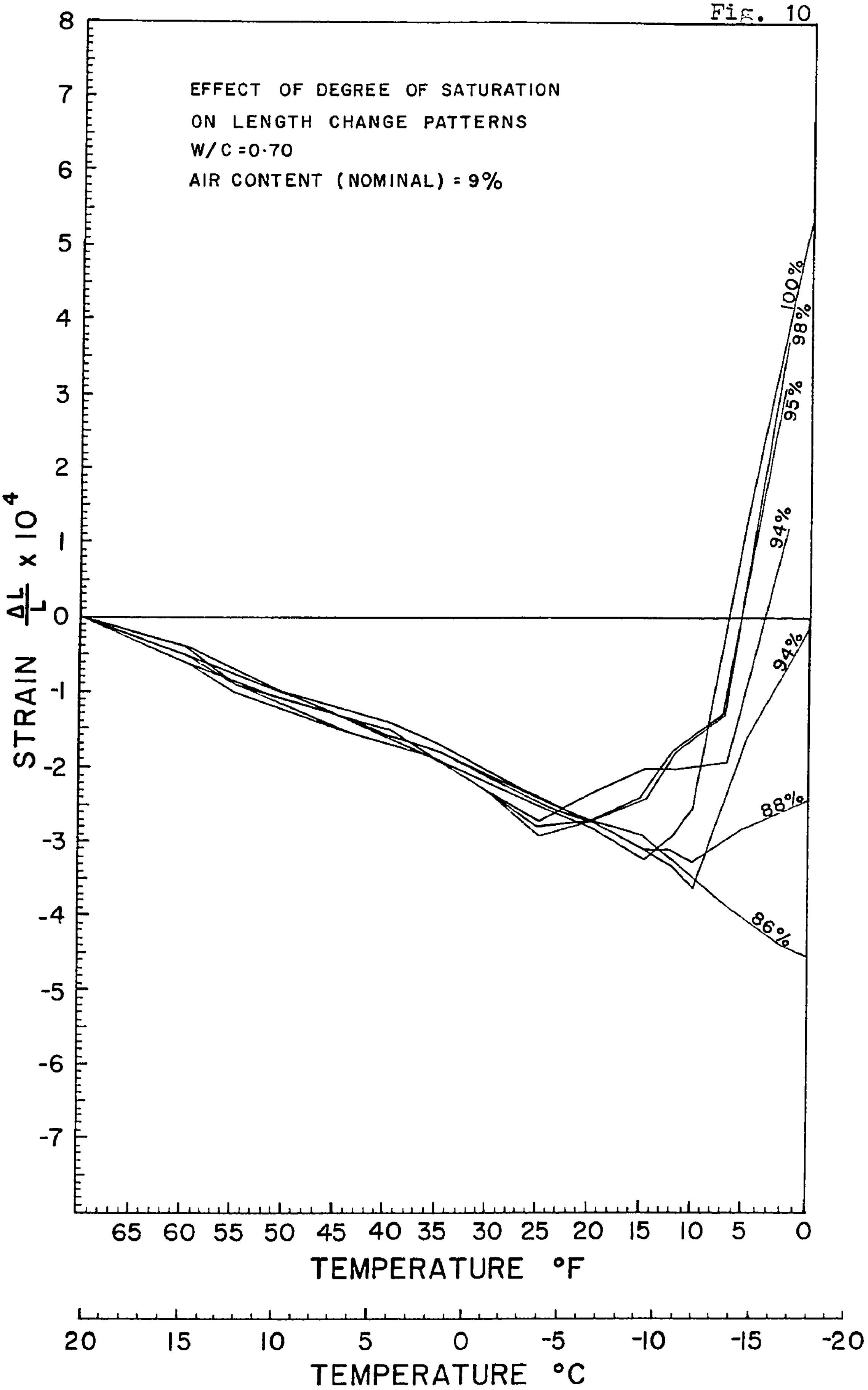

EFFECT OF DEGREE OF SATURATION
ON LENGTH CHANGE PATTERNS
W/C = 0·70
AIR CONTENT (NOMINAL) = 9%
100%
98%
95%
94%
94%
88%
86%
STRAIN $\frac{\Delta L}{L} \times 10^4$
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
65
60
55
50
45
40
35
30
25
20
15
10
5
0
TEMPERATURE °F
20
15
10
5
0
-5
-10
-15
-20
TEMPERATURE °C

Fig. 11

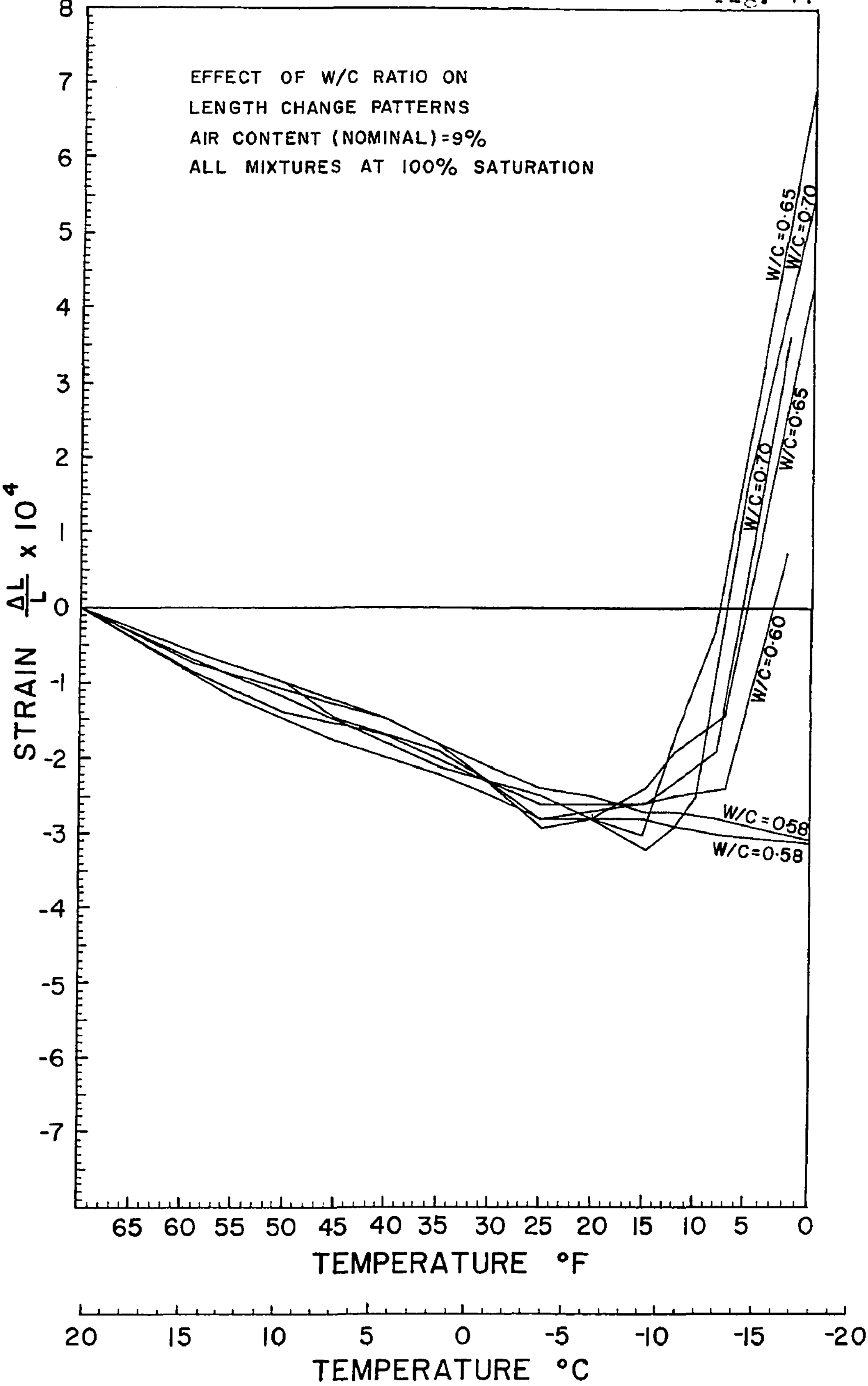

EFFECT OF W/C RATIO ON
LENGTH CHANGE PATTERNS
AIR CONTENT (NOMINAL)=9%
ALL MIXTURES AT 100% SATURATION
W/C=0·65
W/C=0·70
W/C=0·70
W/C=0·65
W/C=0·60
W/C=0·58
W/C=0·58
STRAIN $\frac{\Delta L}{L} \times 10^4$
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
65
60
55
50
45
40
35
30
25
20
15
10
5
0
TEMPERATURE °F
20
15
10
5
0
-5
-10
-15
-20
TEMPERATURE °C

Fig. 12

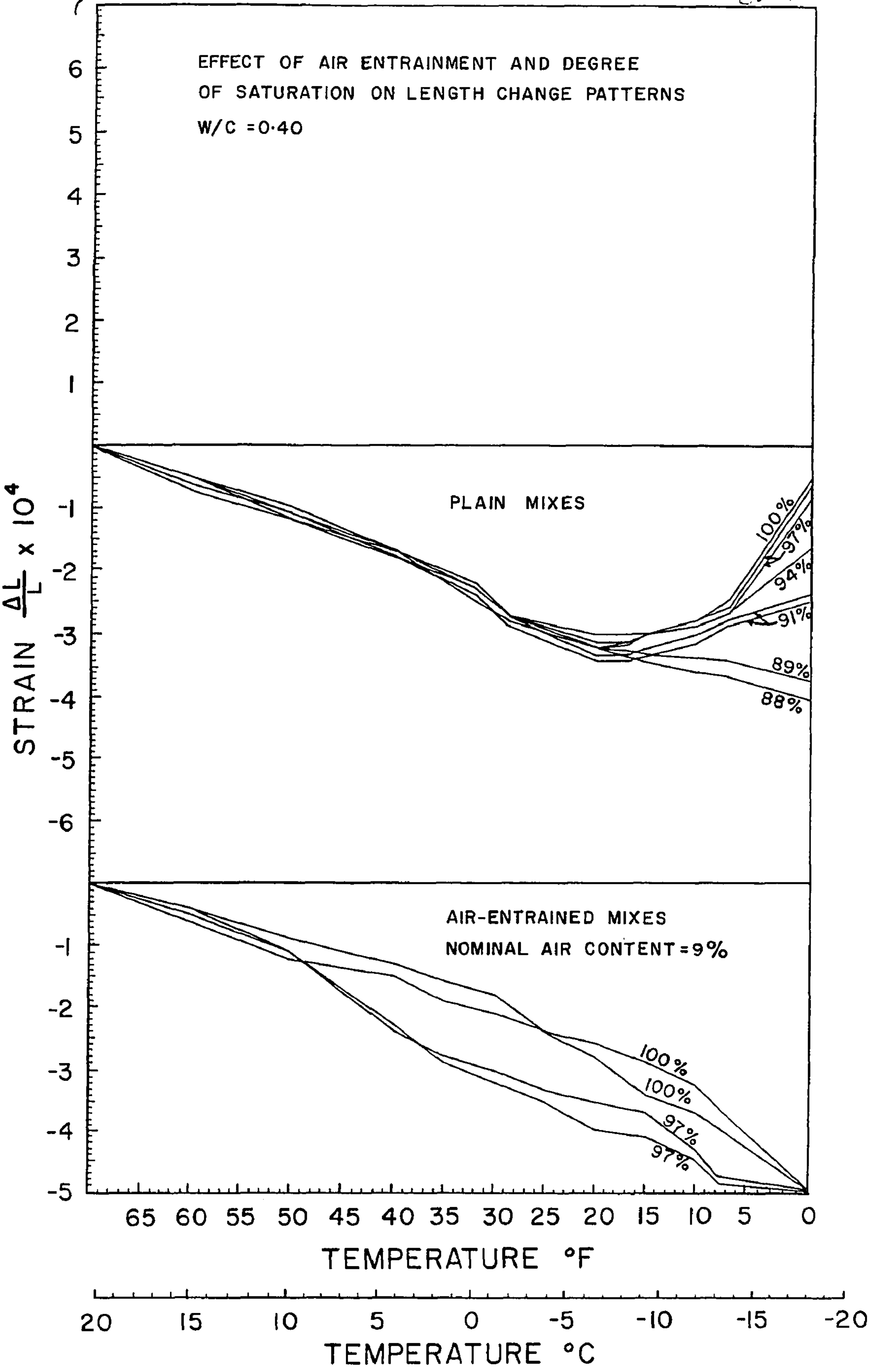

EFFECT OF AIR ENTRAINMENT AND DEGREE
OF SATURATION ON LENGTH CHANGE PATTERNS
W/C =0·40
PLAIN MIXES
100%
97%
94%
91%
89%
88%
AIR-ENTRAINED MIXES
NOMINAL AIR CONTENT=9%
100%
100%
97%
97%
STRAIN $\frac{\Delta L}{L} \times 10^4$
7
6
5
4
3
2
1
-1
-2
-3
-4
-5
-6
-1
-2
-3
-4
-5
65 60 55 50 45 40 35 30 25 20 15 10 5 0
TEMPERATURE °F
20 15 10 5 0 -5 -10 -15 -20
TEMPERATURE °C

Fig. 13

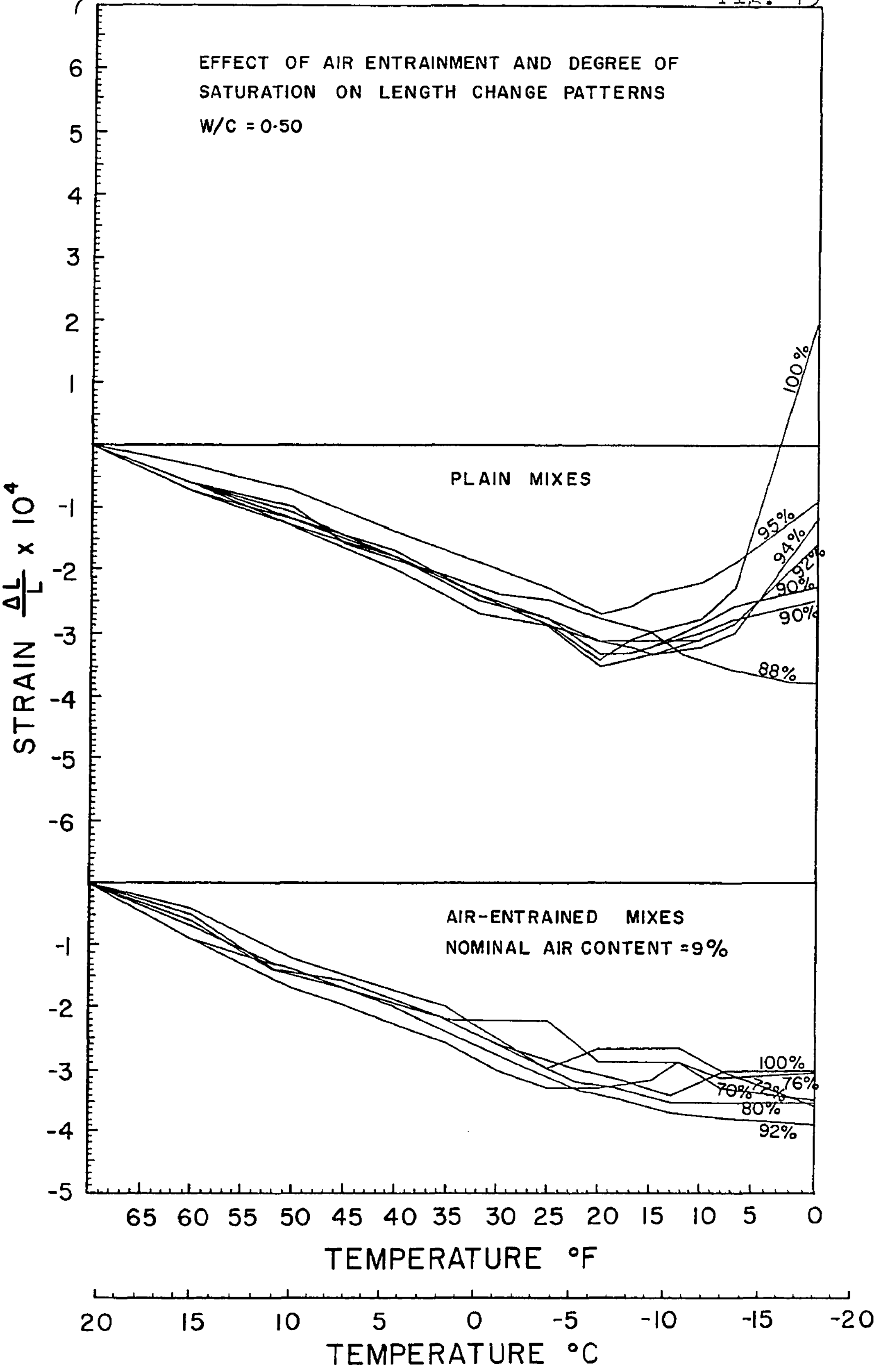
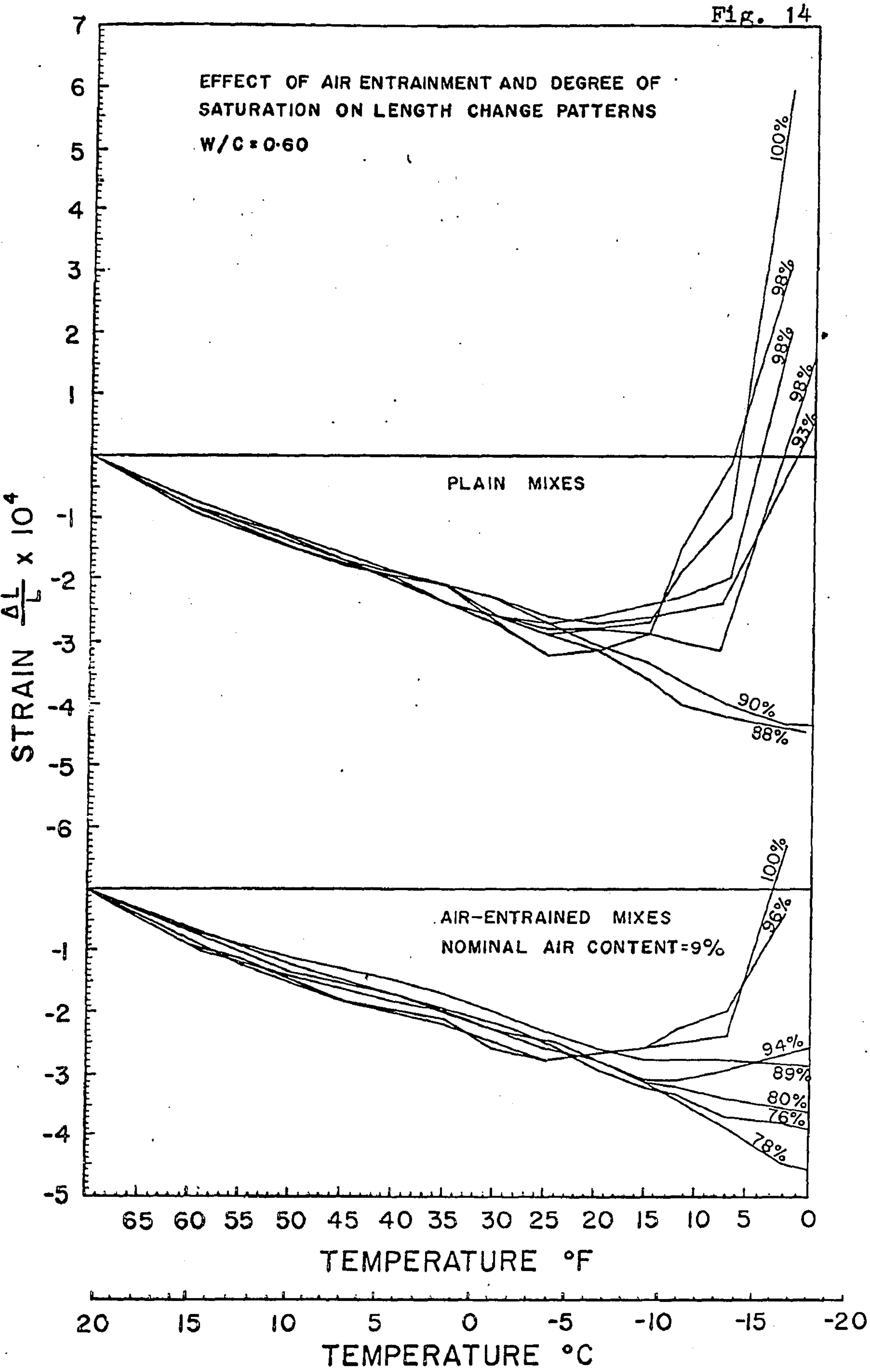

EFFECT OF AIR ENTRAINMENT AND DEGREE OF SATURATION ON LENGTH CHANGE PATTERNS
W/C = 0·50
PLAIN MIXES
100%
95%
94%
92%
90%
90%
88%
AIR-ENTRAINED MIXES
NOMINAL AIR CONTENT = 9%
100%
76%
70%
72%
80%
92%
STRAIN $\frac{\Delta L}{L} \times 10^4$
7
6
5
4
3
2
1
-1
-2
-3
-4
-5
-6
-1
-2
-3
-4
-5
65
60
55
50
45
40
35
30
25
20
15
10
5
0
TEMPERATURE °F
20
15
10
5
0
-5
-10
-15
-20
TEMPERATURE °C

Fig. 14


EFFECT OF AIR ENTRAINMENT AND DEGREE OF SATURATION ON LENGTH CHANGE PATTERNS
W/C = 0·60
PLAIN MIXES
AIR-ENTRAINED MIXES
NOMINAL AIR CONTENT=9%
STRAIN ΔL/L x 10⁴
7
6
5
4
3
2
1
-1
-2
-3
-4
-5
-6
100%
98%
98%
98%
93%
90%
88%
100%
96%
94%
89%
80%
76%
78%
65
60
55
50
45
40
35
30
25
20
15
10
5
0
TEMPERATURE °F
20
15
10
5
0
-5
-10
-15
-20
TEMPERATURE °C

CHAPTER IX

CONCLUSIONS

Based on an evaluation of the freeze-cycle patterns obtained, the following conclusions would appear to be warranted:

(i) The results fortify the position of air-entrainment as an excellent durability aid. Indeed when the degree of saturation of the concrete is likely to be high, air-entrainment would seem to be mandatory even for mixes of water-cement ratios as low as 0.40.

(ii) For exposure conditions where complete saturation is likely to be attained, the limiting water-cement ratio for air-entrained mixes was found to be 0.58.

(iii) The fact that when pronounced expansion occurred, it did so for specimens 90% to 100% saturated suggests that hydraulic pressure is the likely mechanism causing expansion. The results suggest 90% as the limiting degree of saturation; above this degree of saturation is danger of frost damage.

(iv) In climates where there is no likelihood of a high degree of saturation, non air-entrained mixes with water-cement ratios as high as 0.70 could presumably be used safely. However if freezing temperatures are likely to prevail it would seem advisable to use air-entrainment as a precaution.

(v) The limiting water cement ratios recommended by the 1954 ACI code appear to be unduly conservative.

(vi) It is felt that the Powers test should be considered for use in routine evaluation of concrete mixes as well as for research purposes.

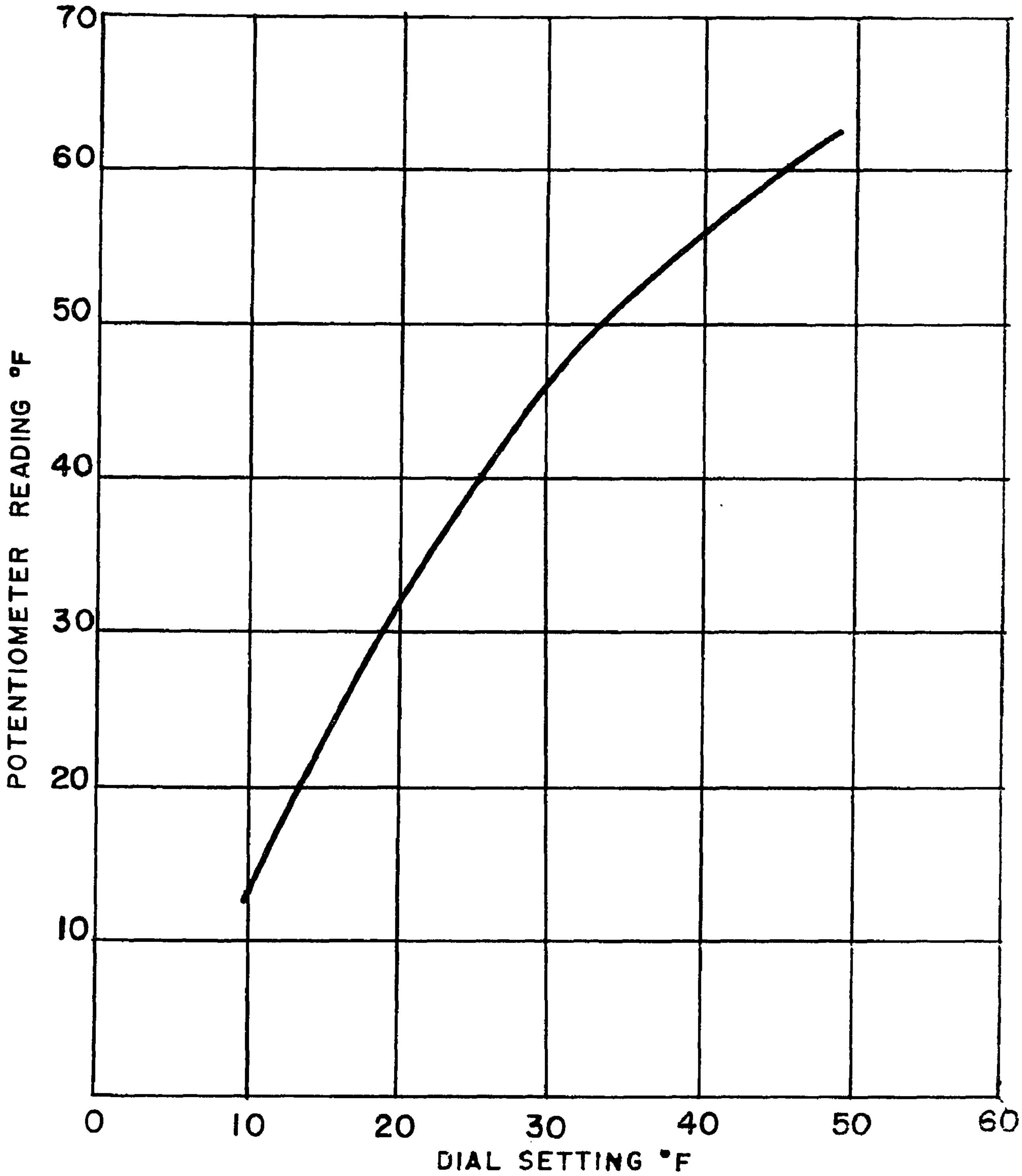


Fig. 15 CALIBRATION OF FREEZING CHAMBER

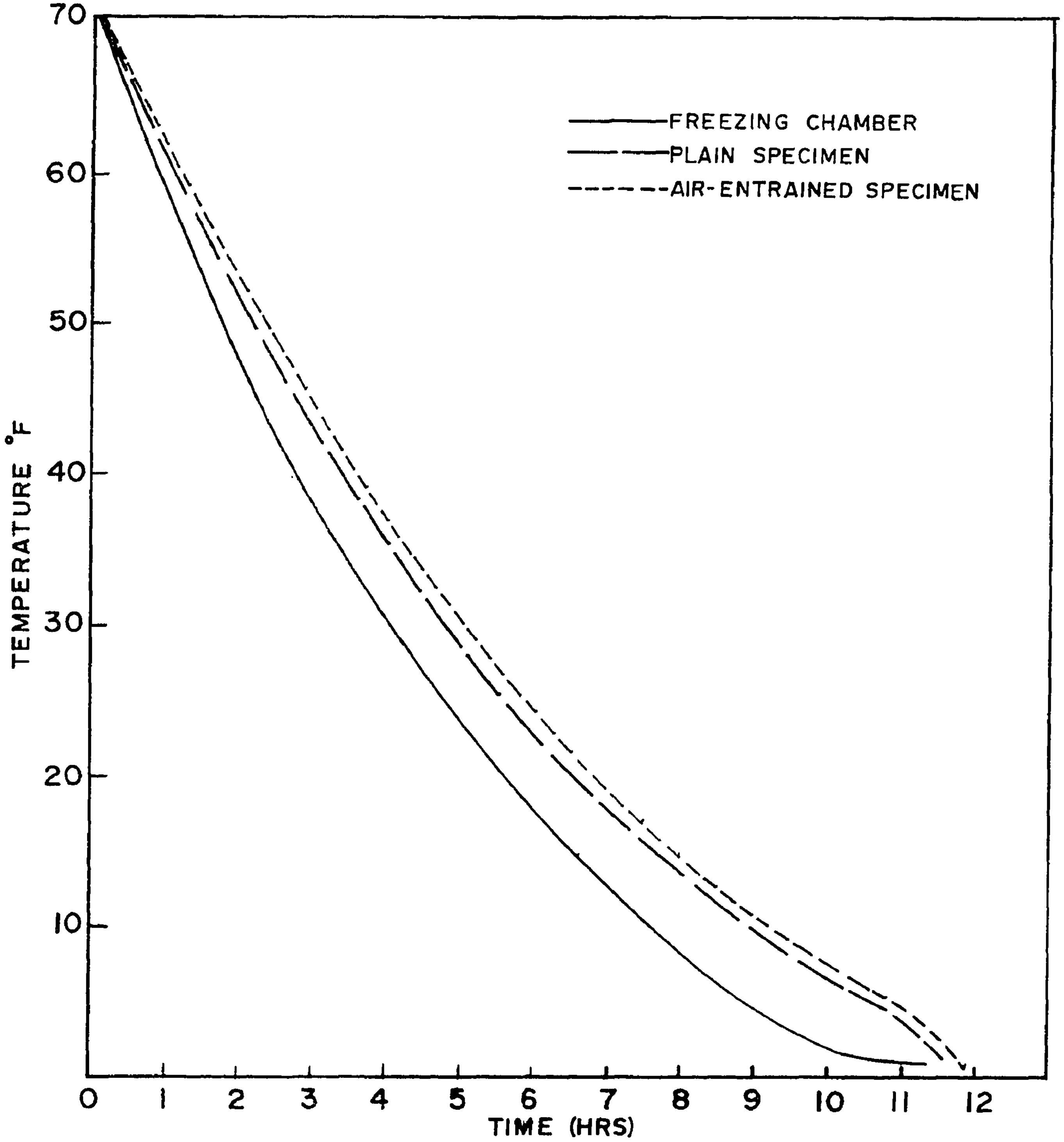


Fig. 16 TIME-TEMPERATURE COOLING CURVES

APPENDIX B

TABLE II

CHEMICAL AND PHYSICAL TEST RESULTS FOR LAKE ONTARIO NORMAL PORTLAND CEMENT

CHEMICAL ANALYSIS	
C_3S	54%
C_2S	22%
C_3A	10.2%
C_4AF	6%
PHYSICAL TESTS	
Blaine Fineness	
Fineness, sq. cm./g	3816
SOUNDNESS	
Autoclave Expansion, Per Cent	0.12%
TIME OF SET, GILLMORE NEEDLE	
Initial, hr : min.	2:25
Final, hr : min.	4:00
COMPRESSIVE STRENGTH P.S.I	
1 Day	1491
7 Days	2257
14 Days	3794
28 Days	4375
Normal Consistency,	24.0%

APPENDIX C

TABLE III

COMPOSITION OF PARIS SAND

Sieve Sizes Per cent Retained	Particles in Per cent by Count in Various Sieve Sizes No. 4	8	14	28	48	100	Total 8 to 100
Dolomite							
Dolomite, pitted	36.5	54.7	55.0	28.0	18.3	16.3	31.1
Dolomite, calcitic	3.6	3.7					.5
(or with coating)	25.0	7.1	5.7	10.0	4.9		5.8
Limestone	3.6	.3	1.7	2.7	2.7	12.7	3.2
Limestone, dolomitic (shaly?)	3.6	2.0	7.0	12.7	6.7		6.7
Marl, aphanitic	12.4	5.3	4.3	5.7	6.3	.3	4.8
" , brittle		.7	1.0	.3	1.0		.7
" , friable	.9	.3	.7	.7	1.0		.6
Shaly, calcareous sandstone, brownish		13.0	6.7	5.0	5.7	1.5	5.9
" " distinctly limonitic	2.7	1.7	2.3	1.0	1.0	1.2	1.3
Ironstone	2.7	1.0	1.0	2.3	1.0	.3	1.3
Sandstone		1.3	1.7	.3	.7	.3	.7
, brittle		.3					x
Recent sandstone		.7	1.0	.7			.6
Chert T. S. 1247	.9	1.0	.3	1.0	.3	.3	.5
Aplite T. S. 1247		2.0	2.7	5.0	6.0	4.1	4.2
Granite	4.5	2.0	2.3	4.0	2.0	3.3	2.6
, brittle		.3	.3				.1
Gneiss		.7	1.3	.3			.4
Diabase	.9	.7		.3	.3		.3
Hornfels T. S. 1247		.3	1.3	1.3			.6

*

For dolomite 25.4% passed the no. 100 sieve.

The physical quality of brittle marl, sandstone and granite is fair and for friable marl poor.

The chemical quality of limonitic sandstone, ironstone and brittle and friable marl is deleterious.

APPENDIX C

TABLE III

COMPOSITION OF PARIS SAND

Sieve Sizes Per cent Retained	Particles in Per cent by Count in Various Sieve Sizes No. 4	8	14	28	48	100	Pass 100	Total 8 to 100
Greenschist (pyrite)	1.8	.3	1.3	1.7	.7	.7		1.0
Slate	.9	.3			.3	.3		.2
Quartz		.3	1.0	9.7	27.1	27.9	19.4	14.9
Quartz with mafics			.7	3.0	2.0	3.0		1.8
Feldspar			.7	4.0	7.0	9.4	4.8	4.5
Mafics (amphibole, Pyroxene)				.3	1.3	4.3	5.7	1.2
Mica (chlorite)					.3	5.3	4.8	.9
Accessory minerals					1.0	3.0	7.0	.0
Opaque minerals					.7	.7	1.0	.3
Dust (carbonate, silicate)							15.0	.7
Carbonate grains					1.0	5.1	16.9	1.7
	100	100	100	100	100	100	100	100
Hcl insoluble residue		26.6	30.4	40.5	56.3	67.2	48.3	45.2
Sulphates		.1	.1	.1	Tr	Tr	Tr	

X - Amounts less than 0.1 per cent

The oversize (No. 4 fraction) amounted to one per cent of the whole sample.

*

The mica (chlorite) showed poor physical quality.

APPENDIX C

TABLE III

PARTICLE SHAPE AND SURFACE OF PARIS SAND

(in per cent)

	----Retained on Sieve Sizes--						Pass	Total
	No. 4	8	14	28	48	100	100	8 to 100
Shape of Particles								
Angular, subangular								
Cubic particles	67	83	89	89	88	78	90	87
Flat particles	8	8	2	1	2	6	5	3
Oblong particles		x	x	x		1	x	x
Rounded, subrounded								
Cubic particles	25	9	9	10	10	15	5	10
	100	100	100	100	100	100	100	100

X - Amounts less than one per cent

The surface of the particles was mainly crystalline, on limestones and on feldspar it was smooth, on the few sandstones, elastic.

APPENDIX C

TABLE III

QUALITY OF PARIS SAND

Fractions	No. 8 to -No. 100 Per cent	No. 4 Per cent
Physical Quality		
Good particles	97.7	99.1
Fair particles	.8	
Poor particles	1.5	.9
	100.0	100.0
Chemical Quality		
Innocuous particles	96.1	93.7
Deleterious (?) particles	2.0	2.7
Deleterious particles	1.9	3.6
	100.0	100.0
Harmful particles	4.8	6.3

Poor particles: Soft marl and micaceous minerals (mica, chlorite)

Deleterious particles: Soft marl and ironstones

Particles suspected of being deleterious: Brittle marl and limonitic calcareous sandstone, rich in limonite.

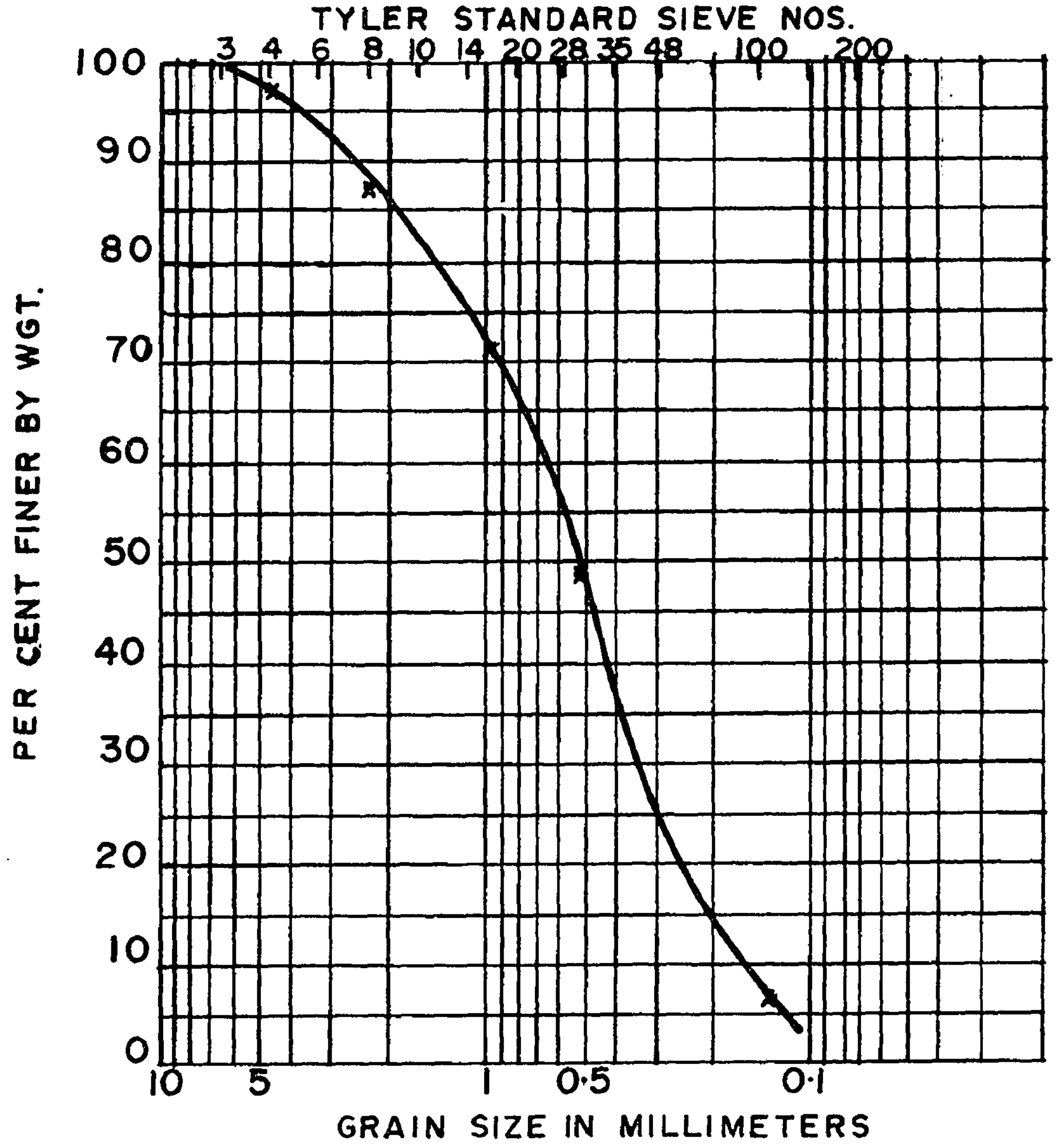


Fig. 17 **GRAIN SIZE DISTRIBUTION FOR PARIS SAND**

APPENDIX D

TABLE IV

W/C	CEMENT (gm)	SAND (gm)	WATER (gm)	DAREX (ml)	TUBE (gm)	TUBE + MORTAR	AIR (%)
0.40	800	2200	320	0.70	292	566	9.00
0.45	800	2200	360	0.80	292	562	9.30
0.48	800	2200	384	0.84	292	559	9.01
0.50	800	2200	400	0.87	292	556	9.75
0.55	800	2200	440	0.90	292	550	9.25
0.58	800	2200	464	0.95	292	570	9.65
0.60	800	2200	480	1.50	292	552	8.0
0.65	800	2200	520	2.00	292	552	7.0
0.70	800	2200	560	3.00	292	558	6.70
0.40NAE*	800	2200	320	0.00	292	581	3.38
0.50NAE	800	2200	400	0.00	292	582	0.77
0.60NAE	800	2200	480	0.00	292	575	0.00

MIX DESIGN DATA

* NAE-Non Air Entrained

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.50	1	1	387	375	12	24
0.50	2	2	386	376	10	20
0.50	3	3	391	377	14	28
0.50	4	4	407	376	31	62
0.50	1	5	404	374	30	60
0.50	2	6	400	377	23	46
0.50	3	7	375	375	0	0
0.50	4	8	374	374	0	0
0.50	1	9	376	376	0	0
0.50	2	10	416	376	40	80
0.50	3	11	421	375	46	92
0.50	4	12	425	375	50	100

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.50	1	13	397	375	22	44
0.50	2	14	393	375	18	36
0.50	3	15	400	375	25	50
0.50	4	16	407	375	32	64
0.50	1	17	413	377	36	72
0.50	2	18	412	376	36	72
0.50	3	19	412	374	38	76
0.50	4	20	412	377	35	70
0.50	1	21	414	378	36	72
0.50	2	22	391	375	16	32
0.50	3	23	388	376	12	24
0.50	4	24	395	377	18	36

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.55	1	25	402	365	37	74
0.55	2	26	404	364	40	80
0.55	3	27	399	364	35	70
0.55	4	28	409	364	45	90
0.55	1	29	401	365	36	72
0.55	2	30	416	366	50	100
0.55	3	31	402	363	39	78
0.55	4	32	400	365	35	70
0.55	3	33	403	365	38	76
0.55	4	34	366	366	0	0
0.55	5	35	365	365	0	0
0.55	3	36	365	365	0	0

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.65	1	37	432	384	48	96
0.65	2	38	431	384	47	94
0.65	3	39	431	384	47	94
0.70	1	40	423	374	49	98
0.70	2	41	422	375	47	94
0.70	3	42	420	375	45	90
0.60	1	43	421	380	41	85
0.60	2	44	429	381	48	100
0.60	3	45	426	380	46	96
0.60 NAE*	1	46	447	404	43	98
0.60 NAE	2	47	447	403	44	100
0.60 NAE	3	48	447	404	43	98

SPECIMEN SATURATION DATA

*NAE-Non Air Entrained

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.70	1	49	418	374	44	88
0.70	3	50	419	375	44	88
0.50 NAE	2	51	454	417	37	90
0.50 NAE	3	52	454	416	38	93
0.60 NAE	3	53	448	405	43	98
0.60 NAE	4	54	444	403	41	93
0.60	2	55	427	382	45	94
0.60	3	56	424	381	43	90
0.65	3	57	435	385	50	100
0.65	4	58	435	385	50	100
0.58	1	59	415	374	41	100
0.58	2	60	416	376	40	97

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.60	3	61	421	383	38	79
0.60	4	62	421	382	39	81
0.70	3	63	418	375	43	86
0.70	4	64	421	374	47	94
0.65	4	65	429	386	43	86
0.65	5	66	427	384	43	86
0.65	5	67	429	385	44	88
0.60	3	68	422	382	40	84
0.65	5	69	427	384	43	86
0.60	4	70	422	382	40	84
0.70	4	71	421	373	48	96
0.70	5	72	421	374	47	94

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.65	5	73	430	386	44	88
0.65	5	74	432	386	46	92
0.65	5	75	434	386	48	96
0.60	3	76	424	380	44	92
0.60	4	77	428	381	47	98
0.60	3	78	428	381	47	98
0.60	4	79	426	380	46	96
0.70	1	80	424	374	50	100
0.70	2	81	419	375	44	88
0.70	3	82	419	374	45	90
0.70	4	83	420	373	47	94
0.65	4	84	428	384	44	88

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.50 NAE	1	85	456	418	38	93
0.50 NAE	2	86	460	419	41	100
0.50 NAE	3	87	454	417	37	90
0.50 NAE	4	88	457	418	39	95
0.40 NAE	1	89	439	407	32	94
0.40 NAE	2	90	442	408	34	100
0.40 NAE	3	91	439	408	31	91
0.40 NAE	4	92	439	406	33	97
0.40 NAE	1	93	439	407	32	94
0.40 NAE	2	94	441	408	33	97
0.50 NAE	1	95	455	418	37	90
0.50 NAE	2	96	456	420	36	88

SPECIMEN SATURATION
DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.40	1	97	440	408	32	97
0.40	2	98	438	406	32	97
0.40	3	99	442	409	33	100
0.48	1	100	422	380	42	100
0.48	2	101	421	384	37	88
0.48	3	102	428	386	42	100
0.45	1	103	433	399	34	97
0.48	4	104	424	385	39	93
0.45	2	105	430	398	32	92
0.45	3	106	431	398	33	95
0.45	4	107	434	399	35	100
0.40	1	108	443	410	33	100

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.58	1	109	416	375	41	100
0.58	2	110	414	374	40	97
0.58	3	111	414	373	41	100
0.58	4	112	416	376	40	100
0.48	1	113	425	386	42	100
0.48	2	114	425	384	41	97
0.48	3	115	426	383	42	100
0.48	4	116	424	385	41	97
0.45	1	117	434	399	35	100
0.45	2	118	434	400	34	97
0.45	3	119	432	397	35	100
0.45	4	120	433	398	35	100

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.60 NAE	1	121	403	404	39	88
0.60 NAE	2	122	444	404	40	90
0.60 NAE	3	123	442	403	39	88
0.60 NAE	4	124	442	402	40	90
0.50 NAE	1	125	456	420	36	88
0.50 NAE	2	126	454	418	36	88
0.50 NAE	3	127	456	419	37	90
0.50 NAE	4	128	457	420	37	90
0.40 NAE	1	129	436	406	30	89
0.40 NAE	2	130	437	408	29	88
0.40 NAE	3	131	436	407	29	88
0.40 NAE	4	132	438	408	30	89

SPECIMEN SATURATION DATA

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.50 NAE	1	*133	456	408	38	93
0.50 NAE	2	134	460	419	41	100
0.50 NAE	3	135	454	417	37	90
0.50 NAE	4	136	457	418	39	95
0.40 NAE	1	137	439	407	32	94
0.40 NAE	2	138	442	408	34	100
0.40 NAE	3	139	439	408	31	91
0.40 NAE	4	140	439	406	33	97
0.40 NAE	1	141	439	407	32	94
0.40 NAE	2	142	441	408	33	97
0.50 NAE	1	143	455	418	37	90
0.50 NAE	2	144	456	420	36	88

SPECIMEN SATURATION
DATA

* Data For Recycling Of Specimens 97-108

APPENDIX E

TABLE V

W/C	BATCH NO.	SPEC. NO.	WET WG'T. (gm)	DRY WG'T (gm)	W (gm)	S (%)
0.50	5	*145	412	377	35	70
0.50	6	146	414	378	36	72
0.50	5	147	416	376	40	80
0.50	6	148	425	375	50	100
0.55	1	149	409	364	45	90
0.55	2	150	401	365	36	72
0.55	3	151	416	366	50	100

SPECIMEN SATURATION DATA

* Data For Recycling Of Specimens 20, 21, 22, 24, 28, 29 and 30

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	* DIAL READINGS & STRAINS**							
	SPEC. NO. 1	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 2	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 3	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 4	$\frac{\Delta L}{L} \times 10^4$
70	9-6.5	-	9-8.1	-	10-2.8	-	11-8.1	-
60	9-5.9	0.6	9-7.5	0.6	10-2.5	0.3	11-7.6	0.5
52	9-5.2	0.7	9-6.8	0.7	10-2.0	0.5	11-7.2	0.4
45	9-4.7	0.5	9-6.5	0.3	10-1.4	0.6	11-6.7	0.5
40	9-4.2	0.5	9-6.3	0.2	10-0.7	0.7	11-6.3	0.4
35	9-3.8	0.4	9-5.9	0.4	10-0.4	0.3	11-6.1	0.2
30	9-3.3	0.5	9-5.4	0.5	10-0.1	0.3	11-5.7	0.4
22	9-2.9	0.4	9-4.9	0.5	9-19.6	0.5	11-4.6	1.1
18	9-2.7	0.2	9-4.6	0.3	9-19.4	0.2	11-4.5	0.1
13	9-2.4	0.3	9-4.1	0.5	9-19.2	0.2	11-4.3	0.2
8	9-2.2	0.2	9-4.3	+0.2	9-18.8	0.4	11-4.5	+0.2
3	9-3.1	+0.9	9-4.4	+0.1	9-19.0	+0.2	11-4.0	0.5

*All dial readings have units of length (in) and are read to 0.0001"

** All strains are dimensionless (in/in)

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 5	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 6	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 7	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 8	$\frac{\Delta L}{L} \times 10^4$
70	9-16.0	-	9-18.6	-	10-1.3	-	8-8.8	-
60	9-15.4	0.6	9-17.2	1.4	10-1.1	0.2	8-8.3	0.5
52	9-15.0	0.4	9-16.9	0.3	10-0.2	0.9	8-7.4	0.9
45	9-14.4	0.6	9-16.2	0.7	9-19.8	0.4	8-7.0	0.4
40	9-14.0	0.4	9-15.7	0.5	9-19.3	0.5	8-6.6	0.4
35	9-13.8	0.2	9-15.6	0.1	9-19.0	0.3	8-6.3	0.3
30	9-13.6	0.2	9-15.3	0.3	9-18.5	0.5	8-5.9	0.4
22	9-12.8	0.8	9-14.0	1.3	9-17.8	0.7	8-5.5	0.4
18	9-12.6	0.2	9-13.9	0.1	9-17.7	0.1	8-5.4	0.3
13	9-12.1	0.5	9-13.8	0.2	9-17.1	0.6	8-5.1	0.3
8	9-12.1	0.0	9-14.1	+0.3	9-17.5	+0.4	8-5.1	0.0
3	9-11.9	0.2	9-14.3	+0.2	9-17.3	0.2	8-5.4	+0.3

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 9	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 10	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 11	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 12	$\frac{\Delta L}{L} \times 10^4$
70	13-1.8	-	9-15.7	-	11-10.9	-	9-11.9	-
60	13-0.8	1.0	9-15.2	0.5	11-10.3	0.6	9-11.2	0.7
52	13-0.0	0.8	9-14.3	0.9	11-9.5	0.8	9-10.6	0.6
45	12-19.6	0.4	9-14.1	0.2	11-9.2	0.3	9-10.2	0.4
40	12-19.2	0.4	9-13.8	0.3	11-8.9	0.3	9-9.9	0.2
35	12-18.8	0.4	9-13.5	0.3	11-8.5	0.4	9-9.6	0.3
30	12-18.5	0.3	9-13.1	0.4	11-8.1	0.4	9-9.3	0.6
22	12-17.9	0.6	9-12.5	0.6	11-7.6	0.5	9-8.5	0.8
18	12-17.6	0.3	9-12.4	0.1	11-7.4	0.2	9-8.4	0.1
13	12-17.1	0.5	9-12.2	0.2	11-7.2	0.2	9-8.1	0.3
8	12-17.9	+0.8	9-12.2	0.0	11-7.1	0.1	9-8.5	+0.4
3	12-18.0	+0.1	9-12.2	0.0	11-7.0	0.1	9-8.5	0.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 13	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 14	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 15	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 16	$\frac{\Delta L}{L} \times 10^4$
70	8-9.2	-	10-19.7	-	11-14.5	-	9-2.8	-
60	8-8.5	0.1	9-18.5	1.2	11-13.3	1.2	9-1.9	0.9
50	8-8.0	0.5	9-17.5	1.0	11-12.5	0.8	9-0.9	1.0
45	8-7.7	0.3	9-17.3	0.2	11-12.1	0.4	9-0.6	0.3
35	8-7.0	0.7	9-17.1	0.2	11-11.5	0.6	9-0.00	0.6
30	8-6.6	0.4	9-16.7	0.4	11-11.5	0.0	8-19.9	0.1
25	8-6.3	0.3	9-16.4	0.3	11-11.5	0.0	8-19.8	0.1
20	8-6.3	0.0	9-16.0	0.4	11-10.5	1.0	8-18.9	0.9
15	8-6.5	+0.2	9-16.5	+0.5	11-10.6	+0.1	8-19.5	+0.6
12	8-6.6	+0.1	9-16.5	0.0	11-10.6	0.0	8-19.8	+0.3
8	8-6.6	0.0	9-16.2	0.3	11-10.9	+0.3	8-19.3	0.5
0	8-6.5	0.1	9-15.9	0.3	11-10.6	0.3	8-18.8	0.5

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 17	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 18	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 19	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 20	$\frac{\Delta L}{L} \times 10^4$
70	9-12.8	-	9-0.5	-	9-14.9	-	8-15.0	-
60	9-12.3	0.5	8-19.8	0.7	9-14.0	0.9	8-14.0	1.0
50	9-11.8	0.5	8-18.4	0.4	9-13.5	0.5	8-13.3	0.7
45	9-11.6	0.2	8-18.1	0.3	9-13.2	0.3	8-13.0	0.3
35	9-11.0	0.6	8-17.8	0.6	9-12.7	0.5	8-12.4	0.6
30	9-10.7	0.3	8-17.6	0.2	9-12.7	0.0	8-12.0	0.4
25	9-9.9	0.8	8-17.4	0.4	9-12.7	0.0	8-11.7	0.3
20	9-10.1	+0.2	8-17.3	0.1	9-12.0	0.7	8-11.7	0.0
15	9-10.1	0.0	8-17.1	0.2	9-12.0	0.0	8-11.8	+0.1
12	9-10.1	0.0	8-17.0	0.1	9-12.0	0.0	8-12.1	+0.3
8	9-10.2	+0.1	8-16.6	0.4	9-11.9	0.1	8-11.7	0.4
0	9-9.8	0.4	8-17.0	+0.4	9-12.0	+0.1	8-11.5	0.2

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 21	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 22	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 23	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 24	$\frac{\Delta L}{L} \times 10^4$
70	11-7.3	-	12-18.8	-	9-0.20	-	10-4.5	-
60	11-6.9	0.4	12-17.8	1.0	8-18.9	0.3	10-3.5	1.0
50	11-6.1	0.8	12-16.9	0.9	8-17.8	1.1	10-2.8	0.7
45	11-5.8	0.3	12-16.6	0.3	8-17.6	0.2	10-2.6	0.2
35	11-5.3	0.5	12-16.2	0.4	8-17.2	0.4	10-2.2	0.4
30	11-4.8	0.5	12-15.7	0.5	8-16.9	0.3	10-1.8	0.4
25	11-4.3	0.5	12-15.2	0.5	8-16.8	0.1	10-1.4	0.4
20	11-4.6	+0.3	12-15.3	+0.1	8-16.2	0.6	10-1.3	0.1
15	11-4.6	0.00	12-15.4	+0.1	8-16.4	+0.2	10-1.1	0.2
12	11-4.6	0.00	12-15.6	+0.2	8-16.6	+0.2	10-0.9	0.2
8	11-4.3	0.30	12-15.4	0.2	8-16.3	0.3	10-1.0	+0.1
0	11-4.0	0.30	12-15.1	0.3	8-16.6	+0.3	10-1.1	+0.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 25	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 26	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 27	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 28	$\frac{\Delta L}{L} \times 10^4$
70	11-8.7	-	10-13.3	-	7-4.5	-	9-13.3	-
60	11-7.5	1.2	10-12.0	1.3	7-3.5	1.0	9-12.3	1.0
50	11-7.3	0.2	10-11.8	0.2	7-3.2	0.3	9-12.0	0.3
45	11-7.0	0.3	10-11.7	0.1	7-3.0	0.2	9-11.6	0.4
40	11-6.7	0.3	10-11.2	0.5	7-2.8	0.2	9-11.2	0.4
35	11-6.3	0.4	10-11.0	0.2	7-2.5	0.3	9-11.0	0.2
30	11-6.2	0.1	10-10.7	0.3	7-2.2	0.3	9-10.8	0.2
22	11-5.9	0.3	10-10.5	0.2	7-2.3	+0.1	9-10.7	0.1
15	11-6.2	+0.3	10-10.7	+0.2	7-2.2	0.1	9-11.0	+0.3
10	11-6.3	+0.1	10-10.7	+0.0	7-2.3	+0.1	9-11.2	+0.2
5	11-6.0	0.3	10-11.0	+0.3	7-2.4	+0.1	9-11.3	+0.1
0	11-5.9	0.1	10-10.9	0.1	7-2.3	0.1	9-11.0	0.3

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 29	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 30	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 31	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 32	$\frac{\Delta L}{L} \times 10^4$
70	9-6.7	-	9-17.5	-	9-6.0	-	11-9.6	-
60	9-5.8	0.9	9-16.5	1.0	9-4.8	1.2	11-8.4	1.2
50	9-5.5	0.3	9-16.1	0.4	9-4.4	0.4	11-8.0	0.4
45	9-5.3	0.5	9-15.7	0.4	9-4.3	0.1	11-7.9	0.1
40	9-5.0	0.3	9-15.5	0.2	9-4.0	0.3	11-7.7	0.2
35	9-4.8	0.2	9-15.3	0.2	9-3.7	0.3	11-7.6	0.1
30	9-4.4	0.4	9-15.0	0.3	9-3.4	0.3	11-7.5	0.1
22	9-4.1	0.3	9-15.1	+0.1	9-3.6	+0.2	11-6.7	0.8
15	9-4.3	+0.2	9-15.1	0.0	9-3.4	0.2	11-6.9	+0.2
10	9-4.4	+0.1	9-15.0	0.1	9-3.4	0.0	11-7.1	+0.2
5	9-4.4	0.0	9-14.9	0.1	9-3.3	0.1	11-7.4	+0.3
0	9-4.3	0.1	9-14.8	0.1	9-3.4	+0.1	11-7.0	0.4

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 33	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 34	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 35	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 36	$\frac{\Delta L}{L} \times 10^4$
70	10-15.8	-	8-0.4	-	9-11.8	-	8-19.0	-
60	10-14.5	1.3	7-18.9	1.5	9-10.6	1.2	8-17.5	1.5
50	10-14.2	0.3	7-18.6	0.3	9-10.2	0.4	8-17.0	0.5
45	10-13.8	0.4	7-18.4	0.2	9-10.0	0.2	8-16.7	0.3
40	10-13.7	0.1	7-18.0	0.4	9-9.8	0.2	8-16.6	0.1
35	10-13.5	0.2	7-17.7	0.3	9-9.5	0.3	8-16.4	0.2
30	10-13.3	0.2	7-17.5	0.2	9-9.3	0.2	8-16.3	0.1
22	10-13.3	0.0	7-17.2	0.3	9-9.1	0.2	8-15.9	0.4
15	10-13.3	0.0	7-17.7	+0.5	9-9.4	+0.3	8-16.2	+0.3
10	10-13.0	0.1	7-17.4	0.2	9-9.3	0.1	8-16.1	0.1
5	10-13.0	0.2	7-17.4	0.1	9-9.2	0.1	8-16.1	0.0
0	10-13.3	0.0	7-17.7	+0.3	9-9.5	+0.3	8-16.4	+0.3

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 37	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 38	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 39	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 40	$\frac{\Delta L}{L} \times 10^4$
70	11-14.1	-	11-3.2	-	8-12.6	-	10-4.1	-
60	11-13.4	0.7	11-2.4	0.8	8-11.9	0.7	10-3.5	0.6
55	11-13.0	0.4	11-2.2	0.2	8-11.7	0.2	10-3.1	0.4
45	11-12.5	0.5	11-1.7	0.5	8-11.2	0.5	10-2.6	0.5
35	11-12.2	0.3	11-1.0	0.7	8-10.6	0.6	10-2.2	0.4
30	11-11.8	0.4	11-0.6	0.4	8-10.2	0.4	10-1.8	0.4
25	11-11.2	0.6	11-0.2	0.4	8-9.8	0.4	10-1.2	0.6
20	11-11.4	+0.1	11-0.4	+0.2	8-9.8	0.0	10-1.4	+0.2
15	11-11.5	+0.2	11-0.7	+0.3	8-9.9	+0.1	10-1.7	+0.3
12	11-11.7	+0.2	11-0.7	0.0	8-10.1	+0.2	10-2.2	+0.5
7	11-11.9	+0.2	11-0.8	+0.1	8-10.3	+0.2	10-2.7	+0.5
2	11-15.3	+3.4	11-4.2	+3.4	10-7.7	+1.4	10-7.7	+5.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 41	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 42	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 43	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 44	$\frac{\Delta L}{L} \times 10^4$
70	10-6.3	-	12-5.8	-	11-5.9	-	11-7.9	-
60	10-5.8	0.5	12-5.4	0.4	11-5.2	0.7	11-7.1	0.8
55	10-5.4	0.4	12-4.8	0.6	11-4.6	0.6	11-6.2	0.4
45	10-5.0	0.4	12-4.3	0.5	11-4.0	0.6	11-6.1	0.6
35	10-4.4	0.6	12-3.9	0.4	11-3.7	0.3	11-5.7	0.4
30	10-4.1	0.3	12-3.5	0.4	11-3.2	0.5	11-5.4	0.3
25	10-3.6	0.5	12-3.1	0.4	11-2.8	0.4	11-5.1	0.3
20	10-3.7	+0.1	12-3.3	+0.2	11-3.1	+0.3	11-5.2	+0.1
15	10-3.9	+0.2	12-3.6	+0.3	11-3.4	+0.3	11-5.3	+0.1
12	10-4.5	+0.6	12-3.6	0.0	11-3.4	0.0	11-5.4	+0.1
7	10-5.2	+0.7	12-3.7	+0.1	11-3.5	+0.1	11-5.6	+0.1
2	10-9.3	+4.1	12-6.8	+3.1	11-4.5	+1.0	11-8.7	+3.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 45	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 46	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 47	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 48	$\frac{\Delta L}{L} \times 10^4$
70	10-9.4	-	12-9.8	-	12-15.0	-	11-4.5	-
60	10-8.5	0.9	12-9.0	0.8	12-14.3	0.7	11-3.6	0.9
55	10-8.3	0.2	12-8.7	0.3	12-14.0	0.3	11-3.3	0.3
45	10-7.6	0.7	12-8.1	0.6	12-13.3	0.7	11-2.7	0.6
35	10-7.3	0.3	12-7.4	0.7	12-12.9	0.4	11-2.4	0.3
30	10-6.8	0.5	12-7.2	0.2	12-12.4	0.5	11-1.8	0.6
25	10-6.6	0.2	12-7.1	0.1	12-12.1	0.3	11-1.3	0.5
20	10-6.7	+0.1	12-7.2	+0.1	12-12.2	+0.1	11-1.4	+0.1
15	10-6.8	+0.1	12-7.4	+0.2	12-12.3	+0.1	11-1.6	+0.2
12	10-7.1	+0.3	12-7.5	+0.1	12-13.1	+0.8	11-3.0	+1.4
7	10-7.4	+0.3	12-7.8	+0.3	12-14.0	+0.9	11-4.4	+1.4
2	10-9.0	+1.6	12-11.8	+4.0	13-0.9	+6.9	11-7.7	+3.3

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 49	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 50	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 51	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 52	$\frac{\Delta L}{L} \times 10^4$
70	10-13.5	-	11-4.4	-	11-3.5	-	8-14.2	-
59	10-13.0	0.5	11-3.7	0.7	11-2.7	0.8	8-13.5	0.7
50	10-12.6	0.4	11-3.2	0.5	11-2.2	0.5	8-13.1	0.4
40	10-12.2	0.4	11-2.6	0.6	11-1.7	0.5	8-12.5	0.6
35	10-11.9	0.3	11-2.2	0.4	11-1.5	0.2	8-12.1	0.4
30	10-11.6	0.3	11-2.0	0.2	11-1.3	0.2	8-11.8	0.3
25	10-11.4	0.2	11-1.7	0.3	11-1.1	0.2	8-11.7	0.1
20	10-11.2	0.2	11-1.7	0.0	11-0.8	0.3	8-11.4	0.3
15	10-11.0	0.2	11-1.6	0.1	11-0.4	0.4	8-11.2	0.2
12	10-11.0	0.00	11-1.6	0.0	11-0.4	0.00	8-11.3	+0.1
8	10-11.0	0.00	11-1.6	0.0	11-0.4	0.00	8-11.4	+0.1
0	10-11.9	+0.9	11-2.8	+1.2	11-1.0	+0.6	8-14.4	+3.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 53	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 54	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 55	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 56	$\frac{\Delta L}{L} \times 10^4$
70	10-17.2	-	9-2.3	-	10-12.3	-	10-3.0	-
59	10-16.3	0.9	9-1.5	0.8	10-11.3	1.0	10-2.3	0.7
50	10-15.7	0.6	9-1.0	0.5	10-10.9	0.4	10-1.9	0.4
40	10-15.2	0.5	9-0.4	0.6	10-10.5	0.4	10-1.5	0.4
35	10-14.8	0.4	9-0.2	0.2	10-10.3	0.2	10-1.3	0.2
30	10-14.5	0.3	9-0.0	0.2	10-10.0	0.3	10-1.0	0.3
25	10-14.4	0.1	8-19.7	0.3	10-9.7	0.3	10-0.7	0.3
20	10-14.4	0.0	8-19.3	0.4	10-9.5	0.2	10-0.4	0.3
15	10-14.3	0.1	8-19.2	0.1	10-9.2	0.3	10-0.2	0.2
12	10-14.2	0.1	8-19.3	+0.1	10-9.2	0.00	10-0.2	0.0
8	10-14.1	0.1	8-19.5	+0.2	10-9.3	+0.1	10-0.2	0.0
0	10-18.8	+4.7	9-2.5	+3.0	10-9.7	+0.4	10-0.1	0.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 57	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 58	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 59	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 60	$\frac{\Delta L}{L} \times 10^4$
70	10-10.8	-	12-7.3	-	8-6.0	-	9-7.7	-
59	10-10.1	0.7	12-6.4	0.9	8-5.3	0.7	9-7.1	0.6
50	10-9.6	0.5	12-5.9	0.5	8-4.9	0.4	9-6.7	0.4
40	10-9.0	0.6	12-5.6	0.3	8-4.5	0.4	9-6.2	0.5
35	10-8.7	0.3	12-5.3	0.3	8-4.2	0.3	9-5.9	0.3
30	10-8.5	0.2	12-5.0	0.3	8-3.7	0.5	9-5.6	0.3
25	10-8.2	0.3	12-4.7	0.3	8-3.4	0.3	9-5.3	0.3
20	10-8.0	0.2	12-4.7	0.0	8-3.4	0.0	9-5.2	0.1
15	10-7.8	0.2	12-4.7	0.0	8-3.4	0.0	9-5.0	0.2
12	10-9.1	+1.3	12-5.0	+0.3	8-3.3	0.1	9-5.0	0.0
8	10-10.5	+1.4	12-5.4	+0.4	8-3.2	0.1	9-4.9	0.1
0	10-18.3	+7.2	12-11.7	+6.3	8-3.1	0.1	9-4.6	0.3

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 61	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 62	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 63	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 64	$\frac{\Delta L}{L} \times 10^4$
70	11-9.3	-	10-8.5	-	13-4.5	-	12-6.0	-
50	11-8.1	1.2	10-7.2	1.3	13-3.5	1.0	12-5.1	0.9
40	11-7.6	0.5	10-6.8	0.4	13-2.9	0.6	12-4.3	1.7
35	11-7.3	0.3	10-6.5	0.3	13-2.7	0.2	12-4.0	0.3
28	11-7.0	0.3	10-6.2	0.3	13-2.3	0.4	12-3.6	0.4
24	11-6.7	0.3	10-6.0	0.2	13-2.0	0.3	12-3.5	0.1
20	11-6.4	0.3	10-5.8	0.2	13-1.8	0.2	12-3.3	0.2
15	11-6.1	0.3	10-5.4	0.4	13-1.6	0.2	12-3.1	0.2
12	11-6.0	0.1	10-5.1	0.3	13-1.3	0.3	12-2.9	0.2
7	11-5.6	0.4	10-4.6	0.5	13-0.7	0.6	12-2.4	0.5
2	11-5.2	0.4	10-4.0	0.6	13-0.1	0.6	12-1.8	0.6
0	11-5.1	0.1	10-3.9	0.1	13-0.0	0.1	12-1.6	0.2

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 65	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 66	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 67	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 68	$\frac{\Delta L}{L}$ x 10^4
70	12-6.9	-	7-16.1	-	11-2.4	-	11-0.0	-
50	12-5.6	1.3	7-15.0	1.1	11-1.2	1.2	10-18.7	1.3
40	12-4.9	0.7	7-14.4	0.6	11-0.6	0.6	10-18.3	0.4
35	12-4.7	0.2	7-14.1	0.3	11-0.4	0.2	10-18.0	0.3
28	12-4.4	0.3	7-13.8	0.3	11-0.2	0.2	10-17.7	0.3
24	12-4.2	0.2	7-13.6	0.2	10-19.9	0.3	10-17.5	0.2
20	12-4.0	0.2	7-13.4	0.2	10-19.6	0.3	10-17.3	0.2
15	12-3.8	0.2	7-13.2	0.2	10-19.3	0.3	10-17.2	0.1
12	12-3.5	0.3	7-12.9	0.3	10-19.2	0.1	10-17.0	0.2
7	12-3.2	0.3	7-12.2	0.7	10-18.3	0.9	10-16.5	0.5
2	12-2.9	0.3	7-11.4	0.8	10-17.4	0.9	10-16.1	0.4
0	12-2.7	0.2	7-11.3	0.1	10-17.3	0.1	10-15.9	0.2

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 69	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 70	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 71	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 72	$\frac{\Delta L}{L} \times 10^4$
70	10-5.2	-	9-15.8	-	13-10.9	-	11-6.6	-
50	10-4.1	1.1	9-14.6	1.2	13-9.8	1.1	11-5.3	1.3
40	10-3.5	0.6	9-14.0	0.6	13-9.2	0.6	11-4.6	0.7
35	10-3.2	0.3	9-13.7	0.3	13-9.0	0.2	11-4.5	0.1
28	10-3.0	0.2	9-13.4	0.3	13-8.7	0.3	11-4.4	0.1
24	10-2.7	0.3	9-13.0	0.4	13-8.4	0.3	11-4.0	0.4
20	10-2.3	0.4	9-12.8	0.2	13-8.3	0.1	11-3.6	0.4
15	10-2.0	0.3	9-12.6	0.2	13-8.1	0.2	11-3.5	0.1
12	10-1.7	0.3	9-12.4	0.2	13-7.8	0.3	11-3.4	0.1
7	10-1.0	0.7	9-11.9	0.5	13-7.1	0.7	11-2.8	0.6
2	10-0.3	0.7	9-11.4	0.5	13-6.4	0.7	11-2.2	0.6
0	10-0.1	0.2	9-11.2	0.2	13-6.2	0.2	11-2.1	0.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 73	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 74	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 75	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 76	$\frac{\Delta L}{L} \times 10^4$
70	10-1.7	-	11-10.0	-	10-12.1	-	12-0.0	-
60	10-1.2	0.5	11-9.4	0.6	10-11.4	0.7	11-19.6	0.4
50	10-0.7	0.5	11-8.9	0.5	10-10.9	0.5	11-19.0	0.6
40	10-0.2	0.5	11-8.5	0.4	10-10.4	0.5	11-18.4	0.6
35	9-19.8	0.4	11-8.1	0.4	10-10.1	0.3	11-18.0	0.4
25	9-19.3	0.5	11-7.7	0.4	10-9.7	0.4	11-17.6	0.4
20	9-19.0	0.3	11-7.3	0.4	10-9.5	0.2	11-17.1	0.5
15	9-18.6	0.4	11-6.9	0.4	10-9.3	0.2	11-16.8	0.3
12	9-18.4	0.2	11-7.0	+0.1	10-9.0	0.3	11-16.6	0.2
10	9-18.1	0.3	11-7.2	+0.2	10-8.8	0.2	11-16.3	0.3
5	9-18.3	+0.2	11-9.0	+1.8	10-10.8	+2.0	11-16.9	+0.6
0	9-18.5	+0.2	11-10.8	+1.8	10-12.8	+2.0	11-17.5	+0.6

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 77	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 78	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 79	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 80	$\frac{\Delta L}{L} \times 10^4$
70	9-13.8	-	10-1.3	-	9-10.8	-	10-0.3	-
60	9-13.0	0.8	10-0.6	0.7	9-10.3	0.5	10-9.7	0.6
50	9-12.6	0.4	10-0.0	0.6	9-9.8	0.5	10-9.2	0.5
40	9-12.2	0.4	9-19.7	0.3	9-9.3	0.5	9-18.8	0.4
35	9-11.7	0.5	9-19.2	0.5	9-8.5	0.8	9-18.4	0.4
25	9-11.2	0.5	9-18.8	0.4	9-7.9	0.6	9-17.8	0.6
20	9-11.0	0.0	9-18.3	0.5	9-7.6	0.3	9-17.5	0.3
15	9-10.7	0.3	9-18.0	0.3	9-7.3	0.3	9-17.1	0.4
12	9-10.5	0.2	9-17.9	0.1	9-7.2	0.1	9-17.4	+0.3
10	9-10.3	0.2	9-17.7	0.2	9-7.0	0.2	9-17.8	+0.4
5	9-10.5	+0.2	9-18.2	+0.5	9-7.8	+0.8	10-1.8	+4.0
0	9-10.7	+0.2	9-18.7	+0.5	9-8.6	+0.8	10-5.7	+3.9

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 81	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 82	$\frac{\Delta L}{L}$ x10^4	SPEC. NO. 83	$\frac{\Delta L}{L}$ x10^4	SPEC. NO. 84	$\frac{\Delta L}{L}$ x10^4
70	10-7.2	-	10-12.4	-	11-12.2	-	10-5.1	-
60	10-6.8	0.4	10-12.0	0.4	11-11.7	0.5	10-4.5	0.6
50	10-6.3	0.5	10-11.6	0.4	11-11.2	0.5	10-4.0	0.5
40	10-5.8	0.5	10-10.9	0.7	11-10.7	0.5	10-3.6	0.4
35	10-5.5	0.3	10-10.7	0.2	11-10.4	0.3	10-3.2	0.4
25	10-4.8	0.7	10-10.3	0.4	11-9.8	0.6	10-2.5	0.7
20	10-4.5	0.3	10-9.8	0.5	11-9.5	0.3	10-2.2	0.3
15	10-4.1	0.4	10-9.3	0.5	11-9.1	0.4	10-1.9	0.3
12	10-4.1	0.0	10-9.1	0.2	11-8.9	0.2	10-1.9	0.0
10	10-4.0	0.1	10-8.8	0.3	11-8.6	0.3	10-1.8	0.1
5	10-4.4	+0.4	10-9.5	+0.7	11-9.5	+2.0	10-2.4	+0.6
0	10-4.8	+0.4	10-10.2	+0.7	11-12.1	+1.5	10-3.0	+0.6

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 85	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 86	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 87	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 88	$\frac{\Delta L}{L} \times 10^4$
70	11-1.5	-	11-11.6	-	10-13.9	-	12-12.3	-
60	11-0.9	0.6	11-10.9	0.7	10-13.3	0.6	12-12.0	0.3
50	11-0.2	0.7	11-10.3	0.6	10-12.7	0.6	12-10.6	0.4
40	10-19.5	0.7	11-9.7	0.6	10-12.2	0.5	12-9.9	0.7
32	10-18.8	0.7	11-9.1	0.6	10-11.5	0.7	12-9.4	0.5
25	10-18.6	0.2	11-8.6	0.5	10-11.1	0.4	12-9.0	0.4
20	10-18.4	0.2	11-8.1	0.5	10-10.6	0.5	12-8.6	0.4
17	10-18.4	0.0	11-8.3	+0.2	10-10.6	0.0	12-8.7	+0.1
15	10-18.3	0.1	11-8.5	+0.2	10-10.7	+0.1	12-8.9	+0.2
10	10-18.5	+0.2	11-8.8	+0.3	10-11.0	+0.3	12-9.1	+0.2
7	10-18.7	+0.2	11-9.2	+0.4	10-11.3	+0.3	12-9.4	+0.3
0	10-19.0	+0.3	11-13.5	+4.3	10-11.6	+0.3	12-10.4	+1.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 89	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 90	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 91	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 92	$\frac{\Delta L}{L} \times 10^4$
70	10-10.1	-	9-19.8	-	12-5.3	-	12-19.0	-
60	10-9.6	0.5	9-19.2	0.6	12-4.8	0.5	12-18.4	0.6
50	10-8.9	0.7	9-18.7	0.5	12-4.3	0.5	12-17.9	0.5
40	10-8.3	0.6	9-18.0	0.7	12-3.6	0.7	12-17.3	0.6
32	10-7.7	0.6	9-17.5	0.5	12-2.8	0.8	12-16.7	0.6
25	10-7.2	0.5	9-17.1	0.4	12-2.5	0.3	12-16.3	0.4
20	10-6.7	0.5	9-16.6	0.5	12-2.1	0.4	12-16.0	0.3
17	10-6.7	0.0	9-16.7	+0.1	12-2.2	+0.1	12-16.0	0.0
15	10-6.8	+0.1	9-16.8	+0.1	12-2.3	+0.1	12-16.0	0.0
10	10-7.0	+0.2	9-16.9	+0.1	12-2.5	+0.2	12-16.2	+0.2
7	10-7.2	+0.2	9-17.1	+0.2	12-2.8	+0.3	12-16.4	+0.2
0	10-7.6	+0.4	9-18.1	+1.0	12-4.8	+2.0	12-18.4	+2.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 93	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 94	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 95	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 96	$\frac{\Delta L}{L} \times 10^4$
70	11-18.7	-	10-10.6	-	11-6.6	-	11-0.8	-
60	11-18.0	0.7	10-10.1	0.5	11-6.0	0.6	11-0.1	0.7
50	11-17.5	0.5	10-9.5	0.6	11-5.5	0.5	10-19.6	0.5
40	11-17.0	0.5	10-8.9	0.6	11-4.8	0.7	10-19.0	0.6
32	11-16.5	0.5	10-8.3	0.6	11-4.2	0.6	10-18.3	0.7
25	11-16.0	0.5	10-7.9	0.4	11-3.7	0.5	10-18.0	0.3
20	11-15.4	0.6	10-7.5	0.4	11-3.1	0.6	10-17.7	0.3
17	11-15.4	0.0	10-7.5	0.0	11-3.2	+0.1	10-17.6	0.1
15	11-15.5	+0.1	10-7.6	+0.1	11-3.3	+0.1	10-17.5	0.1
10	11-15.7	+0.2	10-7.7	+0.1	11-3.4	+0.1	10-17.7	+0.2
7	11-15.9	+0.2	10-7.9	+0.2	11-3.6	+0.2	10-17.9	+0.2
0	11-16.3	+0.4	10-9.9	+2.0	11-5.4	+1.8	10-19.2	+1.3

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 97	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 98	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 99	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 100	$\frac{\Delta L}{L} \times 10^4$
70	11-3.1	-	11-4.7	-	11-10.3	-	9-14.3	-
60	11-2.6	0.5	11-4.3	0.4	11-9.8	0.5	9-13.7	0.6
50	11-2.0	0.6	11-3.7	0.7	11-9.4	0.4	9-13.3	0.4
40	11-0.8	1.2	11-2.4	1.3	11-9.0	0.4	9-12.9	0.4
35	11-1.3	0.6	11-3.0	0.4	11-8.7	0.3	9-12.5	0.4
30	11-1.0	0.3	11-2.8	0.2	11-8.5	0.2	9-12.4	0.1
25	11-0.7	0.3	11-2.5	0.3	11-8.3	0.2	9-12.2	0.2
20	11-0.2	0.5	11-2.3	0.2	11-7.9	0.4	9-12.0	0.2
15	11-0.1	0.1	11-2.1	0.2	11-7.5	0.4	9-11.8	0.2
10	10-19.7	0.4	11-1.5	0.6	11-6.9	0.6	9-11.3	0.5
8	10-19.2	0.5	11-0.9	0.6	11-6.6	0.3	9-10.8	0.5
0	10-19.2	0.0	11-0.9	0.0	11-6.6	0.0	9-10.8	0.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 101	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 102	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 103	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 104	$\frac{\Delta L}{L} \times 10^4$
70	10-0.2	-	11-2.4	-	9-10.6	-	8-19.8	-
60	9-19.7	0.5	11-1.8	0.6	9-9.9	0.7	8-19.2	0.6
50	9-19.3	0.4	11-1.2	0.6	9-9.2	0.7	8-18.5	0.7
40	9-18.7	0.6	11-0.8	0.4	9-8.5	0.7	8-18.0	0.5
35	9-18.6	0.1	11-0.6	0.2	9-8.3	0.2	8-17.8	0.2
30	9-18.3	0.3	11-0.3	0.3	9-8.3	0.0	8-17.6	0.2
25	9-17.9	0.4	11-0.0	0.3	9-8.2	0.1	8-17.4	0.2
20	9-17.6	0.3	10-19.7	0.3	9-8.1	0.1	8-17.1	0.3
15	9-17.3	0.3	10-19.5	0.2	9-8.0	0.1	8-16.9	0.2
10	9-17.0	0.3	10-19.3	0.2	9-7.5	0.5	8-16.6	0.3
5	9-16.6	0.4	10-19.0	0.3	9-7.0	0.5	8-16.3	0.3
0	9-16.3	0.3	10-18.7	0.3	9-6.9	0.1	8-15.2	1.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 105	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 106	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 107	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 108	$\frac{\Delta L}{L} \times 10^4$
70	9-8.8	-	10-16.6	-	10-9.2	-	10-4.9	-
60	9-8.4	0.4	10-16.1	0.5	10-8.7	0.5	10-4.3	0.6
50	9-7.9	0.5	10-15.6	0.5	10-8.1	0.6	10-3.7	0.6
40	9-7.5	0.4	10-15.2	0.4	10-7.7	0.4	10-3.4	0.3
35	9-7.3	0.2	10-15.0	0.2	10-7.4	0.3	10-3.0	0.4
30	9-7.0	0.3	10-14.7	0.3	10-7.1	0.3	10-2.8	0.2
25	9-6.6	0.4	10-14.3	0.4	10-6.9	0.2	10-2.5	0.3
20	9-6.3	0.3	10-14.0	0.3	10-6.7	0.2	10-2.3	0.2
15	9-6.0	0.3	10-13.6	0.4	10-6.5	0.2	10-2.0	0.3
10	9-5.4	0.6	10-13.3	0.3	10-6.2	0.3	10-1.7	0.3
8	9-4.9	0.5	10-13.0	0.3	10-5.8	0.4	10-1.3	0.4
0	9-4.3	0.6	10-12.7	0.3	10-5.8	0.0	10-1.3	0.0

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 109	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 110	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 111	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 112	$\frac{\Delta L}{L} \times 10^4$
70	8-7.0	-	9-7.2	-	8-7.5	-	9-6.9	-
60	8-6.4	0.6	9-6.6	0.6	8-7.0	0.5	9-6.2	0.7
50	8-5.9	0.5	9-6.2	0.4	8-6.5	0.5	9-5.6	0.6
40	8-5.6	0.3	9-5.8	0.4	8-6.2	0.3	9-5.2	0.4
35	8-5.3	0.3	9-5.4	0.4	8-5.8	0.4	9-4.9	0.3
30	8-4.9	0.4	9-5.1	0.3	8-5.4	0.4	9-4.7	0.2
25	8-4.5	0.4	9-4.8	0.3	8-5.1	0.3	9-4.4	0.3
20	8-4.5	0.0	9-4.7	0.1	8-4.9	0.2	9-4.1	0.3
15	8-4.4	0.1	9-4.7	0.0	8-4.8	0.1	9-4.0	0.1
10	8-4.3	0.1	9-4.5	0.2	8-4.8	0.0	9-3.8	0.2
8	8-4.1	0.2	9-4.4	0.1	8-4.6	0.2	9-3.8	0.0
0	8-4.0	0.1	9-4.3	0.1	8-4.5	0.1	9-3.7	0.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 113	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 114	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 115	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 116	$\frac{\Delta L}{L} \times 10^4$
70	9-14.0	-	10-0.0	-	9-13.0	-	10-2.5	-
60	9-13.4	0.6	9-19.5	0.5	9-12.4	0.6	10-2.0	0.5
50	9-13.0	0.4	9-18.8	0.7	9-11.6	0.5	10-1.5	0.5
40	9-12.7	0.3	9-18.3	0.5	9-11.2	0.4	10-1.2	0.3
35	9-12.3	0.4	9-18.1	0.2	9-10.7	0.5	10-1.1	0.1
30	9-12.1	0.2	9-17.8	0.3	9-10.5	0.2	10-0.9	0.2
25	9-12.0	0.1	9-17.5	0.3	9-10.4	0.1	10-0.5	0.4
20	9-11.7	0.3	9-17.2	0.3	9-10.2	0.2	10-0.2	0.3
15	9-11.5	0.2	9-17.1	0.1	9-10.0	0.2	10-0.0	0.2
10	9-11.1	0.4	9-16.9	0.2	9-9.6	0.4	9-19.8	0.2
8	9-10.6	0.5	9-16.5	0.4	9-9.2	0.4	9-19.6	0.2
0	9-10.5	0.1	9-16.2	0.3	9-9.0	0.2	9-19.2	0.4

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 117	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 118	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 119	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 120	$\frac{\Delta L}{L} \times 10^4$
70	9-8.0	-	10-15.0	-	10-8.2	-	10-4.0	-
60	9-7.6	0.4	10-14.4	0.6	10-7.6	0.6	10-3.5	0.5
50	9-7.2	0.4	10-13.9	0.5	10-7.0	0.6	10-2.9	0.6
40	9-6.7	0.5	10-13.4	0.5	10-6.6	0.4	10-2.5	0.4
35	9-6.4	0.3	10-13.0	0.4	10-6.3	0.3	10-2.1	0.4
30	9-6.1	0.3	10-12.6	0.4	10-6.0	0.3	10-1.8	0.3
25	9-5.7	0.4	10-12.3	0.3	10-5.6	0.4	10-1.6	0.2
20	9-5.3	0.4	10-12.1	0.2	10-5.4	0.2	10-1.4	0.2
15	9-4.8	0.5	10-11.9	0.2	10-5.2	0.2	10-1.3	0.1
10	9-4.2	0.6	10-11.6	0.3	10-5.1	0.1	10-1.2	0.1
8	9-3.5	0.7	10-11.2	0.4	10-4.6	0.5	10-0.8	0.4
0	9-3.1	0.4	10-11.1	0.1	10-4.4	0.2	10-0.6	0.2

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 121	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 122	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 123	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 124	$\frac{\Delta L}{L} \times 10^4$
70	12-9.2	-	12-14.5	-	11-4.2	-	11-3.0	-
60	12-8.3	0.9	12-13.8	0.7	11-3.3	0.9	11-2.2	0.8
55	12-7.9	0.4	12-13.5	0.3	11-3.1	0.2	11-1.8	0.4
45	12-7.4	0.5	12-12.9	0.6	11-2.6	0.5	11-1.1	0.7
35	12-6.6	0.8	12-12.5	0.4	11-2.2	0.4	11-1.0	0.1
30	12-6.5	0.3	12-11.9	0.6	11-1.7	0.5	11-0.8	0.2
25	12-6.4	0.1	12-11.5	0.4	11-1.2	0.5	11-0.5	0.3
20	12-6.2	0.2	12-11.2	0.3	11-0.8	0.4	11-0.1	0.4
15	12-5.8	0.4	12-10.9	0.3	11-0.4	0.4	10-19.5	0.6
12	12-5.5	0.3	12-10.5	0.4	11-0.2	0.2	10-19.5	0.0
7	12-5.3	0.2	12-10.1	0.4	11-0.0	0.2	10-19.3	0.2
2	12-5.0	0.3	12-9.8	0.3	10-19.9	0.2	10-19.1	0.2

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 125	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 126	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 127	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 128	$\frac{\Delta L}{L} \times 10^4$
70	8-15.0	-	10-17.0	-	9-15.0	-	10-0.0	-
60	8-14.4	0.6	10-16.2	0.8	9-14.4	0.6	9-19.3	0.7
55	8-13.8	0.4	10-15.4	0.8	9-13.9	0.5	9-18.7	0.6
45	8-13.2	0.6	10-14.8	0.6	9-13.2	0.7	9-18.0	0.7
35	8-12.7	0.5	10-14.3	0.5	9-12.8	0.4	9-17.4	0.6
30	8-12.3	0.3	10-14.0	0.3	9-12.4	0.4	9-17.0	0.4
25	8-12.3	0.1	10-13.8	0.2	9-12.0	0.4	9-16.7	0.3
20	8-12.0	0.3	10-13.5	0.3	9-11.8	0.2	9-16.4	0.3
15	8-11.8	0.2	10-13.0	0.5	9-11.3	0.5	9-16.1	0.3
12	8-11.5	0.3	10-12.8	0.2	9-11.1	0.2	9-15.9	0.2
7	8-11.2	0.3	10-12.6	0.2	9-10.8	0.3	9-15.7	0.2
2	8-11.0	0.2	10-12.2	0.4	9-10.6	0.2	9-15.6	0.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 129	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 130	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 131	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 132	$\frac{\Delta L}{L} \times 10^4$
70	9-19.5	-	9-18.7	-	10-10.5	-	10-9.6	-
60	9-19.0	0.5	9-18.2	0.5	10-9.9	0.6	10-9.0	0.6
55	9-18.3	0.7	9-17.6	0.6	10-9.3	0.6	10-8.3	0.7
45	9-17.6	0.7	9-16.9	0.7	10-8.7	0.6	10-7.6	0.7
35	9-17.1	0.5	9-16.3	0.6	10-8.0	0.7	10-7.1	0.5
30	9-16.5	0.6	9-16.0	0.3	10-7.2	0.8	10-6.6	0.5
25	9-16.0	0.5	9-15.6	0.4	10-6.6	0.6	10-6.2	0.4
20	9-15.3	0.7	9-15.2	0.4	10-6.1	0.5	10-5.8	0.4
15	9-15.0	0.3	9-14.8	0.4	10-5.4	0.7	10-5.2	0.6
12	9-14/7	0.3	9-14.3	0.5	10-5.1	0;3	10-4.9	0.3
7	9-14.5	0.2	9-13.9	0.4	10-4.9	0.2	10-4.7	0.2
2	9-14.1	0.4	9-13.4	0.5	10-4.7	0.2	10-4.6	0.1

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. *133	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 134	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 135	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 136	$\frac{\Delta L}{L} \times 10^4$
70	11-4.7	-	11-16.7	-	10-17.0	-	12-16.2	-
62	11-4.4	0.3	11-16.4	0.3	10-16.6	0.4	12-15.8	0.4
55	11-4.1	0.3	11-16.1	0.3	10-16.3	0.3	12-15.4	0.4
45	11-3.9	0.2	11-15.8	0.3	10-16.0	0.3	12-15.0	0.4
38	11-3.6	0.3	11-15.5	0.3	10-15.6	0.4	12-14.6	0.4
30	11-2.9	0.7	11-15.0	0.5	10-15.3	0.3	12-14.3	0.3
22	11-2.5	0.4	11-14.5	0.5	10-15.0	0.3	12-14.0	0.3
18	11-2.4	0.1	11-14.6	+0.1	10-14.8	0.2	12-13.9	0.1
14	11-2.3	0.1	11-14.7	+0.1	10-14.7	0.1	12-13.8	0.1
10	11-2.0	0.3	11-14.4	0.3	10-14.3	0.4	12-13.5	0.3
7	11-1.8	0.2	11-14.1	0.3	10-14.0	0.3	12-13.3	0.2
0	11-1.7	0.1	11-15.3	+1.2	10-14.3	+0.3	12-14.5	+1.2

* Data for 1st recycling of specimen nos. 97-108

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 137	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 138	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 139	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 140	$\frac{\Delta L}{L}$ x 10^4
70	10-13.2	-	10-3.4	-	12-9.5	-	13-3.3	-
62	10-12.9	0.3	10-3.1	0.3	12-9.2	0.3	13-3.0	0.3
55	10-12.6	0.3	10-2.8	0.3	12-8.8	0.4	13-2.6	0.4
45	10-12.3	0.3	10-2.5	0.3	12-8.6	0.2	13-2.2	0.4
38	10-12.0	0.3	10-2.1	0.4	12-8.3	0.3	13-1.8	0.4
30	10-11.7	0.3	10-1.7	0.4	12-7.9	0.4	13-1.4	0.4
22	10-11.5	0.2	10-1.3	0.4	12-7.5	0.4	13-0.9	0.5
18	10-11.2	0.3	10-1.1	0.2	12-7.5	0.0	13-0.9	0.0
14	10-11.0	0.2	10-1.0	0.1	12-7.4	0.1	13-0.8	0.1
10	10-10.6	0.4	10-0.7	0.3	12-7.1	0.3	13-0.5	0.3
7	10-10.1	0.5	10-0.5	0.2	12-6.9	0.2	13-0.3	0.2
0	10-9.7	0.4	10-0.3	0.2	12-6.9	0.0	13-0.4	+0.1

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EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 141	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 142	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 143	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 144	$\frac{\Delta L}{L} \times 10^4$
70	12-2.1	-	10-14.6	-	11-10.3	-	11-4.4	-
62	12-1.8	0.3	10-14.3	0.3	11-10.0	0.3	11-4.1	0.3
55	12-1.5	0.3	10-13.9	0.4	11-9.6	0.4	11-3.8	0.3
45	12-1.2	0.3	10-13.6	0.3	11-9.2	0.4	11-3.5	0.3
38	12-0.8	0.4	10-13.4	0.2	11-8.8	0.4	11-3.3	0.2
30	12-0.4	0.4	10-12.9	0.5	11-8.5	0.4	11-2.9	0.3
22	12-0.0	0.4	10-12.3	0.6	11-8.1	0.4	11-2.5	0.4
18	11-19.9	0.1	10-12.3	0.0	11-7.9	0.2	11-2.3	0.2
14	11-19.7	0.2	10-12.4	+0.1	11-7.8	0.1	11-2.1	0.2
10	11-19.4	0.3	10-12.1	0.3	11-7.4	0.4	11-1.8	0.3
7	11-19.1	0.3	10-11.8	0.3	11-7.1	0.3	11-1.4	0.4
0	11-18.8	0.3	10-11.7	0.1	11-7.1	0.0	11-0.8	0.6

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EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. *133	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 134	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 135	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 136	$\frac{\Delta L}{L} \times 10^4$
70	11-4.0	-	11-15.7	-	10-16.3	-	12-15.2	-
60	11-3.5	0.5	11-15.2	0.5	10-15.8	0.5	12-14.5	0.7
50	11-2.9	0.6	11-14.7	0.5	10-15.4	0.4	12-13.8	0.7
40	11-2.4	0.5	11-14.2	0.5	10-14.9	0.5	12-13.3	0.5
30	11-2.0	0.4	11-13.7	0.5	10-14.3	0.6	12-12.9	0.4
25	11-1.8	0.2	11-13.2	0.5	10-13.8	0.5	12-12.7	0.2
20	11-1.3	0.5	11-12.7	0.5	10-13.3	0.5	12-12.3	0.4
17	11-1.0	0.3	11-12.6	0.1	10-13.1	0.2	12-12.1	0.2
12	11-0.7	0.3	11-12.5	0.1	10-13.0	0.0	12-12.0	0.1
10	11-0.2	0.5	11-12.2	0.3	10-12.6	0.4	12-11.5	0.5
5	10-19.9	0.3	11-12.0	0.2	10-12.3	0.3	12-11.3	0.2
0	10-19.5	0.4	11-12.5	+0.5	10-12.2	0.1	12-11.9	+0.6

* Data for 2nd recycling of specimen nos. 97-108

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EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 137	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 138	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 139	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 140	$\frac{\Delta L}{L} \times 10^4$
70	10-12.5	-	10-2.7	-	12-9.3	-	13-2.3	-
60	10-12.0	0.5	10-2.2	0.5	12-8.6	0.7	13-1.9	0.4
50	10-11.5	0.5	10-1.8	0.4	12-8.0	0.6	13-1.5	0.4
40	10-11.0	0.5	10-1.2	0.6	12-7.4	0.6	13-0.9	0.6
30	10-10.5	0.5	10-0.7	0.5	12-6.8	0.6	13-0.3	0.6
25	10-10.1	0.4	10-0.2	0.5	12-6.3	0.5	13-0.0	0.3
20	10-9.7	0.4	9-19.9	0.3	12-5.9	0.4	12-19.6	0.4
17	10-9.4	0.3	9-19.8	0.1	12-5.5	0.4	12-19.5	0.1
12	10-9.2	0.2	9-19.7	0.1	12-5.3	0.2	12-19.4	0.1
10	10-8.9	0.3	9-19.2	0.5	12-5.1	0.2	12-19.0	0.4
5	10-8.5	0.4	9-18.7	0.5	12-4.9	0.2	12-18.5	0.5
0	10-8.1	0.4	9-18.6	0.1	12-4.7	0.2	12-18.5	0.0

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EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 141	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 142	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 143	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 144	$\frac{\Delta L}{L} \times 10^4$
70	12-1.4	-	10-13.7	-	11-9.5	-	11-3.7	-
60	12-0.9	0.5	10-13.2	0.5	11-8.9	0.6	11-3.1	0.6
50	12-0.4	0.5	10-12.7	0.5	11-8.4	0.5	11-2.6	0.5
40	11-19.9	0.5	10-12.2	0.5	11-8.0	0.4	11-2.0	0.6
30	11-19.4	0.5	10-11.8	0.4	11-7.5	0.5	11-1.4	0.6
25	11-19.0	0.4	10-11.3	0.5	11-7.1	0.4	11-1.1	0.3
20	11-18.6	0.4	10-10.8	0.5	11-6.7	0.4	11-0.8	0.3
17	11-18.4	0.2	10-10.8	0.0	11-6.5	0.2	11-0.6	0.2
12	11-18.2	0.2	10-10.9	+0.1	11-6.3	0.2	11-0.4	0.2
10	11-17.7	0.5	10-10.5	0.4	11-6.0	0.3	11-0.1	0.3
5	11-17.3	0.4	10-9.8	0.7	11-5.5	0.5	10-19.5	0.6
0	11-17.3	0.0	10-9.8	0.0	11-5.3	0.2	10-19.3	0.2

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. *145	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 146	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 147	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 148	$\frac{\Delta L}{L} \times 10^4$
70	8-15.3	-	11-8.3	-	9-16.9	-	9-13.3	-
60	8-14.9	0.4	11-7.8	0.5	9-16.3	0.6	9-12.9	0.4
50	8-14.5	0.4	11-7.3	0.5	9-15.7	0.6	9-12.5	0.4
40	8-14.0	0.5	11-6.7	0.6	9-15.1	0.6	9-12.0	0.5
35	8-13.6	0.4	11-6.3	0.4	9-14.7	0.4	9-11.8	0.2
30	8-13.2	0.4	11-6.0	0.3	9-14.4	0.3	9-11.6	0.2
26	8-12.7	0.5	11-5.7	0.3	9-14.0	0.4	9-10.3	0.3
21	8-12.4	0.3	11-5.4	0.3	9-13.7	0.3	9-12.8	0.1
17	8-12.2	0.2	11-5.0	0.4	9-13.5	0.2	9-10.0	0.2
13	8-11.5	0.7	11-4.2	0.8	9-12.8	0.7	9-9.6	0.4
9	8-10.7	0.8	11-3.5	0.7	9-12.1	0.7	9-9.1	0.5
2	8-10.3	0.4	11-3.4	0.1	9-12.1	0.0	9-8.7	0.4

*Data for 1st recycling of specimen nos. 20, 21, 22, 24, 28, 29 and 30

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 149	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 150	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO. 151	$\frac{\Delta L}{L} \times 10^4$	SPEC. NO.	$\frac{\Delta L}{L} \times 10^4$
70	9-15.8	-	9-9.3	-	9-19.7	-		
60	9-15.3	0.5	9-8.8	0.5	9-19.1	0.6		
50	9-14.9	0.4	9-8.4	0.4	9-18.6	0.5		
40	9-14.3	0.6	9-7.7	0.7	9-18.0	0.6		
35	9-14.0	0.3	9-7.3	0.4	9-17.6	0.4		
30	9-13.7	0.3	9-6.9	0.4	9-17.2	0.4		
26	9-13.3	0.4	9-6.5	0.4	9-16.8	0.4		
21	9-12.8	0.5	9-6.1	0.4	9-16.6	0.2		
17	9-12.3	0.5	9-5.7	0.4	9-16.4	0.2		
13	9-12.0	0.3	9-5.0	0.7	9-15.9	0.5		
9	9-11.7	0.3	9-4.5	0.5	9-15.3	0.6		
2	9-11.3	0.4	9-4.3	0.2	9-15.4	+0.1		

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. *145	$\frac{\Delta L}{L}$ x 10⁴	SPEC. NO. 146	$\frac{\Delta L}{L}$ x10⁴	SPEC. NO. 147	$\frac{\Delta L}{L}$ x10⁴	SPEC. NO. 148	$\frac{\Delta L}{L}$ x10⁴
70	8-14.9	-	11-7.6	-	9-16.4	-	9-12.9	-
60	8-14.3	0.6	11-7.1	0.5	9-15.8	0.6	9-12.4	0.5
45	8-13.7	0.6	11-6.6	0.5	9-15.2	0.6	9-11.9	0.5
40	8-13.3	0.4	11-6.2	0.4	9-14.8	0.4	9-11.5	0.4
35	8-12.9	0.4	11-5.8	0.4	9-14.4	0.4	9-11.1	0.4
27	8-12.4	0.5	11-5.4	0.4	9-14.0	0.4	9-10.7	0.4
22	8-12.1	0.3	11-5.4	0.4	9-13.5	0.5	9-10.4	0.3
17	8-11.7	0.4	11-4.5	0.5	9-13.1	0.4	9-10.0	0.4
14	8-11.5	0.2	11-4.5	0.1	9-13.0	0.1	9-9.8	0.2
10	8-11.4	0.1	11-4.3	0.1	9-12.9	0.1	9-9.7	0.1
4	8-11.4	0.1	11-3.0	1.3	9-11.9	1.0	9-8.7	1.0
0	8-11.1	+0.5	11-3.9	+0.9	9-12.2	+0.3	9-9.1	+0.4

*Data for 2nd recycling of specimen nos. 20, 21, 22, 24, 28, 29, and 30

APPENDIX F

EXPERIMENTAL LENGTH CHANGE DATA

TABLE VI

TEMP. °F	DIAL READINGS & STRAINS							
	SPEC. NO. 149	$\frac{\Delta L}{L}$ x 10^4	SPEC. NO. 150	$\frac{\Delta L}{L}$ x10^4	SPEC. NO. 151	$\frac{\Delta L}{L}$ x10^4	SPEC. NO.	$\frac{\Delta L}{L}$ x10^4
70	9-15.5	-	9-8.8	-	9-19.5	-		
60	9-15.0	0.5	9-8.3	0.5	9-18.9	0.6		
45	9-14.4	0.6	9-7.8	0.5	9-18.4	0.5		
40	9-14.0	0.4	9-7.4	0.4	9-17.9	0.5		
35	9-13.6	0.4	9-7.0	0.4	9-17.4	0.5		
27	9-13.1	0.5	9-6.5	0.5	9-17.0	0.4		
22	9-12.9	0.3	9-6.0	0.5	9-16.7	0.3		
17	9-12.5	0.4	9-5.5	0.5	9-16.3	0.4		
14	9-12.4	0.1	9-5.5	0.0	9-16.5	+0.2		
10	9-12.3	0.1	9-5.4	0.1	9-16.8	+0.3		
4	9-11.1	1.2	9-4.5	0.9	9-16.5	0.3		
0	9-12.1	+1.0	9-5.5	+1.0	9-17.7	+1.2		

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