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Some Physical Properties of Cements Employed in the Cementation of Orthodontic Bands

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SOME PHYSICAL PROPERTIES OF CEMENTS
EMPLOYED IN
THE CEMENTATION OF ORTHODONTIC BANDS

BY

JAY R. SCHAUER, D.D.S.

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF LOYOLA UNIVERSITY IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

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PREFACE

The orthodontist is probably more dependent upon the performance of a dental cement than any other practitioner. No matter how skillfully an orthodontic band may be constructed, it will not remain on the tooth throughout its functional use without the aid of a cement. In addition to the role that cement plays in attaching bands to the teeth, it has equally an important function of protecting the tooth under the band from hypocalcification and caries. For these reasons the physical characteristics of dental cements and their manipulations are of particular interest to all the practitioners of orthodontics.

This study was undertaken to provide some basic data regarding the setting time, solubility and disintegration, and compressive strength of some dental cements as they may be used for the cementation of orthodontic bands.

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INTRODUCTION

It has been estimated that there are 40,000,000 children between five and thirteen years of age at the present time. Various surveys show that at least one-fifth of these children need orthodontic treatment of some kind. While the present actual membership of the American Association of Orthodontists is about 8,000, it is thought that there is an additional six to nine thousand general dentists practicing some form of orthodontics (1). Most of these clinicians use a multiple banding technique in conjunction with their orthodontic therapy. Comprehensive orthodontic treatment might require the use of twenty-eight bands cemented to the crowns of all the teeth present in the typical fourteen year old patient. Frequently fewer bands are necessary and some clinicians use technical procedures which do not require banding. Since the attachment of brackets directly to the labial or buccal surfaces of the teeth is in the near future, thousands of bands will be cemented to children's teeth in this period.

An undesirable situation arises when orthodontic bands frequently loosen. The situation becomes serious when loose bands are undetected. Loose bands allow irreversible
decalcification of the enamel, which leads to undesirable esthetic results, and may predispose the teeth involved to carious lesions. In this process the tooth enamel is subjected to attack by various agents, and is particularly vulnerable to acids which decalcify the surface resulting in change or loss of both prismatic and interprismatic substance.

The difficulty of loose bands arises particularly from the fitting of bands on the teeth. Since the crowns of the teeth are not altered before the bands are adapted and placed, the tooth morphology dictates in part the adaptation possible. The greatest mesio-distal diameter of the clinical crown is frequently located at the contact areas with more or less convergence of the crown from these areas to the gingival margin. This configuration reduces the amount of frictional retention available to a well-adapted band. This same circumstance prevents close adaptation of the banding material to the tooth at the gingival area. The resulting exposure of cement to the external influence of the oral cavity, i.e., temperature changes, saliva, abrasion, etc., could undermine the strength of the cementing medium. The pH of the saliva is very important. The normal pH range of saliva is between 5.5 and 7.5. This would influence the degree of solubility
and the interchange of ions between the tooth surface and saliva. This is in contrast to the same cements which are used for precision inlays and bridges, the difference being that teeth receiving cast restorations are prepared so that undercut areas do not exist.

Preformed bands for banding within the last eight to ten years have not helped the above problems mentioned. Before preformed bands, the orthodontist fit and soldered his own bands. He did this with only straight band material and usually did get a better fit at the gingival area, thus cutting down on hypocalcification and caries.

Until 1968 all the cements used in the cementation of orthodontic bands were zinc phosphate cements (2). They were introduced in the last quarter of the 19th century and their formulation was essentially similar to that of today. This cement consisted of a powder and liquid. The powder is mainly zinc oxide with small amounts of magnesium oxide, silica and barium sulfate. The liquid was orthophosphoric acid with small amounts of magnesium, aluminum and barium oxides added. Although their good manipulative qualities and high ultimate strength make them valuable in many applications, their acidity makes it imperative to use a pulp protective lining in all deep cavities. Also zinc phosphate cement
retains orthodontic bands by virtue of their ability to etch metals as well as enamel and not bind chemically in any way.

The search for new improved cements has been stimulated by new concepts in four areas. First, recognition of the importance of the biological properties of the cement in terms of tissue reaction; second, better definition of the strength properties required clinically in relation of those of tooth substance and for retention of bands and restorations; third, the studies of marginal leakage which indicates a necessity for reduction in solubility under oral conditions and for positive adhesion of the cement to tooth substance; and fourth, the desirability of therapeutic properties of the cement in relation to the formation of reparative dentin and the presence of anti-caries (2).

The development of new types of cements has been facilitated by the interest in recent years in the possibility of producing materials which are adhesive to dentin and enamel and in composites of improved strength which are obtained by the addition of filler materials. Among some new cements are the reinforced ZOE materials and the polycarboxylate cements (2). Zinc oxide-eugenol materials have been greatly improved by some of the eugenol being replaced by ethoxy benzoic acid and part of the zinc oxide replaced
by mineral fillers. These cements are called EBA cements. This group of materials can have a compressive strength and solubility comparable to zinc phosphate cements and have the virtues of a mild and perhaps palliative reaction to the pulp together with good sealing properties. Polycarboxylate cements are a powder liquid material, the powder being a modified zinc oxide and the liquid a polyacrylic acid in water. This material possesses strength properties comparable to the phosphate cements but in addition have low irritancy similar to the EBA cements and improved adhesion.

In my present investigation, I studied the setting time, solubility and disintegration, and compressive strength of three chemically different cements. The cements were: 1) zinc phosphate "Ames", 2) zinc polycarboxylate "Durelon", and 3) epoxy resin "Epoxylite Crown and Bridge Adhesive 9080". The setting time is an important property because this will determine the number of orthodontic bands one can cement in one mix. It also indicates the working time and the time the bands cannot be moved or disturbed before the initial set is observed. Setting time suggests the time a mouth must remain relatively dry so as not to permit the saliva to react with the tooth or cement. The setting time can vary depending on the consistency of the mix, the
temperature of the mixing slab, the size of the powder particle and the way the powder is incorporated into the liquid. The consistency of the mixes used were denser than the A.D.A. specification. The cements used for the cementation of orthodontic bands is different than that used to cement an inlay. An orthodontic band needs a cement that is stronger and this is usually thicker and cannot be used for the cementation of an inlay or crown because of the confinement of the cement in the cavity preparation.

Solubility and disintegration are important properties of a cement and are used as a relative measure of the resistance of the cement to the effects of oral fluids. This property is of particular importance for the cement is relied upon to fill the void between the tooth and the orthodontic band, thus preventing the formation of bacterial plaques and resultant decalcification under the band.

Compressive strength is part of the complex stress pattern consisting of compression, shear and tension forces. There are significant differences under function demonstrated between cements which possess high or low compressive strength values.

The specific objectives of this investigation are:
1) to determine the consistency of a cement in use by the
practicing orthodontist which is applicable for the cementation of orthodontic bands; (2) to standardize this consistency for some of the most popular dental cements currently used in band cementation; (3) to determine by laboratory testing some of the physical properties, as mentioned above, when mixed to this standardized consistency; (4) to suggest the manner in which these data may be applied by the practicing orthodontist to his clinical practice.
REVIEW OF LITERATURE

According to Ward (4) "Weston's insoluble cement, introduced about 1880, is considered to be among the first successful zinc phosphate cements to be used in America."

The powder was approximately 81% zinc oxide and 19% aluminum silicate. The liquid was phosphoric acid, sodium phosphate, and water. The change to the present day composition, as mentioned above, apparently occurred shortly after the turn of the century. This improved all the physical qualities of the cement (5).

In 1933 there were sixteen brands of zinc phosphate cement manufactured by sixteen different companies. These cements were available to dentists on the open market. The published literature on these cements was lacking in reliable data on the physical and chemical properties. The manufacturer's directions for mixing the cements were vague and in only two instances did the directions which accompanied the packages specify mixing instructions. Under the circumstances, in 1933, the Research Associates of the American Dental Association at the National Bureau of Standards undertook the task of writing a specification. Investigative work was undertaken to determine what physical and chemical properties were essential in zinc phosphate cements regarding the dental
services involved. It was also necessary to establish instruments and methods that would be satisfactory for determining these properties. After determining the above, the manufacturer's technique for using these materials could be tested for adequacy and accuracy.

The first consideration was to determine how much powder should be used with a fixed amount of liquid. This was arbitrarily established as 0.5 milliliter of liquid for 1.0 gram of powder (5). This was a start but the density and powder size varied and your mix did not have the same consistency.

Logically, the second consideration was the rate of powder incorporation. The chemical reaction between the liquid and powder can be controlled to a considerable extent by the amount of powder and particle size drawn into the liquid at any one time. After considerable experimentation, a standardized mixing technique was devised. The powder was incorporated into the liquid in specified amounts over a period of 1½ minutes. This was done on a 3 x 6 inch glass slab cooled to 70° F. (5).

It soon became apparent that to produce mixes of the same consistency, the amount of powder required for a given quantity of liquid would vary with different cements (5).
The amount of powder added to the liquid will always vary just a little because of the particle size and moisture present. The larger the particle size the more porosity the cement will possess and the weaker it will be. Therefore it is imperative to produce mixes of the same consistency. If the relative merits of these types of cements were to be compared satisfactorily, it was necessary that all test specimens be prepared from mixes having the same degree of density or viscosity.

A consistency test was finally devised which was simple, but which did not require expensive apparatus (6). This method was a "slump test" in which a definite quantity (0.5 milliliter) of mixed but unset cement is pressed between two flat plates under constant load (120 grams) for a definite period of time (10 minutes). The soft cement slumps or spreads into a disk. The diameter of the disk is used as a measure of consistency.

This slump test was devised to get just the right consistency for the cementation of inlays and crowns. I followed this procedure for my consistency tests but the disk was a little smaller because of the thicker mix used. The powder/liquid ratio was changed as will be shown below.

The problem remaining was that of determining the
consistency to select for the mixes from which specimens for other tests were to be made. The manufacturer's mixing directions which accompanied the available cements recommended that the cements be mixed to the consistency desired by the individual branch of science. For example, the dentist doing operative or orthodontic dentistry. In order to determine a cementing consistency the American Dental Association Research Fellowship at the National Bureau of Standards decided to engage dentists who were using the cements in their offices.

Thirty-five cooperating committees of dentists throughout the country performed experiments to determine how many grams of powder of a cement they were mixing with 0.5 milliliter of liquid (7). The cementing consistency was to be used for cementing inlays. At this time consistency tests were not determined for the cementation of orthodontic bands. It was found that the average of the consistencies which the cooperators reported in that experiment would produce a disk having a diameter of 30 plus or minus 1 millimeter, when incorporated into 0.5 milliliter of liquid. Therefore, the same amount of powder was used for a subsequent test proposed in the specification. The standard consistency was justified because it was representative of office practice throughout the country, and it has served as a basis for comparing test
results obtained in various laboratories.

The physical and chemical properties which were to be controlled by the specification that became effective July, 1935 were as follows:

1. Consistency of mix - a disk 30 plus or minus 1 mm. in diameter determined by the "slump test".

2. Time of setting at 37°C. - minimum 4 minutes: maximum 10 minutes.

3. Ultimate compressive strength - 7 days minimum 840 kg/cm² (12,000 lbs./in²)

4. Film thickness - maximum 50 microns

5. Solubility and disintegration - maximum percentage by weight 1.0%.

6. The tests for arsenic and similar poisonous materials would conform to those designated by the U.S. Pharmacopeia. Sampling, inspection and testing procedures were defined (6).

In addition, the requirements concerning the manufacturer's directions which were to accompany the cement stated, "Adequate and accurate instructions for proportioning and manipulation shall accompany each package." These instructions shall include the temperature of the slab, the
powder/liquid ratio, the rate of powder incorporation and the time of mixing (6).

Also, between the years 1920 and 1935, one other cement was very popular. This cement was called zinc oxide eugenol cement (8). It consisted of zinc oxide and eugenol plus water which yielded zinc eugenolate, a long needle crystal which in a set mass lock unchanged zinc oxide particles together (8). These materials have the virtues of a mild and perhaps palliative reaction to the pulp together with good sealing properties. But zinc oxide eugenol materials suffer from low strength, and continued loss of eugenol through fluid extraction leading to poor durability in the mouth (2).

The first revision of the American Dental Association Specification No. 8 for Dental Zinc Phosphate Cement was approved in July 1937 (9). Routine testing of certified zinc phosphate cements showed a great improvement in these materials since the initial investigation was undertaken. Therefore, the maximum solubility and disintegration allowed was reduced to 0.3% by weight; film thickness was reduced to a maximum percentage by weight of 0.0002 percent. This was reviewed in 1955 and the physical and chemical requirements remained unchanged (10).
An idea of the effectiveness of this specification may be acquired by comparing the list of zinc phosphate cements available to dentists in 1933 with those certified in 1962. Of the original sixteen cements available on the open market in 1933, only six remained certified (5,10).

Modern zinc phosphate cement powders consist primarily of calcined zinc oxide and magnesium oxide in the approximate ratio of nine to one. Sometimes copper, silver, or mercury salts are added to enhance antiseptic properties (5). Zinc phosphate cement liquids are phosphorus acid solutions buffered by the addition of both aluminum salts and zinc salts. The water content of the liquids is within the range of 33 plus or minus 5 percent (5).

A survey of literature reveals abundant information regarding the benefits and importance of the temperature of the glass slab (11), the powder/liquid ration (11), the rate of incorporating the powder (7), and the time of mixing (5,6). These were kept constant because any deviation from these above procedures would severely alter the strength, solubility and setting time of the cement.

As early as 1955, Rose and colleagues (12) tested the suitability of an epoxy resin for intraoral use. These tests were abandoned because of the difficulty experienced in initiating polymerization.
Bowen (13) in 1956 studied the following properties of an epoxy resin: (1) thermal expansion, (2) adhesive properties, (3) color stability, (4) apparent stability and insolubility in the oral environment.

Until the year 1963, zinc phosphate cement was the cement used in ninety-nine percent of the orthodontic bands being placed. This cement was basically the same for the last 50 years. This cement is still used for the cementation of orthodontic bands but the polycarboxylate cements have shown clinicians better adhesion and less pulpal reactions than the zinc phosphate cements.

In 1963 a silico phosphate cement was introduced (14). Silicate cement was in use for about fifty years. It was a mixture of silica, alumina, lime and cryolite fused together at a high temperature. It was mixed with a liquid containing aluminum phosphate and phosphoric acid. A silico phosphate cement has zinc phosphate and silicate cements in combination. This cement had greater strength and less solubility but the film thickness and working qualities are inferior to zinc phosphate cement (14).

In 1964 Gursin (15) studied the effects of stannous fluoride incorporated in dental cement. He showed it has less effect on decalcifying enamel when the above product is used
in cement (15). Today there are many cements on the market with a form of fluoride added.

In 1965 Newman (16) did work with epoxies and substituted polyamide-polyamines as curing agents for the previously used amines. He found them to have shear strength and rigidity, and excellent wetting properties.

In 1966, a modified zinc oxide eugenol cement was introduced. This cement was referred to as E.B.A. cement (17). There are now three classes of material under this heading: (1) the simple zinc oxide eugenol combination with or without accelerates such as zinc acetate; (2) the harder materials containing natural or synthetic resins in addition; (3) the E.B.A. cements in which a large part of the eugenol is replaced by ethoxy benzoic acid and part of the zinc oxide replaced by mineral fillers. This group possesses a compressive strength and solubility comparable to zinc phosphate cements. These materials have the virtues of a mild and palliative reaction to the pulp together with good sealing properties. E.B.A. cements do not suffer from low strength and continued loss of eugenol through fluid extraction leading to a poor durability in the mouth as in the regular zinc oxide and eugenol cements (2).
In 1968 Simmons (18) evaluated a cement introduced by Hilashi referred to as a "Hydro-phosphate cement". Water was used to substitute for phosphoric acid. All the physical properties of this cement tested inferior to the control zinc phosphate cement. The test cement did not meet accepted American Dental Association Specification No. 8 for compressive strength, film thickness, and solubility and disintegration (18).

In 1968 some of the methods for arriving at the specifications for zinc phosphate cement were altered (19). For example, a ring (inside diameter 20 mm. and 1.5 mm. thick) was used in obtaining the wafer used in the solubility and disintegration test (16).

Also in 1968 a large breakthrough in dental cements came about through the work of Smith (20) and associates in Britain. He referred to his cement as a zinc polycarboxylate cement. The existing dental cements relied principally upon mechanical interlocking to retain restoration and bands on teeth. Polycarboxylate cements produce a true adhesion along with mechanical retention. A clinically satisfactory adhesive material must be hydrophilic and bond chemically to the enamel and dentin through strong polar attraction. Suitable materials for this purpose appeared to be water soluble polymers containing appropriate chelate groups. Chelating agents which form
biologically stable chelates with calcium generally possess a structure in which a carboxyl group is present together with a hydroxyl or amino group. One such polymeric chelate which has been used to obtain a usable cement is polyacrylic acid.

These polyacrylate cements are based upon an aqueous solution of polyacrylic acid. The material is therefore hydrophilic and wets the tooth very well. The acid groups are intended to chelate to calcium ions in the surface of the calcified tissue and react also with other metal ions and form complexes with proteins, which are present on the tooth. The cements are produced by mixing the solution of polyacrylic acid with a modified zinc oxide when setting occurs by a cross linking reaction between zinc ions and the polyacrylic acid molecules (20).

In the year 1970 Lee, Swartz and Smith (21) introduced a new crown and bridge cement that was basically an epoxy resin. The exact formula for this new epoxy resin cement is not known, but they are basically synthetic materials manufactured from by-products of the petroleum industry, most of them by reacting epichlorhydrin with diphenylolpropane in an alkaline medium. To this, stabilizers and fillers are added. Prior to mixing, it is a liquid and powder. As it is
applied it has a creamy gray-white consistency. After final
set, it is a dental-white, hard solid. CBA 9080 cement is
less irritating than silicate cements, and provides good
adhesion to the preparation, and the metal of the inlay or
band. When set, the adhesive provides 30-50% higher adhesion
than zinc phosphate cements, making the restoration more
permanent. This material is mixed similar to that used with
other crown and bridge cements. It may be stored at room
temperature but should not be stored above 85° F. for extended
periods lest the setting time of this material would be
markedly increased.
METHODS AND MATERIALS

Materials

The zinc phosphate cement used for present investigations is known as Ames "Ortho" cement, manufactured by the D-P Company, 543 West Arden Avenue, Glendale, California 91202. This cement was chosen because most of the forty instructors in the Graduate School, Loyola University Department of Orthodontics, preferred this brand. (Batch #B42 powder, #Q3 liquid). Number 2 yellow-white powder and Number C medium liquid were used. This same kit was used for all the tests.

The zinc polycarboxylate cement used was "Durelon". This product is manufactured in West Germany by ESPE and is distributed in the United States by Premier Dental Products Company, Philadelphia, Pennsylvania 19107 (Batch #10476 powder, #025546 liquid). This brand was chosen because it is used exclusively in our orthodontic department.

The last cement employed in the research is an epoxy resin cement called "Epoxylite Crown and Bridge Adhesive #9080", manufactured by the Epoxylite Corp., 1428 Santa Anita Avenue, South El Monte, California 91733 (Batch #CB0005 powder, #CB6907 liquid). This cement was used because of its newness
newness and the unusual qualities its manufacturer has claimed. For example, high compressive and tensile strength and no measurable solubility.

**Consistency Tests**

The consistency tests and the test specimens were conducted at a temperature of 23.0 ± 2.0°C (73.4 ± 3.6°F), and at a relative humidity between 55% and 75%. The powder was weighed to the nearest milligram on a balance sensitive to the nearest 0.05 milligram. All mixes were made using 0.5 milliliter of liquid measured with a Luer-type syringe. Special care was taken to avoid air entrapment in the syringe.

The standardized mixing technique (19) employed in the preparation of the zinc phosphate cement specimens was as follows: the desired amount of powder was placed on one end of a 3 x 6 Caulk glass Thermometer slab; the glass slab had been cooled to between 65-70°F; the powder was divided into five small portions; the Luer-type syringe was utilized to place 0.5 milliliter of liquid near the opposite end of the glass slab; the first small portion of the powder was added to all of the liquid and spatulated thoroughly with a S. S. White Tarno 324 Spatula for 20 seconds as timed by a stop watch. Another portion of the powder was added and
and spatulated for 20 seconds. This was repeated until all 5 portions had been spatulated. The total mixing time was one and one-half minutes.

In the preparation of the polycarboxylate cement, a 3 x 6 inch waxed paper mixing pad was employed. The powder was divided into two equal portions. One portion was added, spatulated for twenty-five seconds with a S. S. White Tarno 324 Spatula. The last portion was added and the whole mix was spatulated for a total of thirty seconds.

In preparation of the epoxy resin cement a 3 x 6 inch waxed paper mixing pad was employed. The powder was divided into four equal portions and mixed together with a plastic spatula in thirty seconds. Then the whole mix was spatulated for another fifteen seconds. Total mixing time was 45-60 seconds.

The consistency tests for the cements adhered to the American Dental Association Specification No. 8 with some variation. The apparatus consisted of two flat glass plates, a weight, and a Luer-type syringe which would deliver 0.50 ml. of mixed cement. The combined weight of the top glass plate and weight totaled 120 gm. Trial amounts of powder were mixed with 0.50 ml. of liquid. Then 0.50 ml of mixed cement was placed on the flat glass plate. Three minutes
after the mixing started, the top glass plate, weighing 20 grams, and the necessary additional weight required to total 120 gm. were carefully placed on the soft cement mix. Trials were made until the average of the major and minor diameters of the slumped mass of cement were 30 plus or minus 1 mm. ten minutes after starting the mix.

The author noted that the ideal consistency mix was a little too thin for the cementation of orthodontic bands. Specification No. 8 is really intended for the cementation of a gold inlay or crown. A thicker mix is used for the cementation of orthodontic bands because of the following reasons: (1) easy placement of bands; (2) can see band position easier; (3) easy removal of excess cement from pits and fissures; (4) a thicker mix can give excellent bonding, for example, polycarboxylate cements which chemically adhere to the enamel; and (5) pressure can be exerted in the placement of the bands to produce a better bond. For these above reasons a thicker mix of cement was used in this study. The ideal consistency for the cementation of orthodontic bands seemed to produce a disk different from 30 plus or minus 1 mm. The powder/liquid ratio therefore was as follows:

Ames - 1 gram powder/0.50 ml. liquid to yield a disk of 25 plus or minus 1 mm.
Durelon - 1 gram powder/0.50 ml. of liquid to yield a disk of 28 plus or minus 1 mm.

Epoxylite 9080 - 1.5 grams powder/0.50 ml. liquid to yield a disk of 23 plus or minus 1 mm.

Setting Time Determinations

The setting time test was conducted by utilizing the following powder/liquid ratios: Ames, 1 gm. powder per 0.5 ml. liquid; Durelon, 1 gm. powder per 0.5 ml. of liquid; and Epoxylite 9080, 1.5 gm. powder per 0.5 ml. of liquid.

For this procedure, a ring 5 millimeters high and 10 millimeters in diameter was placed on a flat glass plate and filled with mixed cement. Three minutes after starting the mix, the specimen was transferred to an atmosphere of 60% relative humidity at 37° C. A precision Universal Penetrometer Catalog No. 73510 was then employed to test the setting time of the three different cements. The sensitivity of the above instrument is recorded in tenths of millimeters.

The diameter of the depth gauge rod was 0.7 mm. and weighed 2.5 grams. The weight of the loading bar was 150 grams and the weight of the test rod was 47.5 grams. Therefore the total force applied with the penetrometer was 200 grams.

The penetration was noted commencing at $3\frac{1}{2}$ minutes and proceeding then at 30 second intervals. The force of
200 grams was released to 15 seconds before the readings were recorded. The time was recorded on a stop watch and the penetration was recorded to the nearest tenths of millimeters. Ten setting tests were done with each cement.

**Solubility and Disintegration Determinations**

The amount of solubility and disintegration of the cement specimens in distilled water was determined gravimetrically (16). Cap style Kimble "Exax" 90 ml. weighting bottles were utilized to contain the residue remaining after evaporation of the water in which the cement specimens were stored. Preliminary work consisted of establishing the method for cleaning, drying, and weighing the bottles. Soaking in potassium dichromate/sulphuric acid cleaning solution was found satisfactory for removing the cement residue. This solution was removed from the weighing bottles by rinsing them in distilled water. The washed and rinsed bottles were then placed in an oven at approximately 150° C., for one hour. When cooled to room temperature, the clean dry bottles were transferred to a desicador containing lump form, purified dried anhydrous calcium chloride. Repetition of this procedure and daily weighing of the same six bottles over a period of three days demonstrated that these containers could be
weighed to a constant weight of plus or minus 0.2 milligrams. When the actual solubility and disintegration tests were performed, one weighing bottle was utilized as a gravimetric control. This bottle was subjected to the same procedure as the others with the exception that no specimens were stored in the 0.50 milliliters of water. The control bottle proved very useful since after testing procedure, it would return to the original weight plus or minus 0.2 milligrams. This signified that the other bottles with their residue were near the time when they would weigh constantly plus or minus 0.2 milligrams for a period of 24 hours.

To determine solubility and disintegration, the American Dental Association Specification No. 8 was followed. One-half milliliter of cement of standard consistency was placed in a stainless steel ring (inside diameter 20 mm. and 1.5 mm. thick) which is sitting on a thin polyethylene sheet backed by a flat plate. This ring was coated with a separating medium of a 3% solution of microcrystalline wax in benzene. Another flat plate faced with a sheet of this polyethylene was used to press the cement into the ring. A piece of 0.006 mm. fine platinum wire which was previously weighed was placed in the soft cement as the specimens were formed to provide a convenient means of holding the specimens. Three minutes
after the mix was started, the plates and cement were placed for one hour in an atmosphere having a relative humidity of 100% at 37° C.

After one hour, the specimens were withdrawn from the oven and one specimen was placed in a tarred weighing bottle and weighed. The combined weight of the specimen and the weighing bottle, less the weight of the weighing bottle and the platinum wire, was taken as the weight of the specimens of cement. The specimens were immediately submerged by pouring 50 ml. of distilled water into the weighing bottle, which shall be stored for 23 hours at 37° C. The specimens were removed from the water. There was no evidence of crystal growth on the surface of the specimens. The water was evaporated from the weighing bottles at a temperature just below 100° C. The weighing bottles were then dried at 150° C. to constant weight. After cooling to room temperature in a desicator, containing thoroughly dry anhydrous calcium sulfate, the weighing bottles and contents were weighed with a precision of 0.2 mg. The difference between the final weight of the weighing bottle and its initial weight was the amount of disintegration recorded. The gain in weight divided by the weight of the specimen time 100 was the percentage of disintegration. Eight solubility and disintegration tests
were recorded for each of the three cements being evaluated, Ames, Durelon, and Epoxylite 9080.

**Compressive Strength Determinations**

The last physical property test performed was for compressive strength and was examined in accordance with American Dental Association Specification No. 8.

The test specimens were 12 mm. high and 6 mm. in diameter. The molds used for the production of these specimens had an outside diameter of 37 x 38 x 12 millimeters, and weighed approximately 130 grams each. The ends of these specimens were flat and smooth and were parallel to each other and at right angles to the long axis of the cylinder. Ten of these particular molds were used and were coated with 3% solution of a microcrystalline wax in benzene to facilitate removal of the specimens.

A cylindrical mold was placed on a flat glass plate and slightly overfilled with cement of standard consistency within three minutes after commencing the mix. A second flat glass was then pressed on top of the mold. The mold and plates were held firmly together with a small C clamp. All of this apparatus was at room temperature. Three minutes after starting the mix, the molds and clamps were transferred
to an atmosphere of 100% relative humidity at 37°C. One hour later the ends of the cylinders were surface planed at right angles to the axis using a flat glass plate with a small amount of 400 grit silicon carbide powder and water. The molds containing the specimens were pushed forward on the glass slab and were rotated one-fourth turn before every forward push motion. The specimens were maintained wet during the grinding.

After surfacing, the specimens were removed from the mold by a screw jack, and immersed in distilled water at 37°C for 24 hours. Care was taken not to chip the 6 x 12 mm. specimens. This above procedure was performed at 5 minute intervals for the three cements being examined and a total of fifteen specimens were formed and made ready for testing.

At the end of 24 hours, the specimens were removed from the distilled water and the diameters of the specimens were noted. They were then placed between small pieces of wet blotting paper (approximately 0.5 mm. thick) and then inserted between the ends of the Instron testing machine. The specimens were loaded at the rate of 0.225 kg. a minute and kept wet during the test. The load applied was recorded on graph paper and the value for compressive strength was reported as
the average of three from the lot of five specimens to the nearest 10 kg. per square centimeter.

The strength of each cement was compiled by dividing the load (in kilograms) by the cross-sectional area (cm$^2$).
RESULTS

The results of tests on the setting time for a standardized mix of Ames, Durelon, and Epoxylite CBA 9080 are shown in Tables 1, 2, and 3. The left hand column represents the time in minutes in which the penetration was performed and the figures to the right of this indicate just how much penetration in millimeters was accomplished. These results are also demonstrated graphically in Table 4. The mean final set of Ames cement is shown to be approximately 12 minutes, Durelon 7 minutes and Epoxylite CBA 9080 5.5 minutes. Statistics for the setting time of the three cements are shown in Tables 5 and 6. Mean setting time, standard deviation, mean deviation, and variance are calculated for the cements at 5 minutes and at final setting.

The results for the solubility and disintegration tests are shown in Tables 7, 8, and 9. The column on the left of these three tables shows the weight of the residue cement left after 24 hours in the weighing bottles. The column at the right shows the amount of disintegration in percentage that was reported in the 24 tests. The results are also demonstrated by the histogram in Table 10, with the amount of solubility, and disintegration shown in the
left hand vertical column. CBA 9080 by far had the lowest amount of solubility, and Ames the highest. The statistics for these tests are shown in Tables 11 and 12. Table 11 shows the mean, mean deviation, standard deviation and variance for Ames, Durelon, and Epoxylite CBA 9080 for the residue remaining after 24 hours. Table 12 shows the mean, mean deviation, standard deviation and variance for the percentage of solubility and disintegration after 24 hours.

The results for the compressive strength tests are demonstrated in Table 13. Beginning with the left hand column and working to the right, they represent the following: column one labels the specimens; column two denotes the time the cements were mixed; column three, which is the time crushed, is twenty-four hours after mixing; column four is the diameter of the specimen which was recorded just prior to crushing; column five is the cross-sectional area of the test specimen, which was arrived at with this formula: \( \frac{\pi D^2}{4} \); column six was the breaking load applied in kilograms; and column seven is the strength in kg./cm\(^2\).

The compressive strength results are also demonstrated by the histogram in Table 14, with the strength (kg./cm\(^2\)) shown in the left hand vertical column. CBA 9080 outperformed the other two cements 3 to 1. The statistics
for these tests are shown in Table 15. It shows the mean strength, standard deviation, mean deviation, and variance of the compressive strength for Ames, Durelon, and Epoxylite CBA 9080.
DISCUSSION

Before discussing the results, I will first explain the consistency of the cements used and how I arrived at the various powder/liquid ratios. This is the most important aspect in the cementation of orthodontic bands, or for that matter any dental cementation. The manufacturers are very vague about powder/liquid ratio. For example, Ames directions say equal amounts of powder and liquid; Epoxylite CBA 9080 instructions say to place one or two drops on a disposable paper slab and add the amount of powder to give the desirable consistency; Durelon is much like the other two. Therefore, before beginning my tests, I composed a powder/liquid ratio for each of the three cements so that the consistency could be duplicated as many times as necessary to perform the physical property tests with accuracy. Consistency tests adhered to the American Dental Association Specification No. 8 with some variation as mentioned before. The size of the disk (after the cement was placed between the two glass slabs) was not 30 ± 1 mm. but was 26 ± 3 mm. depending upon which cement was tested. The following powder/liquid ratios were judged by the author to be of ideal consistency for the cementation of orthodontic bands:
Ames - 1 gram powder/0.50 ml. liquid to yield a disk of 25 plus or minus 1 mm.

Durelon - 1 gram powder/0.50 ml. liquid to yield a disk of 28 plus or minus 1 mm.

Epoxylite 9080 - 1.5 grams powder/0.50 ml. liquid to yield a disk of 23 plus or minus 1 mm.

A comparison of Tables 1, 2, 3, and 4 indicates the various setting times of the cements tested. Table 4 shows that Ames cement does not start to set until 6.7 minutes have elapsed from the start of the mix (pt. D) and that the initial set (pt. A) takes place at 7.6 minutes. The final setting time is 12.5 minutes (pt. J). Ames cement would be useful if the operator had a great deal of time and wanted to cement many bands before the cement became unworkable.

Table 4 reveals that Epoxylite 9080 begins setting (pt. E) at 4.5 minutes, its initial set at 5 minutes (pt. B) and final set (pt. L) at 5.5 minutes. This cement would be used in the cementation of one or possibly two bands in an area that is difficult to dry. The working and setting times are very short, but this can be advantageous when the operator wants to cement bands as quickly as possible.

Table 4 reveals the setting time data for Durelon. It starts to set (pt. F) at 3.5 minutes, initial set occurring at 5.25 minutes (pt. C)
and will reach its final set at 7 minutes (pt. K). This cement has a nice working range and would be ideal for the cementation of from one to six orthodontic bands. Table 4 also shows in addition to start of setting, initial and final setting, the working time of each of the cements. This would be represented by points D-I, F-H, and E-G. Also, the time the bands cannot be moved or disturbed during cementation is represented by points A-D for Ames, B-E for CBA 9080 and C-F for Durelon. The practicing orthodontist is probably more clinically aware of the setting time than any other of the physical properties of cement. The setting time is usually, but not in the case of CBA 9080 and Durelon related to the working time and the working time of a cement is of critical importance in the cementation of orthodontic bands. Sufficient time must elapse between the mixing and the setting of the cement to allow the precise placement of the bands on the teeth. The working time requirements of each individual orthodontist will vary somewhat with the number of bands placed with one mix of cement. The comparative difficulty of cementing certain bands results from such factors as limited access, wetness, and tight interproximal contacts.

One way the operator can assure the working time he desires with any given mix is to allow the filled bands to
remain on the mixing slab until each band is ready to be positioned on the tooth. Since the mixing slab temperature is considerably lower than the mouth temperature, the setting reaction of the cement will proceed at a slower rate than would be the case if all the bands to be set are initially placed on the teeth.

The protection of the setting cement from premature contact by saliva is of sufficient importance to deserve mention in a discussion of setting time. Control of saliva particularly in the mandibular arch, is often a problem in the cementation of orthodontic bands. It is true that premature contact of the cement with saliva before it has reached the initial set results in a significantly weakened cement. It is therefore important that adequate precautions be taken by the orthodontist to insure that the cement is kept dry until the initial set has taken place. In addition to the routine cotton rolls, two suggested methods for accomplishing this goal are: 1) the use of Burlew Dryfoil and 2) the premedication of the patient with a salivary suppressant such as Pro-Banthine prior to band cementation procedures.

The next physical property to be discussed is solubility and disintegration. Tables 7, 8, and 9 show the actual amount of soluble residue left in the weighing bottles
after 24 hours, and the percent of disintegration of the three dental cements being tested. By far, Epoxylite 9080 and Durelon was superior to Ames cement as shown in Table 10. Ames cement had 8.2% more solubility than CBA 9080 and 2.9% more than Durelon. Durelon had 0.35% more solubility than the CBA 9080. It must be pointed out that this was a 24 hour solubility and disintegration test and not all cements have the same solubility rate. Some will have all their solubility in the first 24-48 hours.

The solubility and disintegration of the dental cement is used as a relative measure of the resistance of the cement to the effects of oral fluids. This property is of particular importance for the cement is relied upon to fill the void between the tooth and the orthodontic band, thus preventing the formation of bacterial plaques and resultant decalcification under the band. Solubility testing, as determined in the laboratory, was carried out in distilled water rather than in natural or artificial saliva. Previous investigation (5) has established the fact that the values for specimens immersed in saliva and water were very near to each other, and distilled water has been used as a medium for storing cements. This 24 hour valve in distilled water shown in Tables 7, 8, and 9, is only a guide to clinical
behavior since solubility in saliva under varied dietary conditions may be quite different from those in laboratory tests. Norman and associates (22) have shown that the solubility of phosphate cements in organic acids, such as citric acid, is ten to twenty times greater than in distilled water; furthermore long term solubility may be much greater than indicated by the 24 hour test. The thickness of an exposed cement margin is also very important in this regard. The available data suggest only that solubilities below the specification limits will give reasonable satisfactory clinical performance assuming the solubility is at the same rate.

The last physical property to be discussed is the compressive strength testing of Ames, Durelon, and Epoxylite CBA 9080. The mean value of compressive strength was reported as the average of three from a lot of five specimens and were rounded off to the nearest 0.10 kg. per square centimeter. This is demonstrated in Table 13. No significant difference was found between Ames and Durelon. This is shown graphically in Table 14 and statistically in Table 15.

The test of compressive strength for each of the three dental cements was carried out in the manner prescribed in the American Dental Association No. 8. The specimens were
stored at 23.9 degrees C. and at a relative humidity of 40% for a period of 24 hours prior to crushing.

Peyton (23) has stated that the compressive strength is useful for comparing materials which are brittle and generally weak in tension. The dental cements are brittle materials and are well suited to testing in compression. However, it is questionable whether a dental cement ever fails as a result of pure compression, and it is more likely that the failure of the cement arises as the result of a complexity of forces. Peyton, however, states that when the cylindrical test specimen is subjected to stress in compression, there is a complex stress pattern consisting of compression, shear and tension forces developed in the specimen, and that the failure of the material may occur as a result of this complex stress formation. Either one or all three can cause this failure. Therefore, it can be assumed that testing in compression provides a reasonable measure of the strength properties of cements under function.

Orthodontists are inclined to think of shearing type force as being the most destructive with regard to the loosening of bands. Any time a structure is subjected to shearing action, however, there is a concentration of both tension and compressive forces in the material. Here again is demonstrated
the complexity and close interrelationship of these forces. Peyton also states that the compressive strength test provides a reasonable indication of the behavior of the material in shear, and that probably the difficulty and expense involved in designing a shear test would result in values with no greater significance.

An objection aimed against testing samples in compression by applying a load over a relatively long period of time is that the rates of force application occurring in the mouth more closely resemble impact forces. In spite of this condition, the objection is probably not a valid one since the compressive strength values obtained from the impact testing of these cements would probably be the same order as those evaluated by the present testing procedure except that all the values would be somewhat higher.

A comparison of the characteristics of strength and setting time of the 3 dental cements reveals that these two properties appear inversely related. A slower setting cement also exhibits a lower strength.

Before any valid appraisal can be made of what constitutes significant clinical difference in compressive strengths of the products tested, it would be necessary to subject these materials to a controlled program of clinical
testing. It would seem reasonable, however, that there may be significant difference under function demonstrated between cements which possess high or low compressive strength values. It is possible that the significance of these differences in compressive strength may be somewhat obscured because of the relatively short period of time the cement is in service under orthodontic bands as compared to the time for crowns, bridges or inlays.

A comparison of the physical properties mentioned above using the consistency of mixes outlined in Specification No. 8 and the consistency used in this study show the following:

<table>
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<tr>
<th>Consistency to Yield</th>
<th>Compressive Strength</th>
<th>Solubility and Disintegration</th>
<th>Setting Time</th>
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<tr>
<td>30 ± 1 mm. disk</td>
<td>700 kg/cm²</td>
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</tr>
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<td>25 ± 1 mm. disk</td>
<td>762.8 kg/cm²</td>
<td>0.14%</td>
<td>7.5-12.5 min.</td>
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Note: The consistency tests and minimum physical property requirements for epoxy resin and polycarboxylate cements are not outlined in the American Dental Association Specifications for Dental Materials Publication.
CONCLUSIONS

Epoxylite CBA 9080 seems to be the material of choice for the cementation of orthodontic bands. This material has a faster setting time, less solubility and disintegration and greater compressive strength than either Ames or Durelon cement. It could be suggested from the present investigation that this type of cement, an epoxy resin, will be used in the near future for the direct cementation of orthodontic brackets to dental enamel (24,25). Much research with polycarboxylate cements has gone on in this field because its manufacturers have claimed that the setting cement chelates with the calcium ions in the mineral phase of enamel and dentin to provide adhesion. It could be said from the physical properties mentioned that zinc polycarboxylate cements cannot compare to an epoxy resin cement for the direct banding of brackets to enamel surfaces.

Some of the advantages of an epoxy resin cement other than the above mentioned are: (1) have rapid set up times; (2) desirable properties can be built into the acrylic systems by incorporation of suitable comonomers into the polymer mixture; (3) easy to mix, apply, polymerize, and have relatively long shelf lives; (4) possess minimal mucosal
irritation; (5) they develop powerful adhesive bonds, and (6) the cured resin is hard, abrasion-resistant, and dimensionally stable. Some of the disadvantages of this type of cement are: (1) tooth surface must be prepared before cementation; (2) cleaning teeth after cementation is difficult; (3) rate of cure of resin in mouth may be undesirable; (4) moisture effects adhesion so tooth must be perfectly dry, and (5) ease of removing attachment may be difficult (24,26).

It would be advisable to see this study continue and research done on tensile strength, adhesion, long term solubility, temperature effect, powder size, and mixing techniques on these three types of cements.
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Penetration in Millimeters
TABLE 2. SETTING TIME DATA - EPOXYLITE CBA 9080

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Penetration in Millimeters

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TABLE 3. SETTING TIME DATA - DURELON

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Penetration in Millimeters
## TABLE 4. DISTRIBUTION CURVE OF SETTING CEMENTS

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>setting time Ames</td>
</tr>
<tr>
<td>y</td>
<td>setting time CBA 9080</td>
</tr>
<tr>
<td>z</td>
<td>setting time Durelon</td>
</tr>
</tbody>
</table>

### Diagram

- **Penetration in Millimeters**
- **Minutes**
- **Graph**: Points labeled A, B, C, D, E, F, G, H, I, J, K, L

---

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### Table 5. Statistics for Setting Time

**AT 5 MINUTES**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>x</th>
<th>s</th>
<th>m</th>
<th>s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames</td>
<td>9</td>
<td>7.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Durelon</td>
<td>10</td>
<td>.91</td>
<td>.122</td>
<td>.127</td>
<td>.0149</td>
</tr>
<tr>
<td>CBA 9080</td>
<td>8</td>
<td>.362</td>
<td>.0415</td>
<td>.0375</td>
<td>.00172</td>
</tr>
</tbody>
</table>

- **n** number of tests
- **x** mean penetration in millimeters
- **s** standard deviation
- **m** mean deviation
- **s²** variance

### Table 6. Statistics for Setting Time

*(FINAL SET)*

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>x</th>
<th>s</th>
<th>m</th>
<th>s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames</td>
<td>9</td>
<td>12.0</td>
<td>.408</td>
<td>.389</td>
<td>.166</td>
</tr>
<tr>
<td>Durelon</td>
<td>10</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CBA 9080</td>
<td>8</td>
<td>5.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **n** number of tests
- **x** mean setting time in minutes
- **s** standard deviation
- **m** mean deviation
- **s²** variance
### TABLE 7. SOLUBILITY DATA - AMES

<table>
<thead>
<tr>
<th>Wt. of residue</th>
<th>% Disintegration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0016</td>
</tr>
<tr>
<td>2</td>
<td>0.0015</td>
</tr>
<tr>
<td>3</td>
<td>0.0014</td>
</tr>
<tr>
<td>4</td>
<td>0.0016</td>
</tr>
<tr>
<td>5</td>
<td>0.0016</td>
</tr>
<tr>
<td>6</td>
<td>0.0017</td>
</tr>
<tr>
<td>7</td>
<td>0.0014</td>
</tr>
<tr>
<td>8</td>
<td>0.0014</td>
</tr>
</tbody>
</table>

### TABLE 8. SOLUBILITY DATA - DURELON

<table>
<thead>
<tr>
<th>Wt. of residue</th>
<th>% Disintegration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0008</td>
</tr>
<tr>
<td>2</td>
<td>0.0006</td>
</tr>
<tr>
<td>3</td>
<td>0.0005</td>
</tr>
<tr>
<td>4</td>
<td>0.0006</td>
</tr>
<tr>
<td>5</td>
<td>0.0005</td>
</tr>
<tr>
<td>6</td>
<td>0.0006</td>
</tr>
<tr>
<td>7</td>
<td>0.0006</td>
</tr>
<tr>
<td>8</td>
<td>0.0007</td>
</tr>
</tbody>
</table>

### TABLE 9. SOLUBILITY DATA - CBA 9080

<table>
<thead>
<tr>
<th>Wt. of residue</th>
<th>% Disintegration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0002</td>
</tr>
<tr>
<td>2</td>
<td>0.0002</td>
</tr>
<tr>
<td>3</td>
<td>0.0003</td>
</tr>
<tr>
<td>4</td>
<td>0.0002</td>
</tr>
<tr>
<td>5</td>
<td>0.0001</td>
</tr>
<tr>
<td>6</td>
<td>0.0003</td>
</tr>
<tr>
<td>7</td>
<td>0.0001</td>
</tr>
<tr>
<td>8</td>
<td>0.0003</td>
</tr>
</tbody>
</table>
TABLE 10. % SOLUBILITY AND DISINTEGRATION OF CBA 9080, DURELON, AND AMES
### TABLE 11. STATISTICS FOR SOLUBILITY RESIDUE AFTER 24 HOURS

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>x</th>
<th>s</th>
<th>m</th>
<th>s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames</td>
<td>8</td>
<td>.0015</td>
<td>.0001</td>
<td>.0001</td>
<td>.0000001</td>
</tr>
<tr>
<td>Durelon</td>
<td>8</td>
<td>.0061</td>
<td>.00293</td>
<td>.000055</td>
<td>.0000086</td>
</tr>
<tr>
<td>CBA 9080</td>
<td>8</td>
<td>.0002</td>
<td>.00247</td>
<td>.000062</td>
<td>.0000061</td>
</tr>
</tbody>
</table>

- n: number of tests
- x: mean residue after 24 hours
- s: standard deviation
- m: mean deviation
- s²: variance

### TABLE 12. STATISTICS FOR SOLUBILITY % DISINTEGRATION

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>x</th>
<th>s</th>
<th>m</th>
<th>s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames</td>
<td>8</td>
<td>.142%</td>
<td>.0988%</td>
<td>.095%</td>
<td>.0097%</td>
</tr>
<tr>
<td>Durelon</td>
<td>8</td>
<td>.04925%</td>
<td>.0176%</td>
<td>.0104%</td>
<td>.0031%</td>
</tr>
<tr>
<td>CBA 9080</td>
<td>8</td>
<td>.0173%</td>
<td>.0064%</td>
<td>.0044%</td>
<td>.0000416%</td>
</tr>
</tbody>
</table>

- n: number of tests
- x: mean solubility in %
- s: standard deviation
- m: mean deviation
- s²: variance
### TABLE 13. COMPRESSIVE STRENGTH DATA

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spec.</td>
<td>Time</td>
<td>Time</td>
<td>Dia.</td>
<td>X-sec.</td>
<td>Load</td>
<td>Strength</td>
</tr>
<tr>
<td>No.</td>
<td>Mixed</td>
<td>Mixed</td>
<td>Crushed</td>
<td>Spec.</td>
<td>Area</td>
<td>(kg)</td>
<td>(kg/cm²)</td>
</tr>
<tr>
<td>1</td>
<td>9:13</td>
<td>9:13</td>
<td>.606cm.</td>
<td>.288cm²</td>
<td>480</td>
<td>757.6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9:18</td>
<td>9:18</td>
<td>.606cm.</td>
<td>.288cm²</td>
<td>470</td>
<td>760.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>9:23</td>
<td>9:23</td>
<td>.607cm.</td>
<td>.289cm²</td>
<td>490</td>
<td>771.0</td>
<td></td>
</tr>
</tbody>
</table>

Temp. 23.9°C.  
R.H. 40%  
Average Strength 762.8 kg/cm²

### DURELON

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spec.</td>
<td>Time</td>
<td>Time</td>
<td>Dia.</td>
<td>X-sec.</td>
<td>Load</td>
<td>Strength</td>
</tr>
<tr>
<td>No.</td>
<td>Mixed</td>
<td>Mixed</td>
<td>Crushed</td>
<td>Spec.</td>
<td>Area</td>
<td>(kg)</td>
<td>(kg/cm²)</td>
</tr>
<tr>
<td>1</td>
<td>9:29</td>
<td>9:29</td>
<td>.603cm.</td>
<td>.283cm²</td>
<td>400</td>
<td>642.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9:34</td>
<td>9:34</td>
<td>.603cm.</td>
<td>.283cm²</td>
<td>370</td>
<td>594.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>9:39</td>
<td>9:39</td>
<td>.605cm.</td>
<td>.285cm²</td>
<td>390</td>
<td>622.0</td>
<td></td>
</tr>
</tbody>
</table>

Temp. 23.9°C.  
R.H. 40%  
Average Strength 620 kg/cm²

### EPOXYLITE 9080

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spec.</td>
<td>Time</td>
<td>Time</td>
<td>Dia.</td>
<td>X-sec.</td>
<td>Load</td>
<td>Strength</td>
</tr>
<tr>
<td>No.</td>
<td>Mixed</td>
<td>Mixed</td>
<td>Crushed</td>
<td>Spec.</td>
<td>Area</td>
<td>(kg)</td>
<td>(kg/cm²)</td>
</tr>
<tr>
<td>1</td>
<td>9:50</td>
<td>9:50</td>
<td>.602cm.</td>
<td>.284cm²</td>
<td>1440</td>
<td>2,304.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9:55</td>
<td>9:55</td>
<td>.603cm.</td>
<td>.285cm²</td>
<td>1450</td>
<td>2,312.6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10:00</td>
<td>10:00</td>
<td>.602cm.</td>
<td>.284cm²</td>
<td>1450</td>
<td>2,320.7</td>
<td></td>
</tr>
</tbody>
</table>

Temp. 23.9°C.  
R.H. 40%  
Average Strength 2,310 kg/cm²

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TABLE 14. COMPRESSION STRENGTH 24 HOURS

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Resin</td>
<td>2400</td>
</tr>
<tr>
<td>Zinc Phosphate</td>
<td>1500</td>
</tr>
<tr>
<td>Polycarboxylate</td>
<td>1200</td>
</tr>
</tbody>
</table>

CBA 9080 | Ames | Durelon
### TABLE 15. STATISTICS FOR COMpressive Strength

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>x</th>
<th>s</th>
<th>m</th>
<th>s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames</td>
<td>3</td>
<td>762.8</td>
<td>5.8</td>
<td>5.4</td>
<td>33.64</td>
</tr>
<tr>
<td>Durelon</td>
<td>3</td>
<td>620</td>
<td>19.75</td>
<td>16.6</td>
<td>390.1</td>
</tr>
<tr>
<td>CBA 9080</td>
<td>3</td>
<td>2,312</td>
<td>6.5</td>
<td>5.5</td>
<td>42.25</td>
</tr>
</tbody>
</table>

n  number of tests  
-  mean strength  
s  standard deviation  
s² variance  
m  mean deviation
REFERENCES


BIBLIOGRAPHY


APPROVAL SHEET

The thesis submitted by Dr. Jay R. Schauer has been read and approved by members of the Department of Oral Biology.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

[Signature of Advisor]

Date: May 20, 1971