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# Research on Dental Materials at the National Bureau of Standards

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# Research on Dental Materials at the National Bureau of Standards

## A Review and Bibliography

*By* I. C. Schoonover and Wilmer Souder

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## Contents

# Research on Dental Materials at the National Bureau of Standards

## A Review and Bibliography

By I. C. Schoonover and Wilmer Souder

A general account is given of the research and development work in the field of dental materials that is now being conducted at the National Bureau of Standards. Included are noteworthy accomplishments on design and construction of special equipment, the development of specific techniques for evaluating these materials, fundamental research on the chemical and physical nature and behavior of dental products, development of better techniques for use in dental practice, clinical research, and the development of new products for dental use. The relationship of the work to the dental health of the nation, dental industries, dental schools, and the Federal dental services is discussed. A list of 156 Bureau publications on dental materials is included. The publications constitute the most extensive set of reference material ever produced in any dental research laboratory.

## I. Introduction

The purchase and use of materials employed in operative and restorative dentistry are major considerations in the dental health of the Nation. In 1948, 864 million dollars was spent for dentistry in this country, and of this sum over 100 million was spent for material. It is estimated that 60 to 80 percent of all the dental service received by the public is of a repair or restorative nature involving the use of some type of organic, ceramic, or metallic substance. Good dentistry, therefore, is largely dependent on the quality of these products and the skill with which they are used by the dental profession and industry.

In 1919 this Bureau established a broad program of research in this field, which over the past 30 years has aided materially in the solution of many of the problems encountered in dentistry. In general the work of the Dental Section may be classified under the headings of research, testing, certification, clinical response, and education. The research program includes investigations on the fundamental chemical, physical, and engineering properties of dental products, the development of special equipment and methods for evaluating these properties, and the clinical application of these findings. The certification program is concerned with the development of specifications, routine testing of dental products by the American Dental Association staff at the Bureau, and the certification of these products to dentistry. The educational program is planned to disseminate the information obtained in the other programs, and to encourage its early acceptance and use by the dental profession.

The work of the National Bureau of Standards on dental materials was started in 1919 in response to a request from the War Department for assistance in the evaluation of dental products purchased by the various Federal dental services. The work from 1922–28 was financed in part by the establishment of a research fellowship supported by the Weinstein Research Laboratories. This fellowship continued until 1928 when the Research Council of the American Dental Association established a cooperative research program with the Bureau. The important work undertaken by a staff of chemists, physicists, and dentists maintained at the Bureau by the American Dental Association has contributed greatly to the success of the program and has developed into one of the major research activities of the American Dental Association.

When the dental research program was established at the National Bureau of Standards, it was decided to concentrate on the investigation of materials that are most commonly used in the replacement or repair of teeth or tooth structures lost through dental disease. By limiting the program in this manner, the greatest immediate service was rendered to the public and the dental profession. These investigations have covered such diversified materials as amalgams, silicate cements, zinc phosphate cements, zinc oxide cements, waxes, precious metal alloys, base metal alloys, hydrocolloidal materials, gypsum products, synthetic resins, rubber, and a number of accessory materials employed in the processing of dental restorations.

Because of the widespread acceptance of this service by the dental profession in this country and abroad, and the apparent need for continued and expanded research in this field, the National

Bureau of Standards in 1947 increased the facilities of the Dental Section to include a program of clinical research. Experience gained in the earlier work on dental materials indicated the urgent need for a better correlation between observations on clinical behavior and the data obtained in the laboratory. In order to undertake clinical investigations of the more commonly used restorative materials, a complete operative unit and trained personnel were added to the Section. The increased facilities of the Section also greatly accelerated the investigation of new products that are constantly being offered to the dental profession, often without adequate data to substantiate the claims made for them or to supply sufficient information for their proper use.

During the recent war difficulties were experienced in the use of dental products under the wide variety of conditions encountered by the Dental Corps of the Armed Services. At the request of the various Federal dental services, a cooperative research program was established at the National Bureau of Standards to study the behavior of dental products under conditions not usually encountered in civilian practice.

The work of the Dental Materials Section also includes investigations of the structure of tooth enamel and dentin. This problem is one that the National Bureau of Standards is logically suited to investigate because of its long experience in fundamental research on the physical, chemical, and engineering properties of many substances.

In the sections that follow, some of the more important phases of the work of this Bureau in the field of dentistry are listed and briefly discussed. These investigations have led to over 150 publications by members of the Bureau staff. A complete bibliography is given at the end of this paper.

## II. Physical and Chemical Properties of Dental Materials

The choice and use of the materials employed in operative and restorative dentistry present many difficulties. Small cavities with fixed unyielding walls must be restored with materials that are compatible with the oral tissues, and that have the physical and chemical properties necessary to withstand the forces of mastication and the action of the oral fluids. The cavity must be sealed against oral fluids, numerous chemicals encountered in foods, and especially against the decay products that form so rapidly in small crevices and cavities and contribute to many failures. The problem is further complicated by the great variety of materials needed and the many different brands of each type offered for sale. For example, at the present time several hundred dental gold alloys for making inlays and more than 65 different alloys for making amalgam restorations, and 50 brands of resins for constructing partial or full dentures are on the market.

For many years the only information available to the practicing dentist on the properties of these products came from the limited amount of research, mostly clinical, that was done in a few dental schools, and the research that could be financed by manufacturers of dental products. This information was very often incomplete, conflicting, and in many instances erroneous. Personal endorsement of an item by a popular dentist frequently outweighed careful laboratory tests and clinical research. Therefore, measurement of the properties of these restorative materials was made an important part of the work of the National Bureau of Standards.

Along with these investigations, fundamental research is conducted on the basic chemical and physical nature of dental materials for a better understanding of the factors that alter their properties. This information is especially valuable because all the materials employed in the practice of dentistry must be fabricated by the dentist into a finished restoration, the properties of which may be greatly altered by the methods used and the technical skill of the dentist. The work that has been done in determining the nature and behavior of these products has been one of the primary factors in the general improvement of dentistry in this country in the last 30 years.

The small size and the shape of dental restorations made it impossible to use standard and well-established testing methods. The development of special equipment and test methods therefore became a major part of the dental program. Most of the work of the Bureau in this field has been accepted as standard for similar studies of dental products by dental schools and dental industries throughout this country and abroad. The development of the dental interferometer for

FIGURE 1. *Measurement of heat evolved during the hardening of dental restorations.*

Excessive temperatures resulting from the chemical reactions that occur during the hardening of some types of dental restorations may severely irritate the tooth structures. Measurement of those temperatures under actual oral conditions are being made.

measuring the small changes in dimension that occur during the hardening of amalgam is an example of such special equipment. This instrument, capable of measuring changes as small as one one-hundred thousandth inch on specimens approximately one-half inch long, has been adopted by most leading dental schools and dental industries for measuring dimensional changes that occur in dental restorations. Some of the most important investigations on dental materials conducted at the National Bureau of Standards are discussed below.

## 1. Dental Amalgam

Dental amalgam alloys containing silver, tin, copper, and zinc have been used in dentistry for over 100 years and more restorations are made today from amalgam than from all other materials combined.

Some of the most important work on amalgam at this Bureau is concerned with the fundamental reactions that occur during the hardening of the amalgam. Studies (1, 15, 24, 113) have been made of the alloy-mercury ratio, methods of trituration and condensation, and methods of finishing to determine how they affect such properties as dimensional stability, strength, and corrosion resistance of the amalgam restorations. These investigations have done much to eliminate many of the difficulties formerly experienced with this material and have established amalgam as one of dentistry's finest restorative substances.

Also significant is the work at the Bureau that demonstrated that the severe postoperative pain often experienced with amalgam restorations is caused by moisture contamination (103, 111, 118). It was proved that a small amount of water incorporated in the amalgam during mixing or placing of the restoration reacts with the zinc in the alloy to produce hydrogen. The entrapment of the hydrogen within the restoration creates pressures sufficient to expand the alloy against the underlying tooth structures, causing severe postoperative pain. As a result of this discovery techniques were developed that make it possible to eliminate entirely this type of failure. The extremely painful experiences suffered by thousands during the third to tenth days after an amalgam filling had been placed are no longer necessary if the dentist handles the amalgam with proper care.

The possibility of mercury poisoning, once considered a serious drawback to the use of amalgam in dentistry was also investigated (33). The results show that poisoning from this source is extremely unlikely because the amount of mercury that can be released from these restorations under oral conditions is very small. The possibility of tissue irritation, caused by galvanic action when amalgam is placed in the oral cavity along with more noble metals, was also investigated.

The current work on amalgam concerns the metallurgical reactions which occur during amalgamation and hardening of the alloy. The development at this Bureau of a method for investigating the microstructure of amalgam restorations at room temperature offers a new approach to studies hitherto considered difficult because of the low melting point of mercury, present to the extent of forty to fifty percent in these restorations.

Other investigations (1, 10, 19, 83, 102, 113) on amalgam alloys at the National Brueau of Standards have included the development of test methods and equipment for obtaining data on the chemical composition, flow, hardness, strength, tarnish resistance, thermal expansion and dimensional changes resulting from reactions involved in the hardening of amalgam.

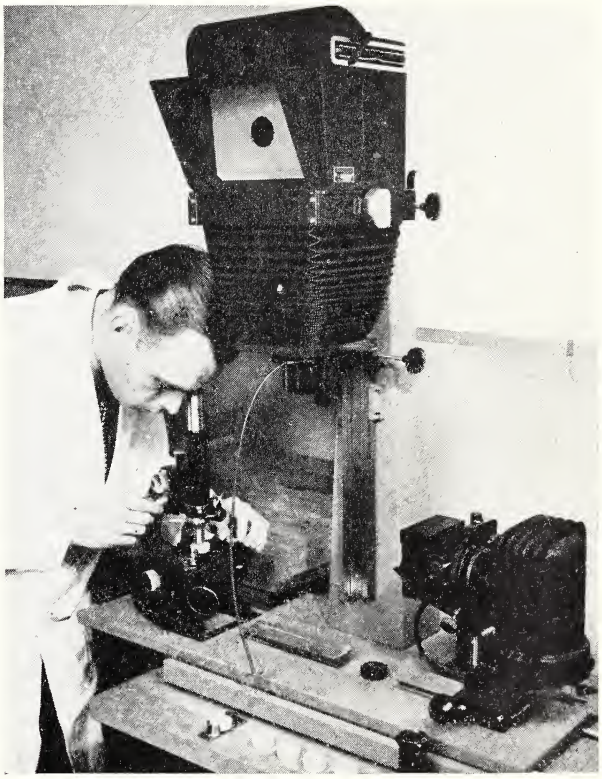

FIGURE 2. *Investigation of microstructure of metallic restorations.*

A knowledge of the metallurgical reactions that occur during the hardening of amalgam is important in the development of techniques for obtaining the best properties in this type of restorative material.

## 2. Dental Gold Alloys

The casting of gold alloys to the extremely small tolerances required for dental restorations was one of the greatest difficulties experienced in the use of these materials in dentistry. Prior to the investigations of the National Bureau of Standards to determine basic principles involved in precision casting, the accurate casting of dental restorations was more frequently accidental than scientific. At the beginning of this investigation 25 of the leading dentists of the country with established reputations for their ability to make inlays,

crowns, and bridgework, were asked to cast a restoration for a standard die supplied by the Bureau. Only 2 of the 25 were successful in making a casting with even a reasonably good fit. The accurate determination at this Bureau of the dimensional changes that occur during the casting of gold alloys, along with similar investigations on the dimensional changes of waxes used for making patterns and on gypsum investment materials used for molds or crucibles (7, 14, 25, 36, 41) made it possible for the first time for the dental profession to make precision castings of dental gold appliances.

As a result of this work, the art of casting is now so well defined that it has been adopted by many industries for the manufacture of small objects that must be cast to precise dimensions.

Investigations (7, 14, 34, 138) of casting golds at the National Bureau of Standards have also included the determination of their tensile strength, microstructure, elongation, modulus of elasticity, hardness, fusion temperature, casting shrinkage, the effect of heat treatment, and chemical composition.

The methods developed at the Bureau for the chemical analysis of dental gold alloys (8, 80) have found widespread acceptance throughout the dental industry, and the data obtained through the use of these methods are being used extensively to develop new and better alloys.

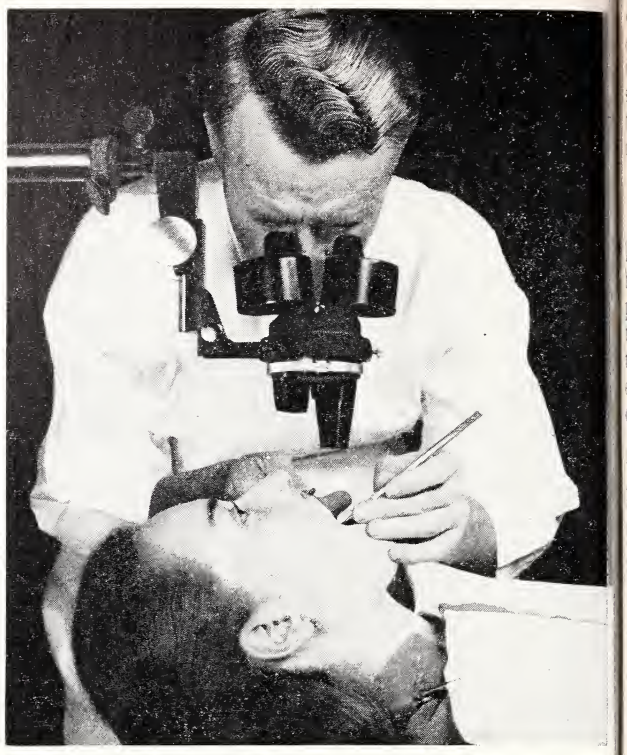

FIGURE 3. *Clinical observation of dental restorations.*

The correlation of the clinical behavior of dental materials with data obtained in the laboratory on their chemical and physical properties is important in the development of methods for evaluating dental products.

### 3. Silicate Cements

The widespread use of silicate cements for restoring anterior teeth and the many clinical difficulties caused by their inherent weaknesses have led to an intensive research on this group of materials at the National Bureau of Standards.

Silicate cements were first introduced to dentistry in 1878, but it was not until 25 years later that a product reasonably satisfactory for dental use was produced. In silicates the dental profession believed they had the ideal restorative substance: a durable material with esthetic properties, which could be inserted in the cavity in a plastic state and which would then harden sufficiently to satisfactorily resist attrition in the mouth. In practice, however, these cements began to discolor, dissolve, and, what was far worse, to cause the death of the tooth pulp.

At about the time the National Bureau of Standards began to work on silicates, Brekhus and Armstrong [1] reported that approximately 8 percent of all fillings were silicates and that 19 percent of the silicate restorations they had observed in a survey had failed. The primary cause for this high percentage of failures was the lack of information on the fundamental chemical and physical behavior of these materials. The chemical composition of the cements was unknown, and the basic principles involved in mixing them were so poorly defined that when a group of practicing dentists was asked to cooperate in determining the amount of powder that could be incorporated in a given quantity of liquid, the values reported ranged from 0.70 to 1.69 grams for the same cement (74). Data on factors that adversely affect the solubility and setting time, crushing strength, hardness, and dimensional stability were either nonexistent or so conflicting as to be of little value. Much of this confusion existed because of lack of standardized testing procedures.

The investigations (74, 84, 96, 97, 113) on silicate cements at the National Bureau of Standards have been concerned primarily with the composition of these cements, the chemical reactions involved in hardening, and the factors that influence these reactions. Methods were developed for determining the factors that influence the solubility, crushing strength, hardness, opacity, acidity, and purity of cements. The first complete chemical analysis of all these complex materials was made at this Bureau.

The use of the data from these various investigations, by the dental profession and industry, produced a marked improvement in silicate cements. For example, a decrease in their solubility of as much as 50 percent has been attained while their strength has been increased by a similar factor. Impurities such as arsenic, which may irritate the tooth pulp and even cause its death, have been reduced to harmless amounts or eliminated entirely. Techniques have been

[1] P. J. Brekhus and W. D. Armstrong, Civilization—a disease, J. Am. Dental Assoc. 23, 1459 (1936).

developed on the basis of these investigations that enable the dentist to manipulate these products with greater assurance that the restoration will be satisfactory and that the underlying tooth structures will not be adversely affected through their use.

### 4. Zinc Phosphate Cements

For many years the zinc phosphate cements, like the silicates, proved disappointing in practice because of the lack of data on their fundamental properties and because of the lack of uniformity in their composition. It was not uncommon at one time to find that some cements were soluble to the extent of 14 percent, whereas the solubilities of others might be as low as 0.14 percent.

Investigations (47, 51, 59, 66, 73, 96, 113) at the National Bureau of Standards were instrumental in materially reducing the solubility and disintegration of these products in the oral fluids and have brought about an increase in their strength, hardness, and ease of manipulation. Also, the development of adequate testing procedures for evaluating the properties of these cements has produced a greater uniformity in the products now available. Dentistry now expects, demands, and obtains cements that have a greater life service.

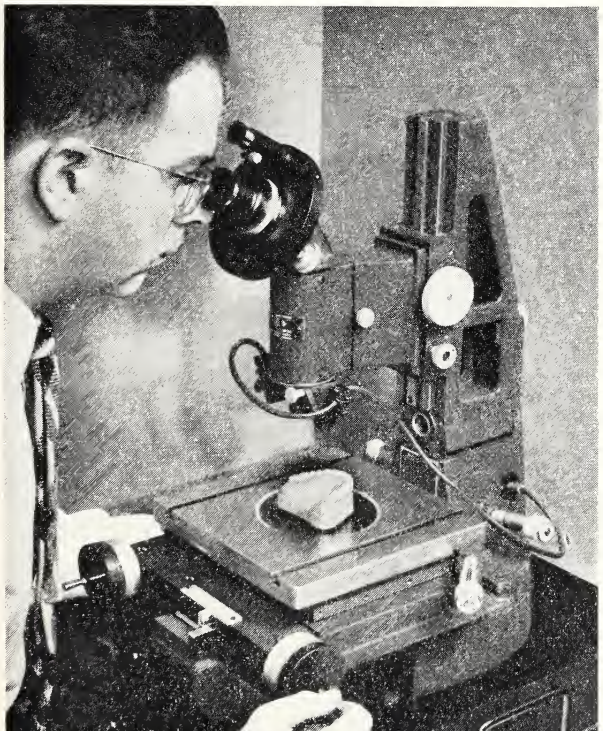

FIGURE 4. *Microscope used in making accurate measurements of small changes in the dimensions of artificial dentures.*

The resin must cure to an exact fit and must maintain its dimensions unchanged for years. Ten years ago most resins warped with age and made the dentures useless.

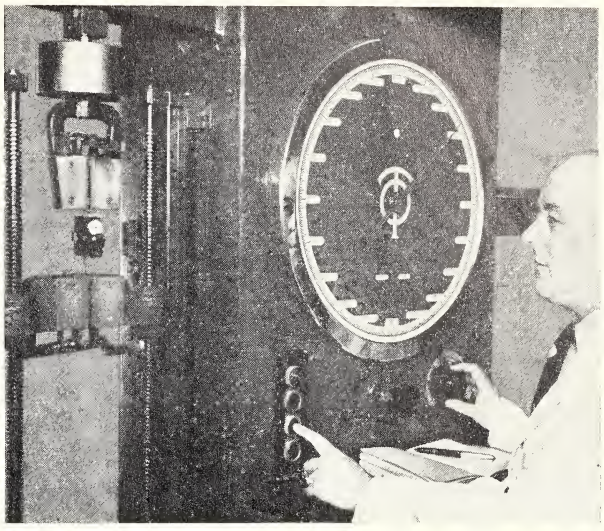

FIGURE 5. *Machine used in testing the tensile properties of dental gold alloys.*

Dental bridges, inlays, and clasps are engineering structures from which the utmost in services are demanded. Accurate data are necessary for correct selections of materials and proper design of structures.

### 5. Synthetic Resins

Synthetic resins are used in dentistry for the construction of complete and partial dentures, inlays, crowns, artificial teeth and, more recently, as direct filling materials. Practically all the synthetic resins produced that have any of the properties necessary for dental use have at one time or another received the attention of dentists and dental manufacturers. During the past 20 years cellulose, phenol formaldehyde, vinyl, styrene, and acrylic resins have been used in turn for making dentures. Probably no other group of materials has caused the dentist so much difficulty.

Most of the failures experienced with resins resulted from a lack of dimensional stability and strength sufficient to withstand the forces of mastication. Under ideal conditions the efficiency of artificial dentures is less than 25 percent of that of natural dentition. Since the efficiency of dentures is related directly to the accuracy with which they can be made to fit the hard and soft tissues of the oral cavity, dimensional stability is particularly important.

Investigations (78) at the National Bureau of Standards showed that cellulose materials were partially soluble in the oral fluids and changed shape radically in service. The phenol formaldehyde (78) resins were brittle, dimensionally unstable, polymerized slowly at room temperature, and changed color with age. The tendency of these resins to polymerize prematurely at room temperature and the lack of any index for determining the extent of such polymerization made it virtually impossible to develop a standarized curing technique.

The vinyl resins failed primarily because of strain introduced into the denture during molding

and because of the inability of the manufacturers to produce a uniform product (78). Experiments on polymer distribution showed variations as great as 100 percent in the amount of some of the higher polymer fractions present. Furthermore, no two lots of the resin were found that had similar polymer compositions. Since the physical properties and the techniques employed in molding are in part dependent on the type of polymers present, this nonuniformity readily explains the failure of these materials.

The data obtained (52, 65, 78, 87, 92, 99, 109, 110, 113, 121, 136, 152) by the Bureau on acrylic resins and some copolymers of these resins with vinyl resins show that they are the best materials that the dental profession has for making prosthetic appliances. Difficulties are often encountered, however, if the basic principles governing the behavior of these resins are not understood.

The investigations at the National Bureau of Standards on acrylic resins have included the development of both methods and equipment for determining the basic properties of resins and the determination of the factors that have an important bearing on these properties during polymerization and molding. In this work investigations have been made on the effect that impurities in trace amounts have on rate and completeness of polymerization, and the effect that temperature, pressure, duration of heating, and mold surfaces have on the type of polymer formed. Methods were developed for fractionally precipitating polymers and determining their number average molecular weight, for determining small amounts of residual monomer in cured samples of resin and correlating the polymerization rate with amount and type of catalyst and inhibitor used in these resins. The data from these investigations explain many of the difficulties encountered in denture construction such as continued shrinkage in service, fracture, discoloration, crazing, porosity, and premature polymerization of these resins.

Investigations similar to those that were made on the resins for denture construction are being made on a new group of acrylic resins that polymerize at low temperatures and that have been advocated for use as "direct" resinous filling materials. At the present time, studies on clinical performance, polymerization shrinkage, hardness, completeness of polymerization, type of polymers formed and the factors that influence their properties are in progress.

Investigations are also underway on the abrasion resistance, elastic properties, dimensional stability, hardness and resistance to crazing of artificial teeth made from synthetic resins.

### 6. Other Dental Materials

Research similar to the investigations reported above has been conducted on numerous other products used in dentistry either as restorative materials or as accessory materials employed in the preparation of restorations. This research includes studies on the chemical and physical nature and properties of waxes (7, 14, 25, 27, 49, 93, 113), reversible and irreversible hydrocolloidal materials that form elastic gels (88, 113, 123, 131), zinc oxyphosphate cements (96), zinc oxide-eugenol cements (96), copper phosphate cements (96), mercury (33, 35, 113), gypsum products (7, 14, 21, 25, 26, 41, 77, 113, 147), base-metal alloys (113, 125), toothpastes (72, 113), rubber (52, 65, 94, 113), casting resins, and nylon (151).

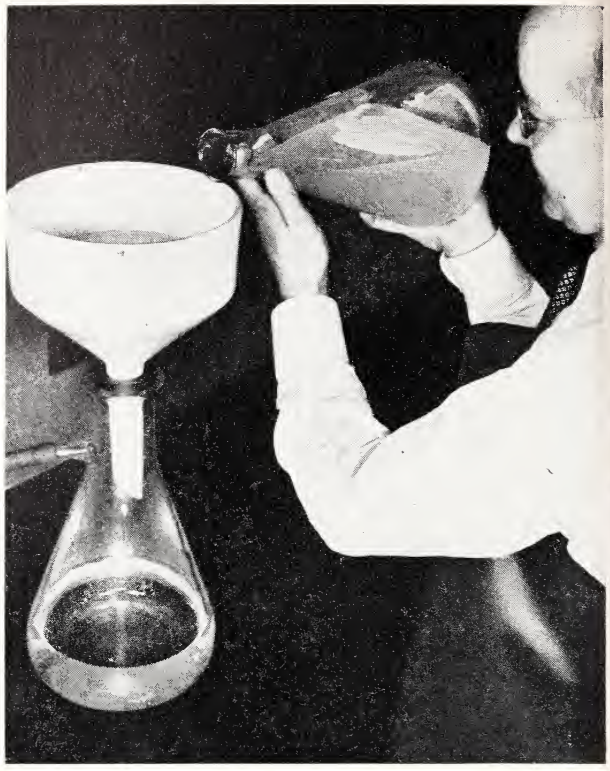

FIGURE 6. *Fractional precipitation of polymers in acrylic resins.*

Polymer ratios determine the probability of cure to exact dimensions, the brittleness and expected permanence of a denture.

## III. Structure of Tooth Enamel and Dentin

One of the most important factors in the development of satisfactory methods for preventing dental decay is an adequate explanation of the processes that occur in the decalcification of teeth. It is generally believed that the radically different behavior of teeth in resisting decalcification is in some way associated with the manner in which the hard calcified structures are deposited. However, no adequate correlation between tooth structures and their resistance to decay has yet been proposed.

Although the work of the Dental Section at the National Bureau of Standards has been primarily concerned with restorative materials, investiga-

tions have also been made on tooth structures. They have included experimental work on the determination of hardness of enamel and dentin, abrasion, and decalcification of tooth structures produced by chemical and mechanical action of some ingredients used in toothpastes. One of the more important problems investigated was the possibility of remineralization of teeth through the use of fluorides and calcium salts. In this work, some of the first electron microscope studies of the structure of enamel were made and reported.

The present program includes an investigation of the chemistry of the basic calcium phosphates, the major inorganic constituent of teeth. The effect that traces of elements have on the precipitation and structural characteristics of these basic phosphates is also being studied. X-ray and electron diffraction and electron microscope methods are employed. It is hoped that the additional information obtained on the chemical and physical structures of teeth will make it possible to give an explanation of the mechanism of decalcification or decay.

FIGURE 7. *Denture being made from acrylic resin.*

Dentures are our best correction for nature's failures. They may never be 100 percent satisfactory, but with careful attention to every detail they will give service that the patient will appreciate.

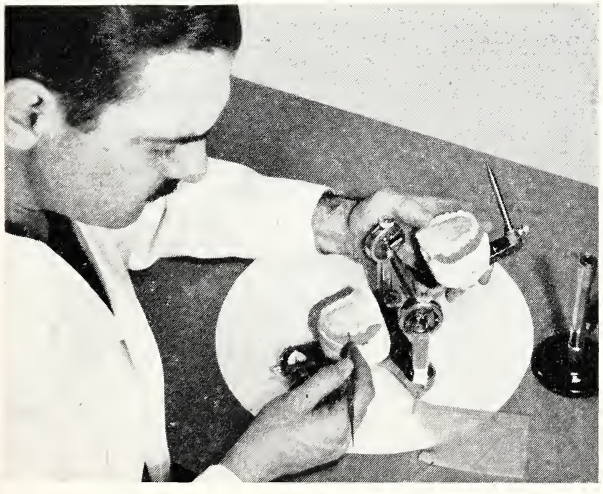

FIGURE 8. *Construction of artificial dentures.*

The maintenance of the occlusal relationship of the teeth in artificial dentures during curing requires a thorough knowledge of the factors that may alter the position of the teeth during processing of the denture. The occlusal relationship between upper and lower dentures mounted on an articulator is being verified

## IV. Clinical Laboratory

The correlation of the laboratory data on dental materials with the performance of these materials in practice is difficult. This is particularly true where small variations in the techniques used in preparing and placing restorations have a pronounced effect on the properties of the restorative material.

In order to investigate these materials under conditions found in dental practice, the Bureau established a complete dental operating unit for carrying on clinical research. Through the cooperation of the members of the Bureau staff, experimental dental restorations are placed under controlled conditions. The behavior of these restorations in service is carefully observed and correlated with the data obtained in the laboratory experiments. As a result of this work, it is possible to develop simple techniques for carrying out dental operations that produce the best properties available from the material used in making the restoration. This work is also very valuable in illustrating the importance of using techniques based upon fundamental data on the chemical and physical properties of these materials.

The clinical program made possible the study of one of the most common types of failure of silicate cements, the erosion and discoloration of the surface of the restoration. The effect of various methods of mixing, placing and finishing silicate restorations can best be studied in the mouth, for it is practically impossible to duplicate in the laboratory the widely varying solution, staining, abrasive and drying and wetting elements that exist in the oral cavity. In these experiments data have been obtained that show that pressure exerted on silicates during the hardening period reduces the porosity and makes it possible to produce a finish that resists staining. Studies on the various methods of finishing (polishing) silicate restorations showed that a fine cuttlefish disk when used from the tooth surface to the silicate surface reduced the incidence of marginal failure and produced a finish superior to that produced by any of the other commonly used methods. An experimental polishing wheel was

developed in which a synthetic resin was impregnated with diamond dust. This wheel gave the best finish obtained on a silicate restoration. In connection with these experiments on finishing, a method was developed for recording the surface of the restoration by the use of a tinfoil replica. This method is also useful in studying the processes of erosion of tooth enamel.

In the investigation of the "direct" resin filling materials, clinical data are being correlated with laboratory data to determine what physical and chemical properties are necessary in a resin satisfactory for restoring teeth.

Data obtained on the wear of acrylic resin teeth in service show that these materials have been improved during the last few years. One of the more important observations made was that many of these teeth fail because of small cracks or crazing that result from processing. Laboratory data show that this crazing is associated with water introduced into the teeth at the time of curing.

Other experiments are in progress on complete dentures made of synthetic resins, partial dentures made from gold and base metal alloys, and on amalgam restorations.

## V. Specifications for and Certification of Dental Materials

### 1. Specifications

The equipment and test methods developed and the data accumulated as a result of this work at the National Bureau of Standards are used to formulate specifications for the purchase and evaluation of dental materials. These specifications have been officially adopted by the American Dental Association and the Federal Specifications Board, and are at the present time available for most of the materials used in restorative dentistry. They are extensively used in this country by dental schools, industry, and the various Federal dental services, and have been adopted by many foreign countries as the basis for evaluating dental products.

### 2. Certification of Dental Materials

It is obviously impossible for the practicing dentist to make tests on each of the many products he uses daily. Since one of the primary purposes of the dental work at the National Bureau of Standards is the improvement of dentistry through the use of better materials, some system of making the results of these investigations available to dentistry was needed. This was done by establishing a "Certification Program." This cooperative program, organized in 1928 between the National Bureau of Standards

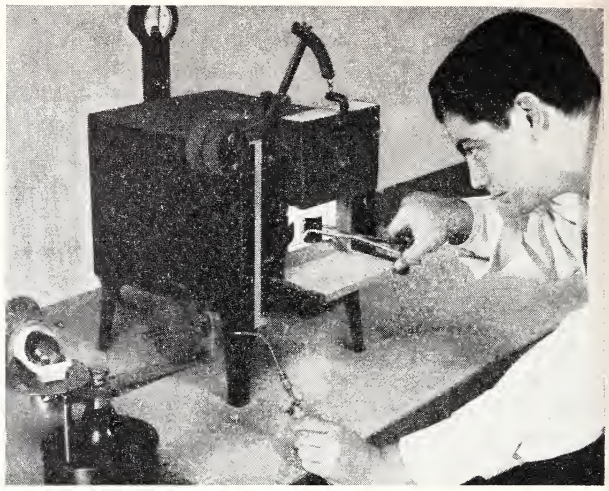

FIGURE 9. *Casting of gold alloys.*

The cast inlay, crown or abutment is called upon for the most severe service of any dental restoration. When cast to exact dimensions and from the proper alloys, these items can deliver the expected service.

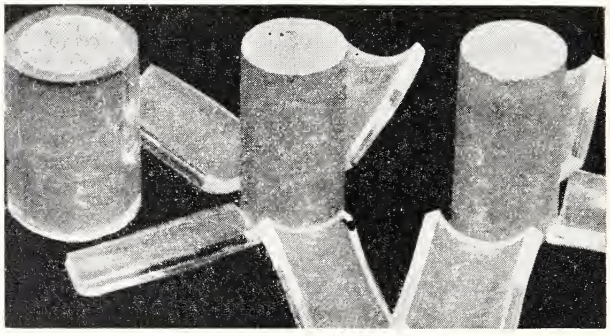

FIGURE 10. *Excessive expansion of dental amalgam.*

The fracture of glass tubing packed with amalgam containing a small amount of water shows the excessive expansion that occurs in such contaminated amalgam and explains the cause of the severe postoperative pain so often experienced when, through carelessness, moisture is incorporated in the amalgam.

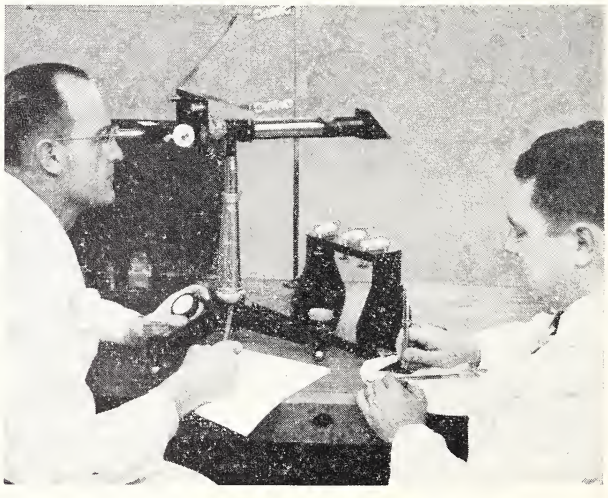

FIGURE 11. *Dental interferometer.*

Few if any defects in dental materials have caused more failures and grief than shrinking amalgams. With this instrument and a small sample of amalgam it is possible to determine within 24 hours the presence or absence of shrinking influences.

and the Council on Dental Research of the American Dental Association, is outlined below.

After a specification has been made an official standard of the American Dental Association, the Research Council invites the manufacturers to certify formally to the Council that their products comply with the specification. The following form is used for this purpose:

Date _____
Research Council American Dental Association.

Gentlemen:

We, the undersigned manufacturers, hereby certify that our Dental _____ (1) sold under the trade name of _____ will meet all requirements and tests as specified in the current American Dental Association Specification No._____ (2) for _____.

We desire to have it placed on the list of materials guaranteed by the manufacturers to meet the requirements established by the American Dental Association.

We, the undersigned manufacturers, agree that the foregoing material will be regularly tested to see whether or not it complies with the appropriate American Dental Association Specification. The frequency of the occurrence of these tests shall be supplied to the Research Council of the American Dental Association with the data accompanying this certificate. We further agree that the test records and data for any particular batch or lot of material shall be made available to the Research Council upon its request. We further agree that a representative of the Research Council may upon request inspect the testing equipment of our company which is used to test our product for compliance with the American Dental Association Specification.

We submit the attached data as evidence that this material meets the requirements.

Signed_____
Title_____
Company_____
Street_____
City_____ State_____

The manufacturer is also requested to furnish the following data at the time the certification is made so that the Council will know that he is in a position to certify his products in a responsible manner:

1. Brand of material.
2. Serial or lot number.
3. Date of manufacture (year and month).
4. Physical properties obtained by standard test methods. The information given as to physical properties must include a brief description of the apparatus used in making each test, the data obtained, the name of the observer, and the date. All test conditions must be so defined as to permit duplication in other laboratories. In the event that tests are made outside the manufacturer's laboratory, the name and address of the testing laboratory must be given. Inasmuch as occasional tests outside a manufacturing plant do not guarantee uniform production control, some mention shall be made of the frequency and scope of outside tests.
5. The data given must cover every requirement of the specification.
6. Specimens of labels, guarantees, and instructions for use, furnished with the product, must be submitted.
7. Policy regarding certification. No manufacturers' certificates will be accepted by the Council on Dental Research of the American Dental Association, until retail sample or samples of the materials under consideration are procured and tested by the Research Associates of the American Dental Association stationed at the National Bureau of Standards.
8. The enclosed requisition blank for the procurement of test samples must be signed and submitted with certificate and accompanying data.

   After a manufacturer has complied with these requirements and the Research Council is satisfied that he is testing or is having a competent laboratory test his material and is maintaining a satisfactory control over his production, the Council will procure on the open market a representative retail sample of the certified product.

The secretary of the Council usually asks some dentist to procure the material from his local supply depot. The dentist sends the sample so procured to the American Dental Association research fellowship at the National Bureau of Standards, where the research associates of the Dental Association under the supervision of the Bureau staff, determine whether the sample meets the specification requirements. If the material is found to comply, the manufacturer's certificate is accepted and the material is placed on the "List of Certified Dental Materials." If the material fails to meet the specification tests, it is not placed on the list. Instead, the manufacturer is requested by the Research Council either to change the product so that it will comply with the requirements or cease and desist from claiming that his product complies with American Dental Association specifications. If the manufacturer refuses to accede to the Council's request, the findings are presented to the Federal Trade Commission.

The names of certified dental materials, which are developed according to the foregoing procedure, are printed from time to time in the Reports of Councils and Committees Section of The Journal of the American Dental Association.

At the present time more than 267 brands of materials, representing products of all the leading manufacturers, are included in the "List of Certified Dental Materials," and new products are constantly being added. The American Dental Association, through its Research Council, urges that only those materials that meet the requirements of these specifications and appear on the "List of Certified Dental Materials" be purchased.

This certification program has had widespread acceptance among the dental profession and is an important factor in bringing about a continual improvement in the materials used in dentistry. For example, in 1920 when the specification for amalgam was released, a survey of the amalgams then available showed that only 25 percent would meet the requirements of the specification. Today 60 amalgams (more than 90 percent of the brands available) appear on the "List of Certified Dental Materials". In fact it is difficult to purchase an amalgam alloy that does not meet the requirements for making a good dental amalgam restoration.

In order to keep the certification program up to date, the Council on Dental Research of the American Dental Association maintains a group of research associates at the Bureau who work continually to test these products, revise the existing specifications, and develop new specifications where they are needed.

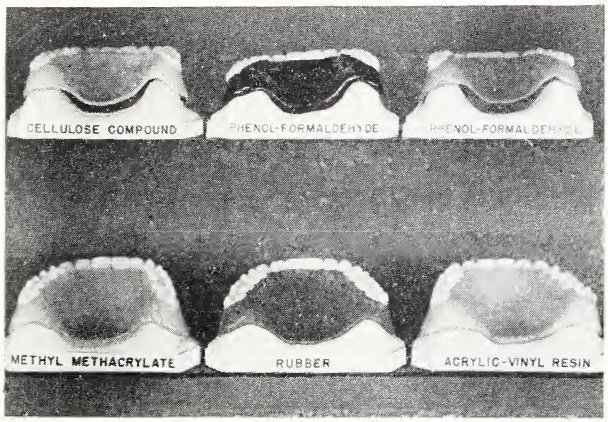


FIGURE 12. *Artificial dentures.*

Dimensional changes incident to cure or age in denture resins (shown at the top) on the market 10 to 15 years ago and (at the bottom) materials known to be stable.

## VI. Educational Program

In order to make possible the application in dental practice of the research findings at the National Bureau of Standards, the dissemination of information has necessarily become an important part of this program at the Bureau. To assist in this plan members of the Bureau staff publish reports and present lectures before dental schools and dental societies on the results of the work of the Dental Section.

Recently the Bureau, in cooperation with the American Dental Association has undertaken the production of a series of colored motion pictures with sound illustrating the fundamental chemical and physical properties of dental materials and showing techniques for their correct use. Three films of this series have been completed on the following subjects: silicate cements, (145), failures of amalgam caused by moisture contamination (148), and denture resins (156). The films are available on loan to dental groups, without cost other than transportation charges. Over seven hundred showings of these films have been made in this country, and the films have been loaned to dental societies in 35 foreign countries. Over one hundred copies of the films have been purchased by dental schools and dental manufacturers.

The Bureau has also undertaken a cooperative training program whereby officers of the Army, Navy, and Air Force Dental Corps and members of the Veterans' Administration Dental Services Division may come to the Bureau on a guest-worker basis to receive training and do research in the field of dental matériel. These guest workers are accepted for a training period of 2 or more years. Since the beginning of this cooperative training program in 1947 six officers of the Dental Corps of the Armed Services have worked or are at present working at the Bureau. Arrangements have been made with the Graduate School of Georgetown University whereby these guest workers may receive 18 credit hours toward the degree of Master of Sciences for their work at the Bureau. Two of the guest workers have received such degrees, and two of the present staff are participating in this program.

The Bureau also makes available its facilities to a limited number of guest workers from other countries to receive similar training. Two members of the faculty of the Danish School of Dentistry in Copenhagen have worked at the Bureau on this program.

In addition to the above activities the Bureau gives consulting and advisory services to dental schools, dental manufacturers, Federal dental services, and practicing dentists on matters pertaining to the properties of dental products. These services are an important part of the educational program.

A book entitled "Physical properties of dental materials" (113) has been published by members of the Bureau staff. This book is widely used as a reference and text book in the dental schools and has been translated into Spanish for use by Latin American dentists.

## VII. Special Problems for the Dental Services of the Armed Forces and Veterans Administration

The Federal dental services are continually confronted with the problem of purchasing and storing dental materials. The evaluation of these materials is often difficult because of the wide range of materials used and the great variety of new products constantly being offered for sale. The problem for some of the Federal services, particularly the armed forces, is further complicated because of the necessity of using these products under conditions not often encountered in civilian practice.

Many of the materials that are quite satisfactory for civilian use are found to be entirely unsuitable

under conditions encountered in military operations. The failure of dental products in field service during the recent war is an excellent example. In tropical areas it was often impossible to place silicate cement restorations, alginate impression materials deteriorated so badly as to be worthless, and many of the synthetic resins polymerized in transit or in storage. Many other dental products in common use in temperate climates needed special handling and special techniques for their use under military conditions in the tropics.

These failures were costly in equipment and shipping and storage space. In order to eliminate as many such difficulties as possible, the Army Dental Corps and the Dental Services Division of the Veterans Administration in 1949 entered into a cooperative research project with the National Bureau of Standards to (1) investigate and evaluate new dental products from the standpoint of their military usefulness, (2) study the behavior of the existing materials under conditions likely to be encountered in military service, and (3) develop adequate equipment and techniques for their use under these conditions.

In this program investigations have been made to determine the causes for the failure of silicate cements and alginate impression materials in tropical areas, the discoloration of some brands of acrylic resin during polymerization, crazing of acrylic teeth, and premature polymerization of acrylic resin at room temperature.

Data have been obtained on the first three of these problems, which explain the reason for these failures, and methods for preventing their recurrence have been proposed.

The cooperative program between the National Bureau of Standards and the Federal dental services also includes research of a fundamental nature on dental materials, the development of new products for specific military use and investigations of the instruments used in the practice of dentistry.

Finally, an instrumentation program is being undertaken to investigate the development of instruments for determining the vitality of teeth, strain gages for determining the forces exerted on full and partial dentures during mastication, and instruments or methods for determining the "free way" space between the upper and lower teeth, a measurement vitally needed for the accurate construction of dentures.

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(130) Midyear report of the Research Commission February 1944. J. Am. Dent. Assn. **31,** 698 (1944).

(131) Elastic impression compositions. George Dickson and I. C. Schoonover. U. S. Patent No. 2,359,512.

(132) Experimental remineralization of dentin. Wilmer Souder and I. C. Schoonover. J. Am. Dent. Assn. **31,** 1579 (1944).

(133) List of certified dental materials (as of December 1, 1944). Research Commission. J. Am. Dent. Assn. **32,** 93 (1945).

(134) List of certified dental materials revised to March 19, 1945. Research Commission. J. Am. Dent. Assn. **32,** 759 (1945).

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(136) "Liners" for dentures. J. R. Beall and H. J. Caul. J. Am. Dent. Assn. **33,** 304 (1946).

(137) List of certified dental materials revised to August 30, 1946. Research Commission. J. Am. Dent. Assn. **33,** 1458 (1946).

(138) Shrinkage during casting of gold and gold alloys. G. C. Paffenbarger. J. Am. Dent. Assn. **34,** 223 (1947).

(139) Additions to list of certified dental materials. Research Commission. J. Am. Dent. Assn. **34,** 423 (1947).

(140) Research Commission reports of failure of artificial dentures processed against tinfoil substitutes. J. Am. Dent. Assn. **35,** 77 (1947).

(141) Past, present and future plans of the Research Commission. J. Am. Dent. Assn. **35,** 399 (1947).

(142) Revision of list of certified denture resins. Research Commission. J. Am. Dent. Assn. **35,** 526 (1947).

(143) Additions to list of certified dental materials. Research Commission. J. Am. Dent. Assn. **35,** 830 (1947).

(144) List of certified dental materials revised to October 31, 1947. Research Commission. J. Am. Dent. Assn. **36,** 224 (1948).

(145) Silicate cement. Color motion picture in sound showing correct and incorrect technics. 16 mm. Running time 18 minutes. Requests for loan of film should be addressed to the Director, National Bureau of Standards, Washington 25, D. C., at least 30 days in advance of the proposed date of showing.

(146) Silicate cements: how to select and use them. G. C. Paffenbarger, North-West Dentistry. **27,** 29 (1948).

(147) Two methods of graphing the contour of the "mucosal" surface of plaster models. W. G. Krogh-Poulsen, G. C. Paffenbarger, and I. C. Schoonover. J. Am. Dent. Assn. **36,** 379 (1948).

(148) Dental amalgam: failures caused by contamination. Color motion picture in sound showing deterioration of the physical and chemical properties of dental amalgam contaminated with moisture. Running time 15 minutes. Requests for loan of film should be addressed to the Director, National Bureau of Standards, Washington 25, D. C., at least 30 days in advance of the proposed date of showing.

(149) Revised list of certified inlay casting gold alloys. J. Am. Dent. Assn. **37,** 444 (1948).

(150) List of certified dental materials revised to November 1, 1948. J. Am. Dent. Assn. **38,** 358 (1949).

(151) Deficiencies of tinfoil substitutes in the processing of acrylic resin. G. W. Ferguson, G. C. Paffenbarger, and I. C. Schoonover. J. Am. Dent. Assn. **38,** 573 (1949).

(152) A method for determining the extent of polymerization of acrylic resins and its applications for dentures. H. J. Caul and I. C. Schoonover. J. Am. Dent. Assn. **39,** 1 (1949).

(153) Additions to list of certified dental materials. J. Am. Dent. Assn. **39,** 79 (1949).

(154) An investigation of Diafil, a dental silicate cement. G. C. Paffenbarger, A. C. Swaney, I. C. Schoonover, George Dickson, and G. F. Glasson. J. Am. Dent. Assn. **39,** 238 (1949).

(155) Additions to list of certified dental materials. J. Am. Dent. Assn. **39,** 489 (1949).

(156) Denture resin. Color motion picture in sound illustrating how temperature, pressure, and rate of curing influence properties of resins as do traces of impurities, moisture content and tinfoil substitutes. Running time 18 minutes. Requests for loan of film should be addressed to the Director, National Bureau of Standards, Washington 25, D. C., at least 30 days in advance of the proposed date of showing.

WASHINGTON, February 7, 1950.


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