AN IN-VITRO STUDY OF THE WETTABILITY CHARACTERISTICS OF ACRYLIC AND SILICONE SOFT DENTURE LINERS

A Thesis

Presented to

The Faculty of Graduate Studies and Research

University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

AMAZIS NASHED LOUKA

May 1973

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks to the many people who aided in the development of this investigation, and in particular, to Dr. Zack Kasloff, who was the supervisor, and contributed his time and effort in reviewing this manuscript.

Appreciation is extended to Dr. Hymie Gesser for his invaluable advice and to Dr. Peter Williams, whose help was instrumental in making this work a reality.

Thanks are also extended to Dr. Farouk Chebib for the statistics and computer programming of the results, to Mr. William Bergman for the technical assistance, to Messrs. Alex Domokos, Arthur Scott and Allan Cox for the art and photography work and to typists Sandra Weisman and Marsha Rodin.

Not the least of all, I acknowledge here, with gratitude, the moral assistance and encouragement afforded to me by my wife Sophy, and the unselfish attitude displayed by her and my daughter Hanaa, throughout the duration of this study.

ABSTRACT

The purpose of this study was to improve the wettability characteristics of acrylic and silicone soft denture liners.

Chemical surface wetting treatments, previously reported to be successful with plastic contact lenses and conventional denture bases, were applied in this study.

Five different materials, representative of: heat curing acrylics, cold curing acrylics, heat curing silicones, and cold curing silicones were randomly selected from those brands currently marketed.

The wetting treatments used in this study were: Durabond, a process of deposition of a micromolecular layer of silica, and hydroxyl radical treatment preceeded by cross-linking the surface in an inert gas atmosphere. A third non-treated group was used as a control.

Wettability was determined by direct contact angle measurement. Softness and weight changes were evaluated throughout the study to determine if such treatments will have any effect on these two important properties.

The results showed that both treatments were significantly effective in lowering the contact angle of the five materials used in the study. Silicone materials responded better to the hydroxyl radical treatment. With both treatments the effect was of a temporary nature. The contact angles of the treated groups approximated those of the control group within two weeks following treatment.

Water storage of the samples was a better medium in maintaining the effect of the treatment than air storage.

Softness of the materials was not affected by the surface treatments. When compared to the control the Durabond heated group showed a higher tendency to water absorption while the hydroxyl radical treated group did not show a significant change. A whitish film was observed to develop on the surface of the Durabond treated group.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Prosthodontists and general practitioners are frequently confronted with the problem of the patient who experiences difficulty or discomfort when wearing complete dentures. Contributing factors include ridges with thin mucosal covering, sharp knife-edge surfaces, bony protuberances and undercut ridges. Persistent generalized inflammation, non-specific in origin and special problems associated with prosthetic appliances for the treatment of acquired or congenital defects are other examples of difficulties encountered.

The usual solution to the problem was to place some form of cushion between the hard denture-base material and the tissue-bearing area. Velum rubber was introduced at the turn of the century, followed by a variety of other materials, as potentially improved methods for achieving the desired result. The recent introduction of soft lining materials has been received with a considerable amount of enthusiasm, however, the property of softness exhibited by these materials initially, did not continue to be displayed indefinitely. Other undesirable properties, such as water absorption, discoloration and odor, were found to develop with time.

Recently, research was undertaken to improve the wetting properties of conventional denture-base materials in order to improve retention and stability. Some degree of success has been reported. To date, no research has been

has been undertaken to improve the wettability of soft lining materials by surface treatment after processing, nor to determine what effect such treatment may have on the properties of such materials.

REVIEW OF THE LITERATURE

Aging is a catabolic process, compared to the anabolic process of youth. In some instances, aging has a pronounced effect on the oral tissues, as elsewhere in the body. Atrophy in the oral cavity affects both hard and soft tissues i.e. bone, mucous membrane and muscle. There is a gradual diminution in the size of the alveolar ridge which may be accelerated by disuse or abuse. Lammie [1] states that as a result of reduction in thickness of the mucosa and a possible reduction in the surface area, the mandibular ridge in particular is covered by a thin layer of soft tissue. Vertically arranged bony spicules and prominent nutrient canals are almost invariably seen in the lower anterior region of such cases. When a masticatory load is applied through a hard denture base to this type of foundation, pain is very likely to result. The pain receptors are compressed between the thin mucosa and the sharp spicules of bone.

It was shown by Marsland and Fox [2], that a marked increase in the amount of nerve tissue may be present in areas causing pain and discomfort beneath a lower denture.

Soft lining of the lower [3][4] denture in such cases frequently gives comfort to the patient. This is achieved by substituting the missing resilient tissue, which normally covers the residual ridge, with a soft material of similar resilience. This material is placed on the tissue side of the denture base. Part of the energy normally transmitted by

the hard denture base directly to the soft tissue, is absorbed by the elastic deformation of the soft liner. Consequently, the direct load on the tissues is reduced.

In prostheses constructed as obturators for defects, a soft liner in contact with the traumatized tissues in the site of operation will minimize the accompanying irritation usually experienced when only a hard base is used, and healing will take place with less discomfort.

When a hard denture base constructed for cases with bilateral bony undercuts or bony prominences such as tori, it is customary to relieve these areas by reducing the fitting surface of the denture base. Unfortunately, the inclusion of air between the reduced surface of the denture and the ridge mucosa causes a reduction in retentive capacity of the denture, especially in critical areas such as the peripheral seal[5]. This problem may not arise when a soft liner is used. If a soft material replaces the hard resin which lies beneath the undercut, it can readily be displaced upon insertion of the denture. For removal, energy is required to spring the elastic flange over the high contour. This provides improved retention in addition to the main objective of closer adaption and elimination of air inclusion[6].

Storer[3] and Swartz[7] discussed the frequency with which many soft lining materials appear on the market and concluded that they were limited in their use and remain in

the category of temporarly materials, because of the unsuitability of their properties.

Soft lining materials are continuing to appear and disappear from the market, with the hope that a satisfactory material will eventually be developed.

An early material, called vellum rubber, was composed of a vulcanite rubber, produced by using a 1:5 ration of sulphur to rubber. This was the prevailing soft liner until the advent of the methyl-methacrylate resins as a material for denture bases. Vellum rubber proved unsatisfactory because putrefaction and disintegration of the material occurred after a short period of time, due to its extreme porosity[8]. Later, a washed rubber formula was advanced by Lammie and Storer[9], who believed that the porosity of the vellum rubber was due to protein impurities. This product was also used on acrylic bases in conjuction with a bonding agent.

Shortly after polymethyl-methacrylate resin was widely accepted as a denture base material, polyvinylchloride (P.V.C.) was introduced as a soft lining material and was described as being most successful, based on clinical and other tests performed at the Bureau of Standards[10]. Lammie and Storer[9] disagreed with these claims and reported technical difficulties and clinical shortcomings with this material. They stated that the gelation

temperature of P.V.C. was quite critical and failure to reach the required temperature resulted in a weak mass, cheeselike in consistency, whereas overheating decomposed the material. Discoloration of the acrylic base and teeth occurred, which is quite unacceptable, esthetically. It was also found that in the mouth, after a period of time varying from six to twelve months, the soft lining hardened and fissures developed on the surface. In their opinion, the greatest disadvantage of P.V.C. was its high and critical gelling temperature. Polyvinyl acetate possessed a lower gelling temperature. Unfortunately, this material had a high water sorption which would contraindicate its use in the mouth, and also, it hardened after months of use. Later, soft acrylic resins, co-polymers of dereivatives of methacrylic acid together with different plasticizers, were introduced as soft liners for acrylic dentures. More recently, silicone synthetic rubbers became available for the same purpose. Physical properties and clinical behaviour of soft denture liners of these two types have been the subject of several investigations and are of special interest from the viewpoint of their behaviour under natural and simulated conditions of the oral environment.

Smith and Bates[11] performed laboratory and clinical tests on a wide group of soft acrylic and silicone materials used as denture liners. Water absorption was appreciably

high in some of the materials and in all cases they showed values for water sorption which were higher than that of regular hard denture base acrylics. They believed that such high rates of water absorption not only affect the hygienic qualities of the material, but on drying, may also induce stresses due to shrinkage which could weaken the bond between the soft and hard layers of the denture base. They also tested the softness of the materials as related to the temperature of the environment during testing, the amount of plasticizer present in the material and the thickness of the soft liner. In their reports on clinical cases, discoloration, surface deposits and abrasion in some areas had occurred over a relatively short period of time, as little as six months.

In another publication[12] the same authors reported on more extensive clinical trials with various materials. The clinical performance of the materials used was less adequate and satisfactory compared to their laboratory testing results. Although the patients' comments were in favour of the soft lined dentures, in general, some of them complained about abnormal taste, loss of colour, staining and calculus formation. They also observed that the silicone material was not wetted by saliva and, when extended to the periphery, created an unpleasant feeling when the movable tissue slid over the surface. They concluded that the silicone material when treated properly in the laboratory and

by the patient, could give satisfactory service for periods up to three years. They were hopeful that further development would lead to a material with a life expectancy comparable to that of the denture base.

Travaglini, Gibbons and Craig[13] conducted a laboratory study on the properties of a number of soft liners belonging to the acrylic resin and silicone groups. Some of the brands were the same as used in Smith's investigations, others were different. Their results also indicated that these soft liners possessed some poor qualities such as inconsistency in the rate of absorption and saturation with water and loss of softness with time.

Storer[3] has also tested some physical properties of a broader group of materials, which included vellum rubber and polyvinyl materials, in addition to acrylic and silicone soft liners. He reported that materials differed in their rate of hardening, depending on the type of plasticizer used. Silicone rubbers maintained their softness over the thirty month test period, while the tests on vellum rubber materials had to be suspended prematurely because of the early deterioration of the specimens. The water absorption rates reported, varied from negative values up to 33.6 per cent volume increase. The negative values were explained as being the result of soluble matter or plasticizer which exceeded the uptake of water. He also related the different rates of water absorption in the silicone materials to different types of fillers used.

Lantz[14] reported results of 15 clinical cases of complete dentures lined with a more recently developed silicone rubber soft liner, known as Siliastic 616 and used by patients for periods of 12-14 months. His results confirmed those of Bates and Smith that the patients were more comfortable with the soft-lined dentures but the material did not retain its good qualities and required replacement after varying periods of time.

A number of other investigators[15-19] also reported on the physical properties of different types and commercial brands of soft liners, in vitro and in vivo, under functioning conditions. They have stressed the fact that there was a need for soft denture liners and that they would provide better prosthodontic service in certain cases, but the deficiencies they exhibited, limited their use; most of them expressed hope that truly permanent soft liner would be developed in the future.

O'Brien and Ryge[20] treated the surface of regular denture-base acrylic resin with silicone tetrachloride in an attempt to improve wettability and thus adhesion of denture bases to the tissues. They reported a 50-70% improvement in wettability which resulted in approximately 15% improvement in retention. This investigation was extended to clinical cases. Ten sets of complete dentures were treated. The dentures had been worn between 1 and 6 months by the patients prior to treatment. Nine of the ten patients were recalled

one month after the dentures had been treated. Three of the 9 patients reported improved retention and all 9 reported that the dentures were easier to keep clean. In a progress report[21], the investigators reported that the treated dentures retained the property of improved wettability, produced a healthy response in the underlying tissues, were easy to keep clean and remained comfortable after a period of 8 months. Boucher et al[22] also reported an increase in the retention of mandibular complete dentures. In 86% of the patients, the increase was more than 20%.

Gesser, Warriner and Funt[23] devised a mothod of reacting the surface of plastic contact lenses with polar-free radicals. The newly created surface of the plastic became more wettable by water. A marked improvement in adhesion was reported by patients wearing treated contact lenses over a period of 4 years. A third method for improving wettability of plastic surfaces was reported by Gesser and Castaldi[24][25]. They used a freshly prepared soltuion of a mixture of 4M H_2O_2, 1M H_2SO_4, and 0.4M $TiCl_3$ to generate free hydroxyl radicals which would hydroxylate the plastic surface and render it more wettable. They applied their techniques to methyl methacrylate denture bases and evaluated them along with the one suggested by O'Brien and Ryge. They found that retention was improved in the order of 16-67%.

STATEMENT OF THE PROBLEM

It is generally agreed that currently available soft lining materials have limited application in the field of prosthetic dental service. Their properties lack the necessary requirements essential for comfort and oral hygiene on a long tem basis. The need for materials to satisfy these requirements still exists.

It was, therefore, proposed to investigate what effect techniques, successfully used to improve wettability of conventional denture-base materials, would have on current soft lining materials. It was also decided to determine how properties of softness and water sorption might be affected by such treatment.

METHODS AND MATERIALS

I General Considerations

Soft denture lining materials used in dentistry can be classified into two major categories, namely, those derived from acrylic resins and those from silicone rubbers.

Almost any hard resin can be given a certain degree of elastomeric quality by increasing the mobility of the polymer molecules and, at the same time by reducing its glass transition temperature. There are several methods by which this can be accomplished:

1. A polymethacrylate which is plastic at room temperature can be selected. There are such resins available.
2. A stable inhibitor could be added to the monomer-polymer dough which might limit the polymer chain length, and thus provide a soft resin. Such a method has not proven satisfactory, however, because the inhibitors are prone to oxidize in the mouth over a period of time and the resin slowly hardens by further polymerization.
3. A soft copolymer acrylic resin can be formed. A copolymer of ethyl methacrylate is one of the popular ones. Theoretically, such resins should be stable in the mouth and provide one of the better liners.
4. Almost any resin can be rendered elastomeric to a degree by plasticizing it with a solvent of

some type. It can only be used temporarily as a soft lining material because the solvent either leaches out or gradually evaporates and the resin hardens.

Acrylic resin liners are usually supplied in the form of monomer and polymer powder. The resin may be cured under heat and pressure or may be of the auto-curing type which can be polymerized at room temperature.

Due to the fact that the monomers employed are solvents for the denture base resin, a reasonably good bond of the liner to the denture base can be expected. Such solvents, however, may reduce the transverse strength of the denture base resin by diffusion from the liner to the denture base[26].

A hydrophilic gel polymer, poly-hydroxy-ethyl-methacrylate that utilizes water as a plasticizer is also available[27]. The material is hard and resembles regular polymethyl methacrylate when dry. In a moist atmosphere, it takes up water and changes to a soft pliable polymer. An important consideration is that there is no limit to the amount of water uptake. Thus, dimensional change is likely to occur and affect the fit of the denture.
Stresses developed from such dimensional change may also result in weakening the bond between the soft liner and the underlying acrylic base.

Silicone rubber materials are basically formed from some type of organopolysiloxane polymer chain, which, when

activated, further polymerizes by cross-linking with adjacent chains to form synthetic rubber. It is a material commonly used in industry and has found extensive application in medicine and dentistry. Either the heat-cured or R.T.V. (Room Temperature Vulcanizing) variety is used for soft denture liners. Ordinarily, the silicone gum and a liquid reactor such as tin octoate, are mixed together, packed in the mold and cured. Recently, a material containing the silicone and reactor together in one tube has been developed The reactor in this case is said to be acetic acid, which is incorporated directly in the silicone gum in an unhydrous form. When the material is squeezed from the tube, the acid becomes hydrated and immediately activates the curing process.

With early techniques, the liner and denture-base were cured separately and cemented together with a special adhesive. The main objection to this method is the poor bond which may exist between the denture-base and the liner. A direct method whereby the liner was cured directly to the acrylic denture base was developed later. A primer was required to enhance the bond between the two materials.

The silicone liners are the most nearly elastic of any of the soft liners. Within one minute after compression, they can recover approximately 85% of their original dimensions[26]. Their resistance to abrasion is so poor that they cannot be polished or trimmed without producing a roughened surface.

Wetting and Contact Angle. It is very difficult to force two solid surfaces to adhere. Regardless of how smooth their surfaces may appear, they are likely to be rough when considered on atomic or molecular scale. Consequently, when they are placed in apposition, only the high spots are in contact (Fig. 1A). Since these areas usually constitute only a small perecentage of the total surface, no perceptible adhesion takes place[28][29].

One method of overcoming this difficulty is to use fluids which will flow into the irregularities and thus provide contact over a great part of the surface of the solid (Fig. 1B). The new situation is created due to the attraction between the fluid molecule and the solid surface on each side, and the internal attraction forces between the fluid molecules. To produce adhesion in this manner, the fluid must flow easily over the surface and adhere to the solid. This characteristic is referred to as wetting. If the liquid adhesive does not wet the surface of the solid adherent because of its low surface energy, the adhesion between the liquid and the solid will be negligible. If there is true wetting of the surface, adhesion will occur.

The ability of a fluid to wet the surface of a solid is mainly related to the surface energy of the solid. In the case of substances having low surface energy, few if any liquids will wet their surfaces. Also, the surface tension and viscosity of the fluid play a less effective role, because of

the bond strength in liquids compared to solids. Consequently, a given solid surface will not be wetted with all liquids to the same degree. Other factors as temperature of the environment, molecular size of the liquid, or surface contaminants of the solid, may affect or prevent wetting.

The extent to which the liquid will wet the surface of the solid is generally determined by measuring the contact angle between the liquid and the solid at their interface(θ). Such an interface is physically a triple boundary line resulting from the forces of attraction between the solid and liquid (SL), the solid and vapour (SV), and the liquid and vapour (LV) (Fig. 2). If the molecules of the liquid are attracted to the molecules of the solid as much or more than they are to themselves and to the vapour around them, the liquid adhesive will spread completely over the surface of the solid and no appreciable angle will be formed (Fig. 3A). However, if the energy of the solid surfaces is less than the other attractive forces, or the surface is contaminated, a medium angle may be obtained (Fig. 3B). A very high angle would result on a solid of low surface energy (Fig. 3C). Resin polymers are considered low surface energy solids.

Either the advancing (θ_A) or receding contact angle (θ_R) may be measured, or both. The advancing angle is that observed when a liquid boundary advances over a clean, dry, solid surface. The receding angle is that observed when the liquid boundary recedes from a previously wetted surface.

Figure 1. The adhesion of two solid surfaces
A. Without adhesive
B. With adhesive
a,b) solid surfaces
c) adhesive

Figure 2. The analysis of forces acting at a solid-liquid interface
LV Liquid-Vapour
SV Solid-Vapour
SL Solid-liquid

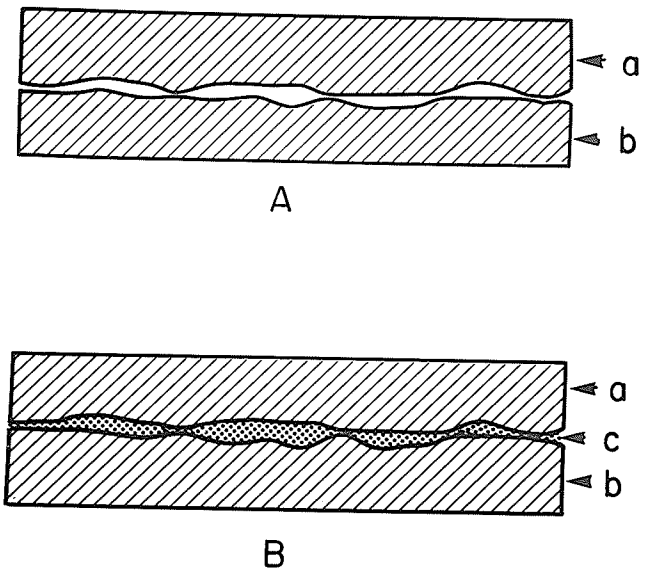


Fig. 1

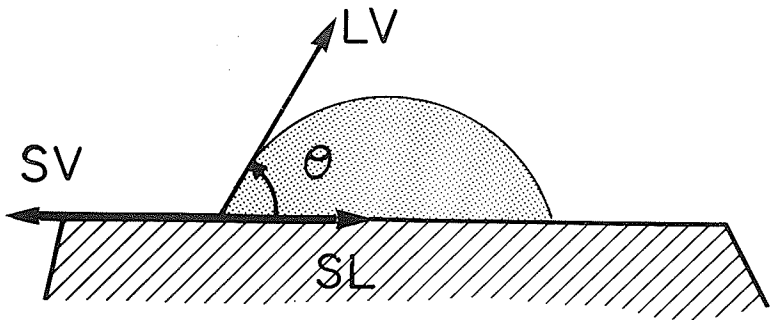
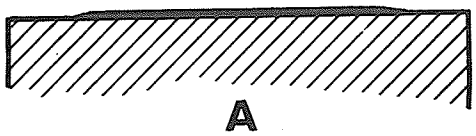


Fig. 2

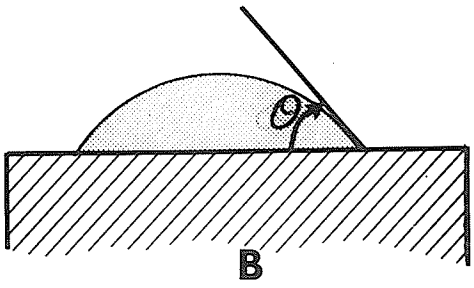
Figure 3. The contact angle

A - zero or spreading
B - low contact angle
C - high contact angle



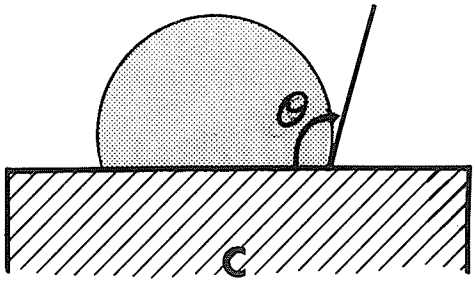
A

$\theta = 0$ SPREADING



B

$\theta = 45°$ LOW CONTACT ANGLE



C

$\theta = 100°$ HIGH CONTACT ANGLE

Fig. 3

The phenomenon of a difference between θ_A and θ_R is known as contact angle hysteresis. It is due to the liquid filling in the pores of the solid, and is mainly dependent on the particle size of the liquid and the intermolecular pore size of the solid [31].

It follows, then, that the smaller the contact angle formed by a drop of liquid on a solid surface, the more wettable will be the solid surface and the better will be its adhesion to another solid surface through a liquid.

II. Selection of Materials

Five commercially available soft liners were used in the present study. They were selected to represent different types of soft liners commonly available to dental laboratories for application to denture bases.

The materials investigated are listed in Table I according to type, physical form and manufacturer.

The first three materials are acrylic resin polymers or copolymers supplied as poweder and liquid (Fig. 4). "Palasiv 62" is a heat-curing acrylic, cured by heating to 70°C. in 30 minutes, maintaining it at that temperature for another 30 minutes, then heating it to boiling in 15 minutes and maintaining it at that temperature for 60 minutes. "Soft Orly" and "Flexacryl-Soft" are cold curing materials. Proportioning measures were supplied with each material. The last two materials are silicone rubber polymers (Fig. 5). "Molloplast-b" is a heat-curing material supplied in dough form, cured by heating to 70°C. in 30 minutes, maintaining it at this temperature for 30 minutes, then heating it to boiling in 30 minutes and maintaining it at that temperature for 2 hours. "Mollosil" is a room-temperature-curing silicone, supplied as paste in a tube along with a dropper bottle containing the liquid reactor

The exact chemical composition of each material as to type of polymer, activator, plasticizer or solvent used could not be obtained from the information supplied in the material

TABLE I

Materials Used in this Study

MATERIAL	TYPE	FORM	MANUFACTURER
1. Palasiv 62	Heat Cyring Acrylic	Powder and liquid	Kulzer & Co., Germany
2. Soft Oryl	Cold Curing Acrylic	Powder and liquid	William Getz Dental Products, U.S.A.
3. Flexacryl-Soft	Cold Curing Acrylic	Powder and liquid	Lang Dental Manufacturing Co., U.S.A.
4. Molloplast-b	Heat Curing Silicone	Paste	Kostner & Co., Germany
5. Mollosil	Cold Curing Silicone	Paste and liquid	Kostner & Co., Germany

Figure 4. The acrylic soft-liners used in the study.

Figure 5. The silicone soft-liners used in the study.

Fig. 4

Fig. 5

packages.

The natural rubber and vinyl groups were not represented in this study. All the natural rubber materials have completely disappeared from the market and there is much less interest in polyvinyl materials as compared to the acrylic and silicone rubber materials at the present time.

"Autocure"* was the self-curing acrylic denture-base material used in fabricating the hard base layer in all the test specimens for different soft liners.

Each material used in the present investigation was drawn from a single batch to avoid possible minor changes in the composition. All materials were processed according to the manufacturer's directions.

---

* The L.D. Caulk Co. Milford, Del.

III. Preparation of the Specimen

The specimens used in the present investigation (Fig. 6) were circular, 50 mm. in diameter and 4 mm. thick. Two mm. of thickness consisted of the hard acrylic base and the top 2 mm. was the soft liner (Fig. 7).

A special metal mold was designed for specimen fabrication. The mold, shown in Figure 8, consisted of 3 parts, a base, an intermediate part and a 2-way top, When the mold was assembled in the fashion shown in Figure 9 , the mold cavity was 2 mm. high. The hard base material was packed into this cavity. When the mold was assembled in the fasion shown in Figure 10, the mold cavity was 4 mm. high and provided the additional 2 mm. space for packing the soft liner on top of the hard base. A vent was milled in the intermediate part to allow for the escape of excess material during packing. Threaded holes were made on the top and the base into which bolts could be driven to facilitate opening the mold after curing the specimen. The bolt, when driven, pushes against a rim in the intermediate part, causing the separation of the parts of the mold. Separating medium between the soft lining material and the top was required only with 2 materials. Aluminum foil 0.02 mm. thick was used. Tinfoil was tried as a separating medium, but did not separate easily from the specimen surface.

Before packing the hard base of the specimen, the mold was thoroughly cleaned and assembled to a 2 mm. cavity space. The cold curing acrylic was mixed in a glass jar using a

Figure 6. The specimen
a - top view
b - side view

Figure 7. The specimen
a - soft liner
b - hard base

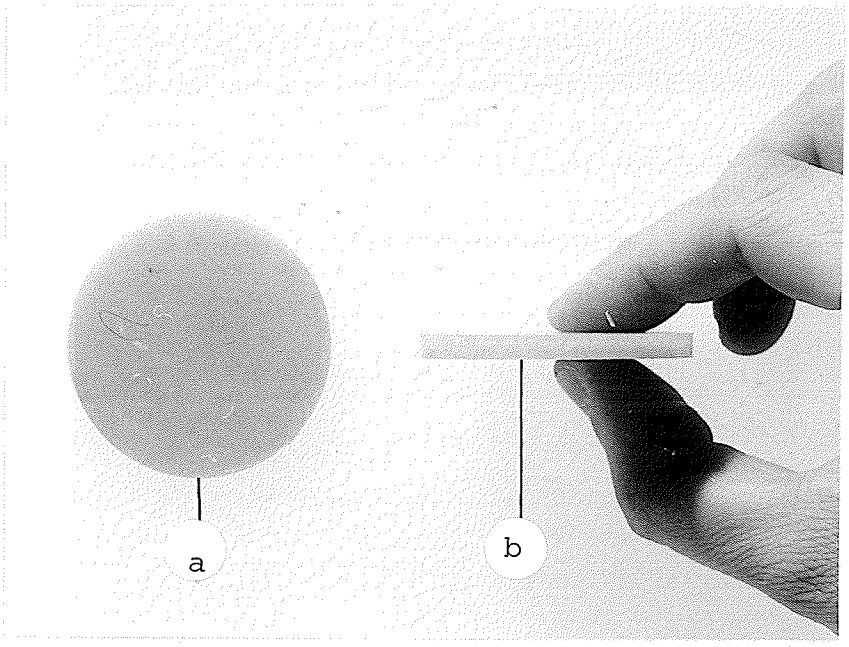


Fig. 6

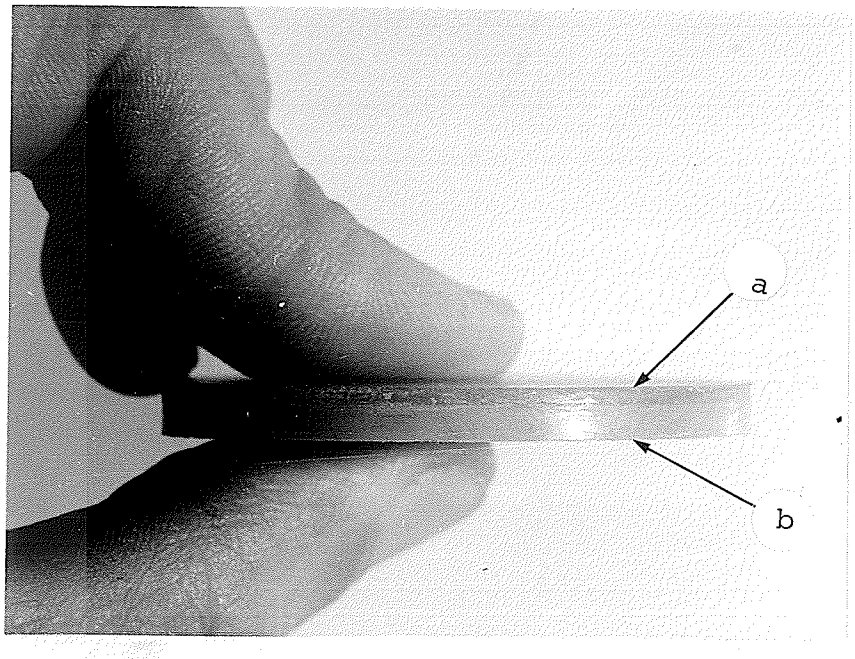


Fig. 7

Figure 8. The specimen mold (disassembled)

a - base
b - intermediate part
c - top
d - milled escape for excess material
e - threaded holes to help specimen deflasking by using a bolt.

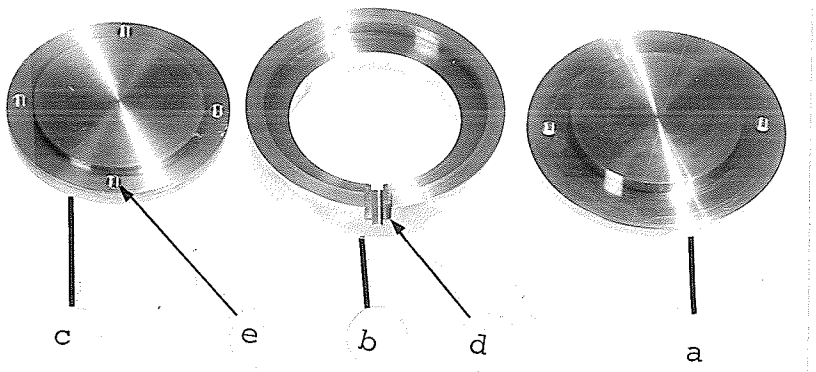
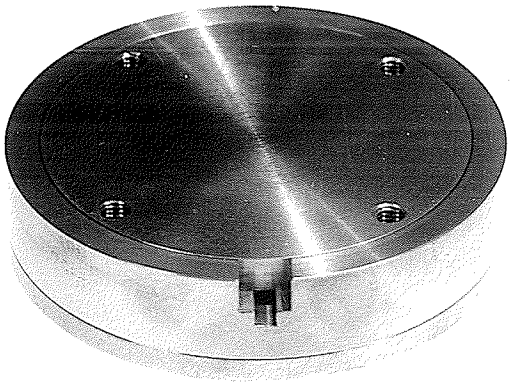


Fig. 8

Figure 9. A. Assembling the mold to provide 2 mm. high packing space.

B. The mold assembled.

A.

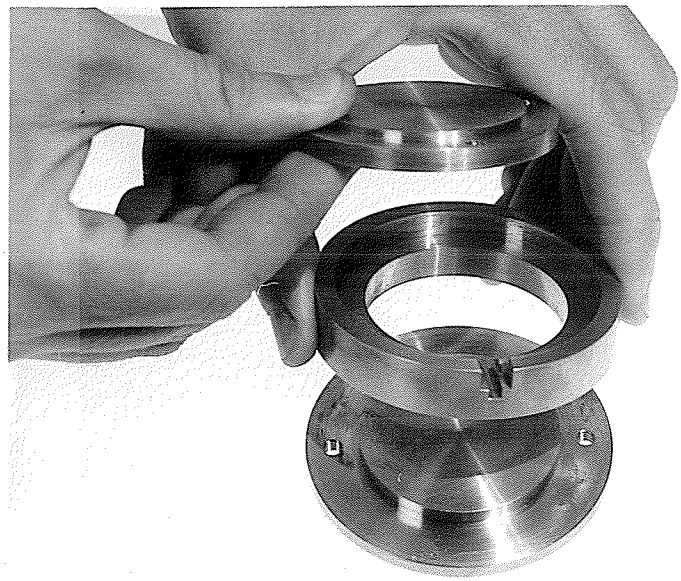


B.

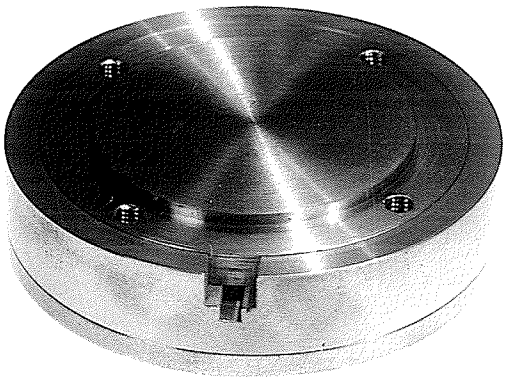
Fig. 9

Figure 10. A. Assembling the mold to provide 4 mm. high packing space.

B. The mold assembled.



A.



B.

Fig. 10

liquid/powder ratio of 1:2 by volume. When the dough stage was reached, the acrylic was packed. Trial closure was made using a polyethylene sheet as a separating medium. A thin aluminum ring, 0.5 mm. thick, was used as a spacer between the top and the rim of the intermediate part to allow for slight overpacking. This helped to maintain pressure to compensate for the polymerization shrinkage. The mold was assembled and closed under pressure. After 2 minutes the mold was opened, the polyethylene sheet and the aluminum spacer removed, deficiencies filled in or flash removed. The mold was finally closed under pressure in a spring clamp.

It was found practical and convenient to run each five specimens together each time (Fig. 11). The molds in the spring clamp were left under pressure for 2 hours during bench curing. After curing the mold was opened and any existing flash trimmed.

Various soft-liners were prepared according to manufacturer's directions. The mold was assembled so that a 4 mm. mold space was formed. With the hard resin base in the mold, the soft resin was packed over this again using the same method described for packing the hard acrylic base. The cold curing soft-liners were allowed to bench cure for 2 hours, whereas the heat cured materials were cured according to the curing cycle suggested by the manufacturer and left to cool slowly overnight.

Six sets, each containing five specimens, were prepared from each soft-liner used in this study. The specimens were

Figure 11. The set of molds in the spring clamps ready for processing.

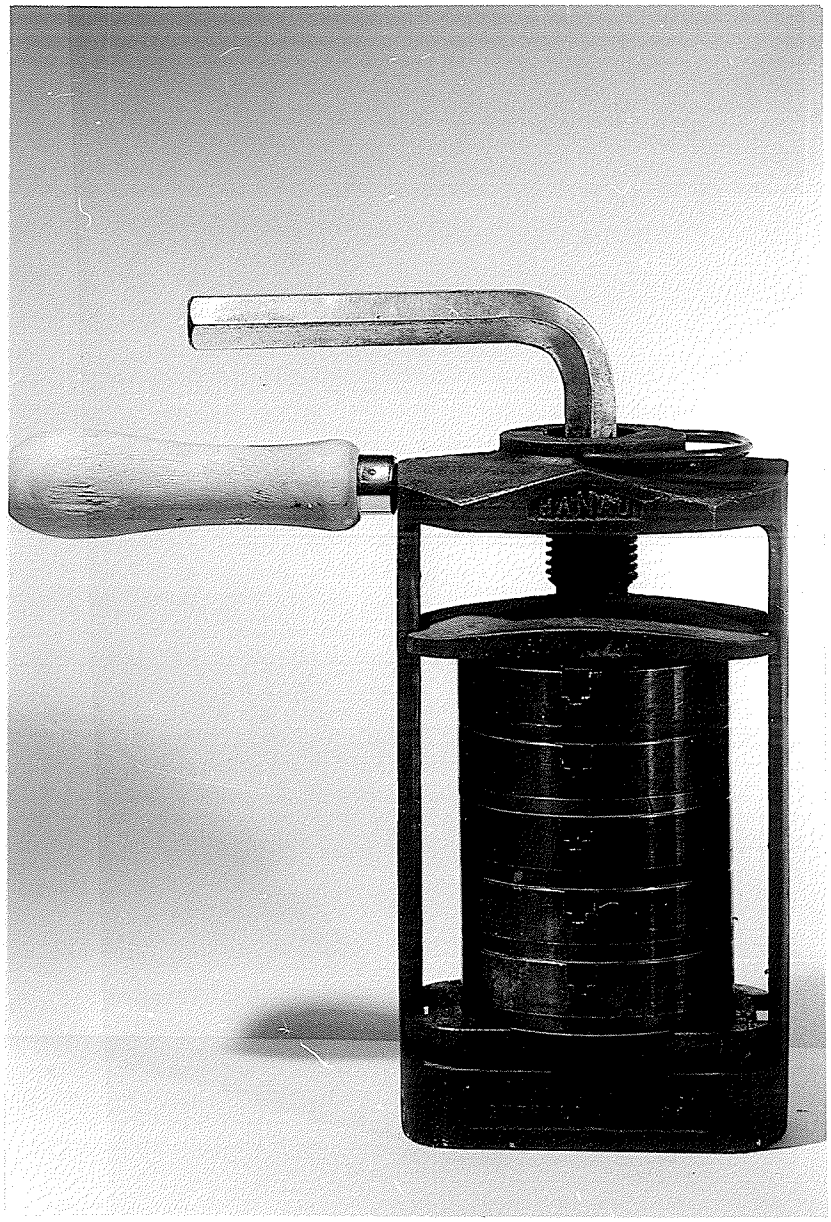


Fig. 11

identified by letters and figures. The letter referred to the type of material and the figures referred serially to the set. The prepared specimens were stored in 100% humidity and $37^{o}C$. till they were withdrawn for the experiment.

IV. Methods of Surface Treatment

The "Durabond Process"* is a method of depositing a microlayer of silica on the polymer surface rendering it more wettable.[20][24] The "paint-on" technique kit was used in the present study. The kit consisted of 3 bottles (Fig. 12) labelled, 1-primer, 2-base, and3-silica. According to the manufacturer's directions the three solutions were painted according to the labelled sequence immediately one after the other. After the third solution was applied, a curing period of 15 minutes was allowed. Contamination of the specimen surface was avoided by using vinyl medical gloves during the handling of the specimens.

The "Vacuum discharge Treatment" is a process in which the polymer surface is altered "in situ" to provide a layer containing hydrophilic chemical groups bonded to it. These hydrophilic groups result in a better spreading of water on the polymer surface. An apparatus was described by Gesser, Warriner and Funt[23] in which water was used to generate free hydroxyl radicals at a pressure of about 1 mm. Hg., at about 3,000 Volts A.C. A high-vacuum fast-flow pump (140 liters per minute) was used to remove the discharge products as quickly as possible. The free radicals formed in the discharge tube can readily abstract a hydrogen atom from the polymer surface group, thus forming surface bonded-free radicals. These free radicals are able to combine with other

---

* The Durallium Co., Chicago Ill. U.S.A.

Figure 12. The Durabond Kit

Fig. 12

free radicals present in the gas discharge system, resulting in the formation of hydrophilic polar surface groups.

However, this treatment proved to be of a rather temporary nature because of the molecular exchange between the treated surface layer and deeper layers. A chemical procedure known as CASING (Cross-linking by Activated Species of INert Gases) was described by Schonhorn and Hansen[31] to produce more stable cross-linked polymer surface layers. A combination of both procedures was suggested by Gasser and Long[32] to provide "knitting-in" of the hydroxyl groups. A mixture of 95% helium and 5% hydrogen was used for CASING before the free OH radicals were reacted with the surface. The term "CASING-hydroxyl treatment" was adopted for this treatment.

The apparatus used (Fig. 13) was similar to that described by Gesser and Castaldi[24], except that a mercury manometer and a controlled leak for supplying the helium-hydrogen mixture for CASING were added. A clean dry specimen was placed on a tripod glass stage, in the removable bottom part of the galss discharge tube just out of the path of the discharge glow. The helium-hydrogen mixture is allowed to enter the discharge tube for five minutes during which the electric discharge was run intermittently. Another five minutes were allowed for the water vapour to enter the tube with one minute in between to allow the pump to remove the gases from the discharge tube. This gave the optimum effect without overheating the specimen surface.

Figure 13. The vacuum discharge tube.

A - water reservoir
B - gas leak
C - flow meter
D - electrode tubes
E - electrodes
F - return trap
G - line to vacuum
H - variac
J - power line
K - high voltage transformer
L - specimen on glass tripod

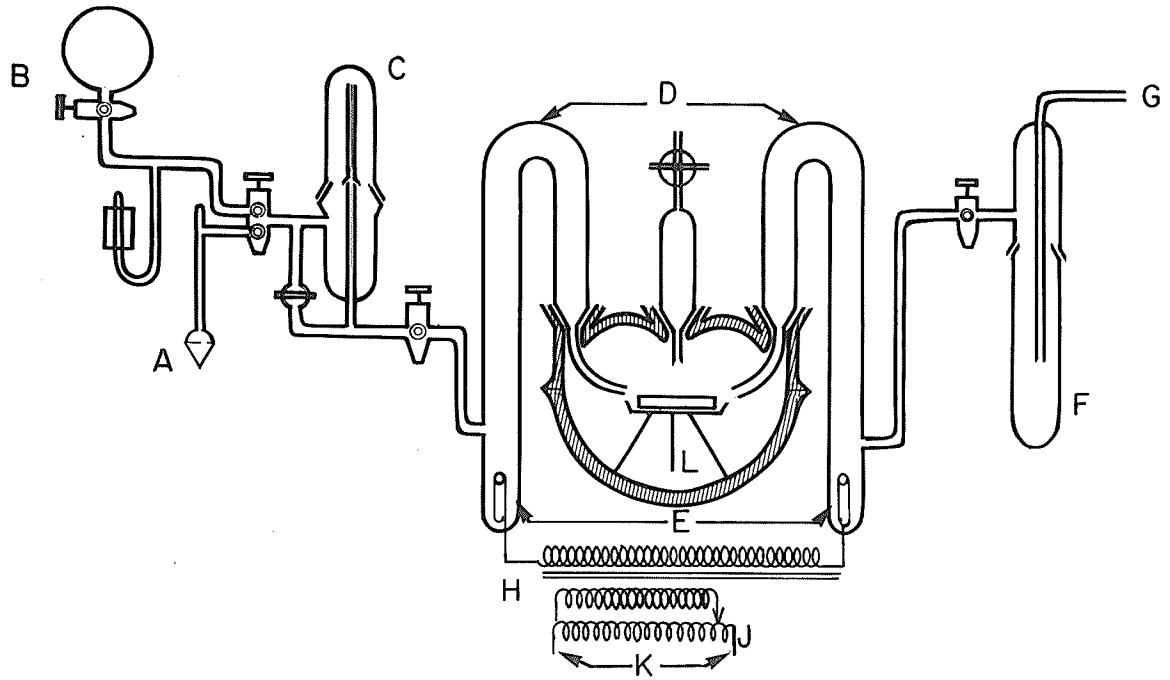


Fig. 13

Other methods of surface treatment were attempted but were not found desirable for application in this study, because either they had an insignificant effect on the contact angle or the procedure was too complicated for practical application to denture treatment.

V. Selection of the Physical Tests

Contact angle determination is the only criterion used to indicate wettability of a solid surface. Distilled water is generally accepted as the liquid to be used to wet the surface for measurement purposes, unless a specific liquid is required for a certain test. In this study, distilled water was used as a standard.

Of the many physical tests on soft-liners performed by various investigators, two tests were selected for this study, namely softness and water absorption. These tests were selected because of the possible relationship of these two properties to the surface treatments that the materials received and their direct effect on the properties necessary for a successful soft-lined prosthesis in the oral environment.

VI. Measurements and Experiment Procedure

Contact angle: A contact angle analyzer* (Fig. 14) was used in this study. The apparatus consists of an internal projector with wide angle optics, a liquid drop dispenser, a movable stage for mounting specimens and a cooling system. The movable stage was originally designed by the manufacturer to carry a 10 mm. wide strip-like specimen. This was modified to a wider stage to carry a specimen with the dimensions selected for this study. The sample was carried on the movable stage under the liquid drop dispenser (approximate drop size : 1 microliter). Drops of the wetting liquid can be placed on or withdrawn from the specimen surface. An image of the drop in contact with the surface is projected on a frosted screen. The contact angle is determined by means of a protractor read-out on the top of the unit. The drop image was visible at about 40X magnification (Fig. 15).

The advancing contact angle θ_A was measured by the drop build-up technique[33]. The contact angle obtained with 3, 4, and 5 drops building up on the surface were recorded and the average of the three readings was calculated. The receding contact angle θ_R can be obtained by one of two methods, either by allowing the liquid to evaporate from the surface or by withdrawing the liquid. The latter method was used in the present study because of the better control on the drop size and less time consumed compared to the evaporation technique.

*Visco-Tec Inc., Downingtown, Pa., U.S.A.

Figure 14. The contact angle analyzer.

a - liquid drop dispenser
b - movable stage for specimen mounting
c - specimen carried on the stage
d - protractor read-out

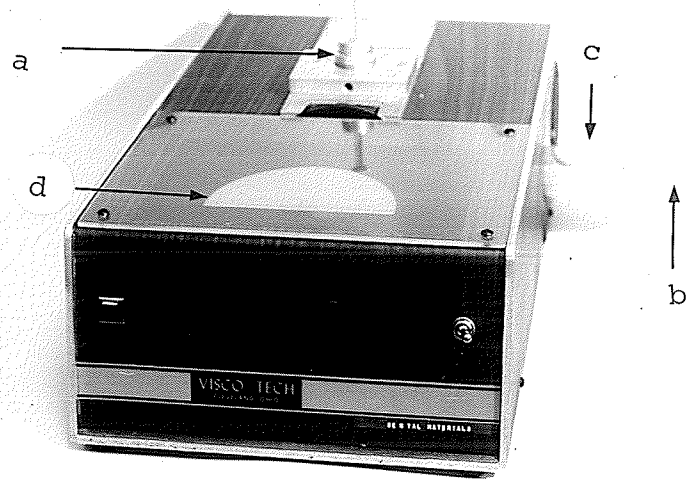
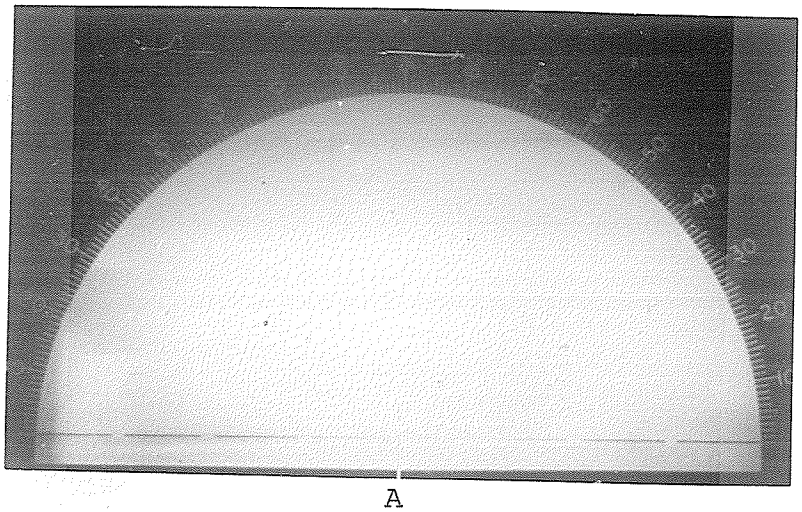


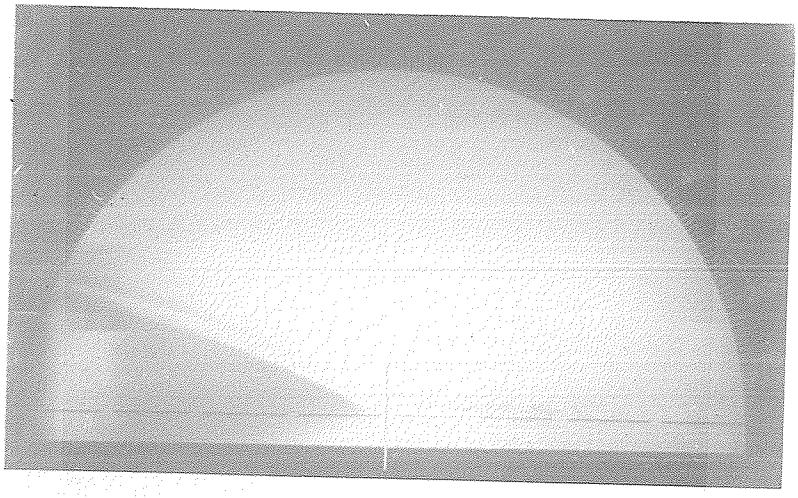
Fig. 14

Figure 15. The contact angle as shown on the protractor read-out.

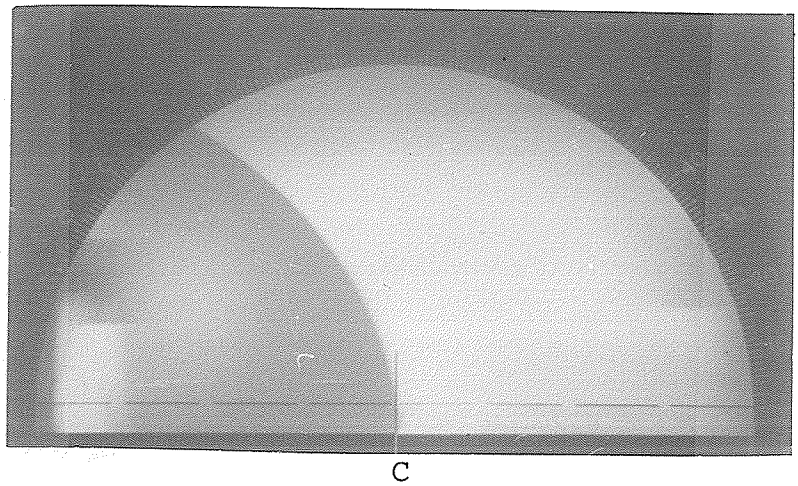
A - spreading
B - low contact angle
C - high contact angle



A



B



C

Fig. 15

Three drops of the liquid were withdrawn from the surface, one at a time. The contact angle was recorded after each withdrawal. The average of the three readings was taken as the receding contact angle.

Providing controlled atmosphere of temperature, pressure and composition of environmental gases[34][35] was found to be a very complicated and difficult procedure to apply in this study and was omitted for the sake of simplicity.

The regular hardness tests used for testing materials in dentistry, namely, Knoop, Brinell, Rockwell and Vickers, could not be applied for testing soft liners because of their rapid recoil after indentation. Tests used in the rubber industry, such as the "British Standards Test 903"* used by Lammie and Storer[9] and the Shore A Durometer used by Travaglini, Gibbons and Craig[13] are commonly used in soft liners research. An instrument, designed on the basis of both theories, was built for this study.

This test consisted of measuring the depth of penetration of a steel ball 2 mm. in diameter into the soft material surface under an initial small load and a final large load. A dial micrometer fitted to the instrument was used to give direct readings. The greater the penetration of the ball, the higher is the reading.

The instrument is shown in Figure 16. It consists of a steel ball soldered to the end of a mandril which fits the

* I.S.O./R 48

Figure 16. The instrument used to compare softness.

a) the steel ball
b) dial micrometer
c) steel rod
d) top stage
e) 500 gm. weight
f) flat base
g) stop watch

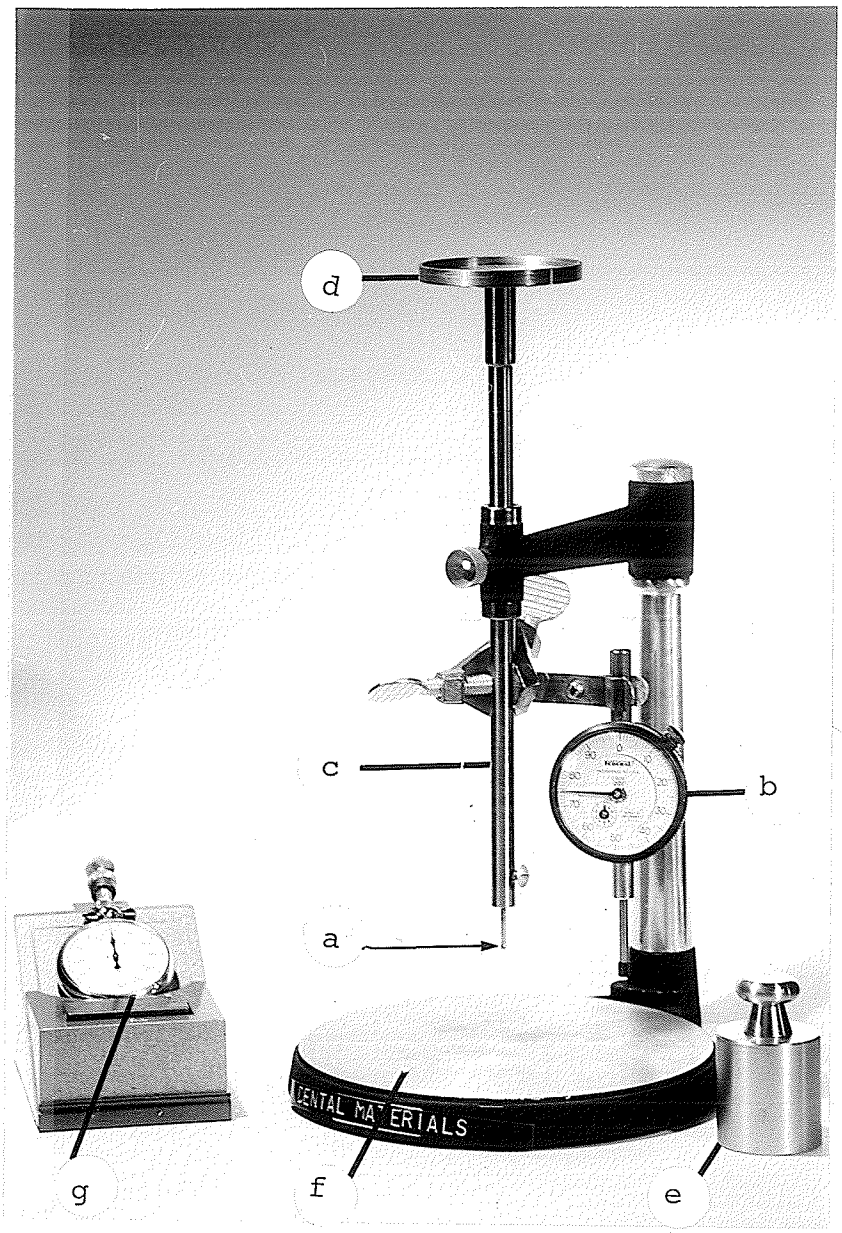


Fig. 16

lower end of a vertical arm. The vertical arm was machined to fit in the spindle bearing on a "Ney Surveyor"* cross arm. The top of the vertical arm is made in the form of a stage to carry the final large load (500 gm.). The dial micrometer is attached to the arm through a wing clamp. The surveyor base served as a smooth flat surface for specimen placing. The arm dial combination weighed 500 grams and was considered the initial small load. The arm moves freely in the vertical and can be locked in any position by a screw.

The zero adjustment was set individually for each specimen (Fig. 17) by lowering the steel ball on the hard surface of the specimen when it was placed on the base. The arm was then lifted, the specimen was turned soft-side up and the ball was lowered and allowed to settle on the specimen surface for a controlled period of time.

The reading under the initial load was determined by taking the average of at least three readings at different, widely separated spots on the specimen surface (Fig. 18). The same procedure was repeated for the final load of 500 gm. on the top stage of the vertical arm (Fig. 19). The suitable time was found to be 30 seconds for the acrylic materials and 15 seconds for the silicone materials. The time-penetration curve is shown in Figure 20.

Water absorption was determined by weight changes of the

* The J.M. Ney Co. Bloomfield, Conn., U.S.A.

Figure 17. The zero adjustment

a) sample hard side up
b) dial adjusted to zero

Figure 18. Reading under initial small weight

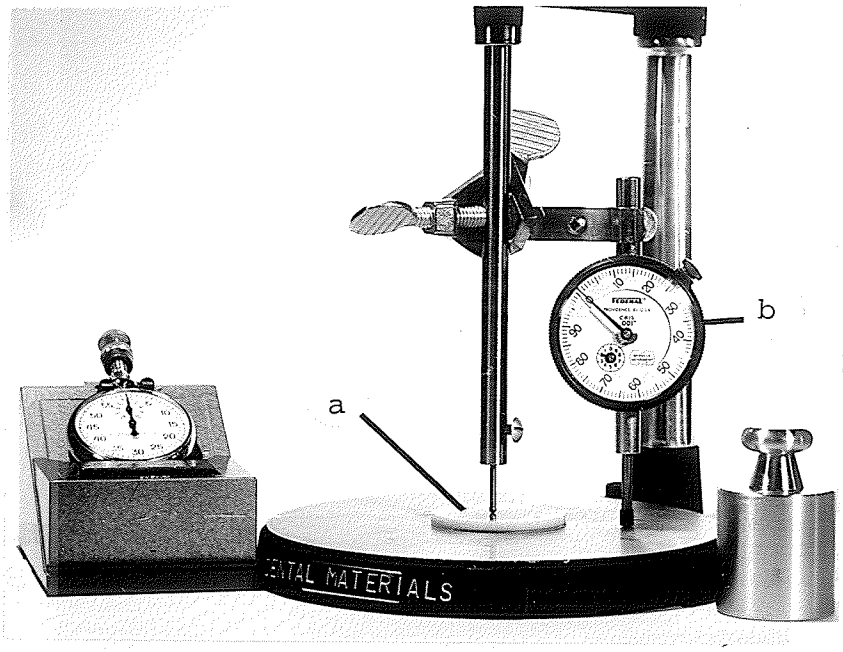


Fig. 17

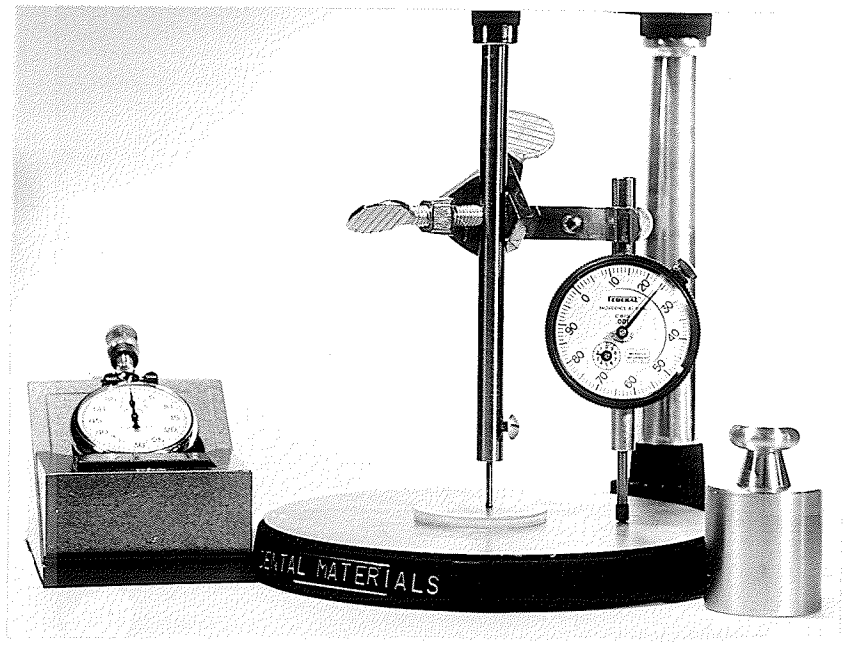


Fig. 18

Figure 19. Reading under final high weight

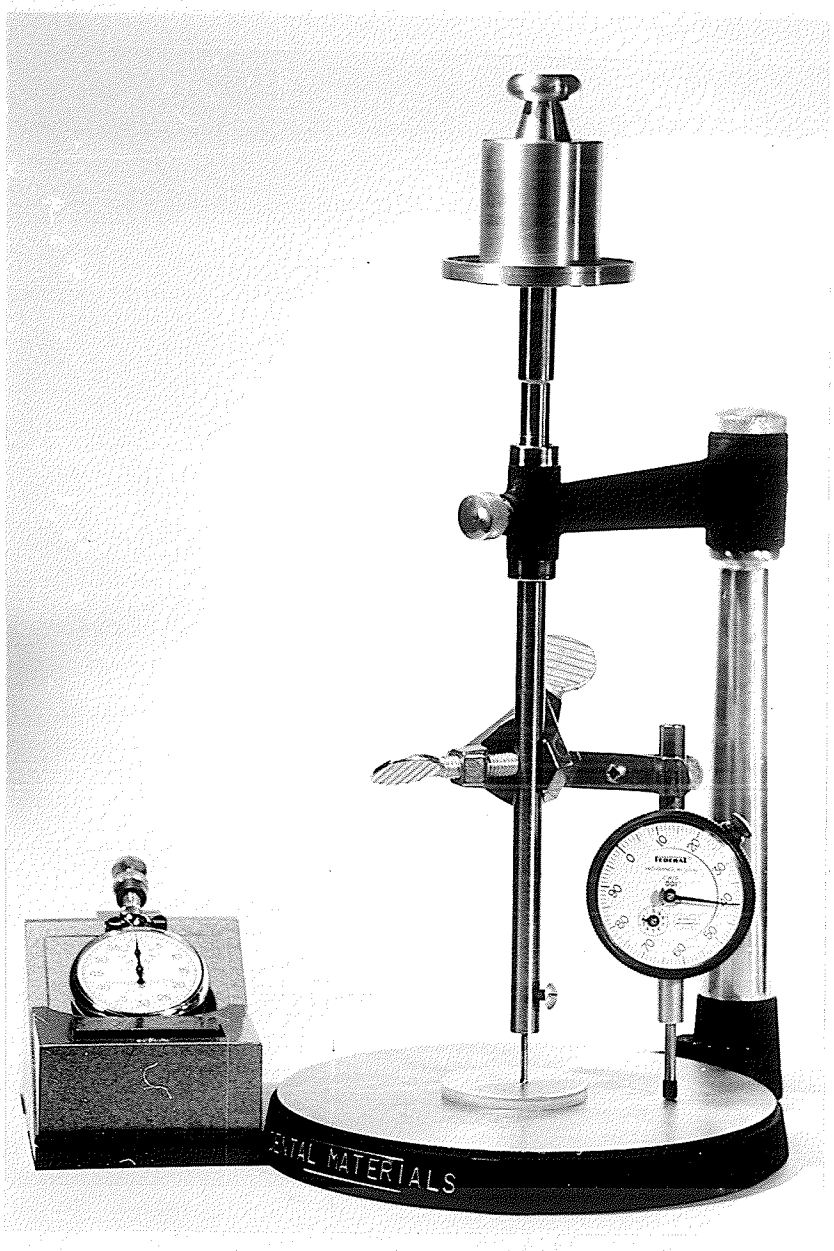


Fig. 19

Figure 20. Time-penetration curve.

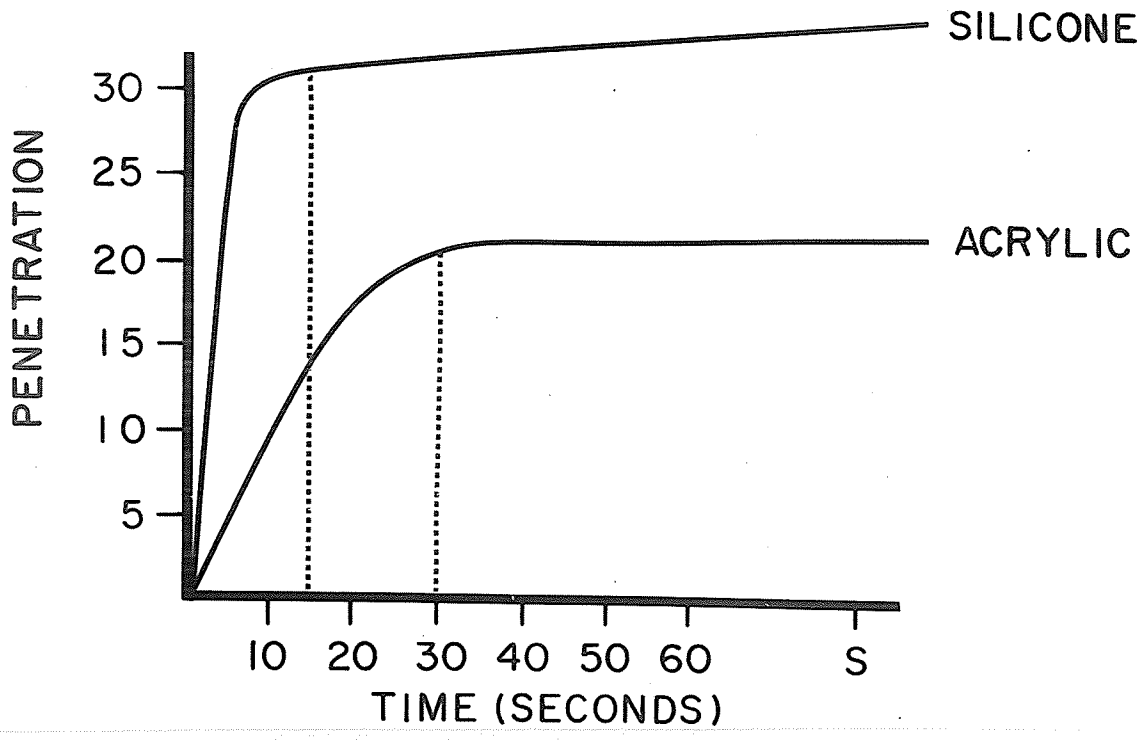

SILICONE
ACRYLIC
PENETRATION
30
25
20
15
10
5
10
20
30
40
50
60
S
TIME (SECONDS)

Fig. 20

specimens in both storage media, namely air and water. A digital analytical balance* was used for weight determination. The weight was recorded in grams to the fourth decimal place.

Ninety specimens were used in the present study. The specimens had been stored in 100% humidity and 37°C. immediately after processing until they were drawn for the experiments. This was to minimize the leaching out of any of the constituents of the soft liners. Each of the 6 specimens for every treatment were drawn from a different processing set, so that any variations in results arising from differences in processing sets would be distributed evenly amongst the 3 treatments. The specimens selected in this manner are known statistically as "brothers".

Each specimen was cleaned in a "Geos"* ultrasonic cleaner, automatically timed for 4 minutes. The contact angle was measured and softness and weight were determined. This was considered in the results as "time 1". After surface treatment, the specimens were again measured for contact angle, softness, and weight. This was considered as "time 2". The specimens were divided after treatment into 2 equal groups. The first group was stored in air at room temperature. Covered glass jars were used for storage (Fig. 21) to protect the specimens from environmental contaminants. The second group of samples was stored in distilled water at 37°C. to simulate mouth conditions. Since no single "in vitro" test can duplicate

---

* Sartorious Model 2400 Sartorious-Werke GMBH Deutschland
* Geoscience Instruments Corporation, Mount Vernon, N.Y., U.S.A.

Figure 21. Storage of samples in a covered glass jar.

Fig. 21

mouth conditions, immersion in distilled water is generally accepted as a standard laboratory test method.

The process of measuring contact angle, softness and weight was repeated after 24 hours, 1,2,3, and 4 weeks and referred to as "time 3,4,5,6, and 7" respectively. The results were analyzed statistically by an "analysis of variance for mixed design" as described by Becker and Chebib[36].

The program was designed as a 4-factor factorial experiment. The factors were:

1. Material, at 5 levels: Palasiv 62, Soft Oryl, Flexacry-soft, Molloplast-b, and Mollosil
2. Storage, at 2 levels: water, and air
3. Treatment, at 3 levels: Durabond, CASING-Hydroxyl, and Control
4. Time, at 7 levels: Before treatment, immediately after treatment, 24 hours, one week, 2 weeks, 3 weeks and 4 weeks after treatment.

The three variables, contact angle, softness and weight were separately analyzed.

RESULTS

Contact Angle

The interaction of the factors with the analysis of variance have shown that the effect of all the factors involved in the experiment were significant ($P<0.01$) as shown in Table II.

The mean values for all combinations of materials, storage media and time is shown by a bar graph in Fig. 22, advancing and receding angles are shown by separate bars. The effect of different treatments considered with each material separately, for combined storage media, is shown in the bar graph in Fig. 23. The bars show the average of the advancing and receding contact angle.

The effect of storage media on different treatements regardless of the type of material is shown by a bar graph in Fig. 24. The changes in the contact angle at different times for the different treatments are shown as continuous curves in Figs. 25 to 27. The first curve shows the average of the 2 storage media while the last 2 curves show the changes in water and air storage.

The effect of different treatments on contact angles hysteresis is shown in Table III. Each figures is the mean value of 210 ovservations made for all specimens of each material at the different times.

A greater decrease in the contact angle was observed with the CASING-Hydroxyl treatment as compared to the Durabond treatment group. Separate materials showed the same trend with one exception,(Soft-Oryl),which responded more to the

TABLE II

Analysis of Variance - Contact Angle

SOURCE OF VARIATION	DF	MS	F	
MAT	4	13592.3828	171.515	**
STR	1	64871.5195	818.578	**
MAT STR	4	1389.2969	17.531	**
ERROR 1	20	79.2491		
TIM	6	6658.0547	334.790	**
MAT TIM	24	593.7205	29.854	**
STR TIM	6	4864.6836	244.613	**
MAT STR TIM	24	217.3o44	10.927	**
ERROR 2	120	19.8873		
ROC	2	20407.8164	805.520	**
MAT ROC	8	2193.1641	86.567	**
STR ROC	2	4667.6602	184.238	**
MAT STR ROC	8	349.5149	13.796	**
ERROR 3	40	25.3350		
TIM ROC	12	8993.4297	423.765	**
MAT TIM ROC	48	561.3423	26.450	**
STR TIM ROC	12	505.6624	23.827	**
MAT STR TIM ROC	48	154.1610	7.264	**
ERROR 4	240	21.2227		
ROC AVR	2	178.0664	32.138	**
MAT ROC AVR	8	95.4478	17.227	**
STR ROC AVR	2	34.4238	6.213	**
MAT STR ROC AVR	8	18.2945	3.302	*
ERROR 7	40	5.5406		
TOTAL	1259			

DF = Degrees of freedom
MS = Means sqare
F = F Value
MAT = Material
STR = Storage
TIM = Time
ROC = Treatment
* = Significant(P<.05)
** = Significant(P<.01)
AVR = Advncing V. Receding Θ

Figure 22. The effect of different treatments on the average contact angle of all combinations of materials and storage media.

Figure 23. The effect of different treatments on different materials for combined storage media.

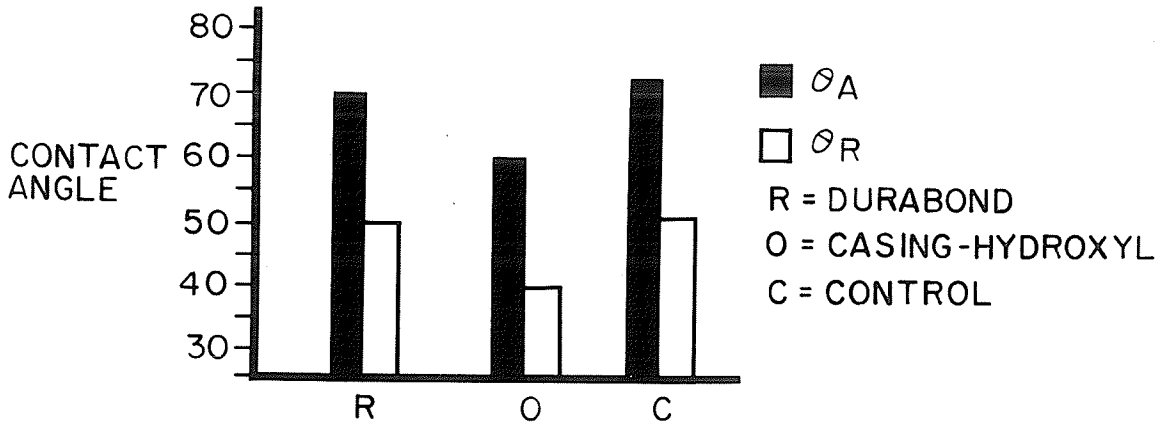

80
70
CONTACT 60
ANGLE
50
40
30
R
O
C
θA
θR
R = DURABOND
O = CASING-HYDROXYL
C = CONTROL

Fig. 22

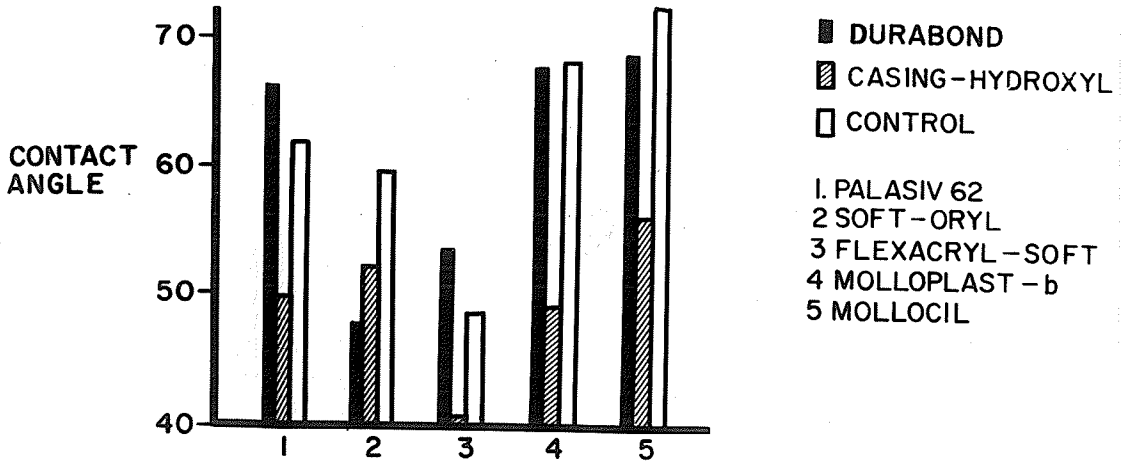

70
CONTACT
ANGLE
60
50
40
1
2
3
4
5
DURABOND
CASING-HYDROXYL
CONTROL
1. PALASIV 62
2 SOFT-ORYL
3 FLEXACRYL-SOFT
4 MOLLOPLAST-b
5 MOLLOCIL

Fig. 23

Figure 24. The effect of storage media on the average contact angle for different treatments.

Figure 25. The effect of different treatments on the contact angle at different times. Average of all materials in both storage media.

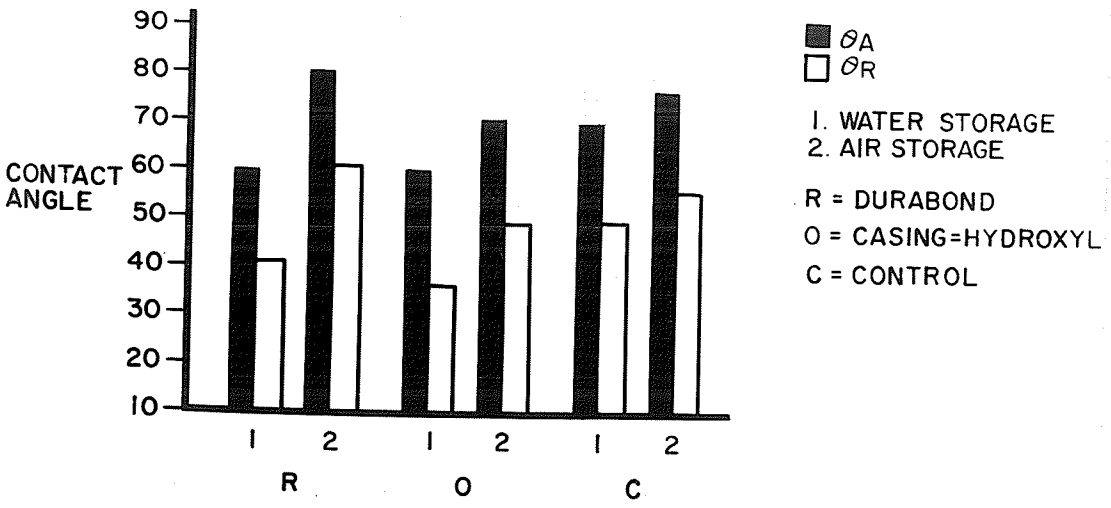

CONTACT ANGLE
90
80
70
60
50
40
30
20
10
1 2 1 2 1 2
R O C
θA
θR
1. WATER STORAGE
2. AIR STORAGE
R = DURABOND
O = CASING=HYDROXYL
C = CONTROL

Fig. 24

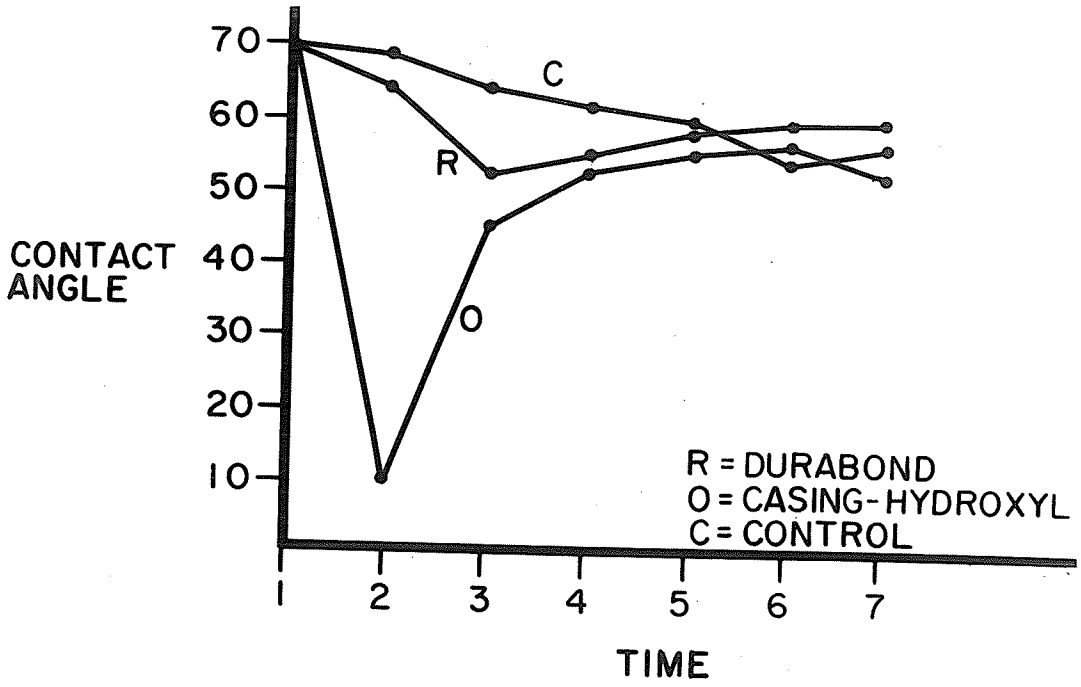

CONTACT ANGLE
70
60
50
40
30
20
10
C
R
O
R = DURABOND
O = CASING-HYDROXYL
C = CONTROL
1 2 3 4 5 6 7
TIME

Fig. 25

Figure 26. The effect of different treatments on the contact angle at different times. Average of all materials stored in water.

Figure 27. The effect of different treatments on the contact angle at different times. Average of all materials stored in air.

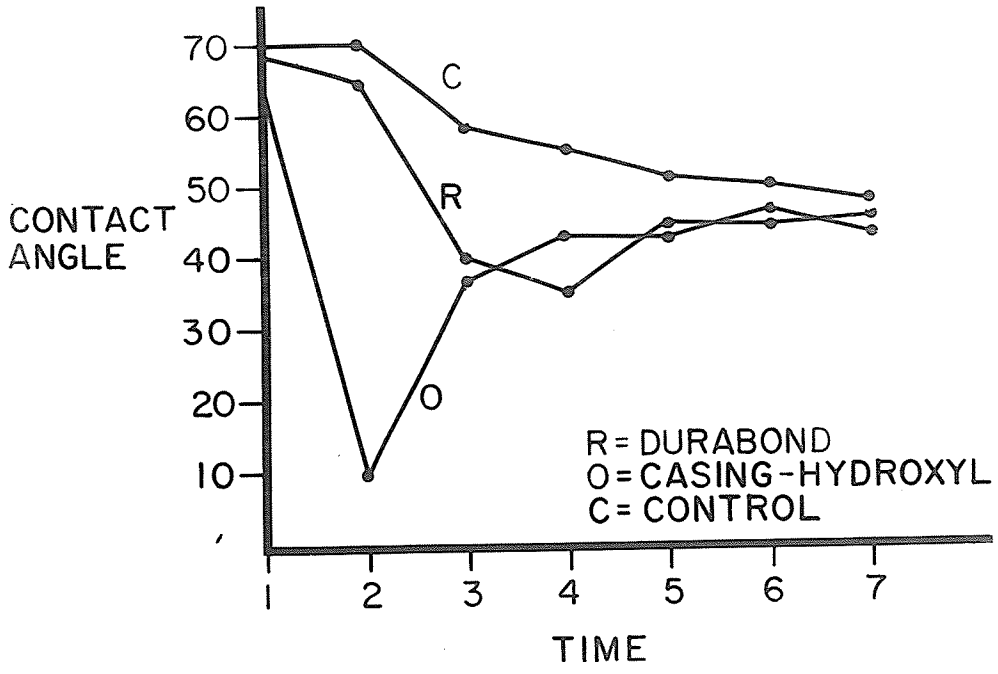

70
60
50
40
30
20
10
CONTACT ANGLE
C
R
O
R = DURABOND
O = CASING-HYDROXYL
C = CONTROL
1
2
3
4
5
6
7
TIME

Fig. 26

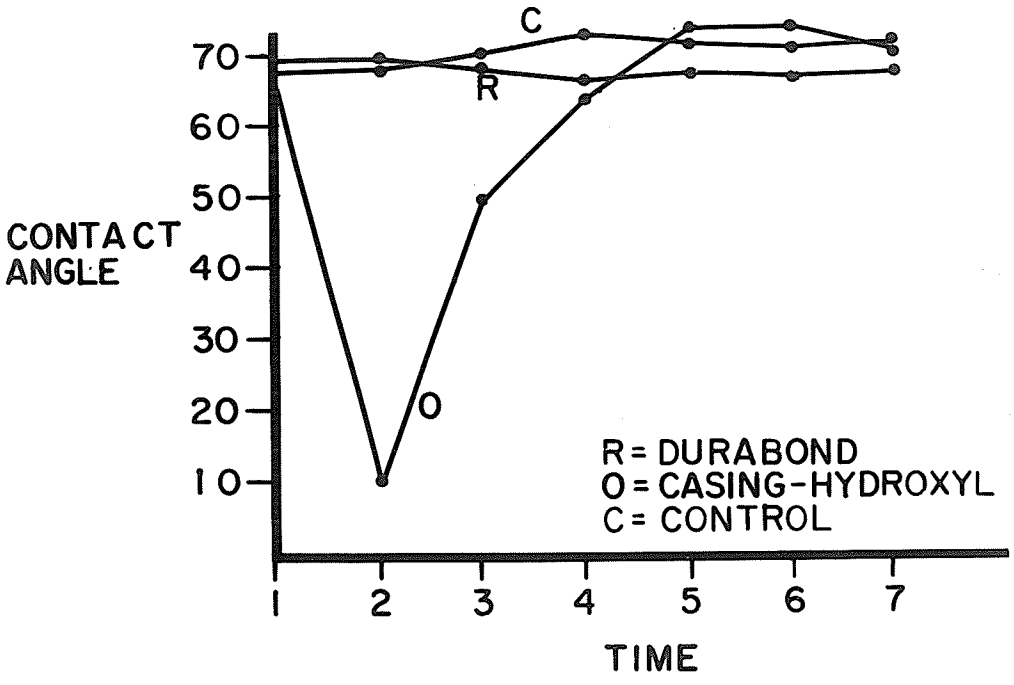

70
60
50
40
30
20
10
CONTACT ANGLE
C
R
O
R = DURABOND
O = CASING-HYDROXYL
C = CONTROL
1
2
3
4
5
6
7
TIME

Fig. 27

TABLE III

TREATMENT	MEAN VALUE R	O	C	S.E.
θ_A	70.4	59.5	73.3	0.162
θ_R	51.3	39.9	51.7	0.162

R = DURABOND
O = CASING HYDROXYL
C = CONTROL
S.E.= STANDARD ERROR

THE EFFECT OF DIFFERENT TREATMENTS ON CONTACT ANGLE HYSTERESIS

Durabond treatment.

Silicone materials as a group were more affected by the CASING-Hydroxyl treatment as compared to acrylic materials as a group. Two materials showed higher contact angles with the Durabond treatment as compared to the control group.

Water as a storage medium maintained the effect of the two treatments better than air storage. Air storage had an adverse effect on the Durabond treatment which showed higher advancing and receding contact angles than the control group.

The effect of both treatments on the contact angle hysteresis was significant ($P<0.01$) irrespective of the type of material or storage media.

While the time-treatment curves showed sharp descent and ascent with the CASING-Hydroxyl Treatment at time 1 (after treatment), Durabond treated group showed: a smoother curve, especially with water storage where the lowest point on the curve was at time 4 (1 week). In both storage media the two treatments approximated the control group from time 5 (2 weeks) to the end of the experiment at time 7 (4 weeks).

Softness. Table IV shows the analysis of variance as computed for softness. Tables V through VII show the effect of different treatments on the softness of different materials, the average of all materials at different storage media, and reaction to initial low and final high load respectively. All the figures show that the effect is insignificant on softness

TABLE IV

Analysis of Variance - Softness

SOURCE OF VARIATION	DF	MS	F
MAT	4	19916.0156	24.760 **
STR	1	193.6772	0.241 NS
MAT STR	4	255.0643	0.317 NS
ERROR 1	20	804.3750	
TIM	6	410.8347	66.399 **
MAT TIM	24	102.7959	16.614 **
STR TIM	6	58.8164	9.506 **
MAT STR TIM	24	10.5474	1.705 **
ERROR 2	120	6.1874	
ROC	2	13.4209	0.109 NS
MAT ROC	8	42.5560	0.347 NS
STR ROC	2	229.3363	1.868 NS
MAT STR ROC	8	253.0460	2.061 NS
ERROR 3	40	122.7578	
TIM ROC	12	10.8278	2.782 NS
MAT TIM ROC	48	16.9076	4.328 *
STR TIM ROC	12	3.9567	1.013 NS
MAT STR TIM ROC	48	7.4061	1.896 NS
ERROR 4	240	3.9063	
ROC BVH	2	2.0449	0.388 NS
MAT ROC BVH	8	3.6519	0.692 NS
STR ROC BVH	2	2.2969	0.218 NS
MAT STR ROC BVH	8	11.3951	2.160 NS
ERROR 7	40	5.2749	
TOTAL	1259		

DF = Degrees of freedom
MS = Means sqare
F = F Value
MAT = Material
STR = Storage
TIM = Time
ROC = Treatment
NS = Non-significant(P>.05)
* = Significant(P<.05)
** = Significant(P<.01)
BVH = Initial V. High load

TABLE V

MATERIAL	PALASIV 62	SOFT-ORYL	FLEXACRYL-SOFT	MOLLOPLAST-b	MOLLOCIL
R	43.9	25.9	32.4	31.4	46.0
O	42.7	26.2	32.7	31.0	47.0
C	43.5	26.0	33.2	30.5	48.3

R = DURABOND O = CASING-HYDROXYL C = CONTROL

THE EFFECT OF DIFFERENT TREATMENT ON THE DIFFERENT MATERIALS IN BOTH STORAGE MEDIA. AVERAGE OF LOW AND HIGH LOAD.

TABLE VI

MEAN VALUE

TREATMENT	R	O	C	S.E
WATER	36.9	36.6	35.8	0.765
AIR	34.9	35.4	36.7	0.765

R = DURABOND
O = CASING - HYDROXYL
C = CONTROL
S.E = STANDARD ERROR

THE EFFECT OF DIFFERENT TREATMENTS ON SOFTNESS IN DIFFERENT STORAGE MEDIA.

TABLE VII

TREATMENT	MEAN VALUE R	O	C	S.E
B	30.5	30.6	30.8	0.765
H	41.3	41.3	41.7	0.765

B = INITIAL LOW WEIGHT
H = FINAL HIGH WEIGHT

THE EFFECT OF DIFFERENT TREATMENTS ON THE AVERAGE REACTION TO LOW AND HIGH LOAD

($P>0.05$). Different treatments did not exhibit any significant effect on the materials used in the present study.

Water Absorption. Table VIII shows the analysis of variance as computed for weight changes.

The effect of different times and storage media are shown in three separate graphs in Fig. 28. The effect of different treatments on weight changes of each material are shown in five separate graphs in Fig. 29. Each line represents a different treatment for combined air and water storage.

The Durabond treated group showed a much higher tendency for water absorption as compared to the CASING-Hydroxyl and control group. Different materials were significantly different ($P<0.01$) in weight changes with general tendency to weight gain with the Durabond treated group and weight loss with CASING-Hydroxyl and control groups. Weight loss which occurred with the Durabond group, was limited to the period after time 4 (2 weeks) and to two materials only (Soft-Oryl and Flexacryl-Soft). There was no significant difference in weight changes between the CASING-Hydroxyl and the control group in both storage media.

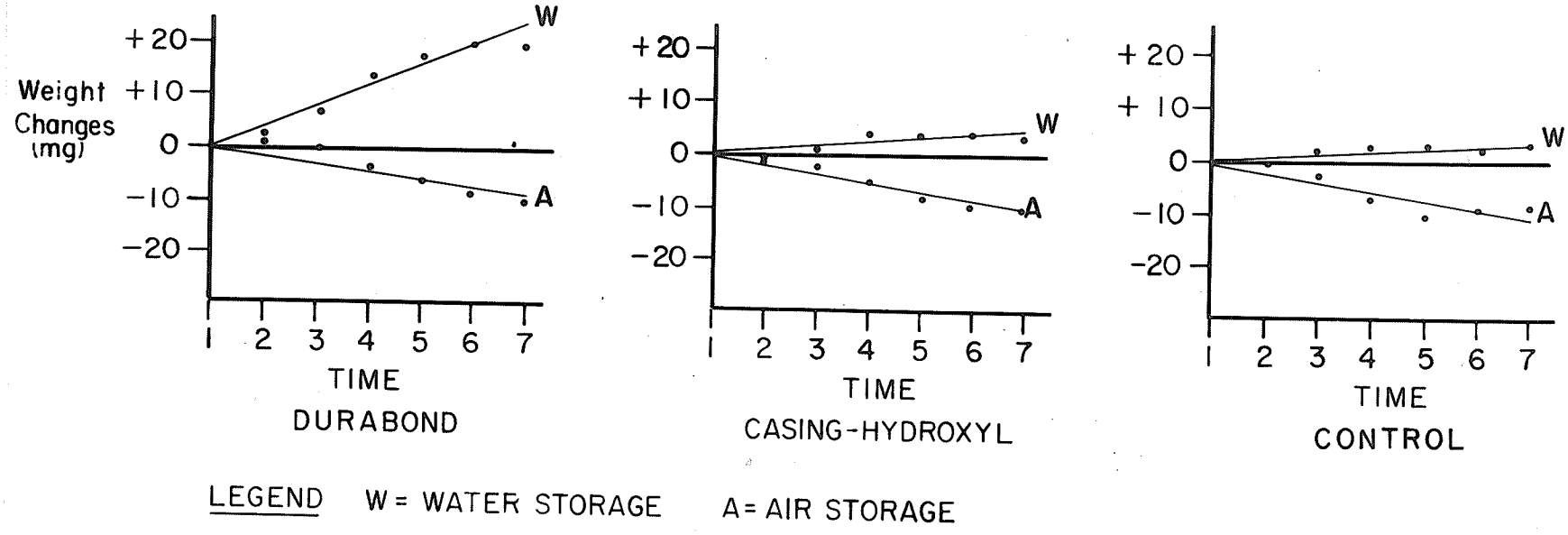
TABLE VIII

Analysis of Variance - Weight Changes

SOURCE OF VARIATION	DF	MS	F
MAT	4	42.4098	61.827 **
STR	1	1.1906	1.736 NS
MAT STR	4	0.4132	0.602 NS
ERROR 1	20	0.6859	
TIM	6	0.0031	4.756 **
MAT TIM	24	0.0051	7.816 **
STR TIM	6	0.1136	173.282 **
MAT STR TIM	24	0.0010	1.458 **
ERROR 2	120	0.0007	
ROC	2	0.0161	0.029 NS
MAT ROC	8	o.5252	o.958 NS
STR ROC	2	0.4080	0.744 NS
MAT STR ROC	8	0.5820	1.062 NS
ERROR 3	40	0.5481	
TIM ROC	12	0.0127	37.141 **
MAT TIM ROC	48	0.0022	6.425 **
STR TIM ROC	12	0.0095	27.864 **
MAT STR TIM ROC	48	0.0021	
ERROR 4	240	0.0003	
TOTAL	629		

DF = Degrees of freedom
MS = Means square
F = F value
MAT = Material
STR = Storage
TIM = Time
ROC = Treatment
NS = Non-significant (P>.05)
* = Significant (P<.05)
** = Significant (P<.01)

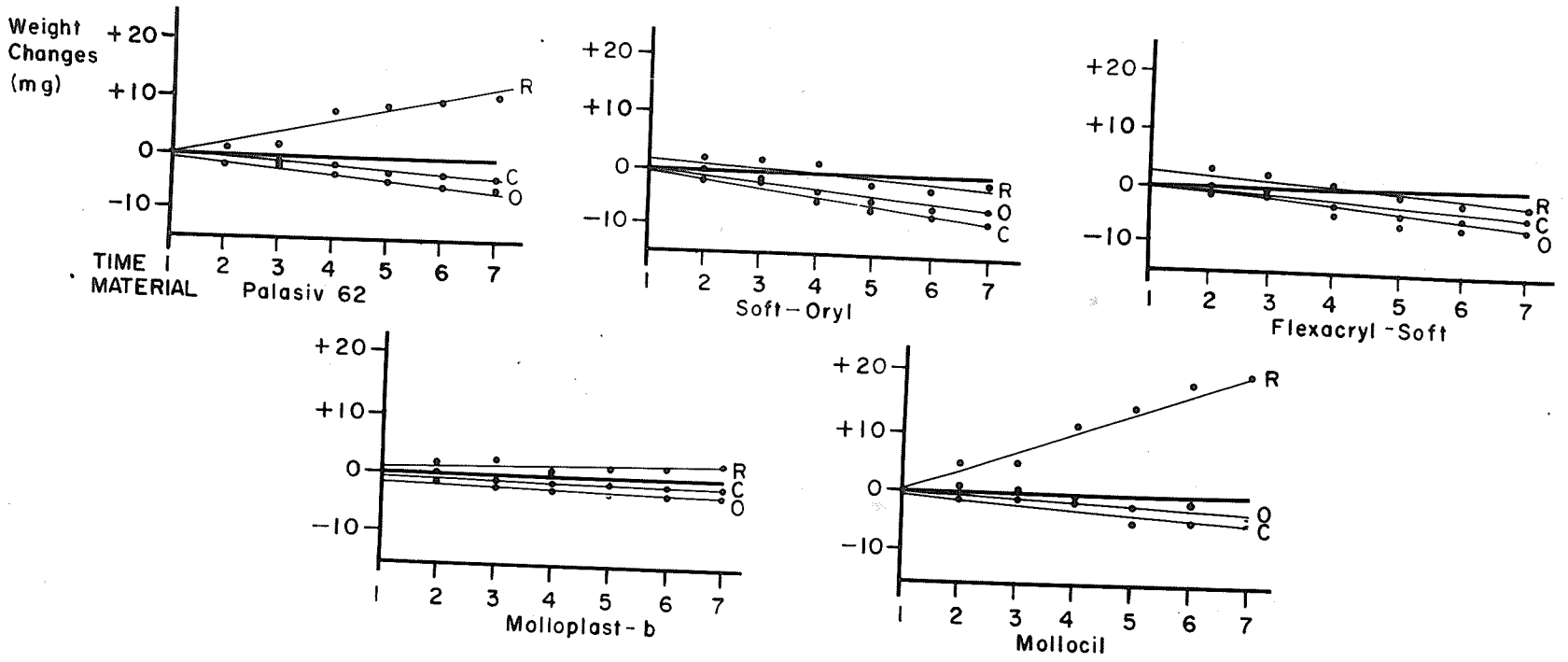
Figure 28. The effect of treatment on water absorption. Average weight change of all materials at different time and different storage media.



LEGEND W = WATER STORAGE A = AIR STORAGE

Fig. 28

Figure 29. The effect of different treatment on water absorption. Average of both storage media for different materials at different times.



LEGEND R = DURABOND O = CASING-HYDROXYL C= CONTROL

Fig. 29

DISCUSSION

The soft-lining materials used in the present study were randomly selected from the materials available on the market. The only criterion in the selection was to represent different groups of material. Previous reports on the properties of different soft liners were not taken into account in selection. Some materials were rejected during the pilot studies either because of their negligible softness or because of difficulties in handling technics.

The choice of the physical tests performed in this study was limited to the properties that have direct bearing on the proper function and success of the soft-lined prosthesis to provide the patient with the desired comfort combined with good hygiene. Storage media were chosen on the basis of the extreme conditions that a prosthesis might be subjected to during normal handling with the average patient. Since the oral environment cannot be duplicated in the laboratory, storage in distilled water at $37^{o}C$ is universally accepted for the in vitro studies.

Hydroxyl treatment produced an immediate sharp drop in the contact angle of the treated specimens. This was more pronounced with the silicone materials. The silicone materials have shown complete spreading of the distilled water after CASING-Hydroxyl treatment, a type of contact angle accepted as zero for practical purposes. Such a sharp drop was followed by a rather sharp increase at the 24 hour period. When Hydroxyl radical treatment was tried without CASING, the 24

hour results were very close to the control group. CASING was effective in prolonging the hydrophilic property gained by the hydroxyl groups attached to the surface. The slower but more continuous type of effect shown by the Durabond treated group indicates that the surface painted layer depends, for its hydrophilic property, on absorbing water from the surroundings. This observation is further documented by the high effect of the storage medium on the treated samples. The manufacturer's instructions supplied with the Durabond kit suggest that the treated denture should be used immediately after the 15 minute curing period, or painted with a hydrator supplied with the kit.

Since the results obtained after 2 weeks storage of the treated samples were similar to the controls, the duration of the experiment was limited to four weeks, although it was originally planned for a longer period. From the observations made during the period of this study, it was noticed that four of the five types of materials treated with Durabond and stored in water developed a whitish film appearance on the treated specimen surface, a phenomenon not observed with the other two groups of treatment, nor with the specimens stored in air.

The significant difference in contact angle hysteresis indicates a difference in the surface pore characteristics and roughness of the specimens after treatment.

The value of the CASING-Hydroxyl treatment is worth

more extensive study. If the drastic initial effect in lowering the contact angle could be maintained for a longer period, such an effect combined with the fact that the treatment had no undesirable side effects such as discoloration or increased water absorption can very likely result in good progress in wettability of soft liners. CASING at higher temperatures and for a longer time may produce such an effect.

The non significant effect of the different treatments on the softness of the materials used in this study indicates that the surface changes had no adverse effect on the internal polymer structure of the materials.

Materials with low water absorption have been always sought in dentistry because of the nature of the oral environment. Increased water absorption per se can be considered an important factor against the success of a wetting treatment.

A more permanent type of treatment with the least side effects on important characteristics as softness, water absorption, and appearance of the material is desirable before clinical in vivo studies are encouraged in the field.

SUMMARY

The effect of two different methods of surface treatment to improve the wettability of acrylic and silicone soft denture-liners was studied. A total of ninety specimens, made from five different soft liners, were used in this investigation. These were divided into three groups. One group received Durabond treatment, a second group received CASING-Hydroxyl treatment, and the last group, which was used as a control, received no treatment. Each group contained an equal number of specimens from each of the five materials tested.

The wettability was determined by contact angle measurement. Two other properties were tested because of their importance as qualities of soft liners and their possible relation to treatments that the materials received. These properties were softness and water sorption.

Statistical analysis of the results was accomplished utilizing an analysis of variance.

It was found that both methods of improving the wettability of soft liners were to varying degrees effective. Distilled water, used as the standard storage medium, maintained the effect of the treatment better than air storage. The effect was, in general, of short duration, not exceeding two weeks under best conditions of material response and storage.

Water sorption was higher for the Durabond treated group, while for the CASING-Hydroxyl group, water sorption was very close to that of the control group.

The treatments had no significant effect on the softness of the materials used.

Further investigations directed towards obtaining a more permanent effect are required before clinical application is to be encouraged. The CASING-Hydroxyl treatment may offer the higher potential since this treatment showed less water absorption and surface discoloration.

CONCLUSIONS

1. Both treatments used in the present study have significantly lowered the contact angle of all the materials used in this study.
2. Different materials have reacted differently in amount of contact angle change to the two treatment methods used.
3. CASING-Hydroxyl treatment was more effective in lowering the contact angle of the silicone materials than the acrylic materials.
4. Air storage had adverse effect on the results of both treatments, more so on the Durabond treatment.
5. At the end of a two week period, and for the next two weeks, the treated groups did not differ significantly from the control group.
6. The effect of different treatments on softness was insignificant ($P>0.05$), regardless of the material or the storage medium.
7. The Durabond treated group showed more water absorption as compared to the other two groups.
8. Different materials have shown significant difference in amounts of water absorption, with a general tendency to higher water absorption in the Durabond treated group than the CASING-Hydroxyl and control groups.
9. Improvements in the permanency of treatment are desirable if such treatment is to be of a practical advantage. The type of results obtained in this study do not encourage "in vivo" studies at the present state.

REFERENCES

1. Lammie, G.A: Againg Changes and the Complete Lower Denture, J. Pros. Dent. 6:450, 1956.

2. Marsland, E.A. and Fox, E.G.: Some Abnormalities in the Nerve Supply of the Oral Mucosa, Proc. Roy. Soc. Med. 51:951, 1959.

3. Storer, R.: Resilient Denture Base Materials, Part I: Introduction and Laboratory Evaluation, Brit. Dent. J. 113:195, 1962.
Part II: Clinical Trial, Brit. Dent. J. 113:231, 1962.

4. Travaglini, E.A.: Resilient Tissue Surfaces in Complete Dentures, J. Amer. Dent. Assn. 64:512, 1962.

5. Lammie, G.A.: The Retention of Full Dentures, J. Amer. Dent. Assn. 55:502, 1957.

6. Lammie, G.A. and Storer, R.: A Preliminary Report on Resilient Denture Plastics, J. Pros. Dent. 8:411, 1958.

7. Swartz, M.J.: Research in Dental Materials, J. Amer. Dent. Assn. 79:901, 1969.

8. Swenson, M.G.: Complete Dentures, ed. 1, C.V. Mosby Co., St. Louis, 1940, pp. 542-3.

9. Lammie, G.A. and Storer, R.: Preliminary Report on Resilient Denture Plastics, J. Pros. Dent. 8:411, 1958.

10. Dental Materials, Current Notes No. 8: Resilient Polyvinyl Denture Lining. Dent. J. of Australia 23:429, 1951.

11. Smith, D.C. and Bates, J.F.: Elastomeric Denture Base Liner. I.A.D.R. Microfilm for 1961 Meeting #41 (abst.) J. Dent. Res. 40:776, 1962.

12. Bates, J.F. and Smith, D.C.: Evaluation of Indirect Resilient Liner for Dentures, Laboratory and Clinical Tests. J. Amer. Dent. Assn. 70:344, 1965.

13. Travaglini, E.A., Gibbons, P. and Craig, R.C.: Resilient Liners for Dentures, J. Pros. Dent. 10:664, 1960.

14. Lantz, H.J.: Evaluation of Silastic 616 as a Liner for Mandibular Denture Problem Patients, Penn. Dent. J. 36:270, 1969.

15. Bell, D.H.: Clinical Evaluation of a Resilient Denture Liner, J. Pros. Dent. 23:394, 1970.

16. Barnhart, G.W.: Silicone Rubber, a Resilient Denture Base Material, J. Dent. Res. 39:1077, 1960.

17. Craig, R. and Gibbons, P.: Properties of Resilient Denture Liners, J. Amer. Dent. Assn., 63:382, 1961.

18. Wilson, H.J. and Tomlin, H.R.: Soft Lining Materials: Some Relevant Properties and their Determination, J. Pros. Dent. 21:244, 1969.

19. Bascom, P.W.: Resilient Denture Base Materials, J. Pros. Dent. 16:646, 1966.

20. O'Brien, W.J. and Ryge, G.: Wettability of Poly (Methyl Methacrylate) Treated with Silicone Tetrachloride, J. Pros. Dent. 15:304, 1965.

21. O'Brien, W.J. and Ryge, G.: A Progress Report, J. Pros. Dent. 15:671, 1965.

22. Boucher, L.J. et al: The Effect of Microlayer of Silica on the Retention of Mandibular Complete Dentures. J. Pros. Dent. 19:581, 1968.

23. Gesser, H.D., Warriner, R.E. and Funt, B.L.: A Method of Improving Wettability of Contact Lenses by Free Radical Treatment, Arch. Amer. Acad. Optometry, 42:321, 1965.

24. Gesser, H.D. and Castaldi, C.R.: The Preparation and Evaluation of Wetting Dentures for Adhesion and Retention. J. Pros. Dent. 25:236, 1971.

25. Gesser, H.D.: Personal communications.

26. Eick, J.D., Craig, R. and Peyton, F.A.: Properties of Resilient Liners in Simulated Mouth Conditions, J. Pros. Dent. 12:1043, 1962.

27. Sclover, I.T. and Tendler, M.D.: The use of a Hydrophilic Polymer as a permanent Soft Liner for Dentures. Dent. Digest, 73:451, 1967.

28. Phillips, R.W.: Skinner's Science of Dental Materials, 7th Edition, W.B. Saunders Co., Philadelphia, 1973, pp. 21-25.

29. Zisman, W.A.: Influence of constitution on adhesion, Ind. & Eng. Chem., 55:19, 1963.

30. Timmons, C.D. and Zisman, W.A.: "The effect of liquid structure on contact angle hysteresis". J. Colloid Sc. 22:165, 1966.

31. Schonhorn, H. and Hansen, R.H.: "Surface treatment of polymers for adhesive bonding", J. App. Polymer Sc. 11:1461, 1967.

32. Gesser, H.D. and Long, R.: "The adhesion of low energy solids", Polymer Letters, 5:469, 1967.

33. Shafrin, E.G. and Zisman, W.A.: "The spreading of liquids on low-energy surfaces", J. Colloid Sc. 7:166, 1952.

34. Livingston, H.K. and Swingley, C.S.: "Contact angles in controlled atmospheres", Surface Science 24:625, 1971.

35. Schonhorn, H.: "Dependence of contact angle on temperatures", J. Phys. Chem.,70:4086 , 1966.

36. Becker, G. and Chebib, F.S.: "Simplified computational programming for mixed analysis of variance design with equal and unequal subclass numbers", Psychological Reports, 25:767, 1969.

BIBLIOGRAPHY

American Dental Association, Council on Dental Research: Guide to Dental Materials and Devices, (6th Edition, Chicago, A.D.A. 1968).

Barnhart, G.W.: Silicone Rubber, a Resilient Denture Base Material, J. Dent. Res. 39:1077, 1960.

_____: Silicone Materials for Lining Dentures, Dent. Progress, 3:246, 1963.

_____: Properties and Procedures of Silicones for Soft Denture Bases, J. Dent. Res. 43:118, 1964.

Bascom, P.W.: Resilient Denture Base Materials, J. Pros. Dent. 16:646, 1966.

Bates, J.F. and Smith, D.C.: Evaluation of Indirect Resilient Liner for Dentures, Laboratory and Clinical Tests, J. Amer. Dent. Assn. 70:344, 1965.

Battersby, B.J.: The Effect of an Elastic Lining on the Retention of Dentures, J. Pros. Dent. 20:498, 1968.

Becker, G. and Chebib, F.S.: Simplified Computational Programming for Mixed Analysis of Variance Design with Equal and Unequal Subclass Numbers, Psychological Reports. 25:767, 1969.

Bell, D.H.: Clinical Evaluation of a Resilient Denture Liner, J. Pros. Dent. 23:394, 1970.

Blahova, Z. and Neuman, M.: Retention of Complete Dentures Lined with Soft Resin, J. Pros. Dent. 25:371, 1971.

Boucher, L.J. et al: The Effect of Microlayer of Silica on the Retention of Mandibular Complete Dentures, J. Pros. Dent. 19:581, 1968.

_____, and Courant, P.: The Effect of Bacterial Growth on Polymethylmethacrylate Treated with Silicone Tetrachloride, IADR meeting #61, Dental Materials Group, 1966.

Cavadini, P.E.: Silicone Soft Denture Liner, Dent. Digest, 72:498, 1966.

Craig, R. and Gibbons, P.: Properties of Resilient Denture Liners, J. Amer. Dent. Assn., 63:382, 1961.

Dental Materials, Current Notes No. 8: Resilient Polyvinyl Denture Lining, Dent. J. of Australia. 23:429, 1951.

Eick, J.D., Craig, R. and Peyton, F.A.: Properties of Resilient Liners in Simulated Mouth Conditions, J. Pros. Dent. 12:1043, 1962.

Feldman, E.E. et al: Relining Complete Dentures with Oral Cure Silicone Elastomer, J. Pros. Dent. 23:387, 1970.

Gardner, A.J.: Silicone Rubber as a Denture Base, Calif. D.A.J. 38:474, 1962.

Gesser, H.D. and Castaldi, C.R.: The Preparation and Evaluation of Wetting Dentures for Adhesion and Retention, J. Pros. Dent. 25:236, 1971.

_____, and Long, R.: The Adhesion of Low Energy Solids, Polymer Letters. 5:469, 1967.

_____, Warriner, R.E. and Funt, B.L.: A Method of Improving Wettability of Contact Lenses by Free Radical Treatment, Arch. Amer. Acad. Optometry, 42:321, 1965.

Gibbon, P.: Clinical and Bacteriological Findings in Patients Wearing Silastic 390 Soft Liner, Mich. Dent. Assn. J. 47: 65, 1965.

Gonzalez, J.B. and Laney, W.R.: Resilient Materials for Denture Prosthesis. J. Pros. Dent. 16:438, 1966.

Grauber, R.G.: Fungus Growth on Tissue Conditioners and Soft Denture Liners, J. Amer. Dent. Assn. 73:641, 1966.

Kliment, K. et al: Study on a New Denture Liner of the Sofdent Type, J. Biomed. Res. 2:473, 1968.

Lammie, G.A.: Aging Changes and the Complete Lower Denture, J. Pros. Dent. 6:450, 1956.

_____: The Retention of Full Dentures, J. Amer. Dent. Assn. 55:502, 1957.

_____, and Storer, R.: A Preliminary Report on Resilient Denture Plastics, J. Pros. Dent. 8:411, 1958.

Lantz, H.J.: Evaluation of Silastic 616 as a Liner for Mandibular Denture Problem Patients, Penn. Dent. J. 36:270, 1969.

Livingston, H.K. and Swingley, C.S.: Contact Angles in Controlled Atmospheres, Surface Sc. 24:625, 1971.

Louka, A.N.: A Report on the Virina Permanent Soft Liner, Unpublished Data, Winnipeg, 1972.

Marsland, E.A. and Fox, E.G.: Some Abnormalities in the Nerve Supply of the Oral Mucosa, Proc. Roy. Soc. Med. 51:951, 1959.

Marrow, R.M. et al: Metal Reinforced Silicone Lined Dentures, J. Pros. Dent. 19:219, 1968.

O'Brien, W.J. and Ryge, G.: Wettability of Poly (Methyl Methacrylate) Treated with Silicone Tetrachloride, J. Pros. Dent. 15:304, 1965.

_____: A Progress Report, J. Pros. Dent. 15:671, 1965.

Paffenbarger, G.C. and Bowen, R.L.: Scientific Development and Methods in Practice, J. Amer. Dent. Assn. 56:785, 1958.

Parker, H.M.: Impact Reduction in Complete and Partial Dentures, A Pilot Study, J. Pros. Dent. 16:227, 1966.

Peyton, F.A. and Anderson, J.V.: Report on Silastic 390, Soft Liner for Dentures, Unpublished Data, U. of Michigan, Ann Arbor, Michigan, 1963.

Pharo, R.C.: Medical Grade Silicone Rubber for Prosthetic Dentistry, Dent. Stud. Mag. 45:210, 1966.

Robinson, J.E. and Barnhart, G.W.: Silicone Soft Denture-Base Materials, Technic and Clinical Application, D. Digest, 70:362, 1964.

_____, _____: Silicone Soft Denture Base Material: Technique and Clinical Applications, 70:362, 1964.

Ruskin, P.F. and Guevara, P.: Controlled Growth of Candida Albicans on Soft Denture Liners, IADR, Dental Materials Group, 1970.

Sauer, J.L.: A Clinical Evaluation of Silastic 390 as a Lining Material for Dentures, J. Pros. Dent. 16:650, 1966.

_____: Relining Dentures with Silicone Rubber, Mich. Dent. Assn. J. 46:101, 1964.

Schonhorn, H.: Dependence of Contact Angle on Temperatures, J. Phys. Chem. 70:4086, 1966.

_____, and Hansen, R.H.: Surface Treatment of Polymers for Adhesive Bonding, J. App. Polymer Sc. 11:1461, 1967.

Sclover, I.T. and Tendler, M.D.: The Use of a Hydrophillic Polymer as a Permanent Soft Liner for Dentures, Dent. Digest, 73:451, 1967.

Shafrin, E.G. and Zisman, W.A.: The Spreading of Liquids on Low Energy Surfaces, J. Colloid. Sc. 7:166, 1952.

Smith, D.C. and Bates, J.F.: Elastomeric Denture Base Liner, IADR Microfilm for 1961 Meeting #41 (abst.), J. Dent. Res. 40:776, 1962.

Stafford, G.D. and Braden, M.: Water Absorption of Some Denture Base Polymers, J. Dent. Res. 47:341, 1968.

Storer, R.: Resilient Denture Base Materials, Part I: Introduction and Laboratory Evaluation, Brit. Dent. J. 113:195, 1962.

_____:_____, Part II: Clinical Trial, Brit. Dent. J. 113:231, 1962.

Swartz, M.J.: Research in Dental Materials, J. Amer. Dent. Assn. 79:901, 1969.

Swenson, M.G.: Complete Dentures, ed. 1, St. Louis, C.V. Mosby Co., 1940, pp. 542-3.

Timmons, C.D. and Zisman, W.A.: The Effect of Liquid Structure on Contact Angle Hysteresis, J. Colloid Sc. 22:165, 1966.

Travaglini, E.A.: Resilient Tissue Surfaces in Complete Dentures, J. Amer. Dent. Assn. 64:512, 1962.

_____, Gibbons, P. and Craig, R.C.: Resilient Liners for Dentures, J. Pros. Dent. 10:664, 1960.

Tsurumaki, K.: Study on Clinical Value of Neoplastupalat, Nihon Univ. Dent. School J., 2:35, 1959.

West, W.H.: RTV Silicone Rubber in Prosthetic Dentistry, D. Progress, 3:125, 1963.

Williamson, J.J.: The Effect of Denture Lining Materials on the Growth of Candida Albicans, Brit. Dent. J. 125: 106, 1968.

Wilson, H.J. and Tomlin, H.R.: Soft Lining Materials: Some Relevant Properties and their Determination, J. Pros. Dent. 21:244, 1969.

Wolfel, J.B. and Paffenbarger, G.C.: Evaluation of Complete Dentures Lined with Resilient Silicone Rubber, J. Amer. Dent. Assn., 76:582, 1968.

Zisman, W.A.: Influence of Constitution on Adhesion, Ind. & Eng. Chem., 55:19, 1963.

Amazis Nashed Louka

1939	Born in Cairo, Egypt
1962	B.D.S. (Bachelor in Dental Surgery), Cairo University, Cairo, Egypt
1962-63	Rotating internship, Faculty of Dentistry, Cairo University
1964-70	Instructor and Senior Instructor, Removable Prosthodontics and Dental Materials, Faculty of Dentistry, Cairo University
1966	H.D.D. (High Dental Diploma), Cairo University. Major: Removable Prosthodontics and Dental Materials.
1970-73	Graduate Student, Faculty of Graduate Studies and Research, University of Manitoba, Winnipeg, Canada