REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1991	THESIS/~~DISSERTATION~~

4. TITLE AND SUBTITLE
The Effect of Thermal Cycling on the Surface Roughness of Dental Casting Investments

5. FUNDING NUMBERS

6. AUTHOR(S)
Thomas F. Helbert, Lt Col

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT Student Attending: University of Texas

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/CI/CIA- 91-048

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFIT/CI
Wright-Patterson AFB OH 45433-6583

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release IAW 190-1
Distributed Unlimited
ERNEST A. HAYGOOD, 1st Lt, USAF
Executive Officer

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

DTIC
ELECTE
AUG 08 1991
S D
D

AD-A239 224

91-07261

91 8 07 139

14. SUBJECT TERMS			15. NUMBER OF PAGES 83
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

THE EFFECT OF THERMAL CYCLING ON THE SURFACE ROUGHNESS OF DENTAL CASTING INVESTMENTS

A

THESIS

Presented to the Faculty of

The University of Texas Graduate School of Biomedical Science

at San Antonio

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science

DTIC COPY INSPECTED 6

Accesion For
NTIS
DTIC
Unannounced
Justification
By
Distribution
Availability
Dist
A-1

By

Thomas Francis Helbert, B.S., D.D.S.

San Antonio, Texas

May, 1991

THE EFFECT OF THERMAL CYCLING ON THE SURFACE ROUGHNESS OF DENTAL CASTING INVESTMENTS

Thomas Francis Helbert

APPROVED:

Supervising Professor

2 April 1981
Date

APPROVED:

Dean

to my wife Lynn
for her fortitude
and love

I wish to express my gratitude to my supervising committee for their support and encouragement in this research project. I thank Dr. Barry K. Norling for his valuable assistance and expert guidance as my supervising professor.

I thank Dr. W. F. P. Malone for bringing to this research project his valuable experience and knowledge of prosthodontics and prosthodontic literature.

I thank Drs. David Kaiser, E. S. Duke and Charles M. Malloy for their thoughtful guidance as members of my research supervising committee.

My sincere gratitude to Lt. Col. Van Dellen and the Staff of the Clinical Investigation Facility, Wilford Hall U.S.A.F. Medical Center, Lackland A.F.B., Texas for their assistance with the scanning electron micrographs presented in this thesis and the statistical analysis of the data. Special thanks for their help goes directly to Sgt. Wayne Stanley and Ms. Tracy White.

The followng companies contributed materials for this study:

J. F. Jelenko & Co., Inc.

Sybron/Kerr Mfg. Co.

Whip Mix Corp.

THE EFFECT OF THERMAL CYCLING

ON THE SURFACE ROUGHNESS

OF DENTAL CASTING INVESTMENTS

Thomas Francis Helbert, M.S.

The University of Texas Graduate School of Biomedical Sciences

at San Antonio

Supervising Professor: Barry K. Norling, Ph.D.

Dental investments are a crucial and integral part of the lost wax method of casting. The investment material is the medium through which the wax replica of the restoration is transferred to the metal alloy. The surface of the original tooth preparation is transferred and reproduced without a significant alteration to the resultant metal restoration. The purpose of this study was to evaluate the surface roughness of six dental casting investments prior to and after the thermal cycling procedures used in the

lost wax method of casting. The surface roughness of Type III gold alloys and ceramometal alloys, cast into the various dental investment samples, was also evaluated. Finally, the Roughness average (Ra) measurement method as outlined by Barrett was evaluated for adaptability to dental casting investments. Ten epoxy resin dies were fabricated from the surface of six dental investment products after they were set against a smooth reference surface. Ten additional epoxy resin dies were fabricated from the six dental investment samples after they were set against the smooth reference surface and then thermal cycled at 1300°F for one hour. The surface roughness of these 120 epoxy resin dies were measured in microns with the profilometer. The next stage of the experiment involved casting Type III gold and ceramometal alloy against the six dental investment products and measuring the resultant surface roughness. The Type III alloy was cast with all the investment samples while the ceramometal alloy was cast only against the phosphate bonded investments. SEM micrographs were taken of a representative dental investment, epoxy resin die, and dental alloy surfaces. The SEM micrographs were used to verify the surface roughness measurements. The SEM micrographs and the Ra data from this investigation showed that the dental casting investments exhibited a wide range of surface roughness among the various products. The gypsum bonded investments are generally smoother than the phosphate bonded investments. After thermal cycling, the gypsum bonded investments became markedly rougher, while the phosphate bonded investments showed only slight increases in general surface roughness. The metal alloys also exhibited a wide range of surface roughness values when cast against the various investment products. The Type III alloy samples cast against the gypsum bonded investments were smoother than those samples cast against the

phosphate bonded investments. The Type III alloy cast against the phosphate bonded investment was smoother than the ceramometal alloy cast against the same investment. The Roughness average method of evaluating the surface roughness of the dental investment produced mixed results. The surface reproduction of the set gypsum bonded investment exhibited suitable detail while the thermal cycled investment reflected vague duplication. The phosphate bonded investment samples also exhibited poor duplication in the epoxy resin in the as set and thermal cycled samples.

TABLE OF CONTENTS

Title i

Approval ii

Dedication iii

Acknowledgments iv

Abstract v

Table of Contents viii

List of Tables ix

List of Figures x

I. INTRODUCTION AND LITERATURE REVIEW 1

II. METHODS AND MATERIALS 15

III. RESULTS 26

IV. DISCUSSION 63

V. SUMMARY 74

APPENDICES

Appendix A: List of Materials and Manufacturers 76

Appendix B: Data 78

Literature Cited 80

Vita 83

LIST OF TABLES

Table 1. Dental Casting Investments 16

Table 2. Test Conditions 18

Table 3. One Way ANOVA of the Surface Roughness of the Gypsum Bonded Investments As Set 40

Table 4. Duncan's Multiple Range Test for the Surface Roughness of the Gypsum Bonded Investments As Set 42

Table 5. One Way ANOVA of the Surface Roughness of the Type III Alloy Castings Fabricated with the Dental Investments 44

Table 6. Duncan's Multiple Range Test for the Surface Roughness of the Type III Alloy Castings Fabricated with the Dental Investments 45

Table 7. Two Way ANOVA for the Surface Roughness of the Gypsum Bonded Investments As Set and the Type III Castings Fabricated with the Gypsum Bonded Investments 48

Table 8. Duncan's Multiple Range Test for the Surface Roughness of the Gypsum Bonded Investments As Set and the Type III Castings Fabricated with the Gypsum Bonded Investments 49

Table 9. One Way ANOVA of the Surface Roughness of the Ceramometal Castings Fabricated with the Phosphate Bonded Investments 53

Table 10. Duncan's Multiple Range Test for the Surface Roughness of the Ceramometal Castings Fabricated with the Phosphate Bonded Investments 55

Table 11. Two Way ANOVA of the Surface Roughness of the Type III and Ceramometal Alloy Castings Fabricated with the Phosphate Bonded Investments 57

Table 12. Duncan's Multiple Range Test for the Surface Roughness of the Type III and Ceramometal Alloy Castings Fabricated with the Phosphate Bonded Investments 58

LIST OF FIGURES

Figure 1: Tapered Cylinder Investment Container Against a Smooth Reference Surface 17

Figure 2: Impression and Impression Tray for Tapered Cylinder Investment Container 21

Figure 3: Epoxy Resin Dies in the Impression Trays 21

Figure 4: Diagram of the Pattern, Sprue Base and Casting Ring Assembly 24

Figure 5: Luster Cast Investment As Set 27

Figure 6: Epoxy Replica of Set Luster Cast Investment 27

Figure 7: Beauty Cast Investment As Set 28

Figure 8: Epoxy Replica of Set Beauty Cast Investment 28

Figure 9: Super Span Investment As Set 29

Figure 10: Epoxy Replica of Set Super Span Investment 29

Figure 11: Ceramigold Investment As Set 30

Figure 12: Epoxy Replica of Set Ceramigold Investment 30

Figure 13: Complete Investment As Set 31

Figure 14: Epoxy Replica of Set Complete Investment 31

Figure 15: Cera Fina Investment As Set 32

Figure 16: Epoxy Replica of Set Cera Fina Investment 32

Figure 17: Luster Cast Investment Thermal Cycled 34

Figure 18: Epoxy Replica of Thermal Cycled Luster Cast Investment . . 34

Figure 19: Beauty Cast Investment Thermal Cycled 35

Figure 20: Epoxy Replica of Thermal Cycled Beauty Cast Investment . . 35

Figure 21: Super Span Investment Thermal Cycled 36

Figure 22: Epoxy Replica of Thermal Cycled Super Span Investment . . . 36

Figure 23: Ceramigold Investment Thermal Cycled 37

Figure 24: Epoxy Replica of Thermal Cycled Ceramigold Investment . . . 37

Figure 25: Complete Investment Thermal Cycled. 38

Figure 26: Epoxy Replica of Thermal Cycled Complete Investment 38

Figure 27: Cera Fina Investment Thermal Cycled 39

Figure 28: Epoxy Replica of Thermal Cycled Cera Fina Investment. . . . 39

Figure 29: Histogram of the Surface Roughness of the Type III Castings Fabricated with the Dental Investments 43

Figure 30: Histogram of the Surface Roughness of the Gypsum Bonded Investments As Set and the Type III Castings Fabricated with the Gypsum Bonded Investments 47

Figure 31: Type III Alloy Cast Against Luster Cast Investment. 50

Figure 32: Type III Alloy Cast Against Beauty Cast Investment. 51

Figure 33: Type III Alloy Cast Against Super Span Investment 52

Figure 34: Histogram of the Surface Roughness of the Type III and Ceramometal Castings Fabricated with the Phosphate Bonded Investments 56

Figure 35: Type III Alloy Cast Against Ceramigold Investment 59

Figure 36: Ceramometal Alloy Cast Against Ceramigold Investment. . . . 59

Figure 37: Type III Alloy Cast Against Complete Investment 60

Figure 38: Ceramometal Alloy Cast Against Complete Investment. 60

Figure 39: Type III Alloy Cast Against Cera Fina Investment. 61

Figure 40: Ceramometal Alloy Cast Against Cera Fina Investment 61

Figure 41: Linear Regression Analysis of the Ra Means of the Type III and Ceramometal Alloys Cast into Phosphate Bonded Investments 62

I. INTRODUCTION AND LITERATURE REVIEW

The casting process was recorded in the earliest of times. According to J. S. Shell (36), "The origin of the lost wax process is obscured by antiquity but castings were probably made by this method many years B. C. and the Aztecs and Mayas are known to have made castings of this nature in gold before the time of Cortez." The investments were probably a mixture of plaster of Paris and either a refractory material or clay from which the wax was melted. Cellini, an Italian artist, used the lost wax process (cire perdue) in his art. The investment in his process contained "gesso de tripoli" as an ingredient. This was either chalk, plaster of Paris, or diatomaceous earth (36).

By 1900, a number of individuals were attempting to make dental castings. Hollenback (19) stated that Philbrook presented a casting process before the Iowa State Dental Society in 1897. Taggart (39) introduced in 1907 his inlay casting technique and machine at the First District Dental Society meeting in New York City. But Taggart's procedure, while innovative, was far from accurate. Lane (24,25) attempted to correct the casting inaccuracies by using a silica and plaster investment. Experiments with a number of materials resulted in his recommended investment that was a combination of plaster of Paris and finely powdered silex (1:3 ratio) which resulted in accurate castings with smooth surfaces. According to the earliest recommendations of Lane (24), the ideal investment should have the following properties:

a) it should neither expand or contract permanently under high temperatures

b) it should impart a smooth surface to the metal

c) it should be sufficiently porous to allow the passage of gases during casting

d) it should be able to withstand the breaking stress of the casting process

e) it must leave no surface residue.

In the early 1920's, the National Bureau of Standards and the Weinstein Research Laboratories began research on the materials and procedures used in the gold casting process (5,37,38). Their research resulted in a thorough understanding of the gold casting process. In addition, their recommendations on the characteristics of investments materials were directly responsible for the American Dental Association Specification No. 2 (5).

Earnshaw (13) reported that the silica bonded investments were introduced in 1933 by Prange and Ray. These investments used ethyl silicate as the binder and were potentially flammable. Alternate binder systems were developed and based on a solution of sodium silicate and, recently, an aqueous suspension of colloidal silica. Earnshaw (13) also stated that these investments were adapted to industrial processes by Focke and were widely used during World War II.

According to Earnshaw (13), the early work with the phosphate bonded investments was done by Moosdorf, Wolski, and Prosen. Moore and Watts expanded upon this early work and later developed an investment of silica, magnesium oxide, monoammonium phosphate, and magnesium acid phosphate (13). This investment was used with alloys of higher melting temperature ranges.

Scientific research into the physical and chemical properties of dental casting investments began at the National Bureau of Standards in the 1920's (5,37). Their investigations illustrated that investments were mixtures of

refractory materials, usually silica as either quartz or cristobalite, and a binder that was a gypsum product in the form of plaster or stone. The refractory materials expand upon heating because of the thermal expansion of the material and the change in the crystalline state (alpha to beta). Of the four common stable forms of silica (quartz, tridymite, cristobalite, and fused or vitreous silica), cristobalite has the greatest expansion and lowest inversion temperature. Sweeney (38) recommended that a satisfactory refractory material for dental investments should be one of at least 85% cristobalite and 15% tridymite. However, Finger (16,17) recommended that a mixture of fine grained cristobalite and coarse grained quartz be used to improve the expansion properties of investments.

Dental casting investments also contain small amounts of modifier substances such as sodium chloride, boric acid, potassium sulfate, graphite, powdered copper or magnesium oxide to vary the physical properties (8). Souder (37) reported in the National Bureau of Standards Circular number C433 that sodium chloride as a modifier to investments will increase expansion. Another minor constituent, boric acid, serves to harden the investment and remove the metallic oxides from the alloy surface. Phillips (33) emphasized that sodium chloride and boric acid seem to counterbalance each other in controlling the set time and setting expansion of investments. Finally, colors are added to the investments with oxide powders (33). To prevent alloy surface oxidation, graphite or powdered copper were also added (8).

In casting with the lost wax method, the invested wax pattern is heated to an elevated temperature. The wax pattern melts, leaving a mold cavity into which the molten alloy metal is introduced. When the investment is heated to the elevated temperature, the various components respond differently to the thermal changes. The silica refractory will expand when

heated, but the percentage of expansion will vary from one polymorphic form to another. According to Craig (8), pure cristobalite expands up to 1.6% at 400°C, quartz will expand up to 1.4% at 600°C, and tridymite will expand up to 1.0% at 600°C. The silica refractory portion of the investment changes from the alpha form to the beta form during the heating process (33). This transformation involves an expansion of the investment mass that is compensated by casting shrinkage. According to Craig (8), the calcium sulfate binder of the gypsum bonded investments is also affected by the elevation in temperature during the heating process. Excess water present in the set investment is evaporated during the early stages of heating. The water of crystallization of calcium sulfate dihydrate is released from the investment at about 105°C. Above this temperature, the calcium sulfate dihydrate is converted to anhydrous calcium sulfate and loses its water of recrystallization.

Another common type of dental investment uses a binder system that consists of magnesium oxide and ammonium diacid phosphate. Neiman (30) stated that as the investment is heated, six different reactions are activated and the compounds complete a series of chemical transformations to form a final product above 1040°C. He also confirmed that the ammonium diacid phosphate binder compound can also react with the silica refractory material at an elevated temperature to form a silicophosphate product. In addition, the phosphate bonded investments utilize a distribution of silica particle sizes rather than a single size of particles to produce higher expansion values.

The surface texture and surface roughness of the cast restoration is effected not only by the dental investment, but also by a number of other factors (35). Phillips (33) distinguished between surface roughness and

surface irregularities in metal castings. Surface irregularities referred to isolated imperfections, such as nodules, that do not characterize the total surface area. Surface roughness, however was defined as finely spaced surface irregularities whose height, width, and direction establish the predominant surface pattern. Pomes (34) stated that surface irregularities consisted of two general types, surface flaws and surface roughness. Surface flaws, such as nodules or casting fins, were usually the result of improper spruing, an incorrect investing technique, or a faulty burnout technique. Surface roughness exists in all castings and is a measure of the smoothness or polish of the surface. Some of the factors that may affect the surface roughness of dental casting investments are 1) vacuum mixing 2) the water to powder ratio, 3) investment fineness, 4) investment composition, 5) temperature of the molten alloy, 6) casting force exerted by the molten alloy, and 7) wettability of the wax pattern by the investment.

Vacuum mixing of dental casting investments has been advocated since the early work by the National Bureau of Standards (5,14,20). Phillips (32) and Ireland (21,22) published articles on the relative merits of vacuum investing procedures. They stated that smooth castings, free from bubbles or nodules, can routinely be produced by vacuum investing techniques. In 1953, Lyon (27) stated that the vacuum investing techniques produced higher percentage of nodule free castings. Also, he found no apparent difference in the surface roughness between castings made with a hygroscopic or thermal expansion technique when vacuum investing was used.

The water to powder ratio can also affect the surface roughness of the dental casting investment. Both Pomes (34) and Docking (9,10,11,12) concluded that the surface roughness of the investment increased with higher water to powder ratios.

The fineness of the investment particles may affect the surface roughness of the casting and other physical properties. According to Phillips (33), the finer the investment particles, the smaller will be the surface irregularities on the casting. However, he also pointed out that the finer investment particles will affect the other physical properties of the investment, e.g. increase the hygroscopic expansion. An investment product meets the American Dental Association Specification Number 2 for dental casting investments when all of the investment powder passes through a Number 30 standard sieve, 95 percent passes a Number 100 standard sieve, while 85 percent must go through a Number 200 sieve. Phillips (33) stated that if an investment met the American Dental Assccіation specification test, the composition is probably not a factor in the surface roughness of the casting.

The composition of the investment also affects the surface roughness of the resultant castings. Investments are classified according to the type of binder utilized (33). When comparing the gypsum bonded with the phosphate bonded investments, Cooney (7) demonstrated that the gypsum bonded investments produced smoother casting surfaces. The ratio of the binder to refractory can also affect the surface roughness. Pomes (34) also studied the ratio of binder to refractory in gypsum bonded investments and its effect on the surface roughness. His studies revealed that the lower the binder content the rougher the surface of the resultant casting.

The next factor that influences the surface roughness is the burnout temperature of the investment. Lewis (26) confirmed that an increased temperature in the gypsum bonded investment produced a poor surface. This temperature increase can occur with a higher burnout temperature or an increased alloy mass. Barone (2) and Cooney (7) believed that the burnout temperatures between 800°F and 1300°F produced consistent and optimum surface

roughness values. Burnout temperatures above 1300°F produced an increase in surface roughness. Barone (2) also stated that casting temperatures within a 300°F limit of the liquidus temperature for the alloy produced optimally smooth surfaces, while casting temperatures beyond this 300°F limit increased the surface roughness of the casting. Phillips (33) stated that if the noble metal alloy was heated to a high temperature, the surface of the investment would be compromised and would deteriorate. In addition, Phillips also concluded that a high casting pressure will produce a rough surface on the casting.

Some authors have advocated the use of wetting agents to reduce the surface roughness of castings. Neill (29) stated that the flow of an investment mix over the wax pattern surface was impeded by the surface tensions of the materials, and steps to facilitate the "wetting" of the wax pattern may need to be taken. He advocated using a non-ionic agent that could be added to either the water or the mixed slurry. Also, Mabie (28) illustrated that a suspension of fine grained zirconia eliminated or greatly reduced surface scale and promoted the formation of smoother castings.

Thus, the dental casting investment can be viewed as a crucial step in the process of fabricating a cast alloy restoration. The research data has shown that a multitude of errors can occur at this stage of the casting process. It is critical that a reliable and predictable dental casting investment be used for this step in the procedure. In 1982, Nilner (31) published a study that brought some doubt as to the predictability of dental casting investments. He evaluated dental casting procedures and the materials used in the lost wax method of casting. Nilner demonstrated that the impression material and dental stone combinations gave more exact surface reproductions than the wax and investment combinations. He concluded that

the dental wax and investment materials were inherently poor in their surface detail reproduction and, therefore, were the weak link in the entire casting process.

Investigations of dental casting investment surface roughness can be divided into two general categories according to their method of evaluation. The first method of investigation involves the visual evaluation of the surface roughness of either the investment or the resultant casting. Bauer (4) evaluated the surface roughness of four casting alloys by way of SEM microscopy. The four alloys were cast into a phosphate bonded investment mold that had been heated to a burnout temperature of 1300°F, 1500°F, or 1650°F. The specimen thickness was also varied among 0.4 mm, 0.9 mm, or 2.0 mm. The results of the investigation showed that the magnitude of inherent roughness of the casting samples increased with the increasing burnout temperature and increasing specimen thickness. He reported that the interdendritic spacing of the casting surface was also larger than the interparticle spacing of the investment material.

Cooney, Doyle and Caputo (6) correlated the inherent surface roughness of castings made with phosphate bonded investments and their marginal fit. They evaluated the surface roughness of the castings by three visual tests. In the first analysis, each observer was asked to arrange the castings in order from smoothest to roughest, based on the visual appearance of a 1 mm square area of the casting surface. SEM micrographs at 600X magnification were then obtained of the casting surface and used in the second test. The SEM micrographs were again arranged by the observers in order from smoothest to roughest. In the third test, the observers were asked to evaluate the castings for the incidence of positive nodules or bubbles and again rank the samples from the least nodular to the most nodular. The results of visual

evaluations were then compared to the marginal opening for each seated casting. The results of the first visual observations indicated that one of the dental investments produced a significantly smoother surface. In the second test, however, the SEM micrographs revealed no significant differences between the dental investments. The ranking of the castings by the incidence of positive nodules indicated no significant differences between the investment samples. When the marginal fit of each of the 25 castings was compared with the relative rank ordering in each of the three roughness tests, no correlation was evident.

In 1981, Cooney and Caputo (7) repeated this study but slightly altered the visual tests. In the experiment, the first test used SEM micrographs of 600X magnification, and four impartial observers ranked them from smoothest to roughest based on the surface texture of the samples. In the second test, the evaluators used a working microscope with a 20X magnification to arrange 30 castings in order from the smoothest to the roughest. In the third test, 10X magnification was used and the castings were ranked from the least nodular to the most nodular. The results from these visual tests were then compared to the marginal opening scores. The data from this evaluation contradicted their previous study. The investment samples used in this experiment showed significant differences in all three visual observation tests. These differences were unobserved in the previous report. In addition, while no significant correlation was discovered when the ranking of the casting on the roughness tests was compared to the marginal fit of those same castings, all three visual tests identified a trend toward a negative correlation with the marginal fit of the castings.

Another visual test analysed the property of the investment material to accurately reproduce the fine line detail. Jones, Barrett and Griffin (23)

adapted the line quality reproduction test from the American Dental Association's Specification Number 19 for dental investments. In this study, the line quality reproduction was evaluated visually with 15X magnification and 20° low angle illumination. The investment casts were rated according to the reproduction quality of the 0.050 mm line. The results from the study indicated statistically significant differences between the investment material and their ability to reproduce the fine line detail. While this study illustrated a high degree of reliability in the reproducibility of line quality, the inherent surface roughness of the investment was not considered in the evaluation of line reproduction quality.

The surface profilometer is a second method for evaluating the surface roughness. This instrument provided a numerical assessment of the surface roughness, known as the Roughness average (Ra). The profilometer stylus traverses the test surface measuring the surface undulations and minute irregularities to produce an integrated mathematical average in microns called the Ra value. The Ra of the irregularities on the surface is defined as the average values of the departures from its center line. Finger and Jorgensen (15) used profilometer recordings from cast alloy surfaces and compared them with SEM micrographs of different investment samples and the cast alloy surfaces. The results indicated that the specific investment materials produced different surface roughness values on the castings. In addition, the cast surface showed distinctive elements that reflected the surface morphology of the original investment surface.

Pomes, Slack and Wise (34) also used the surface profilometer to evaluate the effect of different factors on the dental casting investment as measured in the resultant casting. Their results revealed that thicker mixes of investments (lower W/P ratio) produced smoother cast surfaces. The

surface roughness of the casting also decreased with the incorporation of finer silica particles. As the content of binder was diminished, the surface roughness of the resultant casting was increased. However, this study failed to correlate the relationship of the surface roughness of the investment product with the resultant casting. In 1961, Barone, Huff and Dickson (2) studied the effect of the investment burnout temperature and the casting temperature on the surface roughness of the casting. Profilometer recordings of the cast alloy surface verified that a consistent and optimum surface roughness can be obtained when the burnout temperature is maintained between 800°F and 1300°F and the casting temperature was within 300°F of the liquidus temperature of the alloy. Casting temperatures beyond these limits increased the surface roughness of the resultant castings. Arfaei and Asgar (1) studied the effect of the type of investment, the water/powder ratio, the silica sol concentration, and the mold temperature of the investment on the surface roughness of various dental casting alloys. Gypsum bonded investments produced smoother castings than phosphate bonded investments. The surface roughness of the casting fabricated with the gypsum bonded investments was influenced to a greater degree by the mold temperature and to a lesser degree by the water/powder ratio. The surface roughness of the castings fabricated with the phosphate bonded investments was increased with an elevated mold temperature and a decreased silica sol concentration. This method of indirectly evaluating the surface roughness of the dental investment by measuring the roughness of the resultant casting was also used by Ghazala (18) in 1978. His investigation studied the effect of various investment products and wax coating agents on the surface roughness of castings. His study indicated that the various investment products produced visual differences in the surface roughness of their castings. The

preinvestment coating agents improved the surface roughness in the castings of only two of the investment products tested. He stated that the surface roughness had a direct bearing on the fit of the casting and was the result of the interaction between the mold surface and the molten alloy. The surface roughness, therefore, was related to the investment composition, the investment fineness, the setting, hygroscopic and thermal expansion of the investment, the alloy composition, casting pressure, casting temperature and the alloy's initial cooling contraction. Ghazala recommended that the dental manufacturers publish expected surface roughness values along with the physical properties of the dental investment products.

Barrett (3) investigated the compatibility of impression and duplicating materials with gypsum products. He stated that this is accomplished by evaluating the reproduction of grooves on a standardized metal block. A combination of an impression material with a gypsum material is considered acceptable if the 0.075 mm wide groove has been reproduced on the resultant gypsum cast when examined by direct visual inspection under low angle illumination. However, quantitative analyses cannot be made with this method and no consideration was made for the surface roughness of the cast. Barrett proposed a technique to quantitatively measure the surface roughness of the gypsum surface. In this technique the surface roughness of a gypsum surface is transferred through an impression material to an epoxy resin die. These epoxy resin dies are then used with the surface profilometer instrument to indirectly obtain a measurement of the surface roughness. Barrett also compared the subjective evaluation scores of a direct visual observation of the accuracy of reproduction of the 0.075 mm line with the surface roughness measurements obtained with the surface profilometer. The results indicated that there was a strong positive correlation between the surface roughness

measurements and the subjective visual evaluation scores. No statistically significant difference (P = 0.01) was found in the surface roughness of the reference surface and the replicated epoxy resin surface. This method of indirectly measuring the surface roughness of the dental investment surface had several advantages over visual evaluations: 1) it eliminated the need for subjective evaluation of line quality on duplicate casts, 2) it provided quantitative, numerical measurements of the surface roughness values. The experiments suggested that a quantitative surface roughness measurement with a profilometer instrument would provide an acceptable alternative to subjective evaluations. With the Roughness average (Ra) method, the surface roughness of the dental investment can be indirectly measured and quantitated. Also with this method, the transference of the surface roughness can be quantitatively measured and analyzed from the wax, through the dental investment and to the resultant casting.

The purpose of this study is to evaluate the surface roughness of six dental casting investments prior to and after thermal cycling as well as compare the surface roughness of the dental casting investments with the resultant alloy castings. In addition, this study evaluates the adaptability of the Roughness average (Ra) measurement method outlined by Barrett to gypsum bonded and phosphate bonded dental casting investments. SEM micrographs were made of the various dental investment surfaces in the as set and thermal cycled conditions as well as the resultant surface of the metal alloys cast against the various dental investments. Also, SEM micrographs of the epoxy resin replicas were made and compared to the micrographs of the original investment surfaces. Epoxy resin replicas of the set dental investment and the dental investment after thermal cycling were fabricated according to the technique outlined by Barrett. Surface roughness

measurements of representative epoxy resin replicas and the metal castings were recorded with the profilometer and statistically analyzed.

II. METHODS AND MATERIALS

Part I: Scanning Electron Microscopy of the Various Dental Investments

Six dental casting investment products were selected for this study. These investments were either gypsum bonded or phosphate bonded investments (Table 1). Only two of the gypsum bonded investments were certified as meeting the American Dental Association Specification Number 2. Polycarbonate sheeting (Plastic Supply of San Antonio, San Antonio, Texas) with a smooth, optical quality surface was sectioned into 4.0 cm by 4.0 cm samples. This smooth, optical quality surface was used as the reference surface against which the investment material was poured. Tapered cylinder containers were made from thermoplastic sheeting (Buffalo Dental Mfg. Co., Inc., Brooklyn, New York) and fabricated with the Omnivac II vacuum adapter (Omnidental Corp., Harrisonburg, Pa.). These containers were used to hold the dental investment material against the polycarbonate sample (Figure 1). The dental casting investments were mixed according to the manufacturers recommendations (Table 2). The phosphate bonded investments' special liquid to water ratio was also in accordance with the manufacturer's recommendation. The investment samples were vacuum mixed and mechanically spatulated in a Combination Unit (Whip Mix Corp., Louisville, Kentucky) for the recommended amount of time (Table 2). The phosphate bonded investment samples were also held in the vacuum mixing bowl for an additional amount of time (Table 2) acording to the manufacturers' recommendations. The investment samples were then gently vibrated with a Toothmaster bench vibrator (Toothmaster Co., Racine, Wisconsin) into the containers and against

TABLE 1.

Dental Casting Investments

Gypsum Bonded Investments		Batch Number
Luster Cast	Sybron/Kerr Mfg. Co. Romulus, Michigan 48174	5-1330
Beauty Cast	Whip Mix Corporation Louisville, Kentucky 40217	NA
Super Span	J.F. Jelenko & Co., Inc. Armonk, New York 10504	120651
Phosphate Bonded Investments		
Ceramigold	Whip Mix Corporation Louisville, Kentucky 40217	037561300
Complete	J.F. Jelenko & Co., Inc. Armonk, New York 10504	02045-11
Cera Fina	Whip Mix Corporation Louisville, Kentucky 40217	110150100

Figure 1: Tapered Cylinder Investment Container Against a Smooth Reference Surface

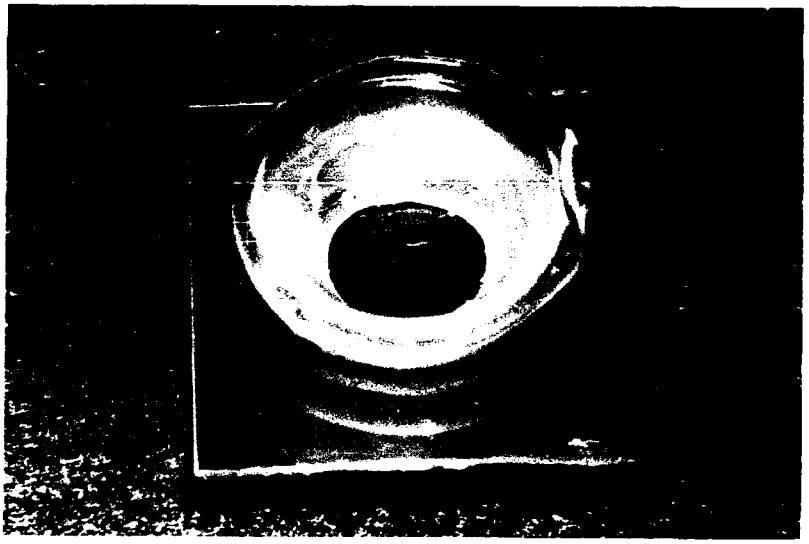


TABLE 2. TEST CONDITIONS

Investment	W/P Ratio	Special Liquid/ Water Ratio	Mechanical Mixing Speed	Mixing Time	Vacuum Hold Time	Set Time	Burnout Temperature	Heat-Soak Time
Luster Cast	15ml/50g	NA	500 rpm	20 sec	NA	1 hour	1300 F	1 hour
Beauty Cast	15-17ml/50g	NA	500 rpm	20-30 sec	NA	1 hour	1300 F	1 hour
Super Span	20ml/60g	NA	500 rpm	30 sec	NA	1 hour	1300 F	1 hour
Ceramigold	10.5ml/60g	1:1	500 rpm	90 sec	15 sec	1 hour	1300 F	1 hour
Complete	9.5ml/60g	3:1	500 rpm	60 sec	15 sec	1 hour	1300 F	1 hour
Cera Fina	21.5ml/90g	3:1	500 rpm	90 sec	15 sec	1 hour	1300 F	1 hour

the polycarbonate testing surface to prevent air inclusions. The samples were then allowed to bench set for one hour. At this time the polycarbonate sheet was gently removed from the investment surface. Extreme care was exercised while removing the thermoplastic container around the investment sample to prevent contact with the dental investment test surface.

The dental casting investments in the next part of the experiment were handled identically to the first part of this experiment, with the exception of a thermal cycling procedure. The investments were again mixed according to the manufacturer's recommendations of water to powder ratio, special liquid to water ratio, mechanical spatulation speed, mixing time, vacuum holding time, and setting time. After the investment samples had set for one hour, the container was carefully removed from around the investment sample and the test surface was protected. The investment samples were placed on a clay oven tray (J. F. Jelenko & Co., Inc., Armonk, New York) and placed in a calibrated burnout furnace (Jelenko Accu-Therm 250, J. F. Jelenko & Co., Inc., Armonk, New York) at room temperature. The investment samples were slowly heated to a burnout temperature of 1300°F and heat soaked for one hour at this temperature. At this time, the samples were removed from the oven and allowed to bench cool to room temperature.

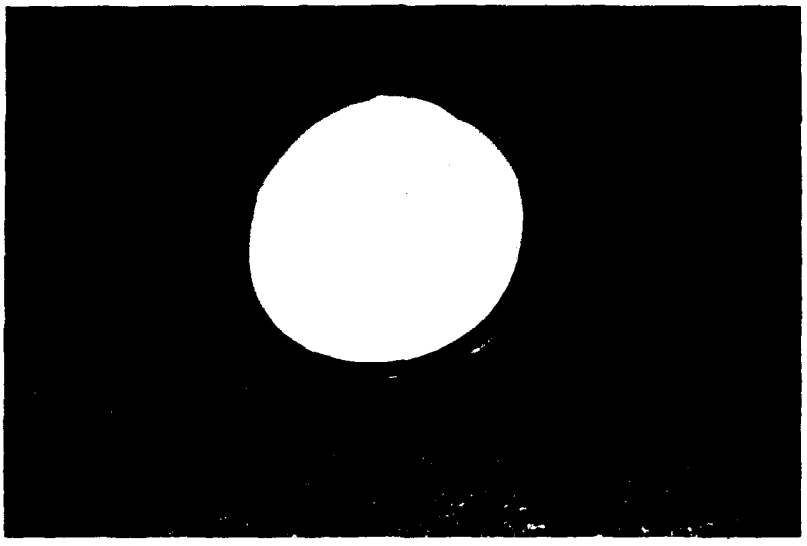
A randomly selected sample of the as set and thermal cycled investment surface was desiccated and sputter coated for the SEM microscopy. SEM micrographs of 600X magnification were obtained with the Phillips SEM 515 microscope. The kilovoltage was set at 4.8 kV and the focus spot at 20 nanometers.

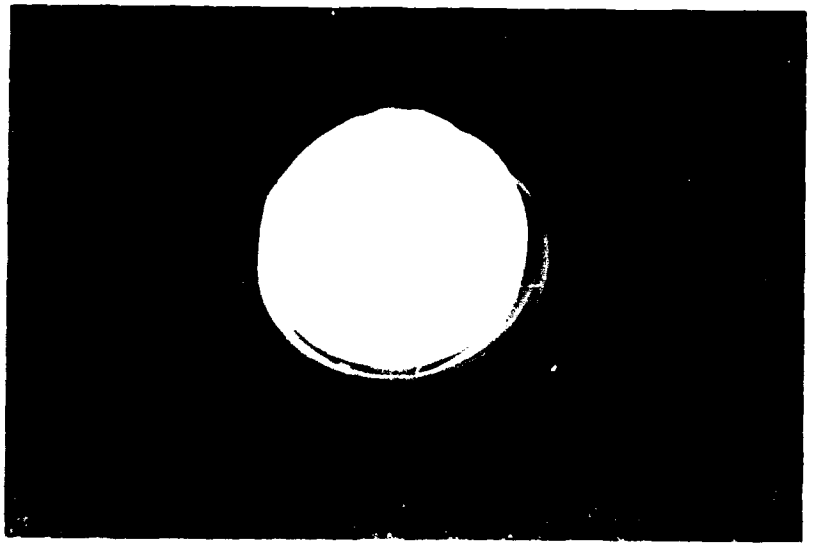
Part II: Evaluation of the Surface Roughness of Dental Casting Investments as Indirectly Measured by the Roughness Average Method

Ten samples each of the six dental investment products were poured and allowed to set against a smooth, optical quality surface as previously described. An impression of the smooth investment surface was then obtained with an addition vinylpolysiloxane elastomeric impression material (President, Coltene AG, Altstatten, Switzerland). Custom impression trays of thermoplastic material (Buffalo Mfg. Co., Inc., Brooklyn, New York) were fabricated with a tapered cylinder shape similar to the investment containers (Figure 2). These impression trays fit over the investment containers controlling the amount of impression material used while supporting the impression material during the epoxy resin die fabrication procedure. The impression material was allowed to set for the recommended time and then removed. The impressions of the investment surface was soaked in a 10% sodium citrate solution then gently washed and carefully cleaned of any debris. The impressions were stored for approximately 12 hours before the epoxy resin dies were fabricated. Epoxide resin (Buehler Ltd., Evanston, Illinois) was used to fabricate the epoxy resin dies. According to the manufacturer's directions, the resin and hardener were mixed and poured into the impressions (Figure 3). The impression trays containing the epoxy resins were then incubated in a BDM Incubator (Buffalo Dental Mfg. Co., Inc., Brooklyn, New York) for 2 hours at 120°F in accordance with the manufacturers directions, after which the impression trays containing the epoxy resins were removed from the incubator and allowed to completely set on the laboratory bench. After 24 hours the impressions were removed from the epoxy resin dies and the dies were visually inspected for defects. The epoxy resin

Figure 2: Impression and Impression Tray for Tapered Cylinder Investment Container

Figure 3: Epoxy Resin Dies in the Impression Trays





dies were then stored for the profilometer recordings. Surface roughness measurements were recorded with the Surftronic 3 profilometer recording apparatus (Rank Taylor-Hobson, Leicester, England) for each of the sixty samples and the Ra (Roughness Average) value subjected to statistical analysis. The right angle stylus was adjusted to travel horizontally across the surface of the epoxy resin specimen. The profilometer instrument was adjusted to provide 2.5mm of cut off distance at a sensitivity level of 9.99 microns.

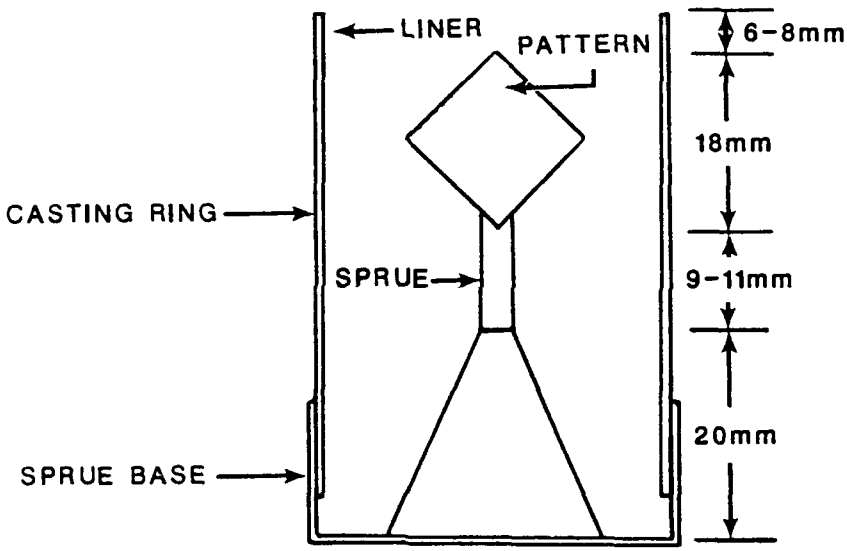
Ten additional samples each of the six dental investment products were poured and allowed to set against a smooth, optical quality surface. After the investment samples had set for one hour, the container was removed and the investment samples were thermal cycled in a burnout furnace. The impression procedure described earlier was carefully performed on these samples. The impressions in their trays were carefully cleaned and stored for approximately 12 hours before the epoxy resin dies were fabricated. The epoxy resin dies were fabricated according to the procedure previously outlined and stored for the profilometer recordings. The surface roughness measurements were recorded for these sixty samples and computed statistically.

A randomly selected epoxy resin replica of the set and thermal cycled investment surface was desiccated and sputter coated for SEM microscopy. SEM micrographs of 600X magnification were obtained of the samples as previously described.

Part III: Evaluation of the Surface Roughness of Type III Gold Alloy and Ceramometal Alloy Castings Fabricated with Various Dental Casting Investments

The dental casting samples fabricated in this part of the study were fabricated according to a standardized laboratory technique and in accordance with the recommendations of the manufacturers. Optical quality polycarbonate sheeting (Plastic Supply of San Antonio, San Antonio, Texas) was sectioned into 1.25 cm by 1.25 cm squares. These squares were attached to 10 gauge plastic sprues (Figure 4). The polycarbonate squares and plastic sprues were attached to a sprue base and a casting ring assembly as prescribed for use with the Hereaus induction casting machine (Hereaus Edelmetalle GmbH, Hanau, West Germany). The dental investments were again mixed according to the manufacturer's recommendations for the water to powder ratio, special liquid to water ratio, mechanical spatulation speed, mixing time, vacuum holding time, and setting time. The mixed investment was carefully introduced into the casting ring and around the polycarbonate pattern to minimize investment turbulence and prevent air entrapment. After the dental casting investment had set for one hour, the casting rings were removed from the sprue bases. The rings were placed in a calibrated burnout furnace at room temperature, slowly heated to 1300°F, and heat soaked for one hour. The gypsum bonded investment samples were then cast in a Type III gold alloy (Firmilay, J.F. Jelenko & Co., Inc., Armonk, New York) while the phosphate bonded investment samples were cast with the Type III gold alloy as well as a ceramometal alloy (Olympia, J.F. Jelenko & Co., Inc., Armonk, New York). The casting operation was performed with an induction casting machine (Hereaus Edelmetalle GmbH, Hanau, West Germany).

Figure 4: Diagram of the Pattern, Sprue Base and Casting Ring Assembly


LINER
PATTERN
6-8mm
18mm
CASTING RING
SPRUE
9-11mm
20mm
SPRUE BASE

The casting operation of the Hereaus casting machine is based upon a pressure and gravity principle. The melting and casting temperature was maintained with a calibrated control rheostat and the alloy melted in a vacuum environment maintained at under five Torr. The pressure during the casting operation was maintained above 20 psi. The castings were bench cooled in the casting rings for five minutes prior to rapid cooling in water and divesting. The Type III alloy samples were pickled in an acid solution (Prevox Pickling Solution, Williams Gold Refining Co., Inc., Buffalo, New York), rinsed with water, cleaned of surface debris with a soft brush, and checked for surface defects. The ceramometal alloy samples were ultrasonically cleaned in an appropriate cleaner (No-San, Trio-Dent, Inc., Union, New Jersey), rinsed with water, also cleaned of debris with a soft brush, and checked for surface defects.

Ten specimens of the Type III gold alloys were cast in each of the six dental casting investments. In addition, ten specimens of ceramometal alloys were cast in each of the three phosphate bonded investments. These ninety samples were stored prior to profilometer recordings of the surface roughness values. The measurements for the surface roughness of the cast alloy surfaces were obtained with the Surftronic 3 profilometer instrument as previously described.

A randomly selected Type III and ceramometal alloy casting sample for each of the six dental investment products was selected for SEM microscopy. SEM micrographs of 600X magnification were obtained of the samples as previously described.

III. RESULTS

Part I

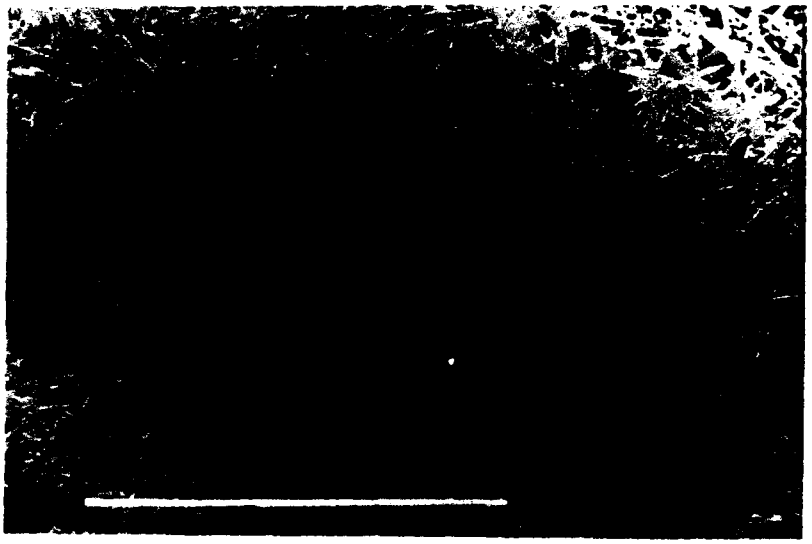
The scanning electron micrographs of the investment samples poured against the smooth reference surface revealed that the gypsum bonded investments were smoother than the phosphate bonded investments. However, there was a high degree of variability in the apparent surface roughness of the dental investments. Luster Cast and Beauty Cast produced the smoothest investment surface when set against the smooth reference, while Super Span exhibited a rougher surface. This was evident in the SEM micrographs where the larger crystalline structure of the Super Span investment was observed (Figure 5,7,9). The smoothest apparent surface for the phosphate bonded investment was obtained with Ceramigold investment. The grain structure appeared small and densly packed. Both Complete and Cera Fina investments showed larger crystalline structure in the micrograph and thus appeared rougher (Figure 11,13,15).

The results of the replication procedure outlined by Barrett (3) provided the following results with the various dental investment products. The gypsum bonded investments as set against the smooth reference surface and transferred through an elastomeric impression material into an epoxy resin produced a surface that was similar to the original investment surface. The micrographs at 600X magnification revealed a similar crystalline structure to the original investment surface with only minimal deterioration (Figure 6,8,10).

The replication results for the phosphate bonded investments, however, were less favorable. The epoxy resin replicas of the phosphate bonded

Figure 5: Luster Cast Investment As Set

Figure 6: Epoxy Replica of Set Luster Cast Investment



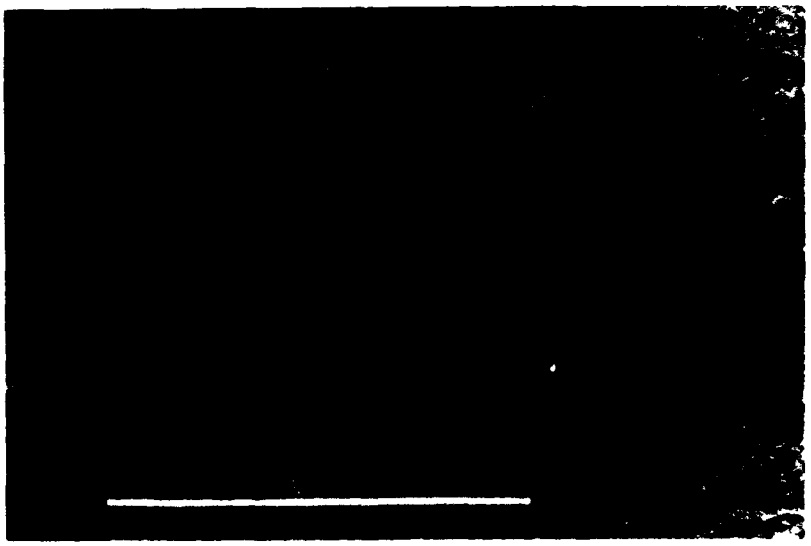


Figure 7: Beauty Cast Investment As Set

Figure 8: Epoxy Replica of Set Beauty Cast Investment

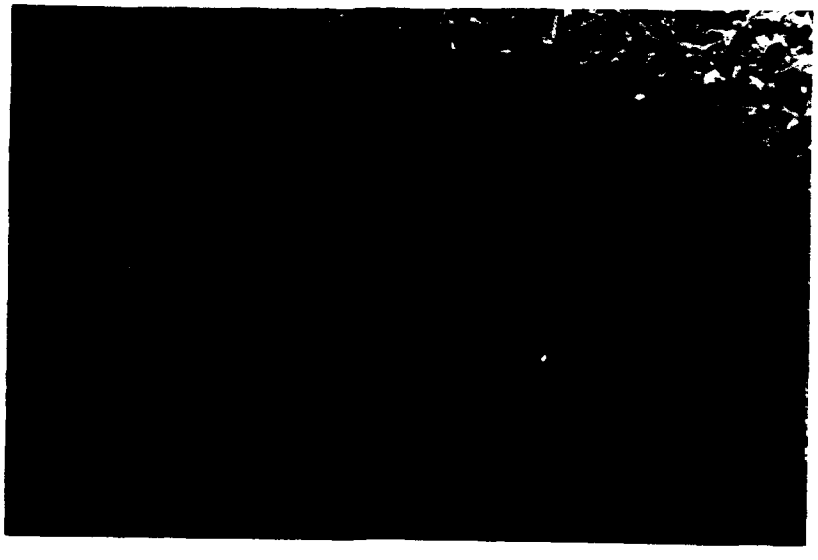


Figure 9: Super Span Investment As Set

Figure 10: Epoxy Replica of Set Super Span Investment

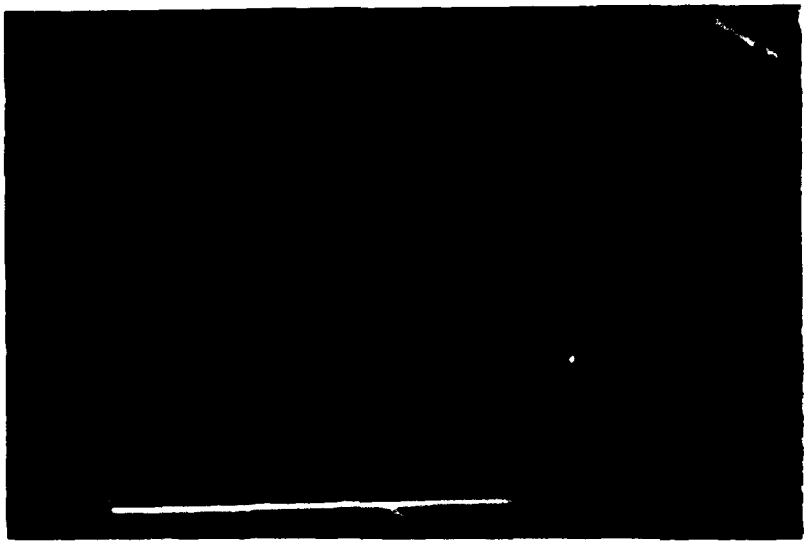
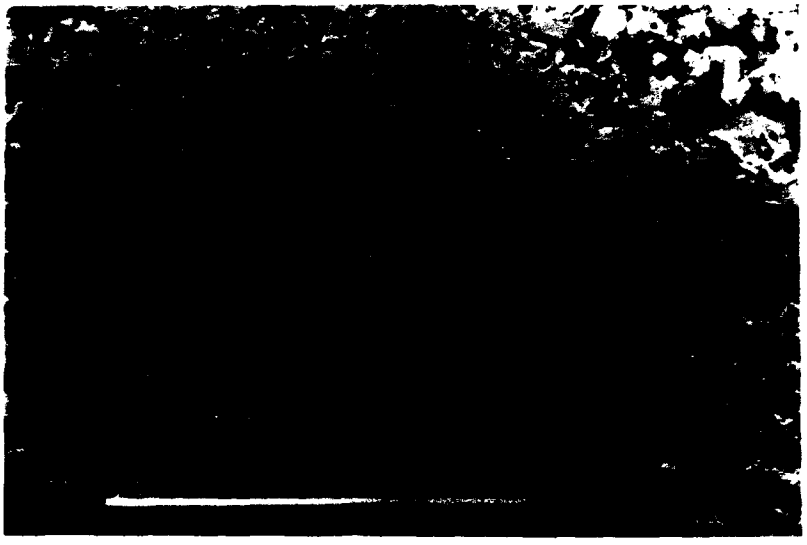


Figure 11: Ceramigold Investment As Set

Figure 12: Epoxy Replica of Set Ceramigold Investment



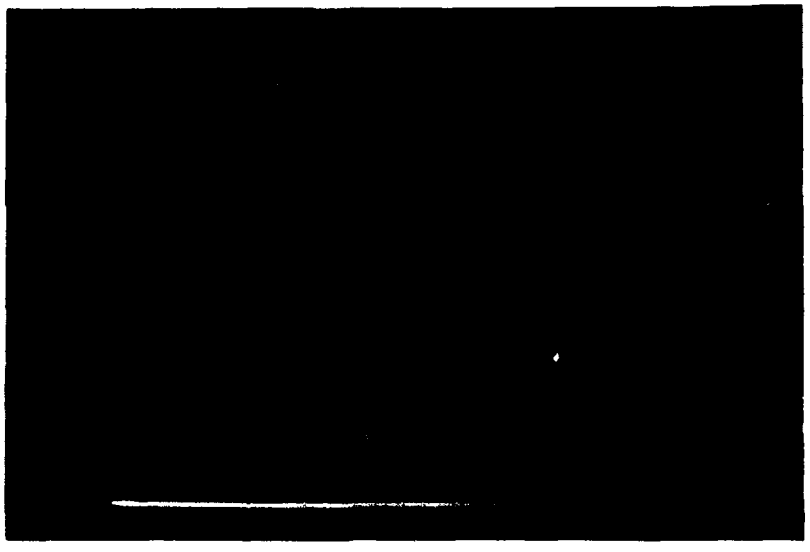


Figure 13: Complete Investment As Set

Figure 14: Epoxy Replica of Set Complete Investment

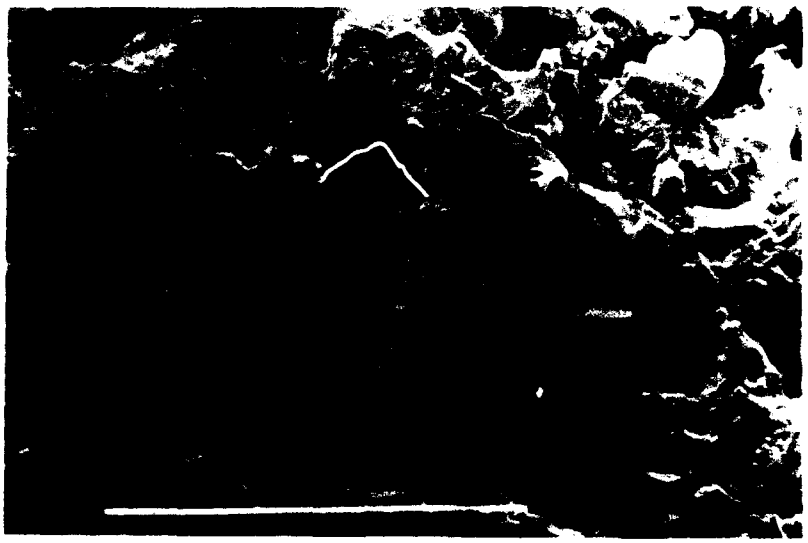
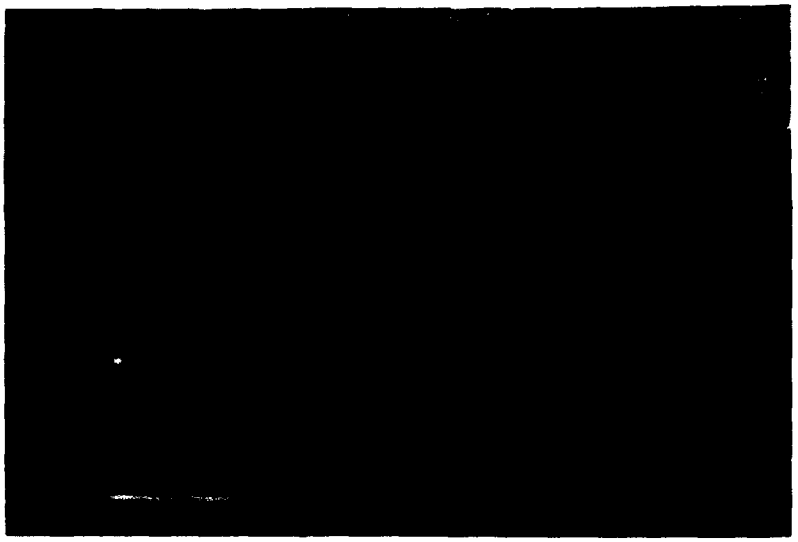


Figure 15: Cera Fina Investment As Set

Figure 16: Epoxy Replica of Set Cera Fina Investment



investments as set against the smooth reference surface demonstrated limited similarity with the original investment surface. Neither the grain nor crystalline structures were evident in the epoxy resin replicas (Figures 12,14,16).

In the next experimental phase, the investment samples were poured against the smooth reference surface and then thermal cycled for one hour. Scanning electron micrographs of 600X magnification were obtained for comparison and confirmed that the gypsum bonded investments become rougher after thermal cycling (Figures 17,19,21). The phosphate bonded investments appeared on SEM micrographs to become only slightly rougher after thermal cycling. However, this roughening was not apparent in all the phosphate bonded investments. The samples of Complete and Cera Fina investment were slightly rougher after thermal cycling while the surface of the thermal cycled Ceramigold investment surface was similar to the set investment surface (Figures 23,25,27). The replication procedure for the thermal cycled samples of the phosphate bonded investments produced less than favorable results. The epoxy resin replicas were not similar to the thermal cycled investment surface (Figures 18,20,22,24,26,28).

Part II

Due to the less than favorable duplication of the phosphate bonded investment samples, only the epoxy replicas of the as set gypsum bonded investments were used in the Ra determination stage of the experiment. The raw data from these samples showed that the Luster Cast and Beauty Cast investment samples were smoother than the Super Span samples. A one way analysis of variance (Table 3) for the epoxy replicas of the as set gypsum

Figure 17: Luster Cast Investment Thermal Cycled

Figure 18: Epoxy Replica of Thermal Cycled Luster Cast Investment

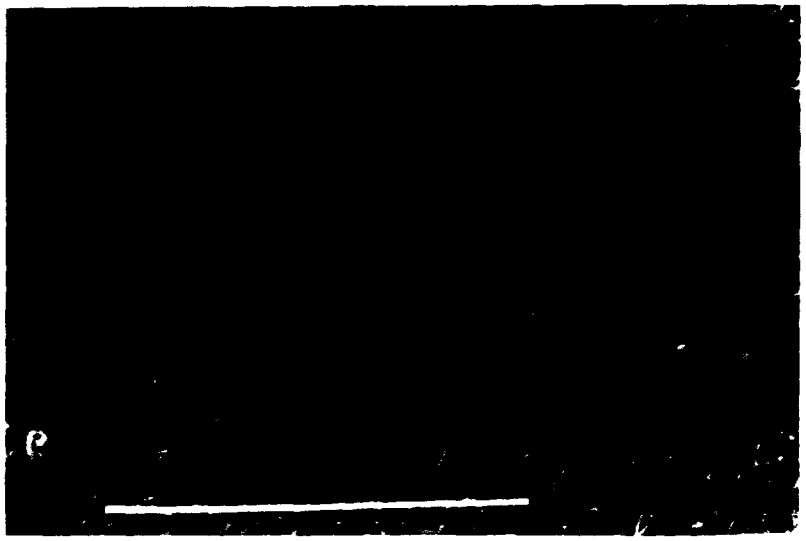
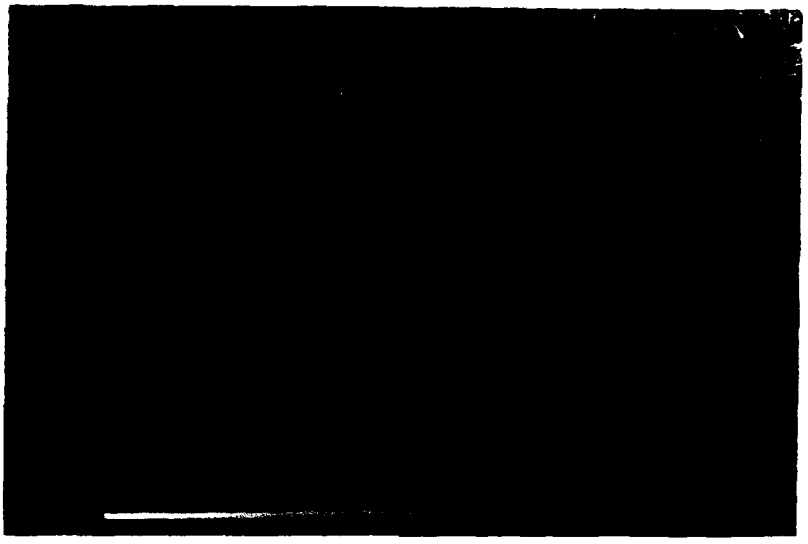


Figure 19: Beauty Cast Investment Thermal Cycled

Figure 20: Epoxy Replica of Thermal Cycled Beauty Cast Investment



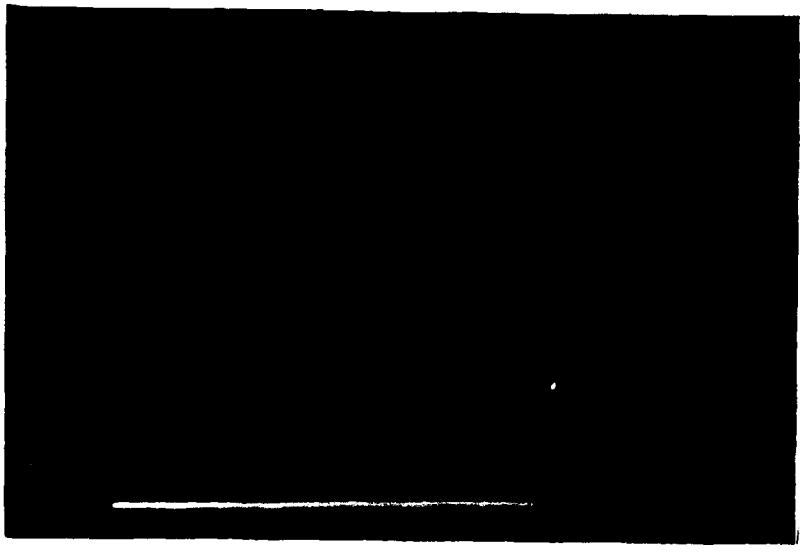


Figure 21: Super Span Investment Thermal Cycled

Figure 22: Epoxy Replica of Thermal Cycled Super Span Investment

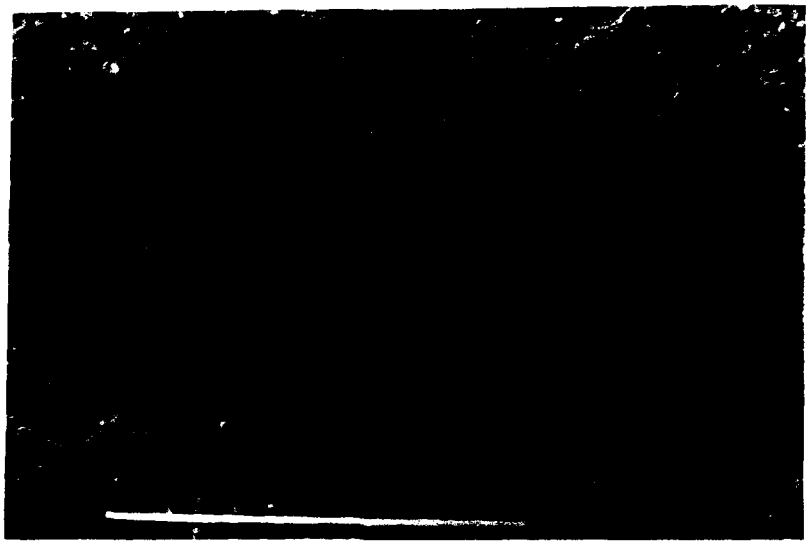


Figure 23: Ceramigold Investment Thermal Cycled

Figure 24: Epoxy Replica of Thermal Cycled Ceramigold Investment

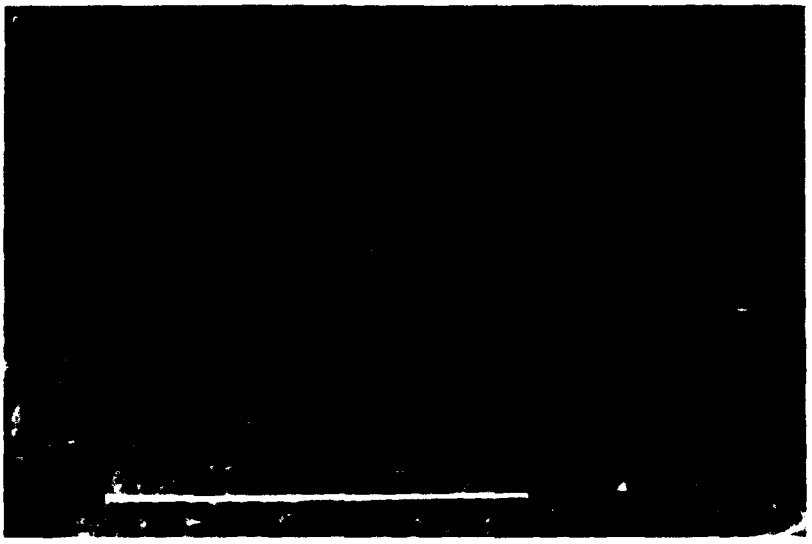


Figure 25: Complete Investment Thermal Cycled

Figure 26: Epoxy Replica of Thermal Cycled Complete Investment

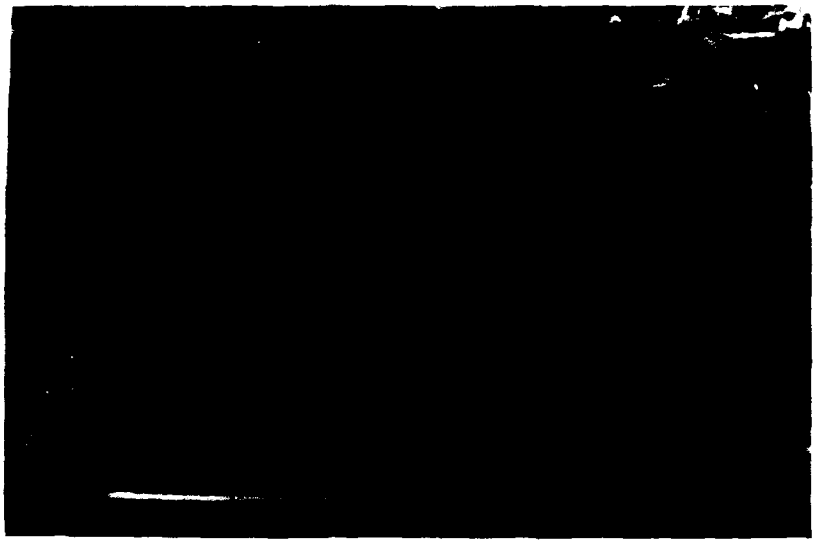
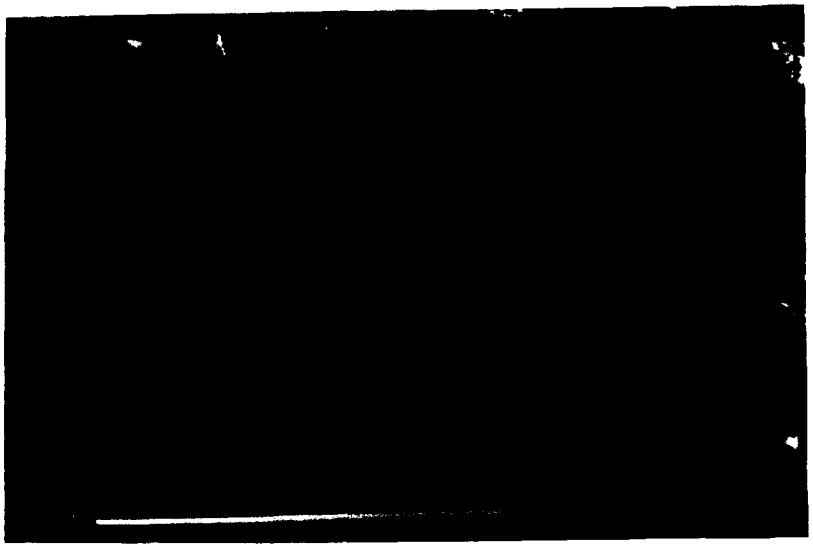


Figure 27: Cera Fina Investment Thermal Cycled

Figure 28: Epoxy Replica of Thermal Cycled Cera Fina Investment



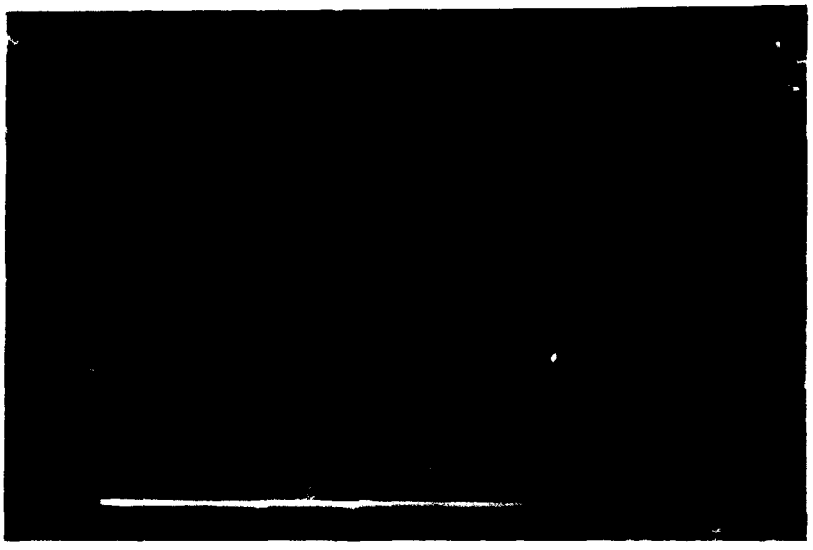


TABLE 3. ONE WAY ANOVA OF THE SURFACE ROUGHNESS OF THE GYPSUM BONDED INVESTMENTS AS SET[1]

Source	Sum of Squares	DF	Mean Square	F Value	Tail Probability
Material	4.5456	2	2.2728	13.47	0.0001
Error	4.5553	27	0.1687		

1. Luster Cast, Beauty Cast, Super Span

bonded investments demonstrated a significant difference (p=0.0001) in surface roughness. The Duncan's Multiple Range Test (Table 4) further demonstrated that the Luster Cast and Beauty Cast investment samples were significantly smoother than the Super Span samples at the confidence level p=0.05.

The epoxy resin reproduction of the thermal cycled investment samples were unfavorable for both the gypsum bonded and phosphate bonded investment samples. While the grain and crystalline structures were evident in some samples, the reliability of the surface reproduction in the epoxy resin was questionable.

Part III

The polycarbonate patterns were invested with the six dental casting investments and a Type III gold alloy was cast against the investment surface. These cast samples exhibited high variability in surface roughness values among the different investment samples (Figure 29). The data of the surface roughness measurements listed the rank of investments from smoothest to roughest: Luster Cast, Beauty Cast, Super Span, Ceramigold, Complete, and Cera Fina. The one way analysis of variance (Table 5) of the surface roughness of these Type III alloy castings demonstrated significant differences (p 0.0001) in the Ra values. Further statistical analysis with Duncan's Multiple Range Test (Table 6) revealed that the castings fabricated with Luster Cast investment were significantly smoother at a p=0.05 confidence level. Also, the Type III casting fabricated with the Complete and Cera Fina investments were significantly rougher than the other castings at the same confidence level.

TABLE 4: DUNCAN'S MULTIPLE RANGE TEST FOR THE SURFACE ROUGHNESS OF THE GYPSUM BONDED INVESTMENT AS SET

Investment	Ra Means (microns)	Sample Size
Beauty Cast	0.88 [1.]	10
Luster Cast	0.89	10
Super Span	1.71	10

1. vertical lines connect the means of Beauty Cast and Luster Cast that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.

Figure 29: Histogram of the Surface Roughness of the Type III Castings Fabricated with the Dental Investments

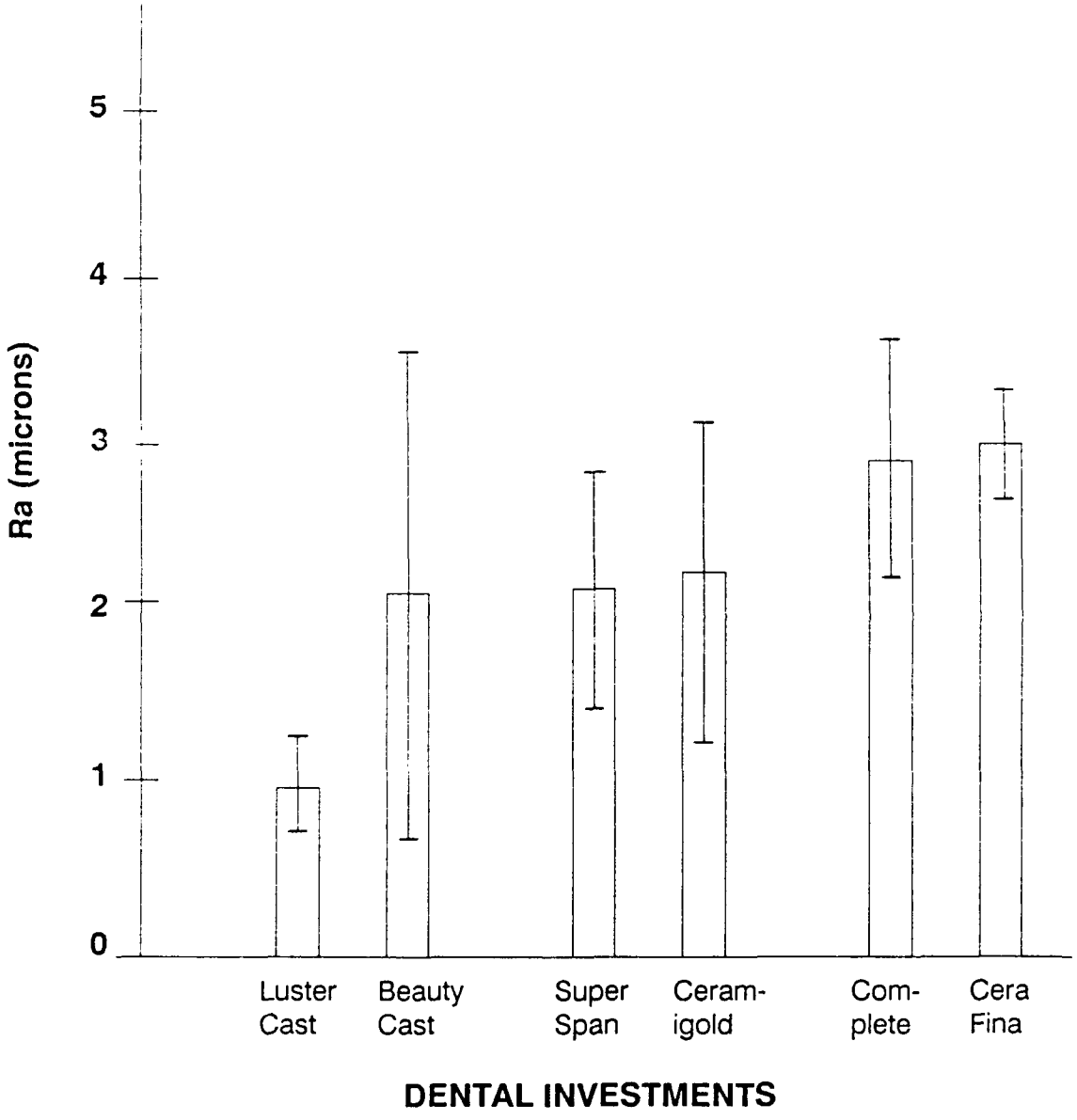

Ra (microns)
5
4
3
2
1
0
Luster Cast
Beauty Cast
Super Span
Ceram-igold
Com-plete
Cera Fina
DENTAL INVESTMENTS

TABLE 5: ONE WAY ANOVA OF THE SURFACE ROUGHNESS OF THE TYPE III ALLOY CASTINGS FABRICATED WITH THE DENTAL INVESTMENTS[1]

Source	Sum of Squares	DF	Mean Square	F Value	Tail Probability
Material	28.0179	5	5.6036	8.38	0.0001
Error	36.0895	54	0.6683		

1. Luster Cast, Beauty Cast, Super Span, Ceramigold, Complete, Cera Fina

TABLE 6: DUNCAN'S MULTIPLE RANGE TEST FOR THE SURFACE ROUGHNESS OF THE TYPE III ALLOY CASTINGS FABRICATED WITH THE DENTAL INVESTMENTS

Investment	Ra Means (microns)			Sample Size
Luster Cast	0.87			10
Beauty Cast	2.07	1.		10
Super Span	2.07			10
Ceramigold	2.23			10
Complete	2.80		2.	10
Cera Fina	3.01			10

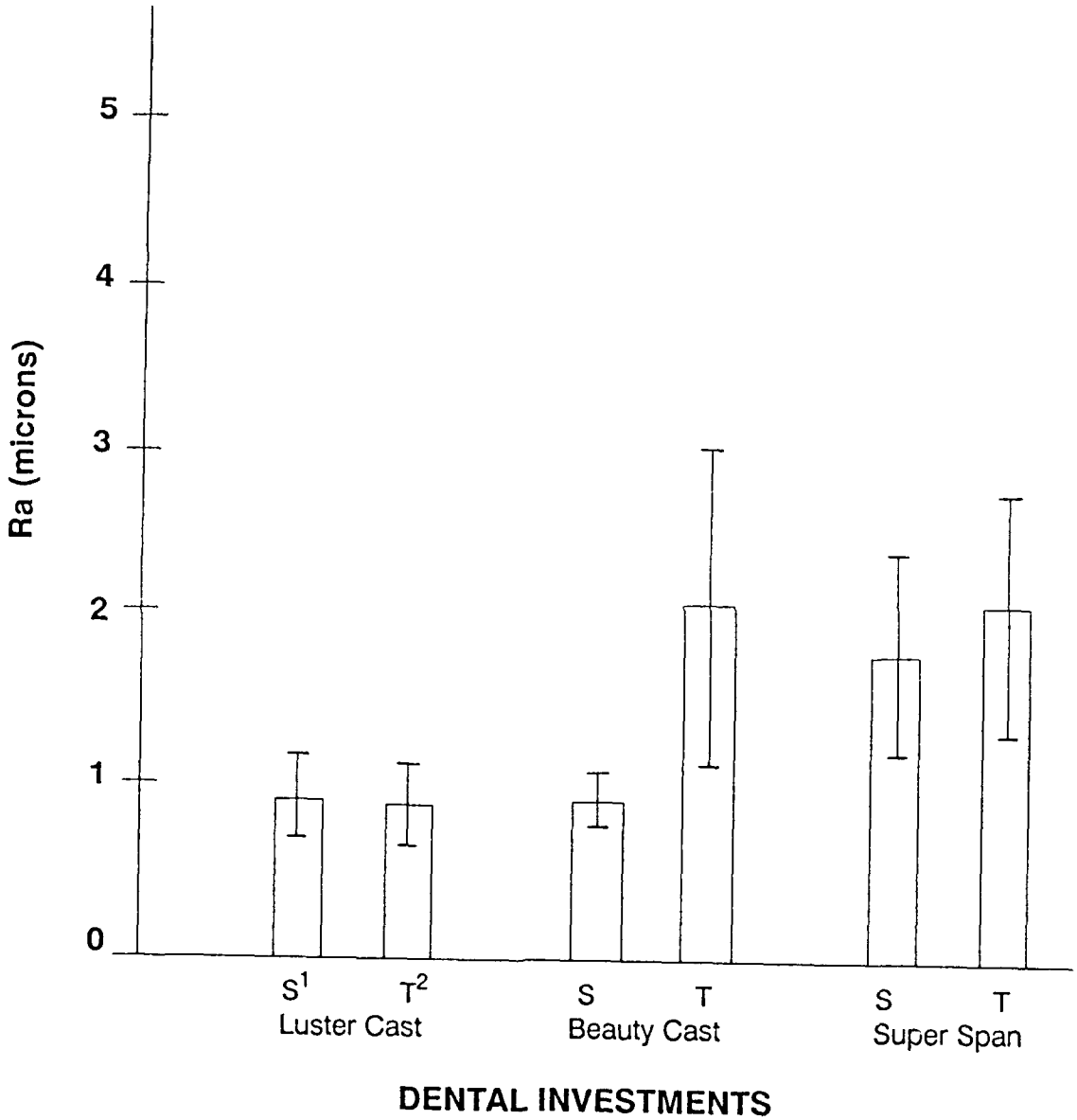
1. vertical lines connect the means of Beauty Cast, Super Span, Ceramigold and Complete that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.
2. vertical lines connect the means of Complete and Cera Fina that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.

When the surface roughness values of the gypsum bonded investments as set against the smooth reference surface and the Type III casting fabricated with these same investments were compared, the results were: the castings fabricated with two of the investments, i.e. Beauty Cast and Super Span, were rougher than the as set investment surface while the castings fabricated with the Luster Cast investment were smoother than the original set investment surface (Figure 30). Statistical analysis was performed with this data and the two way analysis of variance (Table 7) demonstrated a significant difference between the three investment products ($p=0.0002$) and between the surfaces of the investment as set and Type III alloy casting ($p=0.0075$). The test samples were divided into two groups when the data was statistically analysed with the Duncan's Multiple Range Test (Table 8). The Luster Cast and Beauty Cast as set investment samples and the Type III casting fabricated with Luster Cast were combined in a group of smoother samples while the Type III castings fabricated with Beauty Cast and Super Span as well as the Super Span as set investment samples were categorized as rougher samples.

The statistical data agreed with the apparent surface roughness of the SEM micrographs. Samples of Type III alloy cast against Luster Cast investment were the smoothest while castings with Beauty Cast and Super Span were rougher (Figures 31,32,33).

The ceramometal alloy cast against the phosphate bonded investments ranked as follows from smoothest to roughest: Ceramigold, Complete, and Cera Fina. The one way analysis of variance (Table 9) performed on the surface roughness data from the ceramometal casting fabricated with the phosphate bonded investments demonstrated a statistically significant difference ($p=0.0059$). Further analysis utilizing the Duncan's Multiple Range Test

Figure 30: Histogram of the Surface Roughness of the Gypsum Bonded Investments as set and the Type III Castings Fabricated with the Gypsum Bonded Investments



1. Investment as Set
2. Type-III Casting

TABLE 7: TWO WAY ANOVA FOR THE SURFACE ROUGHNESS OF THE GYPSUM BONDED INVESTMENTS[1] AS SET AND THE TYPE III CASTINGS FABRICATED WITH THE GYPSUM BONDED INVESTMENTS

Source	Sum of Squares	DF	Mean Square	F Value	Tail Probability
Material	10.3114	2	5.1557	10.22	0.0002
Condition	3.8949	1	3.8949	7.72	0.0075
Interaction	3.8054	2	1.9027	3.77	0.0293
Error	27.2451	54	0.5045		

1. Luster Cast, Beauty Cast, Super Span

TABLE 8: DUNCAN'S MULTIPLE RANGE TEST FOR THE SURFACE ROUGHNESS OF THE GYPSUM BONDED INVESTMENTS AS SET AND THE TYPE III CASTINGS FABRICATED WITH THE GYPSUM BONDED INVESTMENTS

Investment/Test Conditions	Ra Means (microns)		Sample Size
Luster Cast/Type III Casting	0.87	1.	10
Beauty Cast/Set	0.88		10
Luster Cast/Set	0.89		10
Super Span/Set	1.71	2.	10
Beauty Cast/Type III Casting	2.07		10
Super Span/Type III Casting	2.07		10

1. vertical lines connect the means of Beauty Cast and Luster Cast as set and Type III alloy cast against Luster Cast that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.

2. vertical lines connect the means of Super Span as set and Type III alloy cast against Beauty Cast and Super Span that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.

Figure 31: Type III Alloy Cast Against Luster Cast Investment

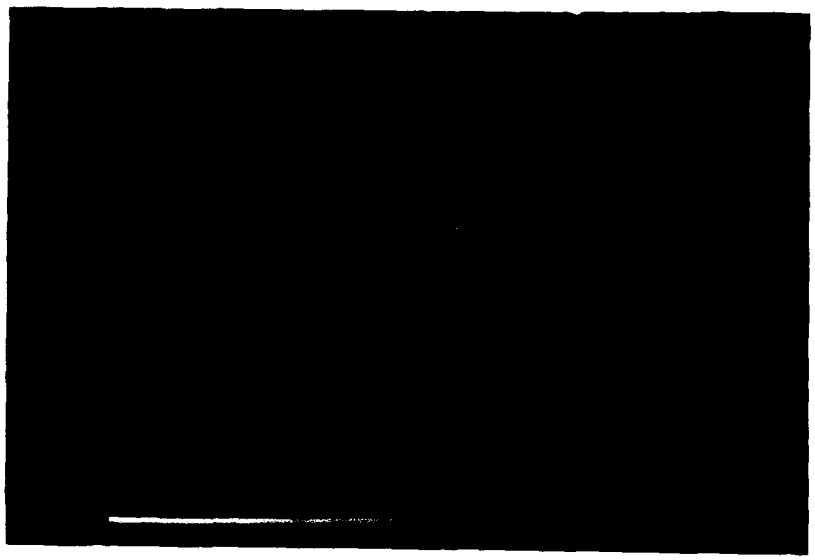


Figure 32: Type III Alloy Cast Against Beauty Cast Investment

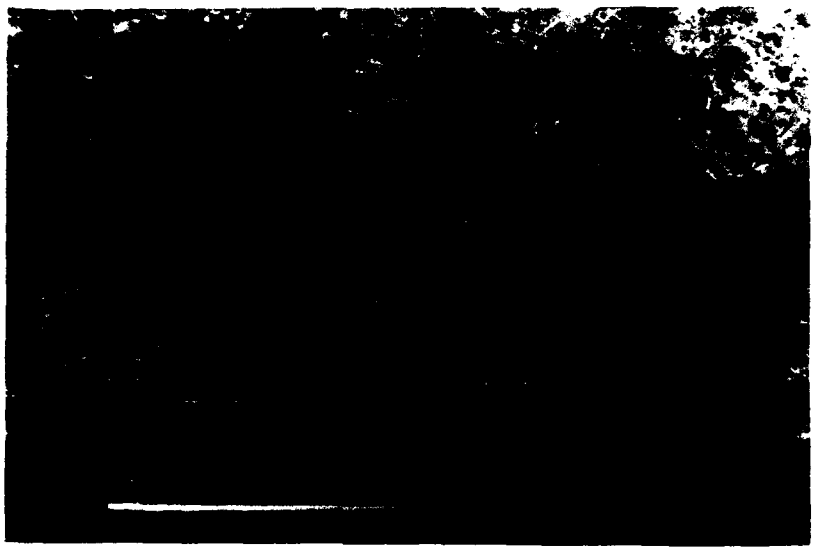


Figure 33: Type III Alloy Cast Against Super Span Investment

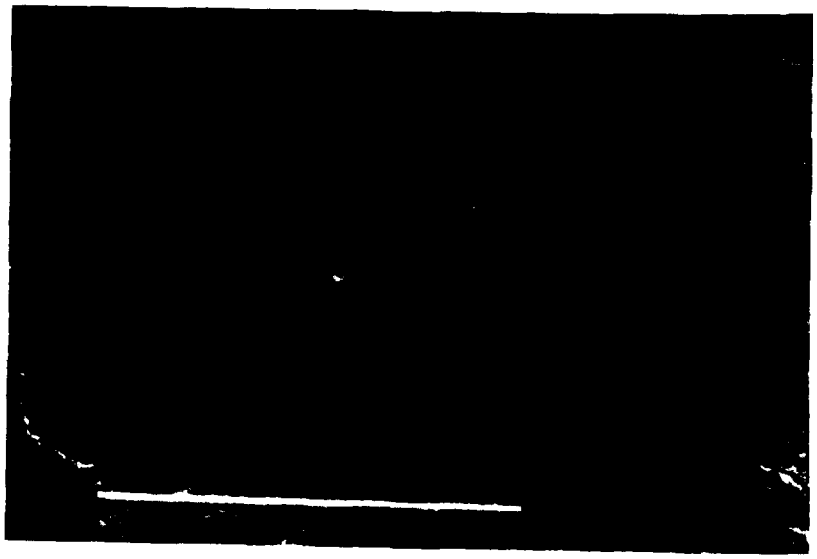


TABLE 9: ONE WAY ANOVA OF THE SURFACE ROUGHNESS OF THE CERAMOMETAL CASTINGS FABRICATED WITH THE PHOSPHATE BONDED INVESTMENTS[1]

Source	Sum of Squares	DF	Mean Square	F Value	Tail Probability
Material	2.8190	2	1.4095	6.25	0.0059
Error	6.0890	27	0.2255		

1. Ceramigold, Complete, Cera Fina

(Table 10) showed that ceramometal castings fabricated with Cera Fina investment were substantially rougher at p 0.05 than castings with either Ceramigold or Complete investment.

The Type III castings appeared to be smoother than the ceramometal castings with the phosphate bonded investments (Figure 34). A two way analysis of variance (Table 11) was performed with this data and revealed a statistically significant difference between the various investment products ($p=0.009$) and between the Type III and ceramometal castings ($p=0.0016$). The Duncan's Multiple Range Test (Table 12) further demonstrated a rank ordering of test samples with Type III alloy cast with Ceramigold appreciably smoother and ceramometal alloy cast with Complete and Cera Fina noteably rougher than the remaining samples.

The general appearance on the SEM micrographs of the Type III and ceramometal surfaces cast into the phosphate bonded investments agreed with the raw Ra data (Figures 35,36,37,38,39,40). The ceramometal alloy castings were rougher than the Type III alloy castings with all the phosphate bonded investment products. Both the Type III and ceramometal alloys cast against the phosphate bonded investment surface produced the following rank from smoothest to roughest: Ceramigold, Complete, and Cera Fina.

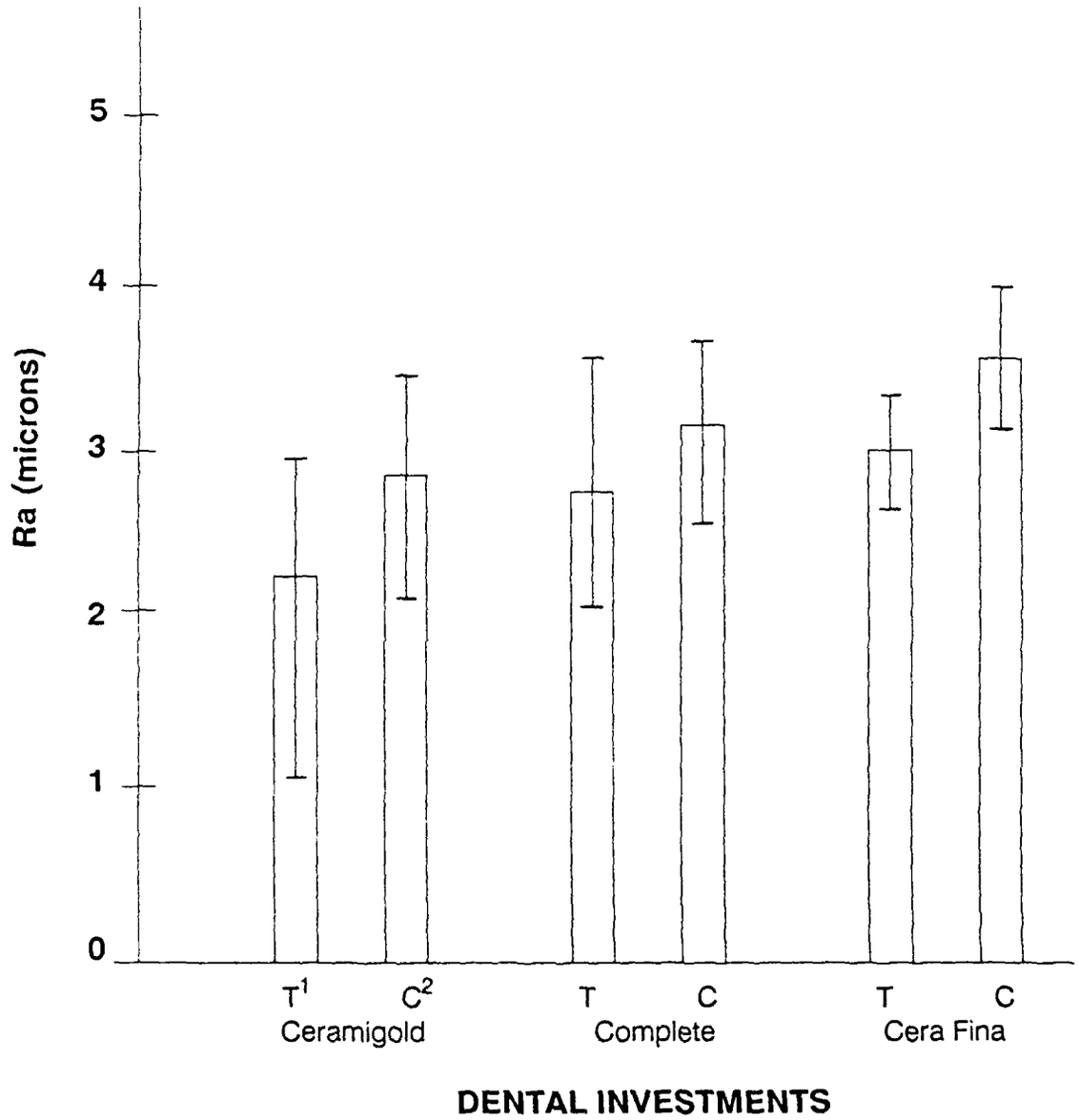
The data in Table 12 revealed that the Ra of the ceramometal alloy was greater than the Type III alloy when cast into the same investment. The means of the Ra's were subjected to linear regression analyses (Figure 41). The resulting regression was not significant, $F = 5.15$, $p = 0.26$. However, there was a trend toward greater roughness of the ceramometal when compared to the Type III alloy.

TABLE 10: DUNCAN'S MULTIPLE RANGE TEST FOR THE SURFACE ROUGHNESS OF THE CERAMOMETAL CASTINGS FABRICATED WITH THE PHOSPHATE BONDED INVESTMENTS

Investment	Ra Means (microns)		Sample Size
Ceramigold	2.86	1.	10
Complete	3.13		10
Cera Fina	3.60		10

1. vertical lines connect the means of Ceramigold and Complete that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.

Figure 34: Histogram of the Surface Roughness of the Type III and Ceramometal Castings Fabricated with the Phosphate Bonded Investments



1. Type III Casting
2. Ceramometal Casting

TABLE 11: TWO WAY ANOVA OF THE SURFACE ROUGHNESS ON THE TYPE III AND CERAMOMETAL ALLOY CASTINGS FABRICATED WITH THE PHOSPHATE BONDED INVESTMENTS[1]

Source	Sum of Squares	DF	Mean Square	F Value	Tail Probability
Material	5.8155	2	2.9078	8.06	0.0009
Condition	3.9650	1	3.9650	10.99	0.0016
Interaction	0.2736	2	0.1368	0.38	0.6863
Error	19.4888	54	0.3609		

1. Ceramigold, Complete, Cera Fina

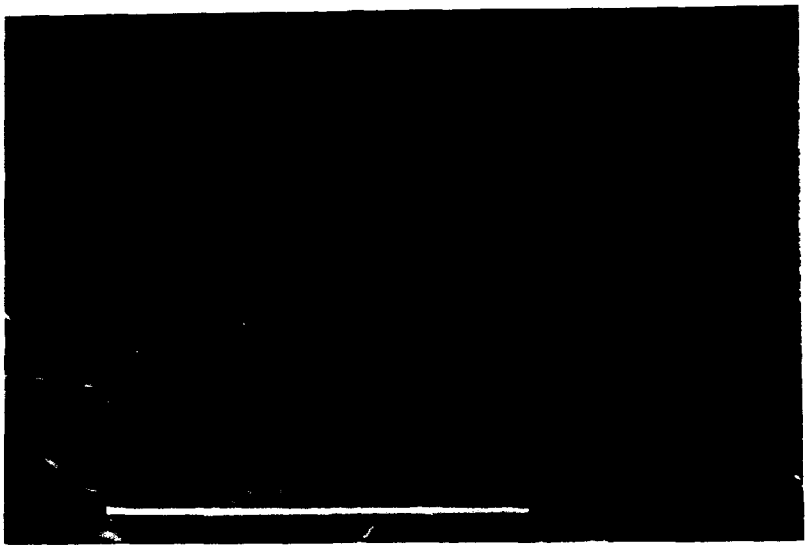
TABLE 12: DUNCAN'S MULTIPLE RANGE TEST FOR THE SURFACE ROUGHNESS OF THE TYPE III AND CERAMOMETAL ALLOY CASTINGS FABRICATED WITH THE PHOSPHATE BONDED INVESTMENTS

Investment/Casting	Ra Means (microns)		Sample Size
Ceramigold/Type III	2.23		10
Complete/Type III	2.80	1.	10
Ceramigold/Ceramometal	2.86		10
Cera Fina/Type III	3.01		10
Complete/Ceramometal	3.13	2.	10
Cera Fina/Ceramometal	3.60		10

1. vertical lines connect the means of Type III alloy cast against Complete and Cera Fina and Ceramometal alloy cast against Ceramigold and Complete that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.
2. vertical lines connect the means of Ceramometal alloy cast against Complete and Cera Fina that are not statistically significantly different at the p 0.05 level by the Duncan's Multiple Range Test.

Figure 35: Type III Alloy Cast Against Ceramigold Investment

Figure 36: Ceramometal Alloy Cast Against Ceramigold Investment



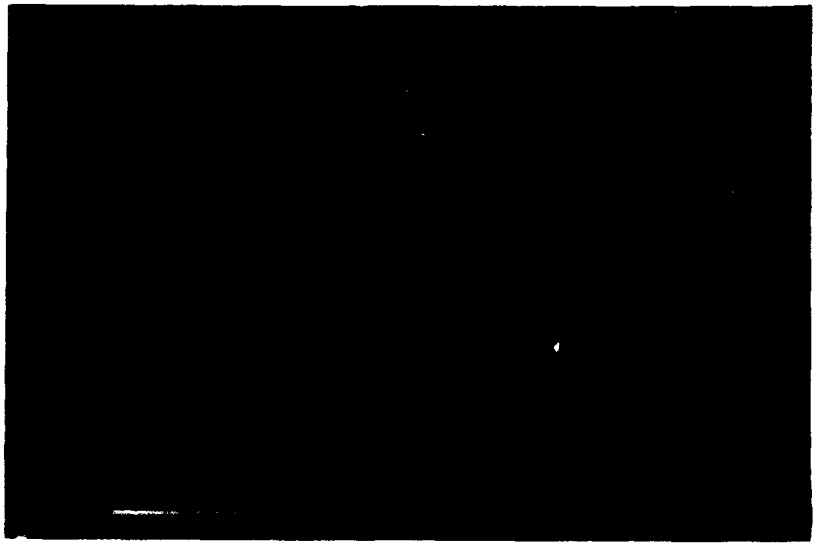


Figure 37: Type III Alloy Cast Against Complete Investment

Figure 38: Ceramometal Alloy Cast Against Complete Investment

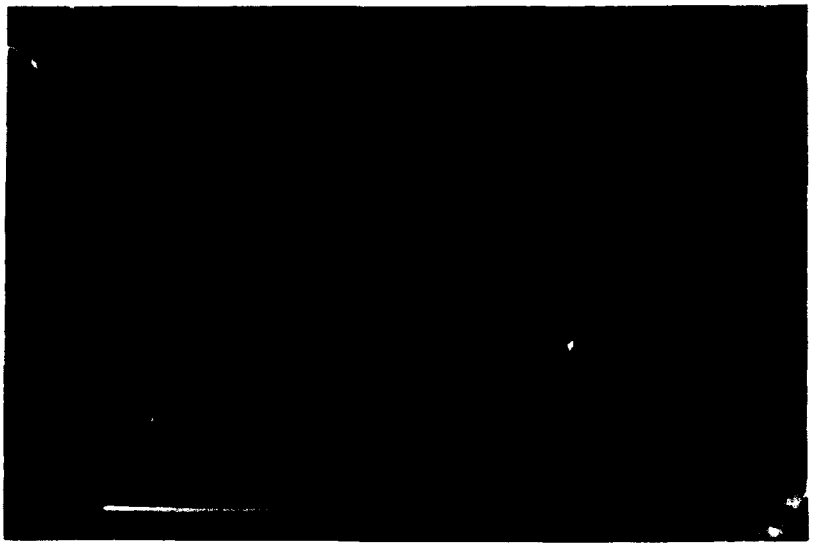
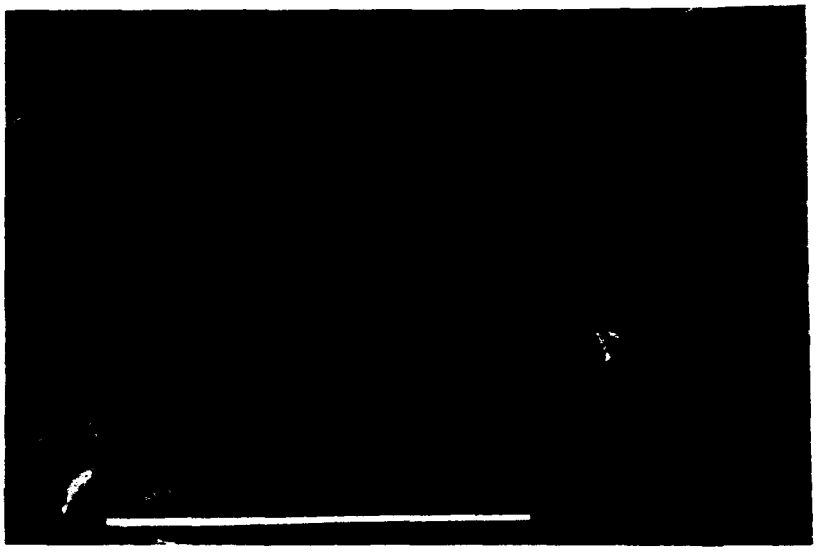


Figure 39: Type III Alloy Cast Against Cera Fina Investment

Figure 40: Ceramometal Alloy Cast Against Cera Fina Investment



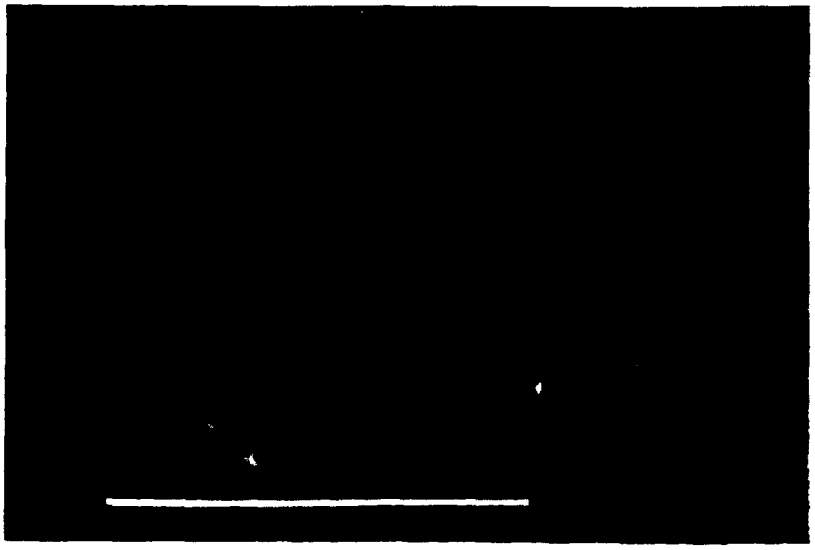
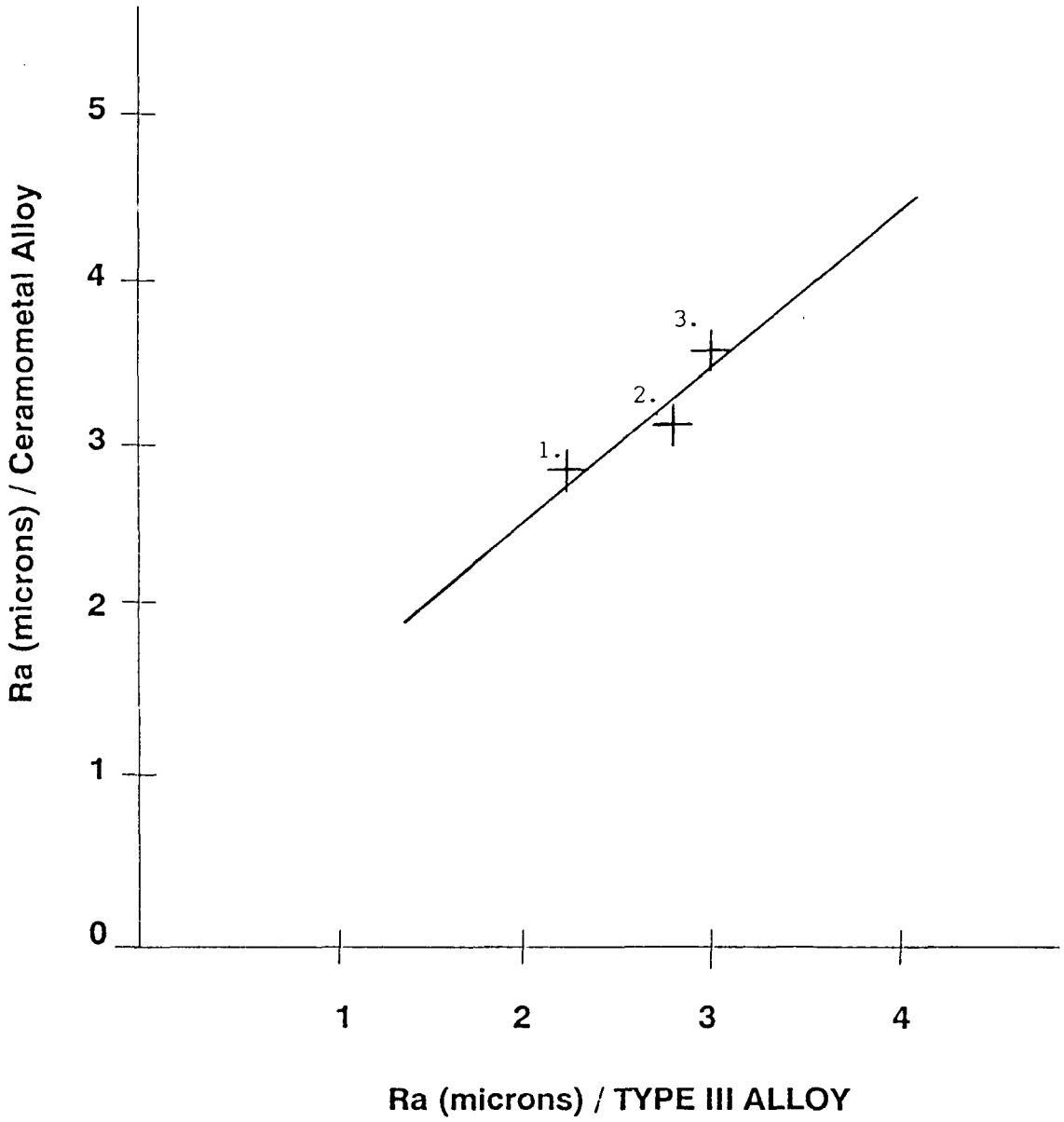


Figure 41: Linear Regression Analysis of the Ra Means of the Type III and Ceramometal Alloys Cast into Phosphate Bonded Investments



1. Ceramigold
2. Complete
3. Cera Fina

IV. DISCUSSION

The surface roughness of the internal aspects (intaglio) of a cast restoration is the product of at least five individual transfers from one surface to another. The surface texture of the prepared tooth is transferred through an impression material to an improved dental stone. The texture of the stone die is then transferred through the wax pattern to the investment mold against which the alloy is cast. The surface roughness of the original preparation is hopefully reproduced without alteration to the restoration. The dental investment is crucial to the lost wax method of casting for it is the medium for transferring the wax replica of a restoration to the metal alloy. The successful transfer of the original surface roughness is directly influenced by a number of factors: namely, the casting investment's composition, fineness, liquid to powder ratio or other physical properties, the casting alloy's composition, the liquidus temperature of the alloy, the casting pressure and temperature and the interaction of the molten alloy with the investment surface.

The first group of dental casting investments evaluated in the study were the gypsum bonded investments Luster Cast, Beauty Cast and Super Span. These investments demonstrated measurable differences in surface roughness. The SEM micrographs revealed a disparity in the apparent surface roughness of the various investment products. This experimental finding agreed with Finger (15) who discovered that different investments produced varying surface roughness. The Luster Cast and Beauty Cast samples exhibited long, thin calcium sulfate crystals closely packed with either silica refractory or modifier particles packed within the interstices. Super Span revealed larger

calcium sulfate dendritic structures with similar refractory particles interspersed between the crystals. The Ra data supported these observations with the surface roughness for Super Span investment being substantially larger than either Luster Cast or Beauty Cast. The data supported the concepts of Phillips (33) and Pomes (34) that the composition and fineness of the investment particles effects the surface roughness of the material.

The epoxy resin replicas of the gypsum bonded investments produced by a method outlined by Barrett (3) exhibited satisfactory surface reproduction according to a comparision of the SEM micrographs. The size and distribution of the crystals and additional particles in the replica agreed favorably with the original investment sample. Therefore, the reproduction procedure outlined by Barrett (3) for gypsum products can be satisfactorily adapted to set gypsum bonded investment products.

The Ra measurements from these epoxy replicas also correlated with the original investment samples. The numerical data demonstrated that the Luster Cast and Beauty Cast investments were significantly smoother than Super Span. The composition and fineness of Luster Cast and Beauty Cast investments created an inherently smoother surface confirmed with the SEM micrographs and indirectly measured. Additional research is needed to evaluate the application of this reproduction and measurement method with the other stages in the lost wax casting technique. The surface roughness of the original prepared tooth could also be measured through the various stages and transfers to the resultant cast restoration.

The next group of dental investments evaluated were the phosphate bonded investments Ceramigold, Complete and Cera Fina. The surface roughness variability in the gypsum bonded products was also observed in these investments. The SEM micrographs of the investment surface revealed a wide

range of surface roughness. Ceramigold displayed the smoothest surface with Complete and Cera Fina exhibiting rougher surfaces. The surface roughness of this class of dental investments was difficult to accurately evaluate with SEM micrographs. However, the roughness resulted from the investment's particle size and density on the surface including the inherent roughness of the particles. Ceramigold had small particle clusters closely packed, while Complete exhibited larger particles with wider spaces. The particles of investment material in the Ceramigold sample appeared more porous than the crystals of Complete investment. Conversely, Cera Fina created a surface that exhibited large amorphous plaques of investment material with a roughened surface and wide spaces. These results were unexpected because the manufacturer of Cera Fina claimed an ultra fine particle size. This data implied that the composition and fineness of the phosphate bonded investments have a different relationship to surface roughness than the gypsum bonded investment products. While the epoxy resin replicas of the gypsum bonded investments corresponded to the original investment surface, the reproduction of the phosphate bonded samples was poorer. The epoxy resin replicas had limited resemblance to the original phosphate bonded investment surface and, therefore, did not depict the initial surface roughness.

The Ra measurement data from these epoxy replicas were considered invalid and not statistically analyzed. A hypothesis for this poor surface reproduction is that the phosphate bonded investment and the elastomeric impression material interacted to create an artifact. This surface reaction may be related to a surface energy phenonenom described by Phillips (33). If the surface energy of the investment and impression material were low, adequate wetting of the surfaces was inhibited and the artifact resulted. Further research is needed to examine this phenomenon and develop an

alternative approach for reliable surface reproduction of the phosphate bonded investments. For example, a hydrophilic polyvinyl siloxane could be used instead of the nonhydrophilic polyvinyl siloxane. An alternative approach to accurately reproduce the investment surface would be another elastomic impression material, e.g. polysulfide or polyether. This approach gives rise to a number of questions concerning the wettability of these impression materials and how they will react to the investment and epoxy resin.

A different approach for further research would involve electroplating of the sputter coated investment surface. The investment surface could be sputter coated with a conductive metal and then electroplated similar to SEM microscopy . The electroplating could then be incorporated into an impression and used to fabricate the epoxy resin dies. Many questions are generated with this approach. For example, what thickness of sputter coating is sufficient? Will the investment surface be disguised or distorted by the metal coating? One of these approaches may be successful in accurately transferring the surface roughness from the phosphate bonded investment to the epoxy resin for measurement with the profilometer.

The next test in this experiment was the thermal cycling of the dental investment samples to 1300°F for one hour. The gypsum bonded investment materials produced visible surface changes from the set condition. During heating, the excess free water and water of crystallization evaporated and the calcium sulfate was transformed to the anhydrous state while the refractory particles were inverted from the low crystalline to the high crystalline form of silica with the associated increase in volume and decrease in density. However, during the cooling phase the silica refractory particles returned from the high crystalline to the low crystalline form

while the calcium sulfate remained in the anhydrous state. According to Phillips (33), this dehydration and inversion during thermal cycling results in an overall contraction of the investment below its original dimensions. These inversions and transformations with the gypsum bonded investments produced results in which Beauty Cast exhibited the smoothest surface after thermal cycling and compared favorably to the original set investment surface. Luster Cast appeared on SEM micrographs to have a rougher surface after thermal cycling than Super Span. The number of calcium sulfate crystals in the Luster Cast sample was diminished after thermal cycling with a corresponding increase of intercrystalline spacing. This increase in space between the crystals was also evident in Super Span, but to a lesser degree. Also, the calcium sulfate crystals of Super Span remained more intact after thermal cycling. The SEM micrographs confirmed that all of the gypsum bonded investments were rougher after thermal cycling and the increase in surface roughness was the result of greater intercrystalline spacing and an increased roughening of the crystals. The epoxy resin replicas were less than favorable. The SEM micrographs confirmed the poor surface reproduction in the replicas and did not resemble the original thermal cycled investment surface. One explanation was that the surface hardness and compressive strength of the gypsum bonded investments was reduced after thermal cycling so the weight and pressure of the elastomeric impression disrupted the investment surface. Additional research is needed to develop a technique to obviate this phenomenon. One resolution may be to strengthen the investment surface with a pressureless material: for example, in an atmosphere of cyanoacrylate adhesive, without distortion. The hardened surface could then be reproduced through a polyvinyl siloxane impression to the epoxy resin die for an indirect surface measurement. Another method to improve the surface

reproduction could involve the electroplating of the sputter coated investment surface, mentioned previously in reference to the phosphate bonded investments.

The phosphate bonded investments responded surprisingly after thermal cycling. While the gypsum bonded investments became noticeably rougher after heating, the change in surface roughness of the phosphate bonded investments was less apparent. The Complete and Cera Fina investment products appeared on SEM micrographs to become slightly rougher than the set investment surfaces after thermal cycling, while the Ceramigold product maintained a similar surface roughness. This data indicated that the formation of various polymorphic forms of the phosphate bonded investment at elevated temperatures may not have a great effect on the inherent surface roughness. Further research is needed to evaluate the unique properties of the phosphate bonded investments that would cause only a slight alteration in the surface roughness after thermal cycling and how the investment compostion and fineness affects the resultant surface roughness. An expanded investigation could evalute the composition and physical properties of an increased number of phosphate bonded investment products and determine their surface roughness. The epoxy resin reproduction in this stage of the experiment produced similar to the set phosphate bonded samples. As with the set investment surface, further research is needed to evaluate this artifact and develop an alternative material or technique to obviate this phenomenon.

In the third stage of this study, a Type III gold alloy was cast against the gypsum bonded and phosphate bonded dental investments and a ceramometal alloy was cast against the phosphate bonded investments. The surface roughness of these castings was measured with the profilometer instrument and a representative sample was photographed at 600X magnification

with the scanning electron microscope. The Type III alloy cast against the gypsum bonded investments produced a ranking in which Luster Cast was substantially smoother than Beauty Cast and Super Span (Table 6). This ranking of surface roughness values did not correspond to the ranking or statistically significant differences exhibited by the set investment surfaces. In Table 4, the set investment surfaces of Luster Cast and Beauty Cast were significantly smoother than the surface of Super Span. However, the data contained in Table 6 illustrated that the Type III alloy cast against Luster Cast was significantly smoother than both Beauty Cast and Super Span. The reduction in the surface roughness of the Type III alloy cast against Luster Cast was unexpected and raised questions as to the investment's unique properties that produced this result. Further research is needed to confirm the data for Luster Cast by repeating the experiment and comparing the surface roughness. Additional research could expand the scope of this investigation by evaluating different types of alloys cast against Luster Cast investment to determine whether the decrease in surface roughness was unique to this alloy-investment combination. The largest change in surface roughness from the set investment surface to the Type III alloy casting surface was evident with Beauty Cast. The set investment surface roughness of Beauty Cast was low, 0.884 ($\pm$ 0.146) microns, while the surface roughness of the Type III alloy casting was relatively high, 2.071 ($\pm$ 1.403) microns. The statistical analysis grouped Beauty Cast with the smoother set investment surfaces and with the rougher Type III alloy cast surfaces. Thus, Beauty Cast investment exhibited the greatest change in surface roughness from the set investment to the alloy surface (Figure 30). This change in surface roughness was statistically significant as seen in Table 8. The SEM micrographs of the casting made with the Beauty Cast investment depicted a

surface that was pitted with possible inclusions of investment material in the alloy. The surface of this casting sample was similar to the surface of the casting with the Super Span investment. This data supported the findings of Phillips (33) because the molten alloy appeared to attack deteriorate the investment surface during the casting process. Further research is needed to investigate the factors of the casting process, e.g. burnout temperature, casting temperature, or casting pressure and study their relationship to the alloy-investment interaction. For example, examine the effects of reducing agents incorporated in the dental investments on the cast alloy surface roughness.

The Type III alloy cast against the phosphate bonded investments produced a ranking in which Ceramigold recorded the smoothest surface while Cera Fina exhibited the roughest. The Type III alloy cast against Ceramigold was significantly smoother than the alloy cast against Cera Fina (Table 6) while the surface roughness of the alloy cast against Complete was intermediate. The data in Table 6 also illustrated that alloy cast against the gypsum bonded investments were smoother than the alloy cast against the phosphate bonded investments. This study supported the research of Cooney, et al and demonstrated that the Type III alloy cast against Luster Cast investment produced the statistically smoothest surface while the Type III alloy cast against Cera Fina created the statistically roughest surface. The Type III alloy cast against Beauty Cast, Super Span, Ceramigold and Complete investments exhibited intermediate surface roughness that was not statistically different from one another.

The ceramometal alloy cast against the phosphate bonded investments produced the same rank observed with the Type III alloy cast against the same investments. The ceramometal alloy cast against the Ceramigold and Complete

investments recorded the smoothest surfaces while the alloy cast against the Cera Fina investment created a significantly rougher surface (Table 10). This ranking agreed with the SEM micrographs of the original set investment surfaces. Upon comparison of the ceramometal and Type III alloys cast against the phosphate bonded investments a composite picture of rank and statistical significance emerged. Type III alloy cast against Ceramigold investment produced the statistically smoothest surface while ceramometal alloy cast against Cera Fina produced the roughest surface. The remaining samples in Table 12 were grouped in an intermediate statistically significant subset. A closer examination of the data revealed that the Type III alloy castings were smoother than the ceramometal alloys. Therefore, the phosphate bonded investments produced smoother castings with the Type III alloy than with the ceramometal alloy. Phillips (33) defined fit as the ability of the casting to reproduce the pattern from which it was constructed. Therefore, it seemed reasonable to deduce that smoother castings: namely, alloys cast against gypsum bonded investments or Type III alloy cast against phosphate bonded investments, should exhibit a better fit. Conversely, Cooney's research (6,7) demonstrated that less marginal opening occured with alloys cast against phosphate bonded investments, exhibiting an increased surface roughness. This contradiction raised questions as to the relationship of the surface roughness and fit of castings. In light of this data, further research is needed to study the correlation between the quantitated surface roughness of the investments and the marginal fit of cast restorations.

There are numerous factors that affect surface roughness during the casting operation. The dental investment and metal alloy have an effect on the surface roughness of the casting while the interaction between the investment and the metal alloy also affects the resultant casting. The SEM

micrographs of the castings in this part of the study graphically verified these statements. The Type III alloys cast against the gypsum bonded investments displayed a relatively flat surface with varying degrees of porosity, investment inclusions and surface roughness. However, the surface of the Type III alloy cast against the phosphate bonded investments was dissimilar to the alloy cast against the gypsum bonded investment. The surface of these castings was globular with alloy spheres of varying sizes, shapes and degrees of roughness. The effect of the alloy or investment was further emphasized in the comparison of the Type III and ceramometal alloys cast against the phosphate bonded investments. The surface of the ceramometal alloy cast against the phoshpate bonded investment had a similar appearance to the Type III alloy casting. However, the alloy spheres of the Type III castings exhibited a tighter packing and a smaller size. These results confirmed that the alloy as well as the dental investment affects the surface characteristics and surface roughness of the resultant castings.

The numerical data from this part of the study also explained the appearance on SEM micrographs of the Type III and ceramometal alloy cast against the phosphate bonded investments and correlated the appearance with the surface roughness. The data in Table 12 indicated that the surface of the ceramometal alloy was slightly rougher than the Type III alloy cast against the phosphate bonded investment. This data correlated with the appearance of the corresponding SEM micrographs. In addition, the Linear Regression Analysis of Figure 41 further acknowledged the trend toward the greater surface roughness of the ceramomaetal alloy compared to the Type III alloy. This data correlated well with the appearance of the surface roughness on the SEM micrographs when the spheres of ceramometal alloy appeared smaller, more tightly packed but smoother than the spheres of the Type III alloy castings.

Therefore, the surface roughness of the Type III and ceramometal alloys cast against the phosphate bonded investments were related to the size and packing density of the alloy spheres on the surface and the roughness of the alloy spheres. This relationship could be further evaluated in an experimental design that included: an expanded number of alloys, different types of alloys, or an expanded number of dental casting investments. In addition, the alloy-investment interaction on the surface roughness could be identified in an experimental design that would systematically alter factors in the dental casting investment or casting alloys to measure the resultant surface roughness.

V. SUMMARY

This study investigated the effect of thermal cycling on the surface roughness of dental casting investments. A recently developed method of measuring the surface roughness of gypsum product was used to indirectly measure the Roughness Average (Ra) values. The dental casting investment surfaces analyzed were: 1) the investment surface set against a smooth reference surface, 2) the investment surface after thermal cycling to 1300°F for one hour, 3) the Type III gold alloy surface cast against the smooth gypsum bonded and phosphate bonded investment surfaces, and 4) the ceramometal alloy surface cast against the smooth phosphate bonded investment surface. The conclusions drawn were:

1) The scanning electron micrographs of the set investment surface revealed that Luster Cast and Beauty Cast exhibited a smoother surface than Super Span among the gypsum bonded investments while Ceramigold was smoother than either Complete or Cera Fina for the phosphate bonded investments.

2) The scanning electron micrographs revealed that all of the investment surfaces were rougher after thermal cycling.

3) The replication procedure developed by Barrett produced favorable results for the as set gypsum bonded investment surfaces and unfavorable results for the as set phosphate bonded investment and all of the thermal cycled investment surfaces.

4) The surface roughness measurements (Ra) for the as set gypsum bonded investment surfaces confirmed that Luster Cast and Beauty Cast were statistically smoother than Super Span.

5) The Type III alloy cast against the smooth gypsum bonded investment surface produced the following rank from smoothest to roughest: Luster Cast, Beauty Cast, Super Span.

6) The Type III alloy cast against the smooth phosphate bonded investment surface produced the following rank from smoothest to roughest: Ceramigold, Complete, and Cera Fina.

7) The ceramometal alloy cast against a smooth phosphate bonded investment surface produced the following rank from smoothest to roughest: Ceramigold, Complete, and Cera Fina.

8) The Type III alloy cast against Luster Cast investment statistically produced the smoothest surface while the Type III alloy cast against Cera Fina investment recorded the roughest surface. The Type III alloy cast against Beauty Cast, Super Span, Ceramigold and Complete investments exhibited intermediate surface roughness values which were not statistically different.

9) The Type III alloy cast against Ceramigold investment produced the statistically smoothest surface among the phosphate bonded investments while the ceramometal alloy cast against Cera Fina investment created the roughest surface. The remaining samples, Type III alloy cast against Complete and Cera Fina investments and ceramometal alloy cast against Ceramigold and Complete investments exhibited intermediate surface roughness values which were not statistically different.

APPENDIX A

List of Materials and Manufacturers

Buehler Ltd. Evanston, Illinois

Epoxide resin # 20-8130-032 Epoxide Hardener # 20-8132-008

Buffalo Dental Mfg. Co., Inc.
Brooklyn, New York

Thermoplastic sheeting
BDM Incubator

Coltene AG
Altstatten, Switzerland

President elastomeric impression material

Hereaus Edelmetalle GmbH
Hanau, West Germany

CL - G vacuum-pressure casting machine

J. F. Jelenko & Co., Inc.
Armonk, New York

Super Span Investment, Lot # 120651
Complete Investment, Lot # 02045-11
Clay oven trays
Accutherm 250 burnout furnace
Firmilay gold alloy
Olympia gold alloy

Omnidental Corp.
Harrisburg, PA

Omnivac V vacuum adapter

Plastic Supply of San Antonio
San Antonio, TX

Polycarbonate sheet, 0.30" thick

Rank Taylor - Hobson
Leicester, England

Surftronic III profilometer, Model # 112/1500
Recorder, Model # CS 78 B176

Sybron/Kerr Mfg. Co.
Romulus, Michigan

Luster Cast Investment, Lot # 011086 - 1330

Toothmaster CO.
Racine, Wisconsin

Toothmaster, Model 6 - H

Trio-Dent, Inc.
Union, New Jersey

No - San Pickling Agent

Whip Mix Corp.
Louisville, Kentucky

Beauty Cast Investment
Ceramigold Investment, Lot # 037561300
Cera Fina Investment, Lot # 110150100
Combination Unit, Model D

Williams Gold Refining Co., Inc.
Buffalo, New York

Prevox pickling solution

APPENDIX B

Data

	As Set	Type III Casting
Luster Cast/		
Mean (microns)	0.892	0.874
SD[1]	0.274	0.294
SEM[2]	0.087	0.093
Max.	1.400	1.540
Min.	0.560	0.660
Beauty Cast/		
Mean (microns)	0.884	2.071
SD	0.146	1.403
SEM	0.046	0.444
Max.	1.200	4.570
Min.	0.700	0.890
Super Span/		
Mean (microns)	1.714	2.073
SD	0.640	0.683
SEM	0.202	0.216
Max.	3.380	3.940
Min.	1.080	1.580

1. Standard Deviation
2. Standard Error of Mean

	Type III Casting	Ceramometal Casting
Ceramigold/		
Mean (microns)	2.227	2.855
SD	0.917	0.548
SEM	0.290	0.173
Max.	3.800	3.600
Min.	0.950	1.900
Complete/		
Mean (microns)	2.802	3.126
SD	0.755	0.478
SEM	0.239	0.151
Max.	4.140	4.070
Min.	1.800	2.520
Cera Fina/		
Mean (microns)	3.007	3.597
SD	0.280	0.384
SEM	0.089	0.122
Max.	3.460	4.030
Min.	2.560	3.000

LITERATURE CITED

1. Arfaei, A.H, Asgar, K., 1976. Influence of Roughness on Fit of Dental Castings. J. Dent. Res. 55:B99.

2. Barone, J.J., Huff, R.L., Dickson, G., 1961. Surface Roughness of Gold Castings. Dent. Progress, 1:78-84.

3. Barrett, N.V.J., 1983. Compatability of Agar Hydrocolloid Duplicating Materials with Dental Stones and Development of a Method for Determining Surface Roughness of Gypsum Casts. Masters Thesis, University of Texas Health Science Center at San Antonio.

4. Bauer, R.W., 1978. A Scanning Electron Microscopy Study of the Surface Roughness of Crown and Bridge Alloys. J. Dent. Res. 57:255.

5. Coleman, R.L., 1928. Physical Properties of Dental Materials (Gold Alloys and Accessory Materials). J. Res. Nat. Bur. Stds. 1:867-938.

6. Cooney, J.P., Doyle, T.M., Caputo, A.A., 1979. Surface Smoothness and Marginal Fit with Phosphate Bonded Investments. J. Prosthet Dent. 41:411-417.

7. Cooney, J.P., Caputo, A.A., 1981. Type III Gold Alloy Complete Crowns Cast in a Phosphate Bonded Investment. J. Prosthet Dent. 46:414-419.

8. Craig, R.G., 1985. Restorative Dental Materials, ed. 7, C.J. Mosby, p.317-330

9. Docking, A.R., 1948. The Hygroscopic Setting Expansion of Dental Casting Investments. Aust. J. Dent. 52:6-11.

10. Docking, A.R., Chong, M.P., Donnison, J.A., 1948. The Hygroscopic Setting Expansion of Dental Casting Investments. Aust. J. Dent. 52:160-166.

11. Docking, A.R., Donnison, J.A., Chong, M.P., 1948. The Hygroscopic Setting Expansion of Dental Casting Investments. Aust. J. Dent. 52:320-329.

12. Docking, A.R., Chong, M.P., 1949. The Hygroscopic Setting Expansion of Dental Casting Investments. Aust. J. Dent. 52:261-271.

13. Earnshaw, R., 1960. Investments for Casting Cobalt-Chromium Alloys, Part I. Brit. Dent. J. 108:389-396.

14. Estes, G.D., 1945. The Casting Process. J. Am. Dent. Assoc. 32:1377-1382.

15. Finger, W., Jorgensen, K.D., 1980. Surface Roughness of Gold Alloy Castings. Scand. J. Dent. Res. 88:273-277.

16. Finger, W., Jorgensen, K.D., 1980. An Improved Dental Casting Investment. Scand. J. Dent. Res. 88:278-284.

17. Finger, W., Koto, K., 1982. A Modified Phosphate Bonded Casting Investment. Scand. J. Dent. Res. 90:243-248.

18. Ghazala, W.A., 1978. Surface Configuration of the Cast Gold Restoration. Egypt Dent. J. 24:373-391.

19. Hollenback, G.M.,1943. Precision Bold Inlays Made by a Simple Technic. J. Am. Dent. Assoc. 30:99-109.

20. Hollenback, G.M.,1948. Simple Technic for Accurate Castings: New and Original Method of Vacuum Investing. J. Am. Dent. Assoc. 36:391-397.

21. Ireland, J., 1949. Vacuum Investing and its Relation to Cast Surfaces. Brit. Dent. J. 86:111-118.

22. Ireland, J.,1949. The Effects of Vacuum Investing on the Compressive Strength of Investments. Brit. Dent. J. 87:148-151.

23. Jones, J.D., Barrett, N.V.J., Griffen, R., 1985. *Line Quality of* Reproduction of Conventional and Metal Ceramic Investments. Submitted for publication.

24. Lane, J.G.,1909. The Casting Process as Applied to Inlays of Gold and Other Dental Uses. Dent. Dig. 15:435-440.

25. Lane, J.G.,1909. The Casting Process as Applied to Inlays of Gold and Other Dental Uses. Dent. Dig. 15:497-502.

26. Lewis, A. J., 1977. The Influence of the Refractory Investment on the Development of Porosity in Cast Structures. Aust. Dent. J. 22:455-457.

27. Lyon, H.W., Dickson, G., Schoonover, I.C., 1953. Effectiveness of Vacuum Investing in the Elimination of Surface Defects in Gold Castings. J. Am. Dent. Assoc. 47:197-198.

28. Mabie, C.P., 1974. Adhesive Refractory Protective Coating for Investment Casting. J. Dent. Res. 53:1181-1188.

29. Neill, D.J., 1956. The Use of Non-Ionic Surface Agents with Primary Investment Coatings. Dent. Pract. 6:320-321.

30. Neiman, R., Sarma, A.C., 1980. Setting and Thermal Reactions of Phosphate Investments. J. Dent. Res. 59:1478-1485.

31. Nilner, K., Owall, B., 1982. Reproduction of Details Using Dental Stones and Investment Material in Impressions of Elastomers and Waxes. Swed. Dent. J. 6:249-255.

32. Phillips, R.W., 1947. Relative Merits of Vacuum Investing of Small Castings as Compared to Conventional Methods. J. Dent. Res. 26:343-352.

33. Phillips, R.W., 1982. Skinners Science of Dental Materials, Ed. 8, W.B. Saunders Co., Philadelphia, p.393-411.

34. Pomes, C.E., Slack, G.L., Wise, M.W. 1950. Surface Roughness of Dental Castings. J. Am. Dent. Assoc. 41:545-556.

35. Schnell, R.J. Mumford, G. Phillips, R.W., 1963. An Evaluation of Phosphate Bonded Investments Used with a High Fusing Gold Alloy. J. Prosthet Dent. 13:324-336.

36. Shell, J.S., 1960. Milestones in the Development of Modern Dental Casting Investment - Part I. Dent. Surv. 36:616-618.

37. Souder, W., Paffenbarger, G.C., 1942. Physical Properties of Dental Materials. Nat. Bur. of Stds. Circ. C 433.

38. Sweeney, W.T., 1933. Cristobalite for Dental Investment. J. Am. Dent. Assoc. 20:108-119.

39. Taggart, W.H., 1907. A New and Accurate Method of Making Gold Inlays. Dent. Cosmos 49:1117-1121.