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A COMPARISON OF TWO TESTS FOR DETERMINING THE CASTABILITY OF DENTAL ALLOYS

by

William Patrick Naylor

Indiana University School of Dentistry
Indianapolis, Indiana

Castability is an important characteristic of dental alloys, since casting completeness and detail reproduction have a direct bearing on the quality of dental restorations. The polyester mesh pattern, or Whitlock test, has gained increased popularity as a castability monitor. Therefore, this study compared castability values (Cv) in the Whitlock test with Cv obtained from measuring the amount of bevel reproduced in a coping pattern using five casting alloys and two investments.

The rank order and mean castability values for the five alloys in the Whitlock test with Ceramigold investment were: Rexillium III (100%), Naturelle (87.7%), W-1 (65.3%), Olympia (48.9%), and Forte (15.6%). For the Whitlock test with Vestra-fine investment, the results were: Rexillium III and W-1 (100%), Naturelle (99.4%), Olympia (85.8%), and Forte (25.0%).

For the coping test with Ceramigold investment the rank order and castability values were: Naturelle (96.9%), Rexillium III (96.4%), Olympia (95.3%), W-1 (93.5%), and Forte (63.2%) with Ceramigold. For the coping test and Vestra-fine investment, the rank order and mean castability values were: Naturelle (97.8%), W-1 (95.9%), Forte (93.0%), Rexillium III (91.7%), and Olympia (88.2%).

The Whitlock test results did not parallel those of the coping test for all alloy-investment pairs as would be anticipated for a reliable castability monitor. In addition, the variability of the Whitlock castability values for some alloys was sufficient to question whether this test should be recommended for "fine-tuning" the casting process. In the interim, it may be more prudent to conduct castability studies with replica test patterns which more closely parallel the application of dental casting alloys.

A COMPARISON OF TWO TESTS FOR DETERMINING THE CASTABILITY OF DENTAL ALLOYS

William Patrick Naylor

Submitted to the faculty of the Graduate School
in partial fulfillment of the requirements
of the degree
Master of Science
in the School of Dentistry
Indiana University

June 1988

Accepted by the Graduate Faculty, Indiana University, in partial fulfillment of the requirements of the degree of Master of Science.

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ABSTRACT

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THE CASTABILITY OF DENTAL ALLOYS

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INTRODUCTION

The fabrication of cast restorations has been a subject of tremendous interest in dentistry ever since the "lost wax" technique was introduced to the profession.[1-8] Foremost among the characteristics of dental casting alloys to receive particular scrutiny is castability, i.e. the ability of an alloy to reproduce a wax or resin pattern.

Gold-base dental alloys have been, and to some degree remain, the standards against which new, alternative alloy systems are judged. Initial comparisons of metal ceramic alloys were made to gold-platinum-palladium alloys, but the gold-palladium system appears to have gained increased popularity among consumers of noble metals. The introduction of low-gold and nongold-base systems led to comparative castability studies. However, determining an appropriate method to measure castability is difficult when dealing with alloys that may differ markedly in composition, density, casting temperature, solidification shrinkage, and investment compatibility. The problem is compounded by the need to extrapolate conclusions from studies based on tests of nondental or simulated dental applications.[9-53]

In 1981 Whitlock et al. described a castability test portrayed as simple to perform and easy to score.[9] The test pattern was prepared from a commercially available polyester sieve material available in different gauges. The specimens used in the Whitlock test were created from a 100-grid pattern of 18-gauge mesh. The number of completely cast mesh squares was measured directly and a castability value (Cv) was calculated from the percentage of the mesh that was reproduced. In a 1985 application of the Whitlock test, Hinman and associates used this same mesh design to assess the castability of 18 dental casting alloys using five phosphate-bonded casting investments.[10] Again, castability scores were calculated on a scale of 0 to 100% for each alloy. The simplicity and ease of test pattern fabrication were highlighted as attractive features of the Whitlock test method.

Byrne et al.,[11] in a 1986 study, compared the casting accuracy of four metal ceramic high palladium and one base metal alloy to a high noble metal. Rather than rely on an abstract model, they chose to determine casting accuracy by measuring casting completeness (gap distances) at designated marginal and axial sites. By including a high-gold content control alloy with a long history of recognized excellence in castability, they established a standard to which the test alloys could be compared. Unlike the mesh test of Whitlock, Byrne's test pattern was a reproduction of a metal ceramic substructure designed for a prepared tooth. Using injection molding, the fabrication of wax patterns was standardized. Despite the practical considerations of the Byrne approach, pattern production and scoring appeared more time consuming and complex as compared to the method suggested by Whitlock et al. for their mesh specimens.[9]

It remains to be seen whether a laboratory experiment, relying as it does on an abstract test pattern, is truly indicative of the performance of an alloy in its actual application, i.e. reproducing a wax dental pattern. The Whitlock test reportedly is a quick, easy, and an inexpensive method to obtain a general means to improve alloy castability. Whether castability studies should be approached more for their ease of production and scoring of test patterns than their replication of a practical application is an issue unto itself. To date, little information has been available to demonstrate that abstract tests are a barometer of castability performance in a dental laboratory. In other words, the utility of the mesh pattern is unclear despite its popularity.

In fact, no previous attempts have been made to compare the results of the Whitlock test with other castability monitors. Consequently, a castability value of 65, 85, or even 95% for a particular alloy has little significance unless it can be shown that complete restorations can be produced at a given castability percentage level. Until comparative studies of different test methods are conducted, no such assessments should be made. Perhaps an even more appropriate question to ask is whether the Whitlock test and other abstract tests like it are sufficiently unbiased in design to permit comparisons between alloy systems.

Therefore, this study was undertaken to compare the Cv of five different alloys using the mesh monitor and a new replica (coping) test to determine if the Whitlock test can actually predict alloy castability.

REVIEW OF THE LITERATURE

Forming solid objects from molten metal is an age old process, yet the casting procedure was introduced to the dental profession only as recently as the late 19th century.[1-4] Taggart's presentation to the New York Odontological Group in 1907 often has been acknowledged as the first reported application of the "lost wax" technique in dentistry.[1] However, in 1890, Swasey described a method to cast gold inlays by investing a gold foil pattern of an inlay preparation.[2] Two years later Martin substituted a wax replica for the gold foil.[3] The resulting pattern was invested, burned out, and molten gold poured into the investment. Philbrook further refined the process in 1896 by describing a series of steps for investing and casting very much like the technique used today.[4] Wax patterns formed directly in the tooth were removed, invested in a metal ring, burned out, and cast. But unlike his predecessors, Philbrook used air pressure to force the melted gold into the mold.

Evidently the dental profession failed to take notice of the significance of these early events. As a result, Taggart has been credited with introducing the casting process to dentistry with his "improved" casting machine some ten years after Philbrook's work.[1,4] Taggart's achievements were indeed historical by virtue of the impact an improved casting technique had on dentistry. However, his casting method was still flawed, often yielding small, ill-fitting castings.[5] It was Van Horn who subsequently suggested thermally expanding the wax patterns.[6] But a thermally expandable mold was not available until 1929 when Coleman and Weinstein[7] developed a cristobalite casting investment. Then in 1932 Scheu introduced the hygroscopic investment technique.[8]

In the intervening years, the casting process was further refined by the addition of new equipment and casting investments. At the same time, numerous alloys were developed and made available to the dental profession. Castability studies traditionally have been a part of research designed to allow comparisons of new alloy formulations with established gold-base systems. The testing formats and the test monitors (specimen configurations), however, have differed widely.[9-53]

Classification of Castability Tests

Over the years, a variety of specimens have been developed and used to assess alloy castability. Despite the absence of any acknowledged classification system, it appears that at least three general categories of castability tests exist. These three test monitors are sufficiently distinct to warrant identification as: abstract tests (nondental pattern), simulation tests (idealized dental pattern), and replica tests (actual dental patterns).

An Abstract Test

Test specimens which are neither replicas of actual metal substructures or full metal castings nor simulations of dental restorations may be classified as abstract patterns. A wide assortment of designs have been created and proposed over the years to include a blade or wedge, nylon lines supported by a solid bar, a spiral, a saucer, a sphere, a parallel-walled cylinder, a polyester nylon mesh with adjacent runner bars, and modifications of the nylon mesh concept.

Mackert et al.[12] introduced the blade or wedge pattern to assess alloy castability in 1975. In 1977 MacNamara et al.[13] and Eames and MacNamara[14] used the blade specimen to measure marginal integrity of castings produced with four different casting machines. Nielsen and Shalita[15] studied the effects of wax pattern orientation on casting completeness. Casting a 5° wedge, 1 cm deep and 3 cm long, they found no difference between patterns oriented with the sharp edge up or down. In fact, there was little variation in results between the leading and trailing orientation when casting centrifugally with this abstract pattern. Barreto et al[16] fabricated 20-mm long, wedge-shaped patterns in an attempt to discriminate castability differences between nine dental alloys. They doubled the length of the wedge pattern in their 1980 study of the effects of three phosphate-bonded investments on casting high-fusing alloys.[17] In 1979 Pines et al.[18] reported that margin filling of the Nielsen-Shalita casting monitor was influenced by variations in alloy surface tension, degree of alloy superheating, and melting range levels. Then in 1984 Nielsen, Sumithra, and Cascone[19] studied the effects of mold temperature and alloy superheating on margin sharpness with the blade casting monitor. Sutow et al.[20] modified the blade test to include three major bevels and a secondary bevel on one surface and a flat, nontapered geometry on the opposite surface.

In a 1977 study, Vincent et al.[21] placed nylon lines of varying diameters on a large cylindrical base and cast these specimens in five base metal alloys to compare their relative castability. Howard et al.[22] and Thomson[23] used the nylon line but supported it with a circular base when they compared low-gold and base metal alloys. DeWald[24] attached fourteen nylon strands to a 13 mm sphere in his study of the casting behavior of alloys.

Preston and Berger[25] selected a spiral pattern in their attempt to measure casting completeness. Lacefield et al.[26] also fabricated a spiral pattern using No. 8 half-round casting wax so each specimen contained seven complete turns spaced 2.0 mm apart. The results for nickel-chromium, palladium-silver, and low-gold alloy castings were compared to the number of complete turns reproduced in what the authors described as a standard gold alloy.

A special saucer-shaped pattern was created by Asgar and Arfaei in their castability studies.[27,28] To enhance the sensitivity of the Asgar and Arfaei test, Meyer et al.[29] perforated the saucer and created four internal T-shaped designs into the test pattern.

Wight et al.[30] fashioned a cylinder 10-mm long, 6-mm wide and 0.5-mm thick, and attached it to a crescent-shaped base with rectangular sprue formers 1, 2, and 3 mm wide. Some patterns were vented and the thickness of investment covering the top of the cylinder was limited to either 1/4 or 1/16 of an inch.

One of the more popular abstract tests has been a polyester mesh design supported by runner bars at two adjacent edges designed by Whitlock et al.[9] in 1981. This particular specimen configuration was recommended because of its simplicity and ease of fabrication. The number of square segments cast in the 100-grid pattern by any alloy can be counted to determine a percentage castability value (Cv). In a study by Hinman et al.[10] castability values for 18 commercially available alloys ranged from a low near 30% to a high approaching 100%. The investigators cautioned against using the Whitlock test to make comparisons between alloy systems. The test was portrayed more as a means to adjust casting parameters, such as burnout and casting temperature, for a given alloy to "fine-tune" the casting process. Hinman et al.[10] indicated that the test was never intended for comparison between alloys or alloy systems. In fact, they held the opposite view.

Dern et al.[31] used the mesh pattern as a vehicle to assess the effect of a two-stage, ringless investment technique on castability. Kois and Youdelis[32] found the castability of two experimental silver-copper-germanium alloys superior to a Type III gold alloy and two silver-palladium alloys with the Whitlock test. However, Presswood could not reproduce the 0.24 mm filament diameter mesh specimens with sufficient detail.[33] He substituted a 25 mm x 32 mm rectangular pattern of 0.3 mm filament mesh and placed it horizontally on an 8-gauge plastic sprue former. Reagan and Kois[34] chose to place the mesh square on a single 8-gauge horizontal bar and eliminated the two vertical runner bars altogether. Then in a 1984 study, Mitchell and Kemper[35] followed the Whitlock design but substituted a 50-gauge mesh for the recommended 18-gauge pattern to compare the castability of nickel-base alloys with and without beryllium. The beryllium-free alloys cast poorly leading the investigator to conclude, in part, that oxides produced by such alloys may clog the mesh network. Rather than employ a single mesh pattern supported by runner bars, Jarvis and associates[36] cast eight No. 20 mesh specimens indirectly from a multiple spoke reservoir.

Smaller gauge sprue formers for the adjacent runner bars, shorter and smaller diameter sprue formers, and longer mesh lengths were changes Kaminski et al.[37] made to the original Whitlock design. In subsequent investigations, Donovan and White[38] and Peregrina and Rieger[39] eliminated the supporting runner bars altogether from the original Whitlock design. When studying the effects of variations in sprue former design on castability, Young et al.[40] chose a 24 x 30 mm rectangle of 0.3 mm diameter polyester mesh for their test pattern.

In another study, Vaidyanathan and Penugonda[41] compared the performance of the Nielsen-Shalita wedge and the Whitlock mesh castability monitors. The mesh test was judged to be particularly sensitive to variations in sprue design. The investigators concluded that the reproducibility of results with the Whitlock test was inferior to that of the wedge pattern. However, it was easier to quantify a castability value (Cv) with the Whitlock test than the wedge monitor.

The inability of the Whitlock test to discriminate between alloys and alloy systems was demonstrated by Covington and associates[42] in their comparison of the castability of 32 alloys. Twenty of the 32 alloys cast 99% of the polyester mesh, so the investigators eliminated the supporting wax sprue formers and oriented the mesh horizontally. Only then were they able to discern differences in performance levels for twelve of these 20 alloys.

A Simulation Test

A major limitation of abstract castability patterns is an inability to measure both casting completeness and casting fit. This obstacle was overcome to some extent by the use of metal dies machined to mimic the general configuration of a prepared tooth. Eden et al.,[43] Yli-Urpo and Karmakoski,[44] Smith and associates,[45] Myers and Cruickshanks-Boyd[46] assessed castability and casting accuracy with simulated full crown preparations. Vermilyea et al.,[47] Brockhurst and associates[48] and Bessing[49] included a bevelled preparation in their simulated crown preparations. Brockhurst and associates measured marginal sharpness of cylindrical forms, simulating a full crown, as a means of evaluating castability.[48] Bessing[49] followed the Brockhurst protocol in his study of four alternative crown and bridge alloys.

A Replica Test

Despite the simplicity of the abstract test and the ease of fabrication of the simulation test, neither method duplicates the actual processing of dental casting alloys. This shortcoming has been recognized by investigators intent on measuring both castability and casting fit. Huget et al.[50] made replicas of a full molar crown preparation on an extracted tooth in an evaluation of four base metal alloys. Later Brukl and Reisbick[51] cast patterns for both a three-quarter crown (premolar preparation) and a full crown (molar preparation). Duncan selected a maxillary central incisor for a metal ceramic crown and cast a cobalt-chromium replica of the preparation for the master die.[52] He determined casting accuracy by direct measurement of marginal fit when the cast copings were returned to the master die.

As recently as 1986, Byrne et al.[11] evaluated both the casting accuracy and casting completeness of four high palladium alloys for comparison with a nickel-chromium-beryllium alloy and a gold-platinum-palladium alloy (control). The test specimens were replicas of a substructure for a maxillary central incisor metal ceramic crown.

Byrne's replica test provided a more definitive assessment of castability (completeness of casting) and casting fit.[11] Unfortunately, that investigation did not evaluate the same alloys used by Hinman and associates,[10] so no direct comparisons between the two test methods could be made.

In one of the more interesting studies, Agarwal and Ingersoll[53] cast six abstract patterns (screw spiral, disc, knife edge, thin sheet, Nielsen and Shalita monitor, and polyester mesh screen) used to assess castability. To compare these tests with practical castings, they included a metal ceramic coping and a three-unit fixed partial denture. All six castability test patterns and the two practical wax-ups were invested in the same ring and cast with a nickel-chromium-beryllium alloy. Castings were made at four mold temperatures, and the patterns were rotated to produce specimens from all four quadrants of the ring. The study demonstrated the strong influence of an elevated mold temperature on results in castability studies. Increasing the burnout temperature from 1200 to 1800° F significantly improved the performance of all the castability monitors. A similar effect was postulated for an increase in alloy casting temperature. As a result, the investigators recommended that both the alloy and the mold temperatures should be standardized in tests conducted to measure alloy castability.

Despite the warning of Hinman et al.,[10] the Whitlock test has been used to compare castability performance among alloy systems as opposed to a monitor to refine the casting process for a specific alloy and investment.

In the absence of direct comparisons between performance in the Whitlock test and the ability to cast dental restorations at a standardized burnout and casting temperature for multiple alloys and investments, this investigation seemed particularly appropriate.

METHODS AND MATERIALS

This study was intended to compare the castability of three noble metal and two base metal alloys using both an abstract (Whitlock) test and a replica (coping) test (Appendix I).

Initially, a two-day training period was conducted on the Autocast Induction Casting Machine[a] by a factory representative. Then a pilot study was run to gain familiarity with specimen preparation, to determine the amount of alloy needed per test, and to establish the most appropriate casting temperature for each alloy. In the actual investigation, five castings were made for each alloy with both castability tests and two casting investments in a standardized technique (Table I). The casting temperature for each of the five alloys was determined through trial and error as is customary for this induction casting unit (Table II). Repeated castings were made at different casting temperatures until a complete coping pattern was reproduced. The carbon-containing investment (Ceramigold)[b] was used primarily for the gold-base alloy[c] and the noncarbon investment (Vestra-fine)[d] was selected for the palladium-[e,f] and nickel-base[g,h] metals.

---

a Autocast. Unitek Corporation, Monrovia, CA

b Ceramigold. Whip-Mix Corporation, Louisville, KY

c Olympia, J.F. Jelenko & Company, Armonk, NY

d Vestra-fine. Unitek Corporation, Monrovia, CA

e W-1, Williams Dental Company, Buffalo, NY

f Naturelle, R_x Jeneric Company, Wallingford, CT

g Rexillium III, R_x Jeneric Company, Wallingford, CT

h Forte, Unitek Corporation, Monrovia, CA

The experiment was designed to be conducted in two parts thereby reducing the amount of alloy needed at any one time. In Part I, five Whitlock specimens were fabricated, invested, and cast for each of the five alloys using Ceramigold. The five replica (coping) specimens for each group were cast later that same day after the burnout furnace had cooled completely (Table III). The casting order, as well as the burnout and casting temperatures, were the same for both tests as suggested by Agarwal and Ingersoll[53] (Table II). In Part II, this sequence was repeated with Vestra-fine and 100 castings were made, fifty in each part (Table IV).

Specimen Preparation

Abstract (Whitlock) Test

The original Whitlock specimens required a 10 x 10 square piece of 18-gauge polyester sieve cloth[a] composed of 100 squares and supported by 10-gauge wax sprue formers[b] along two adjacent edges[9] (Figure 1). In this study, each pattern was attached to an oval crucible former[c] by a 10-mm long 6-gauge wax sprue former[d] at the junction of the lateral sprue formers. The patterns were positioned in an oval ring so the top of the mesh was covered by no more than 5 mm of investment, as specified by Hinman et al.[10] Changes in the original Whitlock method included elimination of sharp line angles in the test specimen and use of oval casting rings (Figure 2).

---

a Polyester sieve cloth. Tetko Corporation, Elmford, NY

b Ready Made Wax Shapes. Kerr/Sybron Manufacturing Company, Emeryville, CA

c Casting Oval System. Belle de St. Claire, Van Nuys, CA

d Round Wire Wax. Ticonium Company, Albany, NY

Fabrication of the Replica (Coping) Test

Master Die

A gypsum die of a metal ceramic crown preparation for a maxillary central incisor, similar to that used by Byrne et al.,[11] was reproduced in wax. An impression of the preparation was first made in a poly (vinyl siloxane) impression material,[a] and the impression was filled with Type II blue inlay wax[b] to produce a wax replica of the stone die. The preparation was modified to include a circumferential bevel that measured approximately 0.5 mm at the midfacial, 0.75 mm at the midinterproximal areas, and 1.0 mm at the midlingual region. The wax die was invested and cast in a nickel-chromium-beryllium alloy[c] to produce a metal master die (Figure 3A). The cast die was adjusted, finished, and polished to a high shine. The four regions of the bevel to be measured were adjusted carefully until the final bevel length was achieved for each of the four measurement sites.

Duplication of the Replica Master Die

Twenty impressions of the master die were made with the poly (vinyl siloxane) impression material. Seven gypsum dies were poured per impression so every coping pattern to be produced would have its own die for margination. Two of the dies would serve as replacements in the event one of the five principal dies was damaged. An ADA certified improved stone (Type IV)[d] was vacuumed mixed according to the manufacturer's specifications for each successive pour. The impressions were

---

a Perfourm. Cutter Dental Company, Berkeley, CA

b Kerr Blue Inlay Casting Wax. Kerr/Sybron, Emeryville, CA

c Rexillium III. Rx Jeneric Gold Company, Wallingford, CT

d Super Die. Whip-Mix Corporation, Louisville, KY allowed to remain undisturbed for one hour after pouring. Immediately upon separation, the stone dies were inspected to ensure complete replication of the master die. Excess stone was trimmed from the base and the dies were permitted to dry thoroughly for a period of 24 hours to achieve adequate hardness and strength.

Preparation of the Coping Wax Pattern for the Replica Test

It was important that the required seventy wax patterns in the replica test be as identical as possible, so an injection molding process was used.

First, one stone die was selected and a master wax pattern for a maxillary central incisor was waxed to full contour, then cut-back for a metal ceramic crown substructure. The final coping was 0.4 mm thick at the midfacial, 1.0 mm thick in the lingual concavity, and had a labial collar slightly wider than the 0.5 mm bevel (Figure 3B).

Second, a 7-mm long, round 10-gauge wax sprue former[a] was luted to and flared from the incisal edge to blend with the completed master wax pattern.

Third, a mold of the master pattern with attached sprue former was constructed from a light body-heavy body combination of the poly (vinyl siloxane) impression material used previously. The mold was fabricated in two stages and split lengthwise. The two components could be separated readily to facilitate removal of the wax patterns. Both segments of the mold were reinforced with stone for added support. With the aid of the completed mold, multiple wax patterns could be produced on a single stone die by injection molding.[11]

---

a Ready Made Wax Shapes. Kerr/Sybron, Emeryville, CA

Fabrication of Wax Patterns by Injection Molding

The master stone die was painted lightly with a die lubricant,[a] placed in the mold, and held securely by the surrounding stone index. The Type II blue inlay wax was heated to approximately 78° C in the wax injection apparatus (wax pot and injector).[b] When the wax was at temperature and fluid, the coping patterns were injection molded one at a time. Sufficient time elapsed between every injection procedure to allow the pattern to cool and permit removal without distortion. Each pattern was inspected for completeness and any flawed copings were discarded but not returned to the wax pot. After a coping pattern was removed from the mold, it was immediately transferred to an awaiting stone die where it would remain until marginated. A total of seven copings were injected for every alloy-investment pairing in the two test categories. Before investing the patterns were marginated with a Darby-Perry marginal trimmer[c] under 10X and 40x magnification.

Sprue Former Attachment

In Part I of the study, five patterns for the two tests were invested in the carbon-containing phosphate-bonded investment (Table III). The same sequence was followed in Part II but the noncarbon investment was used (Table IV).

The specific configurations of the rings, sprue former attachment system, and investment coverage are depicted in Figure 4. Oval rings[d] were chosen to ensure that the patterns were oriented vertically for every casting in both tests.

---

a Slickdie Lubricant. Slaycris Products, Portland, OR

b Pro-Craft Model #5040. Pro-Craft, GFC, Carlstadt, NJ

c DPT Number 6. HuFreidy Company, Chicago, IL

d Casting Oval System. Belle de St. Claire, Van Nuys, CA

A special adaptor[a] was attached to the casting cradle to stabilize the oval rings vertically (Figure 5).

The laboratory technique itself was standardized so patterns from both tests would be invested in the same step-by-step manner (Table I). Separate graduated cylinders and mixing bowls were dedicated to each brand of investment. This precaution was taken to avoid cross-contamination and ensure consistent technique. The mixing bowls[b] were identified with color-coded tape to avoid confusion and mixing of the two investment powders and liquids (Table I). While the debubblizer[c] was drying, each ring was submerged in deionized water to moisten the ceramic ring liner.[d] Excess water was removed with a gentle shaking motion.

Order of Specimen Preparation and Casting

Two sets of oval rings were set aside, one for the Whitlock test (designated 1-5A) and one for the replica test (1-5B). A single set of five oval crucible formers was numbered 1-5 and paired to its corresponding A or B ring. The order of the tests and the sequence in which the alloys were cast are presented in Table III and Table IV. Once the five specimens of each test were attached to their respective crucible former they were painted with wax pattern cleaner. After the debubblizer had dried, the patterns were individually invested. Before investing, each mixing bowl was rinsed with deionized water. Following the format established by Hinman et al.,[10] the special liquid for both investments was used full strength. The special liquid was dispensed, and the appropriate size envelope of investment was

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a Cradle Adaptor. Belle de St. Claire, Van Nuys, CA

b Multivac Mixing Bowls. Degussa Dental Company, New York, NY

c Kerr Debubblizer. Kerr/Sybron, Romulus, MI

d Nonasbestos Ring Liner. Belle de St. Claire, Van Nuys, CA selected and emptied into the bowl (Table I). Once the investment was wet by the liquid, the top was placed on the bowl and the assembly inserted into the automatic mixer[a] to begin the 60-sec mixing cycle. A 30-sec hold time followed the minute long mixing period to maximize the elimination of gaseous by-products.

After investing, each ring was immediately placed in a humidor. When the last ring had set for 1 hour, the glazed top surface of the investment was removed by scraping with a laboratory knife. The five rings were placed in a cold furnace[b] and heated in a two-stage burnout procedure with a 1 and 3/4 hours hold at the manufacturers recommended high temperature setting (Table II). The furnace was calibrated and set for a 25° F/min rate of rise.

The casting sequence was the same as the order of investment and began with ring 1A. The burnout furnace and casting machine were set in the morning at the start of the casting procedure and taped in position. This precaution ensured that the settings used to cast the specimens in the Whitlock test were unchanged for the coping test conducted later that same day for each alloy. Once cast, the rings were allowed to cool to room temperature before devesting. The Forte Whitlock and coping specimens had to be air-abraded with 50-µm aluminum oxide to remove the thick surface oxides and permit evaluation. With the remaining specimens, any investment clinging to a casting was mechanically removed with a hand instrument. Then the castings were scrubbed with a toothbrush under tap water before being placed in an ultrasonic unit for a minimum of ten minutes.

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a Multivac 4. Degussa Dental Company, New York, NY

b Automatic Dual-Temp Burnout Furnace. Unitek Corporation, Monrovia, CA

Determining the Castability Value (Cv) with the Abstract (Whitlock) Test

The number of complete cast segments was totalled, divided by 220, and multiplied by 100 to obtain a "castability value (Cv)" as recommended by Whitlock and associates[9] and Hinman et al.[10] A segment was considered incomplete if it did not extend from the far edge of one crossing segment to the far edge of the next. In order to obtain measurements with this level of precision, all of the Whitlock specimens were scored by examination under 10X magnification in a binocular microscope.[a] Every casting was scored twice. If the second measurement differed from the first, the process was repeated until the correct score was verified.

Determining the Castability of the Specimens *from the* Replica (Coping) Test

Castings were examined macroscopically to assess any gross discrepancies in casting completeness (Figure 6). Then the length of the circumferential bevel reproduced at the midfacial (0.5 mm), midinterproximal (0.75 mm) and the midlingual (1.0 mm) was determined under a measuring microscope. To accomplish this the sprue was removed and each casting positioned in a poly (vinyl siloxane) index that permittec repeated measurement of the same area for all castings. Once in the index, the length of the cast bevel could be viewed and measured directly (Figure 7).

A horizontal and vertical orientation line placed in the index adjacent to the casting bevel served to position the index directly under the horizontal and

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a Binocular Microscope. American Optical, Southbridge, MA vertical cross hairs of the measuring microscope.[a] Once aligned, the microscope was moved to the right and adjusted until the entire bevel length was in focus (Figure 8-1). The point at which the vertical cross hair overlaid the internal aspect of the bevel was recorded (Figure 8-2). Then the vertical cross hair was moved to the end of the cast bevel and that measurement taken (Figure 8-3). The difference between these two readings was then recorded as the length of the cast bevel. An average of three measurements (measured to the nearest one-hundredth of a mm) was obtained for all four selected measurement sites. The means for the four areas in each of the five castings were reported individually and combined. The mean of these five combined means became the overall castability value (Cv) expressed as a percentage.

For comparative purposes, baseline measurements of the four bevel lengths were taken of a wax pattern marginated directly on the master metal die. The values obtained were deemed the highest possible measurements any casting could reproduce (facial-0.499 mm; mesial-0.749 mm; distal-0.750 mm; and lingual-1.004 mm). Any scores higher than these values were attributed to wax overextensions.

Scanning Electron Microscopic Evaluation

The copings cast from the five alloys and two investments were examined with a binocular microscope under 10X and 20X magnification. Replica castings representing the best and worst marginal areas for each alloy with the two investments were selected. These castings were mounted with silver paint for scanning electron microscopic (SEM) viewing at 200X magnification. Marginal sharpness, the level of pattern replication, and the surface character were evaluated and photographed.

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a Measuring Microscope. Gaertner Scientific Corporation, Chicago, IL

RESULTS

In Part I of the study, with the carbon-containing investment only the nickel-chromium-beryllium alloy, Rexillium III, reproduced all of the abstract Whitlock pattern and attained a castability value of 100%. Results for the remaining four alloys varied markedly (Figures 9-33) with mean castability values ranging from 87.7% for the high palladium-copper alloy, Naturelle, to only 15.6% for the nickel-chromium beryllium-free alloy, Forte (Tables V to IX). The palladium-silver alloy, W-1, cast 65.3% of the mesh compared to a mean Cv of 48.9% for the control gold-palladium alloy, Olympia. The rank order of the five alloys, from highest to lowest castability value was Rexillium III, Naturelle, W-1, Olympia, and Forte.

With the replica (coping) test and Ceramigold investment, four of the alloys cast more than 93% and three alloys reproduced more than 95% of the areas measured. Only Forte failed to achieve this level of performance (Table VI). Even the rank order of castability values differed from the Whitlock test. Naturelle had a Cv of 96.9%, Rexillium III 96.4% Olympia 95.3%, W-1 93.5%, and Forte 63.2%. Photographs were taken of the castings for each alloy in both the Whitlock and the replica tests with Ceramigold investment (Figures 9-33).

In Part II of the study only the type of casting investment was changed (non-carbon substituted for carbon-containing) and castability levels rose appreciably (Figures 34-58). Rexillium III and W-1 reproduced 100% of the Whitlock patterns, and Naturelle obtained a mean Cv of 99.4%, casting three of the five specimens completely (Tables X to XIV). Olympia nearly doubled its score obtaining a castability value of 85.8%. The performance of Forte was improved slightly with an average castability value of 25.0%. The rank order from highest to lowest for the Whitlock patterns was: Rexillium III and W-1, Naturelle, Olympia, and Forte. This order differed from that determined in Part I. In the Part II replica test, the rank orders and castability values were Naturelle (97.8%), W-1 (95.9%), Forte (93.0%), Rexillium III (91.7%), and Olympia (88.2%). Rexillium III and Olympia had lower castability values with Vestra-fine, the other three alloys improved their scores. However, four of the Olympia coping specimens cast in Part I had single chamber suck-back porosity and the fifth contained pin-point porosity in the same area (Figure 59). Suck-back porosity did not occur with the Olympia and Vestra-fine castings. Photographs were taken of the castings for each alloy in both the Whitlock and the replica tests with Vestra-fine investment (Figures 34-58).

Although the five Whitlock castings in Part I and Part II were made consecutively by the same individual, the resulting castability values varied over a wide range, except for Rexillium III with Ceramigold and Vestra-fine and W-1 with Vestra-fine. However, all five specimens were cast under similar conditions of controlled burnout and casting temperatures. For example, W-1 had Whitlock castability values from 53.2% to 85.5% with Ceramigold (a range of 32.3%) but a mean Cv of 100% with Vestra-fine. On the other hand, with the coping test and Ceramigold investment W-1 had castability values from 86.0% to 96.3% (a range of 10.3%). With the exception of those alloys scoring 100% with the Whitlock test, the castability scores ranged less with the replica test than with the Whitlock test for both Ceramigold and Vestra-fine (Tables V to XIV).

The castability values of Rexillium III in the abstract test did not appear to be influenced by the type of investment used. However, the castability levels of the remaining four alloys varied according to the type of investment used. Forte was most affected by investment selection for the casting parameters of this particular study. It scored a mean Cv of 15.6% with the Whitlock test and failed to cast the facial margins of the five patterns in the coping test using Ceramigold investment (Figure 17, Table VI). Yet, Forte reproduced 89.0% of the lingual margin in these same castings. In Part II of the study, Forte cast 97.5% of the lingual margins and 82.1% of the facial margins in the coping test (Table XI) for an overall Cv of 93.0%. Naturelle and W-1, on the other hand, were able to cast a minimum of 97.8% and 95.9%, respectively, of the four bevelled measurement sites.

The data obtained for the castability values from the abstract (Whitlock) test, and the overall percentage of the margins cast in the replica (coping) test were statistically analyzed with a one-way analysis of variance. On the basis of the significant findings obtained, a Student-Newman-Keuls Test for variability was applied to the mean grouped data (Tables XV to XVIII). Products that did not differ significantly ($p \leq .05$) in the Student-Newman-Keuls Test are indicated by vertical lines. In Part I, the castability values for all five alloys differed significantly in the abstract test, but only Forte differed significantly in the replica test (Tables XV to XVI). In Part II, Rexillium III, W-1, and Naturelle were not statistically different from one another in the Whitlock test (Tables XVII and XVIII). Olympia and Forte were significantly different from one another and from Rexillium III, W-1, and Naturelle. With the replica test and Vestra-fine investment, alloy performance was more closely grouped and overlap was evident (Table XVIII). While W-1, Forte, and Rexillium III did not differ significantly in performance, Naturelle and Olympia did, with Naturelle attaining the highest Cv of the five alloys.

Although the Whitlock and coping tests permit objective scoring of the test specimens, certain subjective observations were noted. First, prolonged burnout (1 3/4 hours) at high temperature (1600° F) may satisfactorily eliminate carbon from Ceramigold investment, as recommended for nickel-base alloys. However, a substantial amount of carbon remained in the investment at the lower burnout temperatures (1300 to 1500° F) despite the lengthy burnout time (Figure 60). The resultant casting was relatively free of oxides in the portion of the investment containing carbon (reduced area). Second, casting completeness (castability values) alone does not reflect a subjective assessment of casting smoothness.

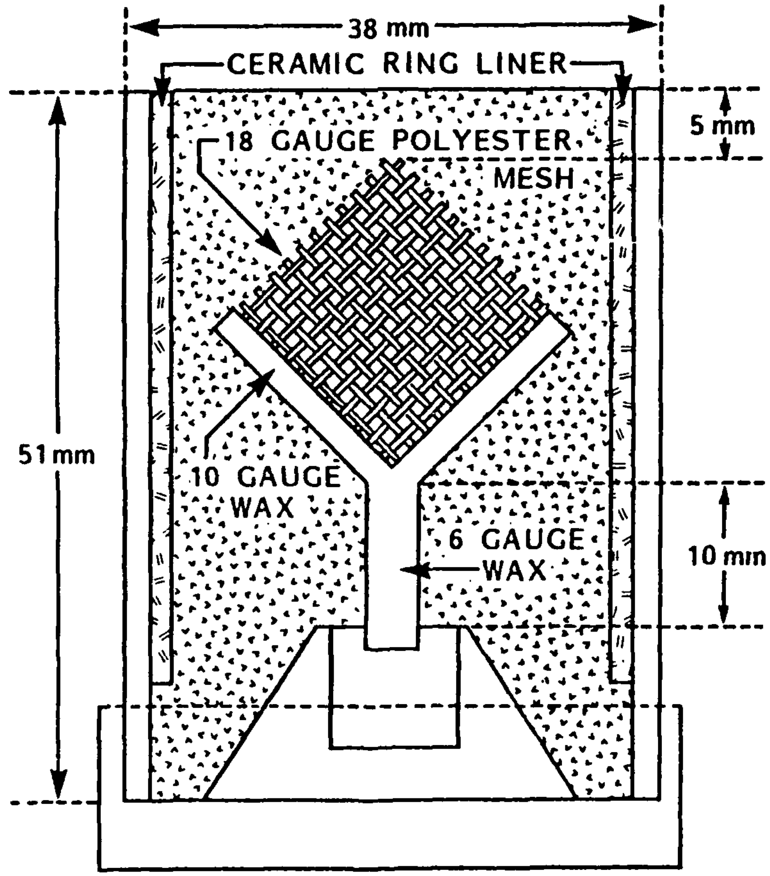
Despite lower castability values, castings made in Ceramigold were judged to be smoother than those produced in Vestra-fine at the burnout and casting temperatures used (Figures 61 and 62). From a comparison of the scanning electron micrographs, the surface of coping specimens cast into Ceramigold appeared denser with more uniform margins than castings produced from Vestra-fine (Figures 63 to 82). Surface and marginal irregularities were more apparent in the copings produced in Part II of the study. However, the castings made with Vestra-fine reproduced wax detail, including marginal overextensions, not noted with the Ceramigold coping patterns.

In general, mean castability values from the Whitlock test differed from mean Cv in the replica test in both Part I and Part II (Table V to XIV). However, the castability values of the two tests were within 1.6 to 4.1% for the following four alloy-investment pairs: Rexillium III and Ceramigold, W-1 and Vestra-fine, Naturelle and Vestra-fine, and Olympia and Vestra-fine. In the remaining six pairs the differences between mean Whitlock and coping Cv ranged from 8.3% (Rexillium III and Vestra-fine) to 68% (Forte and Vestra-fine) (Tables V to XIV). Therefore, the amount of mesh reproduced in the Whitlock test did not directly correspond to the length of bevel cast in the replica (coping) test (Figure 83). Also, some Whitlock specimens had the same castability score but different cast patterns (Figure 84).

To facilitate interpretation of the replica test results a special conversion table was created (Table XIX). Castability values from each of the four scored areas can be converted to millimeter (or micrometer) measurements of the amount of bevel not reproduced in a casting at a specified Cv.

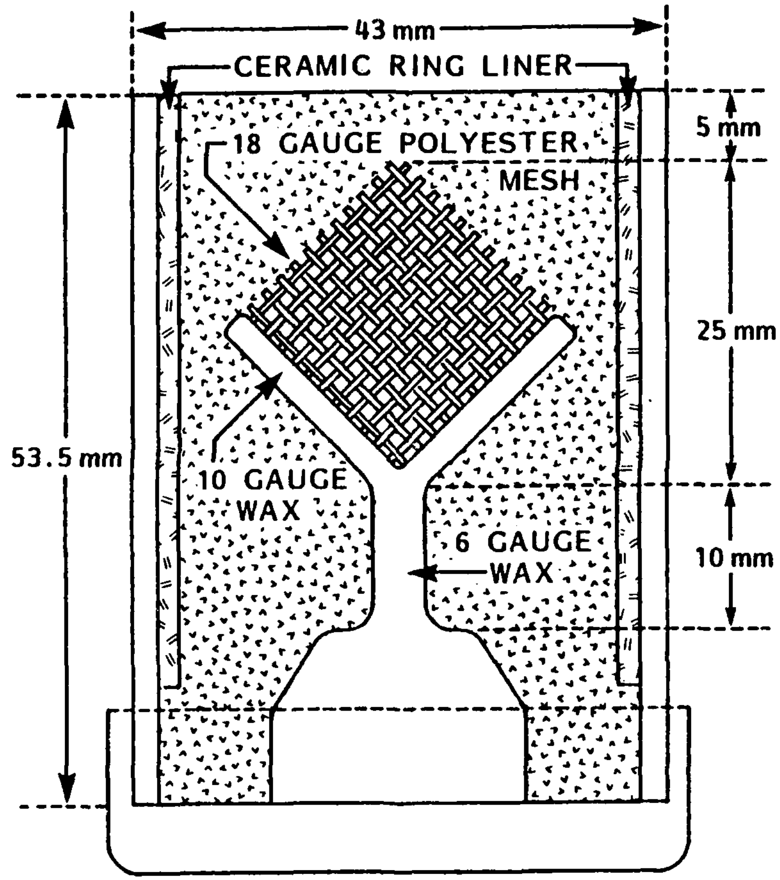
FIGURES AND TABLES

Figure 1. Configuration of the original Whitlock test specimen.


38 mm
CERAMIC RING LINER
18 GAUGE POLYESTER MESH
5 mm
51mm
10 GAUGE WAX
6 GAUGE WAX
10 mm

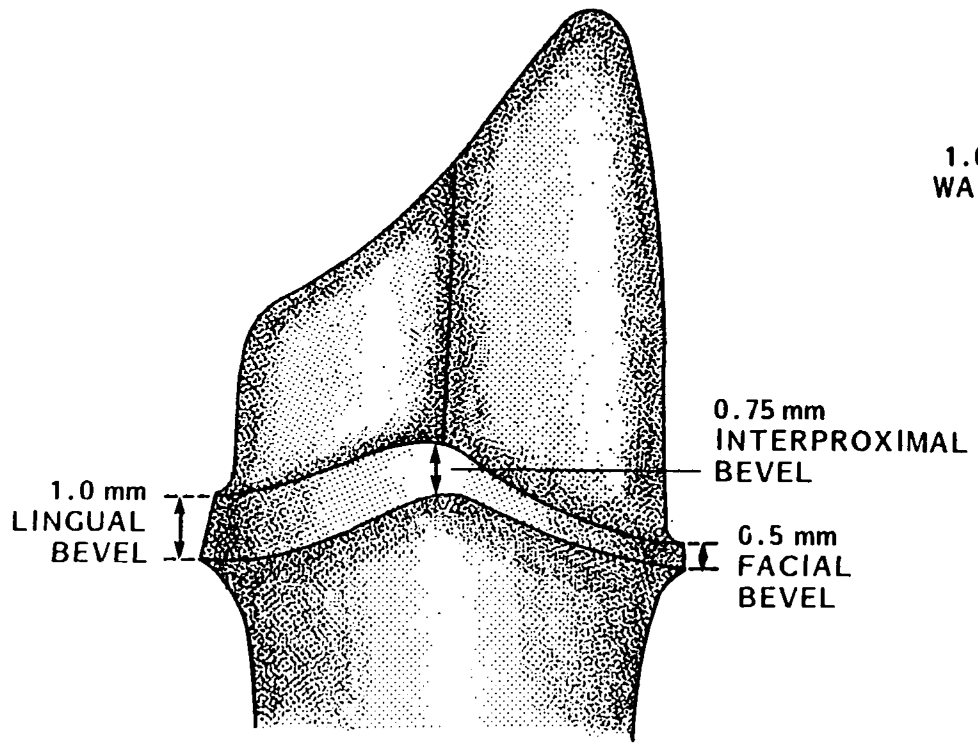
SIDE VIEW

Figure 2. Configuration of the Whitlock specimen used in this study in the oval ring with the sharp line angles of the pattern removed.


43 mm
CERAMIC RING LINER
18 GAUGE POLYESTER MESH
10 GAUGE WAX
6 GAUGE WAX
5 mm
25 mm
10 mm
53.5 mm

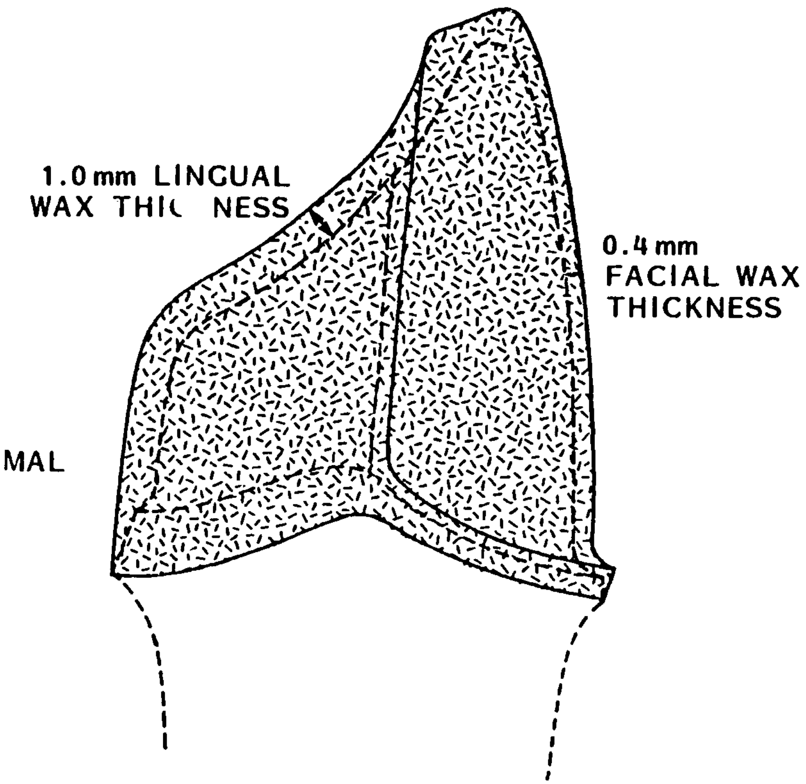
SIDE VIEW

Figure 3. Design of the prepared master die (A) and the completed master wax pattern on the die (B).



MASTER DIE
CONFIGURATION

A



MASTER WAX PATTERN
CONFIGURATION

B

Figure 4. *Orientation of the invested replica (coping) pattern in the oval ring.*

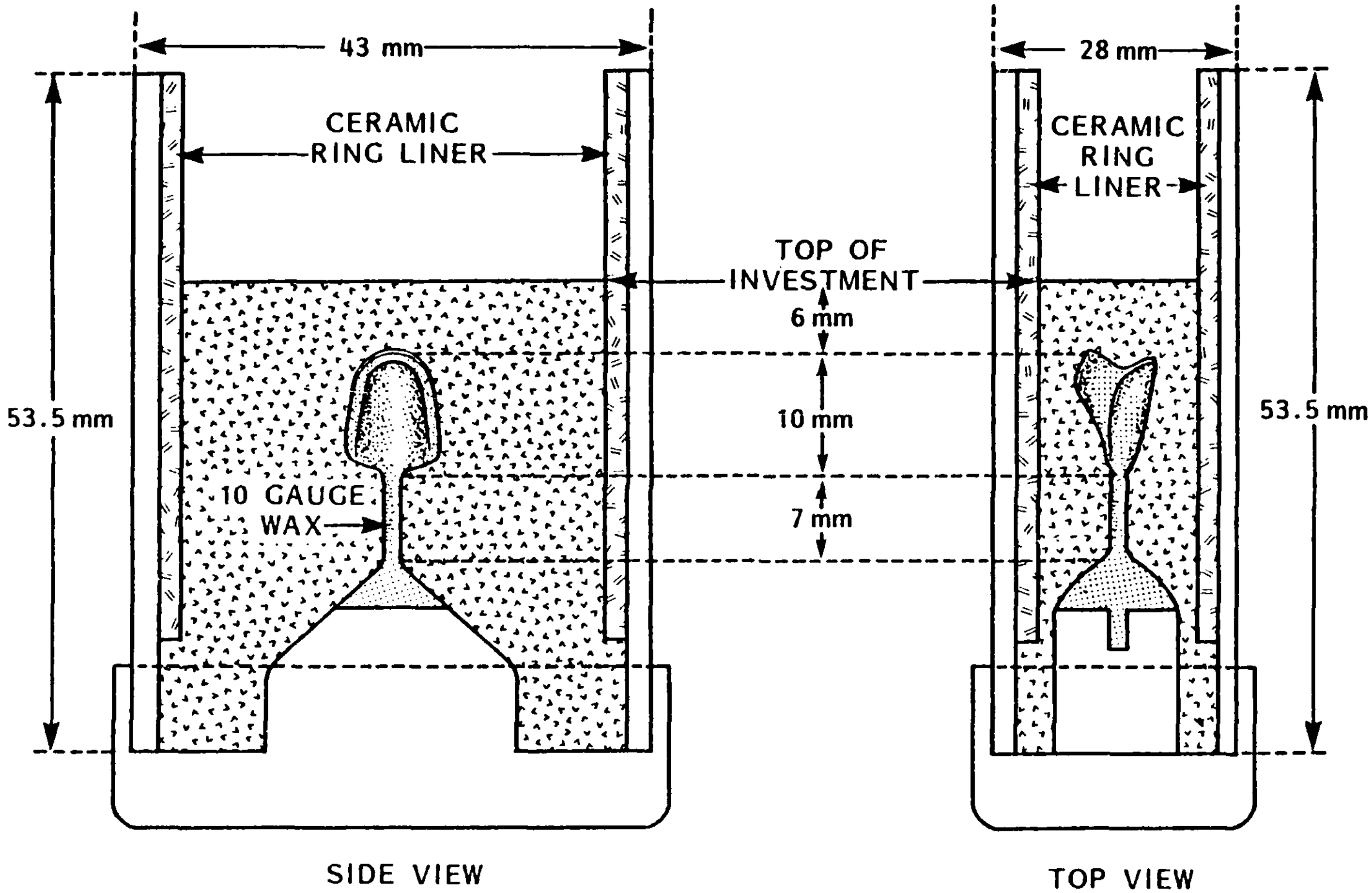

43 mm
CERAMIC
RING LINER
53.5 mm
10 GAUGE
WAX
SIDE VIEW
TOP OF
INVESTMENT
6 mm
10 mm
7 mm
28 mm
CERAMIC
RING
LINER
53.5 mm
TOP VIEW

Figure 5. View of the oval ring and ring adaptor mounted on the cradle in the Autocast.

Figure 6. A representative replica (coping) casting as viewed immediately upon removal from the investment without air-abrading (Olympia-Ceramigold shown).

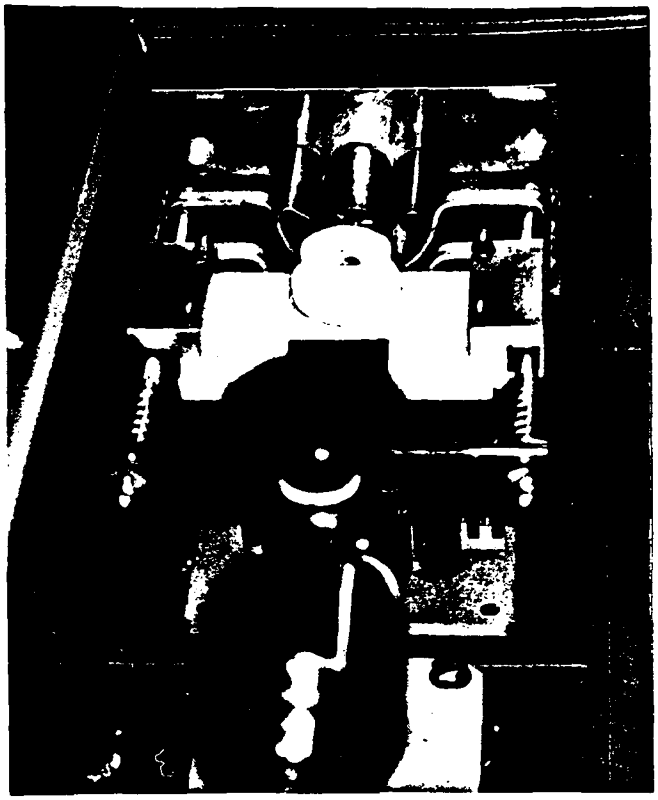


Figure 7. Example of the lingual bevel as seen in wax (A) and later as viewed in the measuring microscope (B) for measurement.

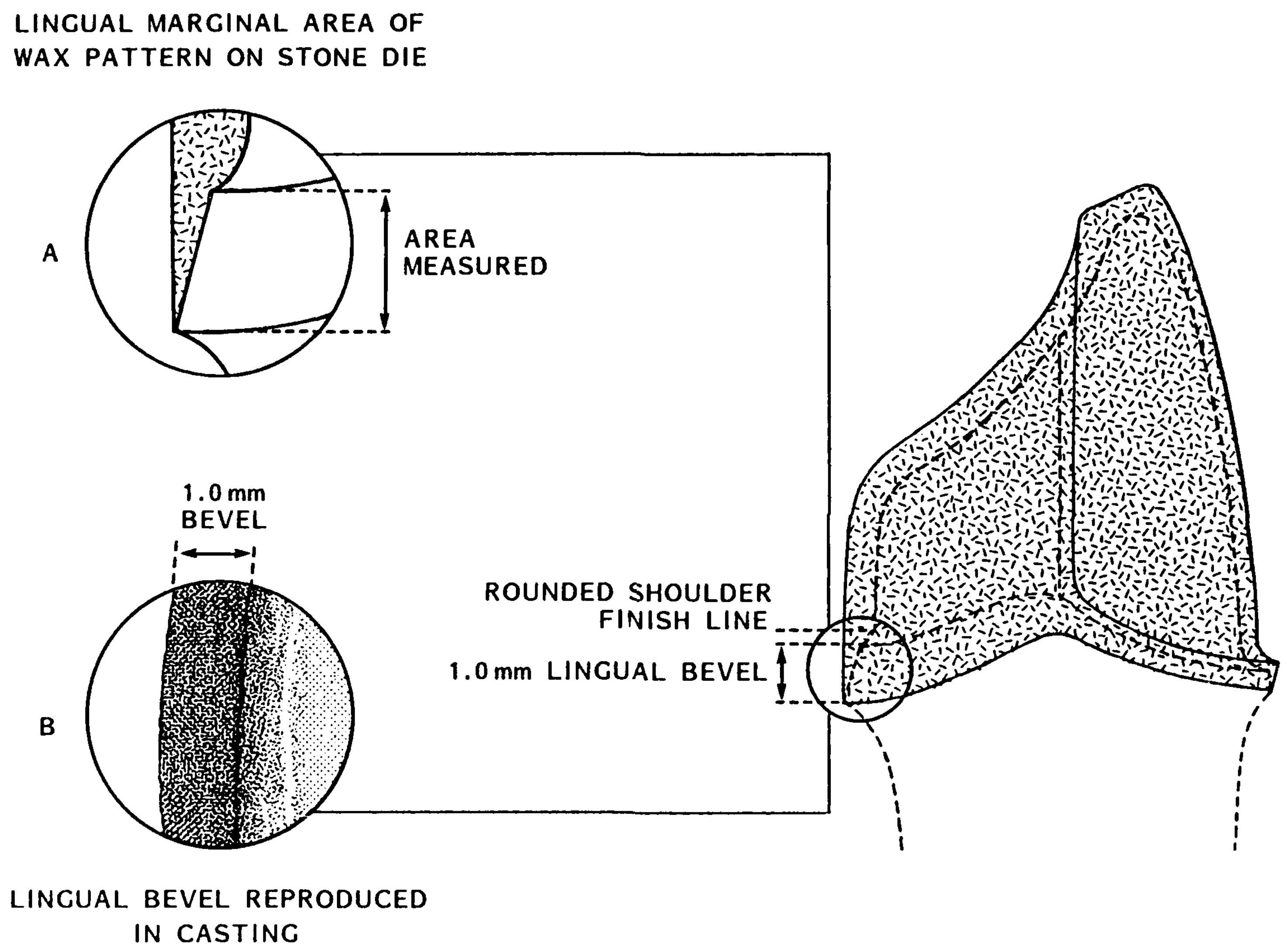
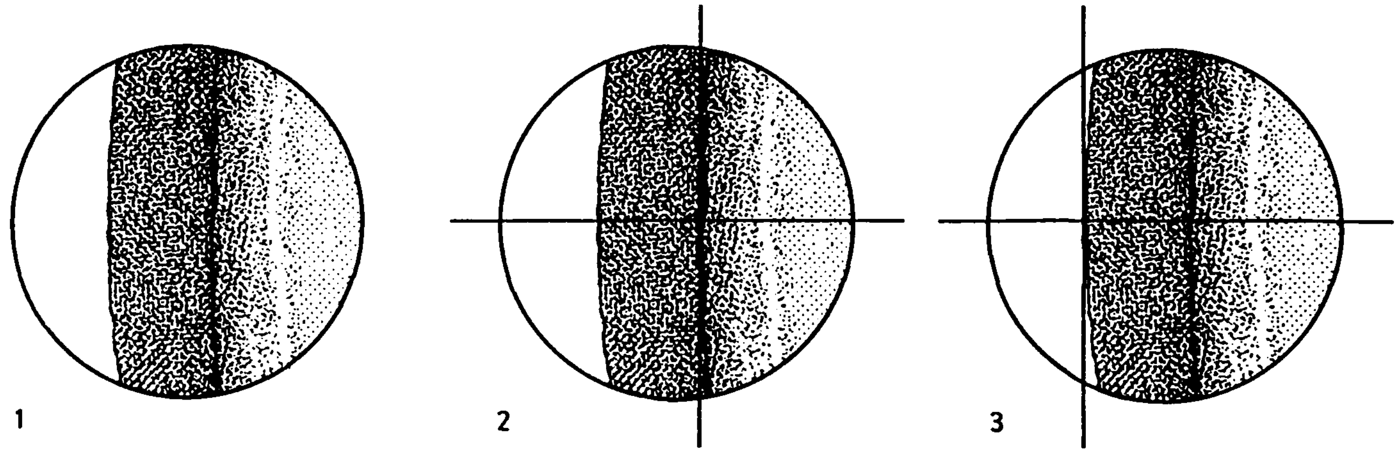

LINGUAL MARGINAL AREA OF
WAX PATTERN ON STONE DIE
A
AREA
MEASURED
1.0 mm
BEVEL
B
LINGUAL BEVEL REPRODUCED
IN CASTING
ROUNDED SHOULDER
FINISH LINE
1.0 mm LINGUAL BEVEL

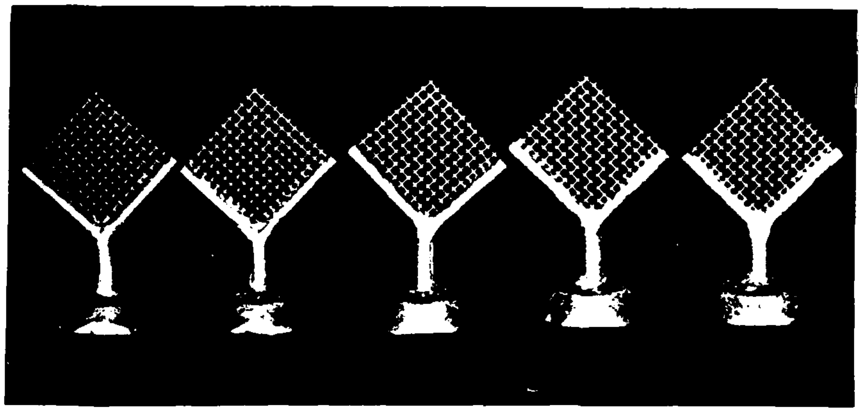
Figure 8. View of a cast lingual bevel as seen in the measuring microscope when positioned for measurement. The entire bevel is placed in focus (1), then the bevel is measured from its inside dimension (2) to its outermost dimension (3).



CROSS HAIR POSITIONS FOR MEASURING BEVEL LENGTH
ON MEASURING MICROSCOPE

Figure 9. The five Rexillium III Whitlock test specimens cast in Ceramigold.

Figure 10. The best (100%) and worst (100%) Whitlock test specimens for Rexillium III cast in Ceramigold.



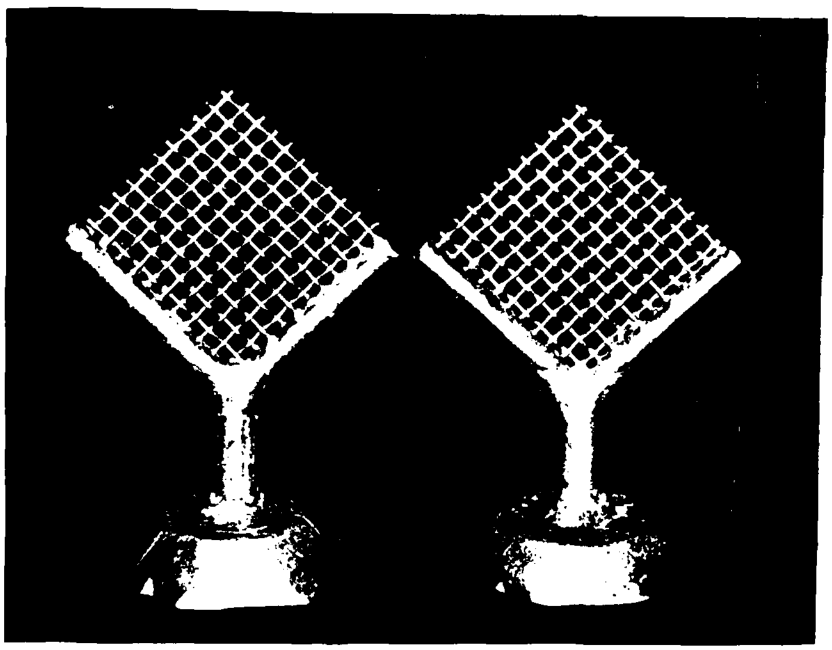
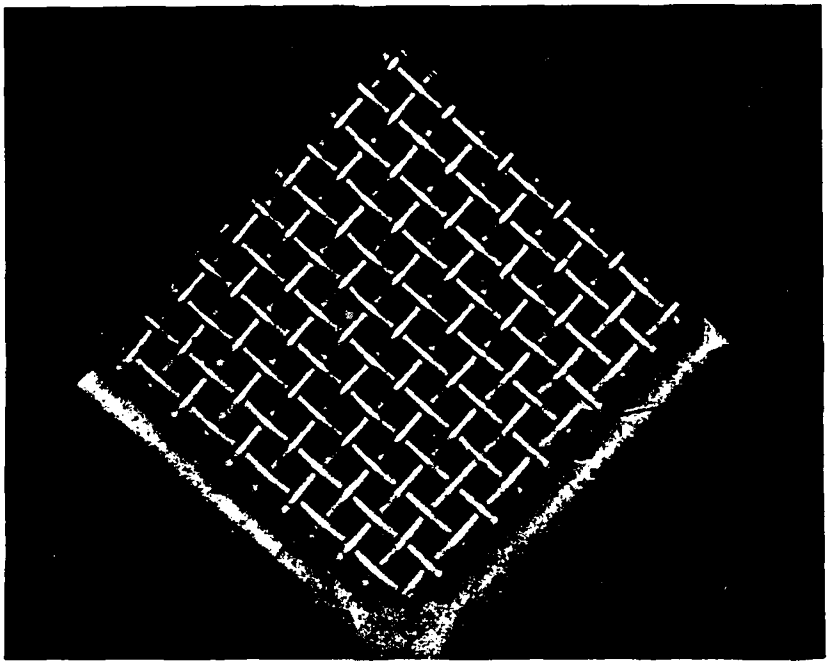
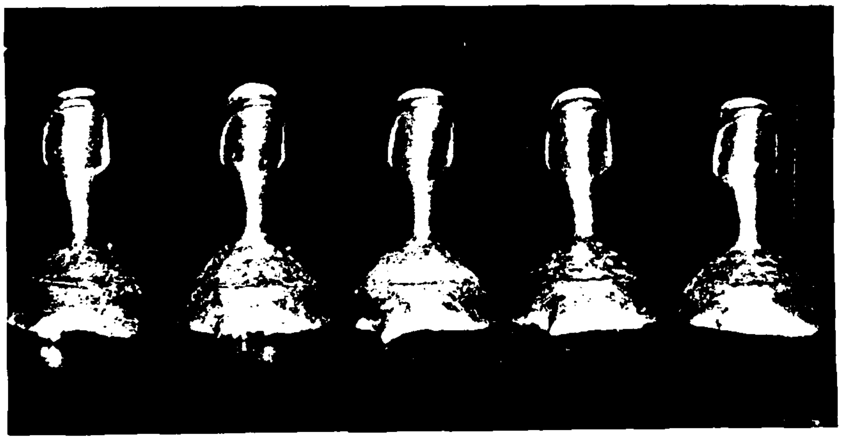


Figure 11. Close-up of the best Rexillium III Whitlock specimen cast in Ceramigold (Cv-100%).

Figure 12. The five Rexillium III coping test specimens cast in Ceramigold (front view).

Figure 13. The five Rexillium III coping test specimens cast in Ceramigold (lateral view).





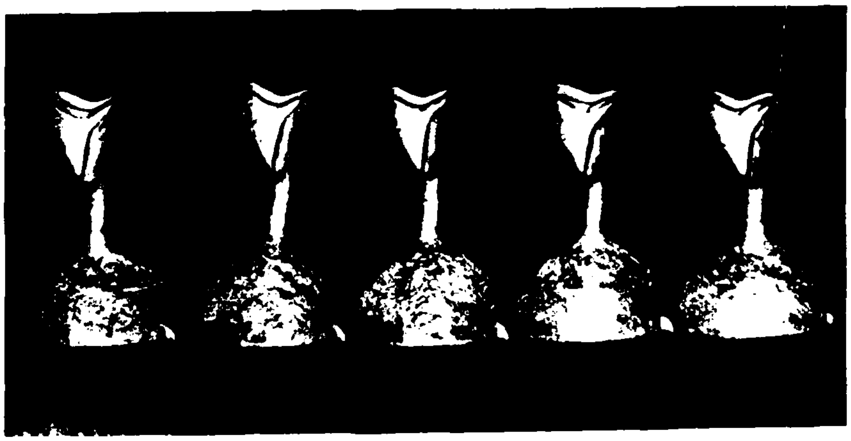
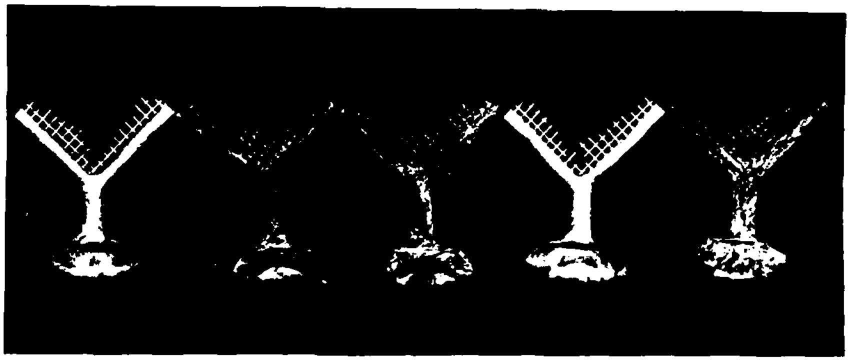


Figure 14. The five Forte Whitlock test specimens cast in Ceramigold. Specimens #1 and #4 have been air-abraded while the remaining castings are in the "as cast" condition.

Figure 15. The best (22.7%) and worst (10.5%) Whitlock test specimens for Forte cast in Ceramigold. Casting #4 (left) was air-abraded but casting #2 was not.



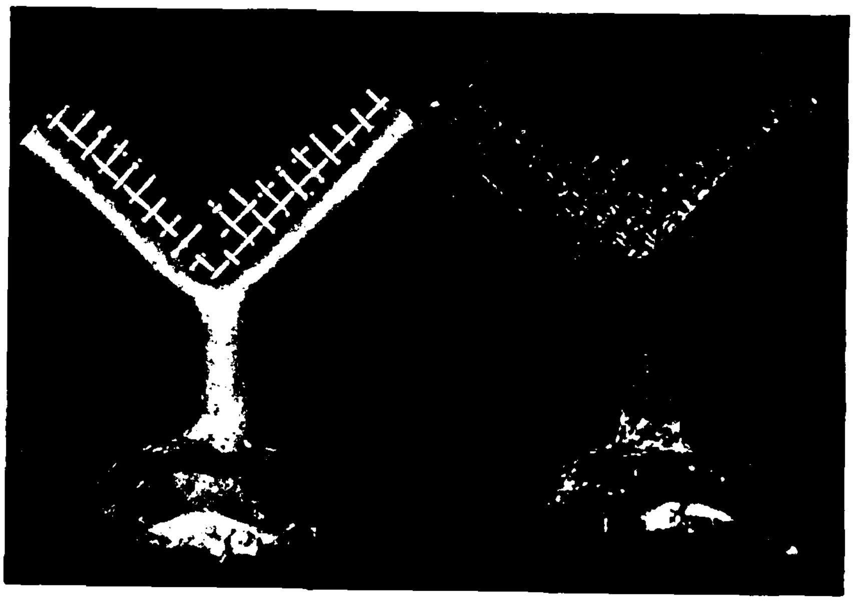


Figure 16. Close-up of the best Forte Whitlock specimen cast in Ceramigold (Cv-22.7%).

Figure 17. The five air-abraded Forte coping test specimens cast in Ceramigold (front view). Note failure of the alloy to reproduce the facial margin.

Figure 18. The five Forte coping test specimens cast in Ceramigold in the "as cast" condition (lateral view).

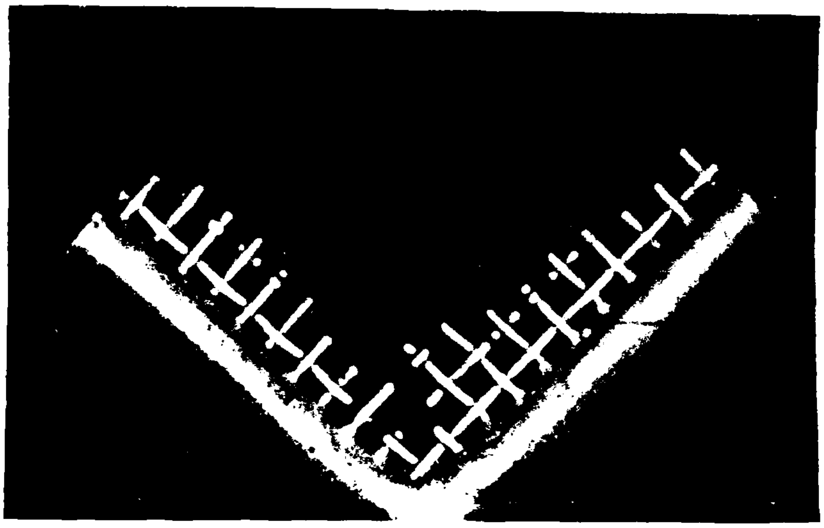
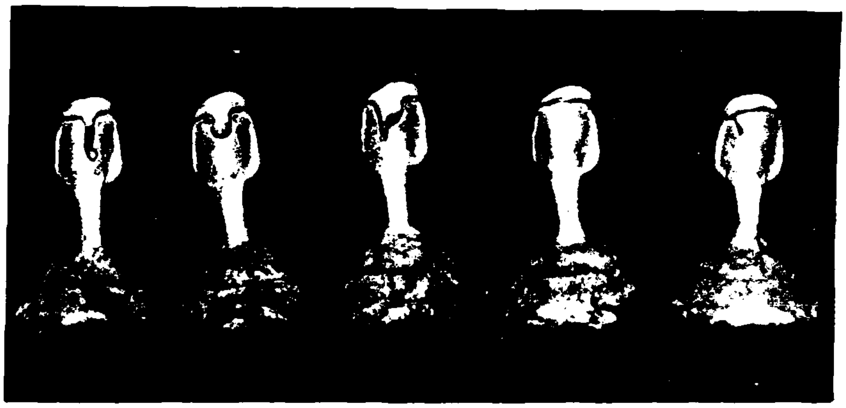
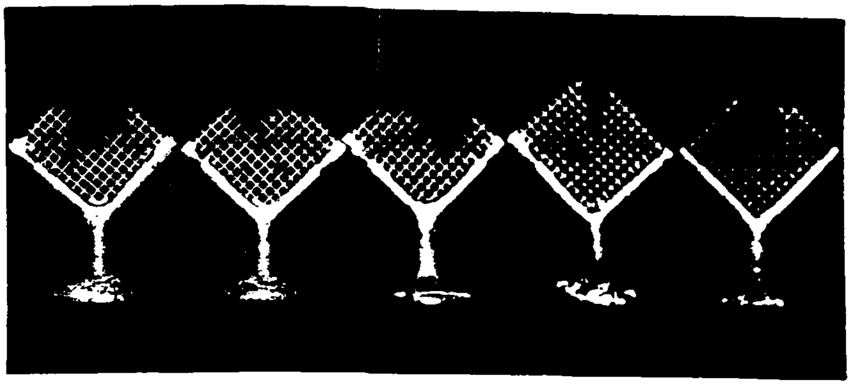




Figure 19. The five W-1 Whitlock test specimens cast in Ceramigold.

Figure 20. The best (70.9%) and worst (53.2%) Whitlock test specimens for W-1 cast in Ceramigold.



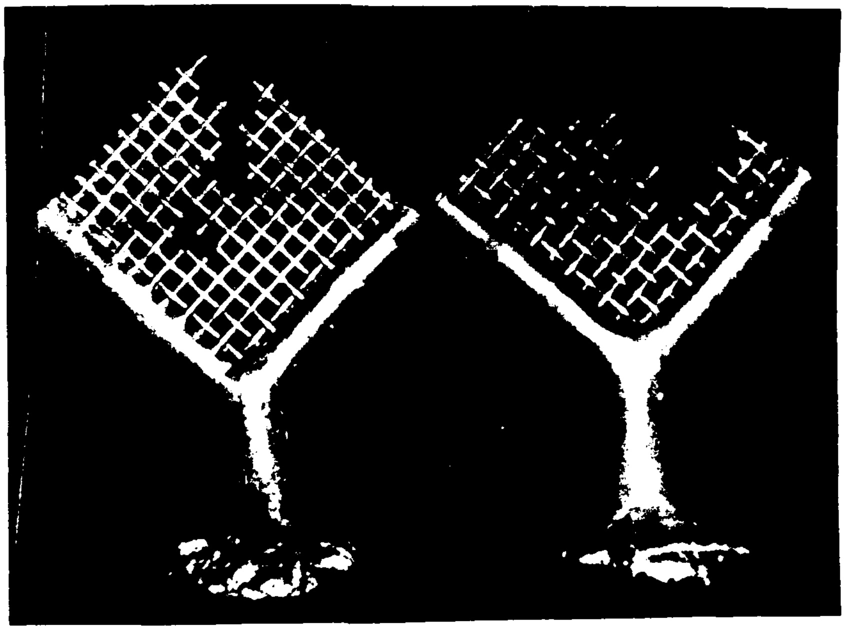
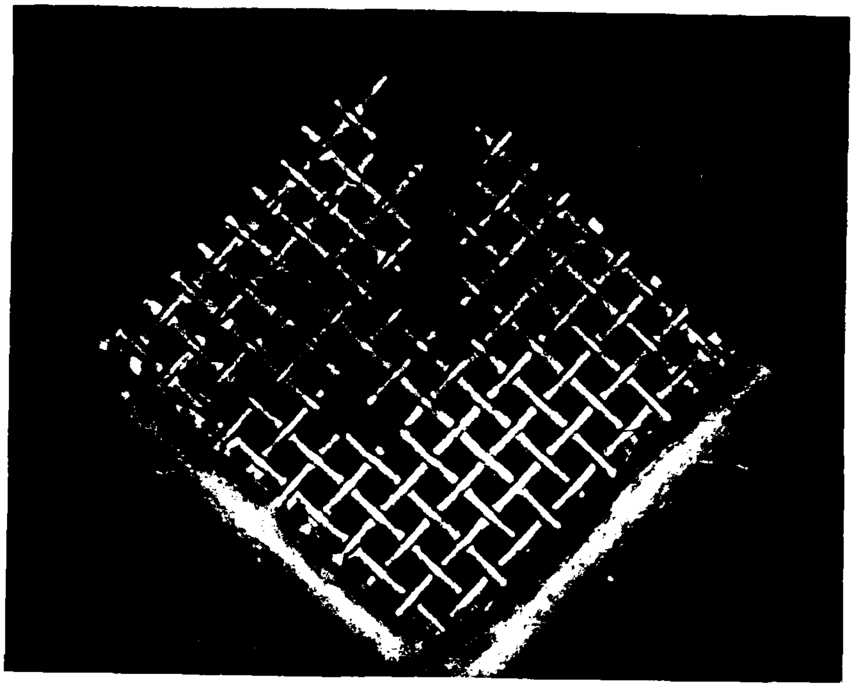


Figure 21. Close-up of the best W-1 Whitlock specimen cast in Ceramigold (Cv-85.5%). Note the difference between the light portions of the casting that were in the reducing zone (carbon-containing) and the dark areas that were not.

Figure 22. The five W-1 coping test specimens cast in Ceramigold (front view).

Figure 23. The five W-1 coping test specimens cast in Ceramigold (lateral view).



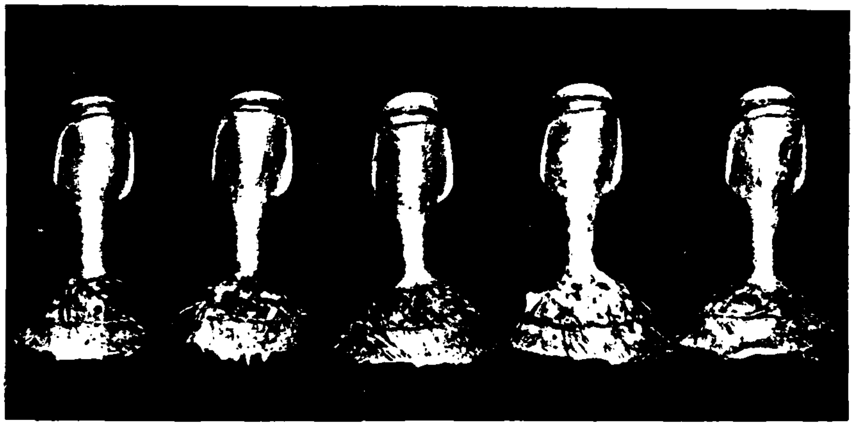
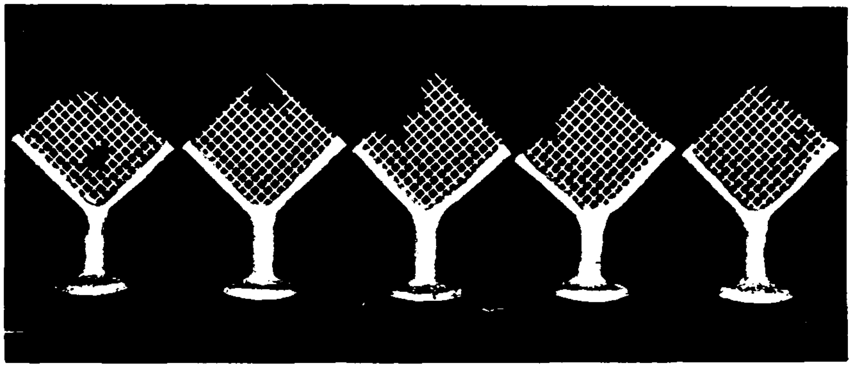


Figure 24. The five Naturelle Whitlock test specimens cast in Ceramigold.

Figure 25. The best (95.5%) and worst (79.1%) Whitlock test specimens for Naturelle cast in Ceramigold.



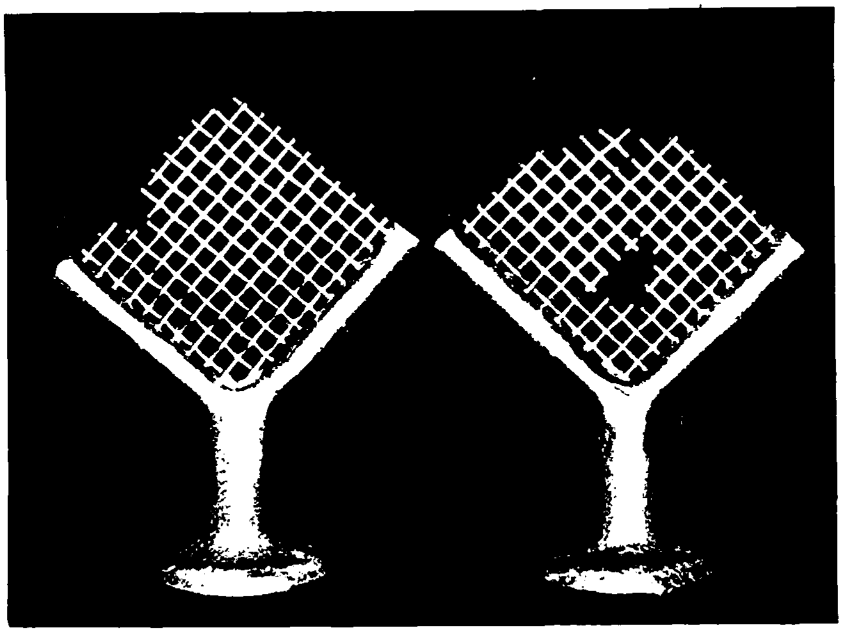
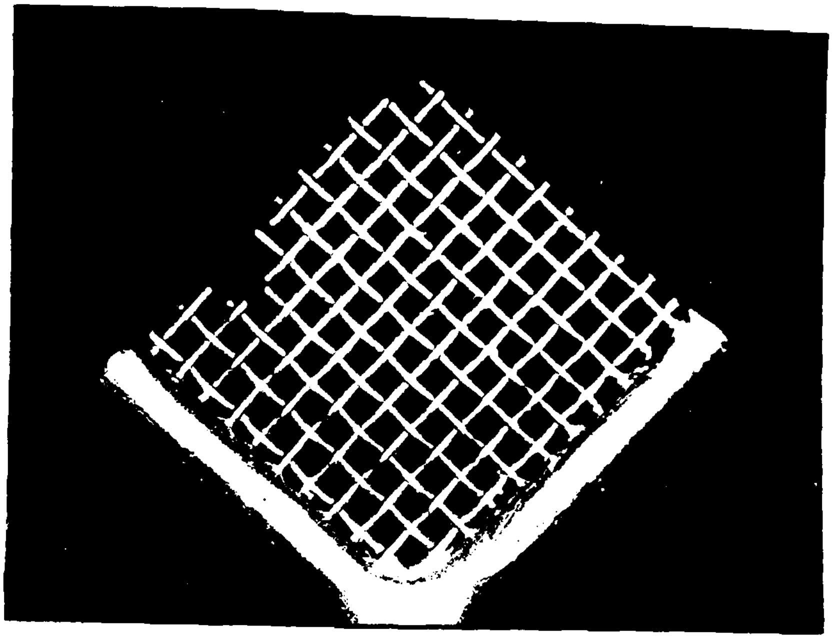
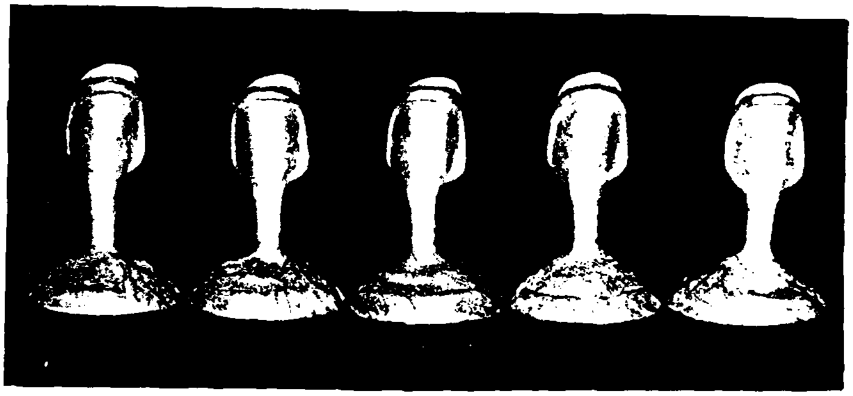


Figure 26. Close-up of the best Naturelle Whitlock specimen cast in Ceramigold (Cv-95.5%).

Figure 27. The five Naturelle coping test specimens cast in Ceramigold (front view).

Figure 28. The five Naturelle coping test specimens cast in Ceramigold (lateral view).





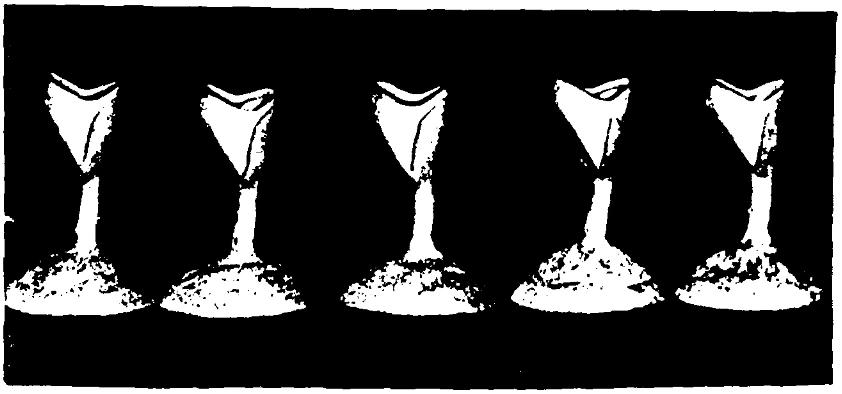
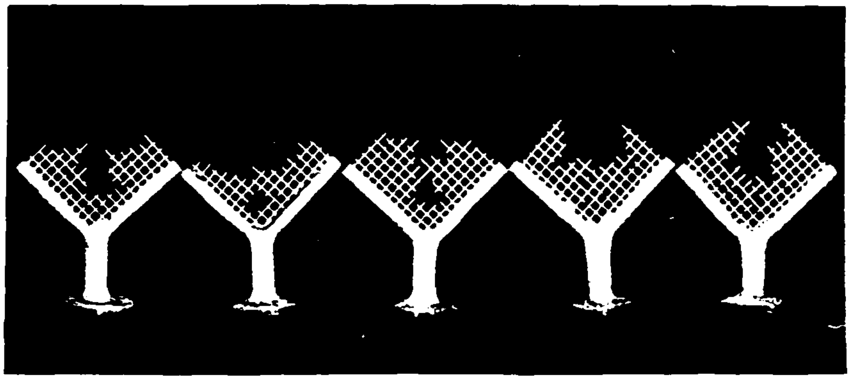


Figure 29. The five Olympia Whitlock test specimens cast in Ceramigold.

Figure 30. The best (58.6%) and worst (35.9%) Whitlock test specimens for Olympia cast in Ceramigold.



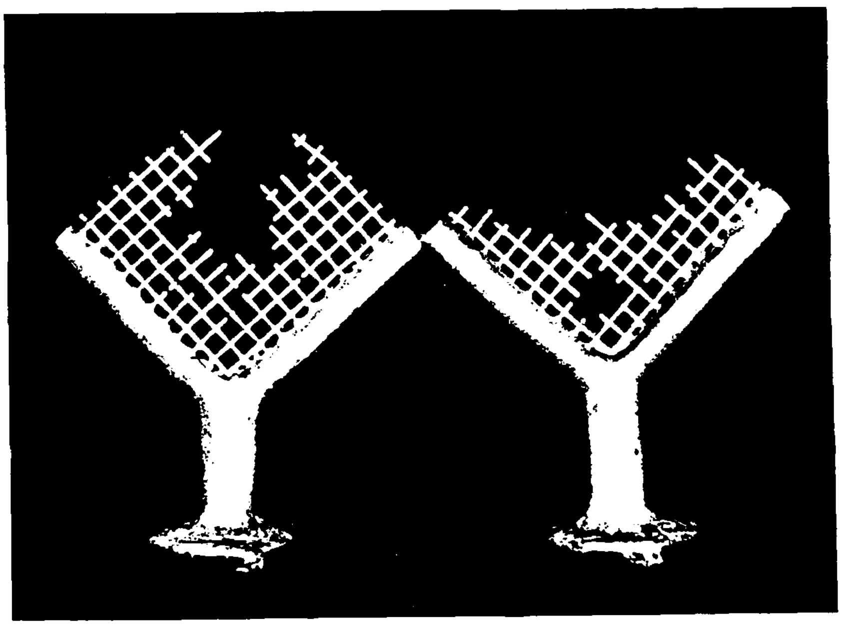
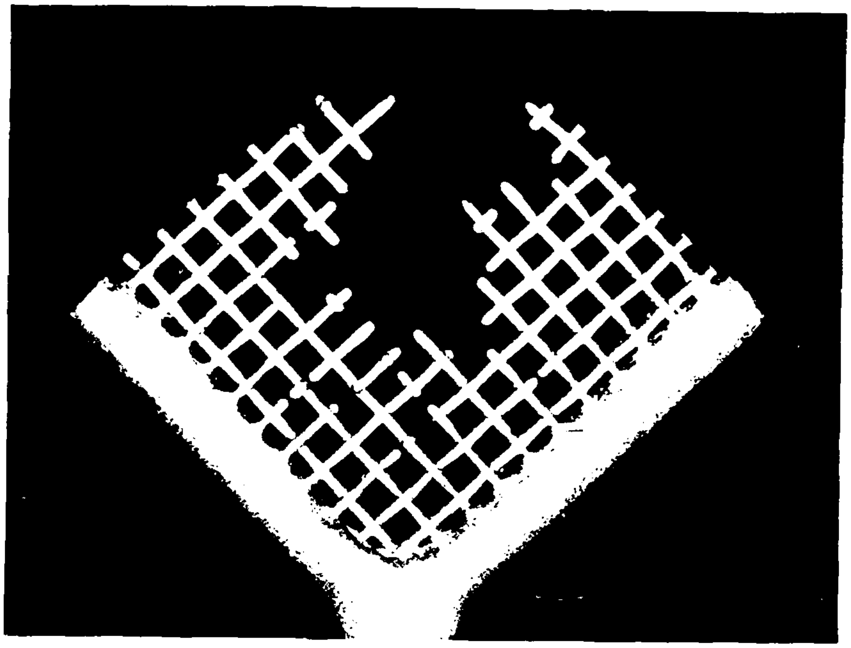


Figure 31. Close-up of the best Olympia Whitlock specimen cast in Ceramigold (Cv-58.6%).

Figure 32. The five Olympia coping test specimens cast in Ceramigold (front view).

Figure 33. The five Olympia coping test specimens cast in Ceramigold (lateral view).



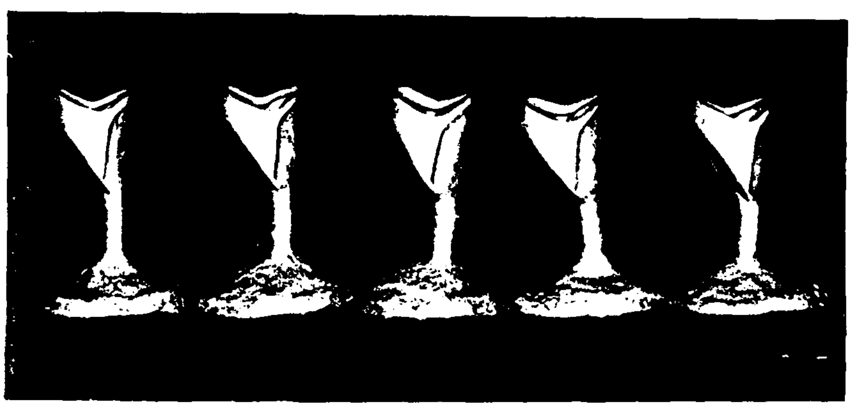
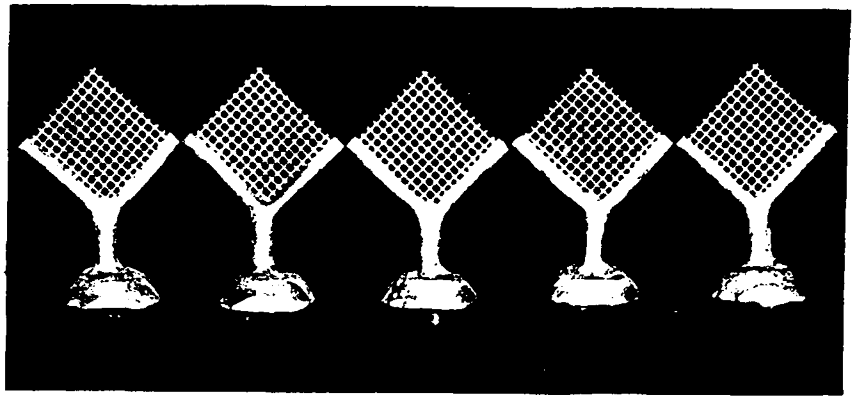


Figure 34. The five Rexillium III Whitlock test specimens cast in Vestra-fine.

Figure 35. The best (100%) and worst (100%) Whitlock test specimens for Rexillium III cast in Vestra-fine.



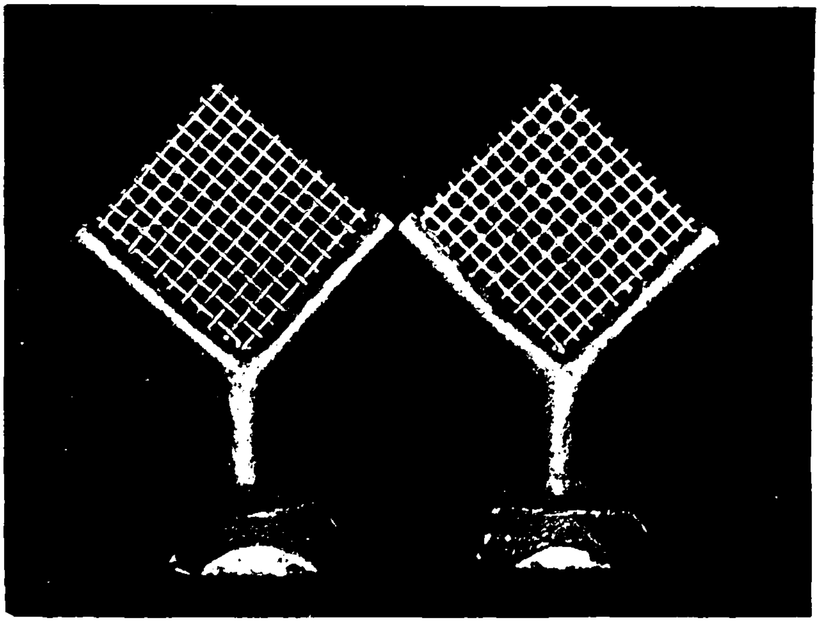


Figure 36. Close-up of the best Rexillium Whitlock specimen cast in Vestra-fine (Cv-100%).

Figure 37. The five Rexillium III coping test specimens cast in Vestra-fine (front view).

Figure 38. The five Rexillium III coping test specimens cast in Vestra-fine (lateral view).

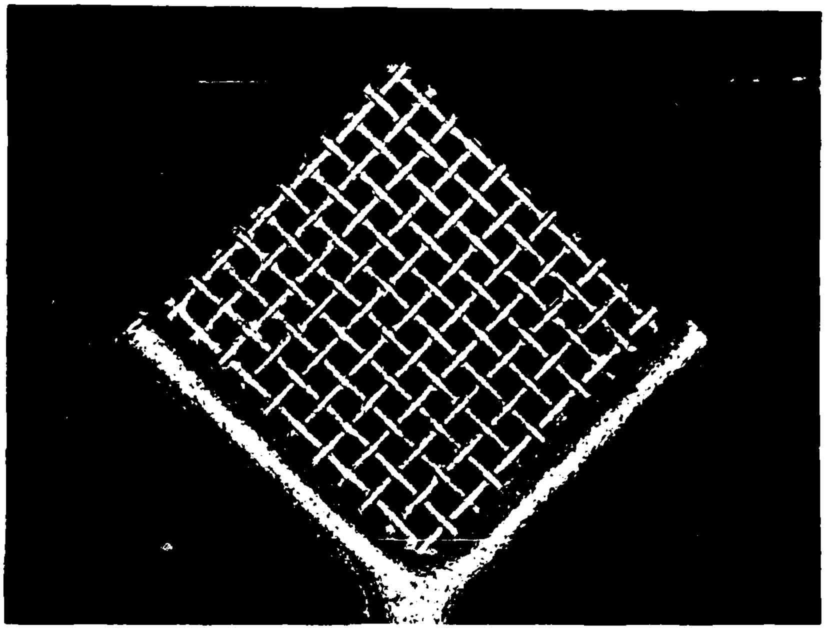
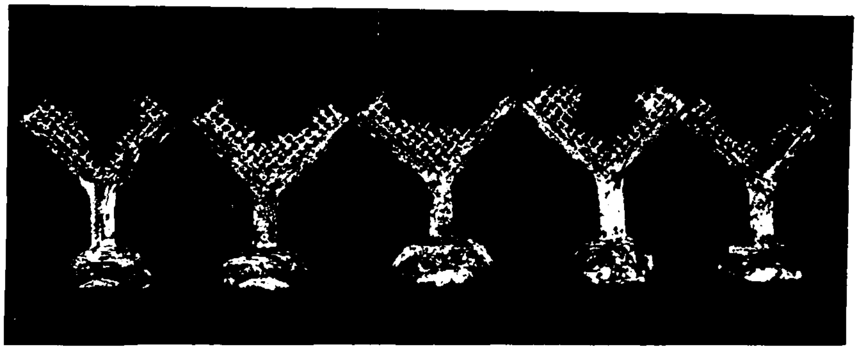


Figure 39. The five Forte Whitlock test specimens cast in Vestra-fine before air-abrading.

Figure 40. The best (30.9%) and worst (16.8%) Whitlock test specimens for Forte cast in Vestra-fine.



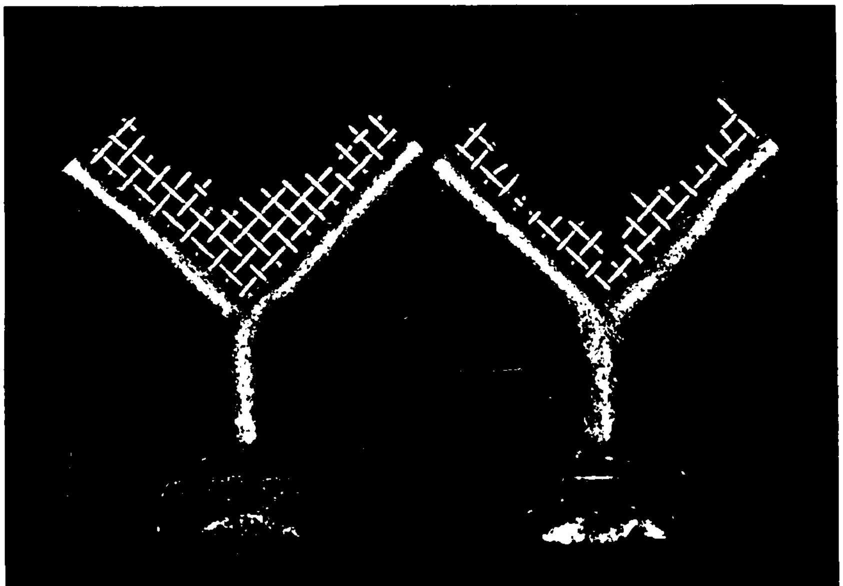
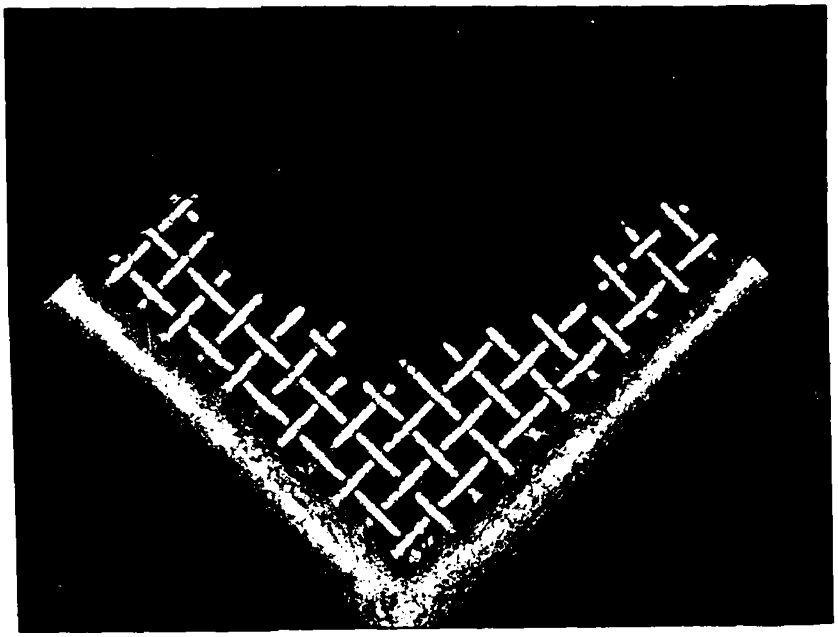
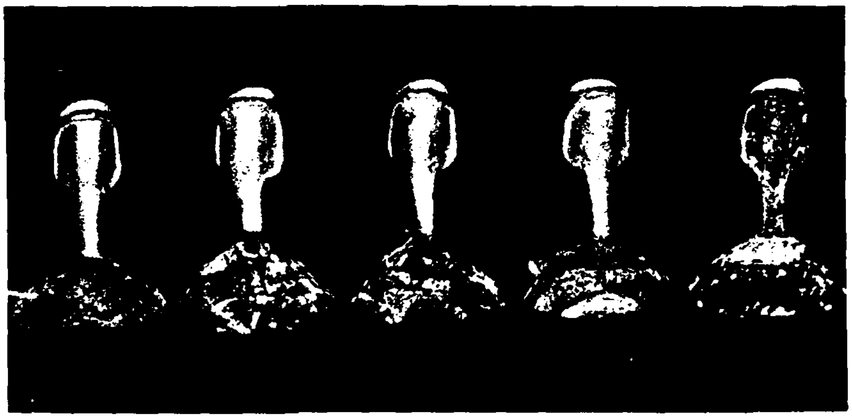


Figure 41. Close-up of the best Forte Whitlock specimen cast in Vestra-fine (Cv-30.9%).

Figure 42. The five Forte coping test specimens cast in Vestra-fine with only castings #1 to #4 air-abraded (front view).

Figure 43. The five Forte coping test specimens cast in Vestra-fine (lateral view).





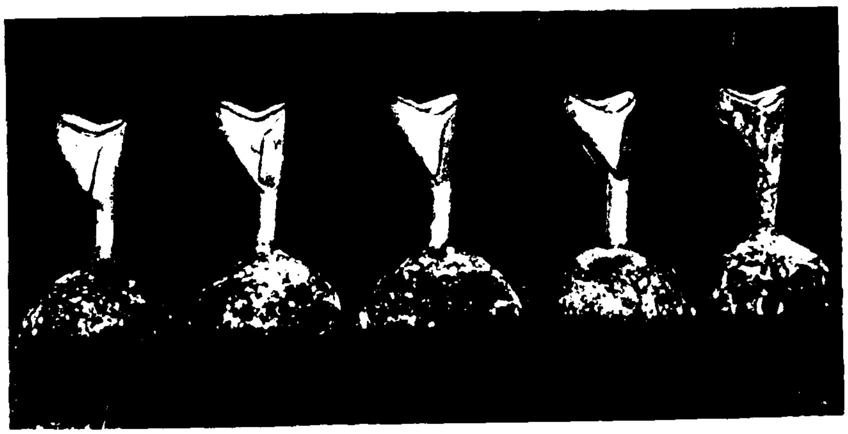
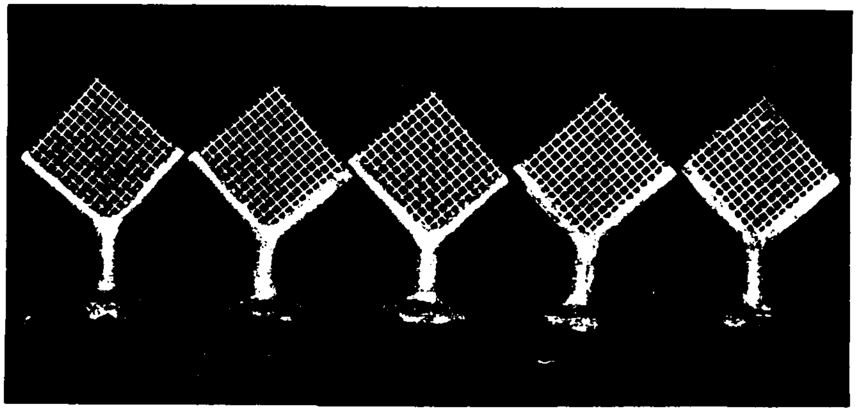


Figure 44. The five W-1 Whitlock test specimens cast in Vestra-fine.

Figure 45. The best (100%) and worst (100%) Whitlock test specimens for W-1 cast in Vestra-fine.



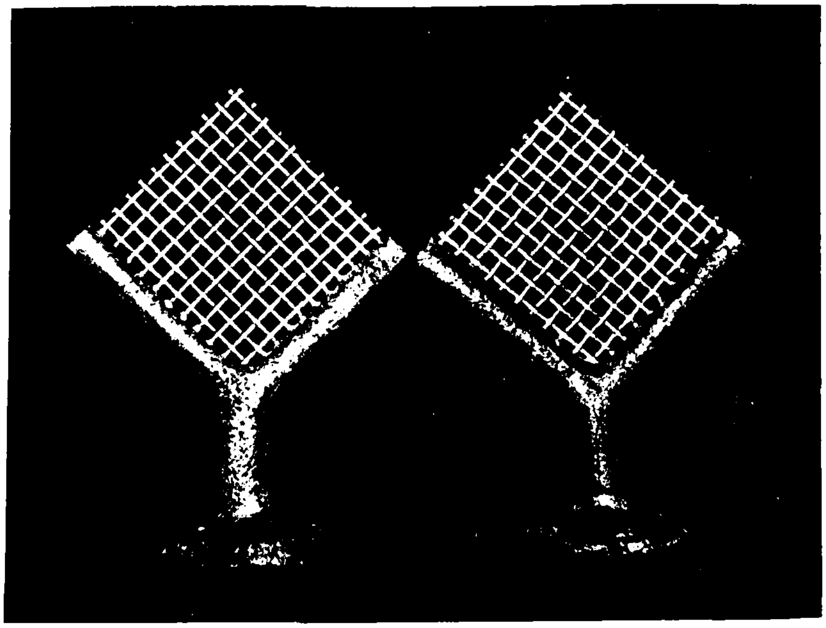
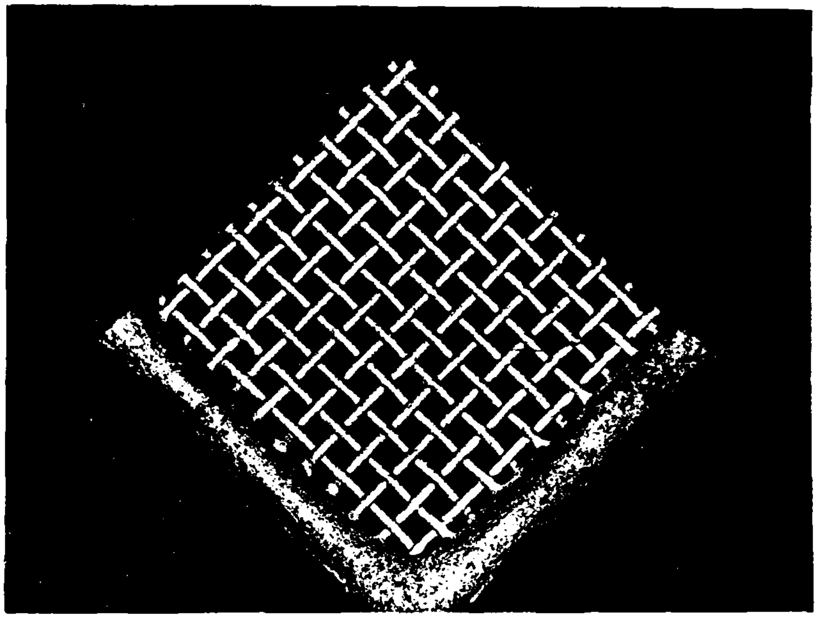


Figure 46. Close-up of the best W-1 Whitlock specimen cast in Vestra-fine (Cv-100%).

Figure 47. The five W-1 coping test specimens cast in Vestra-fine (front view).

Figure 48. The five W-1 coping test specimens cast in Vestra-fine (lateral view).



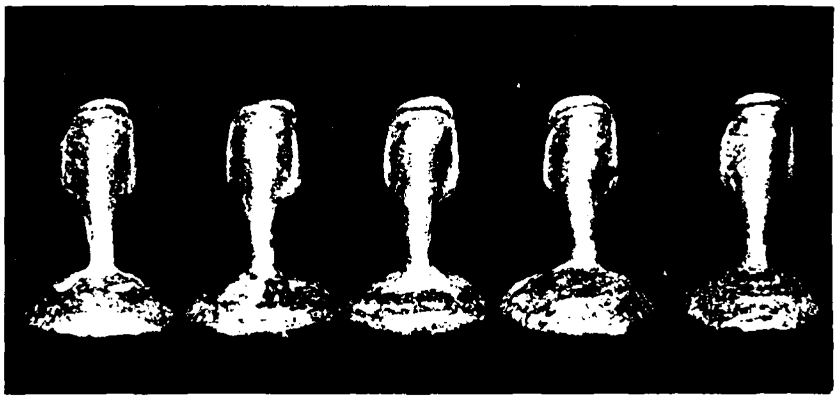
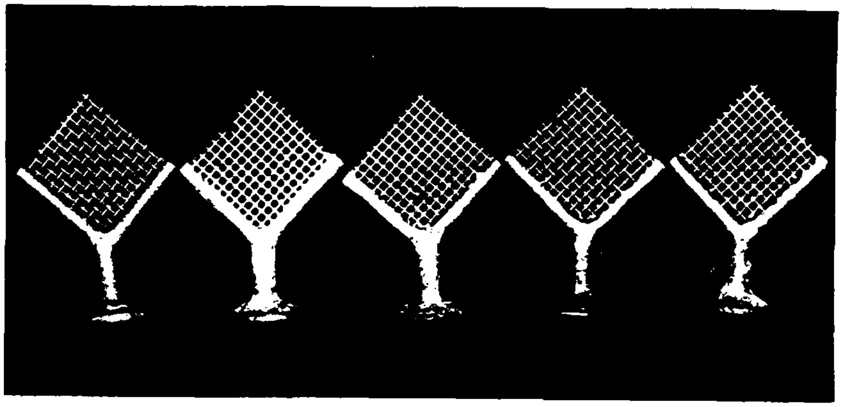


Figure 49. The five Naturelle Whitlock test specimens cast in Vestra-fine.

Figure 50. The best (100%) and worst (98.2%) Whitlock test specimens for Naturelle cast in Vestra-fine.



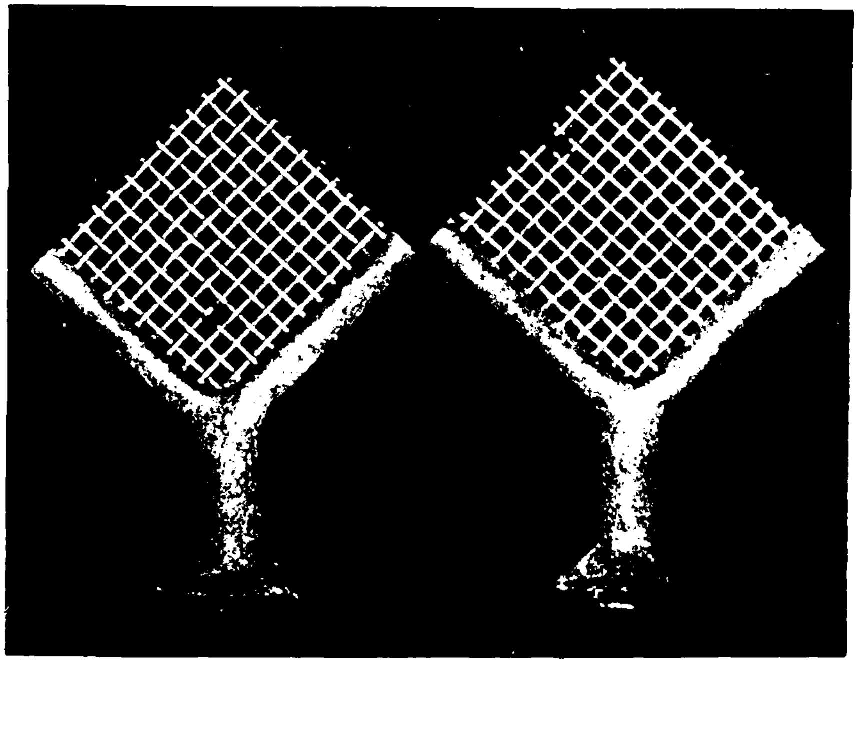


Figure 51. Close-up of the best Naturelle Whitlock specimen cast in Vestra-fine (Cv-100%).

Figure 52. The five Naturelle coping test specimens cast in Vestra-fine (front view).

Figure 53. The five Naturelle coping test specimens cast in Vestra-fine (lateral view).

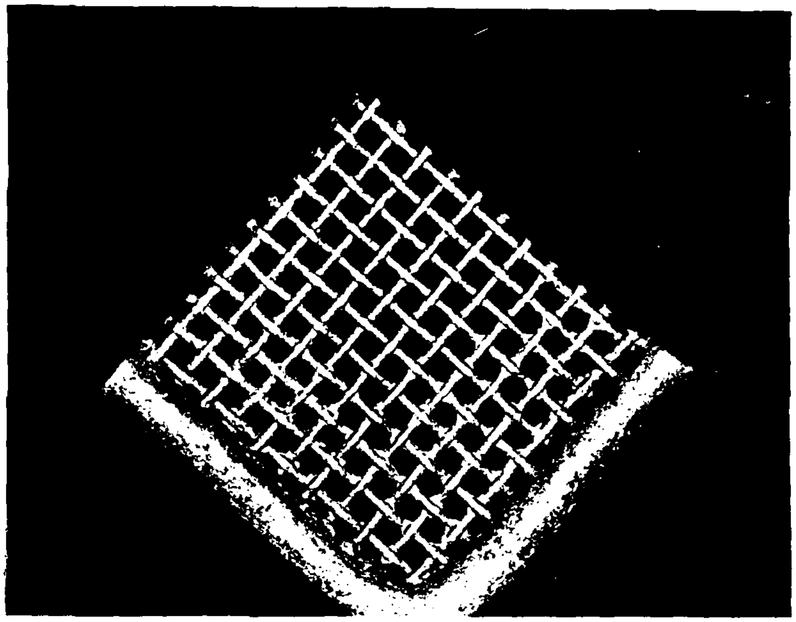
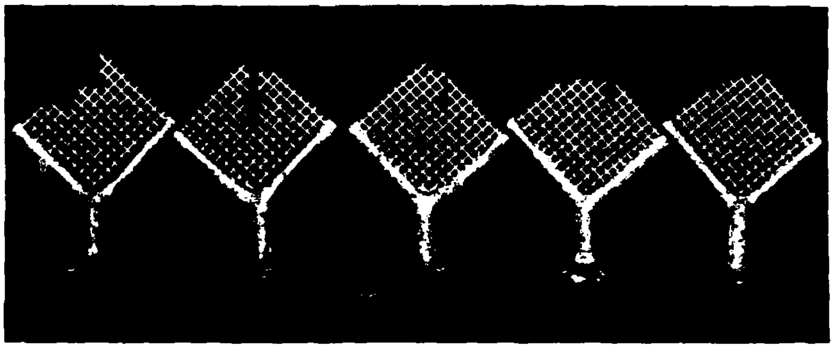


Figure 54. The five Olympia Whitlock test specimens cast in Vestra-fine.

Figure 55. The best (91.4%) and worst (80.5%) Whitlock test specimens for Olympia cast in Vestra-fine.



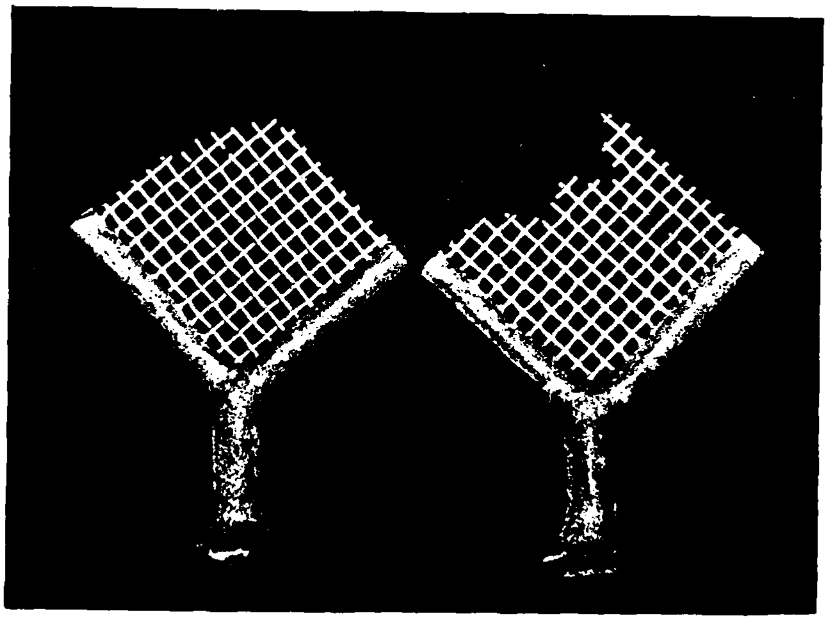
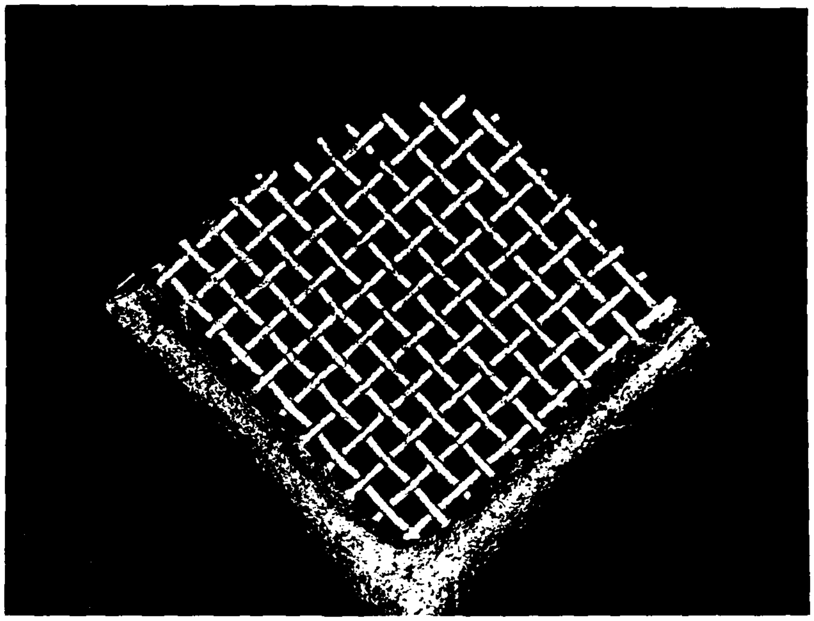
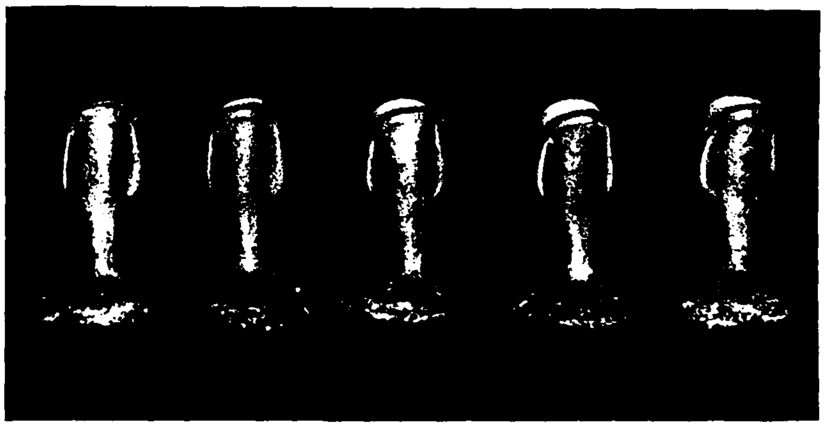


Figure 56. Close-up of the best Olympia Whitlock specimen cast in Vestra-fine (Cv-91.4%).

Figure 57. The five Olympia coping test specimens cast in Vesta-fine (front view).

Figure 58. The five Olympia coping test specimens cast in Vestra-fine (lateral view).





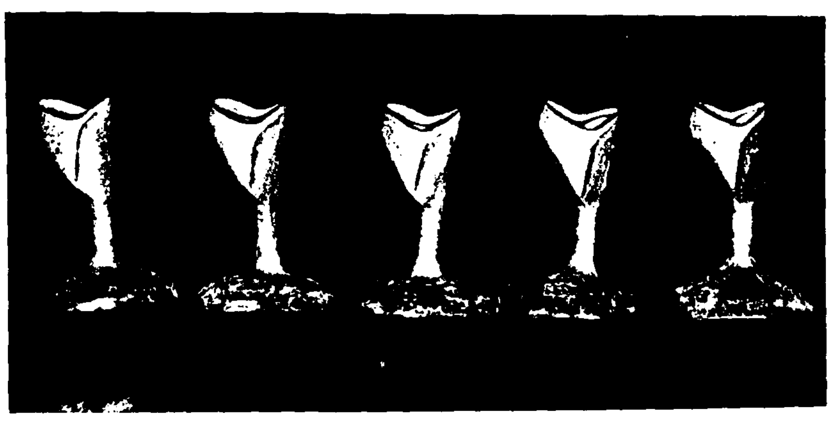


Figure 59. Cross-sectional view of an Olympia-Ceramigold casting with single chamber, suck-back porosity (arrow).

Figure 60. Carbon remaining in the central portion of the Ceramigold investment reduced oxide formation in this W-1 casting.

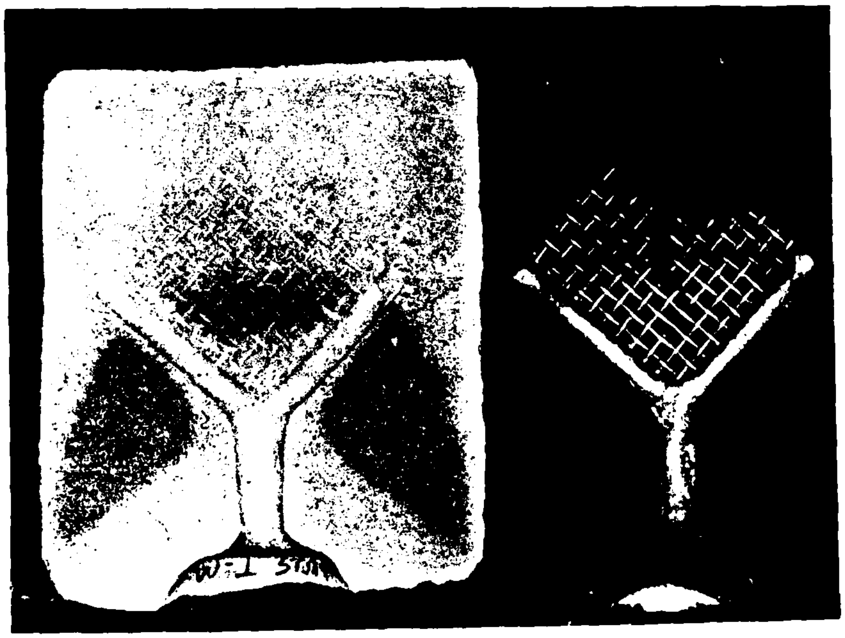


Figure 61. The smooth surface of this Olympia casting was typical of those specimens produced with Ceramigold.

Figure 62. The Olympia copings cast in Vestra-fine were rough in comparison to those specimens cast at the same temperature in Ceramigold.

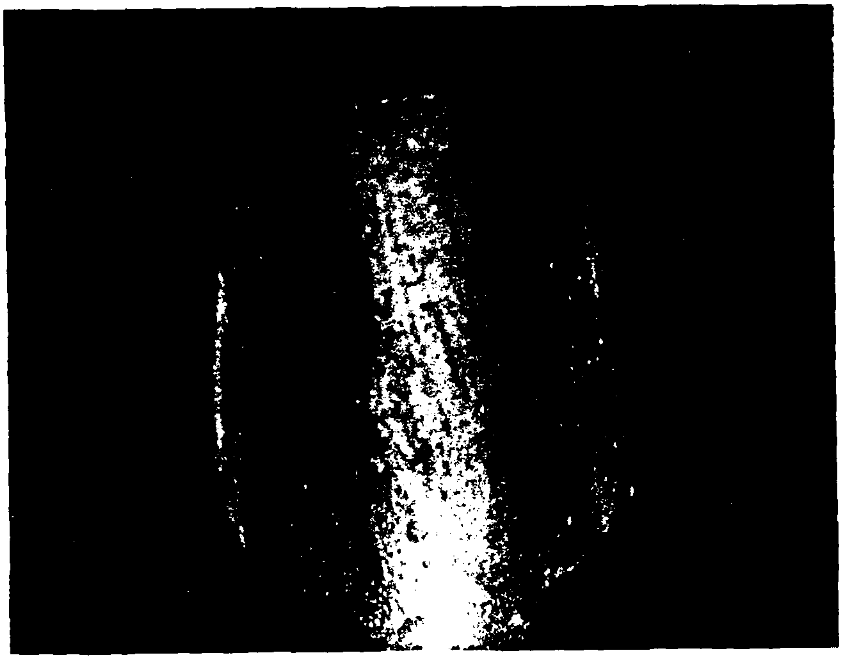
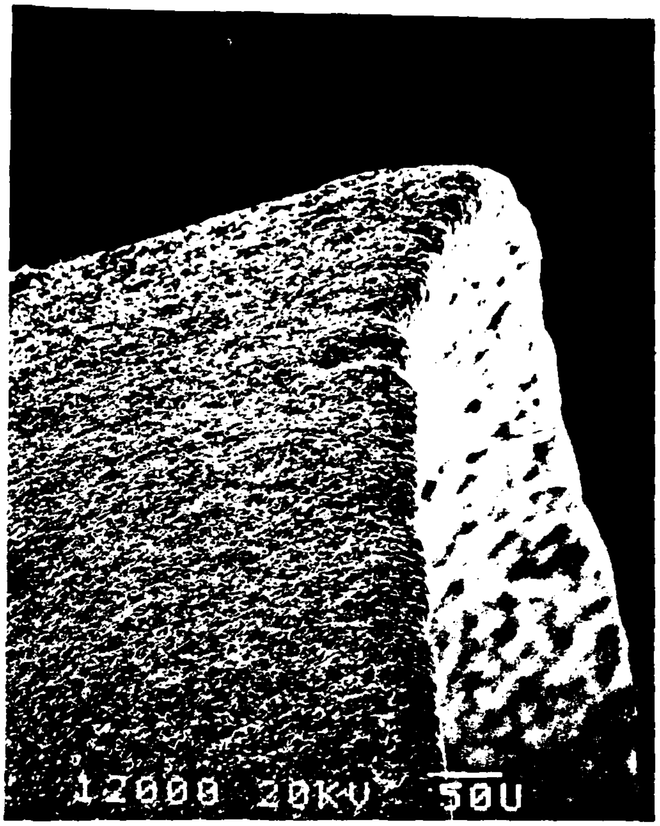


Figure 63. Scanning electron micrograph of best margin (facial #5) for Rexillium III cast in Ceramigold (orig. mag. 200X)

Figure 64. Scanning electron micrograph of worst margin (facial #3) for Rexillium III cast in Ceramigold (orig. mag. 200X)


12000 20KV 50U

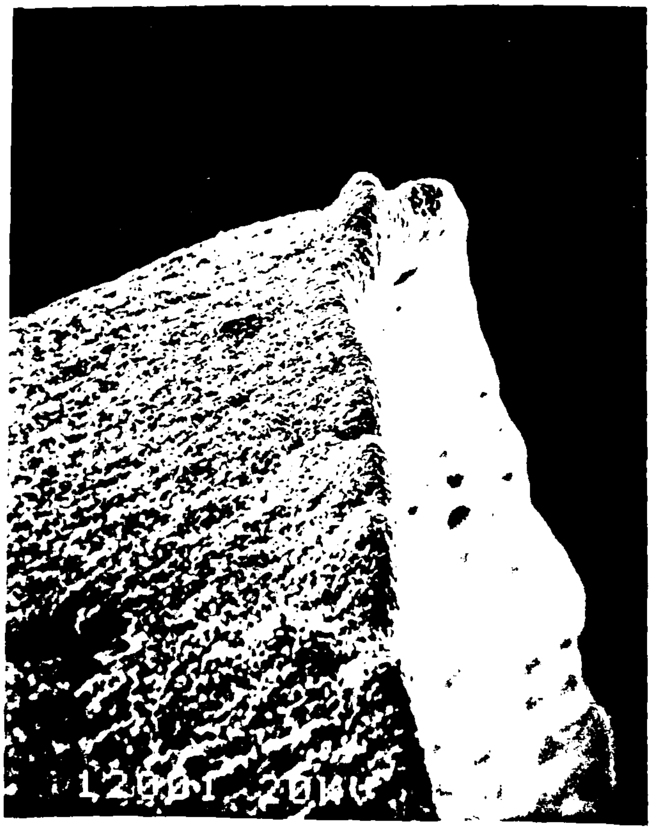
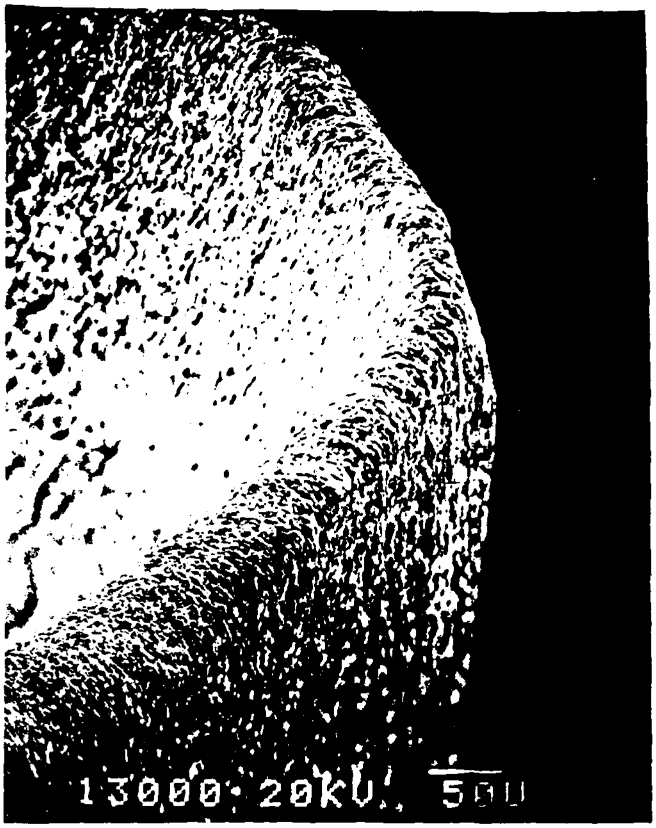


Figure 65. Scanning electron micrograph of best margin (lingual #3) for Forte cast in Ceramigold (orig. mag. 200X)

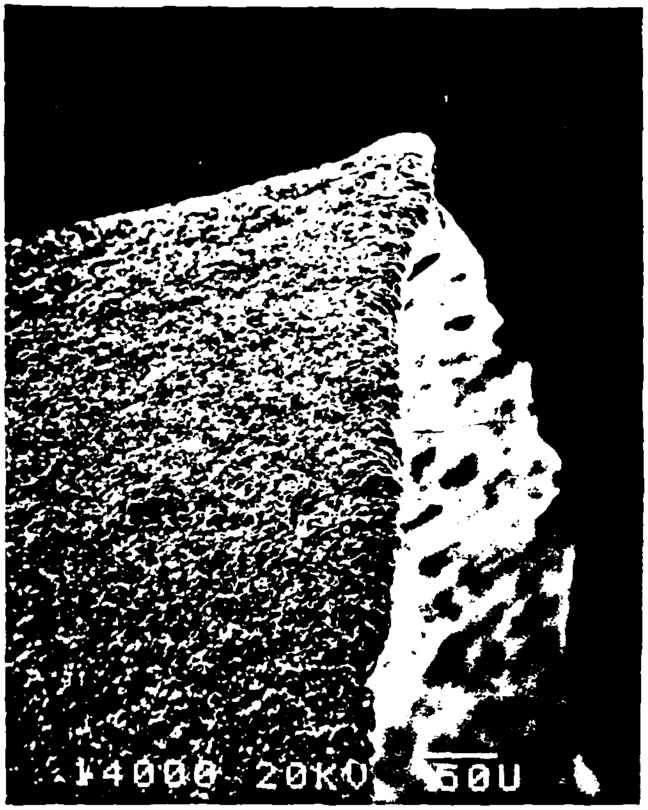
Figure 66. Scanning electron micrograph of worst margin (facial #4) for Forte cast in Ceramigold (orig. mag. 200X)


13000 20KU 50U


13001 20KU

Figure 67. Scanning electron micrograph of best margin (facial #4) for W-1 cast in Ceramigold (orig. mag. 200X)

Figure 68. Scanning electron micrograph of worst margin (facial #2) for W-1 cast in Ceramigold (orig. mag. 200X)


14000 20KV 50U

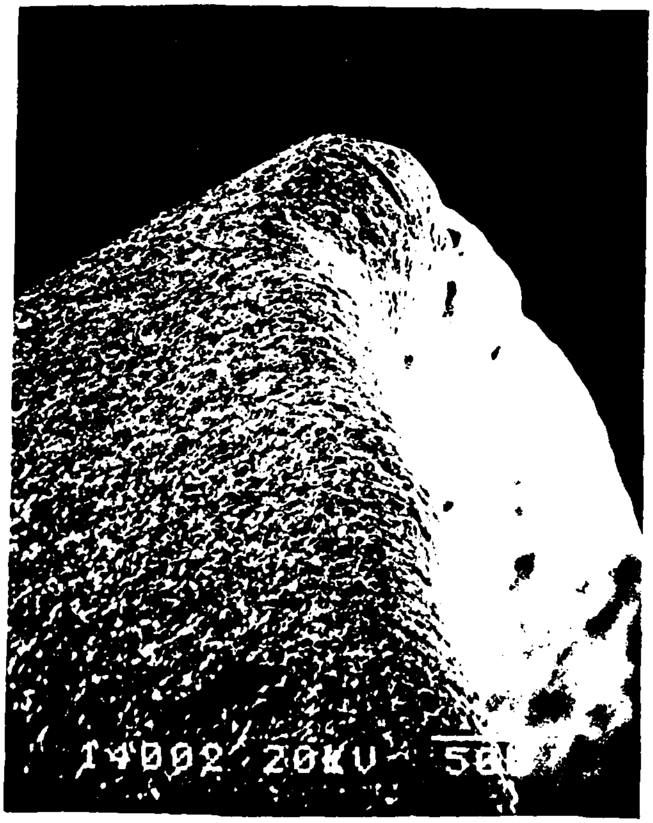
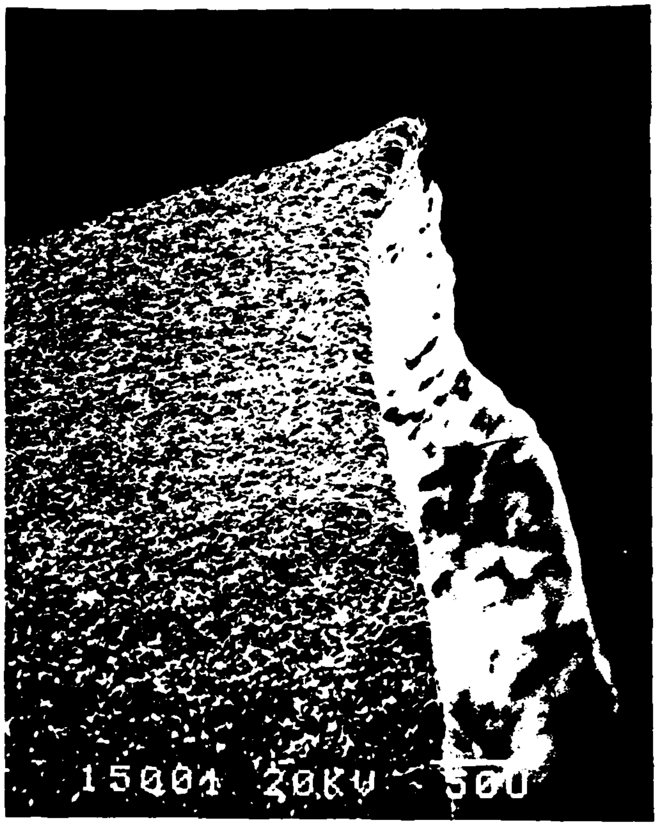

14002 20KV 50

Figure 69. Scanning electron micrograph of best margin (facial #2) for Naturelle cast in Ceramigold (orig. mag. 200X)

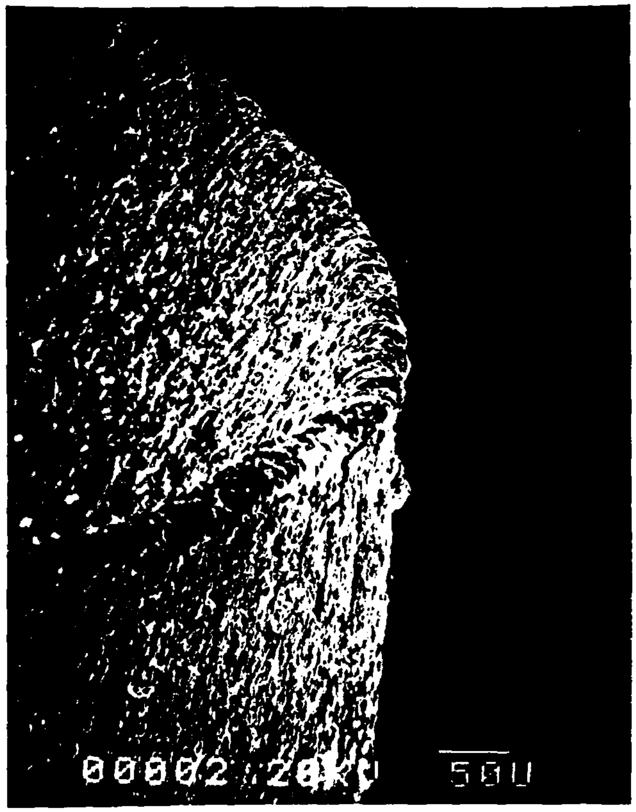
Figure 70. Scanning electron micrograph of worst margin (lingual #4) for Naturelle cast in Ceramigold (orig. mag. 200X)


15001 20KV 50U


15002 20KV 50U

Figure 71. Scanning electron micrograph of best margin (lingual #4) for Olympia cast in Ceramigold (orig. mag. 200X)

Figure 72. Scanning electron micrograph of worst margin (facial #4) for Olympia cast in Ceramigold (orig. mag. 200X)


00002 20KV 50U

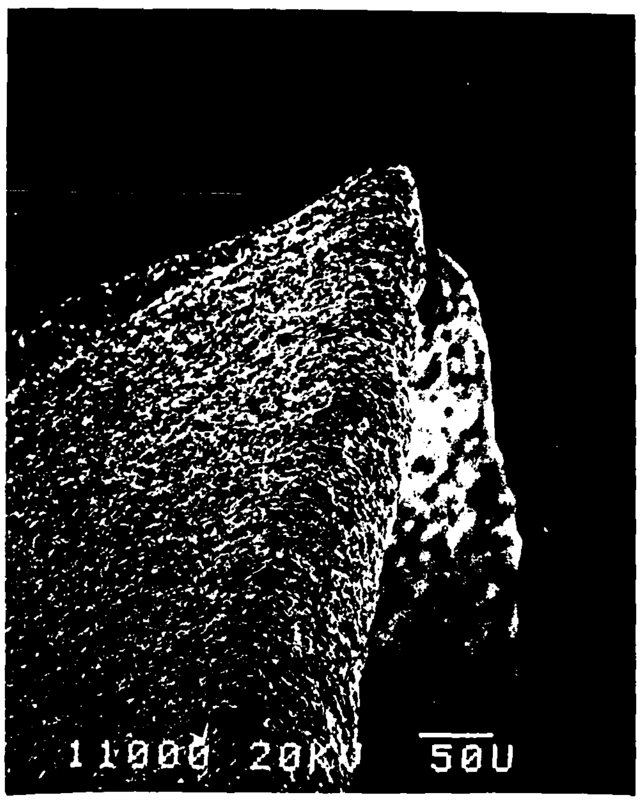

11000 20KV 50U

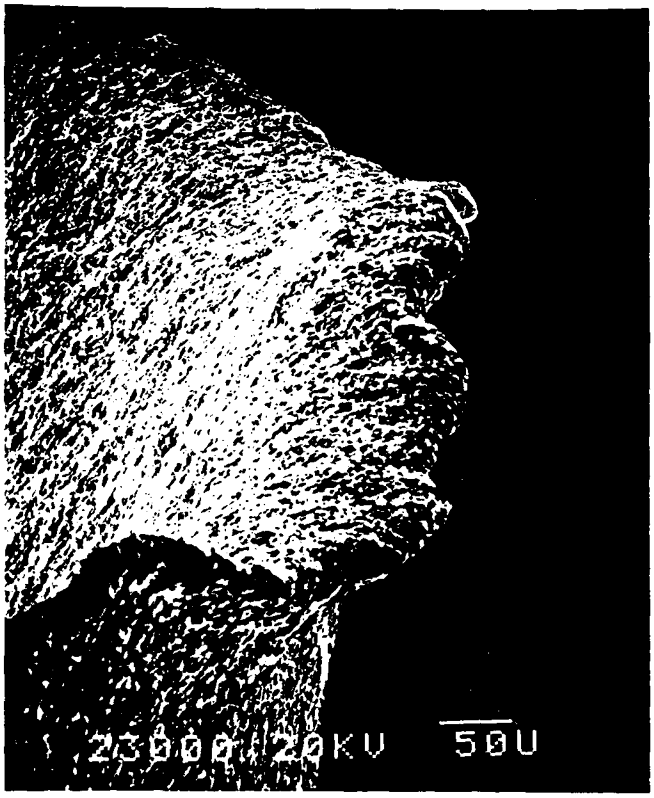
Figure 73. Scanning electron micrograph of best margin (facial #5) for Rexillium III cast in Vestra-fine (orig. mag. 200X)

Figure 74. Scanning electron micrograph of worst margin (lingual #3) for Rexillium III cast in Vestra-fine (orig. mag. 200X)


22001
50U

Figure 75. Scanning electron micrograph of best margin (lingual #5) for Forte cast in Vestra-fine (orig. mag. 200X)

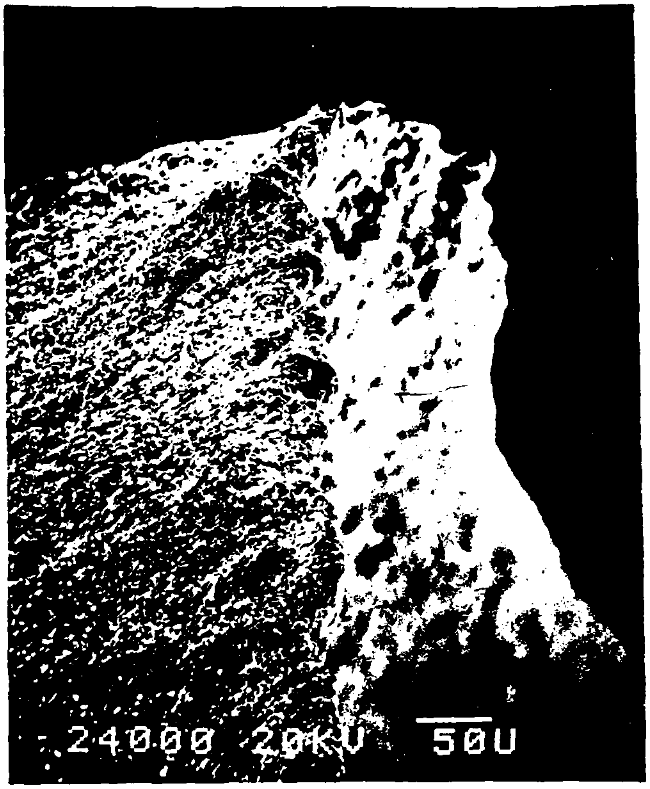
Figure 76. Scanning electron micrograph of worst margin (facial #2) for Forte cast in Vestra-fine (orig. mag. 200X)


23000 20KV 50U


23002 20KV 50U

Figure 77. Scanning electron micrograph of best margin (facial #2) for W-1 cast in Vestra-fine (orig. mag. 200X)

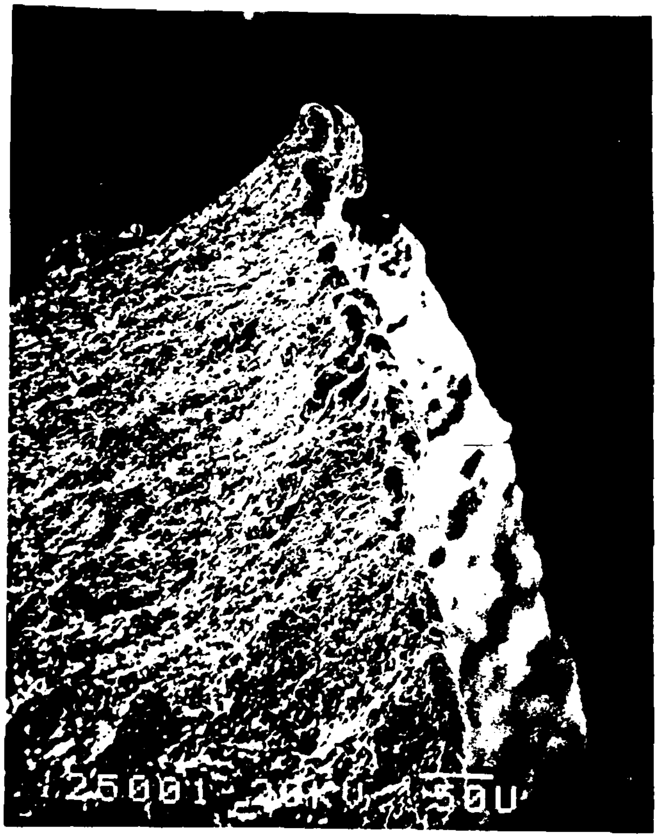
Figure 78. Scanning electron micrograph of worst margin (facial #1) for W-1 cast in Vestra-fine (orig. mag. 200X)


24000 20KV 50U


24002 20KV 50U

Figure 79. Scanning electron micrograph of best margin (facial #5) for Naturelle cast in Vestra-fine (orig. mag. 200X)

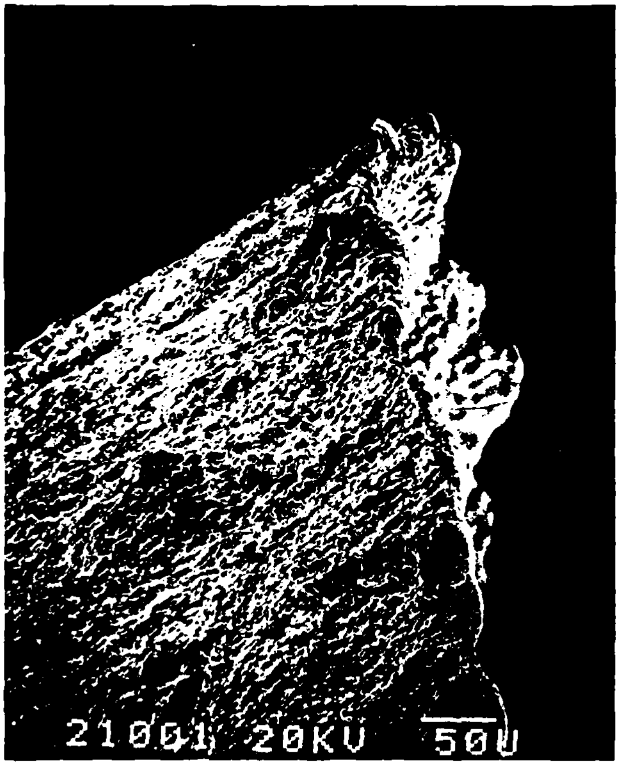
Figure 80. Scanning electron micrograph of worst margin (lingual #5) for Naturelle cast in Vestra-fine (orig. mag. 200X)


25001


25003

Figure 81. Scanning electron micrograph of best margin (facial #3) for Olympia cast in Vestra-fine (orig. mag. 200X)

Figure 82. Scanning electron micrograph of worst margin (lingual #2) for Olympia cast in Vestra-fine (orig. mag. 200X)


21001 20KV 50U

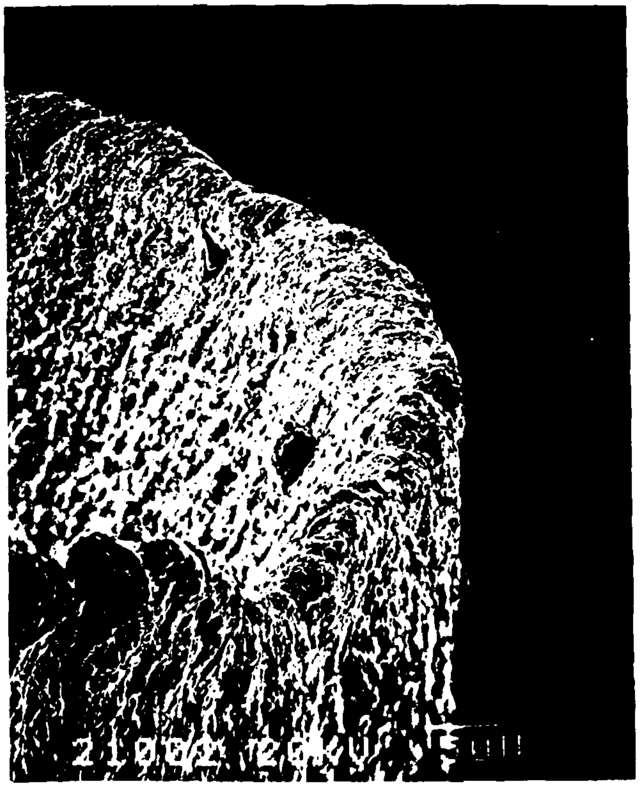
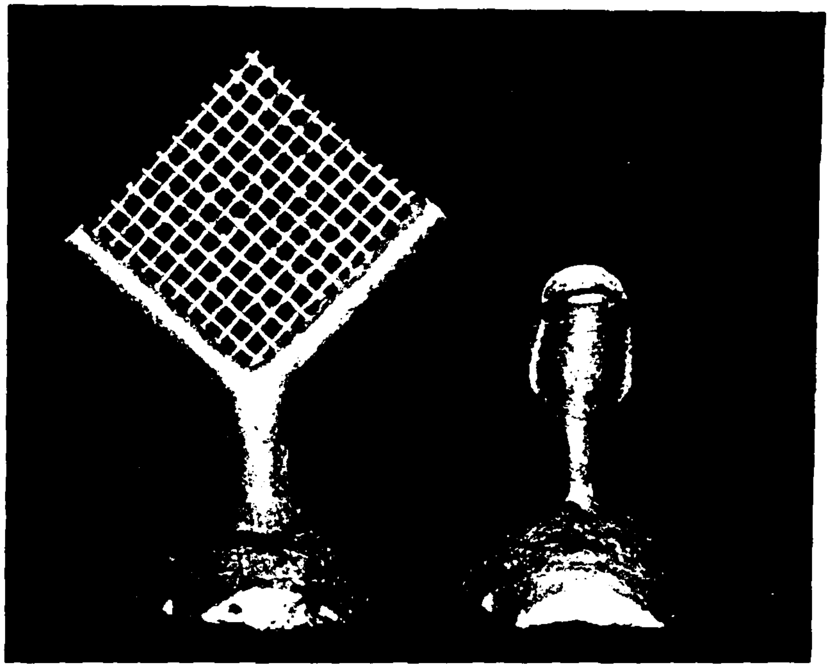


Figure 83. Castability values obtained from the Whitlock test (left) could not predict the level of performance in the replica (coping) test (right).

Figure 84. Castability values (Cv) for these two Whitlock test specimens of Olympia and Vestra-fine were identical (91.4%), but the reproduced patterns were different.



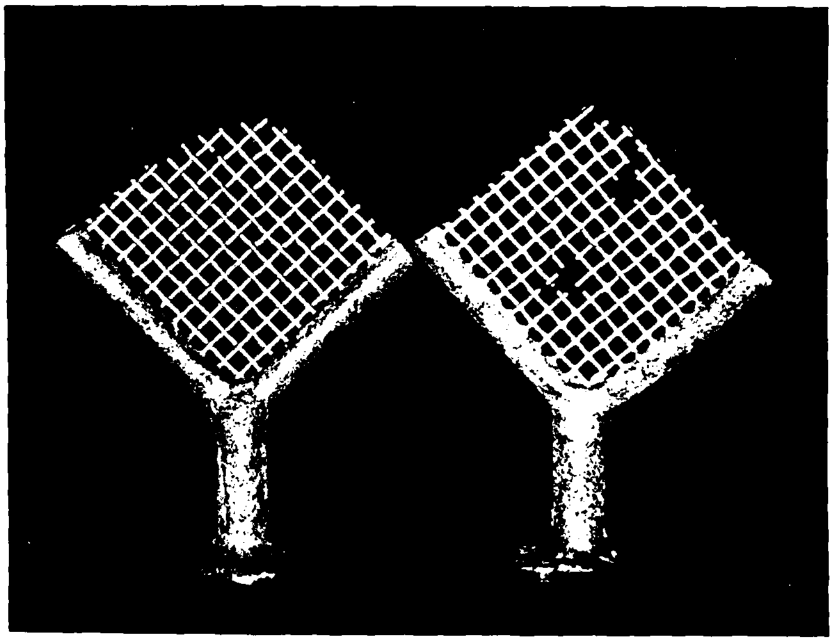


TABLE I

DESCRIPTION OF TECHNIQUE

Mesh Test Pattern	
Dimensions:	No. 18 gauge polyester sieve cloth with 10 x 10 square segments
Runner Bars:	10-gauge round wax
Sprue:	10 mm 6-gauge round wax
Investing and Burnout	
Ring:	Belle de St. Claire Oval Ring 53.5 mm long, 28 mm wide
Ring Liner:	Belle de St. Claire (ceramic type)
Mixing Conditions:	Full-strength special liquid for Ceramigold (9.5 cc/60 g and 14.5 cc/90 g) and Vestra-fine (15.5 cc/65 g), vacuum mixed at 375 RPM for 1 min, then 30-sec hold under vacuum
Setting Conditions:	A minimum of one hour in a humidor
Burnout:	Two-stage technique, 600° C for 30 min then 1-3/4 hr heat-soak at high temperature
Casting Technique	
Amount of Alloy:	Base metals - 2 ingots (approximately 7 dwt for Rexillium III and 8.2 dwt for Forte); noble metals - 5 dwt
Machine:	Unitek Autocast, induction melting
Temperature:	Olympia and Rexillium III - 2925° C; Forte - 2950° C; W-1 - 2650° C; Naturelle - 2850° C
Crucible:	Quartz (heated)
Pattern Orientation:	Vertical

TABLE II

BURNOUT PROFILE

Alloy	Low Temp	Time	High Temp	Time	Rate of Rise
Rexillium III	600° F	30 min	1600° F	1-3/4 hr	25° F/min
Forte	600° F	30 min	1500° F	1-3/4 hr	25° F/min
W-1	600° F	30 min	1550° F	1-3/4 hr	25° F/min
Naturelle	600° F	30 min	1500° F	1-3/4 hr	25° F/min
Olympia	600° F	30 min	1300° F	1-3/4 hr	25° F/min

CASTING PROFILE

Alloy	Casting Temp*	Heat-Soaking Time	Acceleration**	Amount of Alloy
Rexillium III	2925° F	5 sec	7.0	2 ingots (7 dwt)
Forte	2950° F	0 sec	7.0	2-ingots (8.2 dwt)
W-1	2650° F	0 sec	5.5	5 dwt
Naturelle	2850° F	5 sec	5.5	5 dwt
Olympia	2925° F	0 sec	5.5	5 dwt

* These values are nominal temperatures as set by the optical pyrometer and displayed by the casting machine.

** These are speed control settings on the induction casting machine.

TABLE III

PART I FORMAT

ABSTRACT (WHITLOCK) TEST

Carbon-Containing Phosphate-Bonded Investment (CERAMIGOLD):

Group 1	Nickel-Chromium-Beryllium Alloy (Rexillium III)	5 Castings
Group 2	Nickel-Chromium Beryllium-Free Alloy (Forte)	5 Castings
Group 3	Palladium-Silver Alloy (W-1)	5 Castings
Group 4	High Palladium-Copper Alloy (Naturelle)	5 Castings
Group 5	Gold-Palladium Alloy (Olympia - CONTROL)	5 Castings
		25 Castings

REPLICA (COPING) TEST

Carbon-Containing Phosphate-Bonded Investment (CERAMIGOLD):

Group 6	Nickel-Chromium Beryllium Alloy (Rexillium III)	5 Castings
Group 7	Nickel-Chromium-Beryllium Free Alloy (Forte)	5 Castings
Group 8	Palladium-Silver Alloy (W-1)	5 Castings
Group 9	High Palladium-Copper Alloy (Naturelle)	5 Castings
Group 10	Gold-Palladium Alloy (Olympia - CONTROL)	5 Castings
		25 Castings

TABLE IV

PART II FORMAT

ABSTRACT (WHITLOCK) TEST

Noncarbon Containing Phosphate-Bonded Investment (VESTRA-FINE):

Group 11	Nickel-Chromium Beryllium Alloy (Rexillium III)	5 Castings
Group 12	Nickel-Chromium Beryllium-Free Alloy (Forte)	5 Castings
Group 13	Palladium-Silver Alloy (W-1)	5 Castings
Group 14	High Palladium-Copper Alloy (Naturelle)	5 Castings
Group 15	Gold-Palladium Alloy (Olympia - CONTROL)	5 Castings
		25 Castings

REPLICA (COPING) TEST

Noncarbon Containing Phosphate-Bonded Investment (VESTRA-FINE):

Group 16	Nickel-Chromium Beryllium Alloy (Rexillium III)	5 Castings
Group 17	Nickel-Chromium Beryllium-Free Alloy (Forte)	5 Castings
Group 18	Palladium-Silver Alloy (W-1)	5 Castings
Group 19	High Palladium-Copper Alloy (Naturelle)	5 Castings
Group 20	Gold-Palladium Alloy (Olympia - CONTROL)	5 Castings
		25 Castings

TABLE V

CASTABILITY VALUES FOR REXILLIUM III AND CERAMIGOLD

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	100% (220/220)
Casting 2	100% (220/220)
Casting 3	100% (220/220)
Casting 4	100% (220/220)
Casting 5	100% (220/220)
Mean =	100% (220/220)
S.D. =	0
Range =	100% (220/220) - 100% (220/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.499 (100%)	.638 (85.2%)	.750 (100%)	.995 (99.1%)	96.1%
2	.486 (97.4%)	.739 (98.7%)	.724 (96.5%)	.999 (99.5%)	98.0%
3	.492 (98.6%)	.738 (98.5%)	.717 (95.6%)	.950 (94.6%)	96.8%
4	.470 (94.2%)	.627 (83.7%)	.732 (97.6%)	.991 (98.7%)	93.6%
5	.449 (100%)	.702 (93.7%)	.750 (100%)	.975 (97.1%)	97.7%
Mean=	.489 (98.8%)	.689 (92.0%)	.735 (97.9%)	.982 (97.8%)	96.4%
				S.D. =	1.76%
				Range =	93.6 - 98.0%

Overall Castability Value (Cv) = 96.4%

TABLE VI

CASTABILITY VALUES FOR FORTE AND CERAMIGOLD

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	13.6% (30/220)
Casting 2	10.5% (23/220)
Casting 3	16.4% (36/220)
Casting 4	22.7% (50/220)
Casting 5	15.0% (33/220)
Mean =	15.6% (34.4/220)
S.D. =	4.53% (9.90/220)
Range =	10.5% (23/220) - 22.7% (50/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	Not cast	.553 (73.8%)	.671 (89.5%)	.799 (79.6%)	60.7%
2	Not cast	.631 (84.2%)	.656 (87.5%)	.963 (95.9%)	66.9%
3	Not cast	.569 (76.0%)	.682 (90.9%)	.907 (90.3%)	64.3%
4	.028 (4.0%)	.674 (90.0%)	.662 (88.3%)	.865 (86.2%)	67.1%
5	Not cast	.353 (47.1%)	.656 (87.5%)	.935 (93.1%)	56.9%
Mean=	.0056 (0.8%)	.556 (74.2%)	.665 (88.7%)	.894 (89.0%)	63.2%
				S.D. =	4.36%
				Range =	56.9 - 67.1%

Overall Castability Value (Cv) = 63.2%

TABLE VII

CASTABILITY VALUES FOR W-1 AND CERAMIGOLD

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	53.6% (118/220)
Casting 2	63.2% (139/220)
Casting 3	53.2% (117/220)
Casting 4	85.5% (188/220)
Casting 5	70.9% (156/220)
Mean =	65.3% (143.6/220)
S.D. =	13.46% (29.62/220)
Range =	53.2% (117/220) - 85.5% (118/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.433 (86.8%)	.733 (97.9%)	.716 (95.5%)	.968 (96.4%)	94.2%
2	.277 (55.5%)	.691 (92.3%)	.739 (98.5%)	.979 (97.5%)	86.0%
3	.423 (84.8%)	.742 (99.1%)	.746 (99.5%)	1.004 (100%)	95.9%
4	.471 (94.4%)	.726 (96.9%)	.750 (100%)	.941 (93.7%)	96.3%
5	.433 (86.8%)	.706 (94.3%)	.750 (100%)	1.001 (99.7)	95.2%
Mean =	.407 (81.7%)	.720 (96.1%)	.740 (98.7%)	.979 (97.5%)	93.5%
				S.D. =	4.28%
				Range =	86.0% - 96.3%

Overall Castability Value (Cv) = 93.5%

TABLE VIII

CASTABILITY VALUES FOR NATURELLE AND CERAMIGOLD

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	79.1% (174/220)
Casting 2	88.2% (194/220)
Casting 3	85.9% (189/220)
Casting 4	95.5% (210/220)
Casting 5	90.0% (198/220)
Mean =	87.7% (193/220)
S.D. =	5.98% (13.15/220)
Range =	79.1% (174/220) - 95.5% (210/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.499 (100%)	.729 (97.3%)	.731 (97.5%)	1.002 (99.8%)	98.7%
2	.482 (96.6%)	.714 (94.8%)	.744 (99.2%)	1.002 (99.8%)	97.6%
3	.405 (81.2%)	.744 (99.3%)	.739 (98.5%)	1.002 (99.8%)	94.7%
4	.431 (86.4%)	.749 (100%)	.746 (99.5%)	.988 (98.4%)	96.1%
5	.459 (92.0%)	.741 (98.9%)	.746 (99.5%)	1.004 (100%)	97.6%
Mean =	.455 (91.2%)	.735 (98.1%)	.741 (98.8%)	1.000 (99.6%	96.9%
				S.D. =	1.56%
				Range =	94.7% - 98.7%

Overall Castability Value (Cv) = 96.9%

TABLE IX

CASTABILITY VALUES FOR OLYMPIA AND CERAMIGOLD

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	40.5% (89/220)
Casting 2	35.9% (79/220)
Casting 3	55.5% (122/220)
Casting 4	54.1% (119/220)
Casting 5	58.6% (129/220)
Mean =	48.9% (107.6/220)
S.D. =	10.06% (22.13/220)
Range =	35.9% (79/220) - 58.6% (129/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.462 (92.6%)	.749 (100%)	.748 (99.7%)	1.004 (100%)	98.1%
2	.459 (92.0%)	.748 (92.0%)	.745 (99.3%)	.990 (98.6%)	97.5%
3	.499 (92.0%)	.749 (100%)	.694 (92.5%)	.988 (98.4%)	97.7%
4	.430 (86.2%)	.732 (97.7%)	.644 (85.9%)	1.004 (100%)	92.5%
5	.344 (68.9%)	.743 (99.2%)	.714 (95.2%)	1.002 (99.8%)	90.8%
Mean =	.439 (87.9%)	.744 (99.4%)	.709 (94.5%)	.998 (99.4%)	95.3%
				S.D. =	3.41%
				Range =	90.8% - 98.1%

Overall Castability Value (Cv) = 95.3%

TABLE X

CASTABILITY VALUES FOR REXILLIUM AND VESTRA-FINE

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	100% (220/220)
Casting 2	100% (220/220)
Casting 3	100% (220/220)
Casting 4	100% (220/220)
Casting 5	100% (220/220)
Mean =	100% (220/220)
S.D. =	0
Range =	100% (220/220) - 100% (220/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.437 (87.6%)	.668 (89.2%)	.694 (92.5%)	1.000 (99.6%)	92.2%
2	.328 (65.7%)	.737 (98.4%)	.739 (98.5%)	1.004 (100%)	90.7%
3	.499 (90.0%)	.698 (93.2%)	.731 (97.5%)	.968 (96.4%)	94.5%
4	.409 (82.0%)	.569 (76.0%)	.667 (88.9%)	.971 (96.7%)	85.9%
5	.489 (98.0%)	.629 (84.0%)	.746 (99.5%)	1.004 (100%)	95.4%
Mean =	.422 (84.7%)	.660 (88.1%)	.715 (95.4%)	.989 (98.5%)	91.7%
				S.D. =	3.76%
				Range =	85.9% - 95.4%

Overall Castability Value (Cv) = 91.7%

TABLE XI

CASTABILITY VALUES FOR FORTE AND VESTRA-FINE

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	29.1% (64/220)
Casting 2	30.9% (68/220)
Casting 3	22.7% (50/220)
Casting 4	25.5% (56/220)
Casting 5	16.8% (37/220)
Mean =	25.0% (55/220)
S.D. =	5.57% (12.25/220)
Range =	16.8% (37/220) - 30.9% (68/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.3267 (65.3%)	.648 (86.5%)	.738 (98.4%)	.910 (90.6%)	85.2%
2	.439 (88.0%)	.749 (100%)	.734 (97.9%)	.991 (98.7%)	96.2%
3	.459 (92.0%)	.722 (96.4%)	.728 (97.1%)	.993 (98.9%)	96.1%
4	.355 (71.1%)	.698 (93.2%)	.731 (97.5%)	1.002 (99.8%)	90.4%)
5	.469 (94.0%)	.736 (98.3%)	.722 (96.3%)	1.000 (99.6%)	97.1%
Mean =	.410 (82.1%)	.711 (94.9%)	.731 (97.4%)	.979 (97.5%)	93.0%
				S.D. =	5.11%
				Range =	85.2% - 97.1%

Overall Castability Value (Cv) = 93.0%

TABLE XII

CASTABILITY VALUES FOR W-1 AND VESTRA-FINE

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	100% (220/220)
Casting 2	100% (220/220)
Casting 3	100% (220/220)
Casting 4	100% (220/220)
Casting 5	100% (220/220)
Mean =	100% (220/220)
S.D. =	0
Range =	100% (220/220) - 100% (220/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.468 (93.8%)	.722 (96.4%)	.721 (96.1%)	1.004 (100%)	96.6%
2	.499 (100%)	.694 (92.7%)	.704 (93.9%)	.960 (95.6%)	95.6%
3	.472 (94.6%)	.738 (98.5%)	.729 (97.2%)	1.004 (100%)	97.6%
4	.453 (90.8%)	.725 (96.8%)	.687 (91.6%)	1.000 (99.6%)	94.7%
5	.453 (91.0%)	.708 (94.5%)	.711 (94.8%)	1.001 (99.7%)	95.0%
Mean =	.469 (94.0%)	.717 (95.8%)	.710 (94.7%)	.994 (99.0%)	95.9%
				S.D. =	1.20%
				Range =	94.7% - 97.6%

Overall Castability Value (Cv) = 95.9%

TABLE XIII

CASTABILITY VALUES FOR NATURELLE AND VESTRA-FINE

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	100% (220/220)
Casting 2	98.6% (217/220)
Casting 3	100% (220/220)
Casting 4	98.2% (216/220)
Casting 5	100% (220/220)
Mean =	99.4% (218.6/220)
S.D. =	0.89% (1.95/220)
Range =	98.2 (216/220) - 100% (220/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.481(96.4%)	.744 (99.3%)	.750 (100%)	1.004 (100%)	98.9%
2	.499 (100%)	.749 (100%)	.729 (97.2%)	.999 (99.5%)	99.2%
3	.437 (87.6%)	.745 (99.5%)	.729 (97.2%)	1.003 (99.9%)	96.1%
4	.499 (100%)	.741 (98.9%)	.667 (88.9%)	.981 (97.7%)	96.4%
5	.497 (99.6%)	.713 (95.2)	.739 (98.5%)	1.001 (99.7%)	98.3%
Mean =	.483 (96.7%)	.738 (98.6%)	.723 (96.4%)	.998 (99.4%)	97.8%
				S.D. =	1.44%
				Range =	96.1% - 99.2%

Overall Castability Value (Cv) = 97.8%

TABLE XIV

CASTABILITY VALUES FOR OLYMPIA AND VESTRA-FINE

Abstract (Whitlock) Test

Specimen	Castability Value
Casting 1	80.5% (177/220)
Casting 2	81.4% (179/220)
Casting 3	91.4% (201/220)
Casting 4	84.5% (186/220)
Casting 5	91.4% (201/220)
Mean =	85.8% (188.9/220)
S.D. =	5.29% (11.63/220)
Range =	81.4% (179/220) - 91.4% (201/220)

Replica (Coping) Test

Amount of Margin Cast (in mm) and Percentage Reproduced

Casting	Facial (.499 mm)	Mesial (.749 mm)	Distal (.750 mm)	Lingual (1.004 mm)	Mean
1	.315 (63.1%)	.728 (97.2%)	.717 (95.6%)	1.002 (99.8%)	88.9%
2	.352 (70.5%)	.613 (81.8%)	.745 (99.3%)	1.004 (100%)	87.9%
3	.373 (74.7%)	.669 (89.3%)	.746 (99.5%)	.917 (91.3%)	88.7%
4	.367 (73.5%)	.732 (97.7%)	.750 (100%)	.950 (94.6%)	91.5%
5	.309 (61.9%)	.677 (89.7%)	.743 (99.1%)	.858 (85.5%)	84.1%
Mean =	.343 (68.7%)	.683 (91.1%)	.740 (98.7%)	.946 (94.2%)	88.2%
				S.D. =	2.67%
				Range =	84.1% - 91.5%

Overall Castability Value (Cv) = 88.2%

TABLE XV

STATISTICAL ANALYSIS OF ALLOY PERFORMANCE WITH ABSTRACT (WHITLOCK) TEST AND CERAMIGOLD

Alloy	Rexillium III	Forte	W-1	Naturelle	Olympia
Mean	100%	15.6%	65.3%	87.7%	48.9%
S.D.	0%	4.53%	13.46%	5.98%	10.06%
Sample Size	5	5	5	5	5

Analysis of Variance

F Value = 81.58

Critical F Value at 5% Level = 2.87

Therefore, Significant Difference at 0.05 Level

Student-Newman-Keuls Test:

Rexillium III	100%
Naturelle	87.7%
W-1	65.3%
Olympia	48.9%
Forte	15.6%

The five alloys are significantly different at the $p \leq .05$ level.

TABLE XVI

STATISTICAL ANALYSIS OF ALLOY PERFORMANCE WITH REPLICA (COPING) TEST AND CERAMIGOLD

Alloy	Rexillium III	Forte	W-1	Naturelle	Olympia
Mean	96.4%	63.2%	93.5%	96.9%	95.3%
S.D.	1.76%	4.36%	4.28%	1.56%	3.41%
Sample Size	5	5	5	5	5

Analysis of Variance

F Value = 97.03

Critical F Value at 5% Level = 2.87

Therefore, Significant Difference at 0.05 Level

Student-Newman-Keuls Test:

Connected	Alloy	Mean
|	Naturelle	96.9%
|	Rexillium III	96.4%
|	Olympia	95.3%
|	W-1	93.5%
	Forte	63.2%

Alloys connected with a vertical line are not significantly different at the $p \leq .05$ level.

TABLE XVII

STATISTICAL ANALYSIS OF ALLOY PERFORMANCE WITH ABSTRACT (WHITLOCK) TEST AND VESTRA-FINE

Alloy	Rexillium III	Forte	W-1	Naturelle	Olympia
Mean	100%	25.0%	100%	99.4%	85.8%
S.D.	0%	5.57%	0%	0.89%	5.29%
Sample Size	5	5	5	5	5

Analysis of Variance

F Value = 439.96

Critical F Value at 5% Level = 2.87

Therefore, Significant Difference at 0.05 Level

Student-Newman-Keuls Test:

|	Rexillium III	100%
|	W-1	100%
|	Naturelle	99.4%
	Olympia	85.8%
	Forte	25.0%

Alloys connected with a vertical line are not significantly different at the $p \leq .05$ level.

TABLE XVIII

STATISTICAL ANALYSIS OF ALLOY PERFORMANCE WITH REPLICA (COPING) TEST AND VESTRA-FINE

Alloy	Rexillium III	Forte	W-1	Naturelle	Olympia
Mean	91.7%	93.0%	95.9%	97.8%	88.2%
S.D.	3.76%	5.11%	1.20%	1.44%	2.67%
Sample Size	5	5	5	5	5

Analysis of Variance

F Value = 6.79

Critical F Value at 5% Level = 2.87

Therefore, Significant Difference at 0.05 Level

Student-Newman-Keuls Test:

Naturelle	97.8%
W-1	95.9%
Forte	93.0%
Rexillium III	91.7%
Olympia	88.2%

Alloys connected with a vertical line are not significantly different at the $p \leq .05$ level.

TABLE XIX

COMPARISON OF CASTABILITY VALUES (Cv) AND THE PORTION OF THE BEVELLED AREAS NOT REPRODUCED IN THE REPLICA TEST

Castability Value (Cv)	Facial Margin (0.499 mm)	Mesial Margin (0.749 mm)	Distal Margin (0.750 mm)	Lingual Margin (1.004 mm)
99%	0.005	0.007	0.008	0.010
98%	0.010	0.015	0.105	0.020
97%	0.015	0.022	0.023	0.030
96%	0.020	0.030	0.030	0.040
95%	0.025	0.037	0.038	0.050
94%	0.030	0.045	0.045	0.060
93%	0.035	0.052	0.053	0.070
92%	0.040	0.060	0.060	0.080
91%	0.045	0.067	0.068	0.090
90%	0.050	0.075	0.075	0.100
89%	0.055	0.082	0.083	0.110
88%	0.060	0.090	0.090	0.120
85%	0.075	0.112	0.113	0.151
82%	0.090	0.135	0.135	0.181
80%	0.100	0.150	0.150	0.201
75%	0.125	0.187	0.188	0.251
69%	0.155	0.232	0.233	0.311
60%	0.200	0.300	0.300	0.402

Conversion from mm to um: 0.010 mm = 10 μm
(1.0 mm = 1000 μm) 0.100 mm = 100 μm

DISCUSSION

Historically, abstract tests of varied designs have been used to determine or compare the castability of different dental casting alloys. However, no studies have substantiated a direct correlation between castability levels in an abstract test with a corresponding ability to reproduce actual dental restorations (Figure 83). The implication has been that abstract tests are suitable for all dental casting alloy systems, posing no bias for or against alloys with diverse compositions. Less attention has been given to the influences of variables such as the choice of casting equipment (centrifugal, electrical, induction, induction with vacuum), casting investment selection (alloy-investment interactions), or operator skill level (pilot studies with new equipment and alloys). In other words, some investigators have assumed that one test was suitable for casting alloys of all types; one casting machine represented all casting methods; and one investment was not significantly different from another.

Furthermore, users of the Whitlock test have not addressed several questions when reporting results of castability studies. First, is there a minimum or threshold castability value for each alloy with the Whitlock test that would yield an acceptable dental restoration? And second, is that minimum value the same for different alloy systems? For example, should a Whitlock score be at least 80%, 60%, or can it be below 50% for certain alloys and still assure acceptable castings with a replica (coping) test? Third, do the Whitlock test Cv data vary so markedly that performance can not be characterized to the same level as with the replica test method?

In assessing the results from Part I of this study, no direct correlation was found between performance in the Whitlock and replica test. As an example, Olympia's mean Cv in the Whitlock test with Ceramigold investment was 48.9% but an impressive 95.3% in the replica test (Table IX). A similar lack of relationship between the two tests was found for W-1, Naturelle, and Olympia. Unfortunately, the Olympia castings contained suck-back porosity, a defect not even observable by the Whitlock test (Figure 59).

In Part II, similar differences in castability levels in the abstract test and in the replica test were observed. The disparity in test results was nowhere more apparent than with Forte's performance. Although Forte's castability value increased to 25.0% in the Whitlock test with Vestra-fine, such a score would be deemed deficient in comparison to the standards set by the other alloys studied. Yet, in the replica test, Forte's performance ranked third among the five alloys with an overall Cv of 93.0%. In practical terms, casting 93.0% of the facial bevel would mean that only 0.035 mm of the 0.5 mm margin were not cast (Table XIX). In other words, the terminal 35 µm of the wax facial bevel were not reproduced.

In addition, there did not appear to be a uniform minimum Whitlock castability value for the five alloys tested. In fact, the range of Whitlock scores for some alloys varied by as much as 32.3% in one series of five consecutive castings (Table VII). Moreover, there was sufficient variability in the Whitlock castability values for Forte, W-1, Naturelle, and Olympia to make it difficult to characterize castability performance if one wanted to "fine-tune" the casting parameters for these alloys.

Also, the consistently lower castability values in the Whitlock test for Forte coupled with the satisfactory performance in the coping test with Vestra-fine would imply a bias against nickel-base alloys not containing beryllium as suggested by other investigators.[35,54] Putting aside cause and effect theories, it did not appear that the Whitlock test was a reliable indicator of Forte's castability. Additional testing with other nonberyllium, nickel-base alloys would be required before it could be determined if this observation were true for this alloy system in general.

With the replica test, on the other hand, castability values represented the overall amount of bevel reproduced in actual dental castings. Furthermore, these percentage scores can be converted to a millimeter or micrometer measurement. With the aid of Table XIX, Cv can also be evaluated in terms of the portion of bevel not cast for a given area or areas. It then remains for the investigators to determine how much of a marginal discrepancy (maximum amount of bevel not reproduced) they are willing to accept and adjust casting parameters to either achieve or maintain that standard.

The presence of suck-back porosity in four of the five Olympia coping specimens cast in Ceramigold and pinpoint porosity in the fifth was unique to this alloy-investment pairing. None of the Olympia-Vestra-fine copings demonstrated evidence of suck-back porosity although they were all cast at the same temperature. The exact cause(s) of suck-back porosity could not be determined. In an attempt to reproduce the large temperature differential between Olympia's casting and burnout temperatures, Rexillium III was cast into a 1300° F mold but no suck-back porosity resulted. A second mold was heated to 1600° F, held at temperature for 1 3/4 hours, and allowed to cool to room temperature. Two ingots of Rexillium III were cast into this cold mold. Again, no suck-back was observed, but it was noted that as the mold temperature was reduced, marginal sharpness and length also decreased. However, when the mold temperature for Olympia was raised to 1400° F and then 1500° F for two additional castings no suck-back porosity was detected.

Based on these few additional castings it did not appear that the disparity between casting and burnout temperatures was principally responsible for the suck-back porosity as has been theorized by Nielsen.[55] If the cause of this type of porosity were the large temperature differential between alloy and mold, then casting the Rexillium III at lower mold temperatures should have induced such porosity. On the other hand, raising the burnout temperature 100 to 200 °F and reducing the casting temperature-burnout temperature difference did eliminate suck-back porosity in the two Olympia castings. It is possible that the phenomenon of suck-back porosity may also be related to factors such as density, thermal conductivity and diffusivity for certain alloys. However, additional investigations would be needed in order to substantiate this contention.

When Hinman et al.[10] cast their Whitlock patterns with noble alloys they used between 10.1 to 12.4 grams of alloy, or roughly one-third of an ounce, per pattern. They concluded that volume differences between alloys probably had little influence on castability performance in the Whitlock test. It is important to note that such quantities of alloy could translate into an expenditure of between $40.00 and $200.00 per specimen depending on the composition of the alloys involved. This is also a larger amount of alloy than is commonly used to cast single dental restorations. On the other hand, the replica pattern could be produced with less than five pennyweights (7.78 grams) of alloy, thereby reducing the cost per coping specimen. Since multiple castings are necessary for any given set of casting parameters, regardless of the type of test employed, alloy cost quickly becomes an important consideration.

As a general observation, the optical pyrometer appeared to have particular difficulty assessing the temperature of the melt for Olympia. The Autocast indicated apparent temperature fluctuations of several hundred degrees in the interval between opening the door to the casting well and inserting the heated mold. The casting arm was not released until the machine indicated a return to the prescribed casting temperature. In the follow-up investigation into the possible cause of suck-back porosity discussed previously, the casting procedure was altered slightly. The heated ring was placed in the cradle, the door closed, and the casting arm immediately released for a "quick cast." Any fluctuation in the temperature reading as a result of inserting the ring was ignored. This "quick cast" technique improved surface smoothness for the two Olympia castings with Ceramigold and eliminated suck-back porosity but did not improve surface smoothness for the Vestra-fine specimens (Figures 61 and 62).

The observation that carbon was present in the Ceramigold molds after remaining for 1 and 3/4 hours at burnout temperatures between 1300 and 1500° F suggested that carbon elimination is less time-dependent and more temperature-dependent (Figure 60). Consequently, alloys sensitive to carbon contamination, should be paired with noncarbon phosphate-bonded investments.

Aside from variations in sprue former design and investment selection, castability studies using replica tests can also be designed to measure more than one variable. By varying the special liquid concentration (or powder-liquid ratio) for selected casting and burnout temperatures, marginal fit can be determined together with castability. Although casting fit was not assessed in this particular investigation, it could be measured in a replica castability test. The Whitlock test is limited in its applications and can not be modified to serve such a dual function.

SUMMARY AND CONCLUSIONS

The principal aim of this investigation was to determine if the polyester mesh abstract pattern, generally known as the Whitlock test, is an appropriate monitor of alloy castability. When initially conceived and introduced in 1981, the Whitlock test was offered as a simple method to assess castability as a means of ranking dental alloys.[9] In a subsequent 1985 report, the principal investigators responsible for the Whitlock test tempered their earlier recommendations and emphasized that comparisons of castability values between alloys should, in fact, be avoided.[10] The test was recommended more as a means to "fine-tune" the casting process than to compare the castability of different alloys.

Nevertheless, the appeal of the Whitlock test, and abstract tests in general, appears to remain strong as evidenced by the number and frequency of published reports involving these castability monitors.[9-53] In those intervening years the mesh pattern became a comparative test without the benefit of sufficient scientific data on which to base such comparisons. It was and has been assumed that reproducing 100% of the mesh pattern is commensurate with ideal casting conditions.[9,38] The test has been applied as though that premise holds true for all casting alloys with all casting investments and every type of casting machine.

The results of this study suggested that the Whitlock test may not be a reliable indicator of an alloy's ability to cast a dental restoration. In fact, castability values (Cv) may vary widely in consecutive mesh castings for the same alloy and investment pairing. Furthermore, no single minimum castability value appeared to exist to permit comparisons between alloys of different compositions. In some instances the patterns reproduced in the Whitlock specimens differed yet their Cv were the same, thus making interpretation of the results quite difficult (Figure 84).

Furthermore, it was found that alloy-investment interactions can influence results if only one type of casting investment is used in a comparison, a contention supported by this study and other investigations.[10,17] The idea of matching alloys with their most ideal investment is analogous to research pairing specific dental stones with particular irreversible hydrocolloid impression materials.[56]

Certainly the type of casting machine used is a variable of enormous magnitude, and analogies between centrifugal, electric, induction, and induction with vacuum equipment should not be made without the benefit of direct comparisons under controlled and standardized test conditions.

It can not be overemphasized that the casting procedure is a multifactorial process of enormous complexity whose variables are readily altered when substituting different alloys, investments, and casting machines. Consequently, generalizations outside the confines of specific castability tests may not be germane to other alloys of similar composition unless tested under comparable conditions. Pilot studies are strongly recommended and may prove helpful to operators unfamiliar with the handling characteristics of the equipment and materials they have chosen to evaluate.

Based on the results of this investigation the following general conclusions can be made:

1. The rank order of performance and mean castability values (Cv) for the Whitlock test with Ceramigold were: Rexillium III (100%), Naturelle (87.7%), W-1 (65.3%), Olympia (48.9%), and Forte (15.6%); and for Vestra-fine the results were: Rexillium III and W-1 (100%), Naturelle (99.4%), Olympia (85.8%), and Forte (25.0%).

2. The rank order of performance and mean castability values for the replica test with Ceramigold were: Naturelle (96.9%), Rexillium III (96.4%), Olympia (95.3%), W-1 (93.5%), and Forte 63.2%; and for Vestra-fine the results were Naturelle (97.8%), W-1 (95.9%), Forte (93.0%), Rexillium III (91.7%), and Olympia (88.2%).

3. Alloy-investment interactions may have a significant effect on the results of castability tests. Therefore, it may be prudent to use more than one type of investment in a castability test.

4. The assumption that all metal ceramic alloys have the potential to reproduce 100% of the polyester mesh pattern (Whitlock test) does not appear to be valid.

5. No single castability value (Cv) in the Whitlock test correlated with a complete casting in the coping test for the five alloys evaluated.

6. In the absence of established baseline castability values for specific alloy-investment pairs, comparisons between alloys with the Whitlock test may be misleading.

7. Sufficient intraspecimen variability may exist with some alloys to render the Whitlock test a less than reliable indicator of alloy castability. The value of the mesh pattern as a monitor for "fine-tuning" the casting process is also questionable.

8. Replica tests, such as the coping test used in this study, may have more potential for providing a standardized method to assess alloy castability than the Whitlock test. The castability values for any of the four bevelled areas can be converted to a millimeter or micrometers scale to provide castability values (Cv) of equal significance for all alloys.

9. Replica tests enable investigators to conduct experiments which more closely mirror the intended applications of dental casting alloys. Sprue former design techniques, investment compatibilities, and equipment variability can be adjusted systematically in the same way laboratories fabricate dental restorations.

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APPENDIXES

APPENDIX I

CASTING ALLOYS DATA

Rexillium III - Nickel 74-78%, chromium 12-15%, molybdenum 4-6%, beryllium 1.8% and other trace elements

Rx Jeneric Gold Company,
Jeneric Industries, Inc.
P.O. Box 724
Wallingford, CT 06492

Forte - Nickel 64%; chromium 22%, molybdenum 9%, iron 1%, plus columbium 4% and tantalum

Unitek Corporation
2724 South Peck Road
Monrovia, CA 91016

W-1 - Palladium 53.5%, silver 37.5%, tin 8.5%, indium 0.4% and unspecified trace elements

Williams Dental Company
2978 Main Street
Buffalo, NY 14214

Naturelle - Palladium 79%, copper 10%, gallium 9%, gold 2% and trace amounts of aluminum, zinc, and ruthenium

Rx Jeneric Gold Company
Jeneric Industries, Inc.
P.O. Box 724
Wallingford, CT 06492

Olympia - Gold 51.5%, palladium 38.5%, gallium and other trace elements

J.F. Jelenko & Company
99 Business Park Drive
Armonk, NY 10504

APPENDIX II

LOT NUMBERS OF MATERIALS

Casting Alloys:

Rexillium III - #05078776, #08128769, and #08278786

Forte - #U560 and V170-A

W-1 - #32510B, #37194B, #37104C100887 and #37107L100887

Naturelle - #061987 02 and #102687 86

Olympia - #5309-011387

Casting Investments:

Ceramigold - #04757070X (90-gram), #09757040X (60-gram)

Vestra-fine - #071487

Other Materials:

Kerr Type II Wax - #071786 1080

Super Die Improved Stone - 0686704

Kerr Debubblizer - #71128

Kerr Ready Made Wax Shapes - #0924861140

Perfourm Impression Material - 6625C (Light Body), 3342B (Heavy Body)

CURRICULUM VITAE

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1964 - 1968	University of South Carolina Columbia, South Carolina
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Professional Organizations

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