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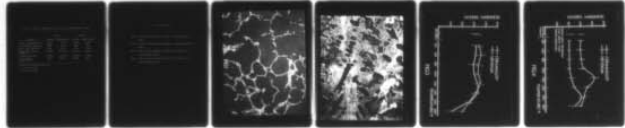
ARMY INST OF DENTAL RESEARCH WASHINGTON D C  
CHARACTERIZATION OF TWO BASE METAL CROWN-AND-BRIDGE ALLOYS, (U)  
MAR 77 E F HUGET, J M VILCA, R M WALL

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REPORT DOCUMENTATION PAGE

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BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Characterization of Two Base Metal Crown-And-Bridge Alloys		5. TYPE OF REPORT & PERIOD COVERED Manuscript
7. AUTHOR(s) Eugene F. Huget, LTC, Jesus M. Vilca, SP-5 and Richard M. Wall, SP-4		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Division of Dental Materials U.S. Army Institute of Dental Research Washington, D.C. 20012		8. CONTRACT OR GRANT NUMBER(s) NA
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Institute of Dental Research Walter Reed Army Medical Center Washington, D.C. 20012		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS OG-6034 00-120-3
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) NA		12. REPORT DATE 11 16 March 1977
		13. NUMBER OF PAGES 16
		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Unlimited		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Base metal alloys; nickel-chromium alloys; economy alloys and crown-and-bridge alloys.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Presently, annual Army expenditures for dental gold casting alloys approach two million dollars. Threats of continued increases in the international exchange value of gold bullion have prompted keen interest within the United States Army Medical Department in the potential application of less expensive metals for the fabrication of fixed dental restorations (crowns and bridges). The substitution of castable nickel-chromium alloys for gold-based materials could reduce current alloy costs by almost 75 percent. Although more than		

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thirty relatively inexpensive base-metal alloys have been developed by commercial sources for dental usage, reliable and substantial data relevant to the properties and handling characteristics of these materials are not available. Therefore, utilization of nickel-chromium alloys in Army dental practice has not been warranted.

The present study assessed composition, microstructure properties and laboratory characteristics of Neydium and Ceramalloy. Analysis revealed that Neydium was based on a Ni (~79%)-Cr (~11%) binary system with minor modifications by Mo (~3.6%), Nb (~3.2%), Al (~1.8%), Si (~1.1%), Fe (~0.05%) and C (~0.09%). Major components of Ceramalloy were Ni (~70%) and Cr (~20%). Minor constituents of this alloy included Mo (~5.6%), Si (~3.96%), Fe (~0.2%), Ti (~0.02%) and C (~0.22%). Neydium exhibited a continuous grain-boundary network as well as isolated spherical carbides. A dendritic carbide-precipitate was the predominant microstructural feature of Ceramalloy. Properties of Neydium-specimens after heat treatment by simulated porcelain firing cycle were: UTS 93,000 psi; YS 85,000 psi; EL 69,000 psi; E 31 X 10<sup>6</sup> psi; El 0.8%; VHN 290. Ceramalloy, after exposure to the same sequence of heat treatments, gave the following values: UTS 109,000 psi; YS 76,000 psi; EL 42,000 psi; E 27 X 10<sup>6</sup> psi; El 1.2%; VHN 330. Thick oxides that formed on the test alloys at temperatures between 1,200 and 1,800F impaired metal-porcelain bonding. Neydium-porcelain and Ceramalloy-porcelain combinations gave relatively low bond strength values of 2,700 and 4,800 psi, respectively. Copings and full coverage restorations cast from the material failed to seat completely. Neydium and Ceramalloy offer the advantages of high strength and rigidity. However, laboratory technique sensitivities, which restrict the range of clinical application of these materials, remain to be overcome.



CHARACTERIZATION OF TWO BASE-METAL  
CROWN-AND-BRIDGE ALLOYS

In recent years, several nonprecious alloys have been marketed for the fabrication of porcelain-fused-to-metal fixed restorations. Compositions of these alloys are, in essence, departures from the compositions of base-metal partial denture alloys.<sup>1-3</sup> Nickel (~60 to 80 percent by weight) and chromium (~12 to 20 percent by weight) are the major constituents of most available products. However, the seemingly similar compositional features of the base-metal crown-and-bridge alloys are countered by the presence of varying amounts of other nonprecious components. Modifications of the nickel-chromium system by minor alloying elements have made possible the availability of a broad selection of castable alloys, the structural features and properties of which are significantly diverse. It would appear that each base-metal restorative alloy must be considered as a unique entity, and that conclusions based on experience with one material can not be used to predict the behavior of another. Hence, the need for adequate characterization of the existing nonprecious crown-and-bridge alloys is obvious.

This report is based upon data on two venerable base-metal alloys: Neydium\* and Ceramalloy<sup>†</sup>.

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\* The J. M. Ney Company, Hartford, CO

† Johnson & Johnson Dental Products Co., East Windsor, NJ

## MATERIALS AND METHODS

Chemical Analysis. Constituents of the "as-received" alloys, with the exception of carbon, were determined quantitatively by atomic absorption spectrophotometry.<sup>#</sup> Carbon was determined by combustion gravimetric techniques.

Preparation of cast specimens. Castings for determination of microstructure, response to heat treatment and mechanical properties were fabricated by routine lost wax laboratory procedures. Phosphate-bonded molds<sup>§</sup> were burned out at 1,500°F. Time at burnout temperature was 45 minutes. Neydium and Ceramalloy were cast with the use of an automatic induction casting machine<sup>¶</sup> at respective temperatures of 2,400 and 2,300°F.

Metallographic and hardness specimens were 13 mm. X 3 mm. discs. The castings were mounted in plastic and polished manually with 240 to 600 grit abrasive papers. An alumina abrasive (0.3 μm) was used with a vibrating polisher<sup>Ω</sup> to reduce gross surface scratches. Final polishing was accomplished with fine alumina abrasive (0.05 μm) on a rotary polisher.<sup>Ⓜ</sup> Polished discs were immersed for 15 minutes in a solution of 55.5 percent (conc.) HCl, 3 percent (conc.) H<sub>2</sub>SO<sub>4</sub>, 1.8 percent (conc.) HNO<sub>3</sub> and 40 percent water, by volume, to reveal the microstructures of the test alloys. Unetched mounted specimens were used for hardness measurement.

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# Spectrophotometer, Model 403, Perkin-Elmer Corp., Norwalk, CO.

§ Ceramigold Investment, Whip-Mix Corp., Louisville, KY.

¶ Electromatic Casting Machine, Howmet Corp., Chicago, IL.

Ω Vibromet Polisher, Buehler, Ltd., Evanston, IL.

Ⓜ Ecomet Polisher, Buehler, Ltd., Evanston, IL.

The design and dimensions of tensile specimens conformed to the requirements of A.D.A. Specification No. 14 for dental chromium-cobalt casting alloy.<sup>4</sup>

Determination of response to heat treatment. As-cast hardness (V.H.N.) of 13 mm. X 3 mm. discs was established through the use of a testing machine<sup>φ</sup> and a 136° square base diamond pyramid indenter. Then the discs were subjected to repeated 15-minute heat treatments at 200-degree intervals from 400 to 1,800°F. for detection of softening temperature ranges. All heat treatments were terminated by water quenching. Hardness was measured for each treatment temperature.

To delineate the hardening temperature ranges of the test alloys, specimens water-quenched from 1,800°F. were reheat treated at 200-degree intervals from 400 to 1,800°F. All discs were water-quenched and retested after a 15-minute treatment at each temperature.

The effect of the porcelain firing procedure on hardness was evaluated with the use of additional 13 mm. X 3 mm. discs. The cycle included four consecutive heat treatments.<sup>\*\*</sup> Hardness was measured

φ Kentrall Hardness Tester, Model MC-1, Riehle Testing Machines, East Moline, IL.

\*\* (1) Degassing: Specimens were heated from 1,200 to 1,950°F., held at 1,950°F. for 5 minutes, removed from the furnace and cooled in open air. (2) Simulated application of opaque porcelain: Specimens were heated from 1,200 to 1,825°F., removed from the furnace immediately on reaching 1,825°F., and cooled to room temperature in open air. (3) Simulated application of body porcelain: Specimens were subjected to two successive firings from 1,200 to 1,775°F. Specimens were cooled to room temperature in open air after each firing. (4) Simulated application of glaze: Specimens were heated from 1,200 to 1,800°F., removed from the furnace immediately on reaching 1,800°F., and cooled to room temperature in open air.

prior to exposure of the specimens to the heat-treatment cycle and remeasured upon completion of the cycle's fourth step.

Determination of tensile properties. As-cast and heat-treated specimens were used for property measurements. Heat treatment of tensile specimens was accomplished by means of the previously described simulated porcelain firing cycle. Tensile strength, yield strength (0.2 percent offset), elastic limit, Young's modulus and elongation were determined on a constant strain rate testing machine<sup>ψ</sup> at a crosshead speed of 0.02 inch per minute. Elongation was measured over a one-inch gage length with a break-away electronic extensometer.<sup>○</sup> Reported values are averages and standard deviations of six determinations.

#### RESULTS

Compositions of the alloys are given in Table I. Neydium was based on the nickel-chromium binary system with modifications by molybdenum, niobium, aluminum, silicon, iron and carbon. Major components of Ceramalloy were also nickel and chromium. Minor constituents of this alloy included molybdenum, silicon, boron, iron, titanium and carbon.

As-cast microstructures of Neydium and Ceramalloy differed markedly. Neydium (Fig. 1) exhibited a semicontinuous grain boundary network. Intragranular precipitates other than those which appeared to be deposits of spherical carbides were not detected. A dendritic precipitate was the predominant microstructural feature of Ceramalloy (Fig. 2).

ψ Instron Universal Tensile Testing Machine, Instron Corp., Canton, MA.

○ Strain Gage Extensometer, Model LG-51-12, Instron Corp., Canton, MA.

Changes in hardness of the alloys elicited by softening and aging heat treatments are depicted in Figure 3 and Figure 4, respectively. Hardness of Neydium remained relatively stable on treatment at temperature ranging from 400 to 1,400°F. (Fig. 3). However, elevation of the treatment temperature to 1,600°F. produced an abrupt decrease in hardness of this alloy. Softening of Ceramalloy (Fig. 3) occurred upon exposure to treatment temperatures in excess of 1,200°F. Significant rehardening of heat softened specimens of Neydium and Ceramalloy was achieved with 15-minute reheat treatments at 1,600 and 1,200°F., respectively (Fig. 4).

Tensile properties and additional hardness data are given in Table II. Comparatively, Neydium was stronger and slightly more rigid than Ceramalloy. Elongation values of both alloys were low. Hardness of Ceramalloy was greater than that of Neydium. Heat treatment by the simulated porcelain firing cycle elicited a marked reduction in yield strength, elastic limit and hardness of both alloys.

#### DISCUSSION

Mechanical property differences exhibited by the two alloys are related to compositional and microstructural differences. Nickel-chromium based alloys are strengthened primarily by precipitation hardening and to a lesser extent by solid solution hardening.<sup>5</sup> Responses of Neydium and Ceramalloy to aging treatments suggest that precipitation plays a prominent role in their hardening. However, these alloys are not hardened by precipitates of similar composition.

Aluminum and titanium are the most common solutes involved in precipitation hardening of nickel-based alloys. It would appear that the presence of aluminum in Neydium results in the formation of a relatively stable, coherent intermetallic phase ( $\text{Ni}_3\text{Al}$ ). This phase provides coherency strengthening of the matrix, acts as a barrier to slip, and contributes its strength to that of the alloy. Data obtained on reheat treatment of previously softened Neydium-specimens further suggest that heat treatments in the vicinity of  $1,600^\circ\text{F}$ . enhance the stability of such a phase. On the other hand, it is likely that heat treatment of Ceramalloy at temperatures close to  $1,200^\circ\text{F}$ . encourages the precipitation of boron and silicon. Massive precipitates of these elements are exhibited by certain age-hardened industrial nickel-chromium-molybdenum containing alloys, the compositional limits of which allow for additions of 2.5 to 6.5 percent boron and silicon.<sup>6</sup>

Data obtained on measurement of the mechanical properties of Neydium and Ceramalloy infer that the desirable as-cast characteristics of high yield strength and high elastic limit may be compromised by heat treatments associated with the application of dental porcelain. Unfortunately, a veneered substructure can not be reheated and water quenched from either  $1,600^\circ\text{F}$ . (apparent hardening temperature of Neydium) or  $1,200^\circ\text{F}$ . (apparent hardening temperature of Ceramalloy) for restoration of strength and hardness without endangering the porcelain-to-metal bond. Nonetheless, yield strengths and elastic limits of these materials tend to be higher than those of high-fusing precious metal alloys used in the porcelain-fused-to-metal technique.<sup>7-9</sup> High modulus of elasticity (rigidity), a property

which is not alterable by heat treatment, suggests the potential usefulness of Neydium and Ceramalloy for the casting of thin copings and retainers, and for the construction of long-span fixed partial dentures.

SUMMARY

→ Compositions, microstructures, properties and heat-treatment characteristics of two base-metal crown-and-bridge alloys were studied. The materials displayed significant compositional and structural differences. Both alloys were strengthened by precipitation hardening. Strength and rigidity of the nickel-chromium alloys suggest their potential usefulness in fixed prosthodontic procedures. ↗

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TABLE I. COMPOSITIONS OF TWO BASE METAL CROWN AND BRIDGE ALLOYS

Element	Neydium (percent)	Ceramalloy (percent)
Nickel	79.0	67.1
Chromium	11.2	19.9
Molybdenum	3.6	5.6
Niobium	3.2	0.00
Aluminum	1.8	0.00
Silicon	1.1	3.96
Boron	0.00	2.90
Iron	0.05	0.12
Titanium	0.00	0.02
Tin	0.01	0.00
Cobalt	0.00	0.01
Carbon	0.09	0.22

TABLE II. MECHANICAL PROPERTIES OF TWO BASE METAL CROWN AND BRIDGE ALLOYS

Property	Neydium		Ceramalloy	
	As-Cast	Heat-Treated*	As-Cast	Heat-Treated*
Tensile strength ( $\times 10^3$ psi)	118 $\pm$ 4 <sup>+</sup>	93 $\pm$ 5 <sup>+</sup>	109 $\pm$ 4 <sup>+</sup>	109 $\pm$ 6 <sup>+</sup>
Yield strength <sup>#</sup> ( $\times 10^3$ psi)	116 $\pm$ 2	85 $\pm$ 4	89 $\pm$ 6	73 $\pm$ 3
Elastic limit ( $\times 10^3$ psi)	96 $\pm$ 9	69 $\pm$ 1	56 $\pm$ 4	42 $\pm$ 4
Modulus of elasticity ( $\times 10^6$ psi)	31.2 $\pm$ 2.4	31.4 $\pm$ 1.8	26.3 $\pm$ 1.3	26.5 $\pm$ 1.5
Elongation (percent)	0.6 $\pm$ 0.3	0.8 $\pm$ 0.3	0.8 $\pm$ 0.3	1.2 $\pm$ 0.2
Vickershardness number (V.H.N.)	350 $\pm$ 6	292 $\pm$ 4	369 $\pm$ 8	330 $\pm$ 5

\* Simulated porcelain firing cycle.

+ Standard deviation.

# 0.2 percent offset.

LEGENDS FOR FIGURES

Fig. 1. As-cast microstructure of Neydium. Initial magnification  
400 X.

Fig. 2. As-cast microstructure of Ceramalloy. Initial magnification  
400 X.

Fig. 3. Effect of heat-treatment temperature on hardness of two  
nickel-chromium alloys.

Fig. 4. Effect of reheat-treatment temperature on hardness of two  
nickel-chromium alloys.

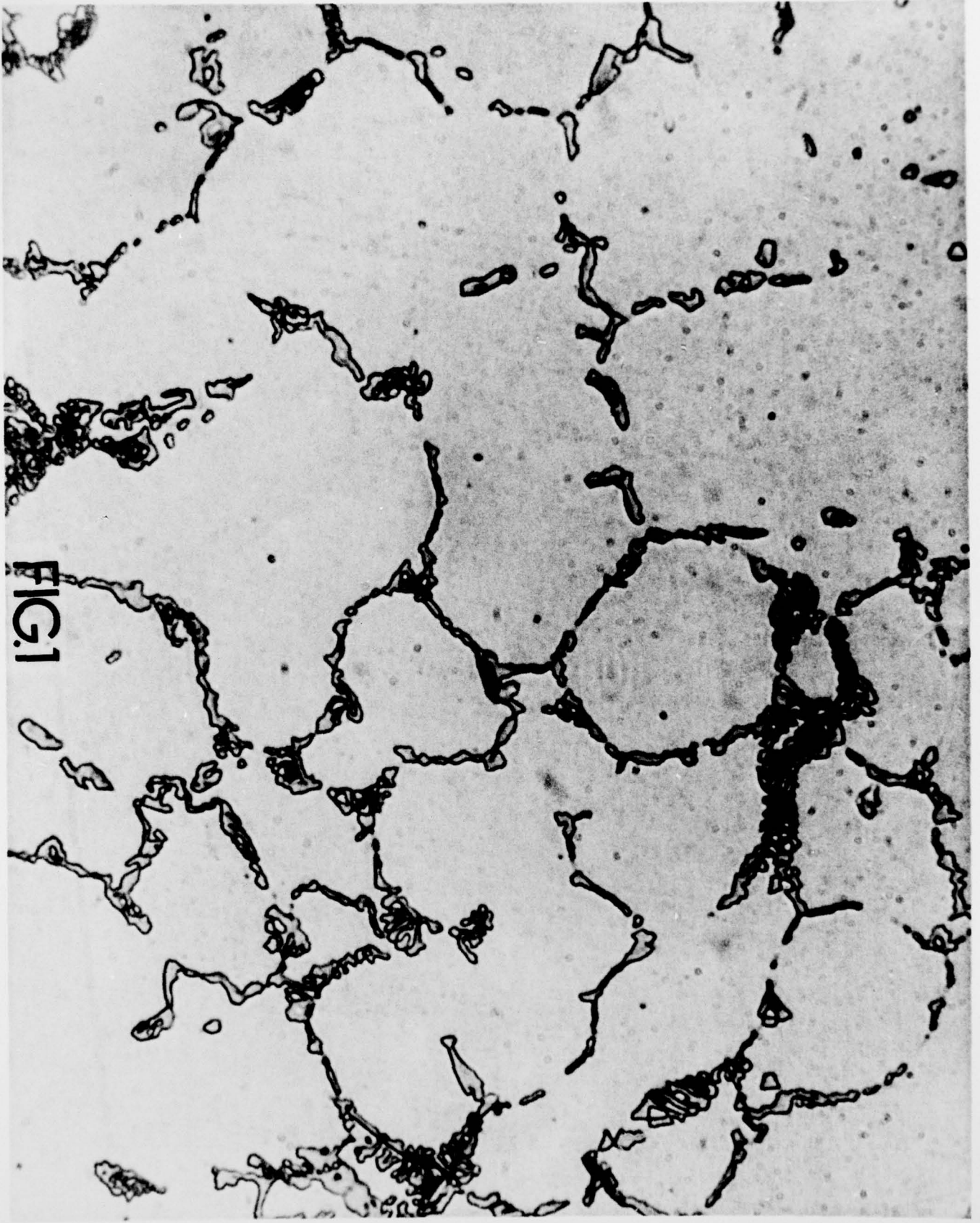


FIG. 1



FIG. 2

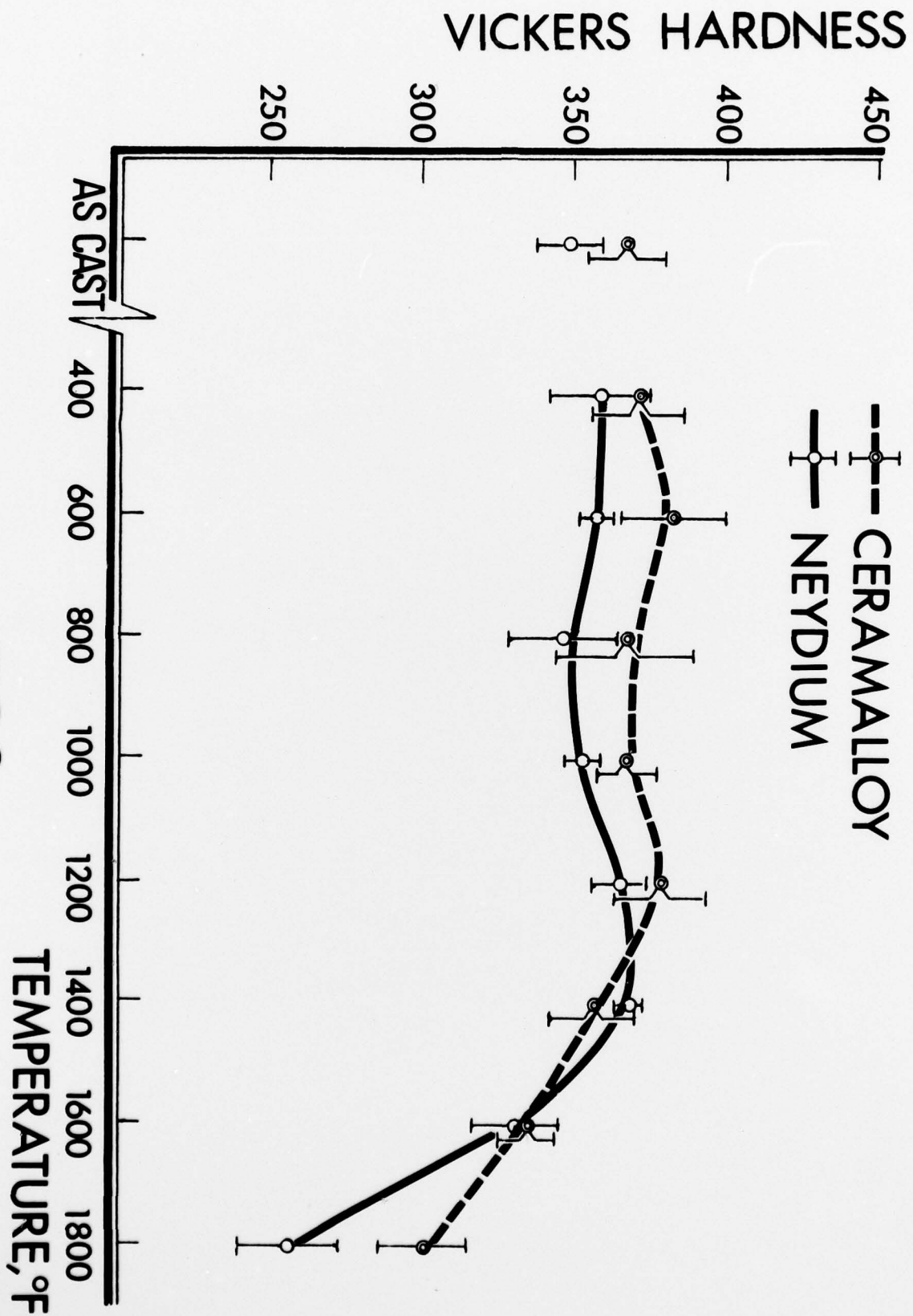


FIG.3

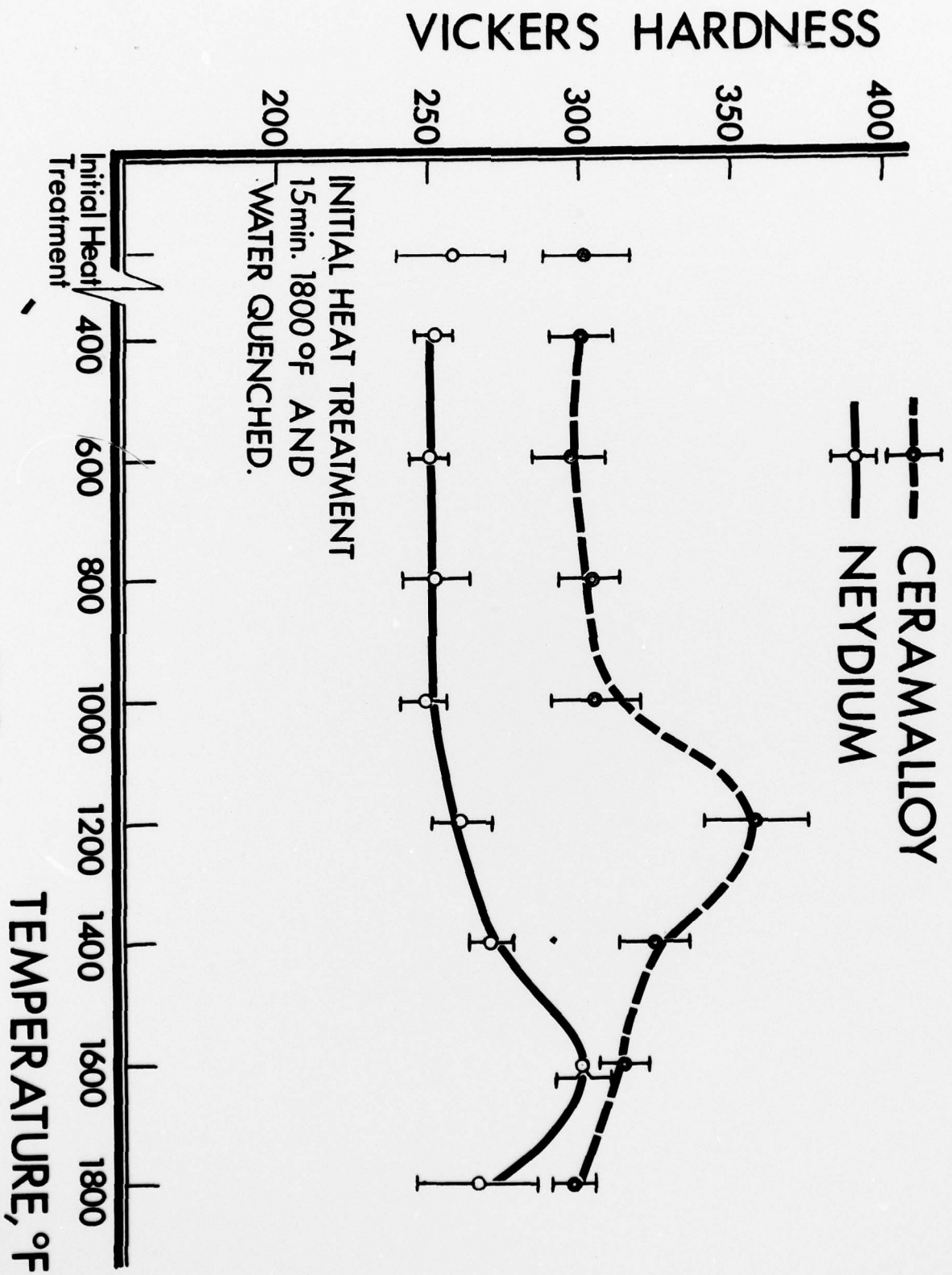


FIG.4