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OBSERVATIONS OF 'ECONOMICAL' FIXED PROSTHODONTIC ALLOYS.(U)
1982 S G VERMILYEA, M J KUFFLER, J J TAMURA

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Composition, microstructure, heat treatment characteristics and mechanical properties of four alternatives to conventional high noble fixed prosthodontic alloys were studied. The material exhibited a broad range of compositional and mechanical property differences. As cast tensile properties of three of the materials paralleled those of type III casting golds. Precipitation and order-disorder transformation appear to be principal mechanisms of hardening.

These alloys exhibit properties suggesting their potential usefulness in fixed prosthodontics; however, the silver-palladium and silver-indium materials require

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OBSERVATIONS ON "ECONOMICAL" FIXED PROSTHODONTIC ALLOYS

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Commercial materials and equipment are identified in this report to specify the experimental procedure. Such identification does not imply official recommendation or endorsement or that the materials and equipment are necessarily the best available for the purpose. Furthermore, the opinions expressed herein are those of the authors and are not to be construed as those of the Army Medical Department.

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OBSERVATIONS ON "ECONOMICAL" FIXED PROSTHOTONTIC ALLOYS

Continued fluctuations in the international exchange value of gold and other noble metals have prompted intense interest within the U.S. Army Medical Department in the potential application of less expensive metals for the fabrication of fixed prosthodontic dental restorations.

Searches for less expensive alloys for the casting of dental restorations have led to renewed interest in alloys containing substantial amounts of palladium and silver as well as those of more conventional composition but with reduced gold content. Formulations for the silver-palladium alloys were established in the 1930's,[1,2] however, the myraid of similar products marketed under a variety of trade names have become a source of confusion to many military dentists and laboratory technicians. The paucity of data relevant to these alloys precludes the rational selection of a specific product for clinical use. Accordingly, studies have been undertaken to characterize a number of these materials. The present report describes the composition, microstructure, mechanical properties and heat treatment characteristics of four alternatives to type III casting gold, Rajah,[§] T-III Lite,[¶] Ney 76[Π] and Salivan.[Ω]

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§ J. F. Jelenko and Company, Pennwal Corp., Armonk, NY 10504.

¶ Howmedica, Inc., Chicago, IL 60632.

Π The J. M. Ney Co., Bloomfield, CN 06002

Ω Dent-Mat, Inc., Santa Maria, CA 93456

Materials and Methods

Constituents of as received ingots of each material were determined qualitatively by spectrographic analysis. Definitive elemental analysis was accomplished by wet gravimetric techniques.

Specimens for the determination of properties were fabricated by conventional dental laboratory procedures. Patterns were invested in a gypsum-bonded refractory material.§§ Wax elimination and melting of the test alloys were accomplished in accordance with their respective manufacturer's instructions. Recommended casting temperatures were 1870° F, 2100° F, 1850° F and 1400° F for Rajah, T-III Lite, Ney 76 and Salivan respectively. The molten alloys were cast by means of a conventional broken-arm casting machine. Cast molds were allowed to cool to room temperature prior to divestment of the test pieces.

The test surfaces of specimens for determination of hardness and microstructure (14 mm X 5 mm discs) were mounted in plastic and polished sequentially with 240 to 600 grit abrasive papers, 6.0 μm diamond paste, 0.3 μm and 0.05 μm alumina. Metallographic specimens of Rajah were etched by application of a solution of 10 percent KCN, 10 percent $NH_4S_2O_8$ and 80 percent water by volume. An aqueous solution of 0.2 percent CrO_3 and 0.2 percent H_2SO_4 was used as an etchant for T-III Lite, Ney 76 and Salivan.

Etched specimens were examined with a metallurgical microscope¶¶ at a magnification of 200 X. Unetched specimens were used for hardness determination. Vickers hardness values (DPN) were obtained with the use of a testing machine∏∏ equipped with a 136-degree square-base diamond

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§§ Beauty Cast, Whip-Mix Corp., Louisville, KY 40217.

¶¶ Vickers 55 Metallograph, Vickers, Instruments, Inc., Malden, MA 02148.

∏∏ Kentron Microhardness Tester, Model AK, Riehle Testing Machines, East Moline, Il 61265.

pyramid indenter. The reported values are averages of six measurements on each of two specimens.

After determination of as cast microstructure and hardenss, the specimens were removed from their plastic mounts, heat treated, remounted, and repolished prior to further testing.

Annealing temperature ranges of the test alloys were determined by monitoring changes in the hardness of castings subjected to successive five-minute heat treatments at 200 degree intervals from 400° F to 1600° F (Rajah, T-III Lite and Ney 76) or from 400° F to 1000° F (Salivan). All heat treatments were terminated by immersion of the test pieces in room temperature water. Hardness was measured after quenching of the specimens from each treatment temperature.

Hardening temperature ranges were revealed by serial reheat treatment of previously annealed discs over the temperatures employed during the annealing process. Again, hardness was measured after a five-minute exposure of each casting of each treatment temperature.

Tensile specimens were invested and cast by procedures described previously for the fabrication of hardness and metallographic specimens. Dimensions of the cast pieces were within the tolerances prescribed by American Dental Association Specification No. 14 for dental chromium cobalt casting alloys.[3] Twelve bars were cast from each material. Six bars of each material were heat treated prior to tensile testing at the annealing temperatures determined from hardness data.

Tensile properties of as cast and heat treated specimens were determined on a constant displacement rate testing machine[ΩΩ] at a crosshead speed of 0.02 inch per minute.

Results

Compositions of the alloys are presented in Table 1. Major components of Rajah were gold and silver whereas those of T-III Lite and Ney 76 were silver and palladium. Salivan was based upon a silver-indium binary. Rajah and Ney 76 contained relatively large amounts of copper, whereas T-III Lite and Salivan were devoid of this element. Zinc was a minor constituent of all four alloys.

With the exception of Rajah, difficulties were experienced in the routine fabrication of sound test specimens. Porosity was a characteristic feature of the castings and several trials were required to produce specimens suitable for evaluation.

Microstructural characteristics of the test materials are shown in Figure 1.

As cast structures of T-III Lite and Ney 76 were cored. In the as-cast condition, specimens of Rajah exhibited equiaxed grains and a continuous grain boundary netowrk, whereas those of Salivan revealed large grains, discontinuous grain boundaries and prominent subgrains. Microstructures of heat softened specimens did not differ significantly from those of the as-cast materials. Although a slight reduction in coring was noted with T-III Lite and Ney 76.

Responses of the as-cast alloys to heat treatment are shown in Figure 2. Initial (as-cast) hardness of T-III Lite was lower than

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ΩΩ Instron Universal Testing Machine, Instron Engineering Corp., Canton, MA 02021.

that obtained for the other materials Hardness of T-III Lite remained relatively stable on heat treatment at temperatures ranging from 200° F to 800° F. Treatment at 1000°F produced a slight increase in hardness, whereas temperatures in excess of 1200° F induced softening. Values obtained for T-III Lite specimens quenched from 1600° F yielded a total reduction in hardness of about 23 percent. As cast hardness of Salivan was not altered by exposure to temperatures ranging from 200° F to 1000° F. With specimens of Ney 76, heat treatment at temperatures between 1000° F and 1400° F elicited softening whereas, temperatures in excess of 1400° F yielded increases in specimen hardness. Rajah, on the other hand, showed a tendency to soften at temperatures ranging from 1000° F to 1600° F.

Responses of heat-softened cast discs to reheat treatment are shown in Figure 3. Maximum hardness values for Rajah and Ney 76 were obtained with a 5-minute reheat treatment at 800° F. A 5-minute reheat treatment at 1000° F was required to reach the maximum hardness of T-III Lite.

Tensile properties of the test materials are summarized in Table 2. As cast specimens of Rajah tended to be stronger, and less ductile than those of the other materials. Annealed specimens of Rajah and Ney 76 gave lower yield strengths but higher elongation values than as cast specimens. With T-III Lite, annealing reduced the yield strength but did not significantly alter the values for elongation.

Discussion

The compositions of the test alloys are significant departures from those of conventional fixed prosthodontic alloys.[4] However, it is interesting to note that the alloys themselves exhibit significant compositional differences. These differences appear to account for differences in casting temperature, microstructure and heat treatment response.

The compositional features of Rajah indicate the potential for development of an ordered gold-copper phase and a silver rich phase during heat treatment procedures. The existance of such phases may account for the observed alteration of hardness values.

T-III Lite appears to be based upon relatively simple silver-palladium binary system. Coring is attributed to disparate solidification rates of silver and palladium which promote diffusion and segregation of constituent elements. It would appear that precipitation of intermetallic silver-indium and palladium-indium compounds promote hardening of this alloy during heat treatment procedures.

With Ney 76, it would appear that copper is involved significantly in the age hardening of this alloy. Hardening may result from the precipitation of copper from a silver-copper solid solution[5] or the formation, precipitation and diffusion of palladium-copper intermetallic compounds.[6]

Tensile properties of Rajah, T-III Lite and Ney 76 fall within the ranges of properties exhibited by type III golds.[4] Salivan, on the other hand, exhibited properties commensurate with type II gold alloys. In the as cast condition, hardness values of Rajah, Ney 76 and Salivan are similar to that of a partial denture casting gold. Conversely, when annealed, the hardness of T-III Lite approaches that of type II golds. From a practical point of view, with the exception of Salivan, the manipulative characteristics of these materials can be enhanced by annealing heat treatments to facilitate adjustment and finishing of cast restorations. Subsequently, aging treatments at temperatures of 800° F (Rajah and Ney 76) or 1000° F (T-III Lite) can be used to restore strength and hardness of previously annealed structures to insure satisfactory mechanical performance.

The test materials exhibit laboratory properties that suggest their potential usefulness for the fabrication of fixed prostheses. Attempts to fabricate full coverage restorations from these materials has been encouraging. However, caution must be exercised in the melting and casting of high palladium or high silver content alloys. Over heating with concommitant gas absorption by the molten alloy producing porous castings are common problems observed when using these materials. Careful monitoring of melt temperatures is required if sound castings are to be produced routinely. Casting machines with integral furnaces and thermocouple temperature monitoring devices would be advantageous during the casting of these materials. Also, the procedure required for the handling of Salivan indicated that the mold is to be burned out at 900° F and then cooled to 600° F in the oven or alternately in open air. Cooling in open air is imprecise and accurate assessment of proper mold temperature is impossible; whereas, oven cooling, although reasonably accurate, would be cumbersome in a busy laboratory where the other types of alloys requiring higher mold temperatures are employed. Furthermore, previous laboratory studies[7] have suggested that alloys of relatively low (<50%) gold content may undergo tarnish and corrosion in the oral environment. Laboratory studies designed to assess potential corrosion resistance of these materials are in progress. Long term in vivo serviceability of these alloys remains to be studied.

Summary

Composition, microstructure, heat treatment characteristics and mechanical properties of four alternatives to conventional high noble fixed

prosthodontic alloys were studied. The materials exhibited a broad range of compositional and mechanical property differences. As cast tensile properties of three of the materials paralleled those of type III casting golds. Precipitation and order-disorder transformation appear to be the principal mechanisms of hardening.

These alloys exhibit properties suggesting their potential usefulness in fixed prosthodontics; however, the silver-palladium and silver-indium materials require meticulous attention to melting and casting technique to minimize the incidence of overheating and casting porosity.

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TABLE 1

ALLOY COMPOSITION

	Rajah %	T-III Lite %	Nev 76 %	Salivan %
Au	57.7	--	--	--
Ag	27.1	70.2	58.4	68.4
Pd	3.2	24.9	25.4	0.4
Cu	10.4	--	14.0	--
Zn	1.2	1.5	1.9	6.9
In	0.4	3.3	--	24.2

TABLE 2

TENSILE PROPERTIES OF LOW-NOBLE ALLOYS

Material	Ultimate Tensile Strength (10^3 psi)	Yield Strength 0.1% Offset (10^3 psi)	Elastic Limit (10^3 psi)	Modulus of Elasticity (10^6 psi)	Elongation (%)
Rajah					
As Cast	88 ± 6	80 ± 3	58 ± 5	14 ± 1	1 ± 1
Heat Treated*	56 ± 1	30 ± 5	26 ± 4	13 ± 1	27 ± 2
T-III Lite					
As Cast	58 ± 1	33 ± 1	24 ± 1	14 ± 1	6 ± 1
Heat Treated*	47 ± 3	28 ± 1	20 ± 1	16 ± 2	7 ± 1
Ney 76					
As Cast	74 ± 4	52 ± 4	37 ± 2	14 ± 2	7 ± 1
Heat Treated+	69 ± 1	35 ± 1	25 ± 1	14 ± 1	18 ± 2
Salivan					
As Cast	42 ± 4	36 ± 2	22 ± 1	11 ± 2	1 ± 1

* 5 min at 1600° F and water quenched.

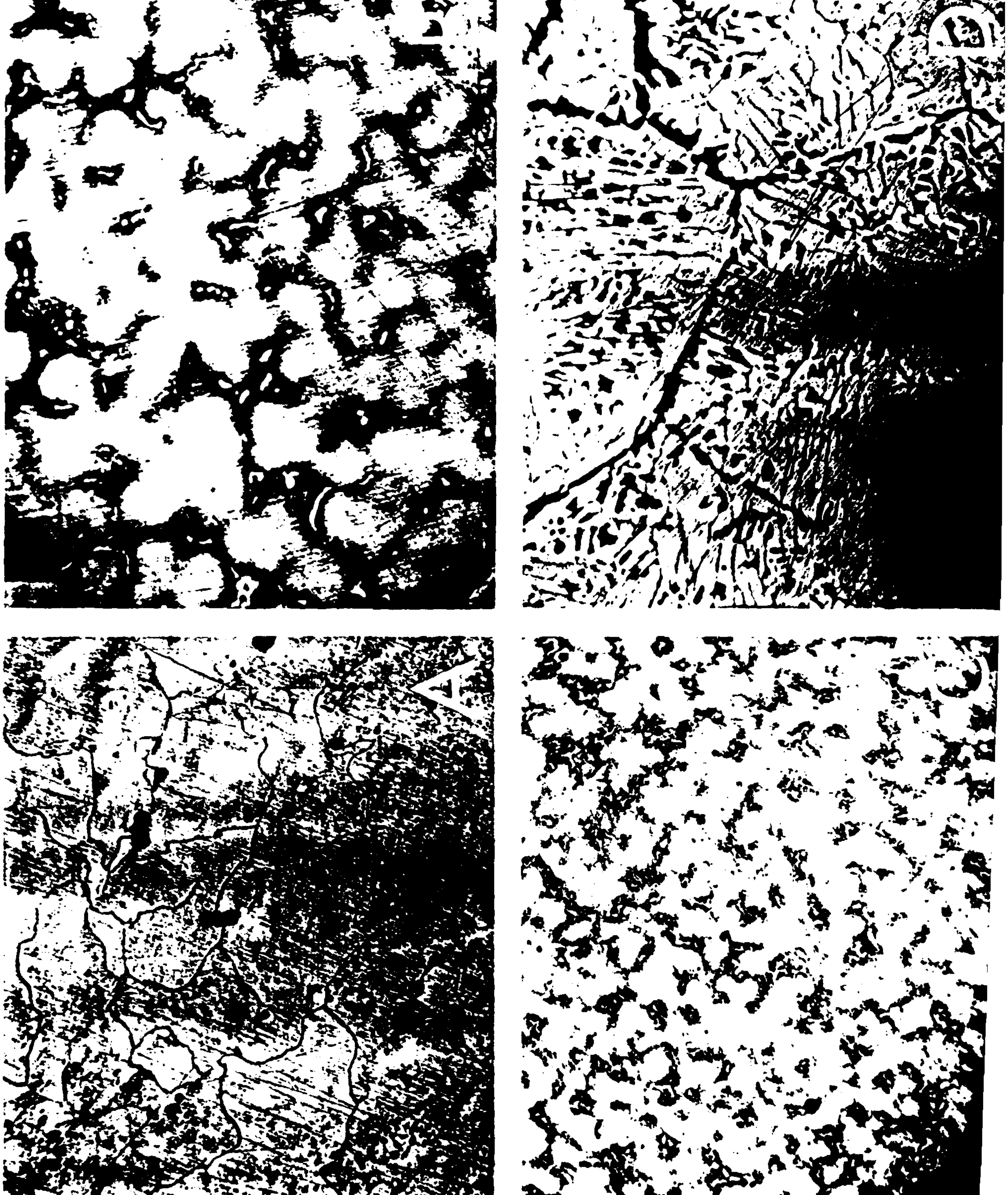
\+ 5 min at 1400° F and water quenched.

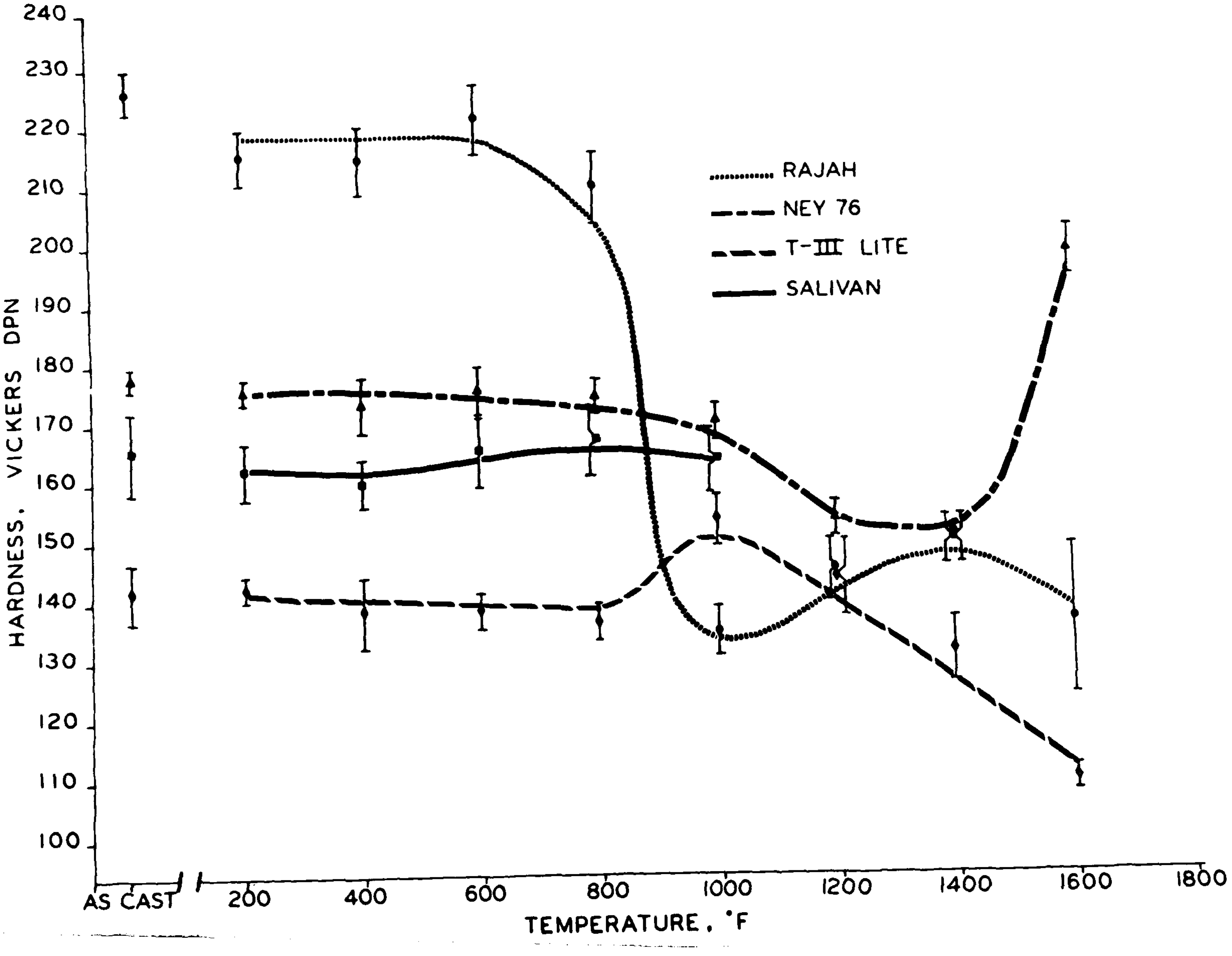
LEGENDS FOR FIGURES

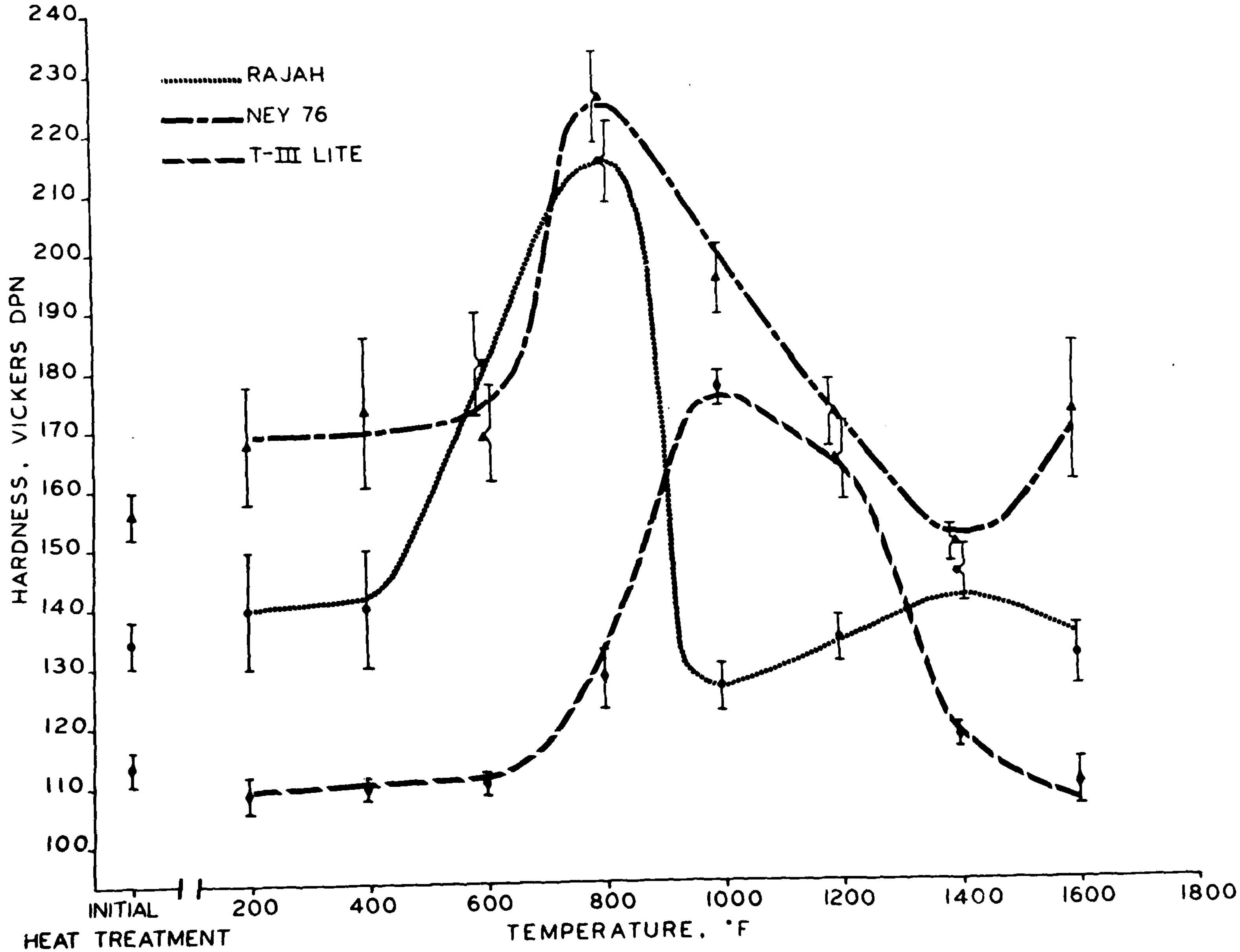
Figure 1. Microstructures of as cast alloys:
A, Rajah; B, T-III Lite; C, Ney 76 and D, Salivan.

Figure 2. Effect of heat treatment temperature on the hardness of Rajah, T-III Lite, Ney 76 and Salivan. Specimens were water quenched after each consecutive five-minute heat treatment.

Figure 3. Effect of reheat treatment temperature on the hardness of Rajah, T-III Lite and Ney 76. Specimens were initially softened at 1400° F (T-III Lite and Ney 76) and 1600° F (Rajah). Specimens were water quenched after five minutes at each treatment temperature.




HARDNESS, VICKERS DPN
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
AS CAST
200
400
600
800
1000
1200
1400
1600
1800
TEMPERATURE, °F
RAJAH
NEY 76
T-III LITE
SALIVAN


RAJAH
NEY 76
T-III LITE
HARDNESS, VICKERS DPN
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
INITIAL
HEAT TREATMENT
200
400
600
800
1000
1200
1400
1600
1800
TEMPERATURE, °F