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ADVANCED POWDER METALLURGY
ALUMINUM ALLOYS VIA RAPID
SOLIDIFICATION TECHNOLOGY

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PROJECT SUMMARY

The objective of this project was to demonstrate the technical feasibility of fabrication of dispersion hardened aluminum alloys using the principles of rapid solidification processing. Aluminum alloys containing transition metal elements having zero or negligible solid solubility in the host matrix when rapidly solidified from melt as powders form metastable highly supersaturated solid solutions. During consolidation processing of such powders at high temperature, an ultrafine dispersion of stable intermetallic phase(s) forms based on aluminum and transition metals. Such aluminum alloys exhibit superior strength at elevated temperatures at or above 350°F.

In this investigation, three aluminum alloys containing 10 to 11.5 wt. pct. of Fe and 1.5 to 3 wt. pct. of Cr were studied. Iron and chromium contents were varied to determine their effects on the mechanical properties of the alloys. Alloys were prepared as thin ribbons (.002 inches thick) rapidly solidified at uniform rate of 10^{6}°C/second by the melt-spinning process. The melt-spun ribbons were pulverized into powders (-60 to 400 mesh) by a rotating hammer mill. The powders were consolidated by hot extrusion at a high reduction ratio of 50:1. The powder extrusion temperature was varied to determine the range of desirable processing conditions necessary to yield useful properties. Powders and consolidated alloys were characterized by SEM and optical metallograph. The consolidated alloys were evaluated for (i) thermal stability, (ii) tensile properties in the range, room temperature to 450°F, and (iii) notch toughness in the range, room temperature to 450°F.

The consolidated alloys showed microstructures consisting of fine dispersion of metallic phases in an aluminum matrix. Microstructure coarsened slightly when the powder extrusion temperature was raised to 930°F from 750°F. Two alloys, Al-10Fe-3Cr and Al-11Fe-2Cr, showed good tensile preperties at elevated temperatures (i.e. 350-450°F); however, they possess little room temperature ductility. Some room temperature ductility was exhibited by an alloy containing a low amount of chromium. This alloy hot extruded at 840°F having the composition, Al-11.5Fe-1.5Cr also showed good high temperature tensile properties. Typical properties at 350°F were as follows: UTS=54 ksi and 0.2% yield strength = 46.8 ksi and elongation of 6.8%. Good notched tensile strength values were exhibited by Al-11.5Fe-1.5Cr alloy from room temperature to 450°F. The present Phase I study demonstrated the feasibility of fabrication of new aluminum alloys for potential spacecraft applications at elevated temperatures above 350°F.

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I. INTRODUCTION

Advanced aluminum alloys are of long-term interest for potential applications as lighweight materials in spacecraft structures at temperatures greater than 350°F. New aluminum alloys with far superior high temperature strength/density and stiffness properties than those from commercial aluminum alloys are a potential area for innovation. Payoffs will result from weight savings of structural components which in turn, lead to increased payload, service life, and decreased life-cycle cost.

Rapid solidification technology (RST) offers outstanding prospects for the creation of new engineering alloys which may have physical properties superior to those otherwise available[1]. In particular, RST can be used to produce metastable highly supersaturated metallic solid solutions wherein a large excess of solute elements can be retained uniformly throughout the host element or alloy. Upon suitable heat treatment, a fine dispersion of particles of the equilibrium intermetallic phases can be produced within the host matrix. In fact, the potential for using this approach to produce unusual dispersion hardened aluminum alloys having improved mechanical properties and superior thermal stability was recognized nearly fifteen years ago when rapid solidification processing techniques first began to emerge as viable engineering tools[2]. A large number of binary and multicomponent aluminum alloy systems have been identified which offer the scope of producing the precipitation/dispersion hardening phase by the nucleation and growth from liquid quenched supersaturated solutions, e.g. Al-Fe, Al-Cr, Al-V, Al-Ti, Al-Fe-Ni, Al-Fe-Mo, etc[3]. The decomposition of such supersaturated solutions has been found to follow the classical Al-Cu sequence of metastable phase nucleation and growth. Transition metal elements, e.g. Fe, Ti, Cr, Mo, Nb, etc. with very low diffusivity flux (i.e. high activation energy for diffusion) and low solid solubility in aluminum, are particularly effective in formation of thermally stable intermetallic particles resistant to Ostwald ripening. High temperature strengthening is achieved by the action of a large amount (25-30% volume fraction) of this dispersed phase, a technique which has been successful in oxide dispersion strengthened aluminum alloys, e.g. SAP alloys and the mechanically alloyed alloys. However, strength also may arise from a highly refined grain size. High modulus intermetallic compounds contribute to increased modulus of the powder metallurgical (P/M) aluminum alloy. Another consideration is the influence of a two-phase microstructure on alloy ductility. It is fairly well accepted that alloy ductility is inversely dependent on the volume fraction of a dispersed second phase. Thus, one alloy design principle indicates an increased volume fraction of second phase is needed for increased elastic modulus and high temperature strength; however, another alloy design principle indicates a decreased volume fraction of second phase is needed for ductility. Several RST powder product manufacturing approaches have been pursued during the past several years by different industrial groups in the United States under the Department of Defense and the Defense Advanced Research Project Agency sponsored programs with goals to develop high temperature dispersion hardened aluminum alloys for aerospace hardware applications. The potential alloy systems that are currently being investigated are Al-Mn-Si, Al-Fe-Mo, Al-Fe-Ni-Co, Al-Fe-Ce, etc.[4-5]. Although, encouraging results have been achieved in these investigations with some alloy compositions, considerably more work is needed to markedly enhance the properties of these alloys in order to be competitive with titanium alloys. Furthermore, RST processes based on melt-atomization techniques are usually plagued with non-uniform, low average cooling rates.

It appears that there is a need to produce aluminum alloy powders uniformly quenched at high solidification rates.

A six-month Phase I SBIR research project was undertaken by Marko Materials, Inc. under the sponsorship of NASA with the aim to develop a technology for production of new aluminum alloys with superior high temperature properties. This effort involved alloy design concepts as outlined in the aforementioned section and an innovative rapid solidification powder metallurgy (P/M) process. The present research on a new materials technology via Phase I and Phase II of this SBIR program is anticipated to provide viable lightweight aluminum alloys which will find applications in future spacecraft.

II. BACKGROUND

The State of the Art in Rapid Solidification Processing

The advent of RST powder processing has added a new dimension in alloy design, an unlimited flexibility in the control of properties by manipulating structures and compositions. RST processes cool a liquid metal at 10^6-10^7°C/second, thus these high cooling rates often lead to metastable phases and complete, or at least greatly enhanced, chemical homogeneity in the solidified alloys. For properly chosen RST alloy powders, powder metallurgy (P/M) processing will result in fully dense bulk materials which will have novel microstructures transformed from metastable phases and which will have highly desirable properties not obtainable by normal ingot casting metallurgy. Many of these processes are based on modifications of melt atomization techniques, e.g. (a) centrifugal atomization of melt coupled with forced convective cooling of molten droplets by helium gas, (b) ultrasonic atomization of melt into extremely fine droplets, and (c) high velocity gas quenching[7]. There are certain limitations of RST powder processes based on atomization. Atomized droplets undergo variable quench rates which result in a wide range of particle sizes. Screening out the larger particles gives material which has been subjected to a more uniform and high cooling rate, but the yield is then reduced causing the process to be less economical. For solidification rates greater than 10^4°C/second, RST powder processes based on gas quenching of atomized melt, as of today, have reached their limit. Metal substrate must be used to achieve faster solidification rates.

Of the various solid substrate quenching processes known in the present state of the art, the chill-block-melt-spinning technique appears to be the most viable approach for economically producing rapidly solidified materials as thin continous ribbon or tape in large quantities. In this process, a free jet of molten metal is impinged onto a moving metal substrate. The molten stream is converted into ribbon which has been uniformly solidified at an extremely rapid rate of 10^6°C/second. One major advantage of the melt-spinning process is its capability to produce rapidly solidified materials with high yield up to nearly 100%.

The technology of metal substrate quenching based on melt-spinning or its modifications has advanced rapidly in recent years. Large production scale metal substrate quenching processes have been established for high speed fabrication of ribbons of rapidly solidified alloys. Such techniques are being applied to aluminum alloy systems for production of materials with one hundred percent yield being cooled at one hundred times faster than gas quenched atomized particulates.

Rapidly solidified ribbons are generally pulverized into powders by a rotating hammer mill for subsequent easy fabrication of bulk products by standard powder metallurgy procedures.

Rapid Solidification Technology of Marko Materials

During the past several years Marko Materials has been engaged in the development of a rapid solidification powder technology based on a melt-spinning process. In this process, the candidate alloys are rapidly solidified as thin, uniform ribbons by melt-spinning. The melt-spun ribbons are in-line pulverized directly off the casting substrate by a rotating hammer mill.

The present research effort funded under NASA's Small Business Innovative Research Program has been geared to extend Marko's rapid solidification technology to aluminum alloys with an objective to achieve superior high temperature mechanical properties. The basic approach adopted followed the underlying principles of design of advanced high temperature aluminum alloys by a dispersion of stable, ultrafine intermetallic phases based on aluminum and transition metals.

III. PHASE I TECHNICAL OBJECTIVES

Marko proposed to develop via its rapid solidification technology based on melt-spinning new advanced aluminum alloys containing 12-14 percent transition metals with improved tensile strength, fatigue, and creep properties at temperatures above 10^{6}°C. An extremely high cooling rate (10^{6}/second) was anticipated to lead to formation of metastable supersaturated solid solution structures in transition metals bearing aluminum alloys as compared to refined dendritic structures which are usually retained at lower cooling rates (10^{4}°C/second). Metastable solid solution structures obtained at the very high solidification rate of 10^{6}°C/second were to be decomposed by thermomechanical treatments to create stable and ultrafine intermetallic phases uniformly dispersed leading to improved mechanical properties at elevated temperatures.

Rapid solidification powder processes which are based on gas quenching of atomized melt have certain limitations; the primary one being, low cooling rate (10^{4}°C/second). Therefore, a need was realized to develop a new rapid solidification powder making process for suitably melting aluminum alloys followed by conversion of melt into powders rapidly solidified at a high and uniform rate of 10^{6}°C/second. Marko proposed to extend its rapid solidification technology to the Al-Fe alloy system. The primary objective of this research effort was to.

investigate three first iteration alloys and optimize the thermal processing treatments so as to achieve high modulus and strength combined with reasonable ductility at room and elevated temperatures upto 450°F. Ternary modifications to binary aluminum-iron alloys were investigated by other workers using zirconium, hafnium, niobium, cerium, and molybdenum to provide additional strengthening. Molybdenum and cerium have been found to have strong beneficial effects on the Al-Fe alloys. Chromium when added to aluminum forms very stable Al_7Cr particles at grain boundaries. Such particles resist coarsening even at 932^{O}F.

In the present effort aluminum alloys containing specific amounts of iron and chromium were selected for study as rapidly solidified powder by Marko's RST process based on melt-spinning. Powders were subjected to consolidation by cold compaction followed by hot extrusion. Some microstructural characterization was carried out using SEM technique. Very fine particles (-400 mesh) were discarded to eliminate possible contaminants eroded from the linings and the hammers of the pulverizer. The consolidated alloys were tested for mechanical properties at room and elevated temperatures upto 450°F. Because of their potential applications in spacecraft structures, some measure of toughness was incorporated in the present alloy investigation program to ensure a usable product. Such a parameter, which is inexpensive and a good indicator of relative toughness, is the notched tensile strength/yield strength ratio (NTS/YS).

IV. PHASE I EXPERIMENTAL WORK PLAN

Marko Materials investigated smooth and notched tensile properties of three candidate Al-Fe-Cr alloys, each hot extruded at three different extrusion temperatures. The experimental matrix of alloy composition and consolidation temperature is shown below. Extrusion ratio was constant at 50:1.

Alloy Composition (weight-percent)	Extrusion Temperature (°F)		
	T_1	T_2	T_3
Al-10Fe-3Cr	750°F	840°F	930°F
Al-11Fe-2Cr	750°F	840°F	930°F
Al-11.5Fe-1.5Cr	750°F	840°F	930°F

The three candidate alloys were prepared as rapidly solidified powders by the melt-spinning-pulverization technique. Ten pounds of powders (-60 to 400 mesh) of each alloy were produced. Consolidation of powders into bars was carried out by the method of extrusion at three different temperatures, 750°F, 840°F, and 930°F. Powders were cold compacted in 4.5 inch OD aluminum cans under 70 tons uniaxial load. Powders were vacuum degassed at 480°F for 4 hours and then the cans were sealed. Powders were directly hot extruded into bars excluding a hot upsetting step prior to extrusion. Extrusion was carried out in two steps to achieve a high overall reduction ratio to ensure complete elimination of interparticle prior boundaries. The first stage extrusion was carried out in a 1400 ton press at a reduction ratio of 5:1. All the cans containing three different alloy powders were soaked at 750°F for 2 hours prior to extrusion. The extruded bars having 2 inch diameter were cut-up in 8 inch long billets. Each alloy was subsequently re-extruded (second stage extrusion) in a 300 ton press at a reduction ratio of about 10:1. The second stage extrusion of each alloy was carried out at three different temperatures: 750°F, 840°F, and 930°F. The billets were soaked at each temperature for 1.5 hours. The second stage extrusion produced 0.63 inch diameter bars. The overall reduction ratio experienced by each alloy was 50:1.

The consolidated alloys were evaluated for (a) density, (b) thermal stability, and (c) smooth and notched tensile properties at room and elevated temperature.

V. RESULTS

SEM and Optical Photomicrographic Investigation

Microstructural characteristics of the consolidated alloys were conducted by optical photomicrography. The characteristics of the powders were investigated by SEM and optical photomicrography.

The powders were examined both in the loose form as well as in the mounted and polished state (see Figures 3-8). Powders prepared by pulverization of melt-spun ribbons were found to have platelet morphology with featureless microstructural characteristics.

Optical photomicrograph of Al-Fe-Cr alloys of various compostitions consolidated at different temperatures are shown in Figures 9-13. The majority of the product microstructure consist of a distribution of small second phase particles which evolved from the nonequilibrium highly supersaturated solid solutions of aluminum-iron-chromium. A small part of the microstructure of the product contains large crystals of the primary phase. The equilibrium hypereutectic solidification morphology in these powders made from ribbons is supressed. It is suggested that at high cooling rates, the growth of the equilibrium primary intermetallic phase is kinetically limited requiring a transition in solidification mode to one in which a supersaturated aluminum is the primary phase.

The photomicrographs (Figure 9-13) show no evidence of prior particle boundaries. The powders appeared to be well-bonded across interparticle boundaries during extrusion at high reduction ratio of 50:1 A slight coarsening of the intermetallic compound is seen in the alloy extruded at 930°F (Figure 11) as compared to the same alloy extruded at 750°F (Figure 9).

<u>Density</u>

The three candidate alloys were found to have the following densities:

Al-10Fe-3Cr: 2.903 gm/cc

Al-11Fe-2Cr: 2.912 gm/cc

Al-11.5Fe-1.5Cr: 2.916 gm/cc

<u>Thermal Stability</u>

The three extruded alloys (Al-10Fe-3Cr, Al-11Fe-2Cr, and Al-11.5Fe-1.5Cr) were isothermally annealed at 660°F and 750°F for various lengths of time upto 500 hours. Following annealing, samples were tested for hardness values at room temperature using a Rockwell B tester. The specimens showed no change in room temperature hardness values (approximately between R_B 88-90) following annealing indicating excellent thermal stability.

Mechanical Properties

Tables 1 to 9 list the results of smooth and notched tensile tests of the three candidate Al-Fe-Cr alloys in the range between room temperature to 450°F. The cylindrical test specimens were prepared according to Figures 1 and 2. Cross head speed was 0.005 inch/inch/min. upto yield point and beyond yielding, cross head speed was 0.05 inch/inch/min. Al-10Fe-3Cr alloys extruded at 842°F and 932°F appeared to have attractive high temperature tensile strength combined with reasonably good ductility in the range 400-450°F. With decreasing chromium contents in the Al-Fe-Cr alloy room temperature ductility was slightly improved. Improvement of room temperature ductility was also achieved by increase in hot extrusion temperature. With high solute contents of the present candidate alloys the probability of occurrence of the coarse primary crystals was high. The presence of coarse particles encourages void nucleation leading to notch sensitivity. This effect places increasing demand on the distribution of the smaller second phase particles.

The temperature selected to consolidate the powder influences the product ductility and strength. Lower consolidation temperature led to reduced ductility, perhaps due to poorer interparticle bonding. High temperature extrusion led to improved interparticle bonding. However, strength was reduced due to enhanced coarsening of the second phase microstructure at higher extrusion processing temperatures. The notch toughness measured as the ratio of notched tensile strength to yield strength was highest for the Al-11.5Fe-1.5Cr alloy consolidated at 932°F.

The development of improved elevated temperature aluminum alloys for spacecraft-aerospace applications has been a goal of research for years. Aluminum alloys having higher strength and improved creep resistance offer the potential for lower weight and reduced costs through the replacement of heavier more costly materials such as titanium. The present Phase I exploratory research indicates that rapid solidification processing based on Marko's melt-spinning technology offers a viable route to fabricate aluminum alloys containing transition metal elements having improved mechanical properties at elevated temperature.

The present research has clearly demonstrated that ductility, strength, and notch toughness of dispersion strengthened P/M Al-Fe-Cr alloys at room and elevated temperatures can be controlled by the amount of various solute elements, and powder consolidation processing conditions.

VI. SUMMARY OF RESULTS

Three aluminum alloys containing about 13 wt% transition metals (Fe and Cr) were investigated. Al-10Fe-3Cr, Al-11Fe-2Cr, and Al-11.5Fe-1.5Cr were prepared as rapidly solidified powders by the method of melt-spinning and pulverization. Powders were consolidated by a two-stage extrusion at three different temperatures between 750 to 930°F. The microstructures of the consolidated alloys were investigated and tensile properties were determined over the range from room temperature to 450°F.

The microstructural characteristics which influence tensile properties of dispersion hardened P/M Al-Fe-Cr alloys were controlled by the consolidation processing conditions and the compositions. The microstructure of rapidly solidified Al-Fe-Cr alloy powders essentially consisted of featureless characteristics which indicate very high cooling rates experienced by the alloys. The microstructures of the consolidated alloys consisted of a distribution of fine second phase intermetallics which evolved from supersaturated solid solution matrix phase during thermomechanical processing of the powders. A smaller part of the product contains somewhat large crystals of the primary phase.

The temperatures selected to consolidate the powders influenced the bulk ductility and strength. Lower consolidation temperature led to reduced ductility. Higher consolidation temperature improved room temperature ductility and reduced high temperature strength.

Of the three alloys Al-11.5Fe-1.5Cr appeared to be most promising when consolidated (i.e. extruded) at 932°F. It combined some room temperature ductility with attractive high temperature (450°F) tensile strength and notch toughness.

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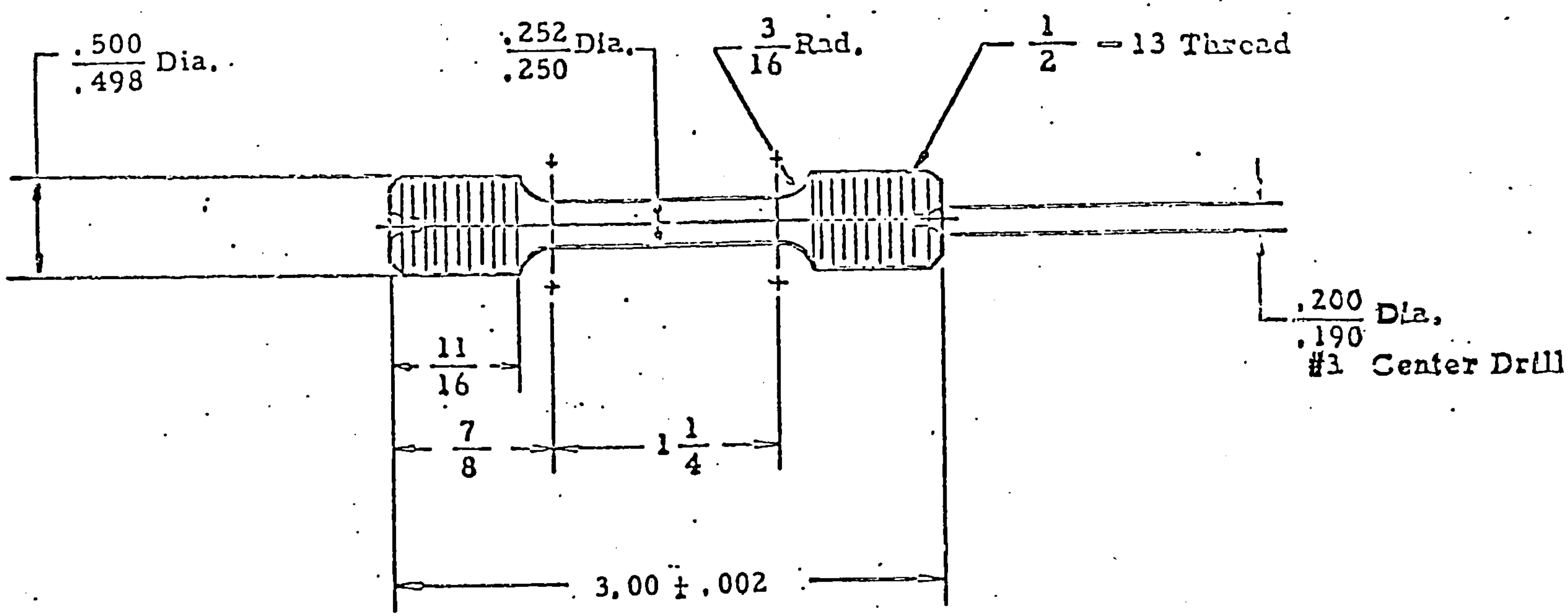


Figure 1. Smooth Tensile Test Specimen.
Dimensions in inches.

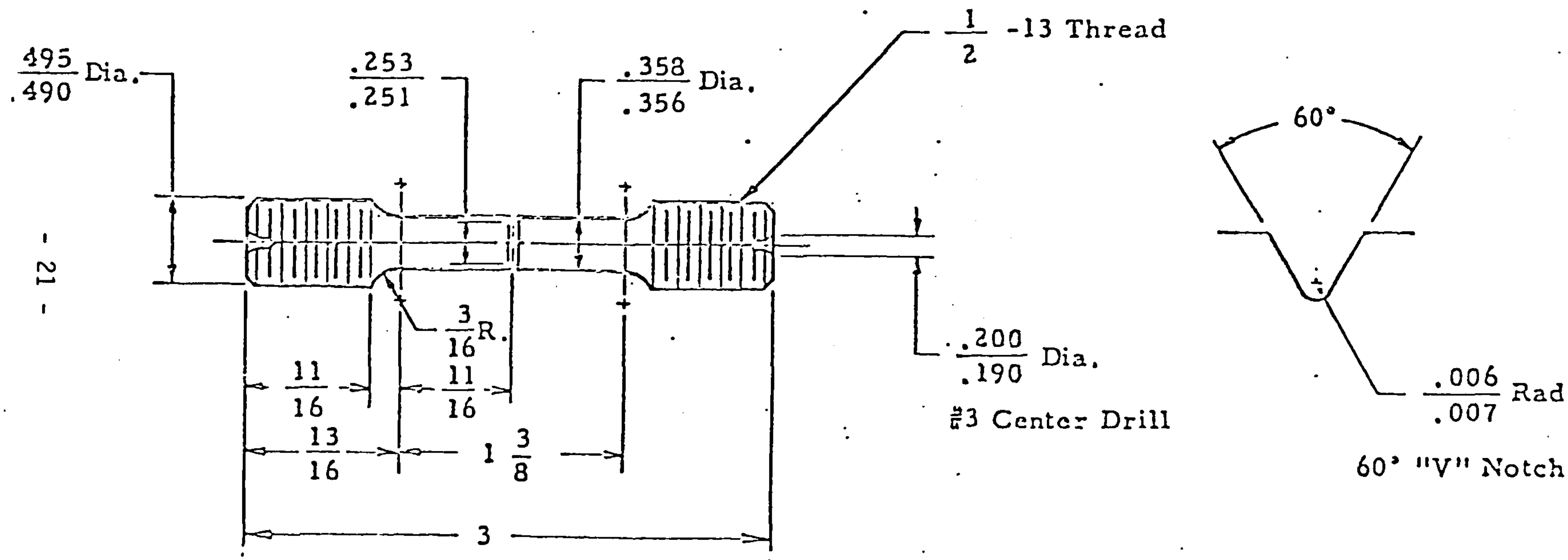


Figure 2. Notched Tensile Test Specimen.
Dimensions in inches.

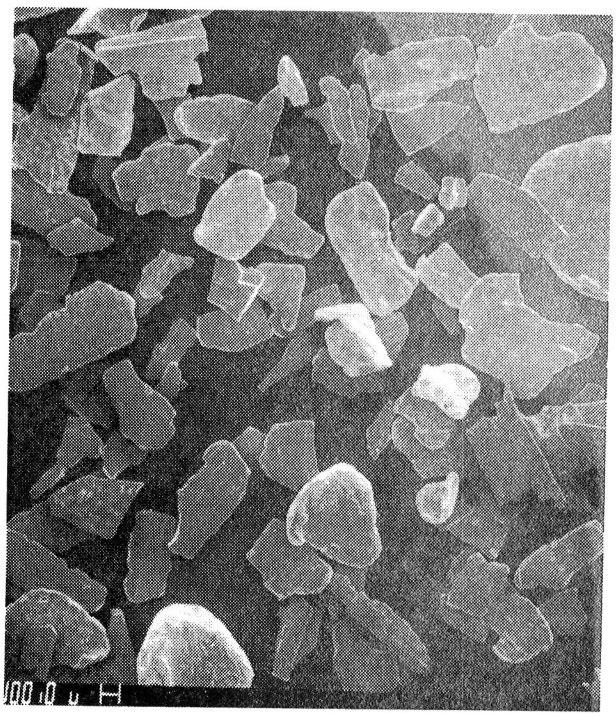


Figure 3. SEM photomicrograph of loose powder of Al-10Fe-3Cr alloy

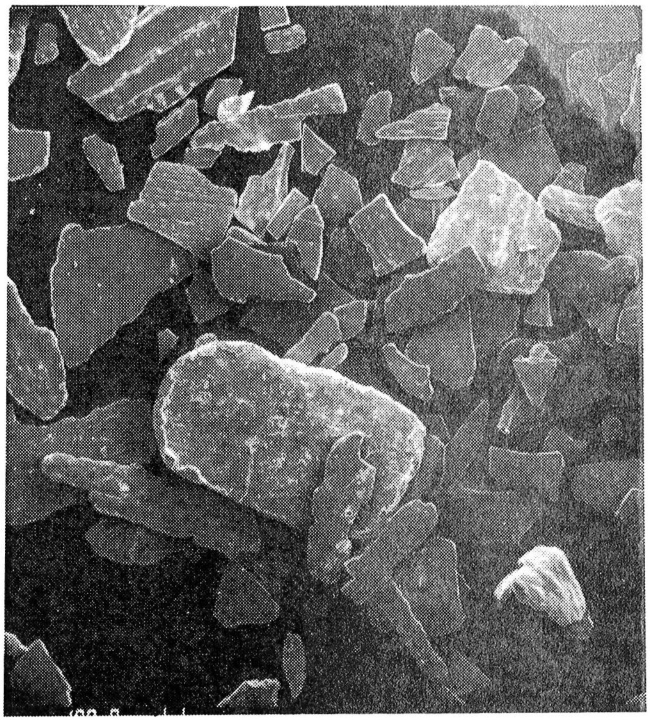


Figure 4. SEM photomicrograph of loose powder of Al-11Fe-2Cr alloy

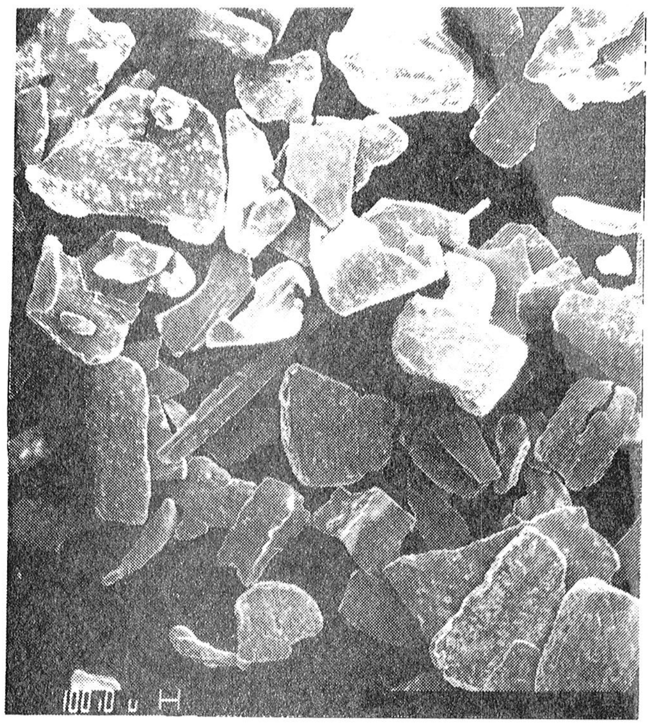


Figure 5. SEM photomicrograph of loose
powder of Al-11.5Fe-1.5Cr alloy

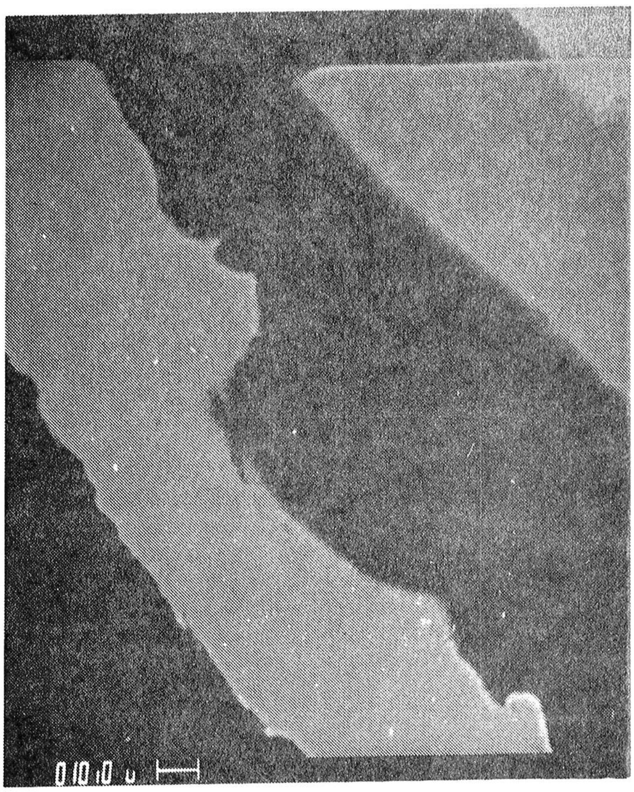


Figure 6. Optical photomicrograph of Al-10Fe-3Cr alloy powder

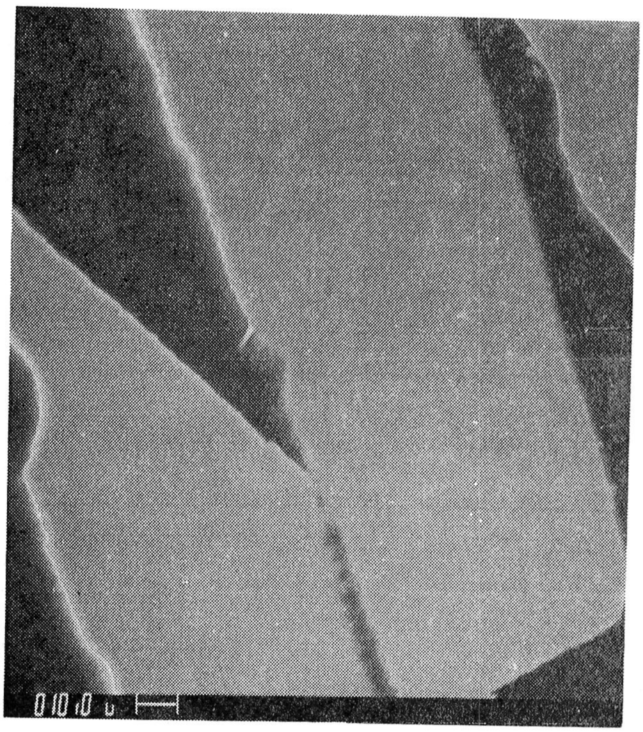


Figure 7. Optical photomicrograph of Al-11Fe-2Cr alloy powder

Figure 8. Optical photomicrograph of Al-11.5Fe-1.5Cr alloy powder

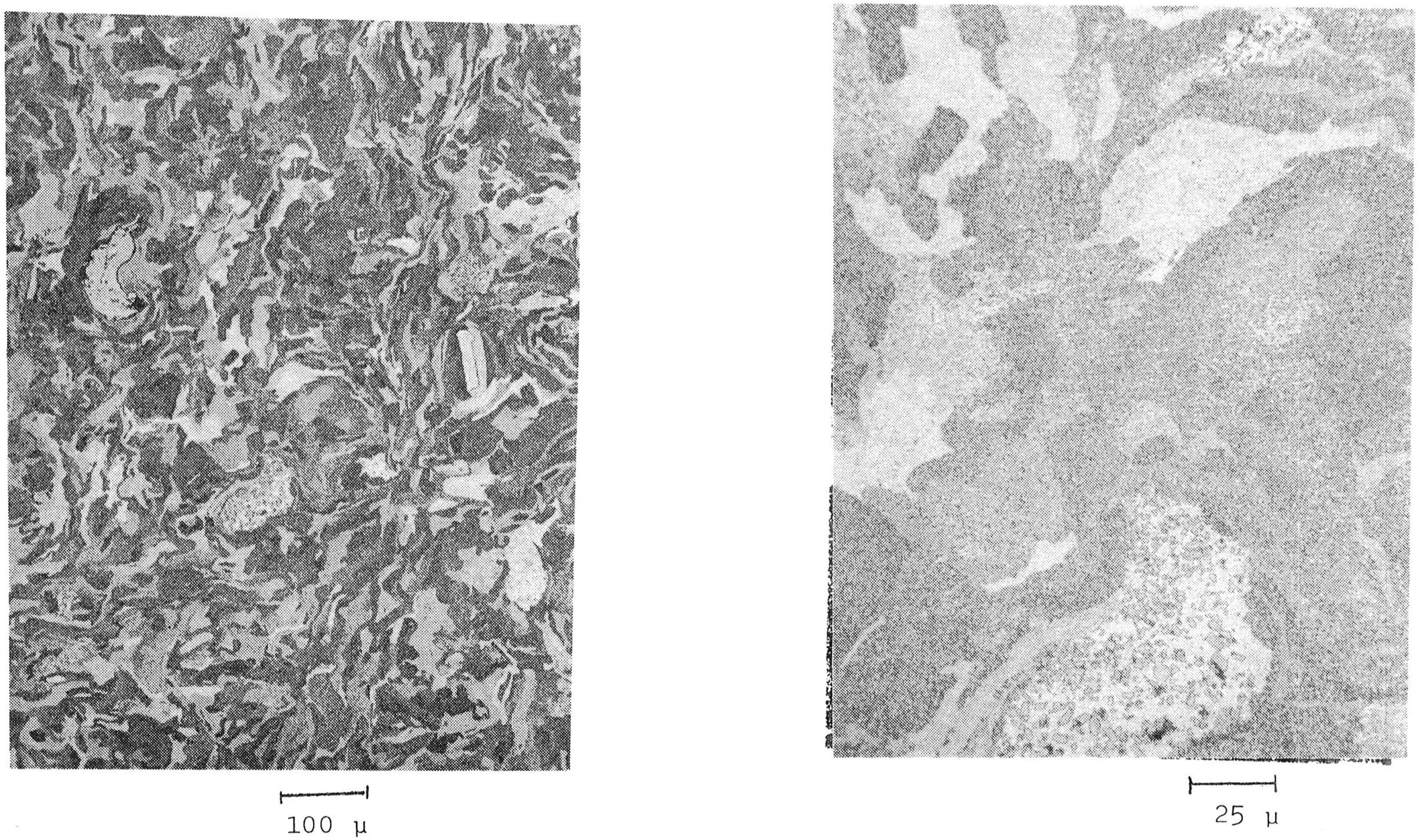


Figure 9. Optical photomicrographs of Al-11.5Fe-1.5Cr alloy hot extruded at 750°F. Etched in Kellers

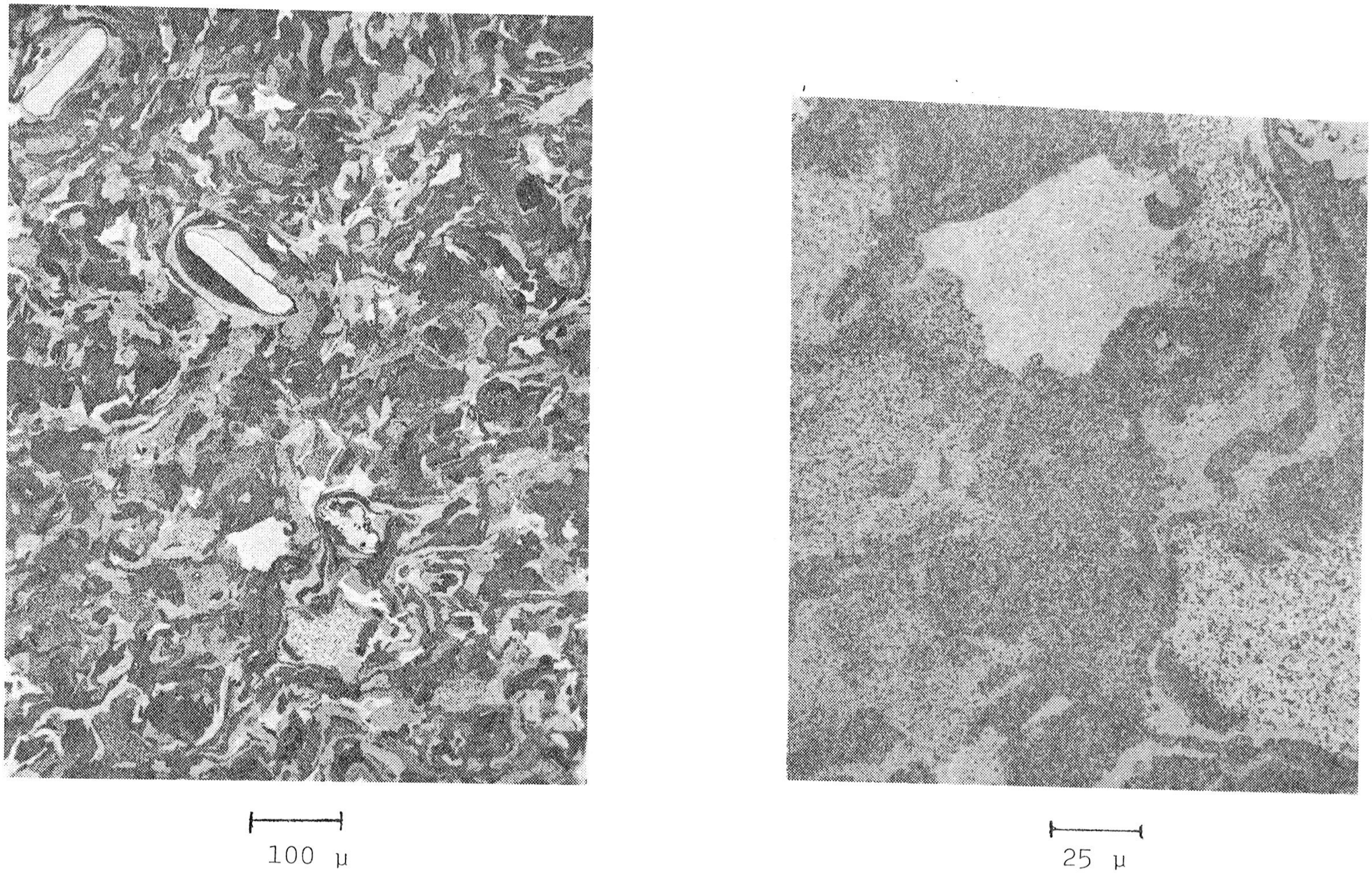


Figure 10. Optical photomicrographs of Al-11.5Fe-1.5Cr alloy hot extruded at 840°F. Etched Kellers

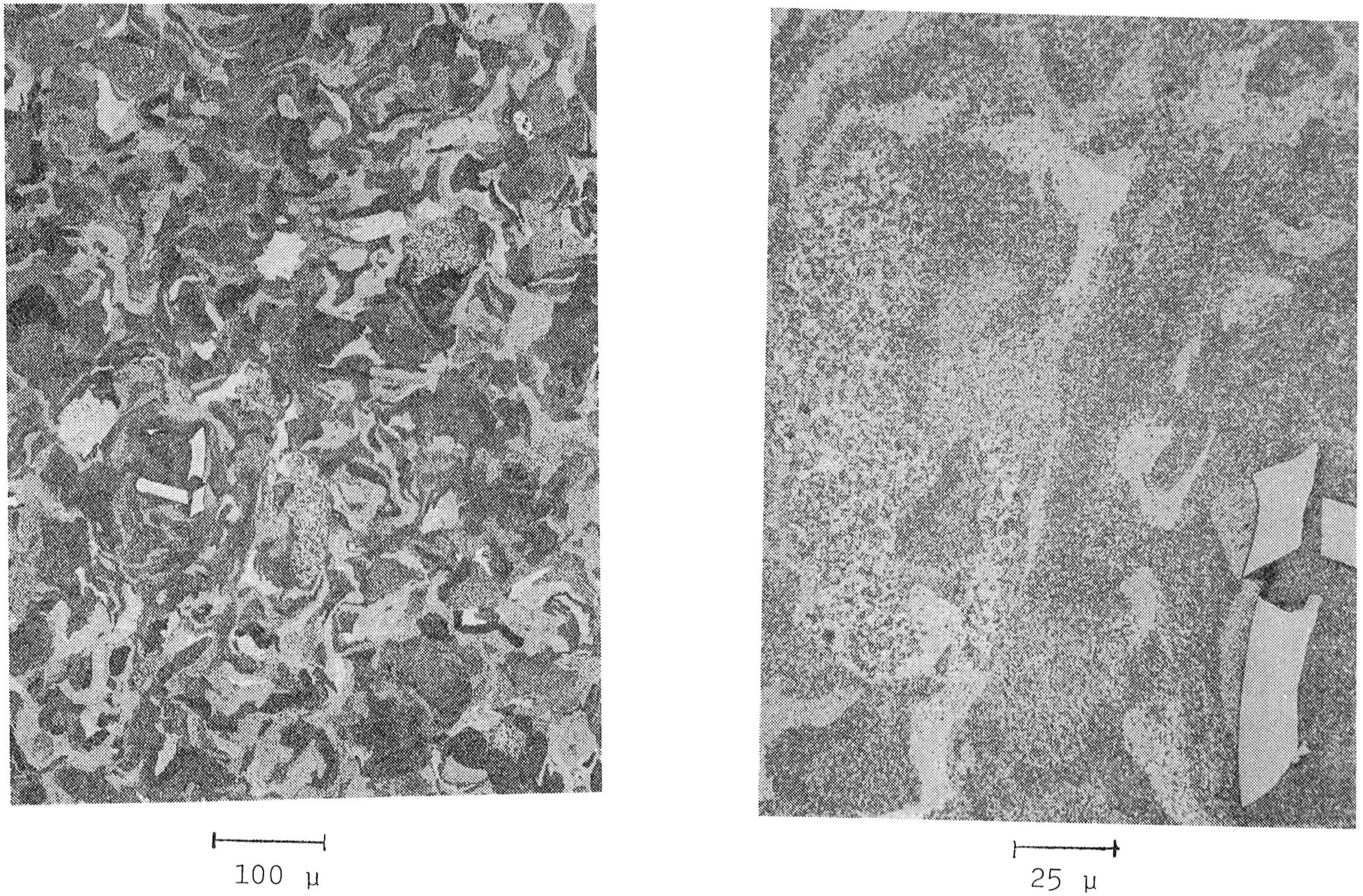
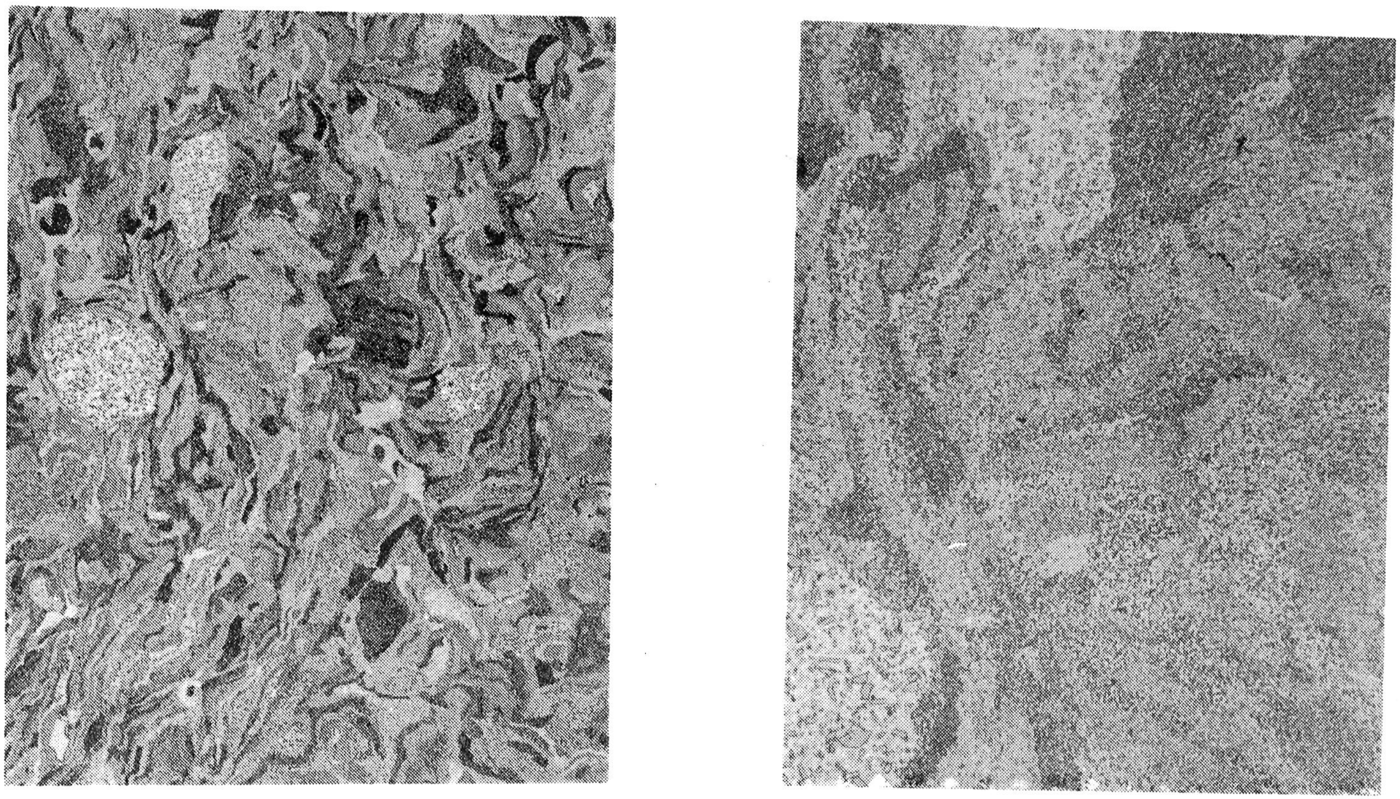


Figure 11. Optical photomicrograph of Al-11.5Fe-1.5Cr alloy hot extruded at 932°F. Etched in Kellers



100 μ

25 μ

Figure 12. Optical photomicrograph of Al-11Fe-2Cr alloy hot extruded at 932°F. Etched in Kellers.

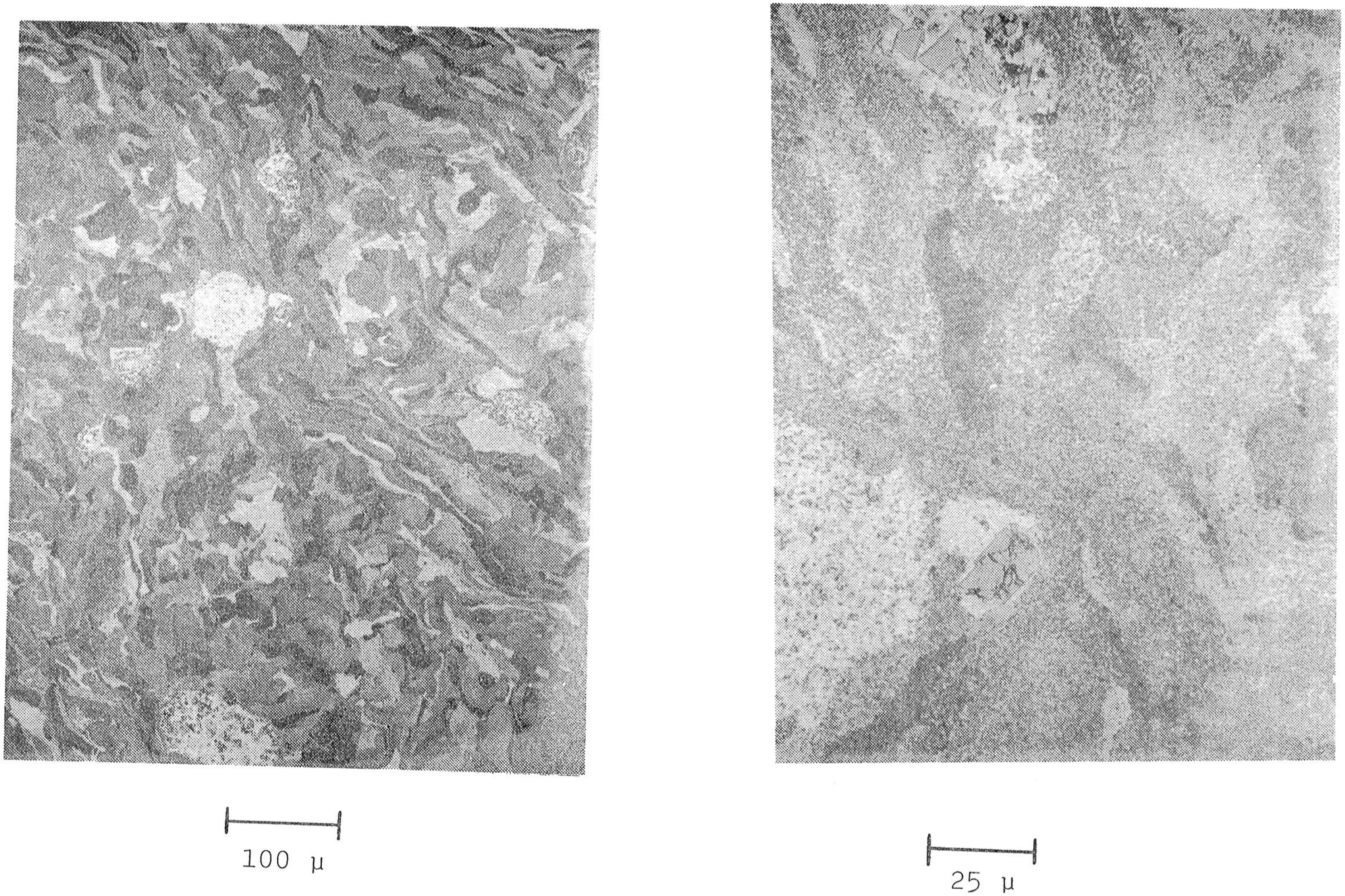


Figure 13. Optical photomicrograph of Al-10Fe-3Cr alloy hot extruded at 840°F. Etched in Kellers.

Table 1

Smooth and Notched Tensile Properties of P/M

Al-10Fe-3Cr Alloy Extruded at 750°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	--	4220*	31,800	--	--	--
250	--	4221*	37,900	--	--	--
300	59,100	62,800	37,400	0.8	1.1	.63
350	54,200	56,200	40,500	0.2	0.2	.74
400	50,100	55,900	42,500	0.9	1.5	.85
450	45,700	54,600	39,100	2.0	3.1	.86

* Thread failure at load indicated

Table 2

Smooth and Notched Tensile Properties of P/M

Al-10Fe-3Cr Alloy Extruded at 842°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	--	2950*	30,600	--	--	--
250	65,700	71,000	34,000	0.5	0.7	.52
300	56,500	67,900	40,500	0.9	1.5	.72
350	55,700	64,600	45,800	1.7	1.3	.82
400	48,100	54,700	45,300	4.3	5.2	.94
450	40,200	48,200	48,700	7.5	8.2	1.21

* Thread failure at load indicated

Table 3

Smooth and Notched Tensile Properties of P/M

Al-10Fe-3Cr Alloy Extruded at 932°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	--	4140*	20,800	--	--	--
250	--	5230*	38,000	--	--	--
300	53,200	63,600	44,600	.09	1.2	.84
350	48,900	59,400	49,600	1.4	2.2	1.01
400	44,900	51,000	41,000	7.1	7.2	.91
450	38,300	44,600	47,400	5.6	5.4	1.24

* Thread failure at load indicated

Table 4

Smooth and Notched Tensile Properties of P/M

Al-11Fe-2Cr Alloy Extruded at 750°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	--	3440*	33,100	--	--	--
250	--	3000*	22,800	--	--	--
300	63,900	65,500	37,000	0.3	0.9	.58
350	52,200	60,100	36,300	1.0	1.8	.70
400	46,100	55,700	46,800	1.5	1.9	1.02
450	40,000	48,200	44,400	4.9	5.0	1.11

* Thread failure at load indicated

Table 5

Smooth and Notched Tensile Properties of P/M

Al-11Fe-2Cr Alloy Extruded at 840°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	--	67,600	1690*	0.2	0.2	--
250	--	3460*	17,300	--	--	--
300	56,700	63,600	29,600	1.0	1.7	.52
350	51,900	58,500	37,500	1.7	3.4	.72
400	44,900	53,000	52,700	5.0	5.0	1.17
450	39,500	46,900	42,900	5.3	8.0	1.09

* Thread failure at load indicated

Table 6

Smooth and Notched Tensile Properties of P/M

Al-11Fe-2Cr Alloy Extruded at 932°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	68,500	72,300	37,000	0.4	0.9	.54
250	58,400	70,500	49,500	1.2	2.1	.85
300	53,900	59,100	61,700	2.4	4.3	1.14
350	49,200	53,900	62,700	4.7	7.8	1.27
400	42,800	48.600	49,200	7.3	7.2	1.15
450	34,500	42,200	46,200	8.6	10	1.34

* Thread failure at load indicated

Table 7

Smooth and Notched Tensile Properties of P/M

Al-11.5Fe-1.5Cr Alloy Extruded at 750°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	75,500	81,600	36,900	0.9	1.4	.49
250	--	5070*	49,500	--	--	--
300	54,200	62,100	61,600	5.4	7.5	1.14
350	44,800	53,500	62,700	10.3	15.2	1.40
400	42,900	48,400	49,200	9.8	13.6	1.15
450	36,200	43,100	46,200	8.5	10.3	1.28

* Thread failure at load indicated

Table 8

Smooth and Notched Tensile Properties of P/M

Al-11.5Fe-1.5Cr Alloy Extruded at 840°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	66,600	77,700	39,100	0.5	1.8	.59
250	63,500	70,600	46,500	1.6	2.3	.73
300	52,800	57,900	60,400	8.8	10.1	1.14
350	46,800	54,100	60,000	6.2	5.8	1.28
400	39,800	45,700	58,500	8.8	14.5	1.47
450	35,000	40,700	47,600	10.9	15.4	1.36

Table 9

Smooth and Notched Tensile Properties of P/M

Al-11.5Fe-1.5Cr Alloy Extruded at 932°F

Test Temp. (°F)	0.2% Offset Y.S. (psi)	Ultimate Tensile Strength (psi)	Notched Tensile Strength (psi)	% Elong	% RA	Notched Tensile Strength / Yield Strength
75	54,800	69,700	54,000	2.0	3.4	.99
250	50,600	60,500	66,000	7.1	7.4	1.30
300	47,300	54,800	71,600	11.1	11.6	1.51
350	42,100	47,600	66,100	13.7	23.7	1.57
400	36,500	41,200	59,800	17.0	21.2	1.64
450	32,000	35,800	45,400	16.7	18.7	1.42

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16. Abstract

A study was undertaken to prepare aluminum alloys containing 10 to 11.5 wt. pct. of iron and 1.5 to 3 wt. pct. of chromium using the technique of rapid solidification powder metallurgy. Alloys were prepared as thin ribbons (.002 inch thick) rapidly solidified at uniform rate of 10^6°C/second by the melt-spinning process. The melt-spun ribbons were pulverized into powders (-60 to 400 mesh) by a rotating hammer mill. The powders were consolidated by hot extrusion at a high reduction ratio of 50:1. The powder extrusion temperature was varied to determine the range of desirable processing conditions necessary to yield useful properties. Powders and consolidated alloys were characterized by SEM and optical metallography. The consolidated alloys were evaluated for (i) thermal stability, (ii) tensile properties in the range, room temperature to 450°F, and (iii) notch toughness in the range, room temperature to 450°F.

The consolidated alloys showed microstructures consisting of fine dispersion of metallic phases in an aluminum matrix. Microstructure coarsened slightly when the powder extrusion temperature was raised to 930°F from 750°F. Two alloys, Al-10Fe-3Cr and Al-11Fe-2Cr showed good tensile properties at elevated temperatures (i.e. 350-450°F); however, they possess little room temperature ductility. Some room temperature ductility was exhibited by an alloy containing a low amount of chromium. Good notched tensile strength values were exhibited by Al-11.5-1.5Cr alloy from temperature to 450°F,

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