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Evaluation of Mechanical and Metallurgical Properties of Fe_3Al-Based Aluminides

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Research supported by the Morgantown Energy Technology Center, U.S. Department of Energy

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METALS AND CERAMICS DIVISION

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EVALUATION OF MECHANICAL AND METALLURGICAL PROPERTIES OF Fe_3Al-BASED ALUMINIDES*

C. G. McKamey, C. T. Liu, J. V. Cathcart, S. A. David,
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ABSTRACT

A study is being conducted to develop aluminide alloys based on Fe_3Al with an optimum combination of strength, ductility, and corrosion resistance for use as hot components in advanced fossil energy conversion systems. Three phases of the study have been planned: (1) Fe-Al base compositions will be prepared for preliminary studies and evaluation of potential for further alloy development; (2) two of the base alloys will be used in the development and characterization of the properties of ternary and quaternary alloys; and (3) based on the results of those two phases of the study, alloys will be selected for preparation and characterization of large heats. Studies will include the fabricability, microstructures, tensile properties, oxidation and sulfidation resistance, and weldability of Fe_3Al-based alloys to which a fine dispersion of TiB_2 particles has been added for grain refinement. This report summarizes the results of the first phase of this study and discusses our plans for future work.

Alloys of Fe-24, 25, 26, 27, 28, and 30 at. % Al (all with 0.5 wt % TiB_2) were chosen as base alloys. They were prepared by arc melting under argon and drop casting into water-cooled copper molds, followed by a homogenization anneal. They were hot rolled starting at 1000°C and finishing at 650°C, then warm rolled at 600°C. All six compositions were easily fabricated and exhibited excellent oxidation and corrosion properties. Negligible weight changes were observed after 500 h in air-oxidation tests at temperatures to 1000°C. Similar results occurred in sulfidation tests conducted at 871°C for 168 h. Resistance to oxidizing and sulfidizing environments is a result of the formation of a self-protecting oxide layer at low oxygen pressures. The tensile strengths of the six base alloys were shown to be higher than those of type 316 stainless steel at temperatures below 760°C and those of modified 9Cr-1Mo steel at temperatures above 550°C. However, room-temperature ductility is slightly higher for alloys containing more than 27 at. % Al. Preliminary weldability studies indicate that the alloys with higher aluminum content develop fewer cracks in the fusion and heat-affected zones.

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Based on considerations of strength, corrosion resistance, fabricability, and weldability, alloys of Fe-28 and 30 at. % Al have been selected for further development. Future work will include alloying with molybdenum, titanium, and zirconium, singly and in combinations, to improve the high-temperature strength and room-temperature ductility.

INTRODUCTION

Iron aluminides based on Fe_3Al are ordered intermetallic alloys that generally have good oxidation and corrosion resistance and low material cost. They also conserve strategic materials such as chromium, and they have a lower density than stainless steels and therefore a better strength-to-weight ratio. However, limited ductility at ambient temperatures and a sharp drop in strength above 600°C are major disadvantages to their use as structural materials. The goal of the present study is to develop aluminide alloys based on Fe_3Al with an optimum combination of strength, ductility, and corrosion resistance for use as hot components in advanced fossil energy conversion systems (such as heat exchangers).

Studies involve the fabricability, microstructure, tensile properties, oxidation and sulfidation resistance, and welding characteristics of Fe_3Al-based alloys with ternary and quaternary additions of molybdenum, titanium, zirconium, or other elements. Because previous studies showed that dispersions of TiB_2 particles served to improve the mechanical properties of Fe_3Al via refinement of grain structure,[1,2] 0.5 wt % (~1 at. %) of TiB_2 was added to alloys of Fe-24, 25, 26, 27, 28, and 30 at. % Al to formulate the base alloys for study. This report summarizes the results to date on these base alloys, presents justification for the selection of base alloy compositions for further development, and discusses our plans for future work.

BACKGROUND

Currently, heat-resistant alloys are either nickel-based or high-nickel-content steels containing a delicate balance of one or more strategic elements such as Cr, Co, Nb, Ta, and W to obtain oxidation resistance, high strength, adequate ductility, fabricability, and thermal stability. In spite of their high degree of development, these state-of-the-art alloys do not meet the desired characteristics of the hot components for advanced fossil energy conversion systems because of their susceptibility to catastrophic hot corrosion by environments containing SO_2 and SO_3 (i.e., combustion gases), H_2S (coal gasification plants), and alkali sulfates (gas turbines). These alloys are also expensive to produce and suffer from aging embrittlement and chromium evaporation at high temperatures.

Because of their ability to form protective aluminum oxide scales,[3,4] iron aluminides near the Fe_3Al composition are expected to meet one of the major requirements of high-temperature components for use in environments that cause oxidation, sulfidation, and carburization. Since Al_2O_3 films form at very low oxygen partial pressures, the potential applications include components for coal gasification, fluidized-bed combustion, gas-cooled reactors, gas turbines, current collectors for fuel cells, and the seed recovery sections of magnetohydrodynamics systems. Their resistance to hot corrosion by SO_2, SO_3, sulfates, and H_2S is expected to be high because the impervious Al_2O_3 scale is not susceptible to formation of a low-melting phase such as the Ni-Ni_3S_2 eutectic (melting point $\approx 650°C$) observed in sulfidized nickel-based alloys.[5] Catastrophic hot corrosion therefore is not expected to occur in iron aluminides.

Iron aluminides are projected to be much cheaper than conventional alloys by virtue of the lower cost of iron and aluminum. Furthermore, the successful substitution of these alloys for the current heat-resistant alloys would reduce our nation's dependence on elements such as chromium and cobalt. Together, those two factors offer alloys based on an abundant supply of raw materials and without the sharp price excursions associated with import disruptions of critical strategic elements.

A practical advantage of these alloys near the Fe_3Al composition for fixed components (e.g., heat exchangers) and rotating components (e.g., steam turbine components) is their lower density ($\rho \approx 6.6\ g \cdot cm^{-3}$) as compared with the steels and nickel-base alloys ($\rho \approx 7.8$ to $8.5\ g \cdot cm^{-3}$).

The usefulness of iron aluminides for structural applications is, however, expected to be limited by their low room-temperature ductility (~1–2%) and their poor hot strength above 600°C. Low ductility, which is characteristic of cast and fabricated aluminides tested at room temperature, ceases to be a problem at high temperatures as the ductility increases to about 50% or more at 600°C.[2] Iron aluminides consolidated by hot extrusion of powders have been shown to have a room-temperature ductility of about 10%.[6] The creep strength of these alloys is comparable to that of a 0.15% carbon steel at 550°C.[7]

Recent revisions of the iron-aluminum phase diagram (Fig. 1) confirm the existence of three bcc phases [a disordered solid solution (α), ordered Fe_3Al (DO_3), and ordered FeAl (B2)] and the two-phase regions α + DO_3 and α + B2 for alloys containing 24 to 30 at. % Al.[8,9] Transmission

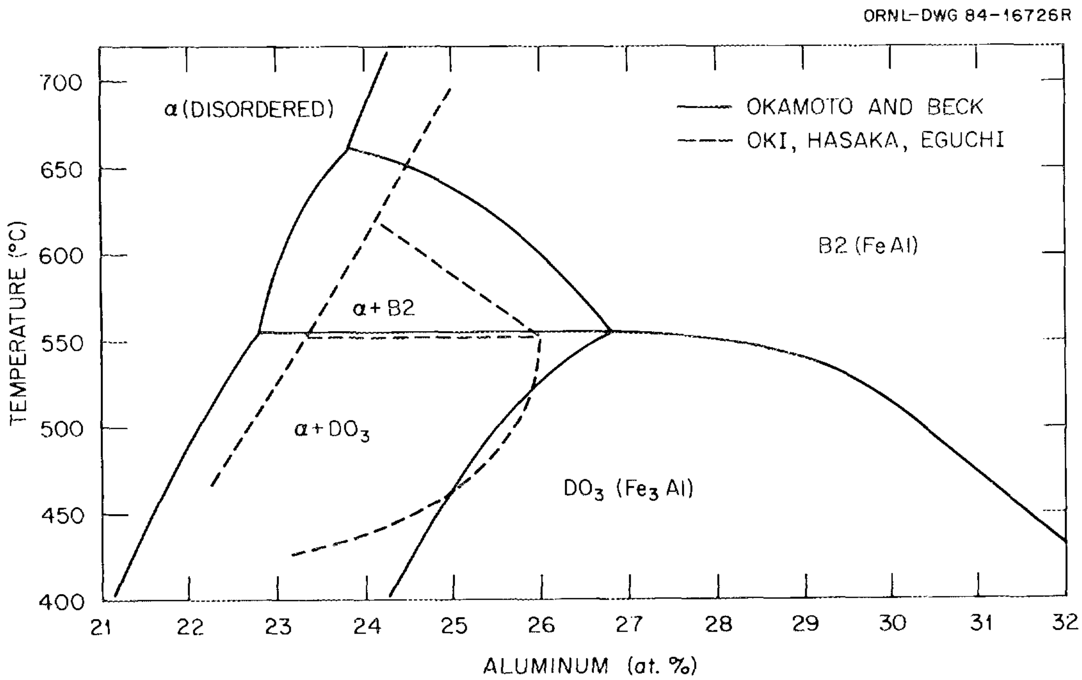

Fig. 1. The iron-aluminum phase diagram showing the phases of interest to this study.

electron microscopy, Mössbauer spectroscopy, and X-ray diffraction studies show that the phase transformations resulting from thermal heat treatments generate large coherency stresses and that these transformations proceed by nucleation and growth, spinodal decomposition, continuous ordering, or combinations of those effects.[10,11] For the purposes of this study, these results indicate that Fe_3Al alloys with less than 26 at. % Al can be age-hardenable through control of precipitation processes.

Grain structures in Fe_3Al alloys, prepared by powder metallurgy methods or by conventional melting and casting techniques, have been refined through additions of 1 to 2% titanium diboride (TiB_2) inclusions,[1,2] produced by adding boron and titanium to the melt during casting. These inclusions effectively strengthen Fe_3Al at temperatures to 600°C.

Most of the data presently available on the iron aluminides was gathered during the 1950s and 1960s on binary alloys of approximately 16 to 28 at. % Al. Some studies in alloy development were conducted at that time, and discussions of these studies can be found in refs. 12 through 15.

EXPERIMENTAL PROCEDURES

ALLOY PREPARATION

Six alloys with compositions shown in Table 1, each containing 0.5 wt % TiB_2 added for grain refinement, were prepared by arc melting under argon and drop casting into water-cooled copper molds of size 12.7 by 25.4 by 127 mm. One half of each 500-g ingot was homogenized for 5 h at 1000°C. The homogenized alloys were then hot rolled to a thickness of approximately 0.9 mm, starting at 1000°C and finishing at 650°C. Final warm rolling to approximately 0.76 mm was done at 600°C. This rolling schedule produced sheet of uniform thickness, with minor edge cracks on all six alloys and a slight curling of one alloy.

CHARACTERIZATION OF ALLOYS

The density of each rolled alloy was measured by the Archimedes[16] method using toluene as the liquid medium. Results are given in Table 1. Wet chemistry techniques were used to confirm the accuracy of the nominal

Table 1. Iron-aluminum alloys presently being studied

Alloy designation	Composition[a] (at. % Al)	Density (g/cm^3)	Grain diameter[b] (μm)
FA-36	24	6.62	38
FA-40	25	6.60	52
FA-38	26	6.56	44
FA-41	27	6.52	55
FA-37	28	6.49	46
FA-39	30	6.42	47

[a]All alloys contain 0.5 wt % TiB_2 (~1 at. %) added for grain refinement.

[b]Grain size was measured after a standard anneal of 1 h at 850°C plus 7 d at 500°C.

compositions. The chemical analyses (Table 2) generally agree well with the nominal compositions, except for FA-39 (Fe-30 at. % Al) where the analyzed aluminum level is lower than the nominal one. However, a plot of the densities of all six alloys versus their nominal compositions (Fig. 2) results in a straight line, indicating that alloy FA-39 should not be off its nominal composition as far as indicated by the chemical analysis. The alloys were also analyzed for carbon, oxygen, hydrogen, and nitrogen. The

Table 2. Chemical analysis of iron aluminides

Alloy number	Nominal composition [wt % (~at. %)]				Chemical analysis (wt %)	
	Fe	Al	Ti	B	Al	Ti
FA-40	85.69 (75)	13.81 (25)	0.38	0.12	14	0.38
FA-41	84.43 (73)	15.07 (27)	0.38	0.12	15	0.37
FA-39	82.45 (70)	17.05 (30)	0.38	0.12	16	0.36

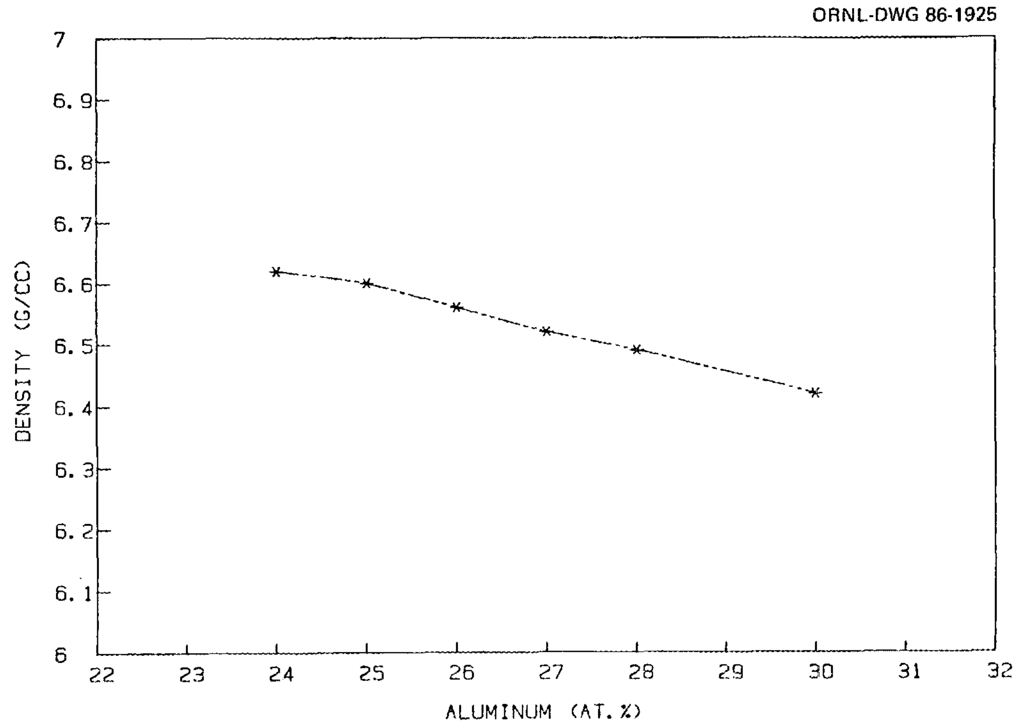

Fig. 2. Composition and density of the iron-aluminum alloys under study. All alloys contain 0.5 wt % TiB_2.

analytical results for three of the alloys, presented in Table 3, indicate that the concentration of these interstitial elements are very low and should cause no complications in the analysis of our results.

TESTING PROCEDURES

Tensile Testing

Tensile samples with a gage section of 0.76 by 3.18 by 12.70 mm were punched from the rolled sheet. For tensile testing at various temperatures, samples were first given a standard heat treatment of 1 h at 850°C plus 7 d at 500°C. All tests were conducted in an Instron testing machine at a strain rate of 3.3×10^{-3} s^{-1}. Temperatures of the tests varied between room temperature and 800°C. Samples to be tested at temperatures below 400°C were cleaned and deburred by either electropolishing or vapor blasting. Three of the alloys in the as-rolled condition were selected for testing at room temperature in air following 30-min vacuum anneals at various temperatures between 550 and 1000°C.

Table 3. Chemical analysis for interstitial elements in iron aluminides

Alloy number	Nominal composition [wt % (~at. %)]				Chemical analysis (wt ppm)			
	Fe	Al	Ti	B	C	O	H	N
FA-36	86.33 (76)	13.17 (24)	0.38	0.12	50	<1	<1	21
FA-38	85.07 (74)	14.43 (26)	0.38	0.12	46	<1	<1	17
FA-37	83.77 (72)	15.73 (28)	0.38	0.12	56	<1	<1	7

Oxidation Studies

Oxidation studies were performed on rectangular samples measuring approximately 10 by 15 mm, cut from the 0.76-mm-thick rolled sheet. The samples were prepared for testing by mechanically polishing with 4-0 emery paper, followed by annealing in vacuum for 1 h at 800°C. Air-oxidation tests were then performed at 600, 800, and 1000°C, each test totaling about 500 h in duration. Measurements of the weight gain as a function of time indicated the degree of oxidation.

Sulfidation Studies

Samples of alloys containing 24 to 27 at. % Al were cut from the rolled sheet in 1- by 1-cm squares for sulfidation studies. Surfaces were sanded with 4-0 emery paper, cleaned, then annealed for 1 h at 800°C in dry hydrogen. The cleaned samples were embedded in $CaSO_4$ powder, wrapped in platinum foil, sealed in evacuated capsules, and heated at 700°C for 168 h. Additional tests were done at 871°C to produce a higher sulfur gas pressure.

Welding Studies

Samples for preliminary welding studies were prepared by mechanically polishing as-rolled material as above, then heat treating in vacuum for 1 h at 800°C plus 7 d at 500°C. Autogeneous electron-beam welds were made on four alloys varying in aluminum content from 24 to 27 at. %. The welds were made with a 15-kW Leybold-Heraeus electron beam-welder. The welding speed ranged from 25 to 102 cm/min at a power level of 75 kV and 5 mA.

Microstructural Studies

Microstructural studies were performed on the samples after polishing with 0.5-μm diamond powder (Linde A), followed by a chemical etch with 50% CH_3COOH, 33% HNO_3, and 17% HCl.

Microprobe Studies

The TiB_2 precipitates, which were added for grain refinement and dispersion strengthening, were identified by using back-scattered electrons in a JEOL Superprobe. Both line scanning and element mapping were used to determine compositions of second-phase particles.

Fractography

The tensile fracture surfaces were examined by using secondary electrons in a Super III-A scanning electron microscope from International Scientific Instrument, Inc.

RESULTS AND DISCUSSION

MICROSTRUCTURAL STUDIES

Figure 3 shows the microstructures of the as-rolled and annealed alloy with a nominal composition of Fe-27 at. % Al. Such microstructures are typical of the alloys used in this study. The as-rolled structure shows elongated grains less than 50 μm wide. A few recrystallized grains were observed in the 25 and 27 at. % Al alloys after the last rolling at a temperature of 600°C, but only fibrous grains appeared in the other alloys. The recrystallized microstructures, studied after a standard anneal of 1 h at 850°C followed by 7 d at 500°C, showed that grain diameters for all alloys varied between 38 and 55 μm (see Table 1).

Second-phase particles, presumably titanium diborides,[1,2] were uniformly distributed over the grains and grain boundaries. Microprobe and scanning electron microscope studies indicated that the particles were no larger than 1 to 3 μm in diameter, although an in-depth study of the size and exact composition of the particles remains to be done.

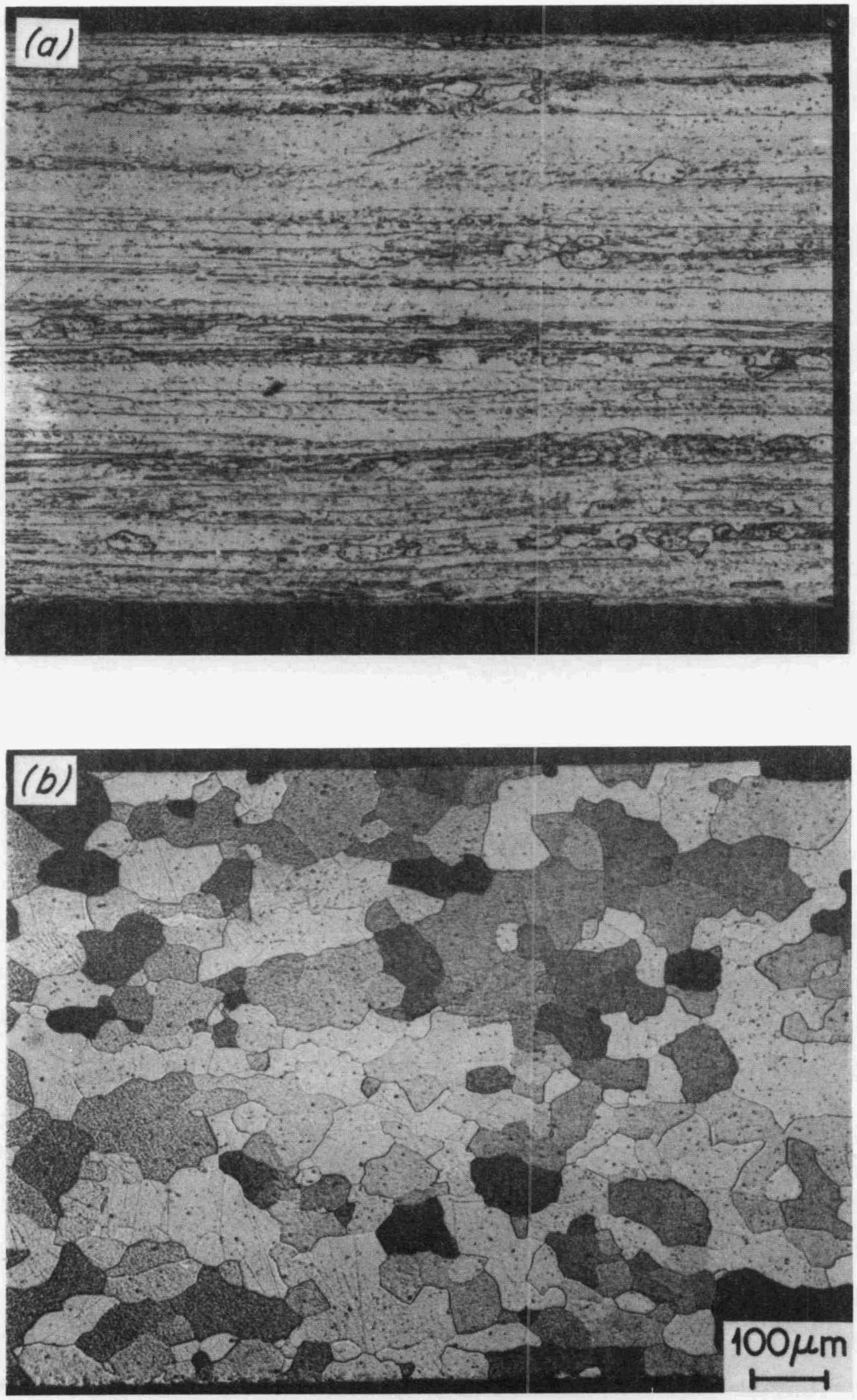

Fig. 3. Optical microstructures of FA-41 alloy (Fe–27 at. % Al + 0.5 wt % TiB_2). (*a*) As rolled. (*b*) After annealing 1 h at 850°C plus 7 d at 500°C.

The Fe–27 at. % Al alloy was studied to determine the recrystallization temperature (Fig. 4). By annealing for 30 min at various temperatures, it was determined that the alloy started to recrystallize at about 650°C, as shown in Fig. 4(*b*). After 30 min at 700°C the alloy is totally recrystallized with a grain diameter of approximately 42 μm. Grain size increased very little with increasing temperature above 700°C, remaining at 40 to 50 μm in diameter to 1000°C. These observations indicate that the TiB_2 precipitates are effective in retarding grain growth in these alloys.

TENSILE PROPERTY STUDIES

Figure 5 shows the tensile properties of iron aluminide as functions of aluminum concentration and test temperature. At room temperature the 0.2% yield stress was highest for the 24 to 26 at. % Al alloys (~750 MPa) and then decreased rapidly to about 350 MPa for the 30 at. % Al alloy. The same trend was seen for samples annealed at 200 and 400°C, although stress levels were lower. The substantial decrease in yield stress with aluminum content from 24 to 27% is possibly related to a change in dislocation structure from unit dislocations to superlattice dislocations; however, detailed transmission electron microscope studies are needed to verify the dislocation structures in these alloys. At test temperatures of 600, 700, and 800°C, the opposite trend was seen: the lower aluminum content alloys exhibited a slightly lower yield strength, e.g., 43 MPa for Fe–25 at. % Al at 800°C compared with 88 MPa for Fe–30 at. % Al. The ultimate tensile strength (UTS) showed similar trends.

The ductility of iron aluminide also depends on aluminum content and test temperature. The 24 at. % Al alloy exhibited a tensile elongation of about 1% at room temperature. The room-temperature elongation increased steadily with increasing aluminum content and reached about 5% for the 30 at. % Al alloy. For samples annealed at 200 and 400°C, the ductility increased with aluminum addition up to 26 to 28 at. %. Further increase in aluminum to 30 at. % caused no significant improvement. Ductility increased sharply above 400°C; the elongation increased to over 50% at temperatures at and above 600°C. Because of the excellent hot ductilities, there is no difficulty in fabricating iron aluminide above 600°C.

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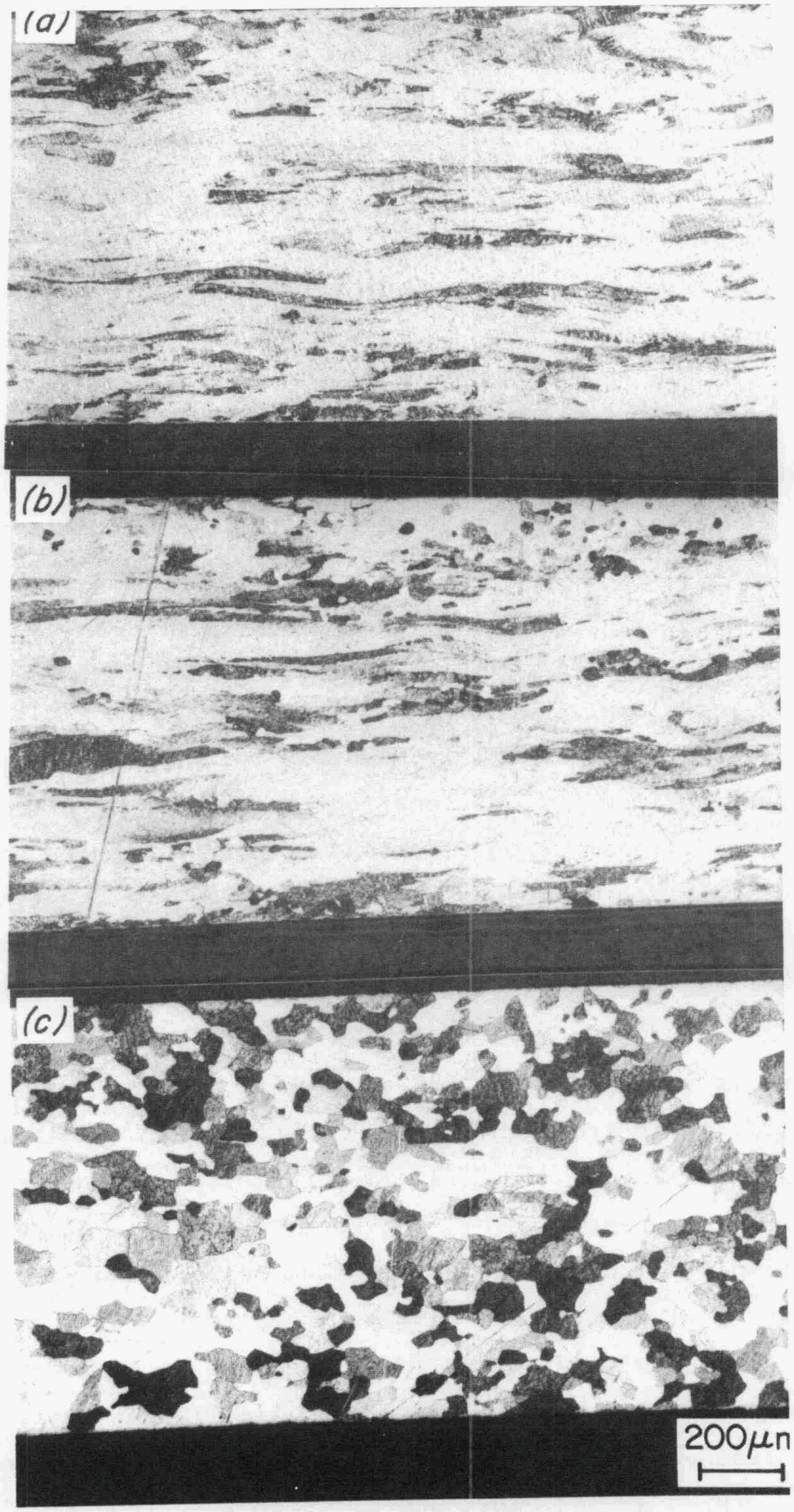
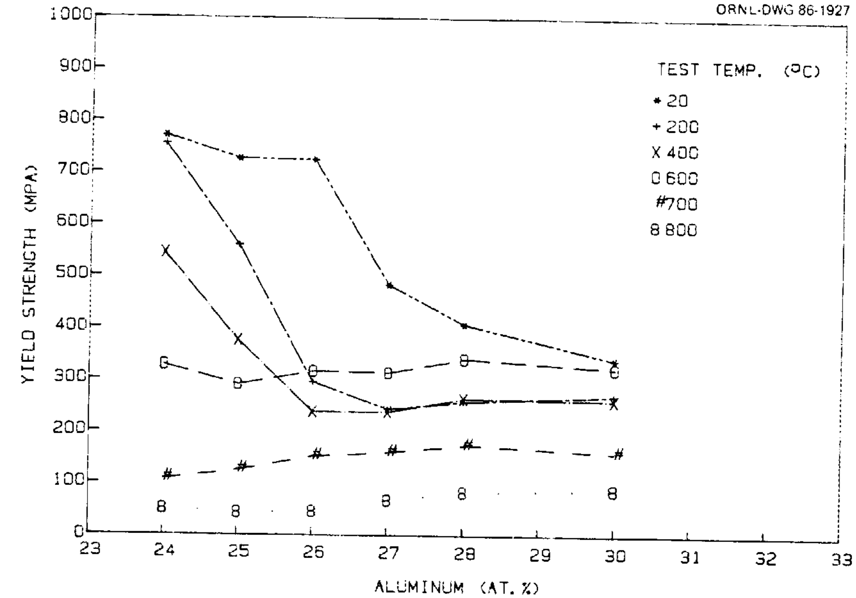
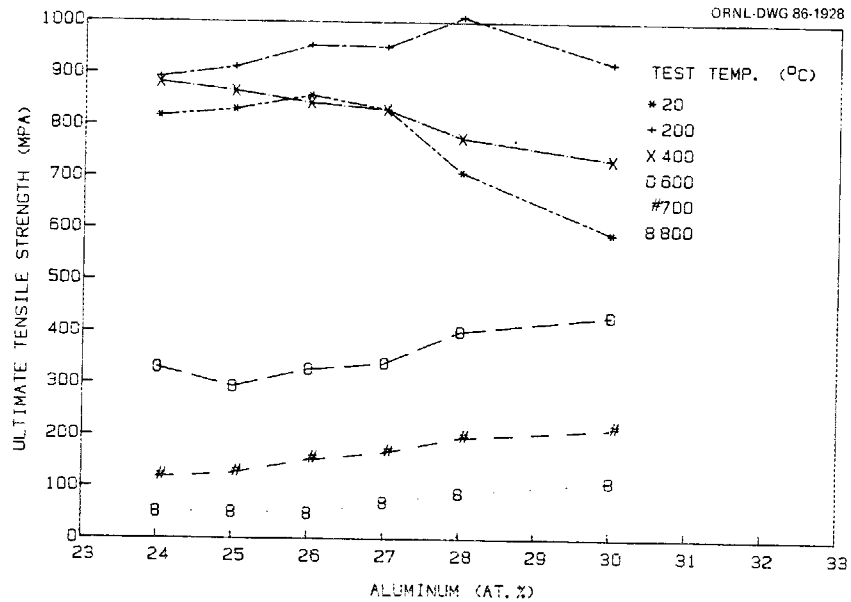


Fig. 4. Optical microstructures of FA-41 alloy (Fe–27 at. % Al + 0.5 wt % TiB_2). (*a*) Annealed 30 min at 600°C. (*b*) Annealed 30 min at 650°C. (*c*) Annealed 30 min at 700°C.





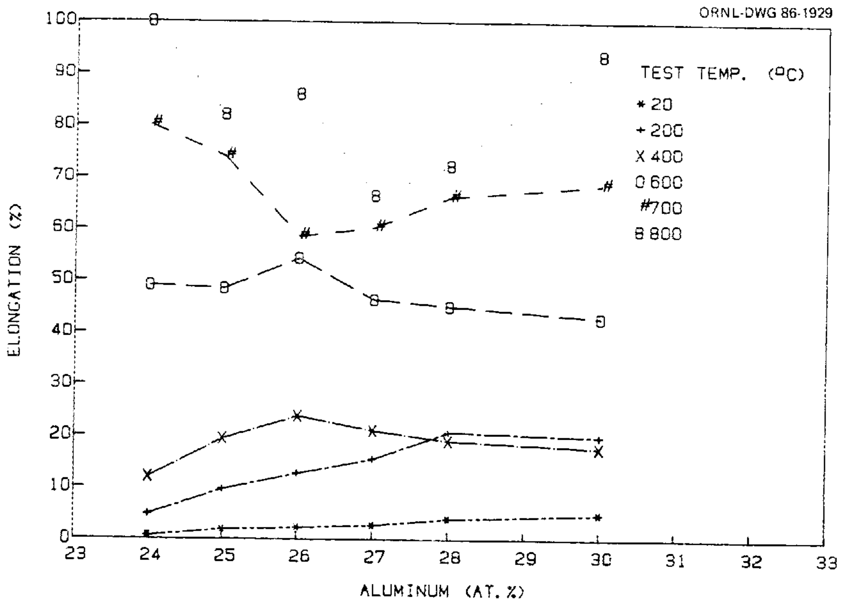


Fig. 5. Tensile properties of iron aluminides as functions of aluminum concentration.

The alloys with higher aluminum content (27, 28, and 30 at. % Al) were further tested by annealing the as-rolled alloys for 30 min at various temperatures between 500 and 1000°C and then tensile testing at room temperature. The results are presented in Fig. 6. The yield stress decreased continuously with increased annealing temperature until about 700°C. From 700 to 1000°C the strength of each alloy in this series remained constant, with Fe-27 at. % Al exhibiting the highest strength (477 MPa) and Fe-30 at. % Al the lowest strength (416 MPa). The trend in room-temperature ductility was for the higher-aluminum alloys (28 and 30 at. % Al) to exhibit the higher elongations. Maximum room-temperature elongations of 7 to 9% were reached for the Fe-30 at. % Al alloy at temperatures of 625 to 700°C.

The tensile properties of Fe-28 and 30 at. % Al alloys as a function of test temperature are compared with the properties of type 316 stainless steel and modified 9Cr-1Mo steel in Fig. 7. It can be seen that the yield strength of the iron aluminides is better than that of type 316 stainless steel up to 760°C and better than that of modified 9Cr-1Mo steel above 550°C. However, the ductility at temperatures below 400°C needs to be improved.

FRACTOGRAPHY

Scanning electron microscopy was used to examine the fracture surfaces of samples that had been tested at room temperature. A previous study showed that the fracture mode in the as-rolled material is mainly transgranular while the annealed samples fail intergranularly.[2] Those results were substantiated by results of the present study. Tensile samples that had been heat treated before testing (1 h at 850°C plus 7 d at 500°C) exhibited a fracture mode typical of mainly intergranular failure [Fig. 8(*a*)], with approximately 10 to 20% transgranular character. At higher magnification, [Fig. 8(*b*)], cracking along grain boundaries is apparent, and TiB_2 particles can be seen on the grain surfaces, as well as the few transgranular fracture regions.

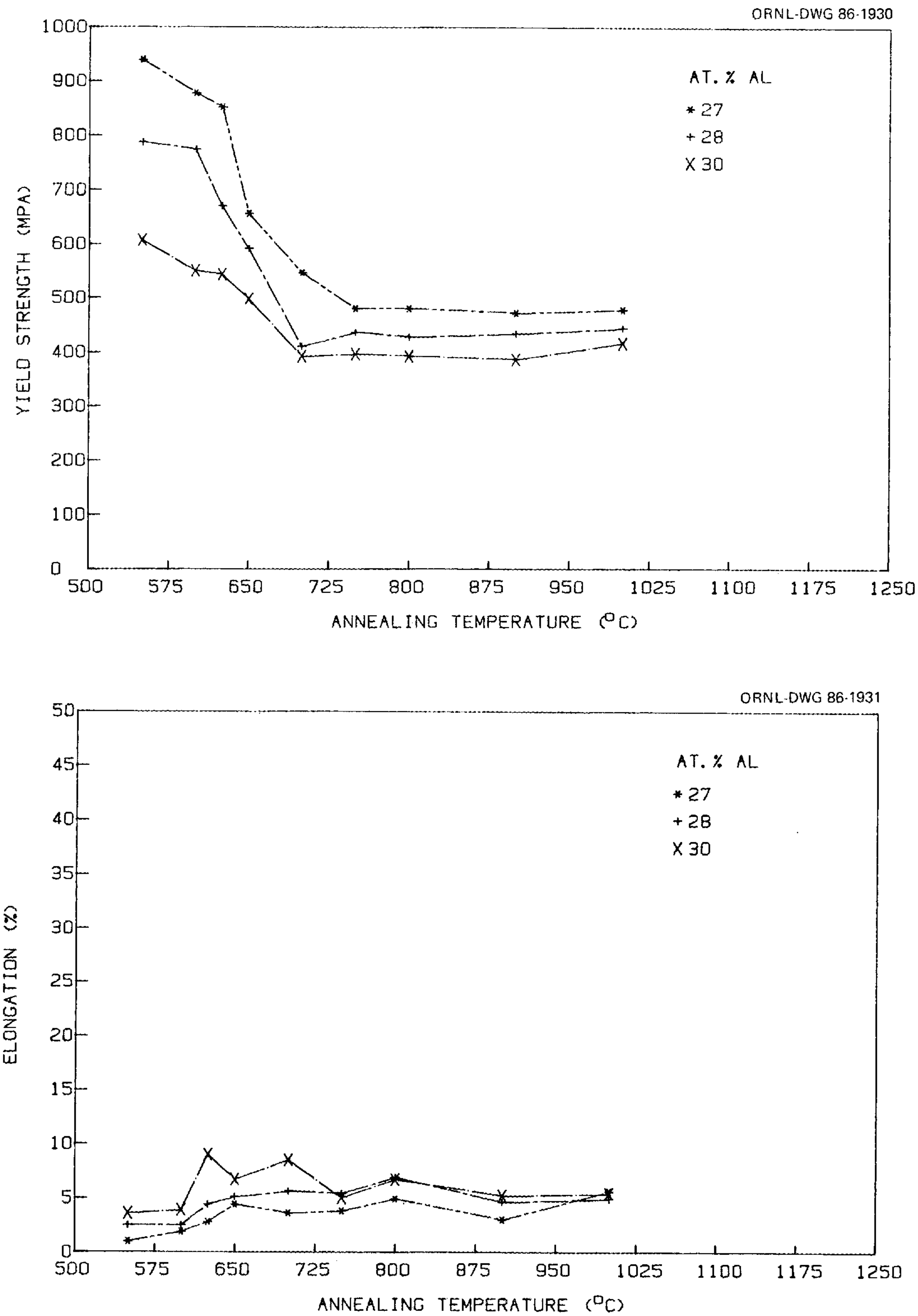


Fig. 6. Effect of 30-min anneals at various temperatures on tensile properties of iron aluminides.

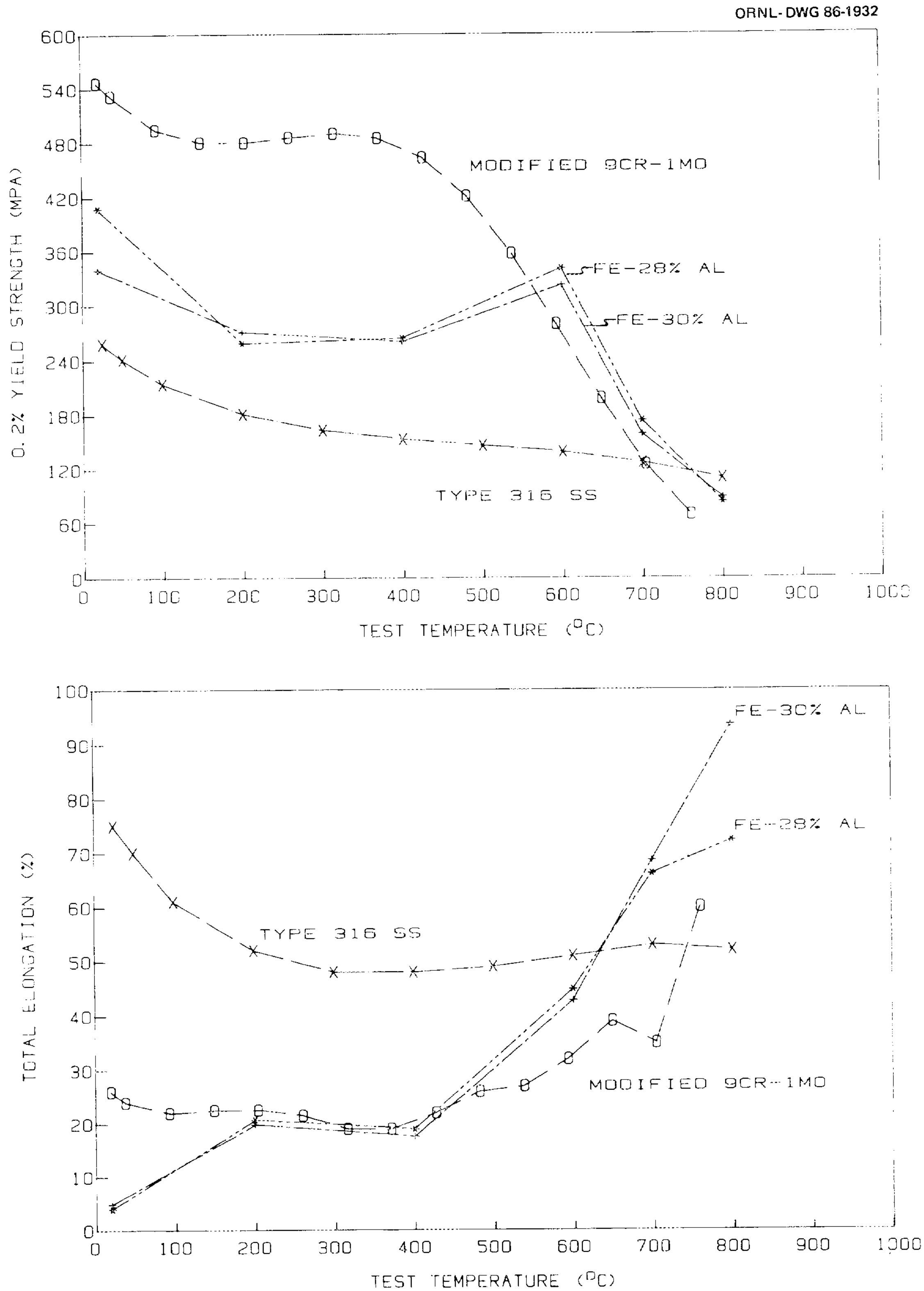


Fig. 7. Effect of test temperature on tensile properties of Fe-28 and 30 at. % Al, and comparison of tensile properties with those of type 316 stainless steel and modified 9Cr-1Mo steel.

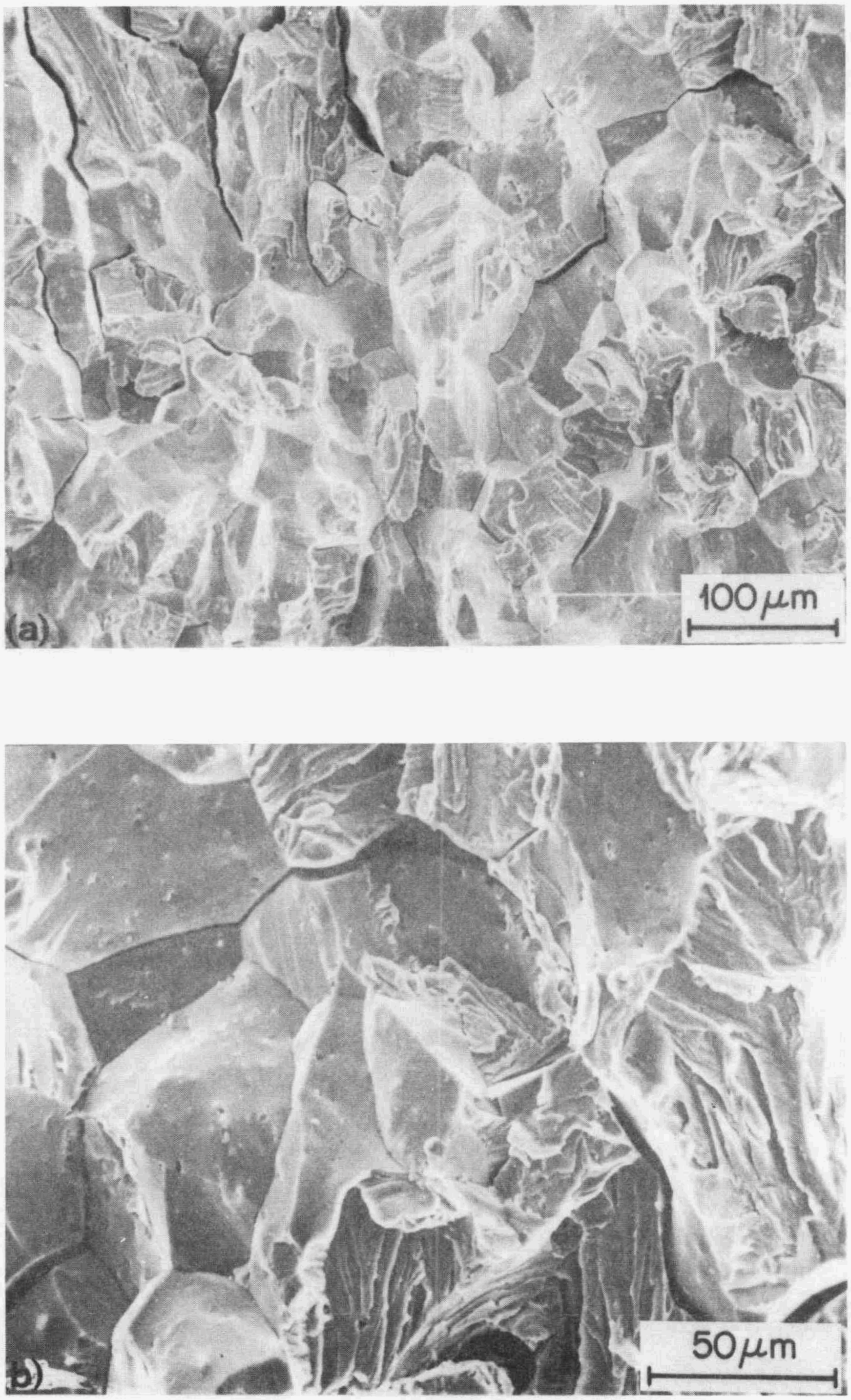


Fig. 8. Fractographs of FA-39 alloy (Fe–30 at. % Al + 0.5 wt % TiB_2) after annealing 1 h at 850°C plus 7 d at 500°C and tensile testing at room temperature.

OXIDATION STUDIES

Oxidation studies were conducted on the Fe–24, 25, 26, 27, and 30 at. % Al alloys at 600, 800, and 1000°C, each test lasting approximately 500 h. At 600°C, weight gains of less than 0.3×10^{-4} g/cm^2 were recorded for all alloys tested, and oxide films with colors in the interference range were observed. The results at 800°C are presented in Fig. 9 for the Fe–24, 27, and 30 at. % Al alloys, along with the data for type 316 stainless steel at this temperature. After approximately 500 h at this temperature, all iron aluminide alloys had a dull bluish gray color, with no apparent spalling, and weight gains of less than 5×10^{-4} g/cm^2. The type 316 stainless steel, on the other hand, gained about 12×10^{-4} g/cm^2 at 120 h, when it began to spall. Results of the tests at 1000°C are shown in Table 4. Weight gains for the iron aluminides remained low

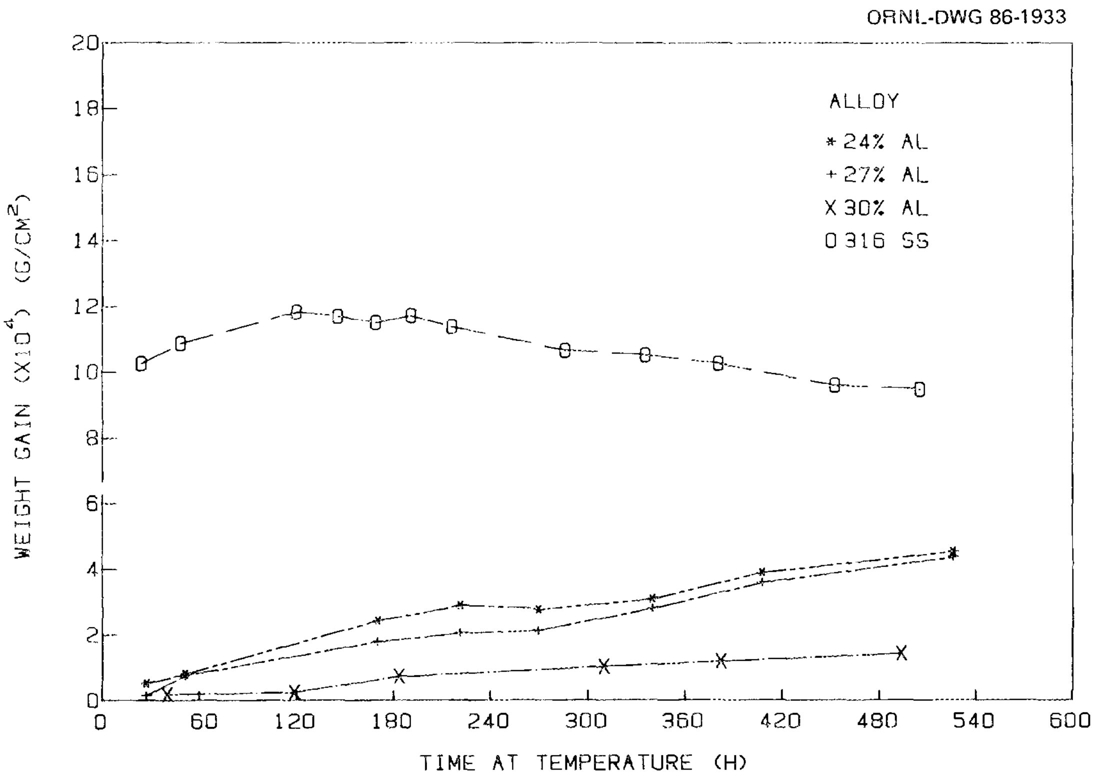


Fig. 9. Oxidation resistance of iron aluminides and of type 316 stainless steel at 800°C.

Table 4. Oxidation resistance of iron aluminides at 1000°C

Alloy	Composition (at. % Al)	Weight change after 526-h exposure (g/cm^2)
FA-36	24	4.49×10^{-4}
FA-40	25	5.40×10^{-4}
FA-38	26	4.48×10^{-4}
FA-41	27	5.38×10^{-4}
FA-39	30	4.74×10^{-4}
316 SS		-1516.78×10^{-4} [a]

[a] Weight loss due to spalling.

($<6 \times 10^{-4}$ g/cm^2) at this temperature, while the type 316 stainless steel had begun to spall badly. The ability of the iron aluminides to form a protective oxide film is quite evident in these studies.

SULFIDATION STUDIES

Four Fe-Al alloys containing 24, 25, 26, and 27 at. % Al were subjected to the gaseous decomposition products of $CaSO_4$ in an evacuated, sealed quartz capsule for 168 h. Tests were conducted at 700 and 871°C. Weight gains for the specimens after testing are listed in Table 5. Attack at 700°C was minimal, the oxide scale on all the alloys being in the interference color range. At 871°C all alloys were covered with a uniform coating of oxide, and the weight gains, which were small, did not vary significantly from one alloy to the next. These results clearly indicate that the iron aluminides containing 24 to 27% Al are very resistant to sulfur-bearing environments. Nickel aluminides based on Ni_3Al, on the other hand, were attacked heavily in similar capsule tests at 871°C.[5]

Table 5. Corrosion of iron aluminides in capsule test[a]

Alloy	Composition (at. % Al)	Weight gain (mg/cm^2)	Remarks
		700°C	
FA-36	24	0.05	All alloys showed interference colors.
FA-40	25	0.03	
FA-38	26	0.02	
FA-41	27	0.04	
		871°C	
FA-36	24	0.24	All alloys were covered with a dull gray coating.
FA-40	25	0.27	
FA-38	26	0.22	
FA-41	27	0.25	

[a]Exposure for 168 h in a sealed, evacuated quartz capsule to the gaseous decomposition products of $CaSO_4$. Samples were not pre-oxidized.

WELDABILITY

Preliminary weldability results from electron-beam welding and microstructural analysis performed on Fe–24 to 27 at. % Al alloys indicated that the alloy with highest aluminum content (Fe–27 at. % Al) had the best weldability, with no cracks (Fig. 10). The welds of other alloys showed transverse or crater cracks and sometimes both. The results are summarized in Table 6.

Table 6. Electron-beam weldability of iron aluminides

Alloy	Composition (at. % Al)	Weldability
FA-36	24	Transverse cracks
FA-40	25	Transverse and crater cracks
FA-38	26	Crater cracks
FA-41	27	No cracks

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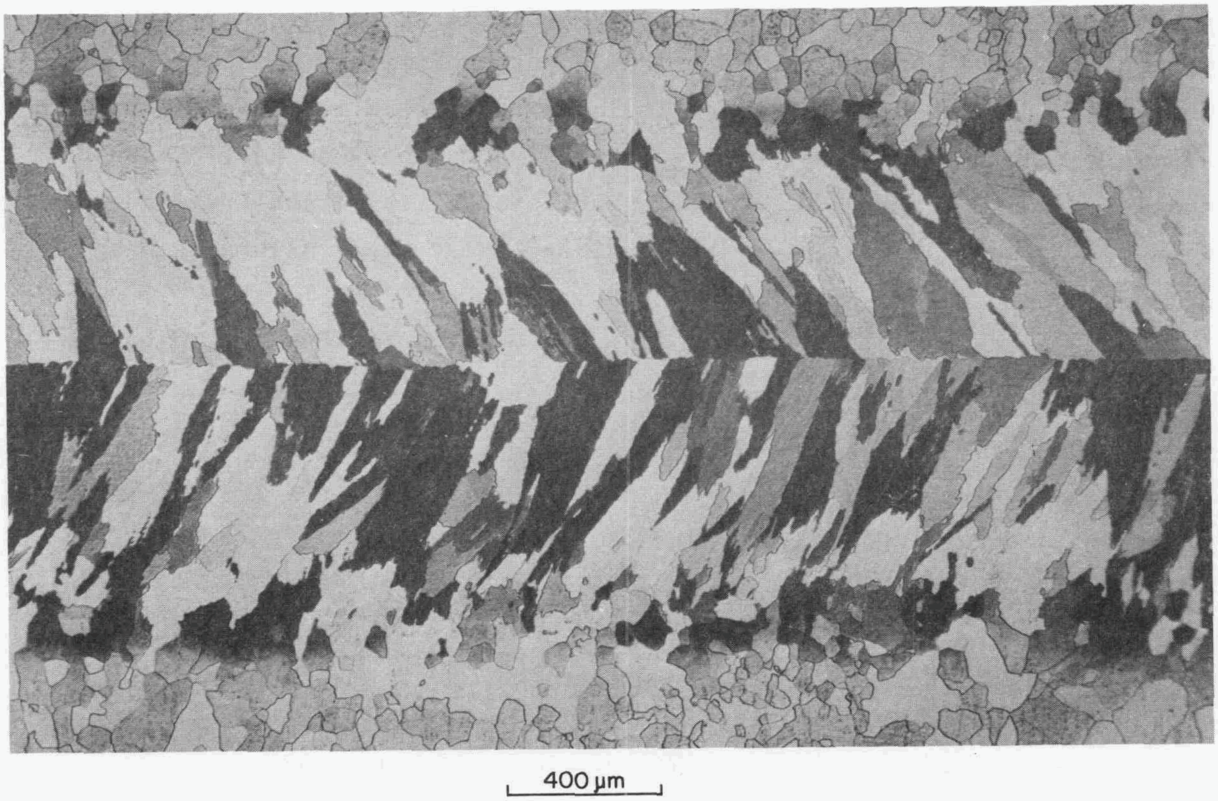

Fig. 10. Section of electron-beam weld in annealed Fe–27 at. % Al.

The top view of the Fe–27% Al weldment in Fig. 10 shows the epitaxial growth of grain structure in the fusion zone, starting from the HAZ. The elongated grains grow and impinge against each other along the fusion line. The HAZ is not well defined, indicating that the TiB_2 particles are effective in pinning grain boundaries even at temperatures to the melting point.

CONCLUSIONS AND FUTURE WORK

The present work indicates that alloys of Fe–24 to 30 at. % Al with small additions of TiB_2 are easily fabricated and exhibit excellent oxidation and corrosion properties. Resistance to oxidizing and sulfidizing environments is conferred on these alloys by a self-protecting oxide layer that forms at low oxygen pressures. The tensile strengths are higher than those for type 316 stainless steel at temperatures below

760°C and for modified 9Cr–1Mo steel at temperatures above 550°C. Of the Fe–Al alloys tested, the room-temperature ductility is slightly higher for those containing more than 27 at. % Al. Our preliminary weldability studies using electron-beam processes indicate that the alloys with higher aluminum content have fewer cracks in the fusion zone and HAZ. Based on considerations of strength, corrosion resistance, fabricability, and weldability, we have selected the Fe–28 and 30 at. % Al alloys as base alloy compositions for further alloy development.

Planned future work includes alloying with molybdenum, titanium, and zirconium to improve the high-temperature strength and room-temperature ductility. Preliminary studies involving molybdenum indicate that molybdenum-containing precipitates form in the matrix, causing a reduction in grain size. Grain diameters in cast ingots were substantially reduced (from 105 to 25 μm) by addition of only 2 at. % Mo. Tests to determine the solubility limit of molybdenum in Fe–28 at. % Al are in progress, along with the fabrication and preparation of specimens for mechanical testing. Future plans also involve further mechanical testing, including creep studies, and further corrosion, oxidation, and welding studies. Electron microscopy studies well be conducted to determine precipitate composition and morphology. Studies of the dislocation structures, antiphase domain structures, and ordering processes and kinetics as a function of alloy additions will also begin.

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