

# MELTING, CASTING, AND PROCESSING OF NICKEL AND IRON ALUMINIDES

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## ABSTRACT

A process for successful melting of Ni<sub>3</sub>Al- and Fe<sub>3</sub>Al-base alloys is described. Casting and welding of these alloys are also briefly described.

## INTRODUCTION

The nickel- and iron-aluminide alloys are an important class of materials because of their unique resistance to oxidizing, carburizing, and sulfidizing environments at high temperatures. They also provide an interesting combination of high-temperature strength and wear resistance. Many applications have been identified for these materials including: furnace fixtures, heating elements, pumps, hydroturbines, and forging and extrusion dies. Because of the large aluminum content of the aluminides, most conventional material vendors are reluctant to melt large-size heats of these materials. The purpose of this paper is to describe a newly developed furnace-loading scheme that permits commercial melting of nickel and iron aluminides. Along with melting, the paper also provides data regarding the casting and processing of Ni<sub>3</sub>Al- and Fe<sub>3</sub>Al-base materials. Examples of commercial successes with component manufacturing of nickel and iron aluminides are also discussed.

## MELTING AND CASTING OF Ni<sub>3</sub>Al- AND Fe<sub>3</sub>Al-BASE ALLOYS

Reluctance on the part of vendors in melting nickel and iron aluminides stems from two factors: (1) for most alloys, the aluminum addition is made to a melt for its deoxidation; thus, using higher aluminum such as that present in the aluminides will result in a large amount of oxide inclusions in the melt from the oxidation process; and (2) if the aluminum is added to the furnace at the beginning of the melt, its significantly lower melting point (than nickel or iron) will cause the aluminum to seep into any cracks in the crucible. If this occurs, the seepage could potentially reach the induction coils and damage them. However, our research in the melting of over 100 heats of nickel and iron aluminides of compositions shown in Table I has indicated that both of the vendors' concerns can be eliminated by understanding how melting of these aluminides occurs by implementing the furnace-loading scheme proposed in this paper.

It is well known [1] that the reaction of aluminum with elements such as Cu, Fe, Co, and Ni is exothermic. The extent of the exotherm depends on the alloying element and the amount of aluminum addition (see Figure 1). Proper use of the exotherm is made in the melting of nickel and iron aluminides by using the furnace-loading scheme shown in Figure 2. The total nickel or iron content of the selected aluminide (see Table I) is divided into two halves. The portion on top is the nickel-to-aluminum or iron-to-aluminum ratio that will yield the maximum exotherm. This is determined from the data in Figure 1. The remaining amounts of nickel or iron are loaded at the furnace bottom, and the alloying elements are loaded between the top and bottom layers. With the furnace-loading scheme in Figure 2, the melting process occurs as follows:

When the power to the furnace is turned on, the entire furnace load starts to heat up. When the temperature reaches 660°C, the aluminum melts and reacts with the nickel or iron setting next to it at the crucible top. The reaction being exothermic causes the formation of NiAl liquid at a temperature ≥ 1640°C and FeAl<sub>3</sub> liquid at a temperature ≥ 1400°C. These high-temperature liquids start running to the crucible bottom and, in the process, dissolve the alloying elements. The heat of the liquids is transferred to the nickel or iron at the furnace bottom, which

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Table I. Ni<sub>3</sub>Al- and Fe<sub>3</sub>Al-base alloy compositions selected for commercial applications

Element	Alloy (at. %)							
	IC-50 <sup>a</sup>	IC-218LZr <sup>b</sup>	IC-396M <sup>c</sup>	IC-221M <sup>d</sup>	FAS <sup>e</sup>	FAL <sup>f</sup>	FA-129 <sup>g</sup>	FAPY <sup>h</sup>
Al	21.73	17.01	15.94	15.93	28.08	28.03	28.08	16.12
Cr	--	8.22	8.00	7.96	2.02	5.03	5.04	5.44
Mo	--	--	1.70	0.80	--	--	--	1.07
Zr	0.34	0.12	0.50	1.00	--	0.08	--	0.11
B	0.01	0.01	0.025	0.04	0.04	0.04	--	--
Ni	77.92	74.64	73.84	74.27	--	--	--	--
Nb	--	--	--	--	--	--	0.51	--
C	--	--	--	--	--	--	0.20	0.13
Y	--	--	--	--	--	--	--	0.06
Fe	--	--	--	--	69.86	66.81	66.17	77.07

<sup>a</sup>Cold workable.

<sup>b</sup>Hot and cold workable.

<sup>c</sup>Castable alloy for static applications (some microporosity).

<sup>d</sup>Castable alloy for dynamic applications (no harmful microporosity).

<sup>e</sup>Sulfidation-resistant alloy.

<sup>f</sup>High room-temperature (RT) tensile ductility.

<sup>g</sup>High-temperature strength with good RT ductility.

<sup>h</sup>Very high RT ductility and high-temperature oxidation resistance.

will be as close to the melting point of aluminum (approximately 660°C). Within a very short time, the average temperature of the melt increases and probably reaches close to the melting point of Ni<sub>3</sub>Al or Fe<sub>3</sub>Al-base alloy. With a slight increase in the furnace power, the melt temperature is brought to the desired level for pouring into ingots or shaped molds.

The proposed melting process provides the following advantages:

1. Significant energy savings by using the exotherm to advantage in the melting process,
2. Reduced melting time from efficient use of the reaction exotherm,
3. Minimize oxidation of alloying elements by reducing time at temperature,
4. Allow ease of vacuum melting because all alloying elements can be loaded at the start,
5. Refractory or crucible life is increased because time at temperature is minimized, and
6. Eliminates vendors' concerns in melting nickel and iron aluminides.

The proposed furnace-loading sequence in Figure 2 has been successfully used for melting 2500-kg heats at Sandusky International (Sandusky, Ohio) and smaller size heats at three other casting foundries.

The Ni<sub>3</sub>Al-base alloys IC-396M and IC-221M (see Table I) have been cast into shapes in sand, ceramic, and investment molds. The Ni<sub>3</sub>Al-base alloys have also been cast into thick-wall (≥ 25-mm) tubes and pipes by the centrifugal casting process. The thin-wall centrifugal casting of furnace radiant tubes is currently in progress. Most of the cast components of Ni<sub>3</sub>Al-base alloys are for furnace fixture applications. A sand-cast heat-treating tray is shown in Figure 3.

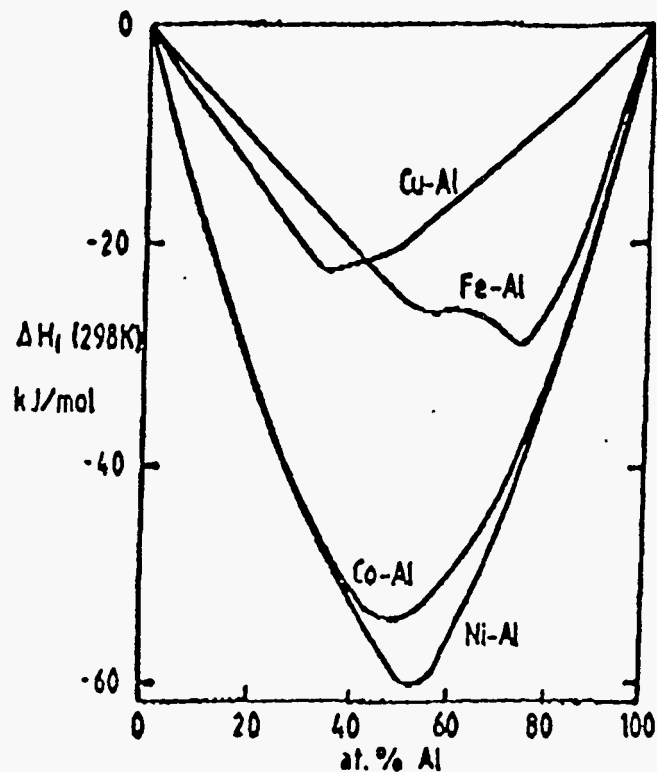


Figure 1. Extent of exothermic reaction in binary aluminum systems with transition metals: iron, cobalt, nickel, and copper [German (1)].

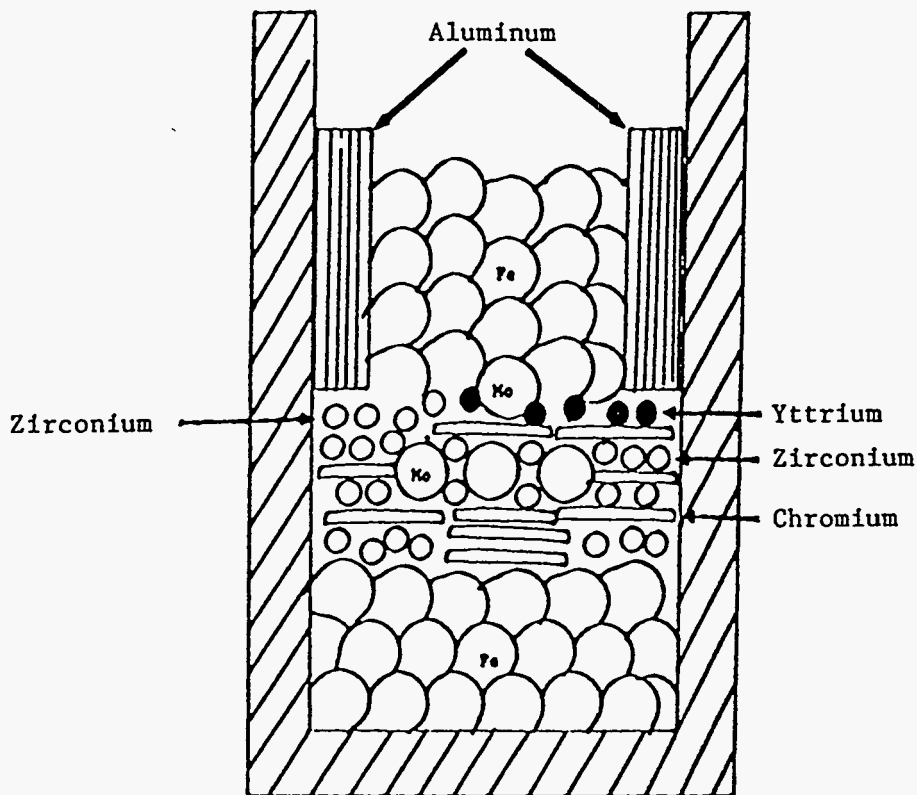


Figure 2. Furnace-loading sequence to take advantage of the exotherms in Figure 1 for melting nickel and iron aluminides. The loading for alloy FAPY is shown here.

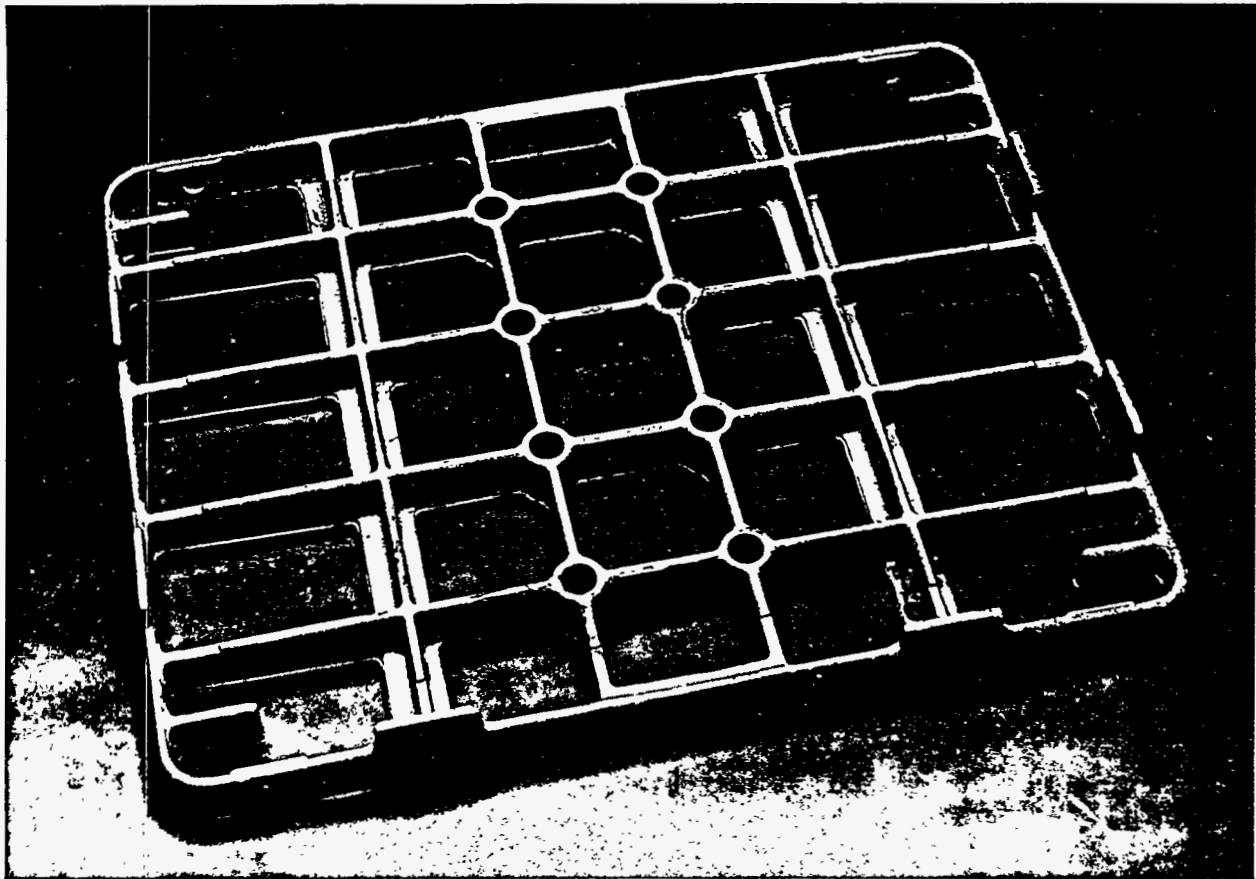


Figure 3. Sand-cast heat-treating tray produced from air-melted nickel-aluminide alloy IC-221M.

The iron-aluminide alloys are prone to gas porosity. The gas porosity results from the higher solubility of hydrogen gas that results from the reduction of any moisture that may be present in the charge by the aluminum content of the alloy. During solidification, the gas solubility decreases and its rejection from the melt causes porosity. The gas porosity in iron aluminides can be reduced by: (1) using dry charge, (2) melting in vacuum, and (3) blowing argon through the melt [2]. The iron-aluminide alloys have been cast into shapes in sand and ceramic molds. The 25-mm-thick wall tubes of iron aluminide have also been cast by the centrifugal process. A step-block cast in a ceramic mold and an investment-cast component for washing machine application produced from FAPY alloy are shown in Figure 4. The 12-, 25-, and 51-mm-thick cast slabs from a vacuum melt after gas tungsten arc welding of the same alloy are shown in Figure 5. The wire used for welding plates was of the same composition as the base metal.

## PROCESSING

The  $\text{Ni}_3\text{Al}$ -base alloys are ductile at both room and high temperature. However, their processing into products such as sheet, bar, and wire is still difficult. The processing response [3,4] is sensitive to alloy composition (IC-50 is cold workable, and IC-218LZr is cold and hot workable); grain size; thickness; processing temperature; processing strain rate; and homogenization. The cold-rolling response of IC-50 is strongly dependent on the starting cast thickness. Because of strain-rate sensitivity and low-intermediate-temperature (600 to 800°C) ductility, the hot processing of  $\text{Ni}_3\text{Al}$ -base alloy IC-218LZr requires a mild steel can or pack. More processing details of this alloy are available in ref. 4. The IC-396M and IC-221M alloys

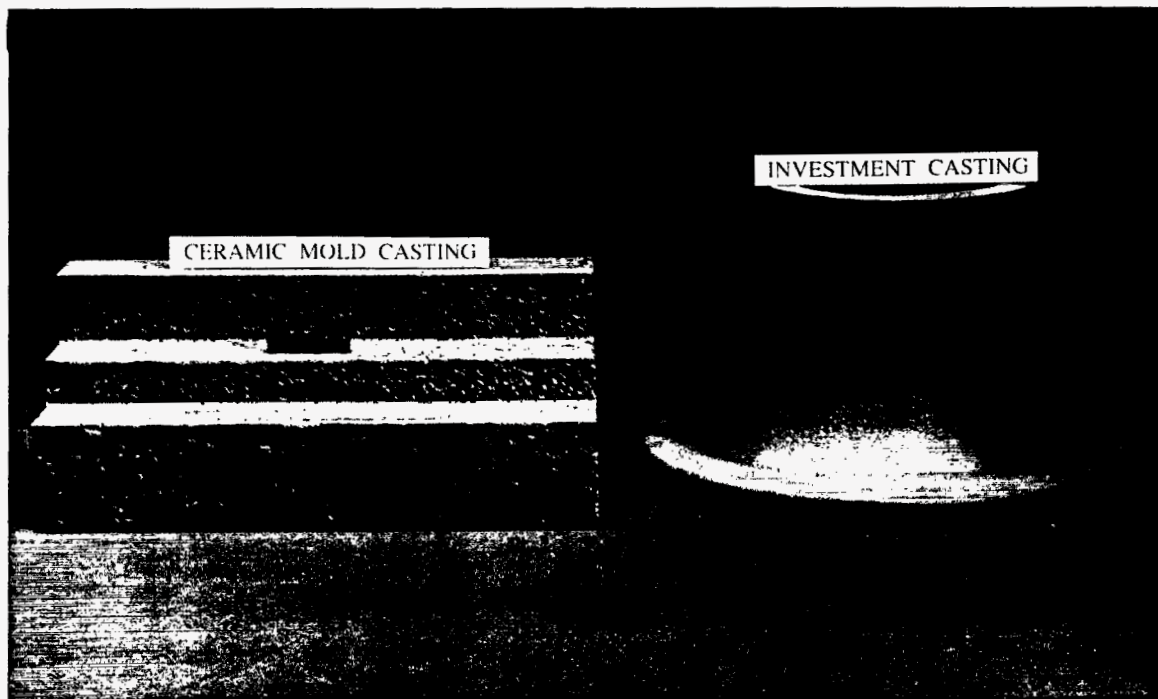


Figure 4. Step-block cast in a ceramic mold from air-melted Fe-16 at. % Al alloy FAPY.

are casting alloys and are not hot workable. However, they possess sufficient ductility at room temperature for fabrication processes such as bending, grinding, and machining.

The  $Fe_3Al$  and Fe-16 at. % Al alloys are very ductile at high temperatures ( $\geq 600^\circ C$ ), and therefore their ingots can be easily processed by extrusion, forging, or rolling. Typical temperatures vary from 900 to  $1200^\circ C$ . Once the cast structure is broken up, the  $Fe_3Al$ -base alloys can be produced in sheets by warm rolling at 500 to  $600^\circ C$ . The warm-rolled sheets can result in 15 to 20% elongations at room temperature. However, the ductility of  $Fe_3Al$ -base alloy is not sufficient for cold rolling or drawing processes. The Fe-16 at. % Al alloy FAPY in Table I can be cold rolled after initial breakdown of the cast structure. Even for Fe-16 at. % Al alloy, the vacuum-induction-melted (VIM) material is easy to work with at room temperature as opposed to air-induction-melted (AIM) material. This difference in the response of the VIM and AIM materials is associated with the effect of melting practice on the ductile-to-brittle transition temperature. Additional information on processing of Fe-16 at. % Al alloy in the VIM and AIM conditions is available in ref. 5.

## SUMMARY

1. A furnace-loading sequence which utilized the exotherm associated with the formation of  $NiAl$  and  $FeAl_3$  was used successfully for melting of  $Ni_3Al$ - and  $Fe_3Al$ -base alloys.
2. Casting methods possible for  $Ni_3Al$ - and  $Fe_3Al$ -base alloys are described with photographs shown of the components produced.
3. Processing possibilities of  $Ni_3Al$ - and  $Fe_3Al$ -base alloys are described briefly.

## References

1. R. M. German, in Thermal Analysis in Metallurgy, edited by R. D. Shull and A. Joshi (The Minerals, Metals and Materials Society, Warrendale, Pa., 1992) pp. 205-231 .

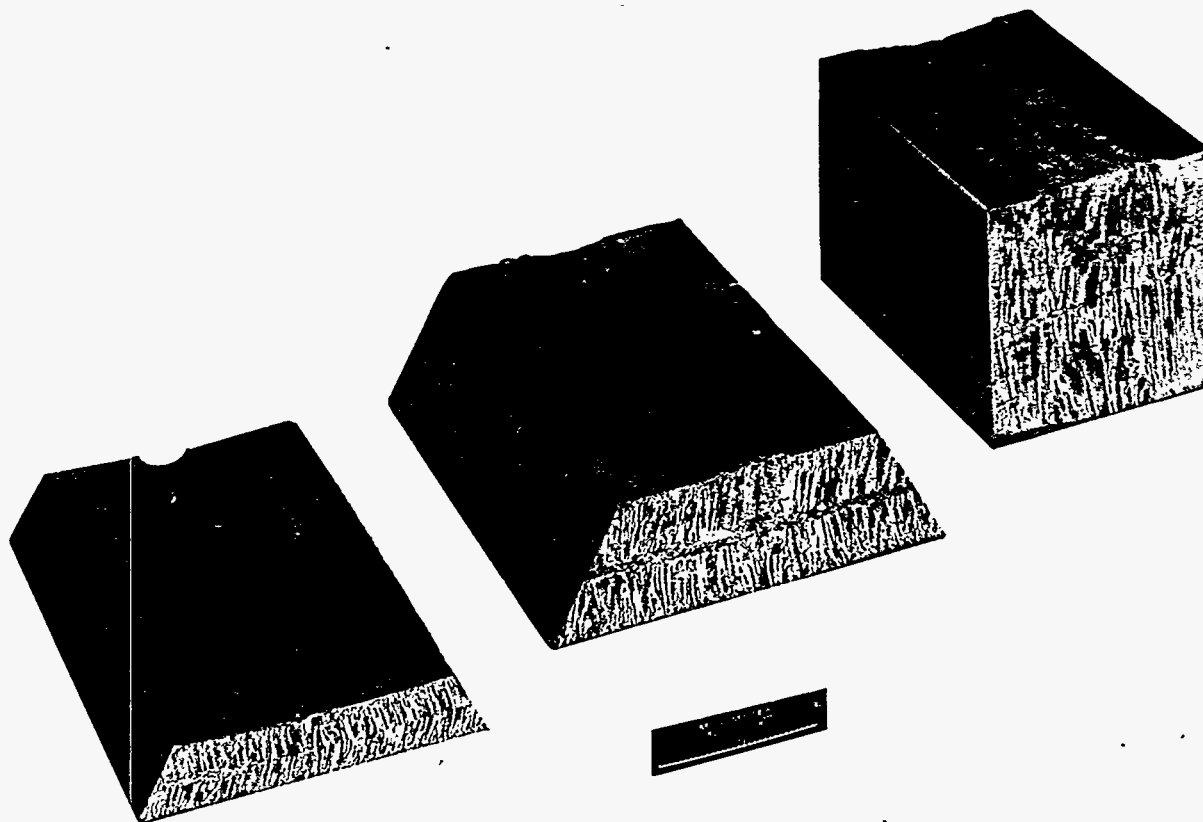


Figure 5. Gas tungsten arc welds in 12-, 25-, and 50-mm-thick cast plates of Fe-16 at. % Al alloy FAPY. The plates were cast in a graphite mold from vacuum-induction-melted material.

2. L. L. Rishel and H. D. Brody, in Heat-Resistant Materials, edited by K. Natesan and D. J. Tillack (ASM International, Materials Park, OH, 1991) pp. 149-157 .
3. V. K. Sikka, *Mater. Manufact. Processes* 4 (1), 1-24 (1989).
4. V. K. Sikka, J. T. Mavity, and K. Anderson, in High Temperature Aluminides and Intermetallics, edited by S. H. Whang, D. P. Pope, and C. T. Liu (Elsevier Science Publishers, New York, 1992) pp. 712-721.
5. V. K. Sikka and H. R. Shih, "Cold Rollability of a Ni<sub>3</sub>Al-Based Alloy," 1994 (to be published).

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