

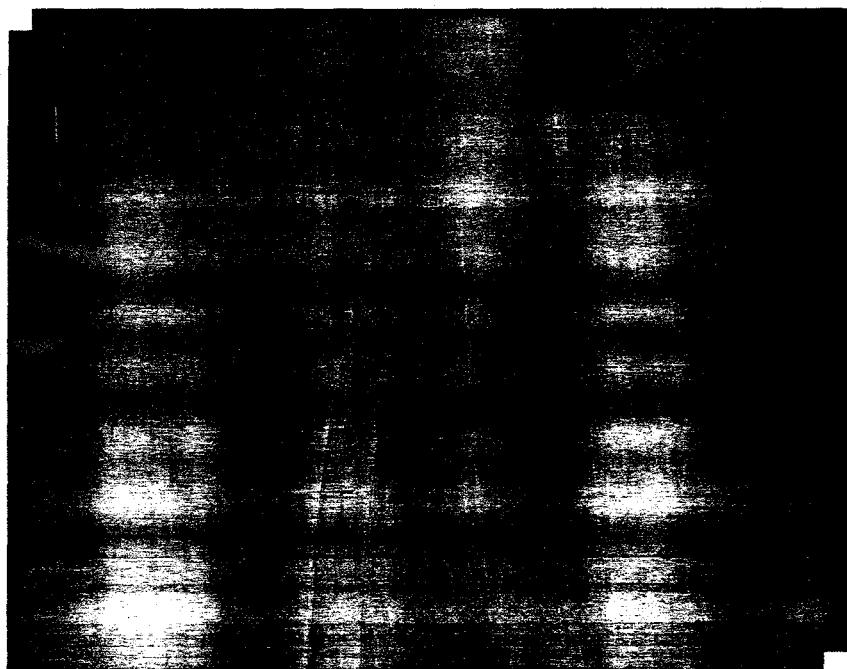
Heat Treating

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High Temperature Performance of Nickel Aluminide Castings for Furnace Fixtures and Components

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Abstract

Nickel aluminide intermetallic alloys, based on the Ni_3Al composition and structure, are a new class of materials for use in the heat treating industries. These alloys provide excellent strength at elevated temperatures combined with very good resistance to carburization (in reducing and oxidizing environments) and high temperature oxidation. The mechanical and physical properties of cast nickel aluminide alloys are presented and compared to other commercially available cast and wrought heat resistant alloys. The advances in the development of these alloys are also discussed.

Materials are often the key to technological advancement. To remain competitive and create new markets, modern heat treating industries must utilize these technological advances to increase production and process efficiencies. These challenges are frequently met by increasing process temperatures and minimizing down time for maintenance and unscheduled repairs. This requirement has frequently been a challenge in the past since an increase in the process temperature typically results in a decrease in the life of the furnace fixtures and components.

To overcome these technical obstacles, new alloys with higher levels of heat and corrosion resistance have been developed. Nickel aluminide intermetallics are formed by the reaction of two elements in proper ratios into compounds. The compounds have ordered structures which exhibit attractive elevated temperature properties due to their reduced dislocation mobility and slower dislocation processes. The lattice of the Ni_3Al intermetallic phase is a primitive cubic structure with the

aluminum atoms on the corner sites and the nickel atoms on the faces. The crystal structure is the ordered $\text{L}1_2$, Cu_3Au prototype.

The research activity in intermetallics accelerated in the early 1980s and has resulted in several symposiums and published proceedings.⁽¹⁻¹¹⁾ Based on literature data and extensive research and development at Oak Ridge National Laboratory, significant advances have been made in the development of nickel aluminide intermetallic alloys.

Compositions of Ni_3Al -based Alloys

Since gaining the knowledge that boron can ductilize polycrystalline Ni_3Al , three Ni_3Al -based compositions have been developed for structural applications. The minor addition of boron increases the grain boundary cohesive strength and changes the fracture mode from intergranular (brittle) to transgranular (ductile). The compositions of these alloys, along with Alloy 617, Alloy 800H, HU* and SuperthermTM* are included in Table 1 for comparison: Alloy 617 is a nickel-chromium-cobalt wrought alloy; Alloy 800H is a wrought iron-nickel-chromium alloy; HU is an iron-nickel-chromium heat resistant casting; and SuperthermTM is a cast nickel-chromium alloy stabilized with cobalt and tungsten. The unique variations of traditional foundry techniques used to cast the nickel aluminides have been discussed elsewhere.⁽¹²⁾

* HU is a heat resistant alloy casting per ASTM A297.

* SuperthermTM is a registered trademark of Abex Corporation.

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Table 1 - Compositions of Ni_3Al -based alloys and commercially available heat resistant alloys

Element	Weight Percent						
	IC-50	IC-218LZr	IC-221M	Alloy 617	Alloy 800H	Supertherm	HU
Al	11.3	8.7	8.0	1.2	0.4	--	--
Cr	--	8.1	7.7	22.0	21.0	26.0	18.0
Mo	--	--	1.43	9.0	--	--	0.50
Zr	0.6	0.2	1.7	--	--	--	--
B	0.02	0.02	0.008	--	--	--	--
C	--	--	--	0.10	0.05	0.5	0.55
Fe	--	--	--		bal.	bal.	bal.
Ti	--	--	--	--	0.4	--	--
Ni	bal.	bal.	bal.	bal.	32.5	35.0	39.0
Si	--	--	--	--	--	1.60	2.50
Co	--	--	--	12.5	--	15.0	--
W	--	--	--	--	--	5.0	--

Mechanical Properties of Ni_3Al -based Alloys

The selection of a particular nickel aluminide alloy depends on the service requirements. IC-50 is a castable and cold workable alloy. This is the basic Ni_3Al alloy with minor alloying additions of boron and zirconium to improve ductility. IC-218LZr is a hot workable composition where the chromium addition improves the high temperature ductility. IC-221M is a castable and weldable alloy suitable for dynamic applications. This is a most highly alloyed nickel aluminide. Chromium improves the high temperature ductility and inhibits internal oxidation. Zirconium reduces solidification shrinkage and increases high temperature strength. Molybdenum increases both the low and high temperature strength.

The cast alloys HU and Supertherm™ are commonly used materials for furnace applications requiring strength, creep resistance, and carburization resistance. The tensile properties of cast Ni_3Al -based alloy IC-221M are compared to HU and Supertherm™ in Figure 1a-c. It is clear from this figure that the IC-221M is nearly twice as strong as these alloys at room temperature. At 982 °C (1800 °F), the ultimate tensile strength of the nickel aluminide alloy is six times stronger than HU and three times stronger than Supertherm™. At this same temperature, the 0.2% yield strength 6 times that of the HU and four times that of the Supertherm™; however, at furnace operating temperatures, creep is the primary deformation mechanism and must be considered. The creep data for these three alloys are compared in Figure 2. For the data generated to date

on the nickel aluminides, the creep properties of Ni_3Al -based alloys are superior by a factor of two to five over HU and Supertherm™, depending on the temperature and alloy.

Corrosion Resistance of Ni_3Al -based Alloys

Since neither nickel or aluminum readily react with carbon, nickel aluminides are expected to be resistant to carburization. For a given application, the benefits of the elevated temperature mechanical properties of Ni_3Al -based alloys can be used as an advantage if their corrosion resistance is superior to the currently used alloys. Previously published data has been updated to include nickel aluminide alloys IC-218LZr and IC-221M. (13-14) The mass change for the nickel aluminides, Alloy 800 and Alloy 617 in $\text{H}_2 - 1\% \text{CH}_4$ at 1000 °C (1832 °F) are compared in Figure 3. As seen in this figure, the mass change resulting from carburization was significantly less for the nickel aluminide alloys. Neither NiO at the metal-oxide interface or internal oxidation were detected in the nickel aluminide after 36 days, indicating that the aluminum activity in the matrix did not fall below the critical value required for alumina formation. The Ni_3Al -based materials form a protective layer of α - Al_2O_3 on the surface and demonstrate significantly better oxidation resistance than the non-aluminum containing alloys. These carburizing environment results are consistent with previously published data for nickel aluminide alloys in both oxidizing and reducing carburizing atmospheres. (15) The oxidation resistance of these

alloys in air with 5% water vapor at 1100°C (2012°F) are compared in Figures 4. Results from 40 days exposure shows that the nickel aluminide alloys are very resistant to oxidation in air. The excellent oxidation resistance of the Ni₃Al-based alloys is very stable over longer test periods. The corrosion data from published literature are in good agreement and demonstrate that the nickel aluminide alloys are very resistant to carburization and oxidation.

Applications

The applications of Ni₃Al-based alloys take advantage of their inherent elevated temperature mechanical properties and excellent oxidation and carburization resistance. Based on the data presented in this paper and reports of industry tests, Ni₃Al-based alloys can provide significant improvements for the heat treating industries where the HU and other heat resistant alloys are currently being used. These applications include furnace fixtures, radiant burner tubes, and other furnace related hardware. The chemical and petrochemical processing industries also benefit from these performance advantages. For example, due to their carburization resistance and high temperature strength, Ni₃Al-based alloys are ideal candidates for ethylene crackers, steam reformers, and other high temperature catalytic units. The payoffs for these applications include: total reduced costs for replacement parts; decreased unscheduled down time and associated costs; and increased process efficiencies through higher operating temperatures.

Summary and Conclusions

The compositions, mechanical properties, and corrosion properties are described. Benefits and performance advantages of Ni₃Al-based alloys include:

- Ni₃Al-based alloys offer significantly higher tensile and creep properties than many other heat resistant alloys.
- Ni₃Al-based alloys are highly resistant in oxidizing and carburizing environments.

Nickel aluminide castings for use as furnace hardware are commercially available. The high temperature strength, creep resistance, thermal fatigue resistance, and carburization resistance of

these alloys provide performance advantages to the heat treating industries.

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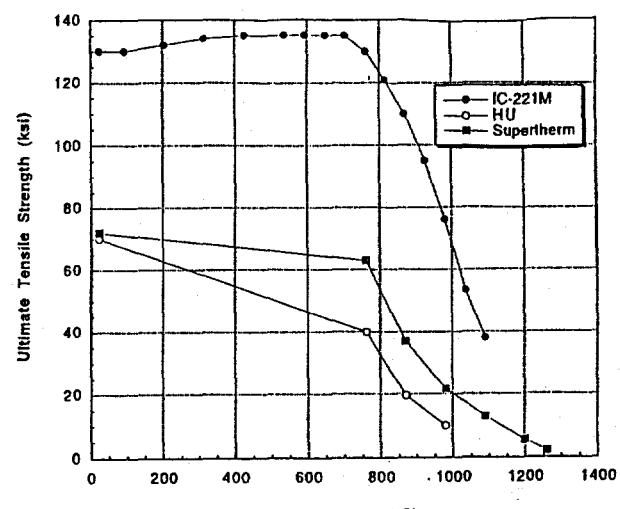
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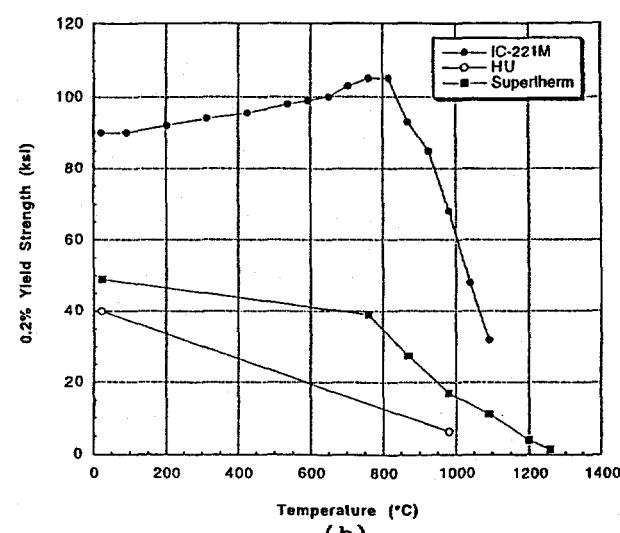
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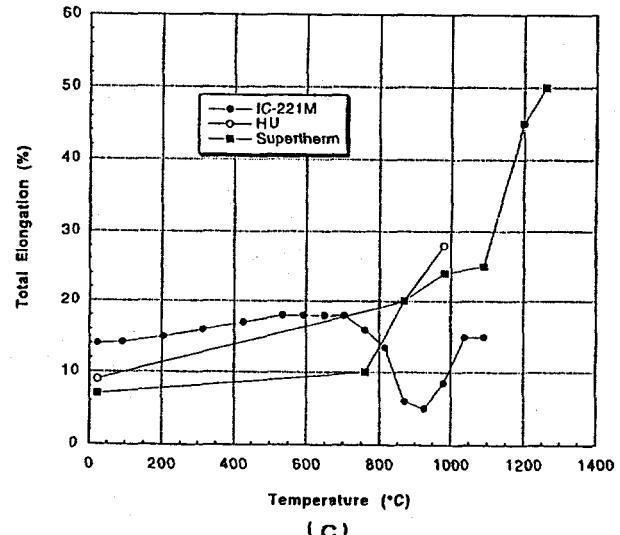
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(a)



(b)



(c)

Figure 1 - Comparison of tensile properties of cast heat resistant alloys:
a) ultimate tensile strength; b) 0.2% yield strength; and c) total elongation.

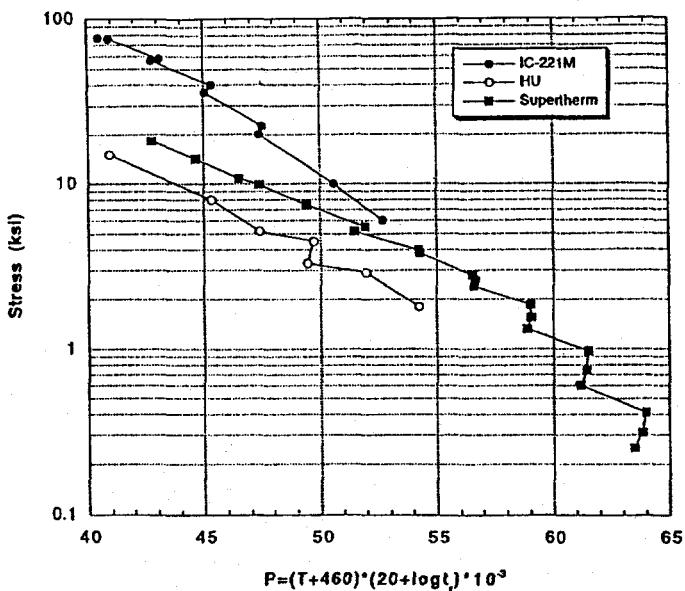


Figure 2 - Comparison of creep-rupture strength of nickel aluminide-based alloys with other commercially available cast heat resistant alloys.

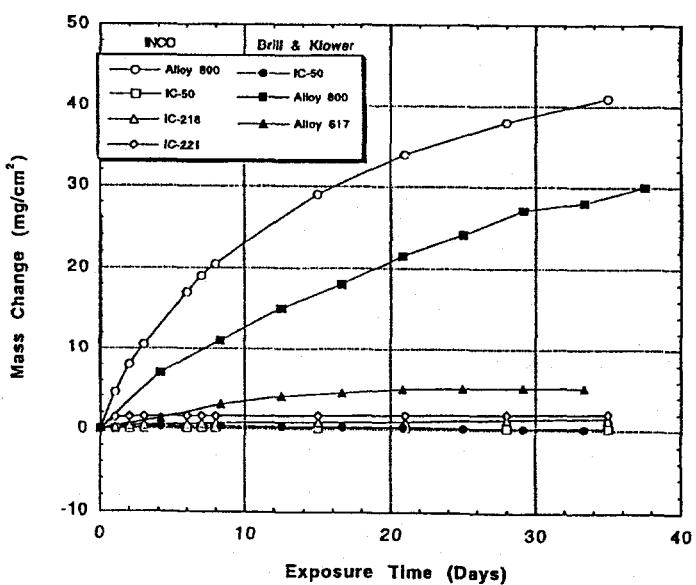
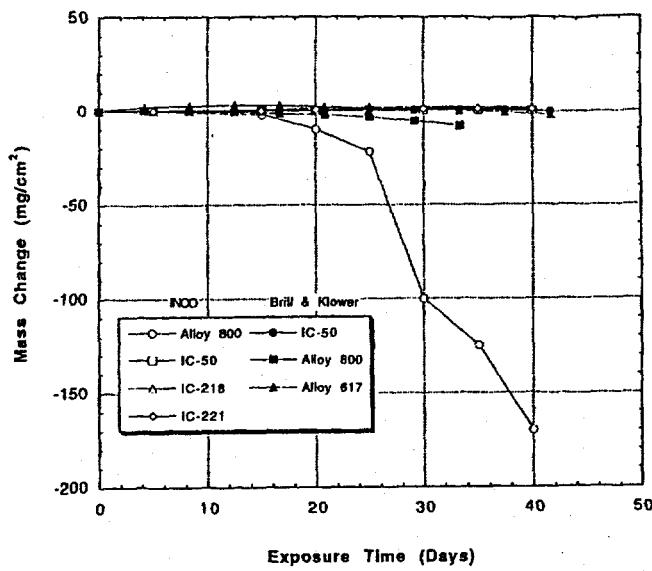
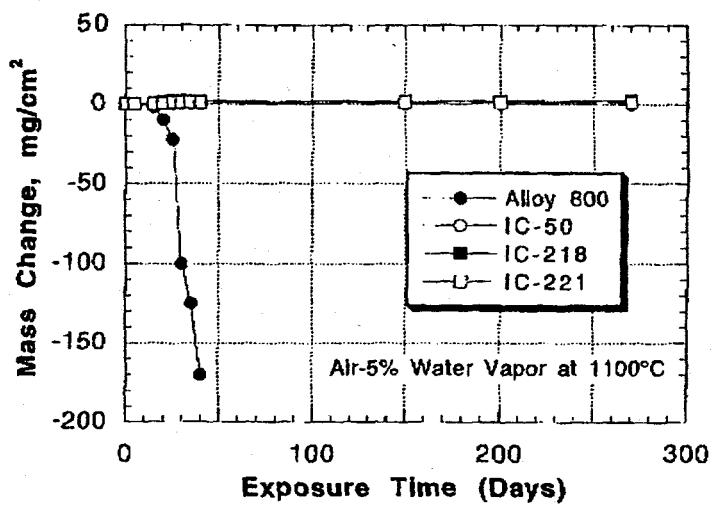


Figure 3 - Comparison of carburization resistance of nickel aluminide-based alloys with alloys 800 and 617.

Figure
with



(a)



(b)

Figure 4 - Comparison of oxidation resistance of nickel aluminide-based alloys with alloys 800 and 617: a) 40 days exposure; and b) 270 days exposure.