

August 2005

# Industrial Heating

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# Intermetallics Solve Manufacturing Challenges

Reported by Ed Kubel, Industrial Heating

Intermetallic compounds are a unique class of materials having characteristics of both metals and ceramics, with properties that can enable the development of new energy-efficient technologies and process systems.

Intermetallic materials have characteristics of metals and ceramics and contain both metallic and covalent bonds, depending on the constituent metals. Mixed bonding provides mechanical properties that are between metals (generally softer and more ductile) and ceramics (generally harder and more brittle).

Intermetallics are excellent candidates for use in high temperature component design due to their high-temperature strength and superior oxidation resistance, providing not only longer equipment service life, but also the potential to operate at above normal temperatures. Promising applications include heat treating fixtures, transfer rolls for hot metal processing, forging dies, radiant burner tubes, or pyrolyzer parts. The high-temperature strength and superior oxidation resistance of these materials would allow increases in operating temperature for many industrial processes, with resulting dramatic improvements in thermal energy efficiency and reduced residence time of chemical reactants at critical temperatures.

The Department of Energy (DOE) began funding the investigation of intermetallic materials at the Oak Ridge National Laboratory (ORNL) in 1981 [1] through the DOE Office of Energy Efficiency and Renewable Energy's Industrial Technologies Program (ITP). The 1990s saw ITP funding for nickel aluminide intermetallics R&D.

## Nickel aluminides

ORNL identified nickel aluminide ( $\text{Ni}_3\text{Al}$ ) as having unique high-temperature



Assembly of cast nickel-aluminide heat treating trays

strength and oxidation resistance. Its highly ordered crystal structure provides increased creep and yield strengths with peak yield strength approximately 30 to 40% higher at 1475 to 1650°F (800 to 900°C) than at room temperature.  $\text{Ni}_3\text{Al}$  alloys contain up to 12 wt% excess aluminum, leading to the formation of a protective aluminum oxide ( $\text{Al}_2\text{O}_3$ ) coating, which slows oxidation. This provides exceptional resistance to carburization and coking at high temperatures, making it ideal for use in heat treating furnaces, steelmaking and other manufacturing processes.

Despite these useful properties, the material's brittle texture has limited its usefulness in industrial applications, which require materials that can absorb and respond to sudden pressure changes and mechanical impact without catastrophic failures typical of ceramic or brittle materials. In addition, intermetallics are difficult to fabricate using traditional metal fabrication techniques,

particularly forming and welding. Further research was required to develop  $\text{Ni}_3\text{Al}$  alloys with reduced brittleness and an increased capability for shape casting, forming and welding into useful structures.

## Path to commercialization

The addition of boron and controlling the nickel-to-aluminum ratio led to the development of  $\text{Ni}_3\text{Al}$  alloys having ductility at room temperature. Further chemistry modifications improved intermediate-temperature ductility and high-temperature oxidation resulting in compositions that were potentially useful for industrial applications.

In the early 1990s, ORNL developed the Exo-Melt™ process, which could produce industrial quantities of intermetallic materials. The process uses a specialized furnace-loading arrangement to control the exothermic heat from the reaction of aluminum with nickel; it provides energy to the materials more rapidly while maintaining the ideal composition concentrations. The process reduces melting and holding times and minimizes silicon pick-up and other reactions with furnace refractories.

Other intermetallics including iron and titanium aluminides showed promise in a wide variety of industrial applications. Further research characterized the materials in greater detail, the results of which were used to predict and adjust alloy compositions for specific industrial applications and fabrication techniques including the casting, welding and coating/cladding of intermetallics having properties suitable for conventional code-approved structures.



Centrifugally cast nickel-aluminide furnace rolls with trunnions welded on for use in plate mill heat treating furnace

### Success stories

In 1992, cast Ni<sub>3</sub>Al heat-treating trays (upper fixtures, lower fixtures, and support posts) were produced for use in a specific industrial application [2]. Each tray assembly could carry 340 kg (750 lb) through a furnace. Over 65 fixtures were

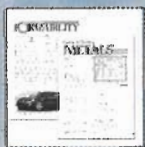
successfully fabricated and installed in 1995 in a continuous carburizing furnace at GM Delphi Saginaw Steering Systems. The Ni<sub>3</sub>Al furnace assemblies provided greater carburization and oxidation resistance, as well as higher elevated temperature strength and creep strength than steel

alloys. The trays lasted more than three times as long, reducing both scheduled and unscheduled down-time considerably. In addition, the lower mass of the assemblies reduced energy requirements for heat-treating by 11% and continue to save over 60-million Btus annually at the Saginaw plant. It is estimated that roughly 30-trillion Btus could be saved annually in the U.S. if such hardware was used across the entire heat treating industry.

The year 2000 saw the initiation of a Ni<sub>3</sub>Al application requiring both casting and welding of intermetallics to make large industrial furnace continuous caster rollers [4]. While traditional roller surfaces warp, crack and blister, Ni<sub>3</sub>Al rollers minimize off-spec product that results from roller surface defects and minimizes furnace maintenance. Techniques were developed to centrifugally cast large rolls (17 in. diam. by 160 in. long, or 432 by 4,064 mm) and to weld trunnions on both ends of the roll. The use of Ni<sub>3</sub>Al rolls resulted in increased roll service life, elimination of the water

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cooling requirement, decreased materials rejection rate, and reduced energy use. Furthermore, efficiency is improved as a result of not needing to: (1) shut down austenitizing furnaces for frequent grinding of current rolls to remove blister; (2) shut down continuous casters to grind roll surfaces because of thermal fatigue cracking; (3) replace rolls as frequently in austenitizing furnaces and continuous casters, thus casting significantly fewer rolls; and (4) remelt and process out-of-specification steel plates due to marring by blisters on current rolls in the austenitizing furnaces or continuous cast systems. It is estimated that if the technology was broadly adopted, resulting energy savings would exceed 32-trillion Btu per year.

A total of 101 rolls were fabricated and installed at the Burns Harbor Plate Mill in 2002, and have provided over two years of uninterrupted superior service [5]. Continuous operation at this mill has resulted in an additional 210 operational days, consistent high quality product and a

35% increase in energy efficiency. Duraloy Technologies Inc. in Scottsdale, Pa. (an ORNL licensed manufacturer of Ni<sub>3</sub>Al) will manufacture 110 new rolls for installation at another U.S. mill.

Other applications include fabricated hairpin radiant tubes and forging dies, and new industrial applications of intermetallics are continuing to emerge. For example, cast or wrought high-alloy stainless steels used for ethylene furnace tubes are subject to coke buildup and carburization. The unique oxide surface chemistry of Ni<sub>3</sub>Al hinders the rate of carburization and coke buildup. The use of Ni<sub>3</sub>Al for ethylene furnace tubes and development of novel tube manufacturing and welding techniques are being investigated [6].

FeAl intermetallics have resistance to carburization and sulfidation that far exceeds that of most commercial metal alloys. Ni<sub>3</sub>Si alloys have good mechanical properties coupled with excellent resistance to oxidizing conditions, such as in sulfuric

acid and seawater, and to ammonia at temperatures up to 900°C (1650°F). Ni<sub>3</sub>Al and TiAl are also being characterized and evaluated for potential uses and commercialization. The intermetallic alloy development



Hairpin radiant tubes made of cast nickel-aluminide tubes

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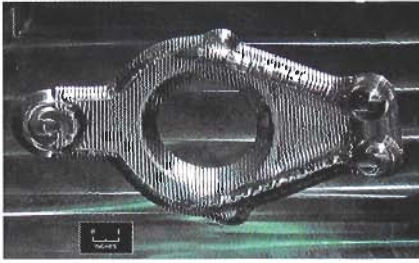
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**Brake spider forgings made in nickel-aluminide forging dies**

program at ORNL has contributed significantly to the understanding of intermetallic materials and processing technologies. The program has been characterized by outstanding research and effective coordination between basic and applied research organizations. Collaborative interactions between DOE, ORNL and industrial participants (metal producers and end-users) have contributed to plant floor energy efficiency improvements through the implementation of innovative alloy compositions and processing methods.

Six licensed companies are producing nickel aluminide alloys for the manufacture of industrial components in the United States. **IH**

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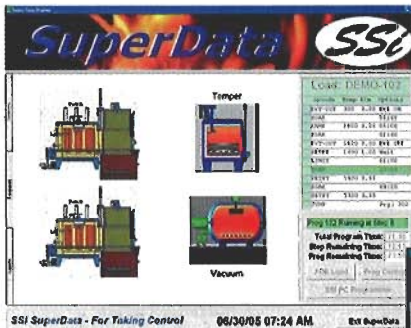
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This article is based on the article "Intermetallics for Manufacturing" in *Advanced Materials*, U.S. DOE, Energy Efficiency and Renewable Energy, Feb. 2005.

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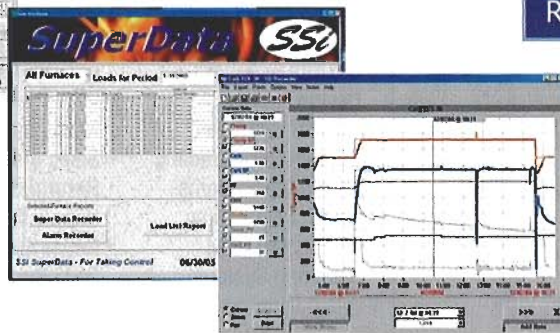
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