INDUSTRIAL MATERIALS *for the* FUTURE

The Dept. of Energy has ongoing programs for the research, design, development, engineering, and testing of advanced materials.

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Through the Industrial Materials of the Future (IMF) program, the Industrial Technologies office of the U.S. Department of Energy (DOE) leads a national effort to research, design, develop, engineer, and test new materials for the aluminum, chemical, forest products, glass, metals, metal casting, mining, and petroleum industries. Supporting industries such as forging, heat treating, welding, powder metallurgy, and process heating and cooling are also of interest.

The DOE provides funds to material developers and others whose efforts result in reduction of energy consumption and waste generation. The scope of the program includes proof of concept, applied research and development, and applications engineering. IMF projects continue to the point of industrial applications. The department seeks additional projects and invites project proposals.

This article summarizes two IMF projects: nickel aluminide intermetallics and high-density infrared processing. It also discusses the continuous-fiber ceramic composite development program that preceded the IMF program.

Nickel aluminides

Nickel aluminides are intermetallic materials that have long been considered potentially useful. Thanks to their ordered crystal structure, they are very strong and hard, and they melt at very high temperatures. Oak Ridge National Laboratory scientists have optimized the processing of intermetallic alloys to maximize physical and mechanical properties. In particular, the composition Ni_3Al has excellent strength at high temperatures, with outstanding oxidation resistance (Fig. 1). This alloy offers approximately 25% reduction in density over superalloys, and has good resistance to both wear and deformation, with fatigue resistance superior to superalloys. Particularly attractive is the unique property of increasing compressive yield strength with temperature to 800°C (1470°F), as shown in Fig. 2.

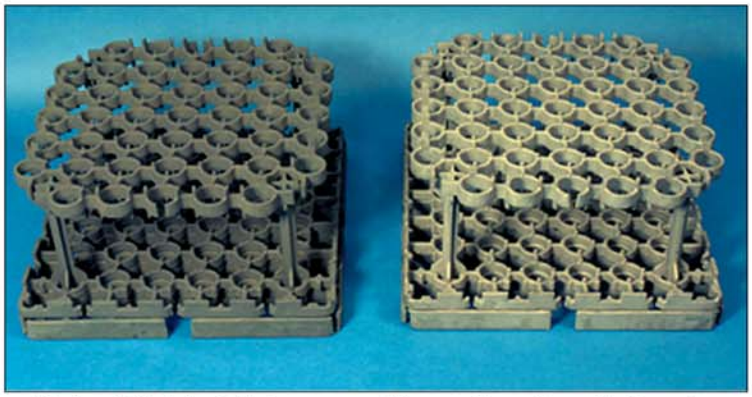

Fig. 1 — Nickel aluminide furnace assemblies provide excellent oxidation resistance and much higher strength and durability than other materials. The Ni_3Al intermetallic enables efficiency improvements of up to 33%.

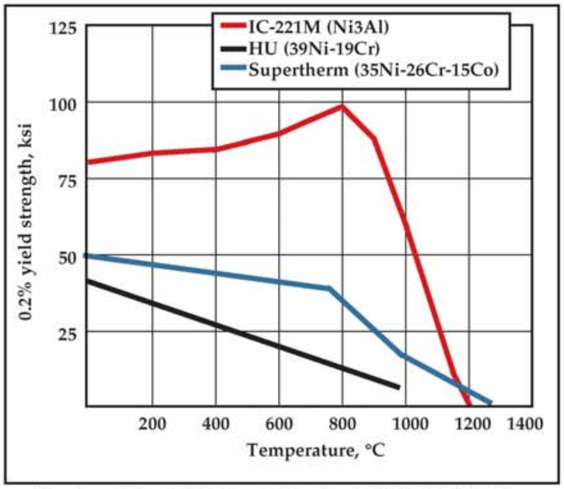

Fig. 2 — The nickel aluminide alloy IC-221M (Ni_3Al) provides higher compressive strength at 800°C (1470°F) than the conventional HU (chromium-nickel alloy steel) or Supertherm (nickel-chromium-iron). The improved high-temperature mechanical properties of Ni_3Al enable higher thermal efficiencies for industrial processes.

The limiting factor in taking advantage of these interesting properties was the brittle nature of the alloy. To overcome this limitation, scientists led by Dr. C.T. Liu developed a method to add ductility to the nickel aluminide alloy. The result is a lightweight material that is significantly stronger than stainless steel. By preoxidizing, the aluminum on this alloy surface is converted to aluminum oxide that is very stable in an oxidizing or carburizing atmosphere.

The commercialization of nickel aluminide alloys was further enhanced through research and development of process technologies, conducted by a team led by Dr. Vinod Sikka. The resulting

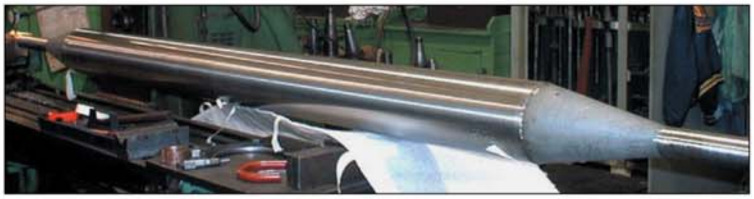

Fig. 3 — This Ni_3Al furnace roll enables increased energy efficiency, and results in higher productivity and improved product quality in the production of steel. Efficiencies result from not having to shut down austenitizing furnaces for frequent grinding to remove blister or fatigue cracks.

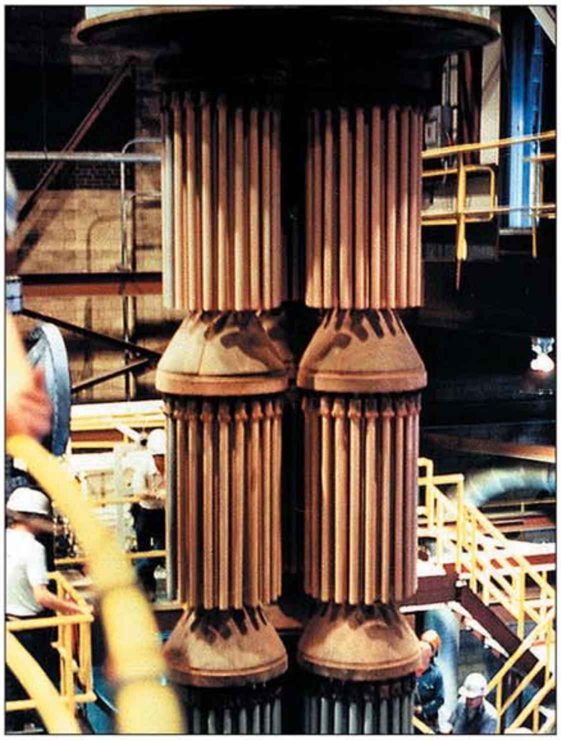

Fig. 4 — Continuous-fiber ceramic composites (CFCCs) make tough, lightweight gas filters. They function well at elevated temperatures, prevent damage downstream, reduce downtime, resist corrosion, and diminish emissions.

patented Exomelt process (See details in *AM&P*, June 1995) ensures that the aluminum is safely contained during the manufacture of the alloy. In this process, the exothermic heat of reaction between aluminum and nickel raises the temperature to >1640°C (2980°F), melting the two metals. Because the process is driven by exothermic heat, energy savings of 33 to 50% can be achieved over the conventional alloying method.

The research team at Oak Ridge worked with industry to develop both suppliers and applications for the intermetallic alloys. The list of suppliers now includes Alcon Industries, Alloy Engineering & Casting Company, Sandusky International, United Defense, Ametek, Stoody Company, and Polymet.

The list of successful applications for Ni_3Al-based alloys is extensive, and includes hardware for heat-treating metal parts, furnace rolls, radiant burner tubes, and similar components. Furnace trays at the Delphi Automotive Systems Corporation support gears during a thermal treatment that includes an air-quenching step from 900°C (1650°F). This repeated thermal cycling in a carburizing atmosphere would destroy most metals, but the nickel aluminide hardware has survived for over 39 months, compared to the six-month useful life for the previous stainless steel alloy. No failures have been experienced during more than three years in production.

Nickel aluminide alloys have proven to be especially cost-effective as hot-transfer rolls that move steel through finishing operations (Fig. 3). The high temperatures cause conventional superalloy rolls to sag, develop oxide particles, and blister, scratching the steel plates in production. However, nickel aluminide rolls withstand the heat and are three times stronger than the conventional rolls. The longer service life of the nickel aluminide rolls significantly reduces downtime and maintenance costs. Other applications include ethylene cracker furnace tubes and radiant burner tubes, both produced by centrifugal casting, and forging dies.

Since the 1980s, ORNL's nickel aluminide alloy compositions have been licensed to over a dozen companies for various applications, ranging from processing glass to making dies for forming beverage containers and other metal shapes. Automobile and tool companies have found the ductile nickel aluminides especially appealing. Because of the high aluminum content, their resistance to both oxidizing and carburizing atmospheres at temperatures to 1100°C (2000°F) is very advantageous. In addition to furnace hardware, applications include trays, belts, muffles, and other furnace components in automotive manufacture.

High-density infrared processing

One of the current IMF projects involves the development of a promising method of surface treatment. Called High Density Infrared (HDI) processing, this breakthrough in infrared lamp technology enables improvements in thermal processing. Infrared heating has many advantages because it is an inherently clean, noncontact heating method. A new design permits power densities of 3.5 kW/cm^2, resulting in faster processing, maintenance of bulk properties, reduced steps during application and curing, and lower costs.

A new high power-density lamp modifies surface chemistry or porosity without affecting bulk properties. Refractories, forging and die casting dies, rolls, and large sheets can be surface-hardened or stress-relieved, even inner diameter surfaces. Thermal spray coatings, paints, thermal barrier coatings, cloth tapes, and bindered spray coatings can all be fused by HDI processing.

A major feature of the infrared technology is the ability to treat large sheets, as scan width can be varied from 10 to 35 cm (4 to 14 in.). The technology provides a homogeneous intensity-distribution of visible radiation, creating a uniform effect that is easily monitored. In addition, the lamp is movable, hence very little space is required, and metals preferentially absorb its radiant output. All of these features translate to a process with low investment and operating costs. Engineers are developing this breakthrough by coupling it with conventional industrial equipment and making it available to industry for process development.

Infrared processing center

Oak Ridge National Laboratory recognizes the value of this technical achievement and has utilized it along with ancillary equipment to create an Infrared Processing Center (IPC) for potential users. The IPC includes 10 to 35-cm plasma arc lamps that provide radiant power of 1.2 to 3.5 kW/cm^2. By coupling this equipment with scientific understanding and machinery such as lathes and welders, the center improves the viability of infrared processing.

A robot controls the motion of the lamp, and is capable of accommodating a range of complex geometries. Once an optimum process is determined, the client can install a fixed or variable-bed furnace to meet specific needs.

Developed initially for fusing coatings that impart wear and/or corrosion resistance, the center now provides other applications. These include gradient hardening and softening, annealing, preheating of dies, and processing of materials. The laboratory is leading in the development and application of this new high-powered infrared technology to industrial heating problems.

Continuous fiber ceramic composites

Ceramic materials have been an integral part of industrial manufacturing for over a century. For example, refractories that line high-temperature furnaces exploit the unique properties of ceramics: strength at ultra-high temperature and relative inertness to the furnace environment. However, ceramics have always been susceptible to failure in brittle fracture, and hence are seldom chosen for critical applications.

The DOE recently concluded a program to determine whether it would be possible to develop fiber-reinforced ceramics that could overcome brittle fracture. This program (which preceded the IMF program) teamed industry, universities, national laboratories, and end-users. Their goal was the development and evaluation of continuous-fiber ceramic composites (CFCCs) that function at high temperatures in a manner analogous to that of resin matrix composites at room temperature.

In the early 1990s, the program included companies such as Babcock & Wilcox, General Electric, Allied Signal, Dow Corning, Dupont, Textron, and Atlantic Research. They began developing CFCCs such as silicon carbide reinforced with continuous fibers of silicon carbide, and aluminum oxide reinforced with continuous fibers of various oxides. Several different components were produced:

- *Immersion tubes* for aluminum holding furnaces were developed by Textron and were tested for over 1700 hours at 870°C (1600°F).
- *Hot-gas filters* (Fig. 4) were developed by Babcock & Wilcox to remove ash from the gas stream in a coal-fired boiler. These filters were tested at 870°C (1600°F) for over 2000 hours.
- *Gas turbine combustor liners* were developed by Dupont/Honeywell and functioned successfully on an operating power turbine for over 20,000 hours.

The limiting variable in all of these components was the ceramic fiber. The overall program resulted in a process for making ceramic components that would not fail in a catastrophic manner in brittle fracture. The upper temperature limit for most of the composites developed was under 1100°C (2000°F) for long-term exposure. Advances in ceramic fiber will be required to allow higher service temperatures for the CFCC components. ■

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