Nickel Alloys

The necessity of nickel alloys

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As the world moves towards increased urbanization and the population heads towards projected 9.7 billion people by 2050, there is a growing need for high-performance materials. One category of such materials is the family of nickel alloys which are valued for their corrosion resistance, ability to withstand high temperatures and their special magnetic and thermal expansion properties. It is these characteristics which mean that nickel alloys have a vital role in helping to provide energy, a cleaner environment, improved health and a host of other services for the expanding population, five billion of whom will be living in cities by 2030.

What are nickel alloys?

Nickel alloys are defined by ASTM, a leading international standards development organization, as metals that have more nickel content by weight than any other element. Sometimes an alloy is known as a nickel alloy if there is less than 50% iron and it contains more nickel than any other alloy element, other than iron. Although there are over 3,000 different nickel alloys in everyday use, their total worldwide production is relatively small. At 300,000 tonnes they represent less than 1% of the total production of stainless steels, yet they play a vital role for industry and society. Nickel alloys can be considered as a continuation of the family of austenitic stainless steels, with higher nickel content to offer enhanced corrosion resistance, or to allow other alloying elements to be added in higher amounts than possible in an iron-based alloy. Unlike stainless steel, there are nickel-alloy families that do not contain chromium, such as Ni-Cu alloys (e.g., Alloy 400, Ni-Mo alloys (the ‘B’ family), the nickel-titanium shape-memory alloys, and the commercially pure (99%+) nickel family.

Essential for new and established technologies

Nickel alloys are essential for both existing and developing technologies. About 50% of all nickel alloys end up in aqueous-corrosion applications, about 40% in high-temperature applications including aerospace, with the balance going to specialized applications, notably in electronics. While fabrication and welding properties differ from stainless steels, the various families of nickel are relatively straightforward to work with. Quality fabricators of higher-alloyed stainless steel can easily produce nickel alloys, as long as they are fully versed in their properties. Nickel Institute’s nickel alloy welding (11012) and machining (11008) publications can prepare specifiers and fabricators who are also able to make use of the Institute’s online Technical Help service to answer specific questions.

Chemical and petrochemical industry

Nickel alloys are used where stainless steels are not suitable. In the chemical industry, for example, where very corrosive chemicals are often handled, nickel alloys can offer a greater degree of safety, environmental protection and longer life. Often nickel alloys are clad on lower-alloyed metals such as carbon steel or stainless steels. The backing material provides strength and possibly corrosion resistance to the external environment, while the nickel alloy provides corrosion resistance to the corrosive internal chemicals. Various cladding techniques exist, including explosion cladding, roll bond cladding and weld overlay. Thermal spray of nickel alloys is also being used extensively, especially for maintenance applications, to extend the life of equipment.

Metal dusting, most commonly experienced in the petrochemical industry, is a form of very rapid carburization and presents a materials challenge. Again, as temperatures are raised to increase efficiency, standard nickel alloys are subject to this form of corrosion. Many new alloys have been tried, giving significantly improved life, but none seem to be immune. Research and testing is currently underway to improve the metal-dusting resistance even further.

Oil and gas extraction

Many existing and new applications occur in the energy sector. In conventional oil and gas extraction, nickel alloys have been used for many years for extracting fluids containing high amounts of hydrogen sulphide and/ or high-chloride water. For example, a small but essential role for nickel alloys is in the wirelines, both the slick and electric types. Slick wirelines suspend ‘bomb hangers’ which, when detonated, drive projectiles through the well-casing pipe to allow oil to flow into and up the well. Electric wirelines consist of insulated electrical signal wires, surrounded by braided metallic wires for protection, that make up the essential load-bearing cable which supports the weight of the measuring tool. While stainless steels are used in many wells, in the most aggressive conditions highly corrosion-resistant high-strength nickel alloys such as Alloy 31 (N08031), Alloy 936 (N08936) and Alloy MP35N (N30035) are required.

Geothermal energy

The USA, the Philippines, Italy, Mexico, Indonesia, Japan, Iceland and New Zealand are the major world producers and users of geothermal power. Here, nickel alloys have a vital role to play in geothermal energy production. Depending on the operational demands, nickel alloys such as Alloy 625 (N06625), C-276 (N10276) and even higher alloys are necessary. Other nickel alloys such as Alloy 600 (N06600), 601 (N06601) and 825 (N08825) are used selectively to cope with specific highly corrosive operations.
nical 605°C would increase the efficiency to 40% or more, whereas increasing it to 710°C or above (advanced ultra-supercritical or AUSC) would bring the efficiency to 50% or greater. Super-critical temperatures mean a complete change of materials throughout the plant and special nickel-containing stainless steels and nickel alloys will be commonly used. At the Grosskraftwerk Mannheim (GKM) power plant in Germany, which came on stream in 2012, different materials are undergoing field testing in an actual power plant where the maximum steam temperature is 725°C. Special materials produced by VDM Metals for these severe conditions include a modified Alloy 617 (N06617) called 617 B and C-263 (N07263). Both have very high creep strengths at the operating temperatures. These alloys are melted and cast under vacuum via Vacuum Induction Melting (VIM), and then remelted via Electroslag Remelting (ESR) and Vacuum Arc Remelting (VAR) respectively, to reduce inclusions. Similar trial AUSC projects are either in the final design stages, in construction or in operation in China, Japan and the United States.

**Destroying hazardous waste**

Super-critical water oxidation (SCWO) is one method of destroying hazardous and toxic waste liquids, rendering them harmless. But the reactors present severe challenges for materials. In Japan, the USA and the UK reactors are operating with various degrees of success. More recently, a French company has commercialized two SCWO units in France and Reunion. These reactors use alloys such as Alloy 625 or one of the C-type nickel alloys.

**Health care**

Longer human life expectancy brings an increased need for medical procedures along with an increasing need for different and complex implants for various conditions linked to ageing. Nickel alloys have a long history of use in implants and have made important contributions to the quality of life of millions of people. A common implant is a ‘stent’ – a small mesh tube made from a nickel-titanium alloy, used to keep arteries open and used in the treatment of coronary artery blockages. The alloy has shape-memory or ‘superelastic’ properties. Each year in the United States alone more than one million people undergo an operation called angioplasty to treat coronary heart disease. Patients have a 90% long-term success rate when treatment includes an antibacterial-coated nickel-titanium (Nickstent). Prior to the advent of this technology, doctors performing angioplasty without stents could expect only a 60% success rate. As society requires industry to look at applications which are more efficient yet demand higher temperatures, higher pressures, and result in high corrosivity, nickel alloys will be necessary to meet the challenges presented by these tougher conditions.

**Nuclear**

And it is not only coal-fired plants that can take advantage of higher steam temperature. The next generation of nuclear plants have special requirements for the materials related to irradiation. One project envisions the supercritical water in contact with the fuel cladding at 825°C. Stainless steels and several nickel alloys such as Alloy 800H (N08810) and Alloy 625 (N06625) are being tested for stress-corrosion cracking resistance.

**Materials are undergoing field testing in temperatures up to 725°C at the Grosskraftwerk Mannheim (GKM) power plant. Photo courtesy of GKM**

**Vascular stents are small mesh tubes made from a nickel-titanium alloy used to keep arteries open and used in the treatment of coronary artery blockages. The alloy has shape-memory or ‘superelastic’ properties. Photo: Shutterstock**

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**About the Nickel Institute**

The Nickel Institute (NI) is the global association of the world’s primary nickel producers who together account for approximately 80% of worldwide annual nickel production outside China. Its mission is to promote and support the use of nickel in appropriate applications. NI grows and supports markets for new and existing nickel applications including stainless steel and promotes sound science, risk management, and socio-economic benefit as the basis for public policy and regulation. Through its science division NiPERA, it also undertakes leading-edge scientific research relevant to human health and the environment. NI is the centre of excellence for information on nickel and nickel-containing materials and has offices in Asia (Beijing and Tokyo), Europe (Brussels) and North America (Toronto, Canada, and Durham, N. Carolina).

Long-term indicators for materials containing nickel are very positive. The most significant driver is the growing world population which is forecast to grow to over 9 billion by 2050 and still increase demand for clean water, safe food, buildings, infrastructure, transport and energy. All these applications use nickel-containing materials and especially stainless steels and nickel alloys.

Nickel magazine, which highlights applications of nickel-containing materials such as those discussed in this article, is available free online or by mail.

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