

(Top right) Photo showing the concentrations of nickel isotopes being expelled from a star as it expands in a supernova explosion. (Middle right) Nickel compacts from BHP Billiton's Queensland Nickel Yabulu Refinery in Queensland, Australia. (Bottom right) Nickel bricks from Botswana.

## The role and significance of nickel

Industry demand for nickel and nickel alloys is still rising despite the relatively high price in recent years. The reason for this is that there is an ever-increasing need for metals offering a higher resistance to all kinds of aggressive chemical stress. By using these metals, systems can be developed with a significantly longer technical life span. Moreover, constantly rising maintenance costs and higher safety demands play an important role in the decision whether to go over to nickel alloys. Nickel is also often used as an alloying element in for example stainless steel and copper alloys. In this article Ko Buijs examines the role and significance of nickel.

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### How nickel is obtained

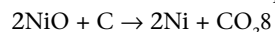
Nickel ore is found in many places on the earth's surface, but mining it is cost-effective only in a limited number of locations, such as Canada, Norway and New Caledonia. Even the best ores contain only 1.2-5% nickel. For example, a frequently found ore composition consists of approximately 40% SiO<sub>2</sub>, 20% MgO, 15% Fe<sub>2</sub>O<sub>3</sub>, 10%

H<sub>2</sub>O, 10% NiO, 1% Al<sub>2</sub>O<sub>3</sub>, 0.7% MnO<sub>2</sub>, 0.2% CoO and 0.1% CaO.

The colour of the ore is green, but according to the amount of iron oxide present the ore takes on a colour ranging from yellow to brown. A frequently used method of obtaining nickel is to smelt the nickel ore in a cupola with cokes to which limestone has been added. The substance

obtained is then pressed into bricks with a flux (usually calcium sulphide). These bricks are smelted in an oven after a 30% coke mixture has been added. In this way we obtain raw nickel oxide that still contains a fairly large amount of iron oxide. Therefore it is purified with a silicon-containing flux in a Bessemer converter. The resulting substance contains about 80%

nickel oxide and about 20% sulphur. It is then pulverized in a ball mill and roasted to get rid of the sulphur. After the roasting, virtually pure nickel oxide remains. This nickel oxide is pressed together with carbon into tablets, then heated for 48 hours. During this heating process the following chemical reaction takes place:



This nickel is about 99.25 % pure.

Whenever a higher degree of purity is required, this can be achieved by means of electrolysis.

By adding any kind of alloying elements the desired nickel alloy can be obtained thanks to the smelt process. For all nickel alloys the contents of phosphorus and sulphur must be kept as low as possible because of the harm they can cause. Above all the element sulphur must be avoided at all costs as it causes nickel to become very brittle. During the smelting of nickel the sulphur can be bound by the addition of a small amount of manganese and/or magnesium.

### Properties of nickel

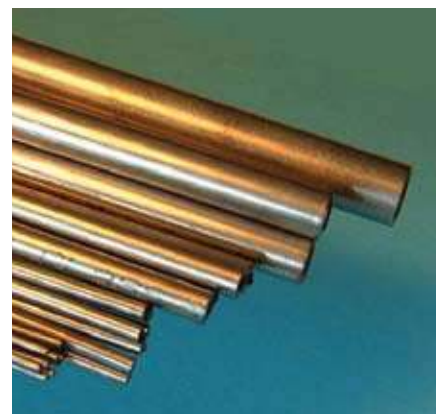
Nickel is the 28th element in the periodic table, and through its face-centred cubic lattice it has relatively high ductility thanks to its many sliding surfaces. Specific advantages of nickel, apart from very good corrosion resistance, include constant magnetic permeability, very slight thermal expansion and extraordinary good properties at high temperatures. Also, it is very often used as an alloying element in iron and copper alloys. Examples

include austenitic stainless steel, duplex, cupronickel, aluminium bronze and special titanium alloys. Nickel is not only used in its commercially pure form, but also, and much more often, as alloyed nickel, generally as plate, rod, strip, tube (welded or seamless), wire, forging and castings. It has excellent weldability as long as the correct welding parameters are respected.

Nickel is also known for its very good creep resistance, caused by the large number of matrix twins and the forming of precipitates, both of which hinder dislocation jumps to a great extent.

### Technically pure Nickel 200 and 201

In its unalloyed condition nickel can be applied with very good results in certain process equipment, for which there are two types available, Nickel 200 and Nickel 201. These grades (material nos 2.4066 and 2.4068) represent the types that fall into the category of pure nickel. Nickel 200 is a grade with high ductility, also called "commercially pure nickel". In addition it has good thermal conductivity and excellent resistance to a great many corrosive media. Because of its high purity nickel has relatively low mechanical values. Nickel 201 is more or less identical to Nickel 200 except that the carbon content is no higher than 0.025%. Both grades offer extremely good corrosion resistance, especially under de-oxidising conditions. In oxidising environments



Hastelloy C276 tubing

a passive oxide film forms on the surface that ensures that the nickel is resistant to caustic soda, dry hydrochloric acid and dry bromines. Nickel 200 and 201 also have excellent resistance to stress corrosion cracking in solutions that contain corrosive alkalines or chlorides. Nickel 200 and 201 can be worked in both hot or cold form. Stress relief annealing or soft annealing is necessary after cold-forming of more than 5%. Hot working is required for temperatures between 800°C and 1250°C. Before the heat treatment the metal should always be cleared of oil, grease or any traces of carbon or sulphur. The oven environment must be lightly de-oxidising or neutral. If one is not sure whether sulphur is present, it is strongly recommended to ensure that the oven atmosphere is lightly oxidising. Sulphur accumulation should always be combated with nickel alloys to prevent the formation of harmful nickel sulphide.

For soft annealing a temperature of 700-800°C should be maintained; for stress relief annealing, a temperature of 550-650°C. The cooling should take place in water or in forced air. Thin components can also be cooled in normal air.

Nickel 200 and 201 are very easy to weld after the products have been degreased. Recommended welding procedures include TIG and MIG, or arc welding with covered electrodes. The correct welding consumables are material no. 2.4155 for TIG and MIG wire and no. 2.4156 for electrodes.

### Nickel alloys

In addition to commercially pure nickel, which is used in a broad range of applications, many nickel alloys have been developed, the most important alloying elements being chro-

### The physical and mechanical properties of nickel

Atomic weight	58.69
Crystal structure (20°C)	CCP (cubic close-packed)
Density (specific gravity)	8.89
Melting point	1435-1445°C
Boiling point	c. 2730°C
Specific warmth (27-100°C)	440 J/kg/°K
Latent heat of fusion	309 J/g
Linear co-efficient of expansion	13.10 <sup>-6</sup> /°K (27-100°C)
Electrical resistivity (20°C)	9.5 micro-ohms/cm
Thermal conductivity (27-100°C)	76 W/m/°C
Curie point	368°C
Tensile strength	461 MPa
Yield point 0.2%	147 MPa
Strain	40%
Necking	45%
Hardness	110 HB
Modulus of elasticity	205.8 GPa

mium, copper, iron and molybdenum. Sometimes additional materials are used, such as cobalt, aluminium, boron, niobium, vanadium, magnesium, silicon and the like. Such elements are usually intended to improve certain properties such as oxidation stability, mechanical behaviour or creep resistance, and sometimes they also have the effect of refining the grain. Examples are alloys 200, 201, 400, K500, 600, 601, 625, 800HT.825.59, C4, C22, C276, C2000, B2, B3 and so on.

### Alloy 400 (material no. 2.4360)

Alloy 400 contains about 30% copper and 70% nickel. It is remarkably versatile, because nickel and copper are completely dissoluble in each other. Not only does it possess favourable mechanical properties, it is also highly resistant to many corrosion-induced stresses. Its mechanical properties hold up well in high temperatures and therefore it is specified for the construction of pressure vessels up to a temperature of 425°C. Alloy 400 above all offers high corrosion resistance to de-oxidising undiluted acids, organic acids, caustic solutions and salt solutions, and also to industrial dry gases such as oxygen, chlorine, hydrochloric acid, sulphur dioxide and carbon dioxide. In flowing sea water, too, this alloy performs excellently, also at the transition between seawater and air. A special advantage of this alloy is its insensitivity to stress corrosion cracking over a very broad range of applications. But the alloy should not be used in environments where components with an oxidising effect could be present, such as iron ions or copper ions that are mostly dissociated from their salts.

Alloy 400, which is known as "Monel 400" and by other names, is found especially in offshore applications such as condensers, piping systems, plate



Hastelloy heat exchanger



Hastelloy reactor (Patterson)

rings and valves. In the chemicals industry too the alloy finds a use in the preparation of all kinds of chemicals and for salt preparation. Among its applications in shipping are valves, fire extinguishing equipment, pumps and propeller shafts. Power generation technology uses the alloy in piping systems and heat exchangers. Recently the metal has been used successfully in environmental technology, in evaporators and waste water crystallisers. Nickel alloy 400 can be hot- or cold-worked. During forging a temperature between 930°C and 1160°C is maintained, while hot bending is carried out between temperatures of 1000°C and 1180°C. After cold working of more than 5%, stress relief annealing is necessary. This annealing treatment is also strongly to be recommended after hot working. The oven atmosphere

should be sulphur-free and slightly de-oxidising.

Welding can best be carried out with the TIG or MIG process, though electrode welding is also fully acceptable in principle. Because of the sensitivity to hot cracking, the parts to be welded must be very clean and grease-free. Pre-heating is not recommended, as is post-weld heat treatment, in order to prevent unnecessary thermal stress. The best TIG and MIG welding wire to use is material no. 2.4377, and the best electrode material is 2.4366. In this way we could examine every nickel alloy. It is generally true to say that chromium-containing nickel alloys are intended for oxidising chemicals, while the chromium-free grades are intended for de-oxidising conditions.

As stated earlier, nickel is also used as



Hastelloy heat exchanger

an alloying element, and it is found regularly in stainless steel copper alloys. It can also be found as an alloying element in titanium. A summary of the effects of nickel on these materials is given below.

### Nickel and stainless steel

Nickel influences both the structure and the mechanical properties of stainless steel to a great extent. If the nickel content is high enough the stainless steel takes on an austenitic structure, which can remain intact even in cryogenic temperatures. Nickel is after all a strong austenite former. Compared with chromium steel, alloying with nickel leads to significant changes in mechanical properties. In addition it ensures better formability and toughness and also greater strength at high temperatures. In addition nickel greatly improves weldability and bring about a change in the physical properties of the material so that it is no longer magnetic. Another important physical characteristic of austenite compared with ferrite is the inferior heat conductivity and the higher electrical resistivity. In some environments the corrosion resistance is increased through the presence of nickel. Remarkably, nickel makes little or no difference when it comes to pitting resistance. This can be seen in the Pitting Resistance Equivalent formula (PREn), in which the element nickel is in fact absent.

### Nickel in titanium

It is generally known that nickel is used in iron and copper alloys. How-



Monel 400 pistons (Getzen)

ever, its incidental use as an alloying element in titanium is not very well known. As a technically pure metal, titanium is capable of resisting very many chemical conditions. However, at higher temperatures the metal is more prone to crevice corrosion. Therefore commercially pure titanium is perfect in seawater and is not itself prone to crevice corrosion below a temperature of 80°C. Above this temperature one can expect problems in this area, so a palladium-alloyed type has been developed, called grade 7 (0.2% Pd). Because palladium is so very expensive and is also sometimes not even obtainable, this metal has



Monel valves



Nickel 201 bar material

been replaced by 10% or more of molybdenum and about 1% of nickel. This gives us an alloy called titanium grade 12, which has a considerably higher resistance to crevice corrosion than grade 2 in seawater that is hotter than 80°C, but whose performance does not come up to that of grade 7.

### Conclusion

All in all, it is clear that nickel is very important in all kinds of alloys for countless applications. Although the price of nickel has massively increased in recent years, a good substitute for this material will not be found easily. In other words, nickel will continue to play a prominent role in many industrial and domestic applications. ■

### ABOUT THE AUTHOR

Ko Buijs is a recognized metallurgical / corrosion specialist on stainless steels as well as special metals. He works for Van Leeuwen Stainless. In addition, Mr Buijs is a lecturer for various organisations such as steel associations, technical high schools and innovation centres. He has published over 100 papers in a number of technical magazines. In close co-operation with Barsukoff Software Mr Buijs has developed the computer programme Corrosion Wizard 2.0. Info [www.corrosionwizard.com](http://www.corrosionwizard.com)