10. Niobium

Niobium is one of the five major refractory elements with very high resistance to corrosion. It is an element in Group VA of the periodic table and has a body-centered cubic (BCC) crystal structure. Niobium is used as an alloying element in carbon and alloy steels as well as in non-ferrous metals to increase strength and improve temperature and corrosion resistance. Due to these properties as well as good cold formability and weldability, niobium-containing alloys are used in jet engines and rockets, chemical instrumentation technology, nuclear power engineering and in oil and gas pipelines where niobium allows for the extreme pressures.[1] Niobium has superconductive properties and thus is used in superconductive magnets which preserve their properties in strong magnetic fields.[2] The main uses of niobium can be identified as: High strength low alloy (HSLA) steel, stainless steel, super-alloys and superconducting NbTi alloy magnets.[3]

Ferroniobium, (66% niobium 34% iron) represents over 90% of world niobium production.[4] Mine production of niobium is clearly dominated by Brazil, with Canada contributing a minor share of world niobium supply. Global niobium demand has grown at 10% annual growth rate over the last 10 years.[4] Niobium is not traded on any metal exchange and, therefore, there are no “official” prices for niobium. The current price of ferroniobium is estimated to be around 40 US$/kg but the tendency has been slightly decreasing in recent months.[5]

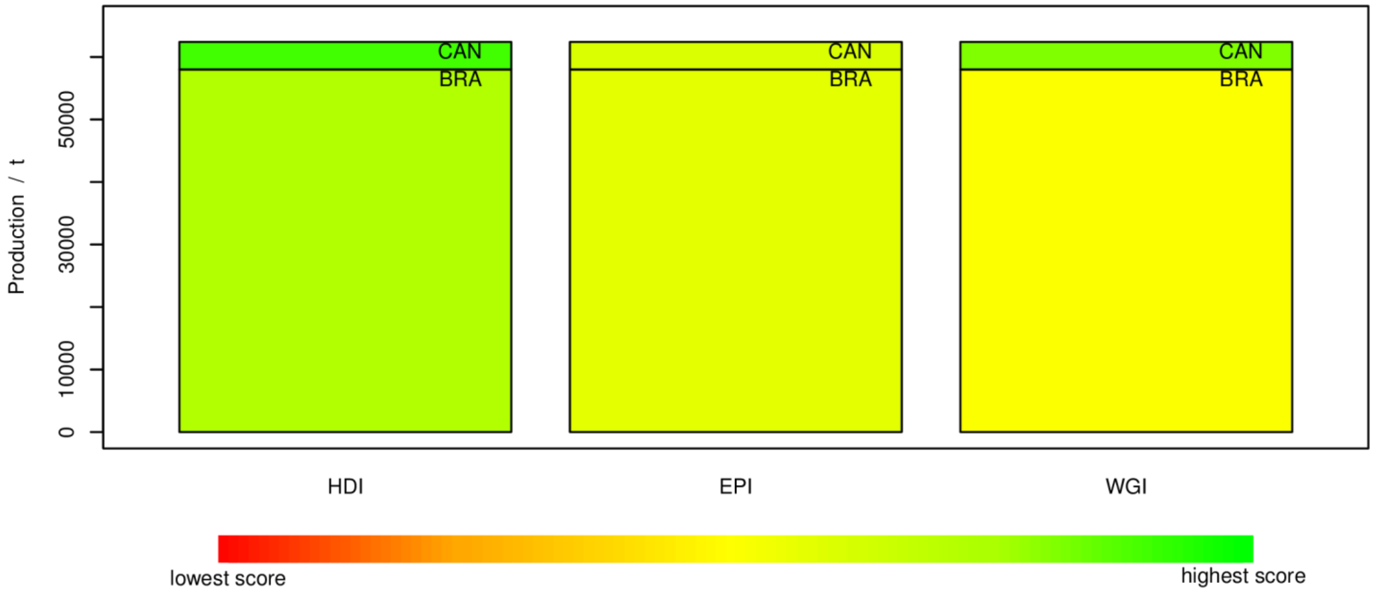

Figure 1: Distribution of niobium production[6] and corresponding scores of the producing countries in the Human Development Index (HDI)[7], Environmental Performance Index (EPI)[8], and World Governance Indicators (WGI)[9]. Both the EPI and WGI are used to assess supply risks with the EU methodology for determining critical raw materials.[10] BRA = Brazil; CAN = Canada.

Uses and substitutability

HSLA steels

Niobium-containing HSLA steels are mainly used in:

- **Construction:** Used for lightweight structures that require additional strength and corrosion resistance and as high strength reinforcing bars with good weldability.
- **Automotive & shipbuilding:** Used in order to improve fuel efficiency through weight reduction.
- **Oil & gas pipelines:** Used due to their superior ability to withstand increased pressure and volumes over greater distances.

Vanadium and molybdenum can be used as substitutes for niobium when material strengthening and refractory properties are required.[11] However, cost and performance penalties can be expected due to the following reasons:

- Niobium prices are lower and much more stable than these substitutes[12],
- Almost twice as much vanadium has to be used to achieve the same strengthening results niobium does,
- Niobium is the lightest of the refractory metals,
- Niobium is unique in that it can be worked through annealing to achieve a wide range of strength and elasticity.

The last reason makes it extremely difficult to substitute niobium-containing HSLA steels in **oil & gas pipelines**, which is enforced due to the need to transport gas long distances under high pressure requires steel pipes with greater toughness to prevent fractures.[13]

Stainless Steels

About 3% of worldwide annual niobium demand accounts for production of stainless steel grades[3] where niobium improves high temperature behaviour and corrosion resistance and strengthens the material. Molybdenum, titanium and tantalum can substitute niobium in these materials, however this can result in some cost increase.

High-nitrogen stainless steels can be a reasonable substitute for niobium-containing steels in many applications due to their high strength combined with high ductility, improved corrosion resistance and increased high temperature tensile strength.

Super-alloys

The unique ways that niobium enhances the properties of super-alloys make them premier materials of choice in today's aerospace and land-based gas turbines.[14] These alloys are developed for elevated temperature service, where severe mechanical stress is encountered and high surface integrity is usually required. They combine high tensile strength and ductility, rupture and creep strength with inherent stability and favourable low-cycle fatigue properties.

Tantalum, molybdenum and tungsten can substitute niobium in these materials to some extent. Another opportunity that appears more attractive is the substitution of super-alloys by ceramic materials in this application. Ceramics are lightweight, strong, and heat-resistant, but have a reputation for being brittle materials that shatter on impact and thus do not meet strict criteria for materials intended for gas turbine service. However, ceramic matrix composites (CMCs) made from a silicon carbide/nitride matrix toughened with a coating of silicon carbide fibers are durable, withstand temperatures as high as 1300 °C and weigh one-third of niobium-containing super-alloys. In September 2010 GE reported that the company for the first time has been able to make CMC rotating parts and test CMCs-based turbine blades. In February 2012, IHI, a leading aircraft engine manufacturer in Japan, announced in a press release that they would finalize mass-production technology of CMC parts for jet engines in 2015, aiming for commercialization of CMC parts in 2020.[15] CMCs appear to be very attractive substitutes for super-alloys as they are strong, tough and can be mass produced. If CMCs parts substitute super-alloys in gas turbines, their engines will become 15% more efficient due to the weight reduction.[16]

Niobium-titanium (Ni-Ti) alloys display superior high-critical-magnetic-field and high-critical-supercurrent-density properties coupled with affordability and good workability. This combination of properties distinguishes this material from thousands of other superconductors and explains its status as the most commonly used superconducting material.

Nb-Ti superconducting magnets have been widely used in magnetic resonance imaging (MRI), particle accelerators and colliders [17]. Vanadium-gallium (V_3Ga) is an example of a currently-available substitute for Nb-Ti alloys with a structure of superconducting phase similar to that of Nb-Ti superconductors. High-temperature superconductors, such as bismuth strontium calcium copper oxide (BSCCO) have great potential as substitutes for Nb-based superconductors. In particular, BSCCO is unique among high temperature superconductors because it can be made into round wires, a product form that is much more flexible for making magnets. BSCCO can enable a new generation of more powerful superconducting magnets in a few years when its production technology becomes sufficiently developed.

Summary

A number of viable substitutes can be found for niobium as an alloying element in stainless steels. Replacement of niobium in HSLA steels seems to be more problematic especially in products intended for use in oil & gas pipelines where substitution of niobium appears unlikely at the moment. Substitution of niobium in super-alloys and in applications typical for Nb-containing super-alloys as well as in superconducting magnets is a matter of time and further technical development in materials science.

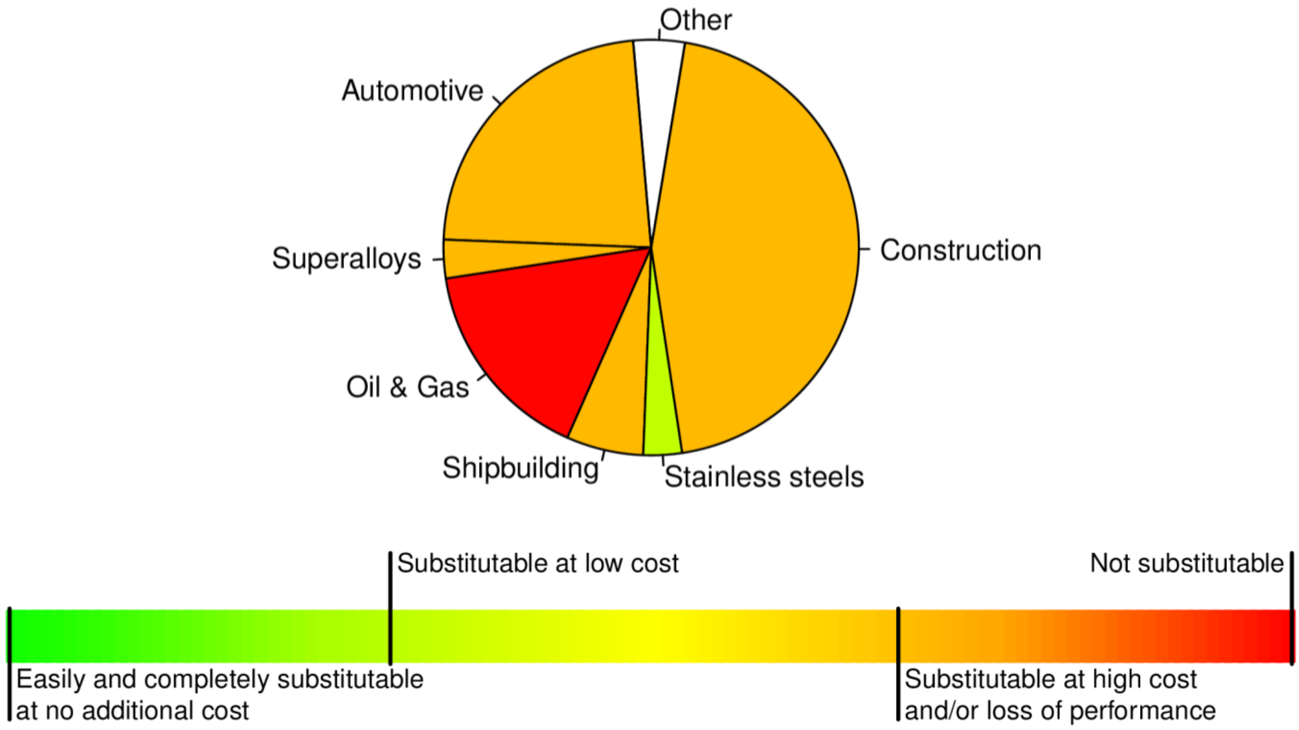

Figure 2: Distribution of end-uses[3] and corresponding substitutability assessment for niobium. The manner and scaling of the assessment is compatible with the work of the Ad-hoc Working Group on Defining Critical Raw Materials (2010).

References

1 Atomistry.com Niobium Applications. http://niobium.atomistry.com/application.html. Accessed 16 July 2013
2 Georgia State University (2007) Superconducting Magnets. http://hyperphysics.phy-astr.gsu.edu/hbase/solids/scmag.html. Accessed 16 July 2013
3 NioCorp Developments Ltd. About Niobium. http://www.quantumrareearth.com/about-niobium.html. Accessed 16 July 2013
4 REE International Niobium. http://www.reeinternational.com/projects/niobium/. Accessed 16 July 2013
5 Metal-Pages (2013) Metal Prices: Ferroniobium. http://www.metal-pages.com/metalprices/ferroniobium/. Accessed 30 August 2013
6 U.S. Geological Survey (2013) Mineral commodity summaries 2013
7 United Nations Development Programme (UNDP) (2013) The 2013 Human Development Report – "The Rise of the South: Human Progress in a Diverse World"
8 Yale Center for Environmental Law and Policy (YCELP) (2013) Downloads | Environmental Performance Index. http://epi.yale.edu/downloads. Accessed 26 July 2013
9 World Bank Group (2013) Worldwide Governance Indicators. http://info.worldbank.org/governance/wgi/sc_country.asp. Accessed 26 July 2013
10 Ad-hoc Working Group on defining critical raw materials (2010) Critical raw materials for the EU: European Commission
11 Papp, J. F. (2013) Niobium (columbium), in: U.S. Geological Survey (ed.) Mineral Commodity Summaries 2013, pp. 110–111
12 ЗАО ТЕХНОИНВЕСТ АЛЬЯНС Market Niobium. http://columbite.ru/?page_id=44. Accessed 16 July 2013
13 IAMGOLD Corporation (2012) Niobium 101. http://www.iamgold.com/English/Operations/Operating-Mines/Niobec-Niobium-Mine/Niobium-101/default.aspx
14 Patel S, Smith G (2002) The role of Niobium in wrought superalloys. WV 25705-1771
15 Hidaka S (2012) Superalloys versus Ceramics: Will Investment Casting survives as key technology of Turbine Blades and Vanes in this century. Kyoto, Japan: The 13th World Conference on Investment Casting (WCIC)
16 Frick L (2012) Ceramic composites give super-alloys strong competition. http://machinedesign.com/news/ceramic-composites-give-super-alloys-strong-competition. Accessed 16 July 2013
17 American Magnetics (2012) Characteristics of Superconducting Magnets. http://www.americanmagnetics.com/charactr.php. Accessed 16 July 2013