14. Tungsten

Tungsten is a very hard, dense, silvery-white metal that forms a protective oxide coating in air. Tungsten is highly resistant to corrosion, has the highest melting point of all metals and at temperatures over 1650 °C also has the highest tensile strength. Tungsten is one of the five major refractory metals.

Current supply of tungsten is dominated by Chinese producers. While the price of WO_3 with a concentration of 7.93 kilograms of tungsten per metric ton remained stable at an annual average of 0.15 US$/kg in the period 2009-2011,[*1] the price of tungsten tradable products[†] is (significantly) higher than it was 6 months ago, but has started to decrease.[2]

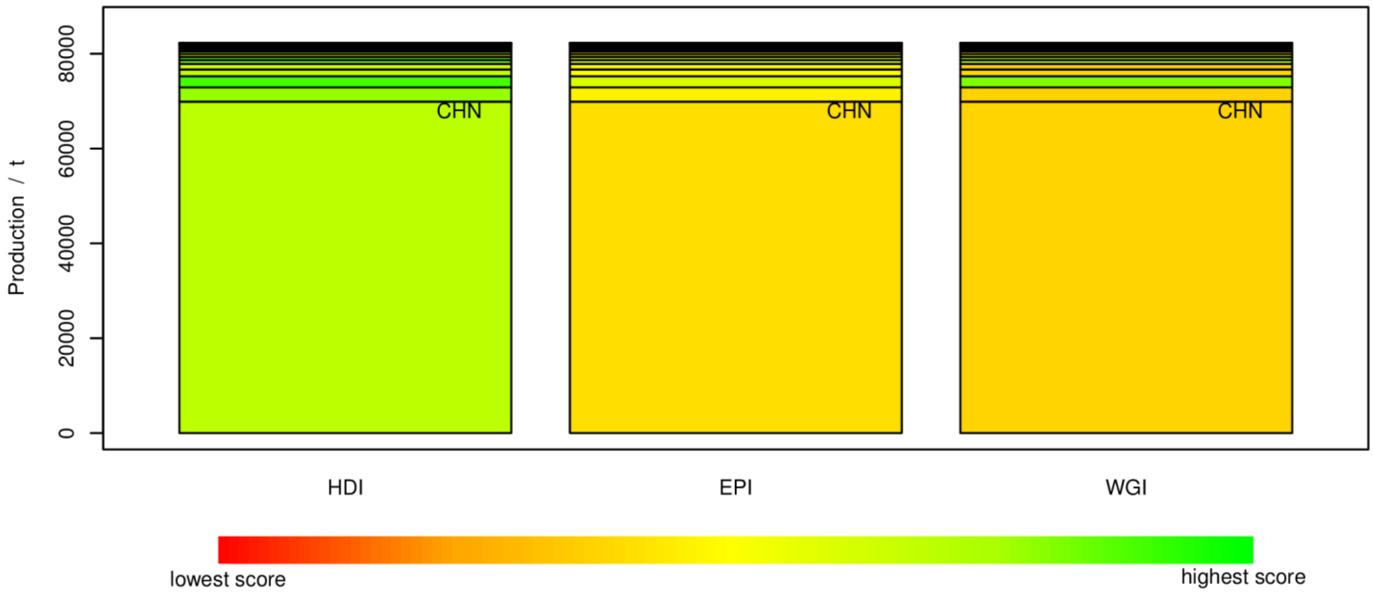

Figure 1: Distribution of natural tungsten[3] and corresponding scores of the producing countries in the Human Development Index (HDI)[4], Environmental Performance Index (EPI)[5], and World Governance Indicators (WGI)[6]. Both the EPI and WGI are used to assess supply risks with the EU methodology for determining critical raw materials.[7] CHN = China.

[*] European market, Metal Bulletin

[†] Concentrate, ammonium paratungstate (APT), tungsten carbide, tungsten oxide.

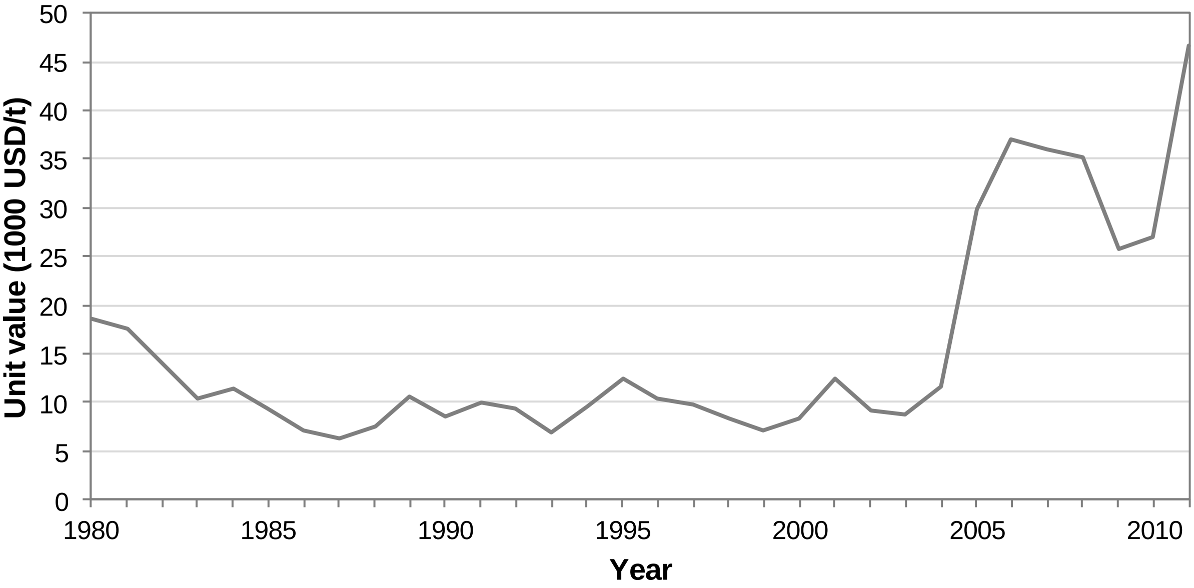

Figure 2: Tungsten price development during 1980 – 2011. The unit value is defined as the value in U.S. dollars of 1 t of tungsten apparent consumption (estimated). [8].

Uses and substitutability

Hardmetals

Cemented carbides, also called hardmetals, are the main field of application of tungsten.[9] The main constituent of the most widely used cemented carbide is tungsten carbide (WC, making up 85-95% of the hardmetal), an efficient electrical conductor with hardness close to diamond and with a melting point of 2770 °C. Hardmetals are used to make wear-resistant abrasives and cutters for drills, circular saws, milling and turning tools used by the metalworking, woodworking, mining, petroleum and construction industries.[10]

The dominance of WC-based cemented carbides in many different tooling and wear-resistant applications indicates the difficulty of establishing adequate substitutes for this material. However, WC-based cemented carbides may be substituted by tool steels, ceramics and cermets in different applications.[11,12] Tungsten-free cemented carbides (TFCC) or cermets are materials based on alternative high-melting compounds (as compared to tungsten carbide, WC), typically, titanium carbide or titanium carbonitride in metallic binder phase (Ni and/o Co), possibly with toughening additives.[13] Cermets combine the advantages of ceramics (excellent hardness and resistance to wear and oxidation, as well as low adhesion to the workpiece material) and metals (strength and impact resistance). The important advantage of TFCC is their microstructure that contains a complex carbide phase (K-phase) forming a frame around each carbonitride particle core and providing a strong bond between these hard phase particles and ductile binder metal. Cermets are also more lightweight as compared to WC-based hard metals [14]. Cermets are a viable alternative to the WC-based hardmetals in two major application areas: tribotechnical and machining applications involving no extreme loads.[13]

Tool/high speed steels

Historically, tungsten was an important alloying element for tool steels and high speed steels used in the working, cutting and forming of metal components. These steels must possess high hardness and strength, combined with good toughness over a broad temperature range. The relative amount of tungsten consumed in steelmaking declined constantly since the 1930s. Nevertheless, steel is currently the second largest consumer of tungsten worldwide, but tungsten consumption for steel differs considerably in different markets, from about 10% in the USA, Europe and Japan to close to 30% in Russia and China.[15]

The development of controlled atmosphere heat treating furnaces made it practical and cost effective to substitute part or all of the tungsten with molybdenum, which, combined with alloying with chromium, as well as with vanadium and nickel, yielded better performance at a lower price. Additions of 5-10% molybdenum efficiently increase the hardness and toughness of high-speed steels and help to maintain these properties at the high temperatures generated when cutting metals. Molybdenum provides another advantage: it prevents, especially in combination with vanadium, softening and embrittlement of steels at high temperature by causing the primary carbides of iron and chromium to form tiny secondary carbides, which are more stable at high temperatures.[16] The exceptional high temperature wear properties of molybdenum-containing high-speed steels are ideal for such applications as automobile valve inserts and cam-rings. Substitution of tungsten in tool/high speed steels seems thus possible.

Super-alloys

Tungsten-alloyed nickel- and cobalt-based super-alloys possess high-temperature strength and creep strength, high thermal fatigue resistance, good oxidation resistance, excellent hot corrosion resistance, air melting capability, air or argon re-melting capability and good welding properties. These super-alloys are used in aircraft engines, marine vehicles, and stationary power units as turbine blades and vanes, exhaust gas assemblies and as construction material for furnace parts. Tungsten accounts for solid solution strengthening, strengthening by formation of intermetallic compounds, and formation of carbides.[15] Molybdenum can substitute tungsten in these materials to some extent.[16]

Another opportunity for substitution in this application is the replacement of super-alloys by ceramic matrix composites. 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 W-containing super-alloys. In September 2010 General Electric (GE) reported that the company for the first time had been able to make a CMCs rotating part and tested CMCs-based turbine blades. GE Aviation plans to start constructing a plant for stationary engine components based on this technology this year. In February 2012, IHI, leading aircraft engine manufacturer in Japan released a news article that in 2015 they would finalize mass-production technology of CMCs parts for jet engine aiming commercialization of CMCs parts in 2020. CMCs appear to be very attractive substitute for super-alloys as they are strong, tough and can be mass produced.[17,18]

Mill products

Tungsten mill products, such as lighting filaments, electrodes, electrical and electronic contacts, wires, sheets, rods etc. or tungsten alloys used for armaments, heat sinks, radiation shielding, weights and counterweights account for about 10% of tungsten consumption.[9,19]

Since the beginning of the 20th century, tungsten has illuminated the world, about 4% of the annual tungsten production is consumed by the lighting industry. It is suited in this application because of its extremely high melting temperature (~3414 °C), low vapour pressure, high stiffness and excellent creep resistance at elevated temperatures.[9,20] The largest market is still for incandescent lamps but more than 70% of artificial lighting is generated today by discharge lamps, and this portion is steadily increasing.[15]

Tungsten is used in the form of wires, coils, and coiled coils in incandescent lamps, and as electrode in low- and high-pressure discharge lamps.

Tungsten is practically the only material used for electron emitters. Although other, more electropositive, metals would yield higher emission rates, the advantage of tungsten is its extremely low vapor pressure even at high temperatures. This property is also important for electrical contact materials. While more conductive metals like copper or silver evaporate (erode) under the conditions of an electric arc, tungsten withstands these.[15]

Tungsten is one of the most important components in modern integrated circuitry and tungsten-copper heat sinks are used to remove the heat of microelectronic devices.

Carbon nanotube filaments, induction technology and light-emitting diodes are potential substitutes for tungsten-containing products in these applications but replacement of tungsten-based products appears at present to be extremely difficult at the moment.

Summary

Substitution of WC-based cemented carbides in majority of applications, while potentially possible in many cases through the successful development of TFCC-technologies, would require significant time since they currently dominate the market. WC-based cemented carbides, however, seem to be less substitutable in tribotechnical and machining applications involving extreme loads.

Substitution of tungsten in super-alloys and in applications typical for W-containing super-alloys as well as in mill products requires further progress in the development of advanced materials, such as CMC and carbon nanotube-based products. A rapid replacement of W is thus rather problematic. At least 5 years' time will be needed for bringing CMC parts to the level of commercial production. In contrast, substitutability of tungsten in tool/high speed steels is, in principle, high.

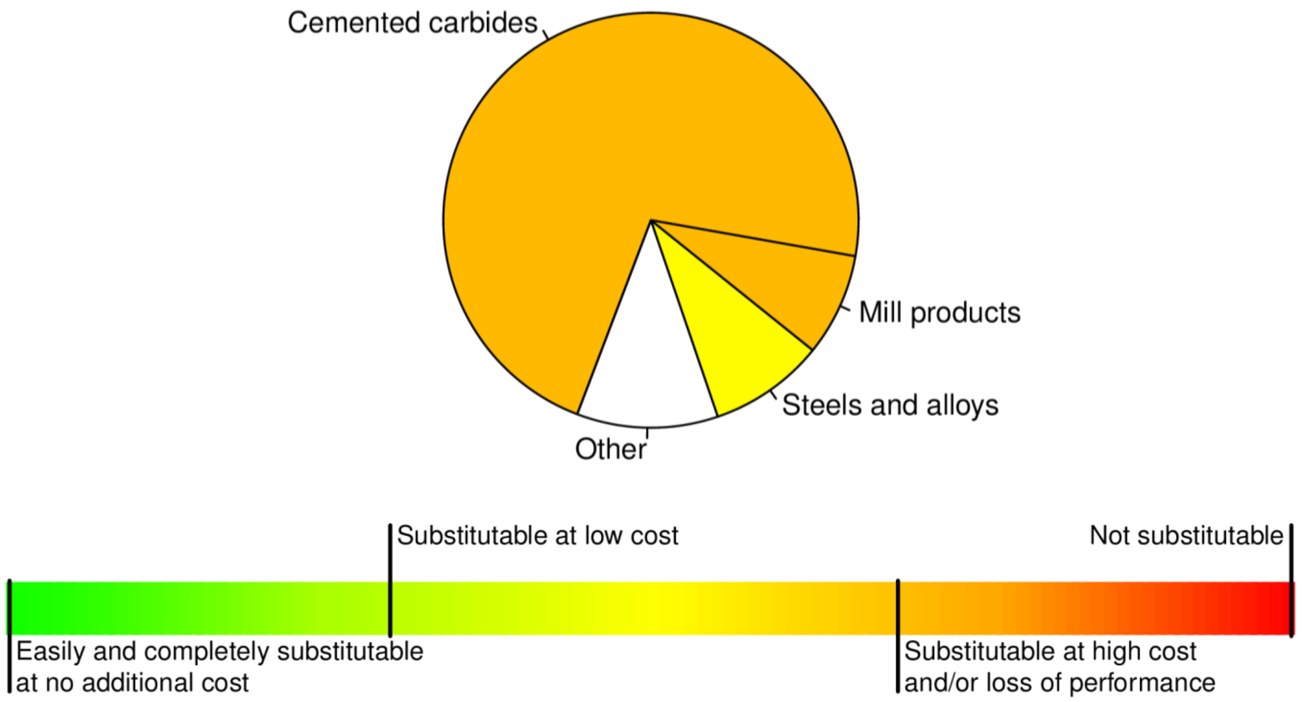

Figure 3: Distribution of end-uses[15] and corresponding substitutability assessment for tungsten. The manner and scaling of the assessment is compatible with the work of the Ad-hoc Working Group on Defining Critical Raw Materials (2010).

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