Materials **Tungsten**

Introduction

History of Tungsten

The history of tungsten goes back to the 17^{th} century. In 1758, the Swedish chemist Axel Fredrik Cronstedt discovered an unusually heavy mineral that he named 'tung-sten', Swedish for heavy stone. Cronstedt was convinced that this mineral contained a new and as yet undiscovered element.

It was not until 1781 that a fellow Swede, Carl Wilhelm Scheele succeeded in isolating the oxide, WO_3 (tungsten trioxide). Independent of Scheele, two Spanish chemists, the brothers Elhuyar de Suvisa, first reduced the mineral wolframite to tungsten metal in 1783.

Jöns Jacob Berzelius (1816) and later Friedrich Wöhler (1824) described the oxides and bronzes of tungsten and gave the new name 'wolfram'. Although both Germany and Scandinavia used this name, the Anglo-Saxon countries preferred Cronstedt's 'tungsten'.

The first attempts to produce tungsten steel were made in 1855, but industrial use was not possible due to the high price of tungsten metal. The alloying and hardening of steel plates with tungsten was not performed until the late 19^{th} century, a process that initiated widespread application and the launch of high speed steels by Bethlehem Steel in 1900 at the Paris World Exhibition.

W. D. Coolidge made the next important breakthrough in tungsten's history in 1903. Coolidge succeeded in preparing a ductile tungsten wire by doping tungsten oxide prior to reduction. The resulting metal powder was then pressed, sintered and forged into thin rods from which tungsten wire was drawn. This procedure proved elemental in the rapid development of the lamp industry.

The year 1923 marks the invention of hardmetal, a combination of tungsten carbide WC and cobalt by liquid phase sintering, by K. Schröter. Hardmetal now constitutes the main application for tungsten.

Tungsten Minerals

Tungsten occurs naturally in the form of chemical compounds with other elements. Although more than twenty tungsten bearing compounds have been discovered, only two of them have industrial importance: wolframite and scheelite.

Compound	Formula	% WO_3
Wolframite	$(Fe, Mn)WO_4$	76.5
Scheelite	$CaWO_4$	80.5

Wolframite is a generic name for iron and manganese tungstates in which the iron:manganese ratio may vary. A mineral with more than 80% $FeWO_4$ is known as Ferberite while one with more than 80% $MnWO_4$ is called Hubnerite.

The world's known tungsten reserves are estimated at 3.3 million tons W, including reserves that are not currently economically workable. At current consumption rates these reserves will last until approximately 2097. The largest reserves are located in China, followed by Canada and the former Soviet Union.

Mining and Processing

Tungsten is usually mined underground although open cast mines do exist but are rare. Most tungsten concentrates are chemically processed to form ammonium paratungstate (APT), the main intermediate in tungsten processing. Wolframite concentrates can be smelted directly with charcoal or coke in an electric arc furnace to form ferrotungsten (FeW) which is used as an alloying material in steel production.

- Ammonium Paratungstate
  APT [$(NH_4)_{10}W_{12}O_{41}\cdot 5H_2O$] is usually calcined (heated) to yellow or blue tungsten oxide (WO_3 or $W_{20}O_{58}$). It is also the main tungsten raw material traded on the market.

- Tungsten metal Powder
  Yellow or blue tungsten oxide is reduced to tungsten metal powder by the use of hydrogen. The reaction is carried out in pusher furnaces, whereby the oxide passes through the furnace in boats at a temperature of 700 – 1000 ^{o}C. A rotary furnace may also be employed for this process.

- Tungsten Carbide
  The majority of tungsten metal powder produced is transformed to tungsten carbide (WC) by a process known as carburization. The tungsten powder is reacted with pure carbon powder at a temperature of 900 – 2200 ^{o}C in pusher furnaces.

- Cast Carbide
  By melting together a mixture of tungsten metal and tungsten carbide, a eutectic composition of WC and W_2C is produced. The molten mixture is cast and rapidly quenched to form extremely hard solid particles have a fine crystal structure.

Recycling

Recycling is an important factor in the world's tungsten industry. The tungsten process industries can treat almost every type of tungsten containing scrap and it is estimated that around 30% is recycled.

Properties of Tungsten

Tungsten is a greyish-white lustrous metal, which is a solid at room temperature. Tungsten has the highest melting point and lowest vapour pressure of all metals, and at temperatures over 1650°C has the highest tensile strength. It has excellent corrosion resistance and is attacked only slightly by most mineral acids. Tungsten is one of the highest melting point materials and exhibits excellent high temperature properties, especially hardness. It is a heavy metal and has the lowest coefficient of expansion of all metals.

Property	Value
Chemical Symbol	W
Atomic number	74
Atomic weight	183.85
Melting point	3410°C
Boiling point	5530°C
Density	19300 kg m^{-3}
Electrical Conductivity %IACS	31
Hardness Vickers	3430 MN/m^2
Tensile Strength	550 MPa
Young's Modulus	411 GPa
Thermal expansion coefficient	4.5 x 10^{-6} cm/°C
Thermal conductivity	1.74 W/cm°C

Use of Tungsten

Cemented Carbide

Cemented carbide or hardmetal, as it is often called, is produced by 'cementing' tungsten carbide (WC) grains in a tough matrix of cobalt metal by liquid phase sintering. The high solubility of WC in cobalt at high temperatures results in a material that combines excellent strength, toughness and high hardness.

The addition of titanium carbide and tantalum carbide considerably improves the high temperature wear resistance, hot hardness and oxidation stability of the hardmetals. Compared to high speed steel, the WC-TiC-(Ta,Nb)C-Co hardmetals increase cutting speeds from $\approx$ 50 m/min to 250m/min for the turning and milling of steel.

Tungsten in Steel

Tungsten was one of the first alloying elements used to improve the properties of steel. It has been one of the most important alloying elements in tool steels and is added to enhance hardness and cutting efficiency.

Tool Steels are highly alloyed steels used primarily in working, cutting and forming metal components. The properties of tool steels include high hardness and strength and toughness over a broad temperature range.

When tool steels contain more than 7% tungsten, molybdenum and vanadium, together with more than 0.60% carbon, they are referred to as High Speed Steels (HSS). This name is indicative of their ability to machine metals at high speeds.

Tungsten Alloys

- Cobalt-chromium-tungsten alloys (stellite) are a group of wear resistant alloys that are used in applications where a tough wear resistant material is required, i.e. bearings, valve seats and pistons.

- Superalloys are nickel, iron or cobalt based alloys with high content of tungsten, molybdenum, tantalum and rhenium for applications where extreme mechanical strength combined with excellent erosion resistance at high temperatures is required (i.e. turbine blades).

- Tungsten heavy metal (heavimet, densalloy) is a sintered pseudalloy with an iron-copper or iron-nickel binder for applications where a non-brittle high-density material is required. For example, counterweights for aircraft, darts or in golf club heads. In addition, it is used in military applications as high velocity penetrators for armour piercing weapons.

Electronic and Electrical Industry

Tungsten is practically the only material used for electron emitters. Although other, more electropositive materials would yield higher emission rates, tungsten's advantage is its extremely low vapour pressure. Tungsten is able to withstand erosion under the conditions of an electric arc whilst other more conductive metals, Silver and Copper (Ag, Cu), cannot. The uses of tungsten in the electrical and electronic industries are too numerous to list within this document.

Lamp Industry

Tungsten wire is ideal for electric lamps filament because it displays excellent creep resistance at elevated temperatures, an extremely high melting temperature and a low vapour pressure at high temperatures.

Glazing

Vapour deposited tungsten oxide layers are functional in self-darkening window panes. Tungsten trioxide (WO_3) is fully transparent in the form of a thin layer. The action of sunlight converts WO_3 to the dark blue $W_{20}O_{58}$ in a reversible reaction to reduce the transmission of bright light through the pane.

Internet Resources

The International Tungsten Industry Association is based in the UK and promotes the use of tungsten around the world. It organises seminars and disseminates information regarding all stages of tungsten use.

Properties of tungsten are presented by webelements.
http://www.webelements.com/webelements/elements/text/W/key.html

Efunda, Engineering Fundamentals present the physical properties of tungsten.
http://www.efunda.com/materials/elements/element_info.cfm?Element_ID=W

Some basic details including the history of tungsten is available on the Midwest Tungsten Service website.