A **METAL**CUTTING **WHITE PAPER**

TUNGSTEN WIRE 101: OVERVIEW OF A UNIQUELY USEFUL MATERIAL

A PRIMER ON THE BASICS OF TUNGSTEN WIRE, ITS PROPERTIES, AND ITS APPLICATIONS

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Tungsten Wire Filament, 1904

Introduction

In the twenty-first century, tungsten wire may be considered by some to be a material whose time has come and passed, as its primary use in incandescent lighting fades with the growing popularity of compact fluorescent lamps (CFLs) and now (and inevitably) light emitting diodes (LEDs). However, while a relatively small percentage of the global tungsten powder production is used for the manufacture of lamp filaments, tungsten wire continues to be a product that has a large number of diverse applications, for many of which tungsten wire has no known substitute.

This paper provides an overview of tungsten wire in order to bring to light its many applications and its importance — even when tungsten wire may no longer be the source of your reading light!

What's in a name?

The name "tungsten," which is used in the United States and in English, French, and several other languages, comes from the Swedish words tung and sten (meaning "heavy stone), and is the old Swedish name for the mineral scheelite, another source of tungsten ore. Ironically, "tungsten" is not used in Sweden or the other Nordic countries; there, and in most Germanic and Slavic languages, the name "wolfram" or "volfram" — from the German name for wolframite — is used. And although the letter T remains available for use on the periodic table, the word wolfram gave us W as the symbol for tungsten.

Tungsten Over Time: A Brief History

Tungsten has a long and storied history dating back to the Middle Ages, when tin miners in Germany reporting finding an annoying mineral that often came along with tin ore and reduced the yield of tin during smelting. The miners nicknamed the mineral *wolfram* for its tendency to "devour" tin "like a wolf."

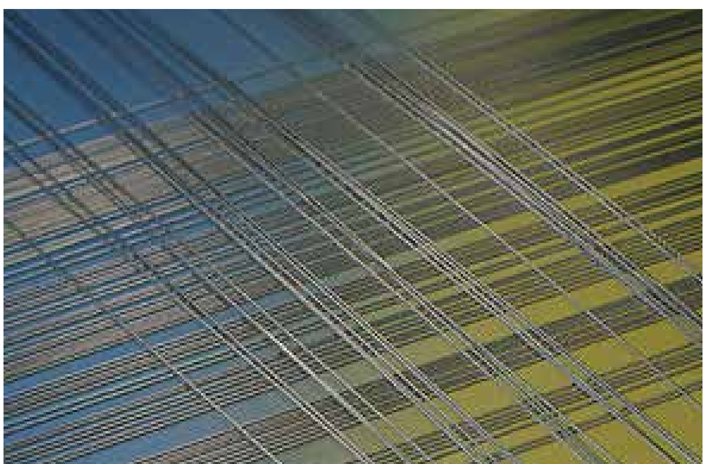
Tungsten was first identified as an element in 1781, by the Swedish chemist Carl Wilhelm Scheele, who discovered that a new acid, which he called tungstic acid, could be made from a mineral now known as scheelite. Scheele and Torbern Bergman, a professor in Uppsala, Sweden, developed the idea of using charcoal reduction of that acid to obtain a metal.

Tungsten as we know it today was finally isolated as a metal in 1783 by two Spanish chemists, brothers Juan José and Fausto Elhuyar, in samples of the mineral called wolframite, which was identical to tungstic acid and which gives us tungsten's chemical symbol (W). In the first decades after the discovery, scientists explored various possible applications for the element and its compounds, but the high cost of tungsten made it still impractical for industrial use.

In 1847, an engineer named Robert Oxland was granted a patent to prepare, form, and reduce tungsten to its metallic format, making industrial applications more cost-effective and therefore, more feasible. Steels that contain tungsten began to be patented in 1858, leading to the first self-hardening steels in 1868. New forms of steels with up to 20% tungsten were displayed at the 1900 World Exhibition in Paris, France, and helped to expand the metal work and construction industries; these steel alloys are still widely used in machine shops and construction today.

In 1904, the first tungsten filament light bulbs were patented, taking the place of carbon filament lamps that were less efficient and burned out more quickly. Filaments used in incandescent light bulbs have been made from tungsten ever since, making it essential to the growth and ubiquity of modern artificial lighting.

In the tooling industry, the need for drawing dies with diamond-like hardness and maximum durability drove the development of cemented tungsten carbides in the 1920s. With the economic and industrial growth after the World War II, the market for cemented carbides used for tool materials and construction parts also grew. Today, tungsten is the most widely used of the refractory metals, and it is still extracted primarily from wolframite and another mineral, scheelite, using the same basic method developed by the Elhuyar brothers.



Tungsten Wire

Production of Tungsten

Pure pre-sintered tungsten is a light gray or whitish metal that is soft enough to be cut with a hacksaw and ductile enough to be drawn into wire or extruded. When contaminated with other materials, tungsten becomes brittle and difficult to work with.

To extract tungsten metal from wolframite, scheelite, and other, less common sources, the ores are crushed, cleaned, and treated with alkalis to form tungsten trioxide. The tungsten trioxide is then heated with carbon or hydrogen gas to form tungsten metal powders.

Tungsten is often alloyed with steel to form tough metals that are stable at high temperatures and used to make products such as high-speed cutting tools and rocket engine nozzles, as well as the large volume application of ferro-tungsten as the prows of ships, especially ice breakers. Metallic tungsten and tungsten alloy mill products are in demand for applications in which a high-density material (19.3 g/cm3) is required, such as kinetic energy penetrators, counterweights, flywheels, and governors. Other applications include radiation shields and x-ray targets.

Tungsten also forms compounds — for example, with calcium and magnesium, producing phosphorescent properties that are useful in fluorescent light bulbs. Tungsten carbide is an extremely hard compound that accounts for about 65% of tungsten consumption and is used in applications such as the tips of drill bits, high-speed cutting tools, and mining machinery. Tungsten carbide is famous for its wear resistance; in fact, it can only be cut using diamond tools. Tungsten carbide also exhibits electrical and thermal conductivity, and high stability. However, it brittleness is an issue in highly stressed structural applications and led to the development of metal-bonded composites, such as the additional of cobalt to form a cemented carbide.

Commercially, tungsten and its shaped products — such as heavy alloys, copper tungsten, and electrodes — are made through pressing and sintering in near net shape. For wire and rod wrought products, tungsten is pressed and sintered, followed by swaging and repeated drawing and annealing, to produce a characteristic elongated grain structure that carries over in finished products ranging from large rods to very thin wires.

Functional Properties of Tungsten Metal

74 183.84
W
TUNGSTEN

Tungsten has the highest melting point of all known metallic elements, at 3422°C (6192°F), and is extremely hard at both normal temperatures and elevated temperatures. It generally resists oxidation and creep, and its electrical resistance is very high. Tungsten also has low vapor pressure at temperatures above 1650°C (3000°F) and high tensile strength. This range of properties makes tungsten uniquely useful in many industries and products around the world, from high-speed cutting tools and jet turbine engines, to ammunition, lighting, and fishing weights. To be fair, tungsten fishing weights are fungible, but how many lead weights do we really want at the bottom of lakes and rivers?

Jet Turbine

Due to its high melting point, tungsten is never manufactured in a liquid state, using powder metallurgy. Unlike the prototypical images of ferrous metal manufacturing, with its vats of molten metal, tungsten manufacturing offers slightly less dramatic photo opportunities, with oxidation during swaging being the most vivid. Its highest melting point is what makes tungsten the absolutely only choice for the highest temperature applications. However, tungsten is widely used at lower temperatures for applications that can benefit from its high elastic modulus, density, or shielding characteristics.

Tungsten's melting point makes liquid tungsten highly impractical for commercial purposes. The fundamental problem is, how do you make a container that could hold liquid tungsten without the container itself melting before the tungsten reached the liquid state? Even carbon, with a melting point of 3550°C (6422°F), cannot be used to hold liquid tungsten, because at high temperatures the two react to form tungsten carbide. While liquid tungsten has been produced experimentally, using super-conductive copper crucibles in which the heat is pulled away from the surface of the crucible so that it remains intact, it remains impractical for commercial volumes.

Beyond the paradox of holding liquid tungsten, there are other practical quandaries presented by the properties of tungsten. Machining pure tungsten has always been a challenge. While diamond tools are indispensable for machining tungsten carbide, interestingly they are not very useful for machining pure tungsten, because the metal will compact into the spaces between the diamonds and eliminate the diamonds' cutting facets. Again, while tungsten carbide can be, albeit expensively, drawn into a tube form, pure tungsten cannot be drawn over a mandrel into a tube, nor extruded into a tube. The only option — and it is a very expensive option, with dimensional ratio limitations — is to "gun drill" a tungsten solid to render a tube.

Despite these challenges, tungsten is widely used in today's manufacturing, in an array of applications including magnets, welding electrodes, television sets, microwave ovens, cutting, mining, and metalworking tools. These products are in addition to tungsten as a staple material in the lighting industry — used to make fluorescent light bulbs as well as filaments for traditional incandescent light bulbs. Tungsten is also used as a target for X-ray production, as heating elements in electric furnaces, and for parts of spacecraft and missiles, which must withstand extremely high temperatures.

Characteristics of Tungsten Wire

In the form of wire, tungsten maintains many of its valuable properties, including its high melting point, a low coefficient of thermal expansion, and a low vapor pressure at elevated temperatures. Because tungsten wire also demonstrates good electrical and thermal conductivity, it is used extensively for lighting, electronic devices, and thermocouples.

Wire diameters are generally expressed in millimeters or mils (thousandths of an inch). However, tungsten wire diameter is usually expressed in milligrams — 14.7 mg, 3.05 mg, 246.7 mg, and so on. This practice dates back to the days when, lacking tools for accurately measuring very thin wires (.001" up to .020" in diameter), the convention was to measure the weight of 200 mm (about 8") of tungsten wire and calculate the diameter (D) of tungsten wire based on the weight per unit length, using the following mathematical formula:

- D = 0.71746 x square root (mg weight/200 mm length)*

The standard diameter tolerance is ± 3% of the weight measurement, although tighter tolerances are available, depending on the application for the wire product. This method of expressing diameter also assumes that the wire has a constant diameter, with no significant variation, necking down, or other conical effects anywhere on the diameter. For thicker wires (.020" to .250" diameter), the millimeter or mil measurement is used; the tolerances are expressed as a percentage of the diameter, with a standard tolerance of ±1.5%.

Most tungsten wire is doped with trace amounts of potassium, creating an elongated, interlocking grain structure that exhibits non-sag properties after recrystallization. This practice dates back to tungsten wire's primary use in incandescent light bulbs, when white-hot temperatures would cause filament sag and lamp failure. The addition of the dopants alumina, silica, and potassium at the powder mixing stage would alter the mechanical properties of the tungsten wire. In the process of hot swaging and hot drawing the tungsten wire, the alumina and silica out-gas and the potassium remains, giving the wire its non-sag properties and enabling incandescent bulbs to operate without arcing and filament failure.

While the use of tungsten wire today has expanded beyond filaments for incandescent lamps, the use of dopants in tungsten wire manufacturing continues. Processed to have a higher recrystallization temperature than when in its pure state, doped tungsten (as well as molybdenum wire) can remain ductile at room temperature and at very high operating temperatures. The resulting elongated, stacked structure also gives the doped wire properties such as good creep resistance, dimensional stability, and slightly easier machining than the pure (undoped) product.

Doped tungsten wire is typically produced in sizes from less than 0.001" up to 0.025" in diameter and is still used for lamp filament and wire filament applications, as well as being beneficial in oven, deposition, and high-temperature applications. In addition, some companies (including Metal Cutting Corporation) offer pure, undoped tungsten wire for applications where purity is paramount. At this time, the purest tungsten wire available is 99.99% pure, made from 99.999% pure powder.

Unlike ferrous metal wire products — which can be ordered in different annealed states, from full hard to a wide range of softer final conditions — tungsten wire as a pure element (and aside from a limited choice of alloys) can never have such a range of properties. However, because processes and equipment vary, the mechanical properties of tungsten must vary between manufacturers, because no two manufacturers use the same pressed bar size, specific swaging equipment, and drawing and annealing schedules. Therefore, it would be a remarkably lucky coincidence if tungsten made by different companies had identical mechanical properties. In fact, they can vary by as much as 10%. But to ask a tungsten wire manufacturer to vary its own tensile values by 50% is impossible.

Medical Devices

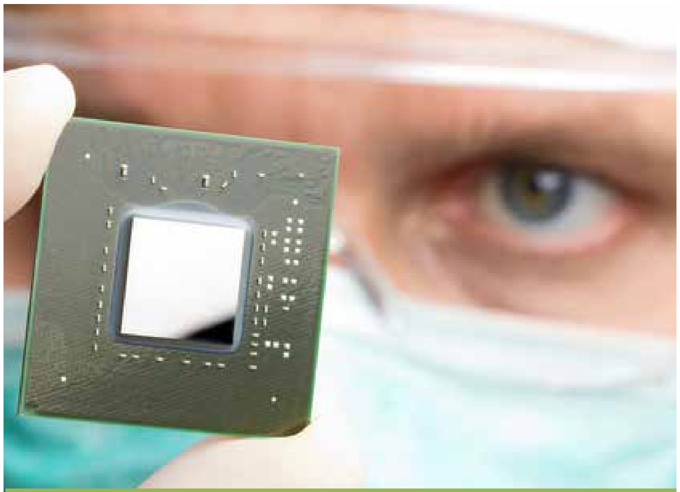
Practical Applications for Tungsten Wire

In addition to being essential to the production of coiled lamp filaments for lighting products, tungsten wire is useful for other goods where its high temperature properties are of value. For example, because tungsten expands at nearly the same rate as borosilicate glass, thicker wire sizes are straightened, finish-ground, and cut into rod pieces that are used for glass-to-metal seal lead parts in the lighting and electronic industries.

Tungsten wire is widely used in medical devices applications where electric current is utilized and where precision is critical. For instance, tungsten wire is used to make probes for the medical technique of electrocautery, where a metal probe is heated by electric current to a dull red glow and applied to the targeted tissue to cut and cauterize — basically, to remove an undesired growth and mitigate bleeding. The tungsten wire can be used in the form of a straight, tapered, solid probe or in lengths that can be curved into a loop that acts as a cutting tool. With its high melting point, tungsten holds its shape and does not flex or deform at the temperatures required to efficiently cut and cauterize tissue.

Despite not being a particularly conductive material, tungsten wire is highly valuable for the purposes of brain stimulation and neural probing, where the diameter of the wire must be incredibly small and narrow. At a small diameter and long length, tungsten wire maintains its straightness and shape — characteristics that are vital for directional accuracy — far more than any other metal. In addition, tungsten wire's high tensile values offer a cost-effective alternative to specialty metals for steerable guide wires in minimally invasive medical procedures. Its high density also makes tungsten wire highly radiopaque, allowing it to excel in fluoroscopic applications.

For use in industrial furnaces, tungsten wire holds its shape at the highest temperatures, making it excellent for support structures, oven mats, and other weight-bearing surfaces that need to maintain the position of the object being subjected to the furnace temperatures. Tungsten wire's heat resistance enables it to hold the object in the proper location in the hot zone without sagging, collapsing, falling apart, or otherwise moving the object out of the optimal position.



Integrated Circuit Maufacture

Although tungsten wire is being replaced in many electronic applications, it is integral to the manufacture of today's integrated circuits. A cable of woven tungsten wire has proven to be the only material suitable for the very high temperature required to turn pure molten silicon into a cylindrical crystal, which is then cooled, sliced into wafers, and polished to provide the substrates for semiconductors. Additionally, tungsten wire is utilized in the probes used to test integrated circuits when they are still in monocrystalline wafer form.

Another industrial application in which tungsten wire's high temperature properties prove to be indispensable is in the borescopes used to take measurements of the interior space of very high temperature environments. For areas that are inaccessible by other means, these borescopes are commonly used in the inspection of engines, turbines, pipes, and tanks.

With its extremely low vapor pressure at high temperatures, tungsten wire is also used in the vacuum metalizing coils utilized in the process of coating the surfaces of low-cost plastic products — such as toys, jewelry, cosmetic containers, and small decorative parts — with metal evaporates. The products or parts are placed in a vacuum with the coating metal, which is heated with the coils until it has evaporated; the vapor settles on the products/parts, quickly and completely coating the surfaces with a thin, uniform film of the metallic evaporate.

Conclusion

Tungsten is widely used as a refractory metal, and in wire form it is essential to the production of lighting products and other goods where its unique set of properties — including high melting point, low coefficient of thermal expansion, and low vapor pressure at elevated temperatures, as well as electrical and thermal conductivity — are highly valuable.

Beyond the production of coiled incandescent lamp filaments, there remain many important applications in which tungsten wire is indispensable. As you read above, these include glass-to-metal seals in lighting and electronics, small diameter probes for high-precision medical procedures, support structures for industrial furnaces, semiconductor manufacture and testing, and evaporation sources in metalizing processes. Like modern lighting itself, tungsten wire continues to evolve as a material whose use is growing as new applications are discovered and new market opportunities arise.

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