Metallurgy for Woodturners

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Part 1 - Metals of concern to woodturners

Metallurgy Definition

1. The science that deals with procedures used in extracting metals from their ores, purifying and alloying metals, and creating useful objects from metals.[1]
2. The study of metals and their properties in bulk and at the atomic level.[1]

   The technology and science of metallic materials. Metallurgy as a branch of engineering is concerned with the production of metals and alloys, their adaptation to use, and their performance in service. As a science, metallurgy is concerned with the chemical reactions involved in the processes by which metals are produced and the chemical, physical, and mechanical behavior of metallic materials.[1]

Iron: Latin - Ferrum

Properties

Hardness – Metallurgy mostly deals with indentation hardness, which is a metals resistance to permanent deformation. However, in the world of cutting tools, hardness also deals with scratch and wear resistance. This is important to a woodturning tool's ability to maintain an edge. Generally, the harder the metal, the better the tools ability to hold an edge.[2]
Toughness/Impact Strength – ability of a material to resist shock [2]
Red Toughness – Ability to maintain hardness, strength and/or cutting edge at high temperatures. Most important property of high speed steels.[2]
Fatigue Strength – ability of a material to resist repeated loading. This includes vibration and repeated loading and unloading.[2]
Ductility – ability of a material to bend, stretch or distort without breaking.[2]
Brittleness – tendency of a material to stretch or deform very little before breaking.[2]
Others - Corrosion/Chemical Resistance, Weight, Machinability, Weldability, etc.[2]

Iron/Ferric Alloys

What is an alloy? - An alloy is hybrid of two or more elements, at least one of which is a metal, and where the resulting material has metallic properties.[3]
Why do we have alloys? - Alloying metals provides a means to improve specific properties of resulting metals.
Overview of iron alloys.
Alloying elements (abbreviated):
Carbon (C) – Present in all steel and is the principal hardening element. Lowers ductility, toughness and machinability.[4]
Boron (B) - Added in amounts of 0.0005% to 0.03% it significantly increases the harden ability of steel.[4]
Chromium (Cr) - Significantly increases hardness, edge-holding capacity , wear-

resistance. Significantly improved hardening ability during heat treatment. Reduces impact resistance.[4]

Cobalt (Co) – Improves the retention of hardness and hot strength. Encourages the formation of graphite.[4]

Molybdenum (Mo) – Improves harden ability, hardness, and strength at elevated temperatures. Helps prevent temper brittleness and promotes fine grain structure. Increases yield point and tensile strength. Forms carbides readily and thus improves edge-holding properties.[4]

Vanadium (V) - Additions of vanadium up to 0.05% increase the harden ability of medium-carbon steels. It is a strong carbide former, increases wear resistance, retention of cutting edges and high temperature strength. Greatly improves red hardness and diminishes overheating sensibility.[4]

Tungsten (W) - Powerful carbide-former; its carbides are very hard. It improves toughness and inhibits grain growth.[4]

Alloying properties

Trade-off between hardness and toughness. Generally, the harder the metal, the more brittle it is.

Cast Iron - 2%-5% Carbon

Grey Cast Iron – Most common. Commonly used for lathes and other machinery due to low cost and vibration absorption properties. Added silicon(2%) in melt causes carbon in the molten iron come out solution to form graphite micro-flakes throughout casting which, along with the weight, helps absorb vibrations.[3] Graphite aids in machining.

Other types of cast iron - White, Ductile, Malleable cast irons. Also special alloy cast irons.

Steel - 0.05%-2% Carbon

Low Carbon (Mild) Steel – 0.05%-0.35% Carbon

Mild steel is the least expensive type of steel. While it lacks the ability to become as hard and strong as other steels, it is still harder than most materials and is one of the most widely used materials.[2]

Medium Carbon Steel – 0.35% - 0.5% Carbon

Between low carbon and high carbon in hardness and strength.[2]

High Carbon Steel – 0.5% - 1%

High carbon steel can be hardened through quenching processes to a point significantly harder than the unhardened steel.[2]

Tool Steel

Carbon and alloy steels that are particularly well-suited for tools.[3]

W1 – Water hardening

ANSI W1 Composition[5]:

C – 0.70-1.50%	Cr – 0.15%	W – 0.15%	P – 0.025%
Mn – 0.10-0.40%	Ni – 0.20%	V – 0.10%	S – 0 .025%
Si – 0.10-0.40%	Mo – 0.10%	Cu – 0.20%	

O1 – Oil hardening

Much more magnesium.

A2 – Air Hardening

More chromium than carbon.

S7 – Shock-resisting.

High Speed Steel

M2 – Molybdenum

Probably most common high speed steel used for woodturning tools.

ANSI M2 Composition[5]:

C – 0.78-1.05%	Cr – 3.75-4.50%	W – 5.50-6.75%	P – 0.03%
Mn – 0.15-0.40%	Ni – 0.3%	V – 1.75-2.20%	S – 0.03%
Si – 0.20-0.45%	Mo – 4.50-5.50%	Cu – 0.25%	

ASP 2030 & 2060

ASP 2030 contains 8.5% cobalt.[6]

ASP 2060 contains 10.5% cobalt plus increase in several other alloying elements.[7]

A11 (Crucible 10V)

"... optimized the vanadium content to provide superior wear resistance while maintaining toughness and fabrication characteristics comparable to D2 and M2."- From Crucible data sheet.[8]

Crucible V15

Intended as an improvement to A11 (CPM 10V). Contains even more vanadium and carbon.[9]

Carbide

Carbide is a compound of carbon with a less electronegative element.[3] It is not a "steel".

Tungsten Carbide (WC)

Tungsten Carbide is produced using a wet chemical process where the carbon and tungsten are mixed at the molecular level in an aqueous solution and processed though proprietary heat treatments.[10]

Cutting tools are usually "tungsten-carbide cobalt", also called "cemented carbide", a metal matrix composite where the tungsten carbide particles are "cemented" together to form the tool with cobalt acting as the matrix, or "glue", holding the particles together.[3]

Tungsten carbide tools are considerably harder than steel and maintain their cutting edges far longer. However, it is also far more brittle, so it usually used in as a replaceable cutting "bit". Note that they cannot be sharpened with conventional aluminum oxide grinding wheels,you must use either a silicon carbide (green) grinding wheel, diamond grinding wheel, diamond sharpening "stone".

Carbide tools usually come in grades referred to as "C-Grades". Grades refer to amount of cobalt binder, hardness and grain size. Grades are used to apply tools to applications, such are roughing or finishing work.

Russ Fairfield argues that carbide tools do not have a "fine" enough edge for most woodturning applications, see http://www.woodcentral.com/russ/russ10.shtml for his article on this subject.

Iron Carbide

Iron Carbide particles form in steel during heat treating processes. They greatly increase the steels hardness and ability to maintain an edge. Several alloying elements

help promote the formation of carbides in tool steels. More on this later.

Aluminum – (or aluminium for the rest of the world)

Properties

Lightweight - Aluminum is about one-third the wight of equal volume of copper, steel or brass.[10]

Strength - Aluminum can withstand heavy loads and pressure; when alloyed appropriately, its strength approaches that of steel.[10]

High strength-to-weight ratio - The ratio of the tensile strength of aluminum, divided by density, is higher than any other metal. [10]

Corrosion resistance - The formation of a microscopic film of aluminium oxide on the surface of the metal protects it against the corrosive influences of water, salt and other influences.[10]

Availability - Alumina is the most abundant metallic element in the earth's crust. [10]

Heat treatable – Many aluminum alloys can be heat treated.[10]

Alloys

Different alloys exist for either extruding or casting aluminum.

Extruded/Wrought

6061 – One of the most common alloys. It has generally good mechanical properties and is heat treatable and weldable.[10]

Zinc alloys

ZAMAK (ZA) alloys – alloy of zinc,aluminum, magnesium and copper.

Offers combination of superior mechanical properties and low melting/manufacturing costs. These alloys melt at low temperatures.[11]

ZA castings are now competing with cast iron, bronze, and aluminum because of various property and processing advantages.[12]

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