Hardness of Materials

Compiled by CD Hepler
Feb, 2008

The subject of harness comes up in two main connections: edge tools (knives, plane irons, etc.) and abrasives (stones, sandpaper, etc.)

The Rockwell hardness scale is more commonly found in connection with edge tools, and Mohs Scale, in connection with abrasives.

Rockwell Hardness Scale

The Rockwell scale is one of several definitions of hardness in materials science. It characterizes the *indentation hardness* of materials through the depth of penetration of an indenter loaded on a material sample, compared to the penetration in some reference material.

There are several Rockwell scales, the most commonly used being the "B", and "C" scales. Both express hardness as an arbitrary dimensionless number. The B-scale is used for softer materials (such as aluminum, brass, and softer steels). It employs a hardened steel ball as the indenter and a 100kg weight to obtain a value expressed as "HR-B". The C-scale, for harder materials, uses a diamond cone, known as a Brale indenter and a 150kg weight to obtain a value expressed as "HR-C".

Readings below HR-C 20 are generally considered unreliable, as are readings much above HR-B 100. Several other scales, including the extensive A-scale, are used for specialized applications. There are special scales for measuring case-hardened specimens.

Common values

Very hard steel (e.g. a good knife blade) HR-C 55 to HR-C 62 or so.
Axes, chisels, etc. HR-C 40 to 45, up to the low 60's
Good Plane Irons HR-C in the high 50's to the low 60's
High Carbon and High Speed Steels: HR-C 55-60
Cobalt Steel: 58-64
Carbide 70+

Moh's Scale

Mohs' scale of hardness characterizes hardness as *scratch resistance*. For example, if some material is scratched by apatite but not by fluorite, its hardness on Mohs scale is 4.5. Mohs' scale is usually applied to minerals.

I think that the original scale used ten minerals, with diamond, the hardest, receiving a 10. The table below shows comparison with absolute hardness measures by a sclerometer. Mohs' is a ordinal scale, so numerical differences and ratios are approximations and may be misleading.

On the Mohs scale, a fingernail has hardness 2.5; copper penny, about 3.5; a knife blade, 5.5; window glass, 5.5; steel file, 6.5. Using these ordinary materials of known hardness can be a simple way to approximate the position of a mineral on the scale.

Hard-ness	Mineral	Absolute Hardness
1	Talc ($Mg_3Si_4O_{10}(OH)_2$)	1
2	Gypsum ($CaSO_4 \cdot 2H_2O$)	2
2.5 to 3	Gold, Silver	
3	Calcite ($CaCO_3$), copper penny	9
4	Fluorite (CaF_2)	21
4 to 4.5	Platinum	
4 to 5	Iron	
5	Apatite ($Ca_5(PO_4)_3(OH^-,Cl^-,F^-)$)	48
6	Orthoclase Feldspar ($KAlSi_3O_8$)	72
7	Quartz (SiO_2)	100
7-8	Hardened Steel	
8	Topaz ($Al_2SiO_4(OH^-,F^-)_2$)	200
9	Corundum (Al_2O_3)	400
11	Fused zirconia	
12	Fused alumina (Aluminum Oxide)	
13	Silicon carbide	
14	Boron carbide	
15	Diamond (C)	1500

Source: American Federation of Mineralogical Societies: Mohs Scale of Mineral Hardness

Other Commercial Descriptions of Steel

The following designations are just a few that I have found used to describe hand tools. They seem to refer to the alloy and tempering process.

O1 - O1 is an oil-hardening, non-deforming tool steel which can be hardened at relatively low temperatures. Tools and dies made from O-1 will have good wearing qualities since the tungsten and higher chromium content gives improved wear resistance over the straight manganese grades. Hardness about HRC-60.
WORKABILITY - - Machinability is high. Grindability is high.
APPLICATIONS - Blanking Dies, Bushings, Forming Dies, Master Tools, Forming Rolls, Guages, Trim Dies

A2 - An air hardened tool steel containing five percent chromium. Replaces the oil hardening (O1 type) when safer hardening, less distortion and wear-resistance are required. Provides an intermediate grade between the oil hardening and the high carbon, high chromium (D2) types.
WORKABILITY - Machinability is medium. Grindability is medium.
APPLICATIONS - Large Blanking Dies, Thread Roller Dies, Punches, Rolls, Forming Dies, Precision Tools, Shear Blades, Etc.

W-1 - water or brine quenched tool steel, Heat treat temperature 1450-1600 F Hardness Rockwell 56c **APPLICATIONS** Blacksmith tools, Cold Chisels, Hand punches, Cold Forming Tools, Knives, Scissors and Shears, Razors, Woodworking Chisels. *Disadvantages*: Water hardening tool steels tend to experience significant distortion during the quench operation. In addition, the hardening operation applies only to the outer "case" of the material, rather than being "through-hardened".

Cutting Materials

Until the early 20th century, high carbon steel was the only material available for manufacturing cutting tools. Then high speed steel (HSS) was developed, followed by cast cobalt alloys (Stellite), sintered and cemented carbides, coatings, ceramic, industrial diamond and cubic boron nitride (CBN).

High Carbon Steels

High carbon (HC) steels contain from 1.16 – 1.30 % carbon. At room temperature, its hardness, 55–60 HR-C, compares favorably with cast cobalt alloy and HSS. The hardness value of HC Steel falls rapidly with increasing temperature.

In woodworking applications this temperature sensitivity is significant mainly when the tool is being sharpened. The operator has to take care not to “draw the temper” of carbon steel by overheating it on a grinding wheel. (See Figure)

There are not many carbon steel drill

bits around any more, but these must be operated at slow speed, with cutting oil and frequent pauses when drilling iron and steel.

High Speed Steels

High Speed Steels (HSS) were developed in the early 20th century. F.W. Taylor and R. White discovered that alloying elements such as tungsten, chromium and vanadium with HC steel and subjecting the resulting alloy to a special heat-treatment resulted in a tool steel that retained hardness at temperatures up to 600^{o} C – a property known as hot hardness.

Use of HSS for tools allows much higher cutting speeds than those for HC Steels – hence the name High Speed Steel. Hardness RC 55-60

Cast Cobalt Alloy (Stellite)

Developed independently of HSS, cast cobalt alloys do not use steel; typically they are composed of 38 to 53% Cobalt, 30 to 33% Chromium and 10 to 20% Tungsten.

Stellite tools have good hardness (H RC 58-64) but are not as tough as HSS. They are suitable for rapid stock removal at elevated temperatures and cutting speeds but are sensitive to impact and shock.

Carbides

Carbides combine hot hardness (See Figure) and thermal conductivity and low thermal expansion. They are produced by a powder metallurgy process, cementing the Carbide particles with a matrix of other metallic powders. The resulting solid is then sintered (pressed together at high temperatures and pressures). At this stage various shapes of tool can be produced prior to final grinding. Hardness RC 70+

Tungsten Carbide (WC) uses cobalt particles as the matrix. The proportion of WC to cobalt affects the property of the finished tool; more cobalt gives less hardness and wear resistance but greater toughness – more WC reduces toughness but increases wear resistance.

Titanium Carbide (TiC) has greater hardness but less toughness than WC It is suitable for machining hard materials and higher cutting speeds.

Ceramics

Ceramic tools are made by cold pressing very pure powders of aluminum oxide and titanium oxide into the required shape and then sintering, in a manner similar to carbide tools. First developed in the 1950s, ceramic tools are chemically inert, have excellent hot hardness and wear resistance but are very brittle.

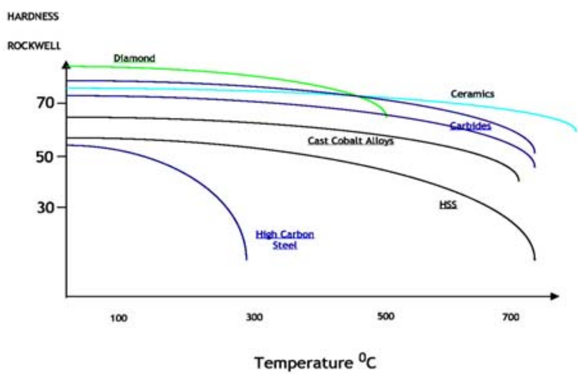
Diamond

Diamond is the hardest known material. It can maintain a sharp cutting edge and has very high wear resistance. Diamond is very brittle; therefore diamond tools usually require a large wedge angle. Diamond tools are usually used for very light cuts to produce exceptionally fine surface finishes and geometric tolerances on soft, non-ferrous alloys and abrasive materials. Very rigid machines and uninterrupted cuts are required (due to the brittleness).

Diamond is not particularly suitable for ferrous metals: as a form of carbon, it possesses a strong chemical affinity for iron, resulting in degradation of the cutting edge. Very high cutting temperatures also cause degradation of the cutting edge as the diamond transforms to amorphous carbon or oxidizes.

Cubic Boron Nitride (CBN.)

CBN is a relatively new invention (introduced in1962). It is second only to diamond in hardness. Many of the precautions taken when using diamond tools need to be applied to CBN. A significant advantage, however, is that even at high temperatures CBN remains chemically inert to ferrous metals and resists oxidation, making it particularly suited to machining hardened steels (hard turning).



Degradation of Hardness With Temperature

References

Adapted from Wikipedia articles
See also
Boljanovic,V.: Metal Shaping Processes, Chapter 10 (Jul, 2009)