Properties of Knife Blade Materials

Articles in knife magazines and discussions on the Internet concerning knife blade steels are getting pretty technical these days. The problem is that many terms are used with the assumption the reader is familiar with them. This article will address the mechanical properties of blade steels in general. Starting with that background we can apply the definitions outlined herein to illustrate how certain properties pertain to the selection of blade materials for 3 different knife types. The following 6 properties are important for knife blade steel:

STRESS AND STRAIN, TOUGHNESS/DUCTILITY, STRENGTH, HARDNESS, RESISTANCE TO WEAR, CORROSION RESISTANCE

STRESS AND STRAIN

All materials have a stress and strain relationship. **Stress** is the force applied to a member and **strain** is the distance that the member moves (**deformation**) under the applied force. Imagine a rubber band stretched between your two hands. The force applied to move your hands apart shows up as a resistance force (**stress**) in the rubber band. The distance the band moves under the force is the strain. If the stress and strain for the band are plotted on a graph a line is drawn representing the behavior of the band from the initial load to the time it finally breaks. This is called a **stress/strain** curve. This curve is unique for all materials and gives a vast amount of information on how the material acts under applied force. Steel acts like a rubber band up to a certain point. That is, it has an **elastic range**. An automobile spring, a folder spring, a skyscraper swaying in the wind and a very flexible fillet knife all are working in the elastic range. If force is applied beyond the elastic range then it enters the **plastic range**. In this area the material acts more like a soft plastic, hence the name. The material will **yield** under the force applied but when the force is removed it won't spring back completely. It has yielded or in the case of a knife blade, "bent". Most knife blades are made from a grade of steel called **cold work tool steel**. This is the same material used for dies, bearings, and some types of machining cutters. We all know from experience that tool steels in general have a limited **elastic** range, and a narrow **plastic** range. They will "flex", take a small permanent bend and then **fracture** suddenly. This property is called **bending fracture strength**. We see an example of this every day in the knife shop working with drill bits, taps and milling cutters.

TOUGHNESS/ DUCTILITY

When a material can absorb forces from many different load types with out breaking then it is very **tough** or **ductile**. Tool steels tend to exhibit the opposite characteristics. That is they are elastic up to a point but have a relatively narrow **ductility** range. The high alloy types, especially those with carbon over about 1.0% and chrome above 5.0% at high hardness (over HRC 57) are moving out of the ductile range and are approaching **brittle** behavior. This is most apparent under **dynamic** or **impact** load conditions. Impact loads magnify the force that the steel feels and can cause large failures very quickly. These steels are also **notch sensitive**. They will fracture at a much lower load if an imperfection is present. This can be in the form of a deep scratch, corrosion spot, small crack, or sudden change in cross section. Steel company data sheets refer to toughness in terms of "**Charpy C Notch**" values. This is a measure of the ability of a notched test piece to resist breaking under an impact load. An example of an impact load is a lawnmower blade spinning at high RPM and hitting a rock, or worse yet, an ATS-34 blade (HRC 60) used to try to chop through a bone. The lawn mower blade (low alloy and soft) is going to get a pretty good dent but the knife blade is probably going to suffer a local break or "chip" out of the thin edge.

STRENGTH

From the above discussion you might say the knife blade was not very strong because it ended up with damage. However the opposite is true. Tool steel heat-treated to the high hardness necessary for a knife blade is very strong. It can be about 10 times stronger than mild steel. The ability of a steel part to withstand force trying to pull it apart is called **tensile strength**. The ability of the part to withstand force trying to push it together or compress it is called **compressive strength**. ASTM A-36, structural steel, or mild steel used for general construction has a tensile strength of 36,000 pounds per square inch. Tool steel at HRC 60 has a tensile strength of about 350,000 pounds per square inch. Note that the ability to take load is related to the cross section area of the piece. The more material the greater the load capacity. For example a two square inch (1 inch x 2 inch) bar of mild steel will withstand 72,000 pounds in tension and a similar size piece of tool steel can withstand about 700,000 pounds in tension. The two steels have a very different stress strain curve (figure 1). Mild steel is very forgiving. It will plastically yield a large amount before breaking therefore avoiding a catastrophic structural failure. Tool steel has to be very stiff and strong because it must endure very high loads at the cutting interface between a tool and the part machined. When it breaks the fracture is usually very sudden. To put it another way mild steel would make a poor drill bit and tool steel would be a poor material to use for a highway bridge. Strength is a very important consideration for a knife blade because we like to make the cutting edge as thin as possible for cutting efficiency. A very high strength material like tool steel is necessary to prevent the very thin edge from yielding under load. Good toughness is necessary to prevent the thin edge from breaking off under bending or impact loads.

HARDNESS

The ability to work in the soft or **annealed** form and then to be hardened is one of the most important properties of tool steels. Steels are delivered from the mill in the annealed form. This allows the knife maker to cut, drill, file, bend and grind the steel. . In the annealed form it acts somewhat like the mild steel described above. To exhibit the positive properties of tool steel it must be heat treated so that the final crystal structure of the steel is changed. The tensile strength of steel is proportional to its hardness. The harder it is the more is resists deformation forces. In other words the edge will resist bending or breaking while cutting some very hard materials. **Hardness** is the most critical property for a knife blade because it is an indication all the other properties. It is the most convenient property to measure. A hardness tester forces a cone shaped diamond penetrator into the sample. The depth of penetration is measured very precisely and is read on a calibrated scale. Hardness for tool steels is usually given in reference to the **Rockwell C Scale**, abbreviated as HRC. The normal range for knife blades is HRC 50-63. Knife making steels have a "sweet spot" hardness range in which they will perform best. At this hardness all the properties are balanced to provide the best overall performance. Very good steel that is heat-treated out side this range will not perform up to expectations.

WEAR RESISTANCE

Abrasive wear resistance (most important type for a knife blade) is a measure of the tool to resist being worn away by contact with other materials. Wear resistance correlates with hardness of the material in general. Even mild steel in contact with an abrasive surface will wear much longer than brass for example. In that case mild steel will make a better knife blade than brass. It gets more complicated with high alloy tool steels because of the **carbides** present in the material. Steels like O-1, A-2, 52100 will all have about the same wear resistance at equal hardness. The addition of chrome in steels like 440C, 154CM, ATS-34 and D-2 adds another dimension. During the initial melt the chrome combines with carbon to form **chrome carbides**. These carbides are harder than the **iron carbides** present in the lower alloy grades and will therefore add some abrasive wear resistance to the cutting edge (see figure 3). Imagine the carbides as the aggregate (rocks) and the surrounding steel matrix as the cement in a concrete road surface. The cement wears away over time leaving the hard aggregate as the road wear surface. The harder the rocks the better the surface will resist wear over time. The same thing is true for a knife edge. The harder the carbides and the more densely they are packed the better the edge will resist wear. This is carried a step further with the high vanadium, high carbon **CPM** (Crucible Particle Metallurgy) steels and to an extreme with **high-speed tool steels.** High-speed tool steels like M2, M4, M42, and T15 will resist wear even when subjected to the red-hot temperatures at the cutting edge of a metal cutting tool.

CORROSION

Plain carbon steel has very little **corrosion resistance**. We all know that a bar of steel out side in the weather will soon form a coating of rust. To prevent this surface must be separated from the elements with a barrier of some type (paint, plating act). Low alloy tool steels act pretty much act the same way. A very fine "non-stain resistant" edge can get dull just due to atmospheric effects over time if it is not protected. A tool steel rifle that has been blued (chemical oxide coating) and oiled will withstand the weather very nicely. The addition of about 12% chromium to steel will improve the corrosion resistance to a point that it can be called **stainless.** Other elements like molybdenum also contribute to limit surface pitting. 154Cm for example has 14% chrome and 4% molybdenum. Chromium can be too much of a good thing because amounts higher than about 14% in 1.0 % carbon steel tend to increase the brittle behavior at higher hardness.

IT ALL COMES TOGETHER AT THE CUTTING EDGE

Given the back ground in the preceding discussion we now should have enough information to specify a range of steels for a knife blade. To illustrate all this lets pick a material for a Chef's knife, a fillet knife and a utility hunter. The first step is to establish the criteria for the knife. It is going to be somewhat different for all three. My criteria may be entirely different from yours but it's a place to start

CHEF'S KNIFE CRITERIA

<u>Excellent corrosion resistance</u> for sanitary reasons as well as appearance- At least 14% chrome content for stain resistance. <u>Very good ductility</u> -Because it will most likely see some chopping action in the kitchen. The <u>hardness</u> should be in the 53 to 58 HRC range. Higher hardness could lead to edge chipping and poor traction on sharpening steel. <u>Good edge holding</u>-Should have some chrome carbides for wear resistance. <u>Good edge strength</u> to prevent edge from rolling over or rippling under normal use against a cutting board-Hardness in the 53 to 55 range should provide high enough tensile and compressive strength to accomplish this. <u>Easy to grind</u> and polish to keep cost reasonable.

Steels like AISI420 modified (0.5% C), AEBL and 440A will make an excellent Chef's knife. They have the right amount of chrome for stain resistance and chrome carbides for wear resistance. These steels hardened to HRC 55 (310,000 psi) have outstanding toughness and are relatively easy to grind and polish. If stain resistance is not a concern then A-2, O1, and 52100 (all with carbon at 1.0%) can be used at HRC 58. This will make for a blade with good toughness and a little better edge holding. Edge strength will also be improved (325,000 psi) which will allow for a little thinner grind and easy cutting ability. 154CM/ATS34 at HRC 58/59 (340,000 psi) will make for a stain resistant blade that has improved edge holding, but will have less ductility because of the added alloy. A little more edge thickness and caution during use will offset both of these factors. These steels are more difficult to grind and finish so the final knife will be more costly. In addition they will require abrasive stone sharpening since the additional hardness will preclude effective use on a sharpening steel.

FILLET KNIFE CRITERIA

Excellent corrosion resistance since the knife will be subjected to salt water environments- At least 14% chrome and some molybdenum to prevent pitting. Reasonable ductility- Knife will not be subjected to chopping so hardness could be as high as HRC 61 depending on the steel. Flexibility will be fine at HRC 61 if heat-treating is correct. Very good edge holding- knife will be used where sharpening is not convenient so should have high wear resistance provided by chrome carbides. Hardness should be HRC 60/61 for edge holding. High edge strength is necessary to prevent roll over. Ease of polishing and grinding will be compromised in favor of high strength, edge holding and corrosion resistance.

These blades will be used in a much more severe environment than the Chef's knife above. 440C and154CM/ATS34/BG42 are probably the best overall choices for a fillet blade. The 440C blade would have to be a little softer (HRC 56/57) to offset the brittle effect of the high chrome at high hardness. 154CM/ATS34 (HRC 60) have good ductility as long as the heat-treating is correct. The edge strength will be very high for slicing through fish bones (350,000 psi). The hardness and presence of chrome carbides will provide very good edge holding. The addition of molybdenum will off set pitting corrosion in salt-water use. CPM440V/420V at HRC 60 will provide additional wear resistance at the edge with excellent corrosion resistance. The higher initial cost and difficulty in grinding and finishing the CPM steels make for a much more expensive knife but may be worth it for some applications.

CRITERIA FOR UTILITY HUNTER

Edge holding is the overriding criteria for this knife. No one wants to have to sharpen a blade in the middle of field dressing an elk at night in a snowstorm. A hardness range of HRC 59-61 and high carbide content is required. This will also provide very high edge strength (350,000 to 360,000 psi). Good corrosion resistance is desirable since the knife will be used in extreme environments like Alaska and some times around saltwater- 14% chromium and some molybdenum are desirable. Ductility should be adequate but can be compromised in the interest of edge holding since an ax or saw will be used in lieu of chopping or prying with this knife. The primary use will be field dressing, skinning, and boning and camp cooking. If very hard use is anticipated then the edge can be left thicker at the expense of ease of cutting and slicing.

Ease of grinding and polishing is compromised in favor of high strength, high hardness, wear resistance, and corrosion resistance. Cost of the blade steel is secondary to performance.

Edge holding is the most important factor in a hunting knife. 154CM/ATS34/BG42 and D-2 (all at HRC 60 or higher) have the properties to accomplish very good edge holding while providing adequate toughness and very good edge strength. The high edge strength allows the blade to be ground relatively thin for ease of cutting. If corrosion resistance is not an overriding consideration then 01, A2, 52100, 1095 and similar high carbon low alloy steels will do the job and provide somewhat better toughness as a bonus. CPM420V (S90V) 440V (S60V) (HRC 60) will provide increased edge holding with very good corrosion resistance and adequate toughness. CPM 10V (HRC 62/63) offers, extremely high edge strength (375,000 psi). The combination of high hardness and very high Vanadium Carbide content make for outstanding edge holding, but with minimum corrosion resistance (5% chrome). If toughness is the overriding criteria then CPM 3V is a very good choice. It offers twice the impact resistance of all the above grades plus good edge holding and some stain resistance (7.0% chrome). The increased performance of the CPM steels is offset by a higher knife cost due to the price of the material and difficulty in grinding and finishing. This increased cost can usually be rationalized when considering the purchase of a custom knife.

Note:

The above article was written before the introduction of CPM S30V. 30V is a great addition to the Crucible list of knife blade materials. At this point it is a favorite of mine for fillet knives and hunters. Toughness is very good and edge holding is only topped by 90V and 10V. It is a little easier to finish than 90V and 10V so fits in a category between 154CM and the alloys which have a higher percentage of carbides.

The above criteria and steel selections are an examples of the many trade offs necessary to match the right steel to a particular knife design and use. These examples also illustrate why some of the more popular steels work so well. Forged and pattern welded blades add another dimension to all of the above because certain of the properties can be modified for improved performance and esthetics

A general knowledge of steel properties is an asset when specifying a particular blade. This can be from the standpoint of a knife maker who is striving to match steel to his customer’s application or from the point of view of a user who wants to get the most out of his knife and under stand the limitations of its use.

The following are my current choices for knife blade materials. The steels are listed in order of preference for each knife type. The preference is based on the best value for the user considering utility and cost trade offs. These preferences are of course mine and can change based on discussion with the user and his/her preferences.

Fillet Knife	154CM, CPM S30V
Hunter/Utility	CPM S30V, CPM S90V, CPM 10V
Chef’s Knife	AISI 420HC, 154CM
Paring Knife	CPMS30V, 154CM