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Blade Materials & Heat Treatment



Summary

- * Introduction to blades & grades of steels
- * Heat Treatment
- * Alternatives materials

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Blade steels fall into two fundamental groups –

Those where high corrosion resistance is not important. – **CARBON STEELS**

Those requiring stainless properties – **MARTENSITIC STAINLESS STEELS**

Worldwide, around 80% of knife blade consumption is stainless steel.

As a general rule non stainless steel blades have the ability to achieve higher hardness levels and therefore better cutting life but not necessarily sharpness.

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Carbon Steels Generally 0.5% - 1.2% C

Razor, craft, scalpel and other disposable specialist blades + occasionally kitchen, trade, military and folding knives.

Hardening

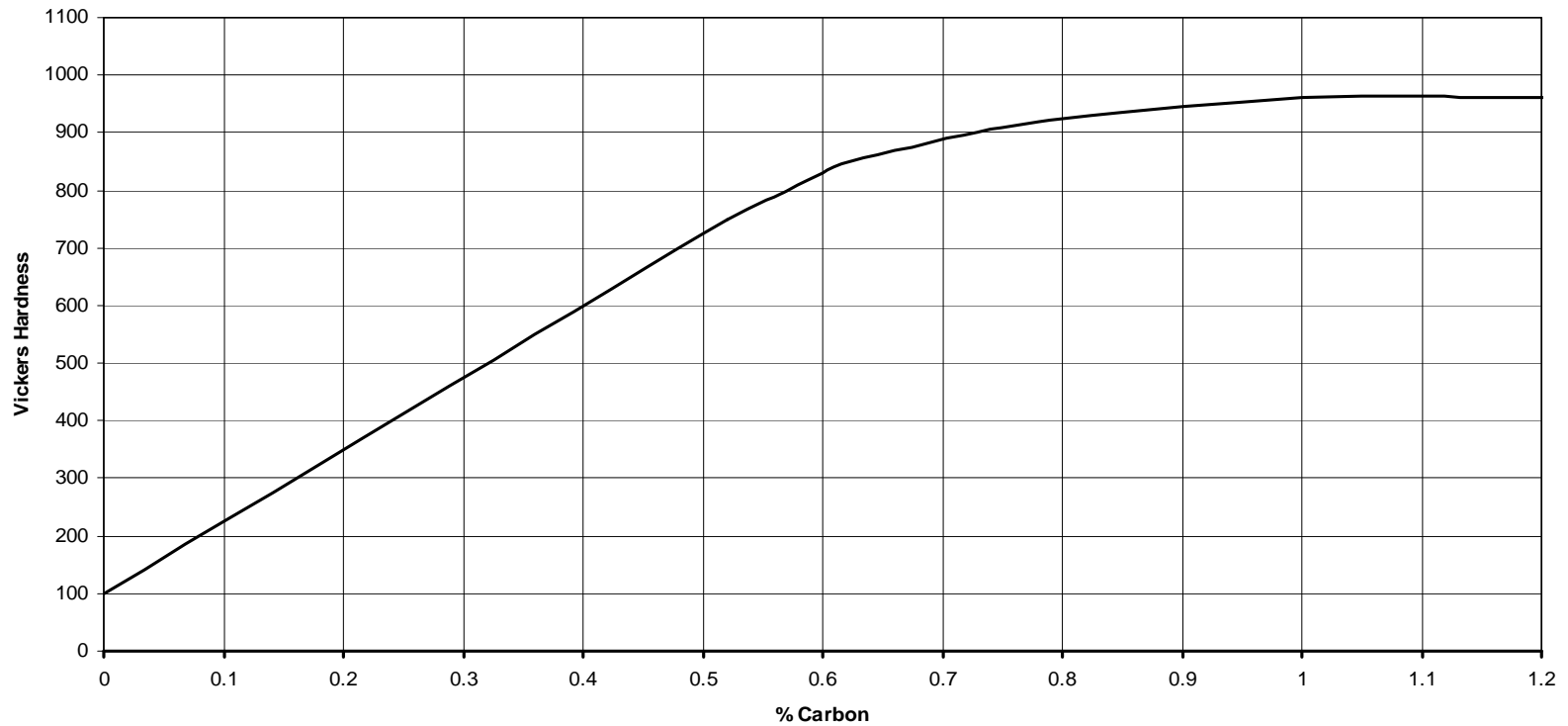
For thousands of years carbon steel blades have been heated to red heat and plunged into water (to produce a martensitic structure) then toughened by tempering at a lower temperature.

Today these blades are hardened by heating to 810 – 830⁰ C depending on carbon content followed by oil quenching and tempering

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Effect of Carbon Content on the Hardness of Fully Hardened Carbon Steel



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Tempering

Usually carried out in an air circulation furnace at temperatures of 200 – 310°C depending on carbon content and application. The process relieves internal stresses and prevents cracking without softening the steel too much.

It is important that once the blades have reached temperature they are soaked for at least 30 minutes to achieve consistency. This is particularly important if the blades are tempered in packs as the blades towards the centre will take much longer to reach temperature than those on the outside.

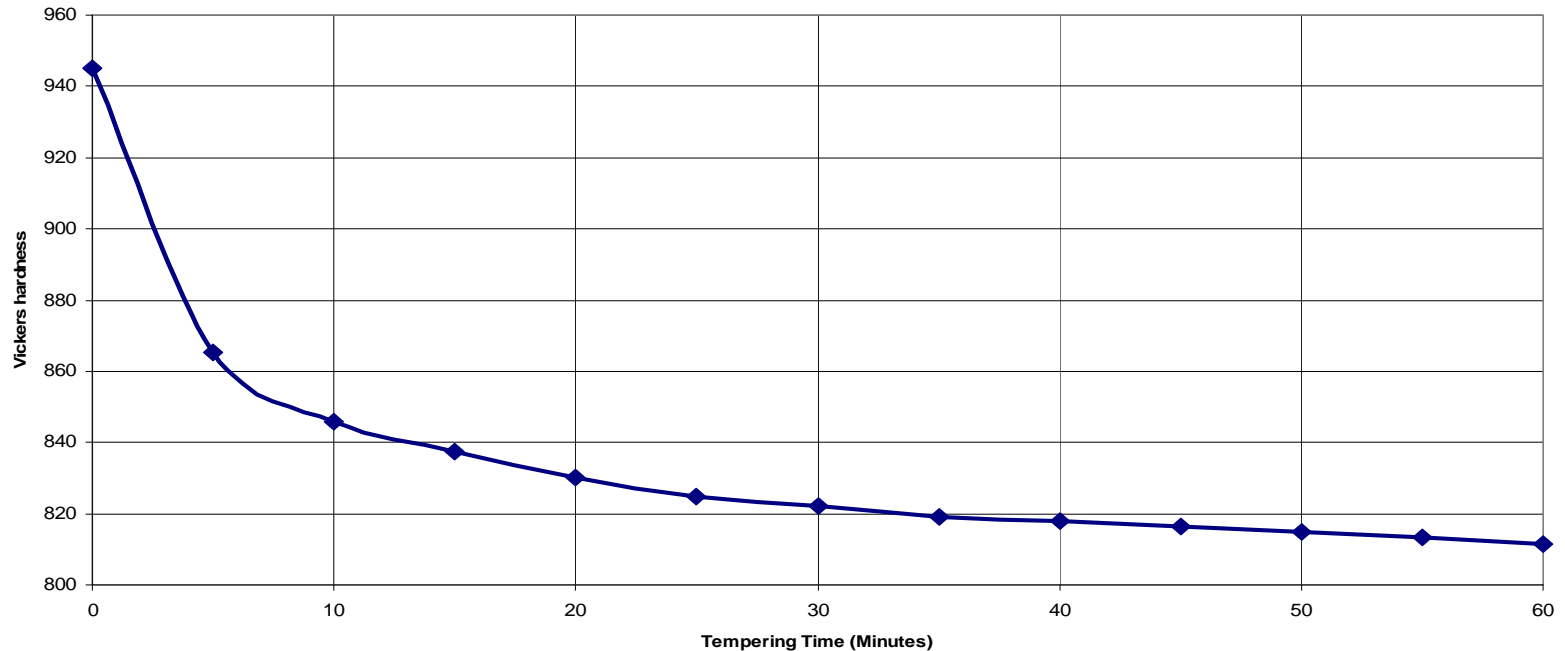
Although by adjusting the tempering temperature, the same hardness can be obtained on steels of different carbon content, they will not have the same edge properties.

Cutting edge retention increases with increased carbon content, even at the same hardness level.

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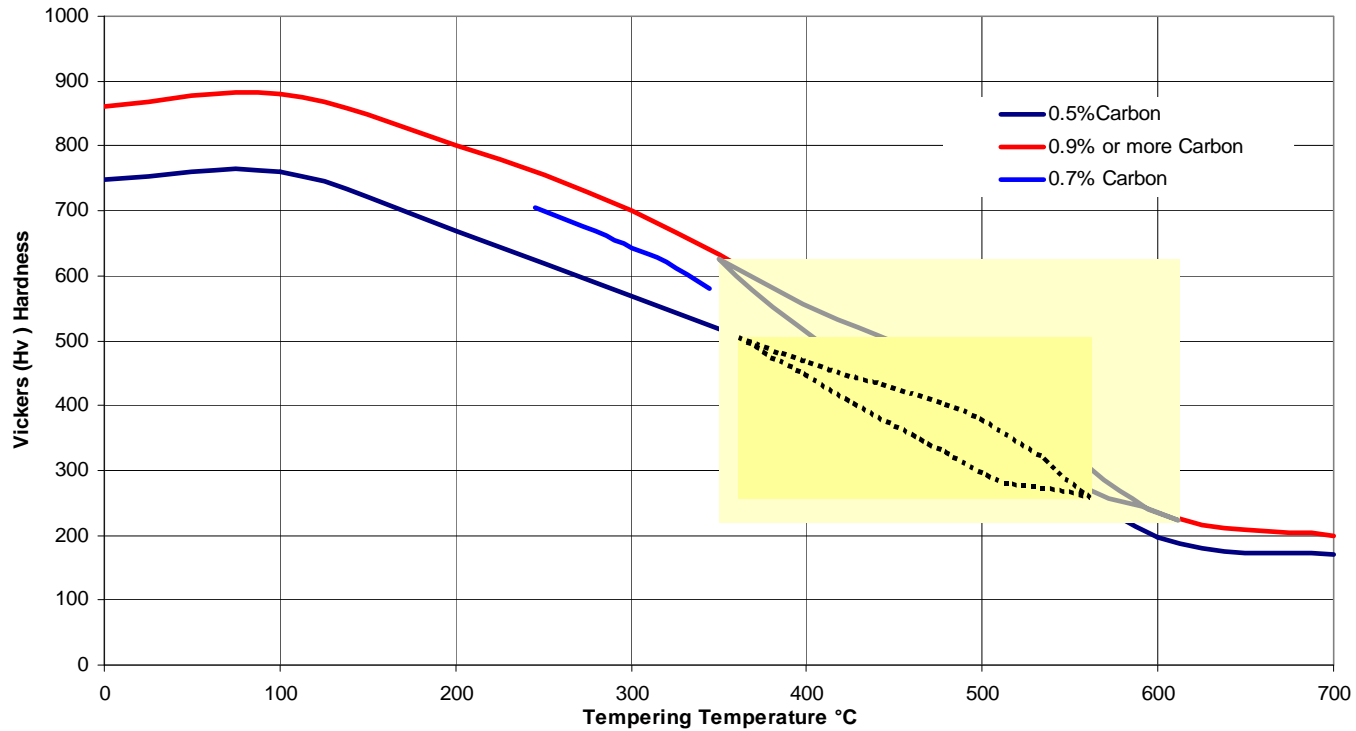
Effect of Tempering Time at 200°C on the Hardness of a 0.9% Carbon Steel



Increasing the tempering temperature causes a corresponding drop in hardness

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Tempering Temperature- Effect on Hardness of Fully Hardened Carbon Steels
(Tempered for 30 mins)





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Review

Carbon steel blades contain 0.5% - 1.2% C

Hardened at 810 to 830⁰C – Oil Quench = martensitic structure = brittle

Tempered 200 - 310⁰C – adequate soaking time = toughened steel

Higher tempering temperatures softens steel

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Stainless Steels

Martensitic stainless steels are used for the vast majority of stainless knife blades.

These steels usually have a minimum chromium content of 11% to provide adequate corrosion resistance and a carbon content in excess of 0.15% to achieve hardenability.

The martensitic stainless steels can be divided into two main groups:

- (i) Plain Chromium grades
- (ii) Grades with alloying addition of molybdenum and/or vanadium usually in conjunction with a higher carbon content

In the annealed condition the steel consists of ferrite containing carbides. Hardening is achieved by heating above the critical temperature, holding at temperature and rapidly cooling. However unlike the carbon steels it is not necessary to quench into oil as the steels are air hardenable.



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Grades of stainless steel

The compositions for martensitic stainless steels used for cutting applications are specified in:

BS EN ISO 8442-1 Kitchen Knives

BS EN ISO 8442-2 Table Knives

BS EN ISO 5194-1 Stainless steels for surgical instruments

The most popular grades used and available in Europe are the 420 types, whilst grades with carbon contents of around 0.5% and with molybdenum additions are popular for high quality products. In the US, the 440 grades typically containing carbon from 0.6 to 1.2%, are extremely popular in the high value knife market.

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Compositional Requirement

		C	Cr	Mo	V
BS EN ISO 8442-1 Kitchen Knives	A	0.36 min	12.5 min		
	B	0.16 min	12.0 min		
BS EN ISO 8442-2 Table Cutlery		0.26 min	12.0 min		
BS EN ISO 5194-1 Surgical Instruments	C	0.26 - 0.35	12.0 - 14.0		
	D	0.42 - 0.50	12.5 - 14.5		
	H	0.35 - 0.40	14.0 - 15.0	0.4 - 0.6	0.1 - 0.15
	I	0.42 - 0.55	12.0 - 15.0	0.45 - 0.9	0.1 - 0.15

Commonly Available Grades of Stainless Steels

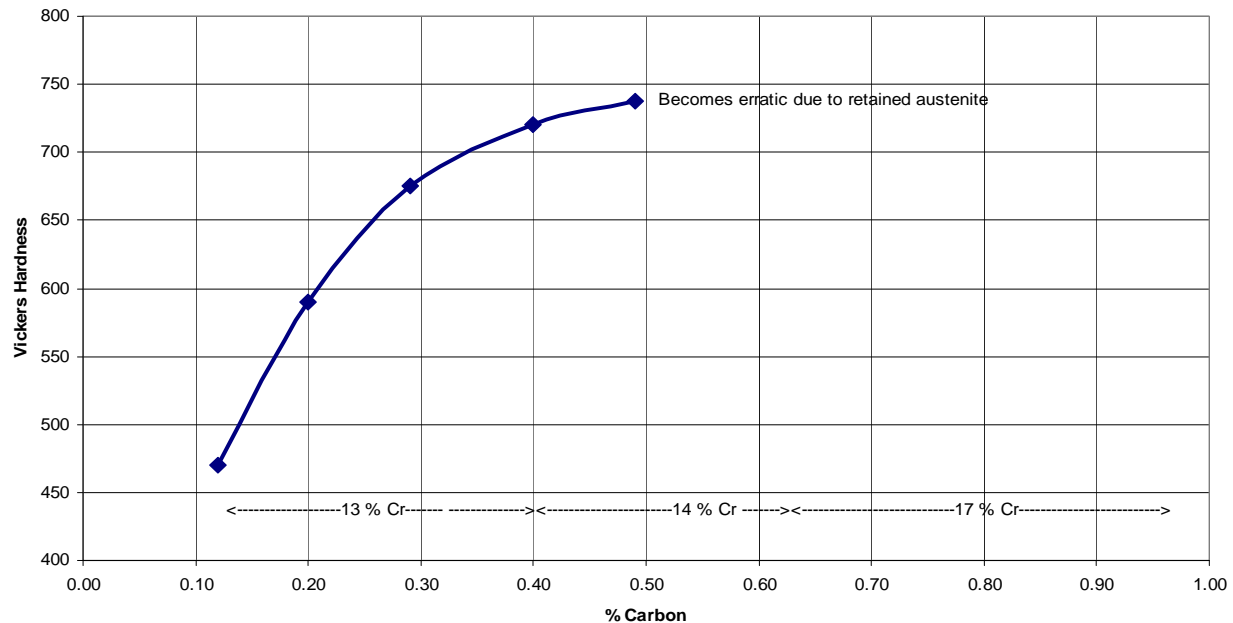
		C	Cr	Mo	V
B S EN 10088-1 Stainless Steels	1.4021	0.16 - 0.25	12.0 - 14.0		
	1.4028	0.26 - 0.35	12.0 - 14.0		
	1.4031	0.36 - 0.42	14.0 - 15.0		
	1.4116	0.45 - 0.55	14.0 - 15.0	0.5 - 0.8	0.10 - 0.20

The higher the carbon content, the higher the hardness attainable

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Effect of carbon content on the maximum hardness of cutlery stainless steels



Grades containing molybdenum have enhanced corrosion pitting resistance in chloride containing environments. This is particularly important when considering potential end use with dishwashers and sanitising products. In addition marketability is increased by perceived added value i.e. "molybdenum stainless steel".

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Hardening

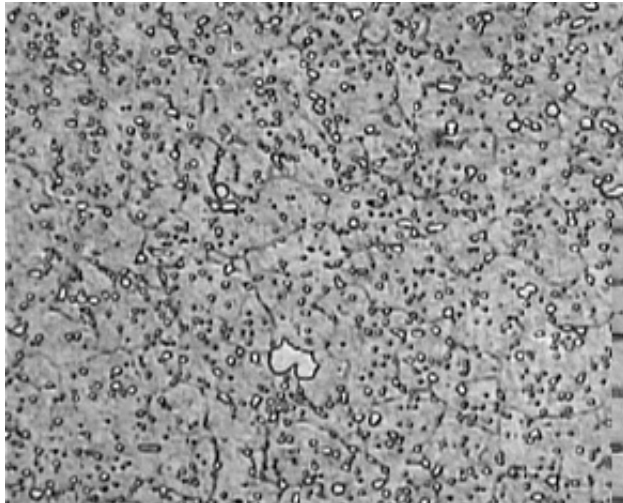
In the annealed condition martensitic stainless steels consist of ferrite and carbides. In a 0.3% carbon grade the ferrite contains hardly any carbon and only about 8% chromium. Consequently the steel in this condition CANNOT be considered as stainless. Hardening results in the dissolution of some of these carbides which enriches the matrix with chromium and significantly increasing the corrosion resistance. Alloying additions of molybdenum and vanadium can displace some of the chromium in the carbides making more available for solid solution, enhancing the corrosion resistance further.

Hardening is relatively straight forward. The product is heated to a temperature of 1010 to 1060°C depending on the grade to achieve austenitisation. It is then held at temperature for sufficient time to become homogeneous. These steels are air hardening and will achieve full hardness by cooling in air although oil quenching and clamp cooling between steel plates will produce better results.

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Although air hardening, these steels can be embrittled by the precipitation of grain boundary carbide networks during slow cooling. This effect becomes more severe with increasing carbon content. The following photomicrographs are from the same steel and illustrate the effect of cooling rates

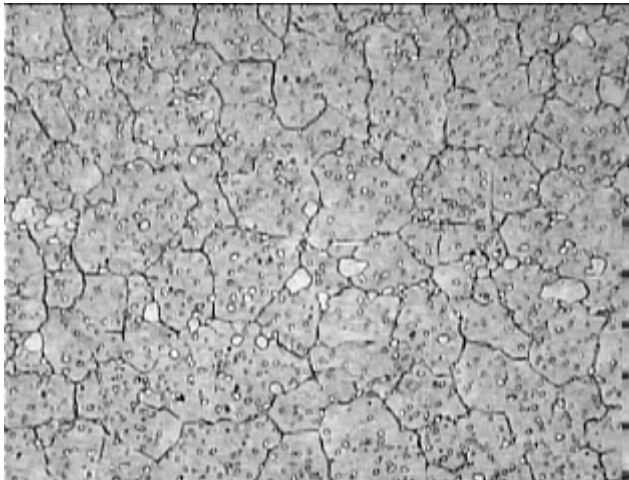


Grade 440A

Oil quenched showing
satisfactory microstructure

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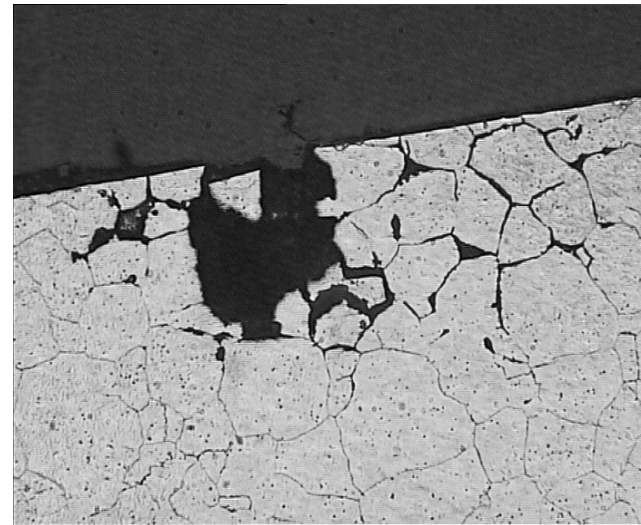
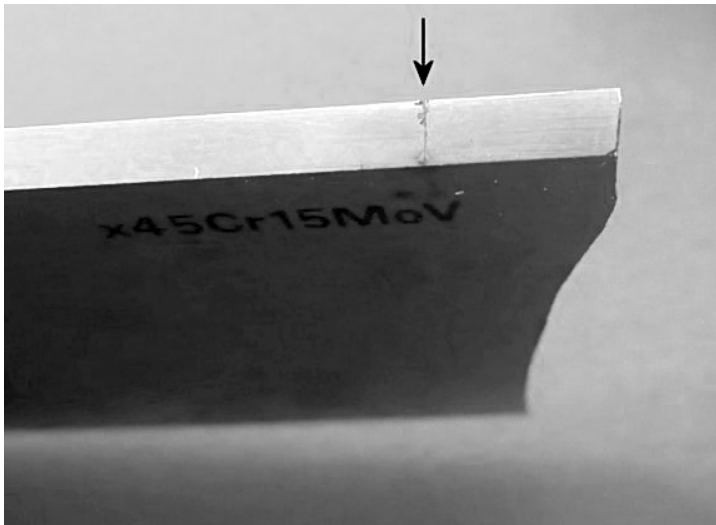


Grade 440A microstructure
– air cooled showing
pronounced intergranular
carbide networks

As well as embrittling the blade, intergranular carbide networks also reduce the corrosion resistance of the steel. The carbides are rich in chromium and the adjacent areas being denuded in chromium are susceptible to stress corrosion cracking, a potentially hazardous failure mechanism, or intergranular corrosion, both shown below:

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Sub-Zero Treatment

Martensitic stainless steels with carbon contents greater than around 0.3% will not transform fully from austenite to martensite on cooling. In practice some austenite remains and this is often referred to as retained austenite. Its effect can be to reduce dimensional stability, which is particularly important in the case of large diameter circular blades and because it is soft, prevent the steel from attaining its maximum hardness.

During sub zero treatment, the steel is cooled down to -80°C , held at temperature for at least 5 minutes and allowed to return to ambient temperature. The blades are then tempered at 200°C . This process can result in a hardness increase in the order of 2 HRC. Sub zero treatment should be carried out as soon as possible after hardening otherwise the austenite stabilises and the treatment will have little or no effect.

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Hardening Methods

Continuous Furnace

These can be either linear or rotary and can be heated by gas, oil or electric elements. Once the temperature and rate of travel have been set, consistent results can be obtained. With the use of protective atmospheres, little if any discolouration of the blade blank occurs.

Knives should be introduced onto the moving belt in single units. However in Far East production it is common practice for the lower carbon grades of stainless steel to bundle blades into blocks approximately 350mm wide, using wire. These are placed onto the belt sometimes two blocks deep and fed through the furnace at a very slow rate – this may be hours. The slow rate is necessary to ensure that the complete pack attains temperature, however it also means that the outer blades of the pack will have been at temperature significantly longer than those towards the centre. In addition it is not possible to cool the pack of blades sufficiently fast enough to avoid the formation of intergranular carbide networks. The net result can mean that the blades will often exhibit poor consistency having microstructures with variable degrees of grain growth, pronounced intergranular carbide networks and erratic hardness values.

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In addition, it is common practice not to temper the blades after the hardening by this method. Normally, omitting to temper after hardening will result in unacceptably brittle blades, however in practice some auto tempering occurs during the very slow cooling cycle. Martensite starts to form above room temperature and greater amounts form as cooling continues. As the cooling rate is extremely slow the martensite already formed is tempered as cooling continues. Whilst this temper treatment may be partially effective it can only be considered as adequate at best and is vastly inferior to a full conventional temper cycle of 200°C for a minimum period of 30 minutes.

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Induction Heating

The blank is placed in a coil through which a high frequency current passes, resulting in rapid heating. The process enables parts to be locally heated and minimal scale is produced. However dimensional and shape variations in the work piece can affect consistency of the heat treatment. Coils may have to be changed for different blanks.

This method is ideally suited to automation. A project carried out at Catra was successful in induction hardening blades using a robotic arm. Individual blades were picked up and heated within a coil whilst oscillating the blade and pulsing the induction amplifier to achieve a stable temperature. The blade was then placed in cooling clamps and the process repeated.

Salt Baths

Salt baths provide an efficient and accurate means of heat treatment. The work is immersed in molten salt, which if correctly maintained will protect the workpiece from oxidation (scaling) and decarburisation. Heating is uniform and rapid and parts can be locally treated by partial immersion. However the salts are often corrosive requiring thorough removal from the workpiece as soon as possible.

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Vacuum Furnace

In this process the blades are heated in a vacuum and quenching is achieved by cooling using an inert gas such as nitrogen or argon. Early furnaces had poor cooling rates which often caused knife blades to be embrittled by the formation of pronounced precipitated carbide networks. However improvements in furnace technology have led to satisfactory cooling rates and this is no longer a problem, assuming good practice.

One of the advantages of vacuum furnaces for hardening surgical scissors produced from martensitic stainless steel is that carbide inserts can be furnace brazed during hardening – by the careful choice of the brazing alloy.

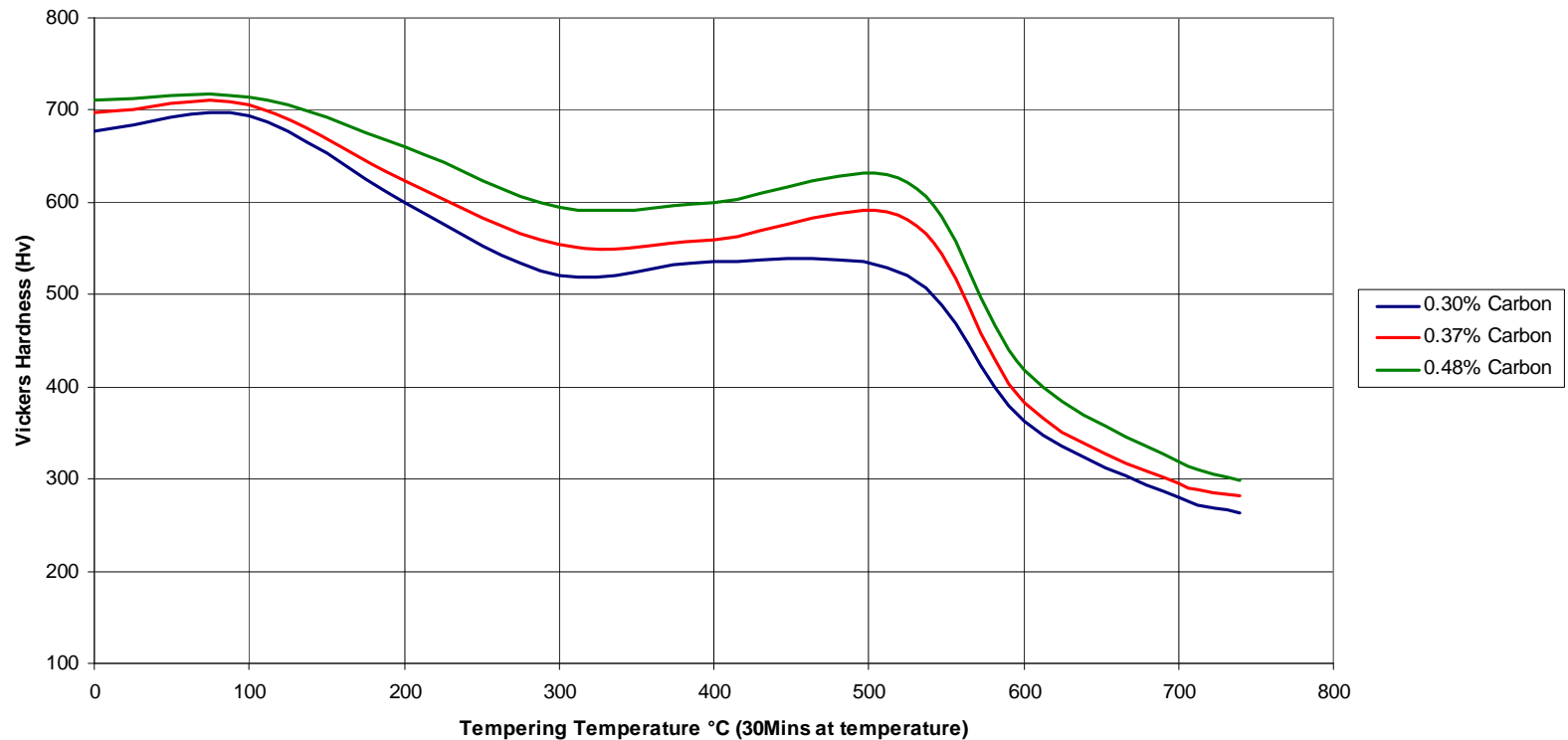
Other advantages of vacuum hardening are:

- 1) No discolouration or surface oxidation so there are no post cleaning operations.
- 2) Near finished product prior to treating
- 3) High degree of repeatability due to computer control

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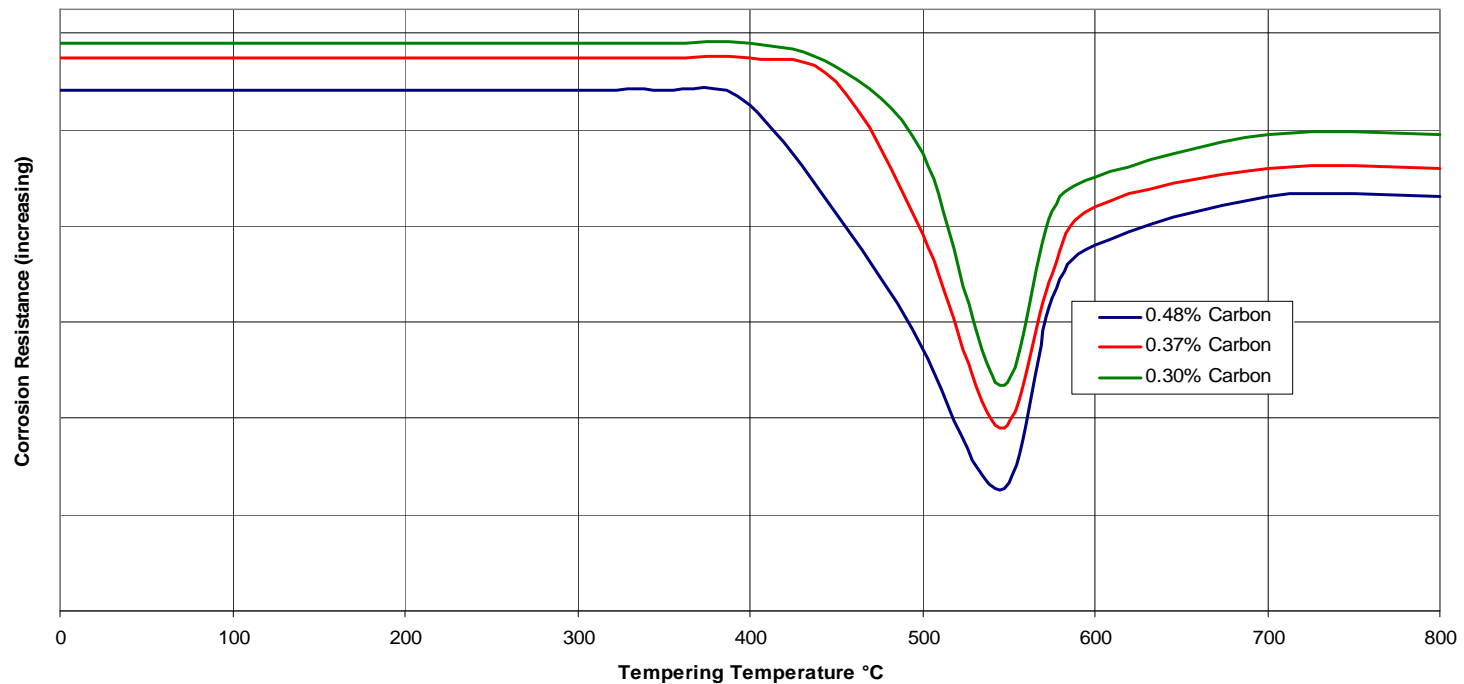
Tempering Temperature - Effect on Hardness for various Carbon Contents (Hardened at 1040°C)



Tempering within the range of 400 to 600°C causes carbide precipitation and above approximately 550°C the hardness is significantly reduced

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Tempering Temperature - Effect on Corrosion Resistance for various Carbon Contents (Hardened at 1040 °C)



Tempering at temperatures in excess of 600°C causes considerable softening, reduces corrosion resistance and is known as sub critical annealing.

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Review of Stainless Steel Blades

Martensitic s/s 11% Cr min; 0.15% C min

Harden typically 1010 – 1060°C – oil quench = brittle structure

Temper 200 - 300°C = tough corrosion resistant stainless steel

Problems

Slow cool from hardening = intergranular carbide networks

Temper 400-600°C = carbide precipitation, softening, loss of corrosion resistance

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Blade Type	Material	C%	Mn%	Si%	Cr%	Ni%	V%	W%	Mo%	Hv
Paper Shear	O1 Tool Steel	.85-1.0	1.0	0.25	0.5	0.4	0.25	0.5		790
Paper Disc	D2 Tool Steel	1.5	0.3	0.25	12	0.4	0.6		1.0	735
Shear/Cropping	M2 Tool Steel	0.75	0.3	0.3	4.0		2.0	6.0	5.0	850
Tobacco	M4 Tool Steel	1.0	0.36	0.23	0.17	0.15	<0.02		0.02	850
Scissors	EN9 & 420 s/s	0.5	0.5	.05-.35						660
Pen knives	EN9 & 420 s/s	0.5	0.5	.05-.35						660
Cook's Knife	Carbon Steel	0.6-1.0	0.5-0.7							600
Craft	1% C Steel	1.0	.25-0.5	0.3max	.15-.35					770
Textile	1% C Steel	1.0	0.27	0.20	0.22	0.11		1.96	0.02	700
Scalloped Knife	420 s/s	.16min			12 min					570
Meat/Skinner	420 s/s	.25-.30			12-14					565
Scalpel	420 s/s	.36min			12-14					560
Ind.Cheese	302 s/s	0.12	0.5-2.0	0.2-1.0	17-19	8-11				385



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Other Knife Blade Materials

The performance of these alternative materials will be discussed later but a brief overview follows.

Tool Steels

For more arduous industrial applications such as tobacco shredding blades, paper shear and circular blades, various grades of tool steels are used such as O1, D2, and M2. These alloys have been widely used for decades.

O1 is a cold work die steel with a nominal carbon content of 0.9% and containing small amounts of vanadium and tungsten which form stable primary carbides preventing grain growth and promoting wear resistance. It can be heat treated to a high hardness > 60 HRC. These steels are often used for utility blades.

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D2 types are air hardening high carbon (1.5%) and high chromium steels (11.5%) and are similar in some ways to the martensitic stainless steels. However the corrosion resistance of D2 is much lower than that of the martensitic stainless steels as much of the chromium content (already lower than a martensitic stainless steel) is bound with the carbides reducing the chromium in the matrix.

M2 is a popular grade of the high speed steels, which are best known for their ability to retain a high hardness at high temperatures generated by cutting at high speeds. Although the corrosion resistance of the high speed steels is relatively good for tools steels it is inferior to that of martensitic stainless steels.

Improvements in tool steel properties have been achieved by powder metallurgy. The uniform composition and carbide distribution produce more consistency in heat treatment and hence hardness. In addition these steels usually have good “grindability”. Excellent edge retention results have been obtained with high carbon (2.45%) - high vanadium (9.75%) and similar grades typically heat treated to 62 HRC.



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Ceramics

Ceramic blades are now available at a low cost and they exhibit high hardness (1300 Hv or 75 HRC) and wear resistance as well as being chemically inert. Once a novelty, ceramic kitchen knives are now available in supermarkets at comparable prices to stainless steel. These have aesthetically pleasing appearances being available in both black and white colours. Both are produced from zirconium oxide but the black version is HIPed to create a tougher blade. However in comparison to conventional stainless steel blades they are inflexible and the edge can be susceptible to chipping. Once the edge is damaged they can only be resharpened by specialised processes usually involving their return to the manufacturer.



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Liquid Metal

Liquid Metal is an amorphous alloy of titanium, zirconium, beryllium, copper, and nickel. It has an amorphous structure and a relatively low hardness of the order of 50 HRC. Whilst it has relatively good corrosion resistance, tests at CATRA have revealed that sharpened edges have poor edge retention properties. In addition, this material is fairly brittle in nature and in order to achieve reasonable edge durability it is necessary to use thicker profiles which has an adverse effect on edge life.

Titanium Alloys

Titanium is the fourth most abundant structural metal found in the Earth's crust. Titanium alloys possess a combination of high strength, toughness, corrosion resistance, wear resistance and are non magnetic. Titanium alloy blades enhanced by confidential secondary processes have been successful in achieving high sharpness and edge retention properties. Some titanium beta alloys can be aged to a hardness of 44 to 46 HRC. These blades have a high corrosion resistance and are popular in Japan for preparing sushi as it is held that they do not taint the raw fish. Titanium alloy knives are also used for specialist applications in marine environments ranging from the arctic to tropical conditions due to their excellent corrosion resistance.