CON MECH ENGINEERS

WORLD CLASS
heat treatment

Why material selection is important for heat treatment

Report Written by M. Williamson BEng

Introduction

Achieving the required mechanical properties from heat treatment is reliant on more than just the correct heat treatment process; it requires raw material to have the right composition. Sending components to a heat treater that conforms to international standards (such as ASTM2750 and API6A) will mean that the ovens they are using should be capable of uniform heat (this can be easily checked by requesting the recent uniformity temperature survey (UTS)), and capable of following the heat treatment parameters of that material to achieve a hardness within the specified parameters.

However the heat treater relies on the material supplied being of good composition and therefore high hardenability (this ensures standardised procedures for heat treatment are implemented and used for each material). But If critical elements are under the required amount it is highly probable that the material will be difficult to heat treat to the desired mechanical requirements of the specification (Beware of mill certificates that display the elements within the specified material parameters but a lot of the elements are at the lower end of the range). In most cases the hardness range of the specification is unrealistic in comparison to what the heat treater needs to obtain to ensure the material will pass mechanical testing. In some cases the heat treater has to narrow the hardness range to the top end (i.e. top end minus 5HBw, e.g. Hardness range required 207 – 235HBw, heat treater needs 230 – 235HBw) to achieve mechanical properties.

Another important check is that the ruling section of the component is within that material’s capability of hardening to the correct hardness throughout. This is known as the limits of ruling section for that material. This information will tell you the maximum thickness that material can through harden to. Outside this limit you will find that the core will always be softer than the surface. The further outside the limit the greater the reduction.

This report will help engineers to ensure that the material they buy will achieve the nominal mechanical values required from heat treatment.

Technical Background

Taking 070 M 20 material as an example; this relies primarily on the Carbon, Manganese and secondary Chrome to achieve its hardness (to harden up). Molybdenum is added to enhance the through hardness (hardenability).
If these elements are not sufficient, the through hardness of the material will be poor (the hardness will drop off sharply as you go from the surface to the core). This means that you may achieve the mechanical properties at the surface of the material but as soon as you go below the surface the material will fail.

Chemical composition range of 070M20

Carbon:	0.16% Minimum	0.35% Maximum
Manganese:	0.5% Minimum	1.0% Maximum
Silicon	0.10% Minimum	0.4% Maximum
Phosphorus		0.05% Maximum
Sulphur		0.05% Maximum
Copper		0.40% Maximum
Nickel		0.40% Maximum
Chrome		0.30% Maximum
Molybdenum		0.12% Maximum
Vanadium		0.08% Maximum

The following elements are added to enhance the material:

Carbon: Up to 0.35%: Primary hardening agent for Iron and the main element to create certain Phases/carbides. Carbon is vital and therefore it is always better to be towards the top of the specified range for that specific material then at the bottom.

Chromium: Up to 0.3% .Improves wear, oxidation and scaling resistance and **hardenability** but increases grain growth and reduces ductility.

Manganese: Range 0.6% to 1.05% always present in steels to reduce the negative effects of impurities carried out from the production process e.g. sulphur embrittlement. It promotes the formation of stable carbides in quenched-hardened steels. Up to 1% acts as hardening agent and from 1% to 2% improves strength and toughness.

Molybdenum: Up to 0.12%. Stabilises carbides and promotes grain refinement and increases high temperature strength, creep resistance and hardenability.

These major defining elements give the material its key characteristics and should allow the mechanical properties to be achieved. However all materials contain some trace/additional elements and these can have a negative or positive effect on the material. For example Boron is one of these elements that can improve the mechanical properties of this material and provide more consistent results. The likes of Lead will reduce the ductility and hardenability of a material. All these factors will influence the material and the way it performs. Aluminium is another, 0-2% increases resistance to oxidation and scaling, aids nitriding but restricts grain growth. In low alloy materials it is normally kept at 0.035% maximum due to the grain growth issues (but it does depend on material). Other trace elements that can also influence the material are as follows:

Copper: Improves corrosion resistance and yield strength of low alloy steels.

Nickel: Improves strength, toughness, and hardenability without seriously affecting the ductility. Encourages grain refinement.

Vanadium: Carbide forming element

Niobium: Niobium (Columbium) increases the yield strength and, to a lesser degree, the tensile strength of carbon steel. The addition of small amounts of Niobium can significantly increase the yield strength of steels. Niobium can also have a moderate precipitation strengthening effect. Its main contributions are to form precipitates above the transformation temperature, and to retard the recrystallization of austenite, thus promoting a fine-grain microstructure having improved strength and toughness.

Boron: Aadditions of Boron up to 0.0023% increase sharply both the yield and ultimate tensile strength. The elongation of steel increases as boron content increases up to 0.0055%. Addition of boron improves impact toughness at 25°C

Other elements and their impact are:-

Cobalt: Enhances air hardenability and reduces scaling. In tool steels it aids use at high temperatures without softening. 8 - 10% Range is used to produce hard tough cutting steels (HSS).

Copper: 0.2% - 0.5% Improves corrosion resistance and yield strength of low alloy steels.

Lead: 0 – 0.25% improves machinability in non-alloy low carbon steels. Reduces strength and ductility.

Manganese: 0.3% - 1.5% reduces the negative effects of impurities from the production process e.g. sulphur embrittlement. Promotes the formation of stable carbides in quenched-hardened steels. Up to 1% acts as hardening agent and from 1% - 2% improves strength and toughness. Alloys containing more than 5% are non-magnetic. Alloys containing large proportions of up to 12% manganese have the property that they spontaneously form hard skins when subject to abrasion (self-hardening). Used heavily in shot blasting machines.

Molybdenum: 0.3% - 5%. Stabilises carbides and promotes grain refinement and increases high temperature strength, creep resistance and hardenability. In nickel-chromium steels reduces temper embrittlement.

Nickel: 0.2% - 5% Improves strength, toughness, and hardenability without affecting the ductility. Encourages grain refinement. Nickel and chromium together have opposing properties and are therefore used together to enhance properties of the steels. At 5% nickel provides high fatigue resistance. When alloyed at higher proportions significant corrosion resistance results and at 27% a non-magnetic stainless steel results.

Phosphorus: 0 - 0.05% residual element from production process. Results in weakness in the steel. Kept below 0.05% it can improve machinability and in larger quantities improves fluidity in cast steels.

Silicon: 0.2% - 3% is used mainly in production of cast iron causing graphitisation and is not used in large proportions in high carbon steels. Up to 0.3% improves fluidity of casting steels without the weakening effect of phosphorus. Up to 1% improves the heat resistance of steels. At 3% improves strength and hardenability. Acts as a de-oxidiser

Sulphur: 0 – 0.5% Residual impurity from production process. Weakens steel and additional process are used to remove sulphur. Neutralised by the presence of manganese. Reduces ductility and weldability.

Titanium: Strong carbide forming element, 0.2%- 0.75% it is used in managing steels to make them age hardening with resulting high strength. Stabilises austenitic stainless steel.

Tungsten: Forms hard stable carbides and promotes grain refining with great hardness at high temperatures. The main alloying element for high speed tool steels.

Vanadium: Carbide forming element and deoxidiser used together with nickel and or chromium to increase strength Improves hardenability and grain refinement and combines with carbon forming wear resistant structure. It is also used as a deoxidiser in casting steels to reducing blowholes and increasing hardness and strength.

<u>Theoretical modelling</u>

Con Mech Engineers has a theoretical modelling tool that can help predict the mechanical properties after quench and temper and a series of iterative inputs have been made to try and establish what material properties are needed to hit the required post heat treatment mechanical properties.

As with all material analysis the major elements that form the basis of the steel grade should be considered. The output from this program gives a suggested minimum requirement for each element to ensure the mechanical properties are achieved:

In this case 070M20 requires a tensile strength of 485N/mm² and a yield of 250 N/mm² with a hardness of 190Hbw Maximum. The simulation program states the minimum alloying elements for the critical elements should be:-

Carbon	0.18%
Chromium	0.08%
Manganese	0.75%
Molybdenum	0.03%

It must be noted that the computer modelling is not absolute however it gives a good place to start. Other factors such as ruling section size and work piece arrangement will have an effect on the results.

<u>Analysing the mill certification before you buy</u>

The mill certification is the best way to ensure that material will comply to the needs of your specification. The mill certification is the only information that accompanies all material from the mill it is produced from. It should contain identity, condition the mill sold it (i.e. As Rolled, Normalised, T condition) and the chemical composition that material is made up from as a minimum. So how do you analyse this data? Below are some examples of mill certificate data for 070 M 20.

The following materials achieved the mechanical results requiring a tensile strength of 485N/mm² minimum and a yield of 250 N/mm² minimum with a hardness of 190Hbw maximum

Mill Certification 1

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.205	0.71	0.22	0.019	0.015	0.03	0.08	0.013	0.29	0.001	0.001

Manganese is slightly down on the theoretical model results, the addition of Copper, Vanadium and Niobium, eliminates this Manganese deficit.

Mill Certification 2

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.18	1.16	.21	0.007	0.012	0.007	0.09	0.03	0.03	0.012	0.001

In this example Molybdenum is down however the high Manganese and sufficient chrome will aid the hardening, and coupled with the presence of Vanadium and Niobium will assist in developing the properties.

Mill Certification 3

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.17	.73	.22	.035	.012	.06	.12	.21			

Molybdenum and Chrome are within/above the recommended levels, but the carbon and Manganese are slightly down. This time the nickel addition and Chrome being higher makes up for this.

Mill Certification 4

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.14	1.28	0.3	0.005	0.009	0.021	0.12	0.09	0.17	0.03	0.002

Nickel, Vanadium and Niobium and Copper will aid the Manganese and chrome to achieve the desired properties even though the carbon is lower than it should be.

The following materials did not achieve the mechanical properties:-

Mill Certification 5

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.18	0.57	0.27	0.024	0.009	0.01	0.1	0.07	0.11	0	0

As you can see this material has failed to achieve the mechanical properties but if the manganese is raised to 0.75%, and the Molybdenum was raised to 0.03%, or if more additional elements were added, the cast would meet the required mechanical properties.

Mill Certification 6

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.17	0.76	0.25	0.025	0.006	0.01	0.04	0.02	0.04		

Failed UTS
Molybdenum, Chrome, Nickel and Copper – at least one of these elements needs to be increased past the recommended limits to achieve the mechanical properties.

Mill Certification 7

C	Mn	Si	S	P	Mo	Cr	Ni	Cu	V	Nb
0.17	0.77	0.22	0.024	0.012	0.01	0.14	0.1	0.18		

Failed UTS
Carbon and Molybdenum are below recommended levels. There are not enough additions of other elements to make up for this.

Sulphur is also high in all the above failures which inhibits the material and therefore more manganese needs to be added to eliminate this problem

Summary

In summary this paper has shown that if all of the major elements are not within a certain criteria then it is reliant on trace/additional elements to be present to achieve the mechanical properties, If these are not present then it may be impossible or difficult to achieve the required mechanical properties within its constraints.

From a supply point of view this means that talking to stockholders and distributors of material is important, to ensure the correct material is sourced. If additional costs are significant in controlling the composition parameters it will be worthwhile to evaluate other suitable materials instead. This will increase confidence within the supply chain, that the material will pass and therefore will not affect lead-times etc.