

# HIGH SPEED STEELS

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High Speed Steels (HSS) are a special class of high alloy steels and are used mainly for the manufacture of cutting tools such as taps, dies, tool bits, drill bits, milling cutter, reamer, broaches, long run punches and dies etc. High speed steel gets its name from the fact that it is used to cut at high speed. The first high speed steels were tungsten type developed by Robert Mushet in UK and FW Taylor in USA towards the end of last century. In 1904 addition of vanadium was patented by crucible steel company leading finally to today's best known grade, the 18/4/1 steel. The addition of cobalt in HSS was first reported in 1912 by Becker in Germany. Due to the shortage of tungsten and its increase in prices, Mo bearing high speed steels were introduced in around 1930 in USA.

Cutting performance of the tools made of HSS primarily depends on the properties such as hot hardness, wear resistance and toughness.

## MECHANICAL PROPERTIES

Hot Hardness: HSS are characterised by its ability to retain its hardness even at high temperature. Fig. 1 is showing the hot hardness value over a range of high speed steels. The hot hardness of HSS obtained due to very slow growth of  $M_2C$  and  $MC$  carbides below  $550^{\circ}C$  while temperature increases to above  $600^{\circ}C$  coarsening of carbides starts. The variation of room temperature hardness and hot hardness at different temperatures is shown in Fig. 2.

Wear Resistance: This property depends on the hardness at the operating temperature. HSS microstructure is composed of a large proportion of uniformly distributed undissolved hard carbides in a relatively less hard

matrix. The undissolved and precipitated carbides are the main contributors to impose wear resistance.

**Toughness:** A wide range of toughness can be obtained by controlling austenitisation and tempering treatments. An inverse relationship is obtained with hardness changes resulting from different tempering temperature in un-notched test data. Impact toughness value decreases with increasing austenitising temperature.

These properties could be obtained by selecting a balanced composition, various processing stages and final heat treatment. The heat treatment is almost last operation of the afore-said tools and considered as the most critical area of technology because of its direct effect on tool life and direct and indirect financial loss if the tools may not have its necessary properties after heat treatment.

### **THE HIGH SPEED FAMILY**

The alloying elements added in Fe-C system to create high speed steels are tungsten, molybdenum, chromium, vanadium and for specific application cobalt.

The three main groups of high speed steels are

- (1) The tungsten high speed steel
- (2) The molybdenum high speed steel
- (3) The tungsten-molybdenum high speed steels

The other classes of high speed steels could be made by addition of cobalt, and increasing the carbon and vanadium content to the above mentioned three main classes. HSS with carbon content more than 1.25% and vanadium content more than 2% could be separately grouped by commercial designation "Super high speed steels". Various grades of high speed steels are shown in Table-1 as per the AISI classification system.

### **ROLE OF ALLOYING ELEMENTS**

**Carbon** The carbon content in high speed steels varies from 0.70 to 1.60%. Carbon is added in steels for increasing the hardenability, proper matrix hardness by forming martensite. It forms complex carbides with W, Mo, Cr, V and provides high wear resistance because of the higher

Table-:1 The AISI classification for high speed steel

Molybdenum Types—Identifying Elements, in %

Type	C	W	Mo	Cr	V	Co	Popular Designation
M1	0.80*	1.50	8.00	4.00	1.00	—	1.5-8-1
M2	0.85;1.00*	6.00	5.00	4.00	2.00	—	6-5-2
M3 Class 1	1.05	6.00	5.00	4.00	2.40	—	6-5-2.4
M3 Class 2	1.20	6.00	5.00	4.00	3.00	—	6-5-3
M4	1.30	5.50	4.50	4.00	4.00	—	5.5-4.5-4
M6	0.80	4.00	5.00	4.00	1.50	12.00	4-5-1.5-12
M7	1.00	1.75	8.75	4.00	2.00	—	1.75-8.75-2
M10	0.85;1.00*	—	8.00	4.00	2.00	—	0-8-2
M15†	1.50	6.50	3.50	4.00	5.00	5.00	6.5-3.5-5-5
M30	0.80	2.00	8.00	4.00	1.25	5.00	2-8-1.25-5
M33	0.90	1.50	9.50	4.00	1.15	8.00	1.5-9.5-1.15-8
M34	0.90	2.00	8.00	4.00	2.00	8.00	2-8-2-8
M35†	0.90	6.00	5.00	4.00	2.00	5.00	6-5-2-5
M36	0.80	6.00	5.00	4.00	2.00	8.00	6-5-2-8
M41	1.10	6.75	3.75	4.25	2.00	5.00	6.75-3.75-2-5
M42	1.10	1.50	9.50	4.75	1.15	8.00	1.5-9.5-1.15-8
M43	1.20	2.75	8.00	4.75	1.60	8.25	2.75-8-1.6-8.25
M44	1.15	5.25	6.25	4.25	2.25	12.00	5.25-6.25-2.25-12
M45†	1.25	8.00	5.00	4.25	1.60	5.50	8-5-1.6-5.5
M46	1.25	2.00	8.75	4.00	3.20	8.25	2-8.25-3.2-8.25
M47	1.10	1.50	9.00	4.75	1.25	5.00	1.5-9.5-1.25-5

\*other carbon contents may be available †not included in January 1970 Steel Products Manual

Tungsten Types—Identifying Elements, in %

Type	C	W	Mo	Cr	V	Co	Popular Designation
T1	0.75*	18.00	—	4.00	1.00	—	18-0-1
T2	0.80	18.00	—	4.00	2.00	—	18-0-2
T4	0.75	18.00	—	4.00	1.00	5.00	18-0-1-5
T5	0.80	18.00	—	4.00	2.00	8.00	18-0-2-8
T6	0.80	20.00	—	4.50	1.50	12.00	20-0-1.5-12
T7†	0.75	14.00	—	4.00	2.00	—	14-0-2
T8	0.75	14.00	—	4.00	2.00	5.00	14-0-2-5
T9†	1.20	18.00	—	4.00	4.00	—	18-0-4
T15	1.50	12.00	—	4.00	5.00	5.00	12-0-5-5

\*other carbon contents may be available †not included in January 1970 Steel Products Manual

Some typical molybdenum-type high performance high speed tool steel compositions produced in Europe and Japan (other than grades corresponding to AISI types)

Identifying elements, in %

Group	C	W	Mo	Cr	V	Co	Popular Designation
A	1.65	7	5	4	5	11	7-5-5-11
B	1.50	7	4	4	5	7	7-4-5-7
C	1.25	10	4	4	3	10	10-4-3-10
D	1.30	9	5	4	3	11	9-5-3-11
E	1.40	9	3	4	4	12	9-3-4-12

hardness of carbides. About 30 percent of carbon is dissolved in matrix and rest of the carbon forms complex alloy carbides.

Tungsten Tungsten is one of the most important alloying element in high speed steel. It forms complex alloy carbide ( $M_6C$ ), where M stands for metals and C for carbon. Tungsten is responsible for high wear resistance and red hardness in high speed steels when dissolves in matrix, it retards to soften on tempering. In dissolved form tungsten increases hardenability.

Molybdenum Molybdenum has similar effect as tungsten has. It can be substituted for tungsten. 1% tungsten is equivalent to 1.6 to 2% molybdenum. Molybdenum bearing HSS can be hardened at lower temperature than tungsten type HSS. Mo-bearing high speed steel has a tendency towards grain growth during austenitising. A narrow austenitising temperature range is to be controlled during austenitising compared to W-type high speed steel. In addition Mo-type high speed steel has great tendency towards decarburization. Retained austenite in Mo-bearing HSS is less stable on tempering compared to W-type high speed steel. Temperature of tempering and time required for tempering in Mo-type steel is lower than the W-type HSS.

Chromium 3-5% chromium is added in almost all high speed steel mainly to promote hardenability. In annealed steel chromium forms  $M_{23}C_6$  carbide. Chromium carbide completely dissolves in austenite in the temperature range between 950 - 1000°C during austenitising treatment. Chromium in HSS also reduces oxidation and scaling during heat treatment and cutting process.

Cobalt Cobalt is added in HSS maximum upto 10%, although a few special steels have higher additions. It raises the austenitising temperature and melting point. The prime effect of cobalt in HSS is to increase the hot hardness, which permits to improve cutting efficiency. The cobalt in HSS does not form carbides, most of it dissolves in the matrix. In annealed steel 88% of cobalt remain in matrix whereas in martensite the amount of cobalt increases to 95%. Cobalt steel slightly reduces the toughness and has a tendency towards decarburisation during heating cycle.

Vanadium Vanadium in HSS forms stable MC or  $M_4C_3$ . Vanadium carbide remains almost insoluble at normal austenitising temperature while other carbides such as  $M_{23}C_6$  or  $M_6C$  mostly dissolve during solutionising. Among the alloy carbides in HSS, vanadium carbide shows maximum hardness. Table-2 shows the hardness of different carbides in HSS. The vanadium carbide at austenitising temperature remains insoluble and restricts grain growth.

**TABLE 2: Micro Hardness of Carbides**

Material	Approx. Knoop Hardness
Vanadium Carbide	2020
Iron Carbide	1150
Chromium Carbide	1820
$Al_2O_3$	2440
Martensite Matrix	790

Vanadium content in steel must be carefully balanced with respect to carbon otherwise partial ferritization or chromium depletion of the matrix can occur depending on whether the ratio of V : C is high or low respectively. Each 1% increase of vanadium in base composition of 0.55%C, 1%V, carbon content in steel to be added by 0.25%.

### **Effect Of Other Alloying Elements**

The effects of other alloying elements are discussed below :

Aluminium About 0.01% (max.) may be present for deoxidation and grain refinement treatments. Attempts were made to replace part of W or Mo but has not been successful commercially.

Boron It may be found in steels if boron containing inoculant is used. Boron content even at 0.008% lead difficulties in hot working and reduces strength due to austenite grain coarsening.

Copper Maximum copper content in HSS is 0.25%. It has detrimental effects as far as cutting performance and hot workability is concerned.

Manganese Maximum manganese content must be upto 0.35%. Larger amounts of Mn may lead to quench cracking and austenite grain growth at normal austenitising temperature.

Silicon Maximum Si content in HSS is 0.35% and has no effect. Large amount of Si if added may cause brittleness of HSS.

Nickel Nickel tends to promote decarburisation and austenite stabilisation. It is undesirable in HSS.

Titanium Titanium forms MC-type carbide and TiC is harder than VC. It can be added in place of vanadium and has similar effect like vanadium. It inhibits grain growth and acts as inoculants for improving carbide size and distribution in HSS.

Niobium It increases secondary hardening response but there is no report to have beneficial effects over vanadium.

Tantalum If added more than 6%, difficult to harden due to the formation of stable carbides. It significantly improves secondary hardening peak and hot hardness stability is upto 650 C.

Sulphur Added upto 0.25% to improve machinability.

Selenium Also added to improve machinability upto 0.25%.

### **CARBIDES IN HSS**

Three types of carbides are observed in high speed steels. The tungsten and molybdenum is found predominantly in the form of  $M_6C$  type double carbides although chromium also remains in these carbides. The  $M_{23}C_6$  carbides are chromium rich and can dissolve iron, tungsten and molybdenum. MC type carbides are vanadium rich which are extremely hard and abrasion resistant.

Various carbides formed in HSS steels its volume % and mean composition of carbides are given in Table-3.

Table-3: Various carbides, its volume % and mean composition of carbides

	Carbides Volume %			
	M <sub>23</sub> C <sub>6</sub>	M <sub>6</sub> C	MC	Total
M2 Annealed	9	16	3	28
Oil Quenched*	0	7.5	1.5	9
T1 Annealed	9	18.5	1.5	29
Oil Quenched**	0	10	0.5	10.5

	Matrix Composition, in %					
	C	Fe	W	Mo	Cr	V
M2 Annealed	0.0	95.5	0.3	0.7	3.3	0.2
Oil Quenched*	0.5	89.0	2.0	3.0	4.6	1.0
T1 Annealed	0.0	95.3	1.5	0.1	3.0	0.2
Oil Quenched**	0.5	85.3	8.6	0.1	4.4	1.0

\*from 2225 F (1220 C)  
 \*\*from 2350 F (1290 C)

After Averbach

For a higher carbon version of M2 and for the more recently developed M41, a similar situation is seen to exist:

			Carbides Mean Composition, in %								Total Weight %
			C	Fe	W	Mo	Cr	V	Co		
Types Present											
M2 (1.1% C)	Annealed	M <sub>7</sub> C <sub>3</sub> , M <sub>6</sub> C, V <sub>4</sub> C <sub>3</sub>	4.9	25.6	26.9	22.9	11.4	8.2	—	22.4	
	Oil Quenched*	M <sub>6</sub> C, V <sub>4</sub> C <sub>3</sub>	3.5**	25.4	37.9	20.7	2.7	8.3	—	13.0	
M41	Annealed	M <sub>7</sub> C <sub>3</sub> , M <sub>6</sub> C, V <sub>4</sub> C <sub>3</sub>	5.0	25.4	30.2	16.5	12.8	8.8	1.2	21.6	
	Oil Quenched*	M <sub>6</sub> C, V <sub>4</sub> C <sub>3</sub>	3.5**	19.5	42.7	19.8	2.5	8.9	1.4	11.0	
			Matrix Composition, in %								
			C	Fe	W	Mo	Cr	V	Co		
M2 (1.1% C)	Annealed		—	96.5	0.26	0.15	1.9	0.01	—		
	Oil Quenched*		0.74	88.9	1.5	2.9	4.1	0.9	—		
M41	Annealed		—	90.3	0.38	0.11	1.9	—	6.4		
	Oil Quenched*		0.78	83.3	2.4	1.6	4.4	1.0	5.7		



## HEAT TREATMENT

The cutting performance of any tool is critically related to its heat treatment. The heat treatment is usually carried out at the end of the manufacturing processes, at which stage a single tool may have a value of more than 20 times from its initial prices. Less serious errors in heat treatment are less noticeable but occur very frequently. A little mistake may cause distortion or cracking which directly involve in financial loss. Some of the errors are difficult to detect without sophisticated instruments and testing but can result in short tool life or premature failure during operation. To avoid these the tool manufacturer must have a system of heat treatment which minimizes the possibility of minor variation of critical factors during heat treatment.

The raw materials available in the market are in the spheroidized annealed form i.e. carbides are uniformly distributed in the form of spheroids in the ferrite matrix. The chemical composition of the raw materials should have very close to its specification.

Heat treatment of high speed steel is done in the following steps:

1. Preheating
2. Austenitising
3. Step quenching/martempering and air cooling
4. Tempering

The furnaces available for heating or austenitising the tools are muffle, salt bath, fluidized bed, and vacuum. Here the heat treatment cycles are considered only with the help of salt bath with electrically heating type.

### Preheating

Austenitizing temperature of all high speed steel is above  $1150^{\circ}\text{C}$ . In order to eliminate cracking or distortion that may arise from thermal shock, high speed steels are preheated first at  $250-350^{\circ}\text{C}$  in air and second at higher temperature at  $800 - 850^{\circ}\text{C}$  and it is carried out in neutral medium like salt bath to avoid any scale formation and decarburization. Again, austenitising temperature of the high speed steel is very near to solidus temperature, so it is better to reduce the austenitising time as much as possible by preheating the sample at lower temperature.



First preheating in air is done normally to eliminate explosion hazards when moisture enters in high temperature molten salt. The soaking time for the tools should be sufficiently long so that entire piece of the tool is become thermal equilibrium. Preheating ultimately reduces decarburization, grain coarsening (by reducing the austenitising time) and uniform dissolution of carbides in austenite solution that also depends on the uniformity and size of the carbides.

### **Austenitising**

Fig.3 shows the phase diagram of 18-4-1 high speed steel. The alloying elements 18% W, 4% Cr, and 1% V increases the eutectoid temperature from 723 to 840<sup>o</sup> C and eutectic temperature from 1130 to 1330<sup>o</sup>C. The eutectoid composition decreases from 0.80% to 0.25 and the maximum solubility of carbon decreases from 2% to 0.7%. The necessary secondary hardening of the steel could be achieved if as much carbide as possible to dissolve in austenite. The austenitising treatment of HSS is carried out just below the solidus temperature to obtain the correct balance of dissolved and undissolved carbides and to control the amount of carbon and alloying elements in austenite. Fig.4 shows the effect of austenitising temperature on the amount of chromium, tungsten and vanadium dissolved in the matrix due to the solution of the carbides.

High speed steel tools are austenitised in the range between 1150-1300<sup>o</sup> C temperature depending on the alloying elements present in that steels. Austenitizing treatment can be carried out in different furnaces like, muffle, salt bath, fluidized bed or vacuum. The cutting performance of the tools are entirely dependent on the austenitising treatment. Lot of troubles may occur if the tools are not austenitised properly as discussed below :

Three basic parameters are to be maintained properly during austenitising, which are as follows:

(a) Temperature : The temperature of the furnace should be controlled as close tolerance as possible. It is better to check the temperature controller before austenitization treatment. There are two possibilities if the temperature is not properly controlled. Either under heating or over heating may occur due to improper austenitising treatment. The effect of proper austenitising, under heating and over heating is shown in Fig.5 in

which Rock well-C hardness vs. tempering temperature is plotted. Initial hardness of the over heated tools are lower than other two cases. But after tempering its secondary hardness peak becomes much more than other two cases. In this case due to higher austenitising temperature most of the carbides dissolve into the solution, therefore, the amount of retained austenite will be more in the as quenched condition shows lower hardness. But after tempering retained austenite will become martensite/bainite and the hardness is increased. In the case of under heating sufficient amount of carbides may not dissolve in austenite, the hardness of the steel after quenching is higher due to its lower retained austenite and large amount of undissolved carbides which are having higher than matrix hardness.

(b) Time : Soaking time at the austenitising temperature is also a very important factor like temperature. Sufficiently long time is required to dissolve the alloy carbides in austenite. But time should not be too long so that grain coarsening may take place. Generally, soaking time at the austenitising temperature also depends on several factors like, austenitising temperature, alloy content, section size, thermal conductivity of the materials to be austenitised, preheating temperature of the materials etc. Large sections, hot worked much lower than the smaller one. So larger sections will have larger carbide size than thin section. So the time of soaking for larger section will be more than smaller one. It is therefore, very difficult to say the exact time of soaking mathematically. Experience is still very important in this regard. If the time of soaking is sufficiently large or very low the possibility of overheating or under heating may occur due to the several reasons discussed already.

#### (C) Neutrality Of The Salt Bath

High speed steels contain mainly carbon tungsten, chromium, molybdenum, vanadium and cobalt in closely controlled amount. It is needless to write that the carbon is the only element to react the desired hardness. Whereas, other alloying elements used in HSS for several purpose like, secondary hardening, hardenability, hot hardness, eliminates temper brittleness, increases wear resistance by forming hard abrasion resistant carbides. So any loss of carbon from the surface of the steel during heat treatment particularly in the case of milling cutter, hacksaw blades etc on a macroscopic scale greatly reduces the cutting

performance as heat treatment is the finishing step for these cutting tools. Any slight loss of other alloying elements also influence the properties. It is well known that the decarburization increases with increasing the working temperature. So special care must be taken to avoid any loss of the aforesaid elements during austenitising. Above 1000 C bariumchloride plus regenerators are used as salt bath hardning high speed steels. The best protection of the surface can be obtained by preparing fresh salt bath. The salt bath gradually saturates with oxygen as the salt gradually reacts with the oxygen and the oxide film on the tool surface. Therefore, it is better to check the salt bath in certain time intervals. Whether the bath has been saturated with oxygen or not can be checked in several ways.

- (1) By chemical analysis of the melt : Two types of oxides are produced in the salt bath, insoluble and soluble. Soluble oxides are responsible for decarburization and insoluble oxide can cause soft spots. The limits of the soluble and insoluble oxides level are shown in Table-4.

**Table-4: Oxide Level in Melt**

	Maximum soluble oxide level	Max. insoluble oxide level
Salt bath 750-950°C	1 %	2 %
Salt bath above 1000°C	3% average work 0% top quality work	5 %

- (2) Microexamination : This process is relatively slow but accurate and costly, requires skilled assesment and is consequently done occassionally.
- (3) Analysis of carbon : In this the standard method for operating saltbaths at 850°C is to immerse high carbon steel foil or blade for about 20 minutes and for 1200°C is about 5 minutes. The amount of carbon in the foil can be determined quickly with the help of appropriate equipments.
- (4) Hardness checking : This process is not very sensitive for detecting surface softness. Severe decarburization can, however, be detected by hardness checking.

- (5) Analysis by high carbon blades      The process is almost same as (c). Here the foil or blade is water quenched and after that it is checked whether the foil is brittle or not. It is known that high carbon steel after quenching is brittle if there is no loss of carbon. Otherwise it will not break. This is the easiest and cheapest way of checking the neutrality of the salt bath amongst all processes.

The salt bath is deoxidized by adding suitable regenerators, like methyl chloride, silicon, silica, borax, magnesium fluoride, ferrosilicon etc. The regenerators react with salt bath oxides and form a sludge. Sludge is removed from the bath after deoxidation. The amount of regenerators required depend on the bath design and type of work being processed. Borax is added normally 4—5% of the mass of the salt bath for operating temperature at 750-900°C.

#### **COOLING FROM AUSTENITISING TEMPERATURE**

To minimize distortion and thermal stresses, high speed steel is generally quenched in a salt bath maintaining at about 550°C. The tools are being kept in the salt bath to equalize the temperature throughout the section and then it is air cooled. Fig.6 shows schematically a full hardening cycle for high speed steel heat treatment and Fig.7 shows the step quenching or martempering cycle of HSS.

Tempering : Quenched high speed steel contains tetragonal martensite, retained austenite and undissolved carbide. The steel in this condition is hard but brittle and dimensionally unstable. The brittleness of this microstructure are due to the carbon atoms trapped in the octahedral lattice sites of martensite, impurity atom segregation at austenite grain boundaries, carbide formation during quenching and residual stresses produced during quenching. Tempering is the heat treatment of quenched steel to modify the mechanical properties by heating the steel in the range of 150 to 700 C.

Tetragonality of martensite is reduced during tempering and finally it forms body centred cubic structure. Carbide is precipitated during tempering, is responsible for the secondary hardening of high speed steels.

Retained austenite is also transformed to martensite/bainite during tempering, develops again internal stress. To relieve internal stress and

to temper martensite formed from retained austenite during 1st tempering high speed steels are double or tripple tempered depending on its alloying elements. All high speed steels are tempered in the range of 540 to 560 C. Tempering of high speed steel is done either in salt bath or in air circulating furnace. However, salt bath furnace is preferred due to its uniform heating. Before tempering as quenched high speed steels consist of highly alloyed martensite, highly alloyed retained austenite and undissolved carbides mainly vanadium carbide and M C.

The changes of as quenched HSS steel are given in Table-5.

**Table-5 : 1st Tempering**

Tempering Temperature, °C	Structural Changes		
	Highly alloyed $\gamma$	Highly alloyed Martensite	$M_6C$ and $V_4C_3$
200		Ppt. $\epsilon$ carbide Forms $Fe_3C$	
425	Ppt. $M_{23}C_6$ + Lower alloy $\gamma$	Forms $M_{23}C_6$	
540	Ppt. $M_6C$ + Lower alloy $\gamma$ To martensite on cooling	Ppt. $M_6C$ (Secondary hardening) Growth of Carbides	No Change

## DOUBLE TEMPERING

°C	Q	Structural Changes	
	Low alloy retained austenite	Low alloy martensite	$M_{23}C_6$ , VC and $M_6C$
200	↓	Precipitate $\epsilon$ -carbide	↓
		↓ $Fe_3C$	
425	Precipitate + retained austenite	↓ $M_{23}C_6$	
	↓	↓ $M_6C$	
540	Precipitate + retained austenite		
	↓	↓	
	Martensite on cooling	Growth of Carbide	No change

The formation of freshly formed martensite after 1st or 2nd tempering operation results microstresses. Therefore, high speed steel is double or triple tempered to reduce micro or macro stresses and to temper freshly formed martensite.

The effect of time and temperature of tempering could be explained by a single parameter, called Larson-Miller parameter, LMP,

$LMP = T(C + \log t)$ ;  $T$  = temperature,  $^{\circ}K$ ;  $t$  = time in hour;  $C$  = a constant; the value of which depends on the composition of austenite.

The effect of tempering time on the variation of hardness is shown in Fig.

## 8. SURFACE TREATMENTS

The performance of the cutting tools can be improved by many folds by a suitable surface treatment of the post heat treated (quenched and tempered) tools. Surface treatment improves corrosion resistance, hardness and wear resistance of the surface. The various methods are discussed below :



### **Steam Tempering**

Steam tempering improves the performance of tool life even upto 50%. It produces a blue coloured porous surface layer of iron oxide,  $\text{Fe}_3\text{O}_4$  usually a case depth of about  $2.5\mu\text{m}$ . The performance of the cutting tool is improved as the porous layer has the ability to retain thin oil film which prevents the welding of the machine chips to the cutting edge. Cutting tools are to be thoroughly cleaned before steam tempering. The tools are placed in a furnace and temperature is raised to  $300\text{--}350^\circ\text{C}$ . Steam is then allowed to pass under pressure  $0.1 - 0.3 \text{ atm}$  for about half an hour in order to remove air from the furnace chamber. Temperature of the furnace will be raised to  $550^\circ\text{C}$  for about one hour and then cooled to  $300^\circ\text{C}$ . Immediately after cooling in air from  $300^\circ\text{C}$  to room temperature tools are dipped in oil.

### **Nitriding**

Salt bath nitriding is widely used in heat treated cutting tools to improve the cutting performance of the tools. Nitriding process increases the life of the tool to double or even more. Salt bath in nitriding contains sodium cyanide, sodium cyanate, sodium carbonate and alkaline chloride. The temperature of the bath is maintained about  $550$  to  $560^\circ\text{C}$ . Cyanate decomposes and provides atomic nitrogen which penetrates into the metal and forms nitrides at the surface. Skin or Surface hardening after nitriding may increase to about  $1100 \text{ HV}$ . This skin hardened layer gives higher wear resistance, a low coefficient of friction and scoring resistance.

### **Tufftriding**

This process was developed by ICI in UK. Tufftriding bath consists of potassium cyanide and potassium cyanate and liberates both carbon and nitrogen. The temperature of the salt bath is maintained about  $570^\circ\text{C}$ . At this temperature nitrogen is more soluble than carbon and diffuses into tools. Carbon forms iron carbide at the surface of the tools. A tough compound zone of carbides and epsilon iron nitride are formed during the process. The tough non-brittle zone formed by this process increases resistance to wear, seizing, galling and corrosion.

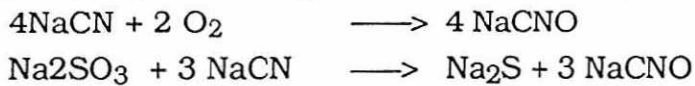


### **Sulfinuz Process**

This process was developed in France. It is carried out in a molten salt bath containing sodium cyanide, chloride, carbonate and sulphite. The composition of the salt bath is as follows :

NaCN	9.4%
NaCNO	11.7%
Active Sulphur as Na <sub>2</sub> S	0.18%

The sodium cyanate is produced by the oxidation of cyanide and sodium sulfide is produced by the reduction of the sulfite as follows :



In this process surface of the heat treated tools are saturated with carbon, nitrogen and sulphur. Sodium cyanate decomposes and liberates nascent nitrogen and carbon monoxide. Finally carbon, nitrogen and sulphur are picked up by the tools. This process is very successful to obtain excellent anti gall and wear properties. It improves resistance to scuffing, hot hardness and reduces the tendency to sticking.

### **Oxynitriding**

The two methods steam tempering and nitriding can be combined into a single method oxynitriding. The operating temperature of this method is about 550°C and is carried out in an atmosphere containing a mixture of ammonia and water. The diffusion case on oxynitrided HSS consists of an external two part-zone of oxides and an internal part enriched in nitrogen and oxygen in the matrix. The outer zone of the oxide past is porous and is almost pure magnetite and inner zone is consisted of magnetite which contain Cr, W, Mo and V.

The oxynitrided tools enhance wear resistance significantly.

## HIGH SPEED STEEL BY RAPID SOLIDIFICATION ROUTE

It is well established fact that the distribution of carbides in steel are the most important single factor responsible for producing the desired mechanical properties of a high speed steel. The conventional method follows a complex solidification processes in steels. The complex solidification process produces segregation of carbon and alloying elements, rendering the steel unsuitable for immediate use in cutting tool applications. In conventional casting practice, the formation of primary carbide net work during solidification and cooling to room temperature results in a coarse carbide particle distribution. Segregation of steels divided into two types i.e. long range macro-segregation occurs over long distances and short range micro-segregation occurs within the grains on the dendritic scale. Even longtime homogenisation treatment are not effective to eliminate the macro-segregation while microsegregation can be significantly minimised by homogenisation treatment. The segregation phenomenon changes the distribution pattern of carbides in HSS.

Several attempts have been made to develop an alternative processes to obtain uniformly distributed carbides in HSS. The powder metallurgy route has been studied extensively to produce uniform carbide distribution and refinement in HSS.

The first commercial development HSS by rapid solidification route was carried out by crucible steel company, USA and Uddeholm in Sweden. The liquid steel is atomised by high pressure inert gas or nitrogen jet and the droplets cooled at a controlled rate to produce a spherical powder. These powders are then consolidated by hot isostatic press and then rolling or forging is carried out by conventional route. HSS produced by this route gives a finer and more uniform distribution of carbides than conventionally produced HSS. HSS produced by this route has not shown remarkable increase in cutting performance over conventionally produced HSS, although powder metallurgy processes can produce extremely fine uniformly distributed microstructures.

The cooling rate achieved by gas atomisation process are limited to  $10^4$  -  $10^5$  K/s.

Heat treatment procedures to be followed are similar to that followed in conventional route.

The super saturated solid solution phase is possible to produce by increasing the cooling rate to  $10^6 - 10^8$  K/s. Such type of cooling rate could be achieved using heat removal by conduction into a solid heat sink. This process is called splat quenching or cooling process. In this process a thin liquid film is rapidly quenched on a solid substrate that has high thermal conductivity.

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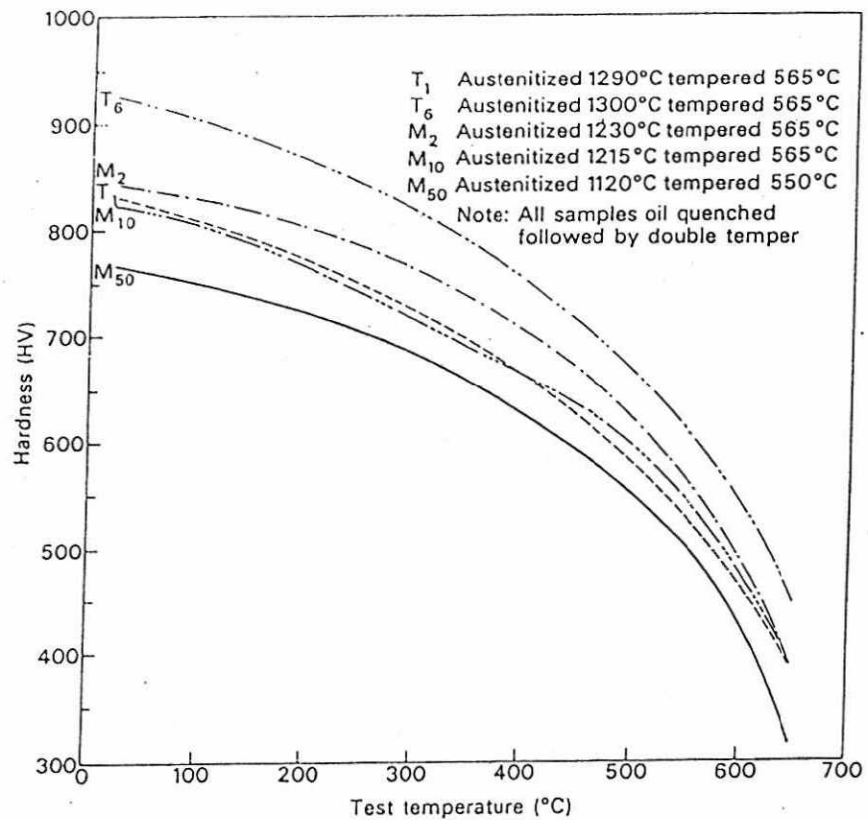


Fig.1: Hot hardness over a range of high speed steels (Courtesy of Climax Molybdenum Co., London)

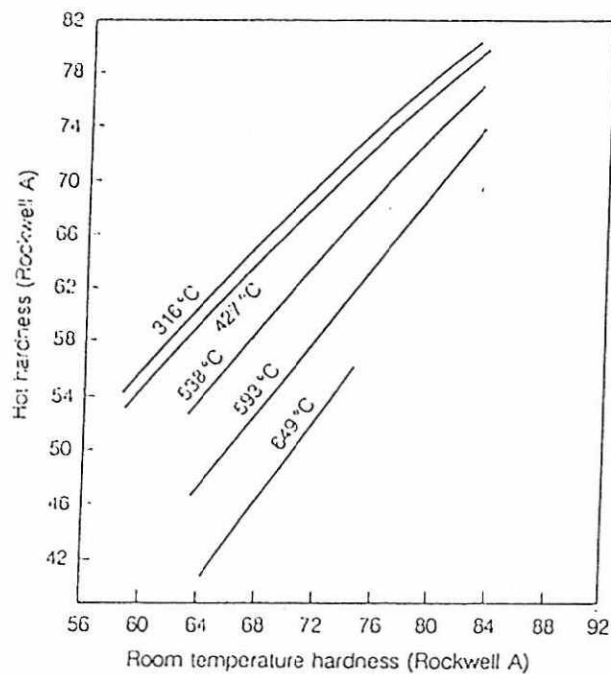


Fig.2: The relationship between the room temperature hardness and hot hardness at different temperatures (Payson, 1962)

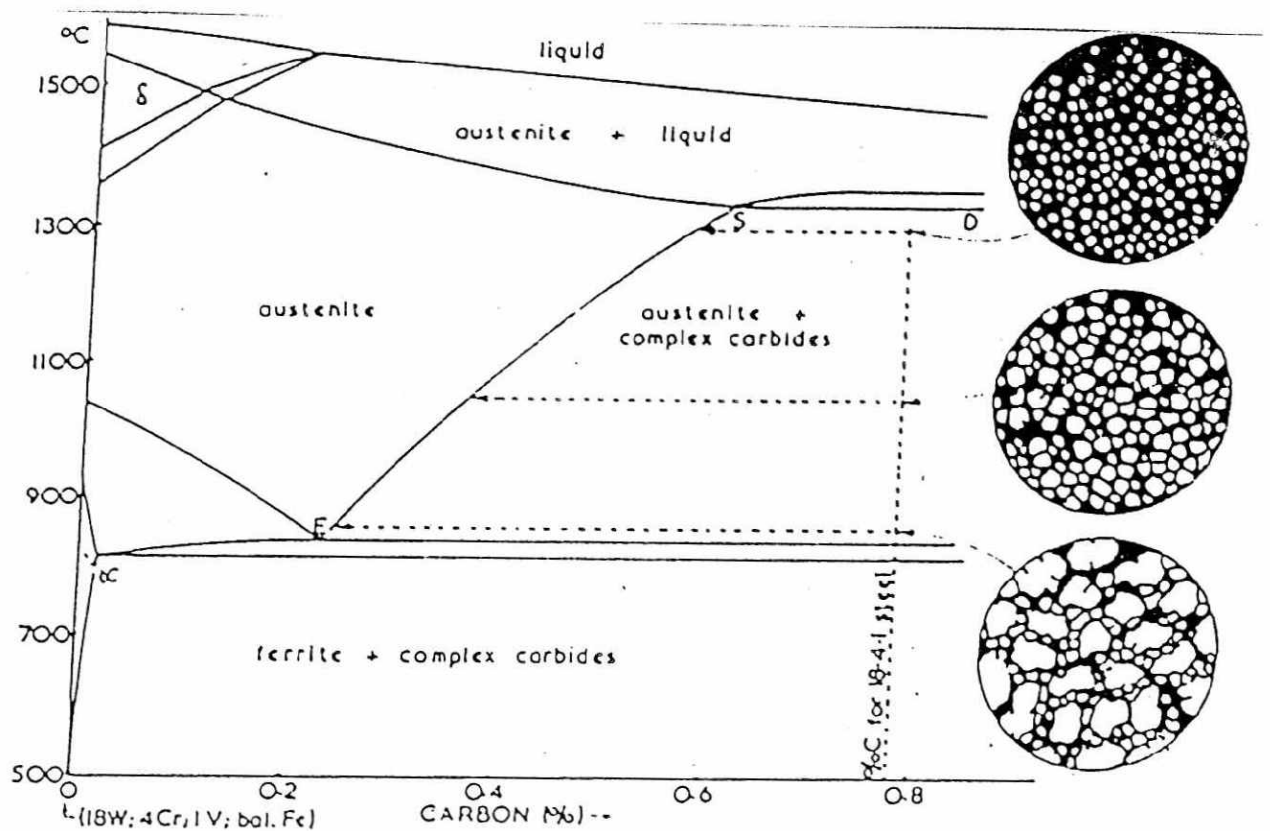


Fig.3 - A 'pseudo-binary' diagram representing the structure of 18.4.1 high speed steel.

Here the tungsten-chromium-vanadium content is kept constant but carbon remains variable. The sketches of microstructures show the effects of solution temperature upon the extent of solubility of the complex carbides (light) in the matrix (dark) following quenching. The higher the quenching temperature the greater the solubility of carbides (indicated by the slope of ES).

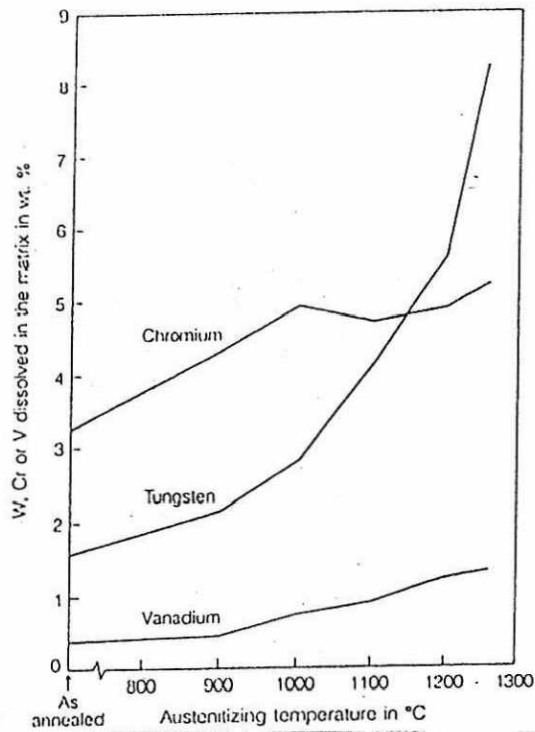


Fig. 4 The effect of austenitising temperature on the amount of Cr, W, and V dissolved in the matrix due to the solution of the carbides in a steel containing 0.7 wt.%C, 18 wt.%W, 5 wt.%Cr, 1wt.%V.

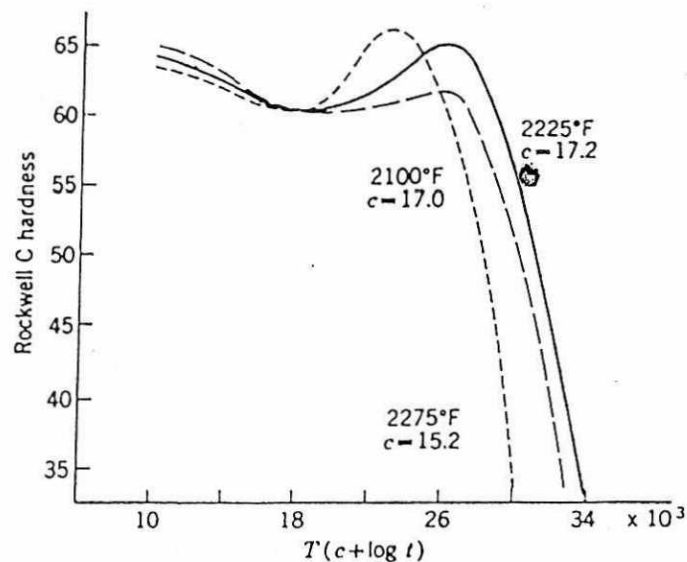


Fig. 5 Tempering curves for 6-5-4-2 high-speed steel austenitised at three different temperatures. Tempered hardness is plotted against the parameter  $T(c + \log t)$ , where  $T$  is the tempering temperature,  $t$  the tempering time, and  $c$  a constant for a specific steel and austenitisation treatment. (Roberts, Grobe, and Moersh)

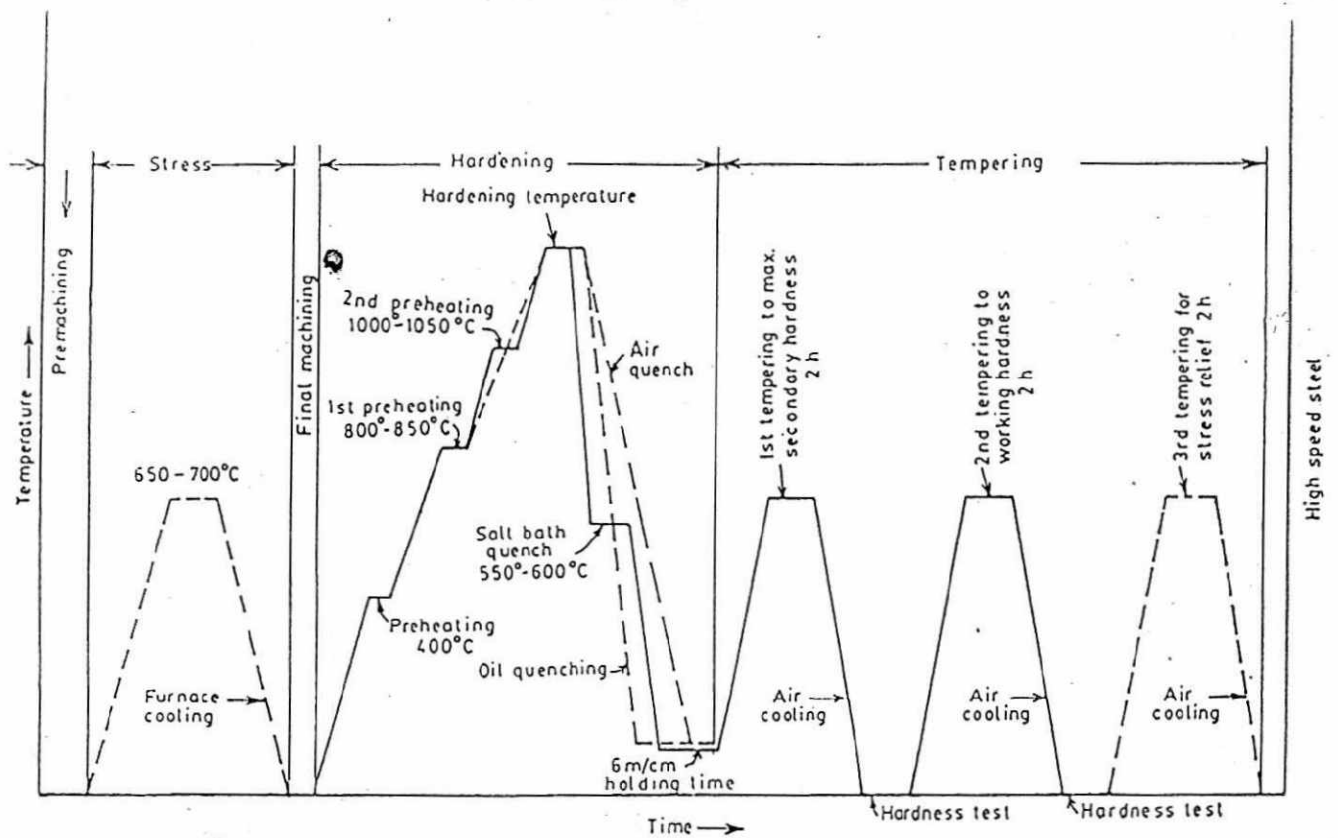


Fig. 6 Heat treatment sequence for high-speed steels.

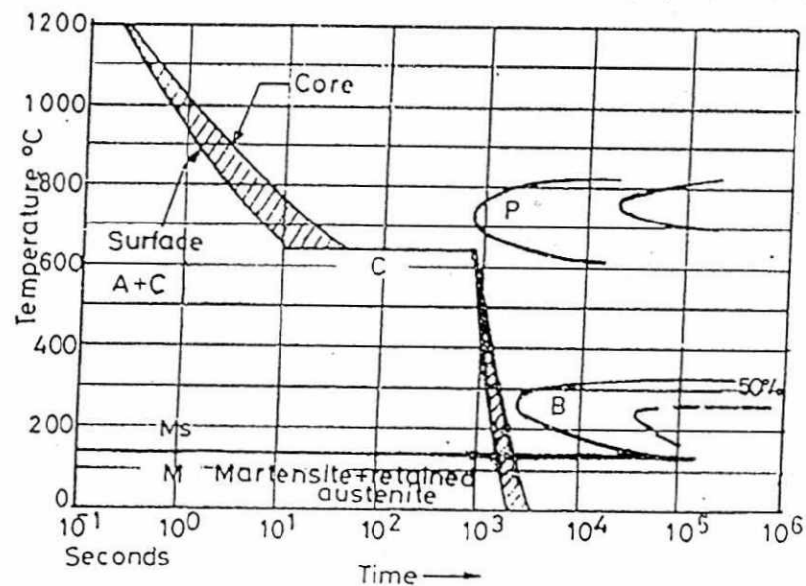


Fig. 7 TTT diagram showing a quenched specimen subjected high-temperature martempering.



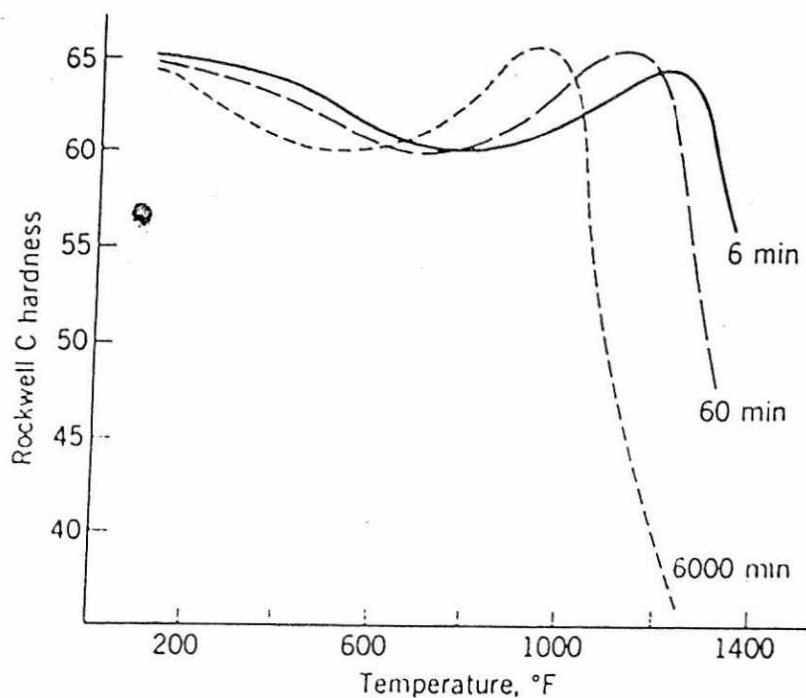


Fig. 8 Tempering curves for 18-4-1 high speed steel, quenched in oil from the usual hardening temperature of  $2350^{\circ}\text{F}$ ; curves for hardness after tempering 6, 60, and 6000 min are reproduced. Almost identical tempering curves are obtained for the 6-5-4-2 high speed steel when oil-quenched from its usual hardening temperature of  $2225^{\circ}\text{F}$ . (Roberts, Grobe, and Moersh)