COLD WORK AND HOT WORK TOOL STEELS

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INTRODUCTION

Tool steels are used for various applications such as cutting, drilling, machining, grinding and forming metals and alloys at room as well as elevated temperatures. The important requirements of tool steels are : (i) High hardness (ii) good wear resistance (iii) adequate toughness (iv) high hardenability (v) special properties specific for specific applications such as resistance to fire cracking for hot work tool steels.

Cold work tool steels are used for applications at room temperature while hot work tool steels are meant for high temperature jobs such as extrusion dies for not extrusion of aluminium or brass. The different types of tool steels belonging to both categories and the heat treatments given to them are briefly discussed in this lecture.

COLD WORK TOOL STEELS

Cold work tool steels are specified either according to their hardenability or according to the application or composition. The various categories are :

(a) Water hardening tool steels
(b) Oil hardening tool steels
(c) Air hardening tool steels
(d) Shock resisting tool steels
(e) High Carbon high chromium tool steels

There are several steels in each category but for simplification only one is chosen for this lecture.

WATER HARDENING TOOL STEELS

These are indicated by the symbol W followed by a numeral (for instance, Wi has a composition of 0.85 - 0.95 %C). There are either plain carbon or very low alloy hyper eutectoid steels and are so named because they have to be water quenched for getting martensite in the centre of the tool due to their poor hardenability. In practice, they may be water or oil quenched for getting the optimum properties. They are generally received in the annealed condition that would have a spheroidised carbide structure (because this would give a soft condition), easily amenable for machining . After rough machining they may be stress relieved prior to finish machining and are preheated at about 600°C (especially for large tools when they are to be charged directly into a furnace maintained at the austenitisation temperature). After quenching in oil or water they are tempered at about 200°C for getting a hardness of Rc 58-64.

The heat treatment sequence for Wi tool steel is given in Table-1 while its tempering curve is shown in Fig.1(a).

OIL HARDENING TOOL STEELS

These are invariably low alloy hypereutectoid steels and are so named because of their intermediate hardenabiity, needing oil-quenching for obtaining maximum quenched hardness. Their heat treatment sequence is also similar to water hardening tool steels and the sequence for O2 steel (0.9%C), 1% Mn, 0.5% Cr and 0.5% W) is also shown in Table-1. The tempering curve is shown in Fig-1(b).

The microstructures of W and O series of steels are very similar for a given treatment and those for a spheroidised Wi steel and quenched and tempered 01 steel are shown in Figs 2(a and b) respectively. It is obvious that these steels are quenched from a temperature between the Al and Acm temperatures to get better toughness (obtained because of prevention of proeutectoid cementite along the prior austenite grain boundaries and finer martensite structure).

AIR HARDENING TOOL STEEL

As the name implies these contain higher alloy content (about 5%) to allow martensite formation on air cooling itself or alternatively tools with larger cross section could be used because of better hardenability. (For eg. the A2 steel contains 1% C, 5% Cr and 1% Mo). They are also processed like the W and O type steels except that they need a higher austenitisation temperature (because of the larger quantity of carbide forming elements) and they may need stabilisation treatment at a sub-zero temperature after quenching to transform the retained austenite (the retained austenite in these steels is higher due to the lower M_s temperature). The sequence of treatments for A6 steel are given in Table-1 and its tempering curve is given in Fig-1(C). Because of the high alloy content, alloy carbides do not fully dissolve at the austenitisation temperature (as shown in Fig.2c). These coarse alloy carbides contribute to better wear resistance because of their higher hardness as compared to the matrix.

SHOCK RESISTING TOOL STEELS

The shock resisting steels are used for applications where the loading could be by impact (as in chisels and hammers) and the toughness of the steel is a very important consideration. For this purpose, the carbon content is kept at about 0.5% and the alloying is made to increase the hardenability and quenched hardness. S6 steel contains 0.45% C, 1.4% Mn, 2.25% Si, 1.5% Cr and 0.4% Mo. In view of the lower carbon the austenitisation temperature is higher (875 - 925°C) but otherwise the heat treatment is similar to O-type steels (Table-1 and Fig.1d).

HIGH CARBON HIGH CHROMIUM TOOL STEELS

As the name implies these steels contain a high carbon content of 1.5% to 2.25% and a high chromium content of 12% and most of them contain 1% Mo. (some of them contain vanadium upto 4%). These are given by the initial symbol D. The D2 steel is a very popular grade and contains 1.5% C and 12% Cr and 1% Mo. These steels are known for their outstanding wear resistance

These steels have a different metallurgical basis of heat treatment than all other cold work tool steels. They are similar to high speed tool steels as far as the heat treatment consideration are concerned. These are :

(a) In view of the high C and Cr contents these steels contain about 5 to 10% undissolved alloy carbides even at the highest austenitisation temperature (in this sense they are alloy cast irons). These coarse carbides contribute to the superior wear resistance because of their high hardness.

(b) In view of their high Cr content these steels are amenable to secondary hardening on tempering at 550°C.

(c) Since both C and Cr decrease the Ms temperature, these steels contain significant quantities of retained austenite in the as-quenched condition. This necessitates low temperature stabilisation treatment and/or a double tempering treatment.

A study of Fe-Cr binary phase diagram shows that the maximum solubility of Cr in austenite is at 1040°C (because of the γ-loop formation) and these steels are therefore austenitised at 1025 - 1040°C. A lower or higher hardening temperature results in a lower as-quenched hardness because of less amount of C in austenite (due to the insolubility of alloy carbides at a lower temperature) or higher amounts of retained austenite at the higher temperature do to more C and Cr going into solid solution in γ. Because of higher hardenability they could be air hardened but in larger sections they are oil quenched to avoid pro-eutectoid cementite formation. In the as-quenched condition they contain 5- 10% alloy carbide and about 10% retained austenite. To transform the retained austenite these steels may be given a stabilising treatment and are tempered at 550°C to make effective use of the secondary hardening that occurs in these steels. More commonly they are given the "**Double tempering**" treatment. On first tempering at 550°C, the alloy carbides precipitate in retained austenite increasing its M_s temperature thereby transforming it to martensite on cooling the steel to room temperature. The steel is therefore given the second tempering treatment at the same temperature to temper this martensite and to get better toughness. They can develop a hardness of Rc 62 - 64 with adequate toughness due to double tempering.

The heat treatment schedule for steel D2 is given in Table-1 and the tempering curve in Fig-1(e). The optical microstructure of the steel in the quenched and tempered condition is shown in Fig.2(d).

HOT WORK TOOL STEELS

These steels are used for work at high temperature and since the tool is cooled to room temperature soon after the job, the hot work tool steels are subjected to repeated thermal cycles. This "thermal fatigue" leads to the formation of surface cracks (known as fire cracks) if the steel does not have adequate toughness to withstand the thermal strains. The high temperature hardness rather than the room temperature value, is more important for these steels. Because of these considerations the carbon content of these steels is kept at a low value of 0.35%.

There are three types of steels, based on Cr, W or Mo as the principal alloying element. H1 to H19 are Cr-based, H20 - H39 are w-based and H40 - H59 are Mo-based. The Cr-based steels have the best toughness of all these steels but their highest temperature of usage is the lowest (upto 475°C) among the three categories. The W or Mo steels are used for service upto about 600°C but their toughness is inferior to Cr steels.

Since H11 is one ofthe most popular steels in this category (used extensively as the extrusion dies of Al), the physical metallurgy of this steel will be presented here.

In view of the lower carbon content, the H11 steel is hypo-eutectoid and hence needs a higher austenitisation temperature of 1000 - 1025°C and it becomes fully austenitic at this temperature. In view of the high Cr and medium Mo content it possesses excellent hardenability but to avoid thermal strains (which build up residual stresses and distortion) it is usually quenched in a molten salt bath kept at about 500°C and held for a few minutes (to bring thermal gradients in the steel to a minimum) before cooling in air to room temperature. It is then immediately double (or even triple) tempered at 575 - 600°C for 2+2 hours to achieve good toughness and a room temperature hardness of Rc 45 - 50.

The heat treatment schedule and tempering curve for H11 steel are given in Fig.3.

BIBLIOGRAPHY

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Table 1. Heat Treatment Schedules for Cold Work Tool Steels

Schedule	Wi	O2	A6	S5	D2
Rough Machining					
Stress Releive(°C)	620	650	675	675	675
Finish Machine					
Preheat (°C)	600	650	650	760	650
Austenitise (°C)	800	800	850	900	1025
Quench	W/O	0	A/O	0	A/O*
Stabilise (°C)	Not Reqd	-75	-75	Not Reqd.	-75/-196
Temper (°C)	200	200	200	200	550
Final grind to size					

* A : Air, O : Oil, W : Water

FIGURE CAPTIONS

Fig.1 Tempering curves for cold work tool steels :
(a) W1 (b) 02 (c) A6 (d) S1 (e) D2

Fig.2 Optical microstructures of tool steels :
(a) Spheroidised structure in W1 (b) Tempered martensite structure in 02 (c) Quenched and tempered A2
(d) quenched and tempered D2

Fig.3 Heat Treatment schedule and tempering curve for H11 steel

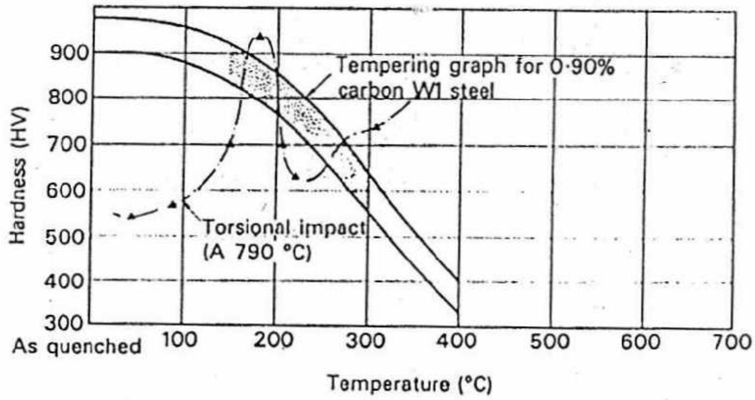

Fig. 1(a)

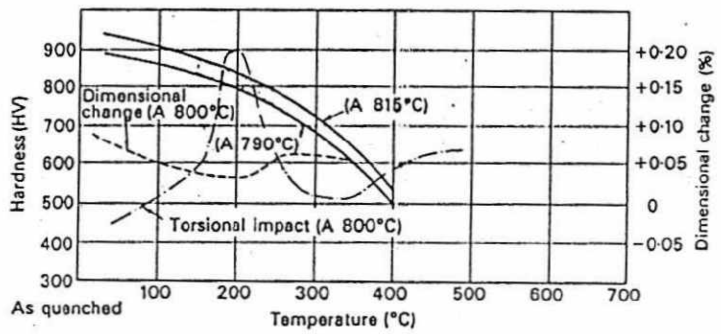

Fig. 1(b)

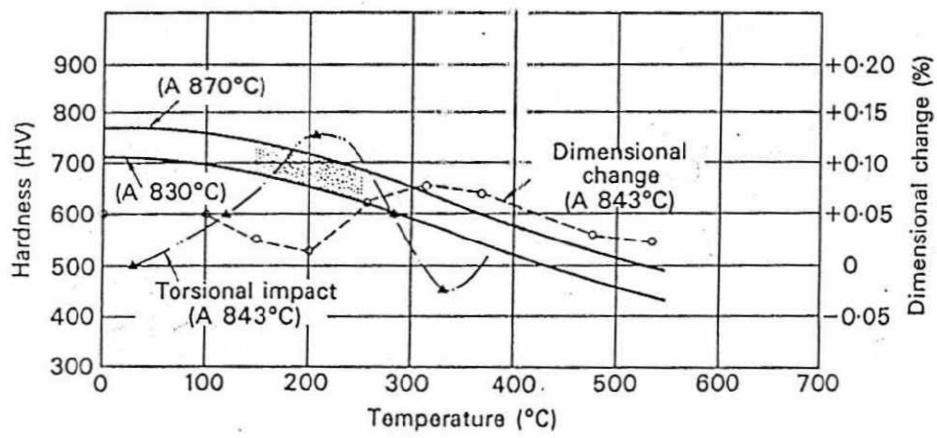

Fig. 1(c)

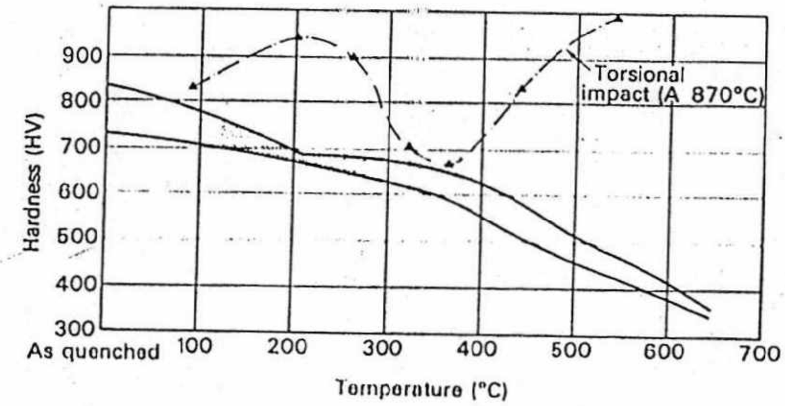

Fig. 1(d)

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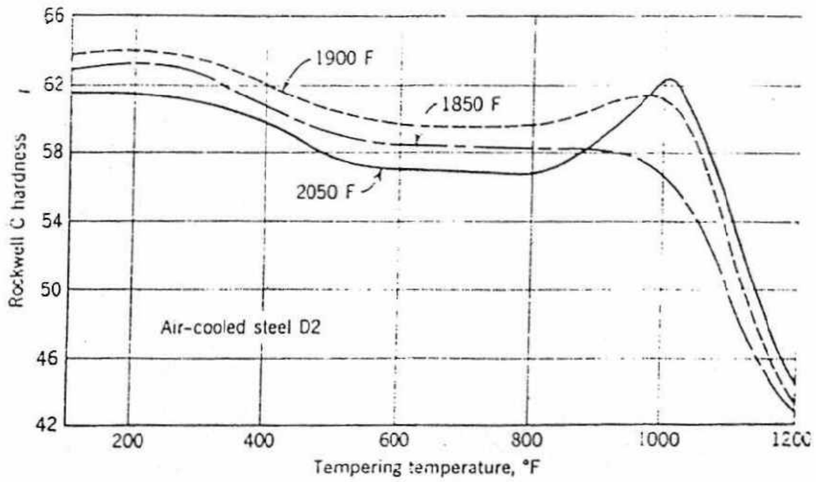

Fig. 1(e)

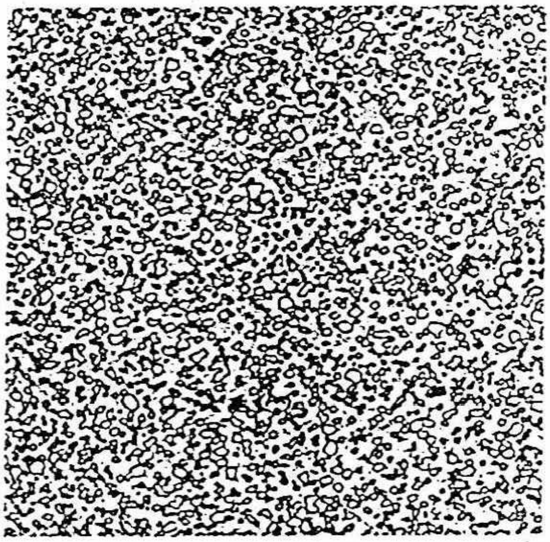

Fig. 2(a)

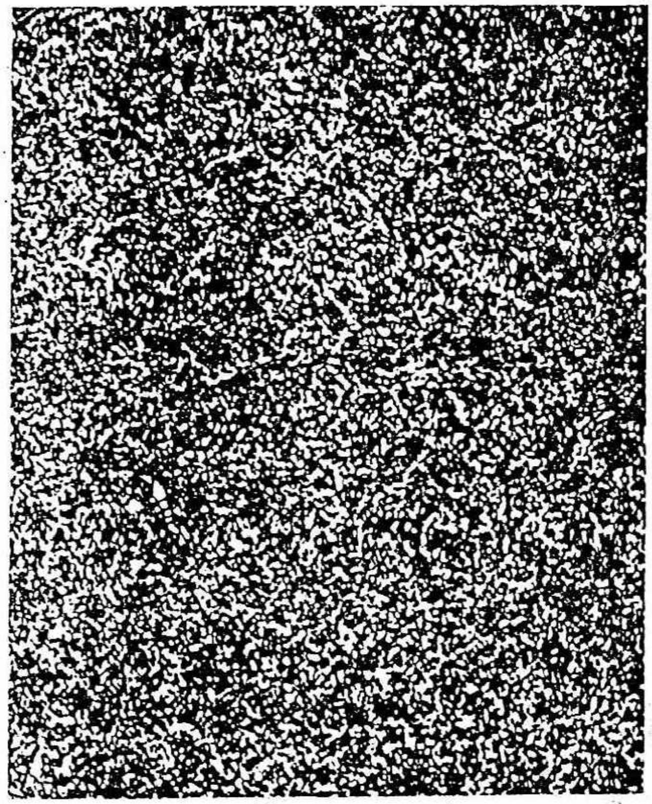

Fig. 2(b)

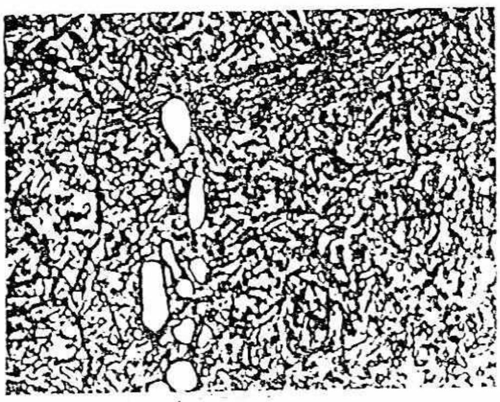

Fig. 2(c)

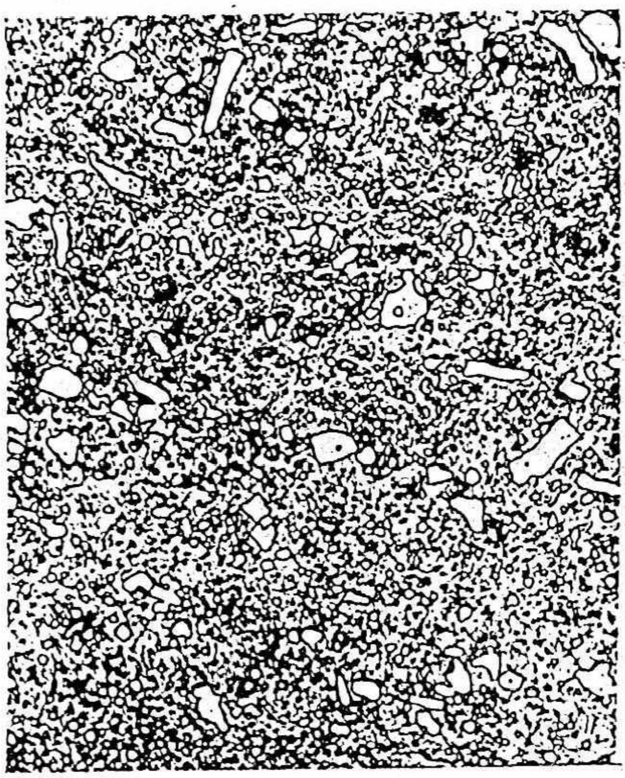

Fig. 2(e)

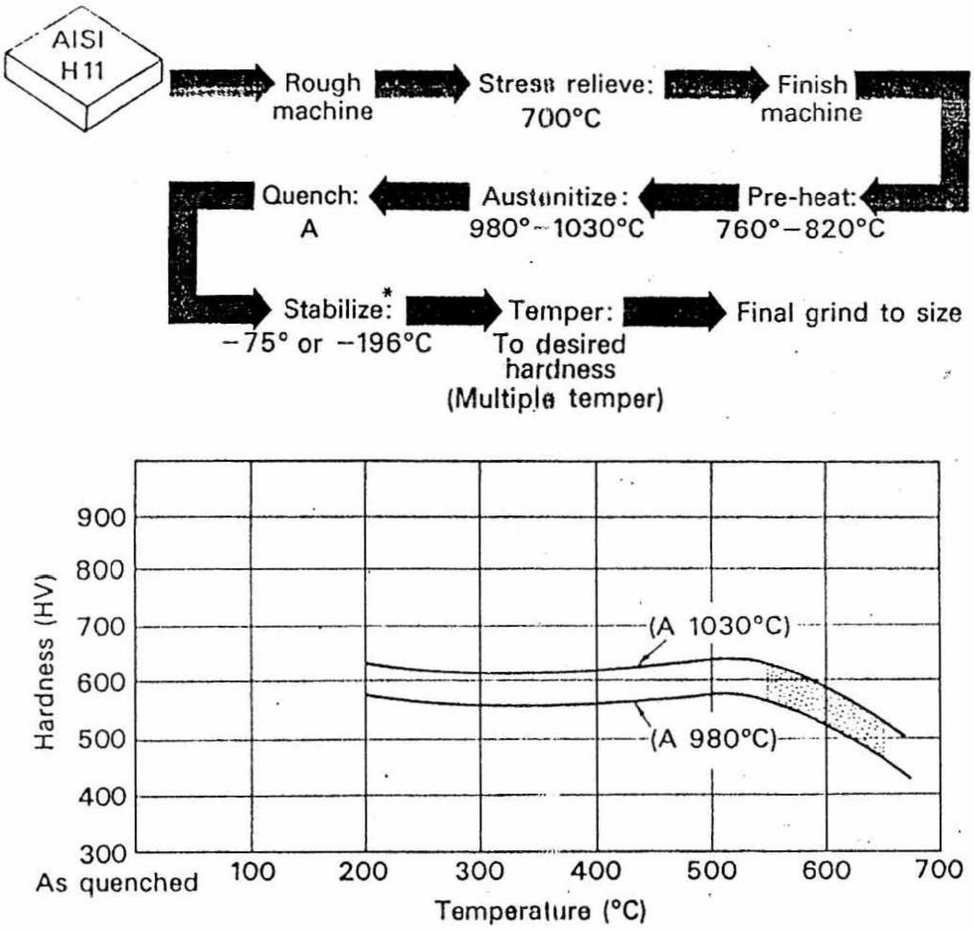
AISI
H11
Rough
machine
Stress relieve:
700°C
Finish
machine
Quench:
A
Austenitize:
980°–1030°C
Pre-heat:
760°–820°C
Stabilize:*
–75° or –196°C
Temper:
To desired
hardness
(Multiple temper)
Final grind to size
Hardness (HV)
900
800
700
600
500
400
300
As quenched
100
200
300
400
500
600
700
Temperature (°C)
(A 1030°C)
(A 980°C)

Fig. 3