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An Investigation of Optimum Heat Treatment Strategy for M2 Tool Steel.

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Abstract

M2 tool steel is categorised as molybendum tool steel. Due to high hardness and wear resistance it is well suited for drill bits, milling cutters and hobs. The current work reports and analyzes results of mechanical testing performed on various heat treated samples of M2 tool steel (Twist Drill size 16mm dia.). It was found that maximum tool life obtained when M2 tool steel hardened at 1200^{0}C and tempered at 560^{0}C temperature.

I. INTRODUCTION

One of the higher-grade tool steels that can be used in various hot and cold-work manufacturing processes is M2 tool steel. It has relatively high-carbon and high-chromium contents compared to other tool steels, and are therefore categorized as a Molybdenum based tool steel. It possesses high strength, and good wear resistance. It is therefore suited for the manufacturing of some tools including milling cutters, drill bits and hobs. During these manufacturing operations, various damage mechanisms act simultaneously to produce cumulative damage to the tool and because increasing deviations from the original tool geometry due to wear, micro-chipping, heat-checking, or breaking of the tool or a part of the tool .For better tool performance, material of the tool must be improved by changing its properties. The two most relevant properties are toughness and hardness; toughness prevents instantaneous fracture of the tool or tool edges, and hardness must be sufficiently high to avoid local plastic deformation so that tool geometry remains unchanged.

In soft annealed tool steel, most of the alloying elements are bound up with carbon in carbides. In addition to these there are the alloying elements cobalt and nickel, which do not form carbides but are instead dissolved in the matrix. When the steel is heated for hardening, the basic idea is to dissolve the carbides to such a degree that the matrix acquires an alloying content that gives the hardening effect without becoming coarse grained and brittle. When the steel is heated to the hardening temperature (austenitizing temperature), the carbides are partially dissolved, and the matrix is also altered. It is transformed from ferrite to austenite. This means that the iron atoms change their position in the atomic lattice and make room for atoms of carbon and alloying elements. The carbon and alloying elements from the carbides are dissolved in the matrix.

If the steel is quenched sufficiently rapid in the hardening process, the carbon atoms do not have time to reposition themselves to allow the reforming of ferrite from austenite, i.e. as in annealing. Instead, they are fixed in positions where they really do not have enough room, and the result is high microstresses that can be defined as increased hardness. This hard structure is called martensite. Thus, martensite can be seen as a forced solution of carbon in ferrite. When steel is hardened, the matrix is not completely converted into martensite. Some austenite is always left and is called “retained austenite.”The amount increases with increasing alloying content, higher hardening temperature and longer soaking times. After quenching, the steel has a microstructure consisting of martensite, retained austenite and carbides. This structure contains inherent stresses that can easily cause cracking. But this can be prevented by reheating the steel to a certain temperature, reducing the stresses and transforming the retained austenite to an extent that depends upon the reheating temperature. This reheating after hardening is called tempering. Hardening of a tool steel should always be followed immediately by tempering. It should be noted that tempering at low temperatures only affects the martensite, while tempering at high temperature also affects the retained austenite. In case of tool steel toughness and hardness can be inter-dependent, and a good combination can be achieved by optimum heat treatment.

II. EXPERIMENTAL WORK

Samples of M2 tool steel were subjected to different heat treatment sequences: annealing,pre-heating,high heating hardening, salt bath quenching, and three tempering at four different temperatures: 540^{0}C,550^{0}C,560^{0}C,570^{0}C.Heat treated specimens were mechanically tested for impact toughness, and hardness.

TABLE I CHEMICAL COMPOSITIONS OF M2 TOOL STEEL

Steel Type	C	Mn	Si	Cr	W	Mo	V
M2	0.85	0.3	0.3	4.15	6.4	5.0	1.9

Heat treatment was carried out in line with the standard procedure. Three sets of specimens were prepared in this way:

(a) Hardening temperature 1180^{0}C and tempering at 540^{0}C,550^{0}C,560^{0}C and 570^{0}C temperature.
(b) Hardening temperature 1200^{0}C and tempering at 540^0 C,550^{0}C,560^{0}C and 570^{0}C temperature.
(c) Hardening temperature 1220^{0}C and tempering at 540^{0}C,550^{0}C,560^{0}C and 570^{0}C temperature. (All samples were three tempered for two hour)

TABLE II HEAT TREATMET SEQUENCE

1.Normalising **770-820^{0}C**	**2.Annealing** **870-900^{0}C**	**3.Warmimg** **400^{0}C**	**4.High heating** **850^{0}C**
5.Austanising **1180-1220^{0}C**	**6.Quenching** **760^{0}C**	**7.Tempering** **540-560^{0}C**	

A. Normalising

In this process tool steel specimen is heated 650^{0}C for 24 hour and then cooled in air. As shank and flute part of twist drill is butt welded it become necessary to relive the stresses due to welding.

B.Annealing

This is the softening process in which tool steel specimen were heated to 820^{0}C for eight hour and cooled at room temperature.

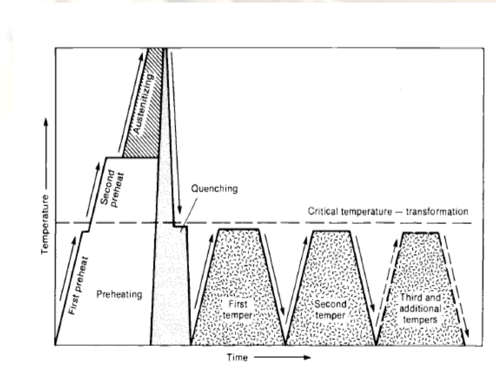

Fig.1 Time versus temperature plot illustrating sequences required to properly heat treat high-speed tool steels

C.Austenitizing (Hardening)

Before austenitizing, warming and preheating of tool steel specimen was carried at 850^{0}C in salt bath furnace. The purpose of this process is to reduce thermal shock, reduce danger of excessive distortion or cracking and to reduce time required in high heat furnace.

Tool specimens were hardened at 1180^{0}C,1200^{0}C and 1220^{0}C for 5 minutes soaking time. This soaking time is depend upon type of tool and size. In hardening process ferrite is converted into austenite.

D.Quenching

In quenching process samples were quenched in salt bath furnace at 570^{0}C temperature for 5 minute. Then samples were reload from furnace and air cooled at room temperature. During quenching carbon atom not get enough time to reposition and they fix in the position where they really do not enough room. As a result of this high microstresses developed i.e martensite which responsible for hardness due to quenching.

E.Tempering

Quench-hardened samples are brittle and hardening stresses are present. In such a condition it is of little practical use and it has to be reheated, or tempered, to relieve the stresses and reduce the brittleness.

In this process, furnace is set to the desired tempering temperature. Samples were load inside the furnace immediately after they reach room temperature after quenching for two hours. Then samples were removed from the furnace and allow them to cool to room temperature in still air. In multiple tempering (Generally two or three) samples cool for at least two hour and again place in furnace at the same tempering temperature and air cool to room temperature.

Tempering causes the transformation of martensite into less brittle structures. Unfortunately, any increase in toughness is accompanied by some decrease in hardness. Tempering always tends to transform the unstable martensite back into the stable pearlite of the equilibrium transformations. After tempering as quenched martensite precipitate to fine carbide. Nucleation of this carbide relieves microstresses in martensite matrix and prevent cracking. Tempering is done in following steps.

1. Hardening at 1180^{0}C and then tempering at four different temperatures 540^{0}C, 550^{0}C, and 560^{0}C resp.
2. Hardening at 1200^{0}C and then tempering at four different temperatures 540^{0}C, 550^{0}C, 560^{0}C and 570^{0}C resp.
3. Hardening at 1220^{0}C and Temping at four different then temper temperatures 540^{0}C, 550^{0}C and 560^0 C 570^0 C resp.

IV. MECHANICAL TESTING

Heat-treated samples (with different heat treatment sequences) were tested for various mechanical properties. For hardness testing, oxide layers etc formed during heat treatment were removed by stage-wise grinding. Average VPN readings were determined by taking three hardness readings at different positions on the samples, using a vicker hardness tester. Impact energy (CVN) was recorded using the Charpy impact tester. All testing was done in accordance with ASTM standard test procedures.

V. RESULTS AND DISCUSSION

As described above, samples were subjected to three types of heat treatment sequences. All mechanical testing was performed at room temperature. (a) Hardening temperature 1800^{0}C, (b) Hardening temperature 1200^{0}C and (c) Hardening temperature 1220^{0}C and all double tempered. Variation of mechanical properties of M2 tool steel after these heat treatments is presented below in a graphic format.

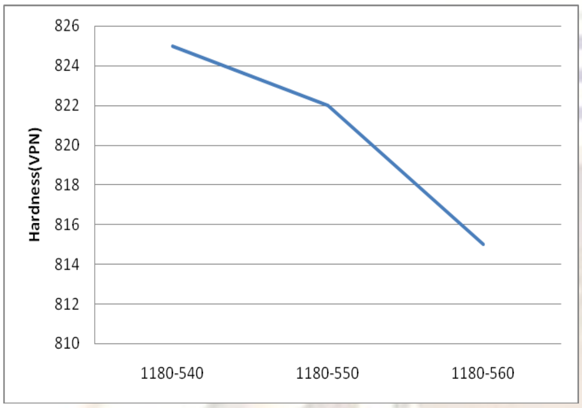

Fig.6 Variation of hardness against tempering temperature for different heat treatments at 1180^{0}Chardnenig temperature.

Fig.6 shows that as tempering temperature increases, hardness first increases to a maximum and then gradually decreases. For all three heat treatments, maximum hardness is obtained for samples tempered at 550^{0}C at 1800^{0}C hardening Temperature.

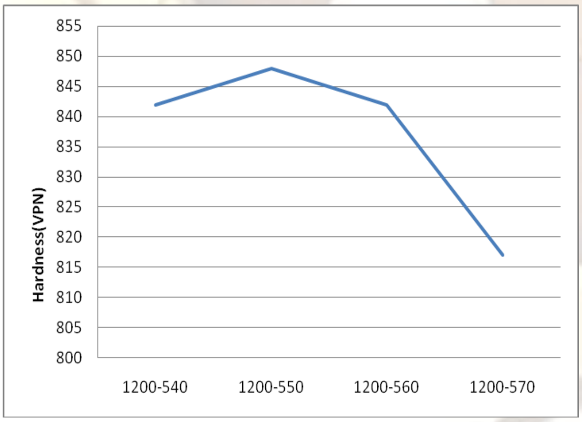

Fig. 7 Variation of hardness against tempering temperature for different heat treatments at 1200^{0}C hardening temperature.

Fig.7 shows as tempering temperature increases, hardness first increases to a maximum and then gradually decreases at 1200^{0}C hardening temperature.

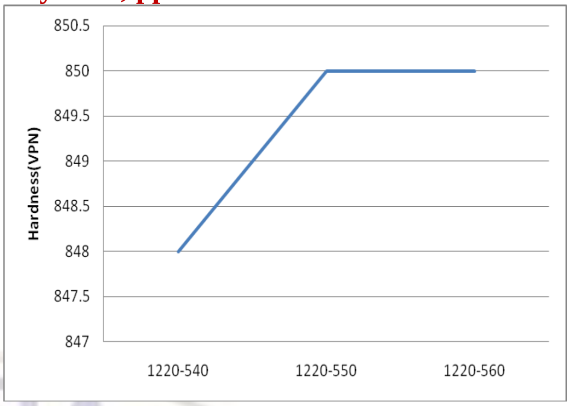

Fig 8. Variation of hardness against tempering temperature for different heat treatments at 1220^{0}C hardening temperature.

Fig.8 shows as tempering temperature increases, hardness first increases and remains constant to a maximum at 1220^{0}Chardening temperature.

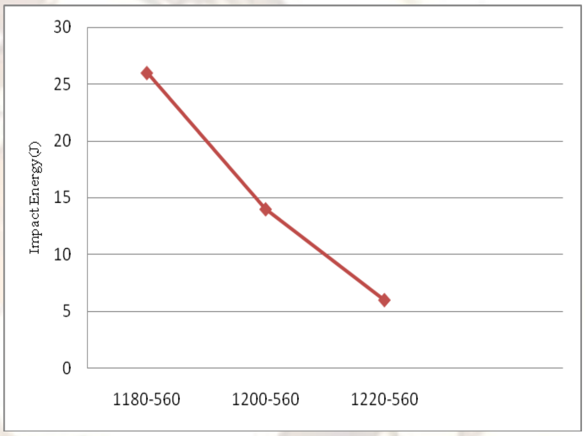

Fig. 9 Variation of impact energy against tempering temperature for different heat treatments at 1180^{0}C hardening temperature

Fig.9 presents the variation of impact strength against tempering temperature for heat treatment sequence at 1180^{0}C hardening temperature. With an increase in tempering temperature, impact strength decreases.

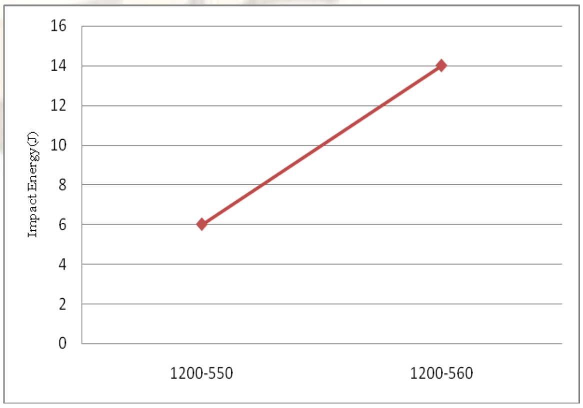

Fig. 10 Variation of impact energy against tempering temperature for different heat treatments at 1200^{0}C hardening temperature.

Fig.10 presents the variation of impact energy against tempering temperature for heat treatment sequence at 1200^{0}C hardening temperature. With an increase in tempering temperature, impact energy increases. Maximum impact energy occurs for samples tempered at 560^{0}C.

VII. TOOL LIFE

The tool life of hardened and tempered drill tool is calculated based on number of hole drilled.

TABLE III DRILL MATERIAL AND WORKPIECE MATERIAL DETAILS

Drill Tool Material	M2 (Dia.16 mm)
Workpiece Material	EN8 (Hardened)

Sr. No.	**Hardening Temperature (^{0}C)**	**Tempering Temperature (^{0}C)**	**No. of Hole Drilled befor failure**
01	1180	540	5
02	1180	550	6
03	1180	560	13
05	1200	540	4
06	1200	550	12
07	1200	560	18
08	1200	570	7
09	1220	540	7
10	1220	550	8
11	1220	560	13

VIII. CONCLUSION

1) Heat treatment result shows that secondary hardness of M2 tool observed at 550^{0}C.

2) The experimental results show that maximum tool life is achieves when tool specimen hardened at 1200^{0}C and tempered at 560^0 C. This might due to less impact energy at 550^{0}C tempering temperature.

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