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INVESTIGATION OF WEAR PROPERTIES ON AISI D2 - TOOL STEEL BY VARIOUS HEAT TREATMENT PROCESS - A REVIEW

MD Rahel*[1], K. Siva Satya Mohan[2] & Ram Subbiah[3]
[*1]PG Student, Department of Mechanical Engineering, GRIET, Hyderabad, India
[2]Associate Professor, Dept. of Mechanical Engineering, Raghu Engg College, Visakhapatnam, India.
[3]Associate Professor, Department of Mechanical Engineering, GRIET, Hyderabad, India

ABSTRACT

D2 steel is an air hardening, high-carbon, high-chromium tool steel. It has high wear and abrasion resistant properties. It is heat treatable and will offer a hardness in the range 55-62 HRC, and is machinable in the annealed condition. In the present experimental investigation, the author deals with the improvement of mechanical properties of cold work tool steels through different heat treatment processes. An attempt was made to get optimal combination of hardness and toughness through changes of microstructure by heat treatment. The toughness of D2 tool steel increases with tempering temperature. The hardness of D2 tool steel decreases with increase of tempering temperature. At lower tempering temperature range (160^{0}C-200^{0}C), the effect of tempering temperature on hardness is very small but as the tempering temperature increases hardness becomes prominent. The hardness of D2 tool steel increases with austenitizing temperature and the lowest and highest hardness were obtained at 970^{0}C and 1000^{0}C respectively. Results were compared with standard conventional test results. It is observed that different heat treatment processes significantly improves the mechanical properties like hardness, toughness and microstructure of cold work tool steel.

Key words: *Hardness, Toughness, Heat treatment, Hardening grade*

I. INTRODUCTION

Most of the die materials are subjected to extremely high loads that are applied rapidly. Dies must be able to withstand these loads a number of times without breaking and without undergoing excessive wear or deformation. The die manufacturers are commonly facing the problem of selecting proper system parameters while doing heat treatment operations of different die components. They are selecting the parameters either based on their experiences or using trial and error method. Thus the mechanical properties of the dies are not optimized and die failure occurs within a short period of time.

For avoiding such failure of the dies, the selection of proper die material and its proper heat treatment is very important. Qualities of a die material directly depend on percentage of carbon, percentage of alloying elements present, microstructure of the die steel, grain size after heat treatment, and heat treatment operation carried out on it. By varying the process parameters, an attempt has been made in this experimental investigation to heat-treat the cold work tool steels to improve its mechanical properties, to increase the die life, and get optimum service out of it so that the die manufacturers are able to optimize mechanical properties of the dies. Many relevant research works has been carried out by different research scholars on improvement of mechanical properties of cold work die steels and other tool steels through different heat treatment and allied techniques.

A brief review of the following research papers was given so that it helps to create a better understanding of previous researches supporting the present experimental investigation. The possibility of improving properties of D2 cold work tool steel by an unconventional vacuum furnace heat treatment. A double quenching, the first quenching from a temperature higher than that for the second quenching, followed by normal tempering enables an excellent combination of toughness and hardness as a consequence of improved micro-structural homogeneity (first quenching) and re-precipitation (second quenching) of carbides, due to a large amount of fine dispersed carbides in the matrix and due to the preset of a controlled amount of retained austenite. Experiment taken martensitic hot work tool steel die block for use in the manufacture of molds for plastic injection molding. The die block has hardness within the range of 35 to 50 HRC, a minimum Charpy V-notch impact toughness of 3 foot pounds when heat-treated to a hardness of 44 to 46 HRC. The die block contains sulfur within the range of 0.05 to 0.30 weight percent. The hot work tool steel includes mar-aging and precipitation-hardening steels of this type.

Followed by oil quenching (after conventional austenitization), has been applied to three high-carbon low-alloy steels with different levels of nickel and chromium contents at similar molybdenum levels. The carbon allowed replacing relatively expensive additions of nickel and chromium, for their ultra-high strength application. The cryogenic treatment was an inexpensive supplementary process to conventional heat treatment, which improves the properties of tool steels. The earlier research works clearly indicate that most of the mechanical properties of good quality die steel can be further improved by performing different heat treatment processes and thus the life of a die can be significantly increased. Austenitizing is the most critical of all heating operations performed on die steels. Excessively high Austenitizing temperatures or long holding times may result in excessive distortion, excessive grain growth, loss of ductility and low strength. Under-heating may also result in low hardness and low wear resistance.

Austenitizing is the treatment where the final alloy element separating between the austenitic matrix (which will transform to martensite on quenching) and the retained carbides. Quenching is also another important treatment to control the mechanical properties of die materials. The quenching medium must cool the work piece rapidly to get full hardness. Hot quenching minimizes distortion without affecting hardness. Tempering modifies the properties of quench-hardened tool steels to produce a more desirable combination of strength, hardness, toughness and wear-resistance. The as-quenched structure is heterogeneous mixture of retained austenite, un-tempered martensite and carbides.

II. METHODOLOGY

The following steps were carried out in the present experimental investigations: Samples of cold work tool steels D2 was prepared for metallographic tests and toughness measurement. Microstructures were examined; hardness and toughness were measured and recorded. By varying the system parameters necessary hardening and tempering operations were carried out in conventional furnace. Metallographic tests were carried out to observe the changes in microstructures after heat treatment. Hardness and toughness were measured for each specimen after heat treatment operations. From the different readings, curves were plotted to know the trends of the properties.

Table 1: Chemical Composition of HCHCr (D2 grade) steel

Composition	**Cr**	**C**	**Mn**	**V**
Percentage	12%	1.0%	1.0%	0.90%

Hardness test

The same rectangular samples of D2 prepared for impact testing were used for hardness testing. The hardness values after heat treatment were measured on hardness tester on Rockwell C-scale. For measurement of toughness after heat treatment, U-notch of 2 mm depth x 2mm width was cut on the specimens with the help of a rubber bonded parting off wheel on a surface grinder.

Heat Treatment of Specimens

Six additional specimens were also made in same way for measuring the toughness and hardness before and after annealing. To remove the effect of machining and residual stresses, cyclic annealing was done by using the muffle furnace for all D2 specimens by heating to900^{0}C and holding for two hours, then cooling to 775^{0}C and holding for six hours, finally cooling in open air. The eighteen annealed specimens of D2 divided into four groups consisting of six, three, three and six specimens for investigating their hardness and toughness after hardening and after tempering. The temperature range and hardening/tempering soaking times for the experimental investigations were selected based on the material composition of the specimens. The microstructures of the specimens of D2 before and after annealing, hardening and tempering have also been studied in the present investigation.

III. RESULTS AND DISCUSSION

Investigations on D2 tool steel

Before studying the effect of heat treatment, the specimen microstructure was made stress free and uniform in structure. Due to the machining operations performed on D2 material for sample preparation, there were changes in hardness and toughness, which were measured as 47Rc and 32 Joules respectively. This is due to the formation of martensite in the microstructure. By annealing, the hardness was reduced to 38Rc and toughness was increased to 45 Joules. The microstructure was also got refined with transformation of martensite to cementite. The said material properties of D2 tool steel are given in Table- 2

Table 2: Material Properties of D2 Tool Steel

Material properties	**Before Annealing**	**After Annealing**
Hardness (Rc)	47	38
Toughness (Joules)	32	45
Microstructure	Cementite - carbide- martensite	Cementite – alloy carbides

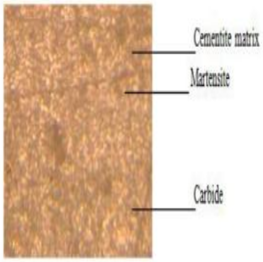
The six D2 specimens of first group, three D2 specimens of second and third groups each and six D2 specimens of fourth group were hardened at the austenitizing temperature of 970^{0}C, 980^{0}C, 990^{0}C and 1000^{0}C respectively. After hardening, hardened D2 specimens of each group were tempered at 160^{0}C, 200^{0}C, 250^{0}C, 350^{0}C and 550^{0}C respectively. The specimens used for tempering in second and third group have increased from three to five because of one pre-tempered specimen being used for toughness measurement thereby breaking that specimen into two pieces. In the first and fourth group, the pre-tempered specimen used for toughness measurement was discarded, thereby reducing the group specimen to five. Hardening soaking time of 30 minutes and tempering soaking time of 180 minutes were used for D2 tool steel material. After hardening and tempering, their hardness and toughness were measured and the respective values are shown in Table 3. The microstructure of D2 specimens after hardening is martensite with retained austenite and carbides whereas after tempering the microstructure obtained under metallographic microscope was only tempered martensite and carbides. Taking the data from the Table 3, the hardness Vs austenitizing temperature curve, the ardness Vs tempering temperature curve, the tempering temperature Vs toughness curve and toughness Vs austenitizing temperature curve have been drawn.

Fig.1: Effect of tempering temperature on toughness of D2 tool steel

The above diagram shows the influence of austenitizing temperature on toughness of the investigated cold work tool steel (D2) at selected tempering temperatures. It was observed that the influence of austenitizing temperature on toughness at lower tempering temperature (200^{0}C) is negligible.

Effect of austenitizing temperature on toughness on D2

When specimens were tempered at 200^0C the toughness of samples changes from 5 to 6 Joules at Austenitizing temperature from 970^0C to 1000^0C. Moreover, toughness varies between 9 to 13 Joules for same Austenitizing temperature when tempered at 550^0C. It is due to the fact that at low temperature tempering only hardening stresses are removed but at high temperature tempering there is change of microstructures from martensite to tempered martensite that have better combination of mechanical properties.The microstructures of D2 specimens before annealing, was expected to be same as that of the microstructure of specimens after annealing. But it was not so because of the effects across the cross-section of the specimens due to heat developed during machining. It causes the formation of martensite along with the cementite-carbide/pearlite. The annealed specimens of D2 show the uniform distribution of microstructure of carbides and cementite combination.



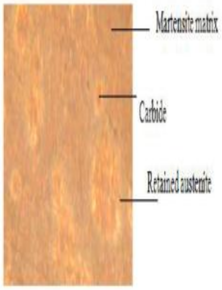


Fig:2 - D2 tool steel specimens with
Fig.3 Microstructures of D2 tool steel cementite-carbide structure after annealing. Specimen before annealing.

The microstructures of D2 specimens after hardening show carbide particles throughout the martensite matrix. It was observed Very less retained austenite and precipitation of carbides were noticed along the grain boundaries. The microstructure of D2 specimen after tempering is comparatively finer because (during tempering of the specimens) the martensite decomposes into emulsified form of pearlite called troostite (tempered martensite). It is very fine in nature with reasonable toughness. Thus the microstructure obtained after tempering provides a good combination of mechanical properties likes high hardness, high strength, high wear resistance, greater dimensional control and considerable toughness and temperature resistance. It serves our main objectives of increasing the die life through heat treatment.

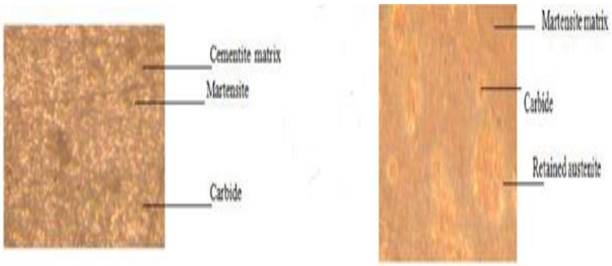


Fig-4 - D2 tool steel specimens with martensite & D2 tool specimens with fine tempered retained austenite

IV. CONCLUSIONS

Based on the results obtained from the extensive tests and investigations performed on cold work tool steels D2, the following conclusions are drawn:

Annealing should be done for the tool steels before performing any heat- treatment to avoid the effects of any changes on material properties caused during the sample preparation. The hardness of D2 tool steel increases with austenitizing temperature and the lowest and highest hardness were obtained at 970^{0}C and 1000^{0}C respectively. The hardness of the D2 tool steel decreases with increase of tempering temperature. At lower tempering temperature range (160^{0}C-200^{0}C), the effect of tempering temperature on hardness is very small but as the tempering temperature increases hardness becomes prominent. At lower tempering temperature range 160^{0}C-200^{0}C, the rate of increase in toughness was 25% (i.e. 4 to 5 Joules). As the tempering temperature increases from 200^{0}C to 250^{0}C and 250^{0}C to 300^{0}C, the toughness was increases by 20% and 33% respectively. It may be interpreted that at lower tempering temperatures only relieves the hardening stresses without any change in microstructures but higher tempering temperature causes the changes in microstructures.

When specimens were tempered at 200^{0}C the toughness of samples changes from 5 to 6 Joules at Austenitizing temperature from 970^{0}C to 1000C. Moreover, toughness varies between 9 to 13 Joules for same Austenitizing temperature when tempered at 550^{0}C. It is due to the fact that at low temperature tempering only hardening stresses are removed but at high temperature tempering there is change of microstructures from martensite to tempered martensite.

The microstructure of D2 specimen after tempering is comparatively finer because (during tempering of the specimens) the martensite decomposes into emulsified form of pearlite called troostite .(tempered martensite). It was very fine in nature with reasonable toughness. Thus the microstructure obtained after tempering provides a good combination of mechanical properties likes high hardness, high strength, high wear resistance, greater dimensional control and considerable toughness and temperature resistance.

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