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Experimental Investigation of the Effect of Thermal Treatments on Mechanical Behaviour of D2Tool Steel

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Abstract **– Tool steels are one of the most widely used verities of steels where forming or shaping of the other material is the primary requirement. Therefore characterization of the properties of tool steels is of great significance. Alteration and improvement in the mechanical properties of tool steels may lead to extend their application in a broader way. For this purpose the thermal treatments were considered as the main signal factors for altering the properties of tool steels in the present research work and Mechanical behavior of the specimen material was studied in terms of variation of their mechanical properties when subjected to different sequences of thermal treatments. The study comes up with very positive findings which can be an eye opener to many of the researchers.**

Keywords **– Tool Steel, Thermal Treatment, Hardness Test, Impact Test, Microstructure.**

I. INTRODUCTION

Several types of Carbon and alloy steels are generally made into a category called tool steels to be used as tools. Bye virtue of their specific mechanical properties such as wears resistance, abrasion resistance, hardness, ability to carry a cutting edge and resistance to distortion at elevated temperatures. Tool steels are subject to various thermal treatments in order to enhance their mechanical, electrical and magnetic properties. Many high carbon tool steels are also more resistant to corrosion due to their higher ratios of elements such as vanadium and niobium. Tool Steels are made to controlled chemical compositions and processed to develop properties useful for working and shaping of other materials. Tool steel are useful for blanking, die casting, forming, plastic moulding etc. [1]

Tool steels are usually supplied in the annealed condition, around 200/250 Brinell (about 20 HRC), to facilitate machining. In this condition, most of the alloy content exists as alloy carbides, dispersed throughout a soft matrix. These steels must be heat treated to develop their characteristic properties. The heat treating process alters the alloy distribution and transforms the soft matrix into a hard matrix capable of withstanding the pressure, abrasion and impacts inherent in metal forming. Each step of the heat treating cycle is designed to perform a specific function, and, like links in a chain, the final product is only as good as its weakest component. Although it may only represent 10% or less of the cost of the tool, the heat treat process is probably the single most important factor in determining the performance of a tool. [2]

The cryogenic treatment is an inexpensive supplementary process to conventional heat treatment, which improves the properties of tool steels [3].Cryogenic treatment (CT) is done by deep–freezing materials at cryogenic temperatures to enhance the mechanical and physical properties of materials being treated. Cryogenic treatment (CT) of materials has shown significant improvement in their properties .Various advantages like increase in hardness, increase in wear resistance, reduced residual stresses, fatigue Resistance, increased dimensional stability, increased thermal conductivity, toughness, by transformation of retained austenite to martensite, the metallurgical aspects of eta-carbide formation, precipitation of ultra-fine carbides, and homogeneous crystal structure. [4]

II. MATERIALS AND METHODS

A. Specimen Material

Specimen material selected for the proposed Research work was D2 tool steel with the following chemical composition:

Table 1: Chemical composition of D2 tool steel

Statistics	Max	Min	Average	Standard Deviation
C	1.52	1.52	1.52	0
O	3.29	3.29	3.29	0
Al	0.14	0.14	0.14	0
Si	0.23	0.23	0.23	0
P	0.02	0.02	0.02	0
V	0	0	0	0
Cr	1.17	1.17	1.17	0
Mn	0.51	0.51	0.51	0
Fe	93.05	93.05	93.05	0
Ni	0.05	0.05	0.05	0
W	0.02	0.02	0.02	0

Experimental data for D2 steels was gathered through a comprehensive search of published literature and from tool steel suppliers/manufacturers.

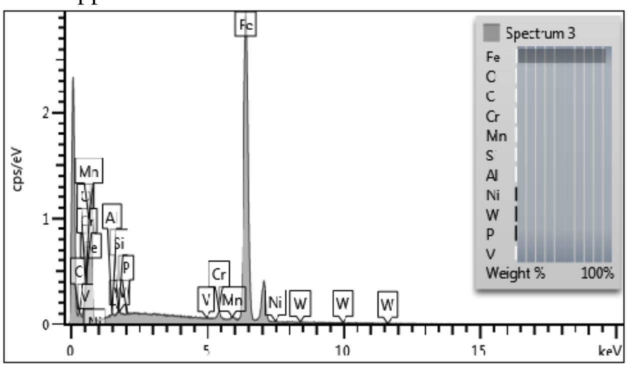

Fig.1. Chemical composition of D2 steel

B. Thermal Treatments selected for the proposed Research:

- *Heat Treatment:*

The heat treatment includes heating and cooling operations or the sequence of two or more such operations applied to any material in order to modify its metallurgical structure and alter its physical, mechanical and chemical properties. Usually it consists of heating the material to some specific temperature, holding at this temperature for a definite period and cooling to room temperature or below with a definite rate. Annealing, Normalizing, Hardening and Tempering are the four widely used heat treatment processes that affect the structure and properties of the material. D2 tool steel was selected. It categorised in four group and it has gone under various heat treatment process listed below.

1) Hardening
2) Tempering

- *Cryogenic Treatment:*

Cryogenic treatment is a one-time permanent treatment process and it affects the entire cross-section of the material usually done at the end of conventional heat treatment process but before tempering. Also it is not a substitute process but rather a supplement to conventional heat treatment process. It is believed to improve wear resistance as well the surface hardness and thermal stability of various materials

The cryogenic treatment was done in BA-03 Cryocan manufactured by Indian Oil Corporation.

The heat treated specimen of group II, group III and group IV were subjected to deep cryogenic treatment. For group II the hardened specimen were quenched in liquid N_2 to -196^{0}C soacked at -196^{0}C for 27 hours and finally heated upto room temperature in atmospheric air followed by tempering at 700^{0}C for 1 hour. For group III the hardened specimen followed by tempering followed by cryogenic treatment. For group IV, hardened specimen followed by cryogenic treatment followed by tempering.

- *Microstructural examination:*

The microstructural examination is carried out by putting a well polished, properly etched and dried sample on base of the microscope. The micro structural examination of metal and alloys is generally accomplished for the following purposes:

i) Study of the effects of heat treatment and other processes on mechanical properties of metal.
ii) Study of phases present in material.
iii) Determination of grain size.

Microstructure determination was carried out by Radical Metallurgical Microscopeat Sam Higginbottom Institute of Agriculture, Technology & Sciences Allahabad, India.

C. Layout of the proposed work:

Based on the previous literature reviews specimen materials were set in four different groups as follows:

- *Group I:*

The machined specimen of the D2 tool steel were slowly and uniformly heated to temperature of 1053^0 C and were soaked for one hour in the furnace and then quenched in a cold water(4^0 C) bath bring it to room temperature followed by tempering to a temperature of 700^{0}C for one hour and allowed to cool in air.

- *Group II:*

The machined D2 tool steel were slowly and uniformly heated to a temperature of 1053^{0}C and soaked for one hour in the furnace and then quenched in the cold water (4^{0}C) bath to bring it room temperature followed by tempering to a temperature of 700^{0}C for one hour and allowed to cool in air. After cooling the specimen were cryogenic treated to a temperature of -196^{0}C for 27 hour. After cryogenic treatment the specimen were again tempered to the temperature of 700^{0}C for one hour and allowed to cool in air

- *Group III:*

The machined specimen of the D2 tool steel were slowly and uniformly heated to temperature of 1053^0 C and were soaked for one hour in the furnace and then quenched in a cold water(4^0 C) bath bring it to room temperature followed by tempering to a temperature of 700^{0}C for one hour and allowed to cool in air. Followed by cryogenic treatment to a temperature of -196^{0}C for 27 hour and allowed to maintain room temperature.

- *Group IV:*

The machined specimen of the D2 tool steel were slowly and uniformly heated to temperature of 1053^{0}C and were soaked for one hour in the furnace and then quenched in a cold water (4^{0}C) bath bring it to room temperature followed by cryogenic treatment to a temperature of -196^{0}C for 27 hour and then allowed to maintain at room temperature followed by tempering process to a temperature of 700^{0}C for one hour and allowed to cool in air.

III. Experimental Procedure

Table 2: Response data of D2 tool steel

	Brinel hardness number	Impact energy(For two specimen in each group in joule)	
Raw material	42.76109	6.9	7
		7.1	
Group-I	46.6408	6 .0	6.4
		6.8	
Group-II	51.0062	5.9	5.95
		6.0	
Group-III	61.5732	4.7	4.6
		4.5	
Group-IV	55.9526	8.0	7.25
		6.5	

A. Hardness Test

The hardness of the final prepared specimens was measured by Brinell-cum-Rockwell Hardness testing machine at Sam Higginbottom Institute of Agriculture, Technology & Sciences, Allahabad, India. This method consists of indenting the test material with a hardened steel ball indenter. The indenter is forced into the test material under a load usually 250kgf. When equilibrium has reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position.

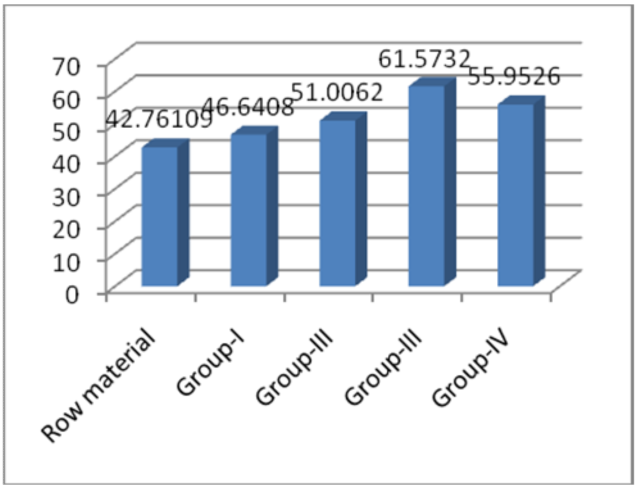

Fig.1. Based on the values of hardness test

The permanent increase in depth of penetration, resulting from the application of the load is used to calculate the Brinell hardness number, which can be calculated through the following formula:

$$BHN = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

Where
P = Load Applied
D = Diameter of steel ball in mm
D = Diameter of indentation in mm

B. Impact Test

Notched-bar impact test of metals provides information on failure mode under high velocity loading conditions leading sudden fracture where a sharp stress raiser (notch) is present. The energy absorbed at fracture is generally related to the area under the stress-strain curve which is termed as toughness in some references. Brittle materials have a small area under the stress-strain curve (due to its limited toughness) and as a result, little energy is absorbed during impact failure. As plastic deformation capability of the materials (ductility) increases, the area under the curve also increases and absorbed energy and respectively toughness increase. Similar characteristics can be seen on the fracture surfaces of broken specimens. The fracture surfaces for low energy impact failures, indicating brittle behavior, are relatively smooth and have crystalline appearance in the metals. The charpy impact test was done at charpy impact testing machine at Sam Higginbottom Institute of Agriculture, Technology & Sciences, Allahabad, India. The specimen of (55x10x10) with notch of $45^0$was taken for this test.

C. Study of Microstructures

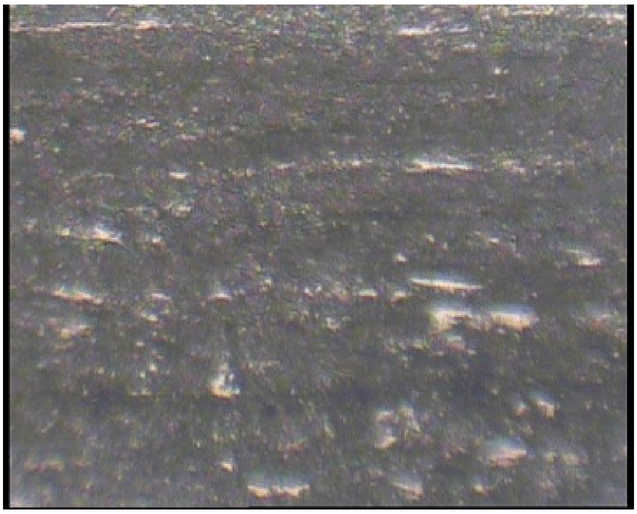

Fig.2. Raw material

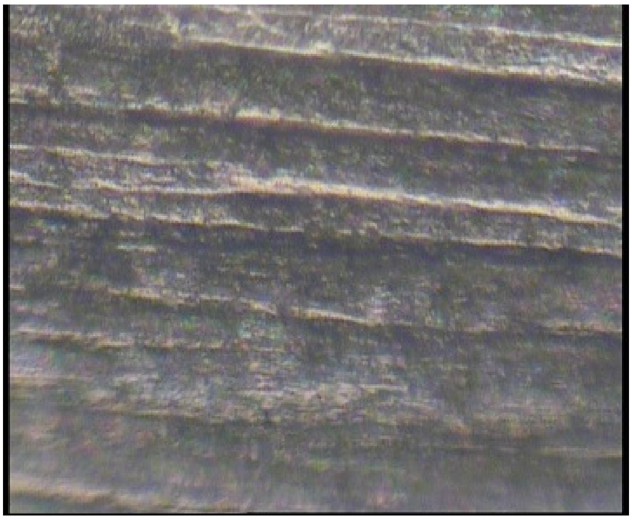

Fig.3. Group-1(hardened followed by tempered)

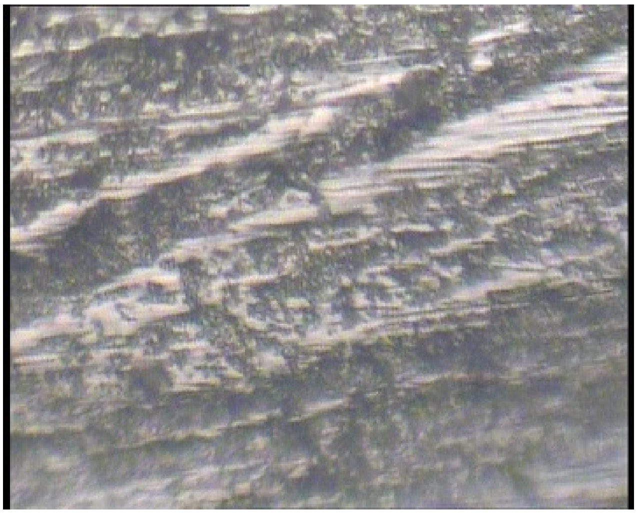

Fig.4. Group-2(hardened followed by tempered followed by cryogenic treated followed by tempered)

Fig.5. Group-3(hardened followed by tempered followed by cryogenic treated)

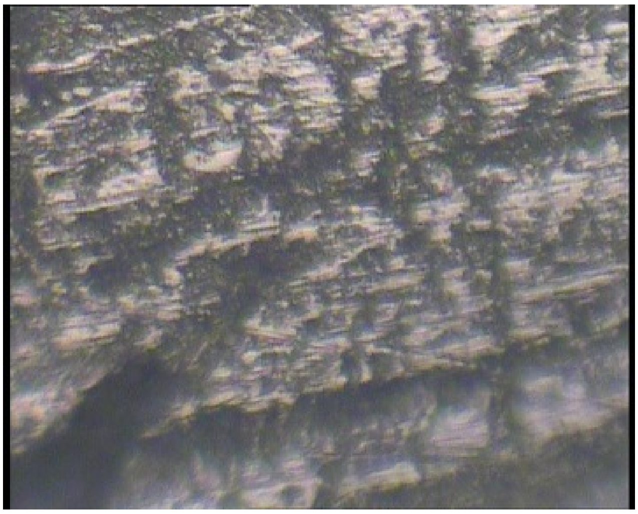

Fig.6. Group-4(hardened followed by cryogenic treated followed by tempered)

III. Results and Discussion

C. Hardness and Toughness behaviour:

D2 tool steel Specimens with above chemical composition were found to have the following changes in mechanical properties which are listed below:

- Steel Specimens of Group III (hardened followed by tempered followed by cryogenic treated) was found to be the hardest material with hardness number of 61.5732 and lowest impact energy value of average 4.6J.
- Steel Specimens of Group-IV (hardened followed by cryogenic treated followed by tempered) was found to be the second hardest material with hardness number of 55.9526 and impact value of 7.25J. In this case tempering increases the value of impact energy with respect to Group III material i.e Group IV specimens were tougher than Group III specimens.
- Steel Specimens of Group II (hardened followed by tempered followed by cryogenic treated followed by tempered) had hardness number of 51.0062 with impact value of 5.95J.
- Steel Specimens of Group I (hardened followed by tempered) had lowest value of hardness number of 46.6408 with respect to other groups with impact energy value of 6.7J.

D. Analysis Microstructure

Group III Specimens had maximum HN value as its microstructure appeared to be sharper and needle like structure with larger cracks on its surface.

It is seen that retained austenite is transformed in to martensite creating a more uniform granular structure from Group I to III.

IV. Conclusion

Cryogenic material increase Hardness and toughness behaviour drastically. Cryogenic treatment increases the decomposition of martensite which increase the hardness behaviour.

Along with heat treatment cryogenic treatment shows the remarkable change in mechanical properties of material.

Cryogenic materials form an integral part of the near future.

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