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Evaluation of Microstructure and Hardness of AISI D2 Steel by Time Quenching in Comparison with Water and Oil Quenching

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Abstract— **Due to an account of its excellent hardness and wear behavior, AISI D2 is used widely in producing of blanking and cold-forming dies, Punches, Shafts, Studs, and Bolts. Increasing toughness at a fixed high level of hardness is growing requirement for this kind of applications. Improving microstructure characteristics, especially carbides distribution by specific heat treatment, is an appropriate way to meet such requirement. The effect of quenching media on microstructure and hardness of pre-heated and austentized (at 980°C) AISI-D2 tool steel has been studied, and hardness and carbides morphology have been investigated. Three different medias, water, oil and water/oil (time quenching) have been used, then all samples were followed by the same tempering 350°C/1 hour. It has been found that the optimal carbides distribution and optimum hardness have been resulted from a time quenching method.**

Index Terms: **cold forming, microstructure, absorbed energy, time quenching**.

I. INTRODUCTION

The average size of high-carbon high-chromium tool steel has gradually increased over the past years for producing cutting-tools, dies and other applications where high wear resistance and hardness and low cost are needed [1]. The mechanical characteristics of this steel can be widely improved by appropriate heat treatment cycle. This treatment usually consists of pre-heating and austenitizing at appropriate temperature followed by quenching to harden the steel and tempering to eliminate its brittleness [2]. The steel microstructure plays the most important role in determining the wear behavior and the hardness of the alloy [3], which will be changed by different quenching medias [2]. To obtain the mechanical characteristics with a good compromise between strength and toughness, it is necessary to optimize the structure parameters such as the size, carbides distribution, volume fraction of the carbides. [1,2]. High quantity of coarse carbides in martensite matrix produced by Water quenching may cause premature cracking which is mainly responsible for the low level of toughness and tensile strength. Decreasing size and coincidently morphology modification of carbides at a given high level of carbides volume fraction is desired [4]. A. Ajay et al. [5] have reported that the size and morphology of carbides in AISI D2 steels undoubtedly effect on the fracture and fatigue life of steel. On the other hand, oil quenching Possesses a low martensitic transformation and as well as a number of significant disadvantages, including toxicity, flammability, in addition to being susceptible to global supply issues [6] In this work, a new technique of quenching has been applied by using time quenching (water/oil), where the sample first rapidly quenched in water then rapidly moved to an oil bath provided with mechanical agitation. It has been found that a time quenching produces a higher volume fraction of carbides thereby an optimal hardness compared with oil quenching. Where the water quenching possesses a higher hardness but with high cracking susceptibility

II. METHODOLOGY AND IMPLEMENTATIONA

A. Material

Investigated steel in this study was supplied by Central Research Laboratories-Tripoli. A sample from this steel cleaned to remove the oxide layer then taken to the spectrophotometer analysis (ARL3460). The chemical composition in mass precent (%) of the studied steel is shown in Table 1.

Table 1. Chemical composition of the studied steel sample

AISI	C	Cr	Mo	Mn	Ni	Si	V
D2	2.6	19.9	0.54	0.61	0.52	0.76	9.3

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B. Heat Treatment

A Nabertherm Muffle furnace has been used for heat treatment of D2-steel samples. First the samples were pre-heated for 350ºC for one hour, then temperature is raised to 980ºC for half hour to get fully hardened structure. Three quenching medias were prepared close to the furnace and the three samples were rapidly immersed, the first one with a sign (W) in a cold water bath, the second one with a sign (O) in an oil quenching tank, where the third sample (with a sign of W\O) quenched in the water bath then rapidly moved to an oil tank provided with mechanical agitation. All samples then taken to the tempering treatment furnace with 450ºC for one hour followed by an air cooling.

C. Microstructure Investigation

Three heat treated samples as W, O and W\O have been prepared for microstructure investigation in order to evaluate the carbide fraction and distribution by sample preparation steps starting with grinding the samples using emery papers size 240 to a size of 1200. The samples then taken to the surface polishing using metallographic polishing clothes and alumina suspension up to the final polishing step. W, O and W/O samples then investigated under Nikon Epiphot inverted optical microscope connected with N70 digital camera. The microstructures were optically examined after etching the mechanically polished specimens by 5% Nital and ferrite-pearlite are present in the microstructure. An ImageJ software has been applied to measure carbide volume fraction of the heat treated samples, and five images with same magnification were measured from each sample to get the average percentage of carbides to the whole area.

D. Hardness Test

The same cleaned metallographic samples then taken to Welpert-Hardness test machine using HRC gauge with ball indenter and 150 Kgf of load is applied. An average of five hardness readings was recorded.

III. RESULTS AND DISCUSSION

Table 2, shows the results of hardness measurements of the quenched and tempered samples. It is clear to say that the higher hardness comes from water quench sample due to rapid cooling, and the less readings came from the oil quench samples. However, time quenching (W/O) shows a suitable hardness reading higher than oil samples and very close to cutting blades specifications.

Table 2. Hardness measurements of quenched samples

Quenching Media	**Hardness (HRC)**
Water	59
Oil	51
Time (W/O)	55

The Charpy test was performed to evaluate the toughness of the as received and heat treated samples. "Figure. 1", shows the experimental results wherein the toughness values are compared due to quenching medias. The Charpy test results show the opposite tendency with respect to the hardness. The total absorption energies of the as recieved-D2 samples, was an average of 3.8 J. where the absorbed energies of the heat treated samples were; 1.6, 2.26, and 2.9 J, for water quenched, time quenched (W/O) and oil quenched respectively. The hardness of the water quenched samples are higher than those of the oil and time quenched samples, whereas the impact toughness of oil samples is higher than those of water and time quenched samples. Furthermore, the impact toughness of (W/O) slightly decreases and shows an average absorbed energy after the samples were water and oil cooled.

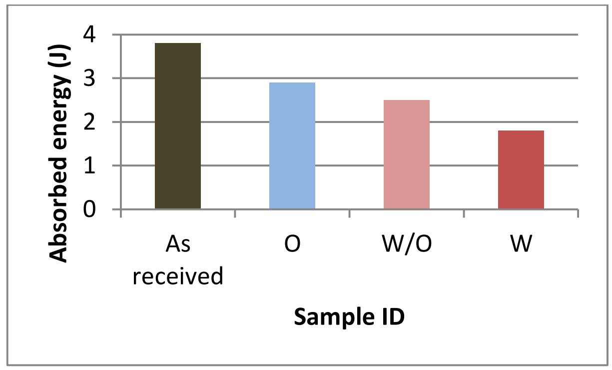

Figure 1: Total absorbed energy in the Charpy impact test.

"Figure. 2", depicts microstructure of the as received D2 studied alloy, it shows that there are two types of carbides primary dispersion of rounded carbides and clusters of secondary carbides and both are randomly distributed.

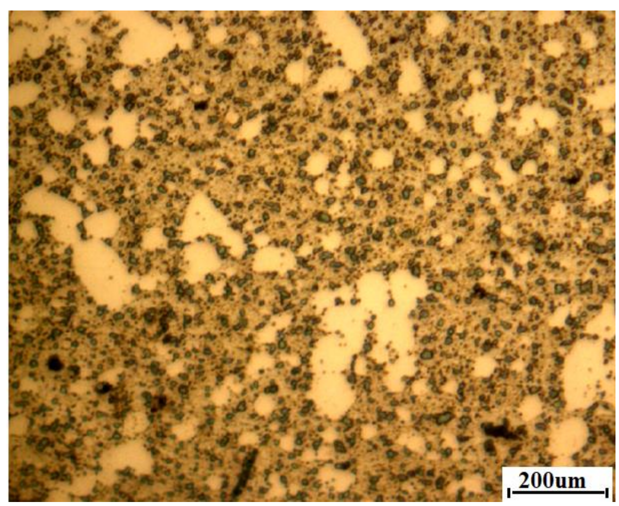

Figure. 2: Microstructure of an as received D2 sample.

As the samples austenitized and quenched in a water bath, the carbides were seen of finer in size and less random distributed as seen in "Figure. 3,". As no enough time for dissolving of carbides in the matrix, some clusters of carbides were seen.

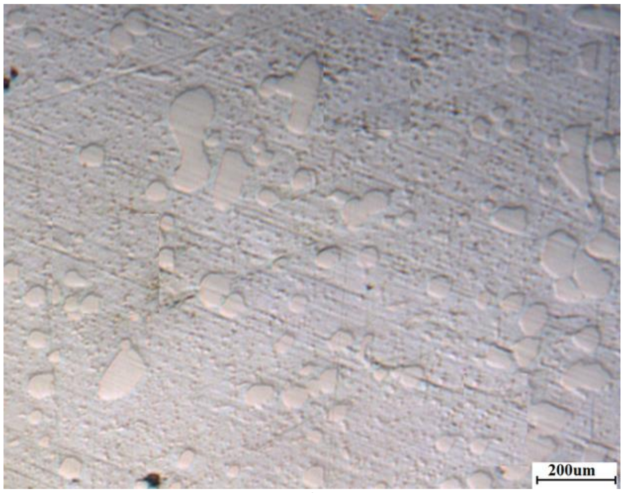

Figure. 3: Microstructure of a Water quench D2 sample.

But microstructure of an oil quench sample shows a less clusters of carbide particles and less amount of fine particles in the unit investigated area as seen in “Figure. 4”, which is expected due to longer time for carbides dissolution.

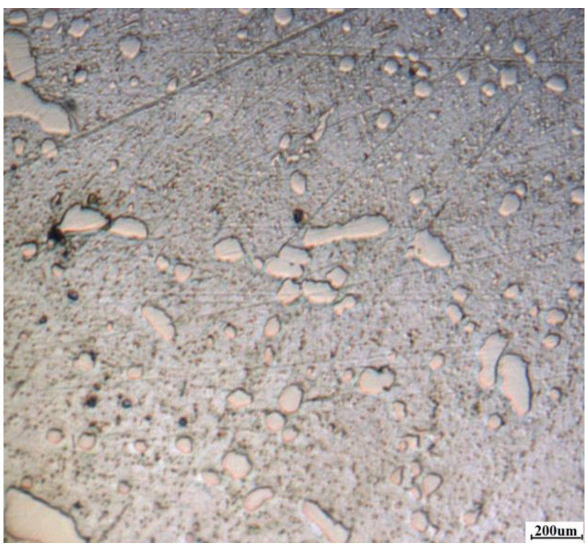

Figure 4: Microstructure of an oil quench D2 sample.

When sample was time quenched where very rapid immerse in a water bath then rapidly moved to an agitated oil tank then tempered together with the other samples. Microstructure of the time quench (W/O) sample shows a less volume fraction of fine precipitated particles compared with water quench sample and higher clusters of carbide particles as shown in “Figure. 5”.

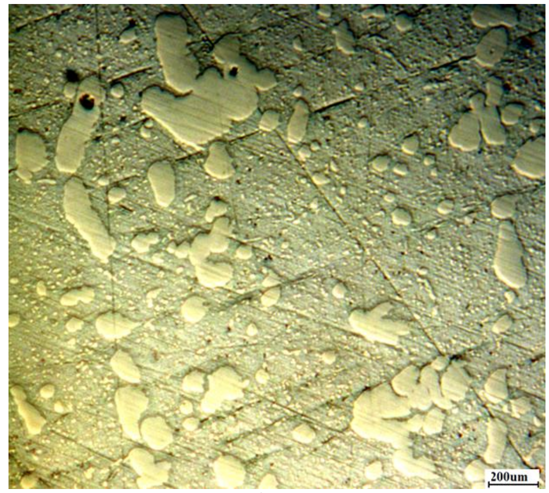

Figure 5 : Microstructure of time (W/O) quench D2 sample.

Due to very quick cooling in water but for very short of time and long oil cooling time which causes precipitated particles to make a clusters and less fraction of fine precipitated particles. This regime of cooling causes enough fine particles to make second phase compounds responsible for increasing of hardness compared with oil quench sample.

ImageJ software was used to evaluate the volume fraction of precipitated carbide particles in the three different quenching cases by using three optical micrographs for each case and the evaluation is shown in Table 3.

Table 3. Carbide particles volume fraction

Quenching Media	**Carbide volume fraction (%)**
Water	46
Oil	37
Time quench (W\O)	41

IV. CONCLUSION

1. Three quenching medias with same tempering treatment were studied as a result of different hardness and impact tests and microstructure investigations.
2. Results of hardness and absorbed energy show an average in the case of time (W/O) quenching which is very close to cutting blades specifications.
3. Precipitated particles size and distribution in the time quenched and tempered samples is expected to be the reason behind the hardness and impact tests.
4. Time (W/O) quenching gives an optimal results to avoid surface cracks and to get suitable hardness of cutting tools made from D2 tool steel.

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