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Influence of Hot Forging and Heat Treatment on Mechanical Properties of D-Series Cutting Tools

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Abstract

In this experimental work D2 and D3 type cutting tool samples have hot forged and heat treated. The belt a drop hammer of weight 500N was employed to press forge the selected steel tool materials. In the forging operation the materials were heated to 1100°C-1200°C. The structures of hot forged and heat treated tool samples were observed through metallurgical microscope. The hardness and impact strength of the tool materials were studied using Vickers micro hardness tester and Charpy impact testing machine. The wear resistance of the tool materials was assessed using pin on disc wear tester at constant sliding speed (1.675m/s) and sliding distance (1005m) at room temperature condition. The hardness, impact strength and wear resistance of the 20% forged and heat treated D2 tool and D3 tool materials were found comparatively better and the same was discussed under the background of microstructural changes.

Keywords: *D2 and D3 steel tool; forging; heat treatment; hardness; impact strength; wear resistance; micostructure.*

1. Introduction

Cutting tool materials must be harder than the materials which need machining and tool must withstand high frictional heat during metal-cutting process. A cutting tool must have desirable strength, hardness, wear resistance and toughness properties. Further the properties of cutting tools can be enhanced by forging. Modern manufacturers use either a powered hammer or dies to achieve mass production and complex shapes for the cutting tools [1].

The forged tools heat treatment further enhances the property value and make them more advantageous. Heat treatment process especially enhances grain structure, hardness, toughness, wear resistance and tool life as well. A steel material which is possessing balanced toughness and hardness can be justified the manufacturer demand.

The ageing at 800°C for 2 hours improves the tensile ductility, reduces the dislocation density and the stress concentration. The austenitized and tempered AISI D3 tool steel exhibits refined structure and thus hardness and wear resistance of new modified tool are equal to or even better than that of standard wrought D3 steel [2]. The heat treatment greatly influences the microstructure and abrasive wear resistance of AISI D2 steel. The volumetric abrasive wear found as increased with increasing tempering temperature and test conditions range [3].

The AISI D2 tool steels subjected to cold work showed a flat surface fracture. The SEM images showed dimple-like structures as a indication of ductile fracture [4]. The microstructure evolution and mechanical properties of D2 tool during annealing process showed that higher soaking time causes the carbides of uniformly distributed and round shape carbides in a pearlite matrix [5]. H. Torkamani et al., [6] have done bright hardening and oil quenching of AISI D2 steel and noticed that there is a mechanical properties improvement along with decrease in risk of cracking. The microstructural observations showed that the samples quenched using hot alkaline salt bath resulted finer and more uniform distribution of carbides. The impact toughness and tensile strength and hardness of bright-hardened samples are superior to those of oil-quenched samples.

The attempts were made to improve the microstructure which led to an optimal combination of hardness and toughness upon heat treatment. At 160°C-200°C, the influence of tempering temperature on hardness is very small but as the tempering temperature increases hardness becomes prominent. It is concluded that the hardness, toughness and microstructure of cold work tool steel can be improved significantly by using different heat treatment processes [7]. M. Hakem et al., [8] have studied the impact of heat treatment on microstructure and mechanical properties of micro alloyed steels. The micro alloyed steels have a better mechanical properties compared to carbon steel. The alloying elements are necessary to improve the structures and they can retard the softening during the ageing. The form hard carbides such as Mo, Cr, V, Nb and Ti are most effective in delaying softening during ageing. A review on hot forging influences on structure and strength was studied by J. J. Jonas et al., [9] and stated that microstructural changes represent the deformation mechanism. Further the structural reforms can happen at constant deformation temperature and room temperature cooling.

The AISI D2 and D3 steels are widely used in manufacturing industries and recommended for tools requiring very high wear resistance, combined with moderate toughness. The D type cutting tools being solution for cheaper tools demand because of the properties closer to that of conventional tools. An attempt was planned to study the microstructures and mechanical properties of forged and heat treated D2 and D3 tool steels in search of an answer to the demand of cheaper cutting tools.

2.0 Experimental Details

The commercially available AISI D2 and D3 type steel tool raw materials with a size of 30*50*100 mm were purchased and the accessed for chemical composition using atomic absorption spectrometer and the details are given in Tables 1 and 2 respectively. The photographs of raw materials have been shown in Fig.1.

The D2 and D3 type steel tool raw materials heated to recrystallization temperature; 1160°C and subjected to hot forging process with the help of belt drop hammers of weight 500N showed in Fig 2 (a)-(c). The dimension of tool steel materials cross section before forging was 30*50 and it has reduced by 10%, 20 % and 30% upon forging.

In the process of heat treatment samples were heated to 700°C and put into air bath for air quenching. The materials were placed in induction coil furnace for heating to the prescribed temperature. After attaining the prescribed temperature the red hot materials are placed in air blower. Then the material is allowed to cool rapidly. Air quenching was used as a means to

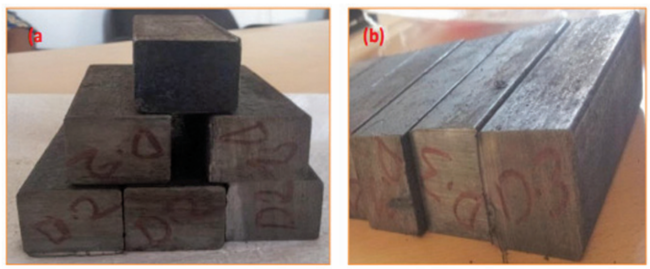

Figure 1: Steel tool raw materials (a) D2 Type and (b) D3 Type

Table 1 Chemical composition of D2 tool

Content	C	Si	Mn	Cr	Co	Ni	V	Mo	P	S	Cu
Wt.%	1.4-1.6	0.6	0.6	11-13.5	1	0.3	1.1	0.7-1.2	0.03	0.03	0.25

Table 2 Chemical composition of D3 tool

Content	C	Si	Mn	Cr	Ni	V	W	P	S	Cu
Wt.%	2-2.35	0.6	0.6	11-13.5	0.3	1	1	0.03	0.03	0.25

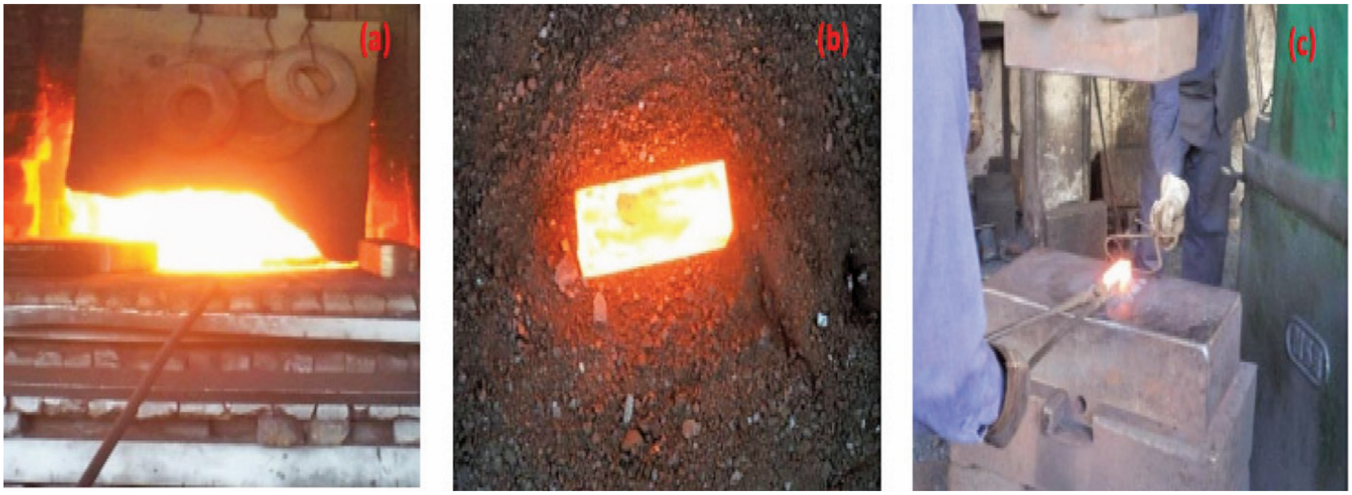

Figure 2: Forging Process of tool steels; (a) Electrical Furnace (b) Raw material heating to 1000^{o}C & (c) Hydraulic Press

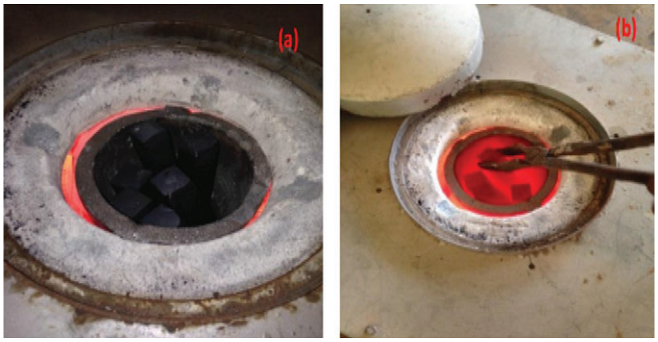

Figure 3: Heat treatment of tool steels; (a) Induction Furnace (b) Forged material heating to 700^{o}C

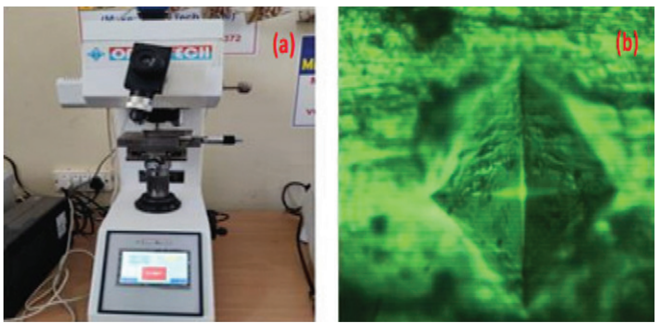

Figure 4: Hardness Test; (a) Micro hardness Tester and (b) Indentation onto specimen surface

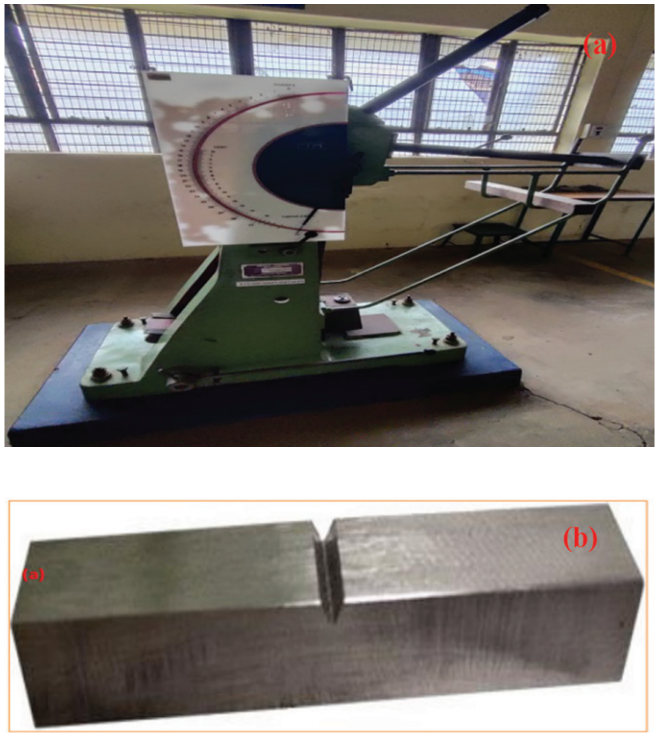

Figure 5: Impact test; (a) Charpy Testing machine and (b) Photograph of Charpy test specimen

limit the residual stresses as well as the brittleness that occurs during the quenching process. The hot induction furnace and the materials heated in the furnace are shown in Fig.3.

The Omnitech micro hardness tester was used to measure hardness values. The hardness values for all tool steel specimens were taken. The indentations onto the samples were noticed upon putting one kg load for 10 seconds dwell time. Hardness value was calculated by semi-automatic method. The specimen of D2 and D3 having highest hardness value were selected. It was observed that 20% hot forged heat treated D2 and D3 tool specimen having comparatively higher hardness value.

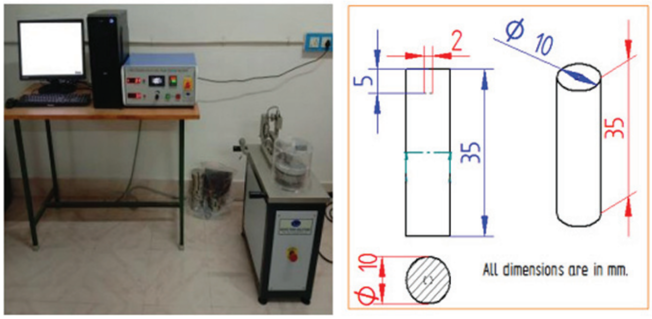

Figure 6: Wear test (a) Pin on disc wear testing machine and (b) Wear test pin.

The Fig. 5 shows charpy test specimen of dimension 55 mm × 10 mm × 10 mm, having a notch and impact testing machine. In the charpy test the specimen was stroked with a hammer on a pendulum arm by holding it securely at both the end. The decrease in pendulum arm motion measures the energy absorbed by the specimen during impact test. The high strain rates, stress concentrations at notches, voids and cracks are the main factors which affect material toughness.

The wear and friction performance of the tools were studied using pin-on disc type wear tester (TR-20, PHM/CHM-400, DUCOM Make) has been shown in Fig.6. The disc material in wear tester is of En-31 steel (carbon 0.9%, silicon 0.35%, manganese 0.75%, sulpur 0.05%, chromium 1.6% and balance Iron) with a hardness HRC 61. The roughness of disc surface was found as 0.47 to 0.87μm. The disc and wear test pin were ground using different fineness sand papers, cleaned with acetone and dried to maintain that the tests were performed at dry sliding conditions before commence of every test. A constant 80mm track diameter, 1.675m/s sliding speed and 1005m sliding distance was used throughout the experimental work for at room temperature. A 0.0001g precision analytical digital weighing balance was used to measure the wear test pin. The average of three weight loss measurement readings was considered to record as pin weight loss with all the samples. The volumetric wear rates of the test pin wear calculated using weight loss data. The frictional sensor of accuracy ±2% was used to notice the frictional force during the experiment and the same was used to calculate friction coefficient.

As per ASTM C177 procedure.

3.0 Results and Discussions

From the Fig.7, it can be observed from the above pictures of microstructure, elongated carbide particle can be seen at D2 forged specimen and it can be seen that carbide particles are elongated at martensite phase. It is also observed from the above pictures of microstructure, elongated carbide particle can be seen at D3 forged specimen and it can be seen that carbide particles are elongated at martensite phase.

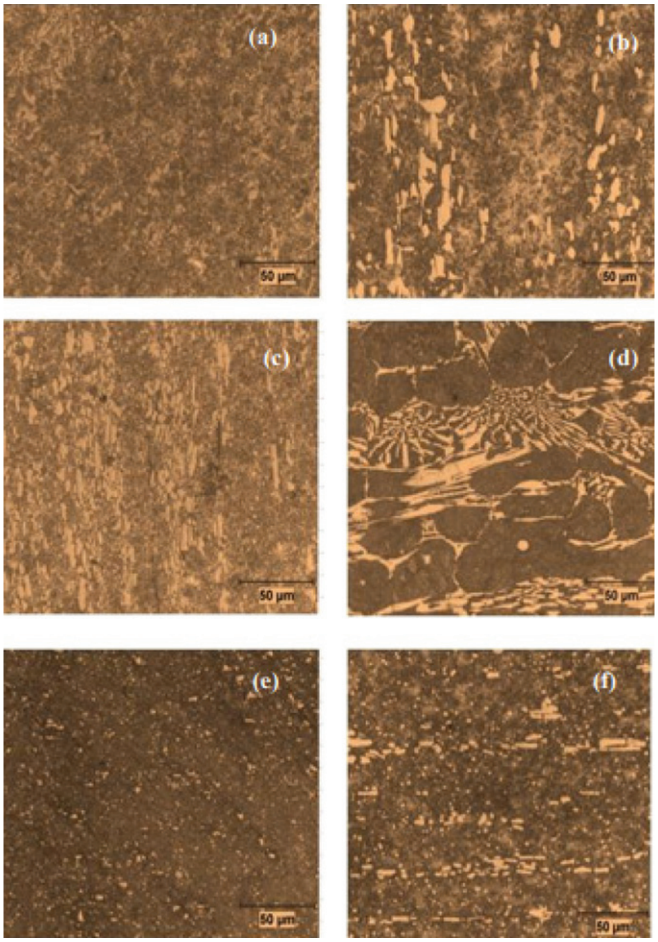

Figure 7: Optical Micrographs (a) D2 Raw (b) D2 20% Forged (c) D2 20% Forged & HT (d) D3 Raw (e) D3 20% Forged (f) D3 20% Forged & HT at 500X magnification

The micro Vickers hardness values comparison among forged D2, D3 and forged cum heat treated D2 and D3 tool steel materials have been shown in Fig.8. Among D2 series specimens D2 20% forged and heat-treated is having highest hardness number 628.45. Among D3 series specimens D3 20% forges and heat treated is having highest hardness number 609.83. Among all the samples of D2 and D3 having highest hardness value are employed as cutting tool for further study point of view.

The impact strength variations in D2 and D3 tool steel materials have been shown in Fig.9. Among D2 and D3 series specimens with 20% reduction of

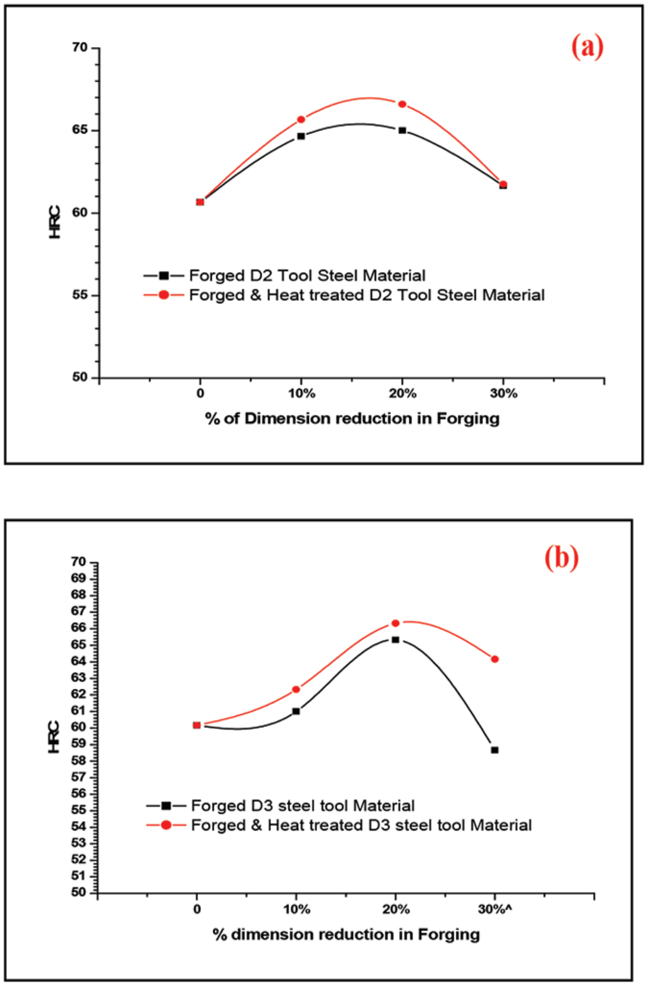

Figure 8: Comparison of Micro Vickers Hardness values; (a) D2 steel tool and (b) D3 steel tool

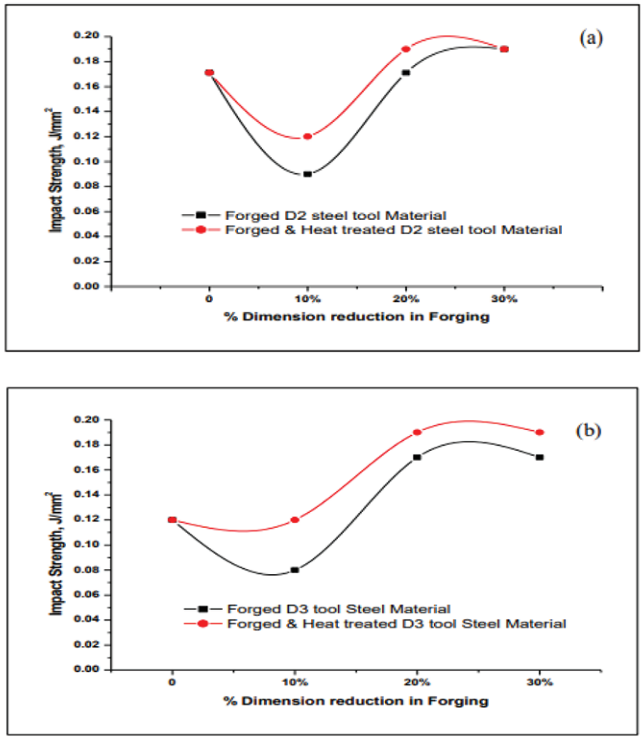

Figure 9: Variation of Impact strength; (a) D2 steel tool materials and (b) D3 steel tool materials

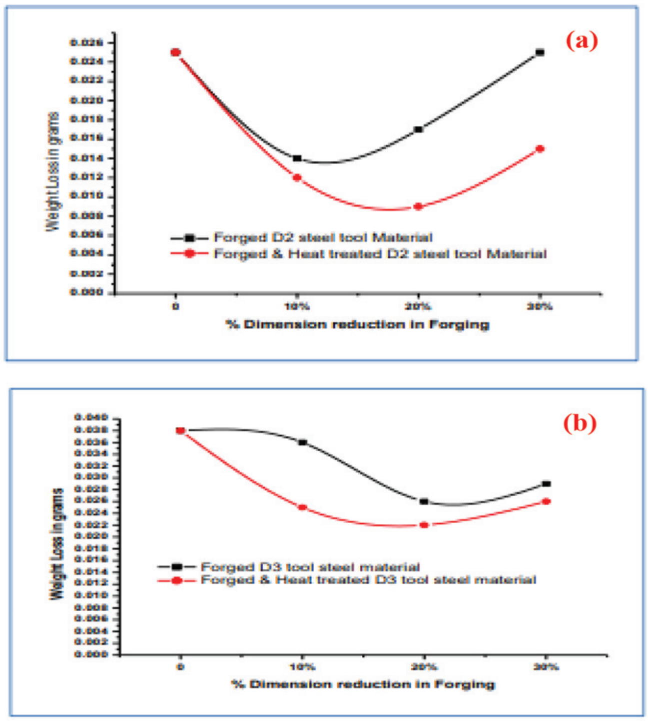

Figure 10: Wear of steel tool materials at 40N Load, 400RPM and 1000 m sliding distance; (a) D2 steel tool materials and (b) D3 steel tool materials

dimensions under forging cum heat-treatment process have exhibited comparatively higher impact strength. However the impact strength values found decreasing with 10% reduction of dimensions in both D2 and D3 steel under forging cum heat-treatment process. The decrease in impact strength could be due to concentration of induced thermal stresses.

The wear rate study carried out at 40N normal load, 400 rpm disc speed, 1005 m sliding distance for the D2 and D3 tool steel materials has shown in Fig. 10. Among D2 series specimens D2 20% forged and heat-treated has been shown least wear rate. Among D3 series specimens D3 20% forges and heat treated has been shown least wear rate. Among all the samples of D2 and D3 which are having least wear rate have been employed as cutting tool for further study point of view.

4.0 Conclusions

- The micro hardness value is more in heat treated and forged heat treated for all D series tool steels. Hardness is improved in D2 and D3 tool steels with forged and heat treated condition.
- The impact strength of heat treated and forged D2 and D3 tool steels is distinctly higher when compared to all other tested alloys.
- Weight loss reduces and thus wear resistance is enhanced in 20% forged and heat treated D2 and D3 tool steels when compared to other tested versions.

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