Effect of forging & heat treatment on d-series materials*

HS Bharath[1*], C Shashishekar[2] and KS Shashishekar[3]

Department of Mechanical Engineering, SIT Tumkur, Karnataka

*Presented in 1st National Conference on Smart Manufacturing & Industry 4.0 (NCSMI4) at Central Manufacturing Technology Institute (CMTI), Bengaluru, during May 30-31, 2019.

Keywords:
Micro Hardness,
Forging Process,
Heat Treatment,
Impact Test.

ABSTRACT

In this paper an attempt has been made to improve the properties of cutting tool like hardness, toughness & wear resistance by forging & heat treatment processes, hence we have selected D-Series tool steel (D1,D2,D3,D4) for our test. Common applications of these tool steels are in forging dies, die-casting die blocks, drawing dies etc.. This is an attempt to check whether these tool steels can be used as cutting tools at high temperature. This work evaluates Rockwell hardness, micro hardness, force analysis and impact properties. The results reveal that, hardness of D-series tool steels improved by forging and heat treatment processes.

1. Introduction

Metal cutting is one among the oldest & most important material shaping processes which is widely used in the automotive, railway, ship-building industry, aircraft manufacture, home appliance, electronics & construction industry, etc. Cutting tool is a very important in the manufacturing industry, hence lot of discussions & studies have been made to improve the quality and usage of cutting tool. Cutting tool has to have certain aspects or criteria such as hardness, toughness & wear resistance.

Commonly used cutting tool materials are High Speed Steel (HSS), diamond tools, abrasive tools, carbide tools etc., for several applications.

D-type tool steels contain between 10% and 18% chromium. These steels retain their hardness up to a temperature of 425°C (797 °F). Common applications for these tool steels include forging dies, die-casting die blocks, and drawing dies. Due to their high chromium content, certain D-grade tool steels are often considered stainless or semi-stainless; however their corrosion resistance is very limited due to the precipitation of the majority of their chromium and carbon constituents as carbides. [1-5]

*Corresponding author,
E-mail: bharathhs@sit.ac.in(Bharath H S)

2. Problem Identification

The main disadvantage of abrasive, HSS and super abrasives are cost which can be as much as ten times greater than ceramic or carbide. Even machining some composite materials, carbide or diamond tools fails unpredictably. Also, at high temperatures oxide formation takes place on high/low carbon steel and even carbide tools which leads to friction in machining.[6,7]

To overcome this problem a tool must be developed such that it must be cost effective, have good mechanical machine ability and properties should match the conventional tool's properties. Here we are making an attempt to make cutting tools of high carbon steel which can be forged and heat treatable. Further the tool must also able to with stand the heat generated in the metal-cutting process. This cutting tool must have good characteristics like hardness, strength, toughness, and also retain cutting edge at high temperature.

Heat treatment for the forged tool will helps to attain a good property value, preheating, normalizing, annealing, nitriding are some of the heat treatment processes done for forged tool. These heat treatment processes will helps to improve grain structure, improves toughness, hardness and as well as tool life.

In this work we are focusing on study on effect of forging on cutting tool properties. These tools will have standard geometry and specifications. This forging includes cold forged/hot forged and subjected to some specific heat treatment. This will improve grain structure, toughness, hardness and as well as tool life and reduce cost and help to cut specific materials in different industrial application.

3. Experimental Procedure

3.1. Selection of material

The raw materials selected are D-series tool steels (D1, D2, D3, and D4), because According to American iron and steel institute (AISI), D1, D2, D3 & D4 steel is the high-carbon, high-chromium tool steels alloyed with molybdenum and vanadium AISI D1, D2, D3 & D4 steels are the most widely used steel in the industry. AISI D2 & D3 steels are recommended for tools requiring very high wear resistance, combined with moderate toughness, these steels are most suitable for testing. (Ref Table 1)

Table 1.
Composition of D1- tool steel.

Content	%
C	0.9-1.10
Si	0.1-0.4
Mn	0.2-0.4
Cr	11.5-12.5
Mo	0.7-0.8
V	0.3-0.8

Table 1.
Composition of D2- tool steel.

Content	%
C	1.4-1.6
Mn	0.6
Si	0.6
Co	1
Cr	11.2-13
Mo	0.7-1.2
V	1.1
P	0.03
Ni	0.3
Cu	0.25
S	0.03

Table 1.
Composition of D3- tool steel.

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

Table 1.
Composition of D4- tool steel.

Content	%
C	2.05-2.4
Mn	0.6
Si	0.6
Cr	11-13
Ni	0.3
Mo	0.7-1.2
V	1
P	0.03
S	0.03
Cu	0.25

3.2. Forging process

D type tool steels D1, D2, D3, and D4 are subjected to Press Forging individually by using belt drop hammers of weight 500N. The Dimension of D-type tool steel before forging is 15*15*100 (b * h * l). The Dimension of D-type tool steel after forging is 13*13*120 (b * h * l).

The materials are hot forged by heating it to above its re-crystallization temperature. Finally the specimens are heated in furnace up to 1000^{o}C. (Ref Fig, 1)

3.3. Heat treatment process

Heat treatment is a process used to alter the physical, and sometimes chemical, properties of a material. Heat treatment involves the use of

Fig. 1. Forging of D series tool steels.

heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material.

Heat treatment technique includes annealing, case hardening, precipitation strengthening, tempering & quenching. In this work, D-series tools are heated and oil-quenched.

- Heating temperature – 980^0 for D1 & D2
  940^0 for D3 & D4
- Oil used – servo quenching oil
- Hardening time – 30min
- Type of furnace – salt bath
- Pre-heating temperature – 550^0

3.4. Rockwell hardness test

The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. (Ref. Fig. 2.)

- Type of scale – C scale
- Load – 150kg
- Indenter – Diamond cone indenter
- Time – 20sec

Fig. 2. Digital rockwell hardness machine.

3.5. Force analysis

The Force analysis of D-type tool steel is to measure force that tool steel can sustain. The cutting forces were measured using strain gauge type three component lathe tool dynamometer mounted on specially designed fixture. It consists of three force components measurement circuit's i.e. cutting force (thrust), feed force and radial force components with balancing for initial zero setting of the bridge settings. The strain gauge with D- type tool was attached to the tool post of the lathe machine. The readings for cutting forces were recorded after output stabilization and have been used for analysis. (Ref. Fig. 3.)

3.6. Impact test

Impact is a very important phenomenon in governing the life of a structure. An arm held at a specific height is released. The arm hits the sample and breaks it. From the energy absorbed by the sample, its strength is determined.

The Izod impact test differs from the Charpy impact test in that the sample is held in a cantilevered beam configuration as opposed to a three-point bending configuration.

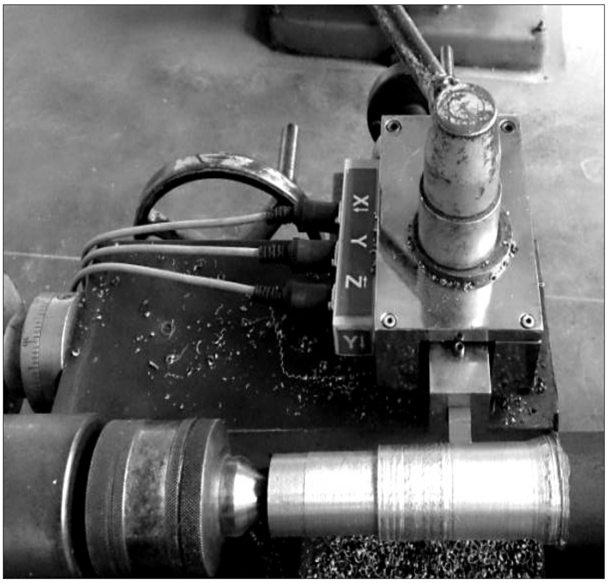


Fig. 3. Finding force using lathe tool dynamometer.

Impact test are used in studying the toughness of material. A material toughness is a factor of its ability to absorb energy during plastic deformation. Brittle materials have low toughness as a result of the small amount of plastic deformation that they can endure.

Impact value of a material can also vary with temperature. Generally, at low temperature, the impact strength of a material is decreased. (Ref. Fig. 4.)

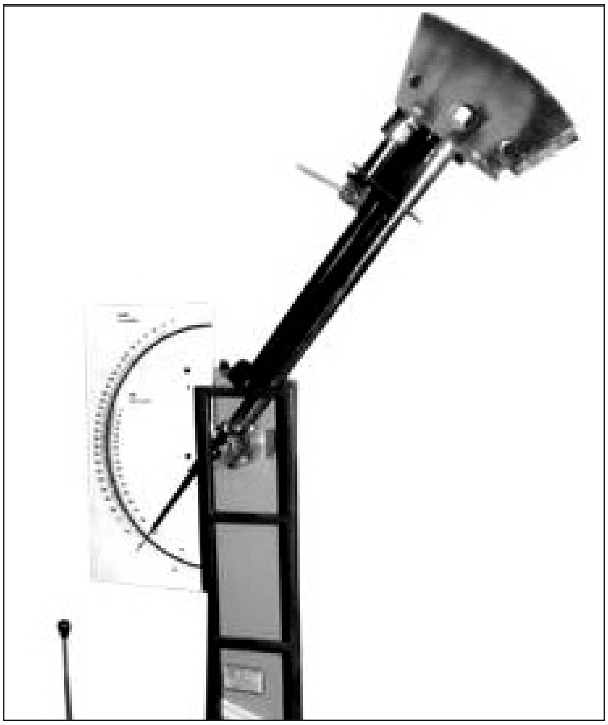
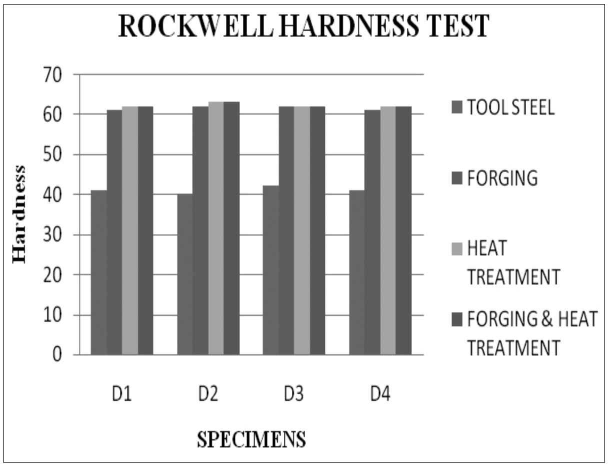


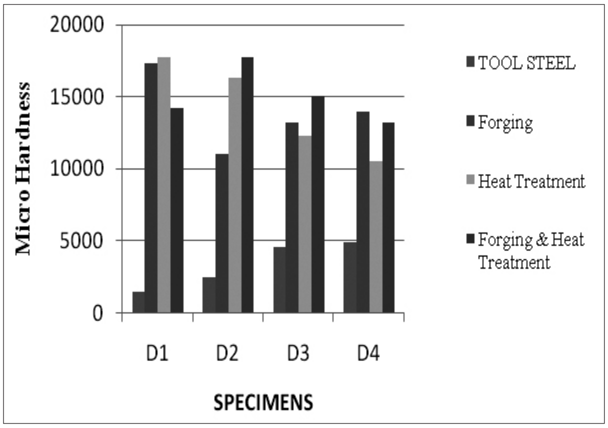
Fig. 4. Impact testing machine.

4. Results and Discussion

4.1 Hardness Test

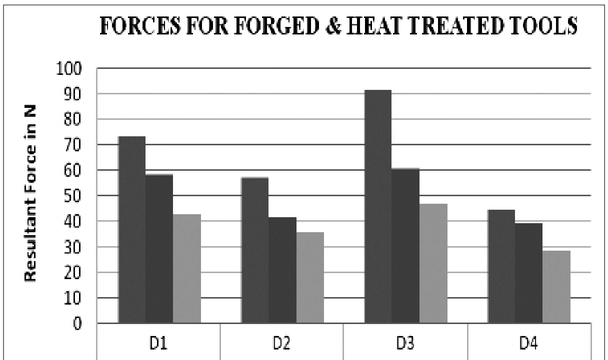


Graph 1. Rockwell hardness of the D-series tool steel.



Graph 2. Micro hardness of the D-series tool steel.

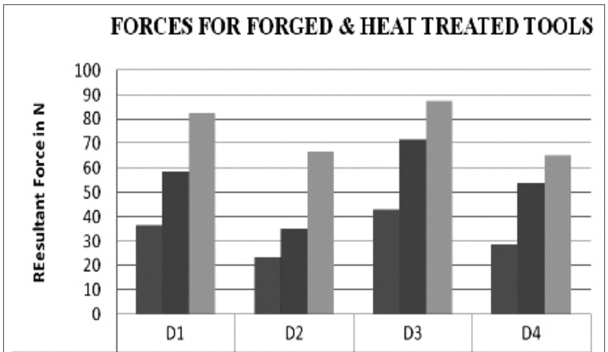
4.2. Force Analysis



	D1	D2	D3	D4
52 rpm	73.36	57.31	91.79	44.72
150 rpm	58.31	41.4	61.03	39.35
250 rpm	42.94	36.05	47.17	28.65

Graph 3. Resultant forces for tools that are both forged & heat treated.

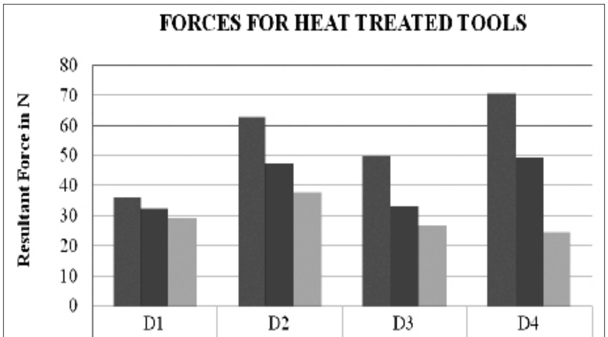
From graph it cn be observe that resultant force decreases as cutting speed increases. During turning operation D2 & D4 of forged & heat treated tools get blunted at 150rpm, but D1 and D3 tools perform effectivelt at all the three kinds of cutting speeds.



	D1	D2	D3	D4
0.2 mm/rev	36.68	23.32	43.01	28.65
0.3 mm/rev	58.52	34.98	71.59	54.08
0.4 mm/rev	82.76	66.85	87.46	65.19

Graph 4. Resultant force by varying feed rate.

Graph shows that resultant force increases as the feed rate increases. D3 & D1 tool perform better cutting at various feed rates than other tool. All the tools are operated at a cutting speed of 150 rpm

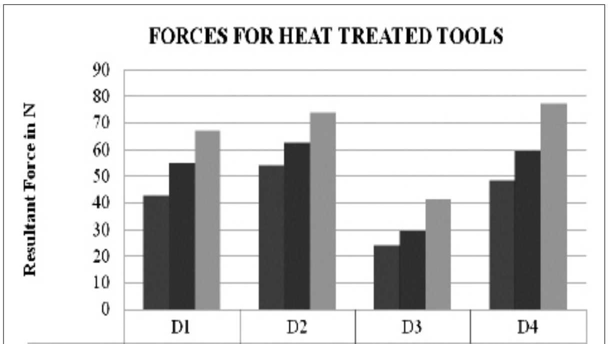


	D1	D2	D3	D4
52 rpm	36.05	62.64	50	70.49
150 rpm	32.25	47.43	32.8	49.4
250 rpm	29.15	37.73	26.63	24.41

Graph 5. Resultant forces for the tools that are only heat treated.

Hear also as the cutting speed increases resultant forces decreases. At 52rpm & 150rpm D2 & D4 perform better, at 250rpm D4 perform better than D1 & D3 tool. During turning operation no tool get blunted at various cutting speed. (Ref. Graph 6)

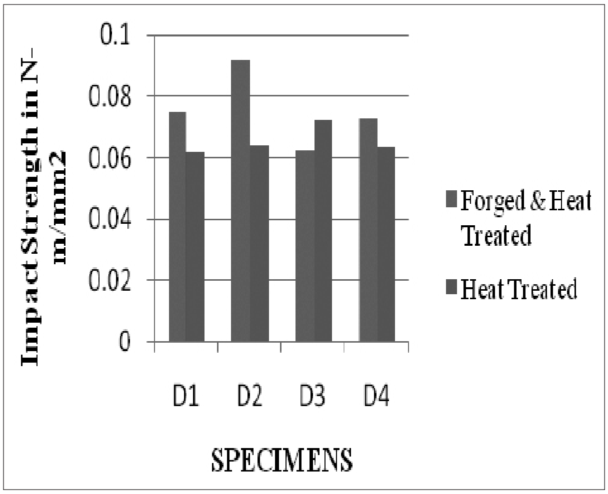
Graph shows that resultant force increases as the feed rate increases. Hear D2 tool perform better in all the three different feed rates when compare to other tools & heat also tools did not get blunt so we can say that heat treated tools perform better by varying both cutting speed & feed rate the forged & heat treated tool.



	D1	D2	D3	D4
0.2 mm/rev	42.72	54.08	24.16	48.25
0.3 mm/rev	55.09	62.43	29.15	59.36
0.4 mm/rev	67.08	73.78	41.23	77.38

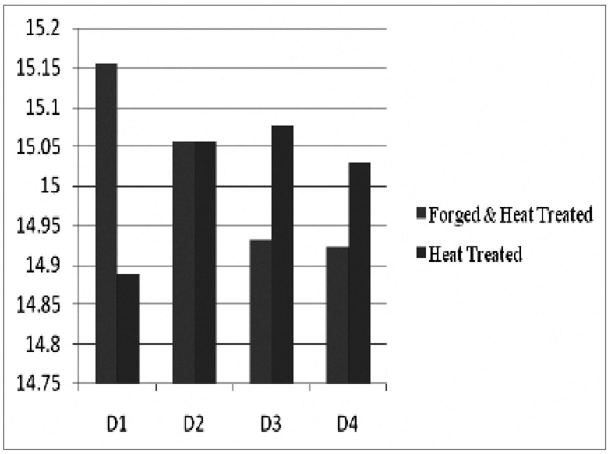
Graph 6. Resultant forces by varying feed rate.

4.4. Impact test



Graph 7. Impact strength of the IZOD Test.

From graph forged & heat treated D2 tool steel has more Impact strength than other tool steel hence toughness of the D2 tool steel is hingh in Izod test.



Graph 8. Impact strength of CHARPY test specimens.

The above graph shows that an heat treated forged & heat treated tool steel in Charpy test also has more impact strength than heat treated & forged and heat treated tool steel. So in both case forged & heat treated tool steel has more Impact strength hence the toughness of the material increses.

5. Conclusions

From the results it is observed, tool steel after forging & heat treatment exhibits better hardness than untreated tool steel also D2 & D4 proved to be better than D1 & D3.

From force analysis , performance of D2 & D4 are better than D1 & D3 for variable speed & feed rates.

D2 exhibits better toughness in both izod & Charpt test.

Hence among D1, D2, D3 & D4. D2 tool steel performance is better and it can be used as a cutting tool with improved properties like toughness, hardness and less cutting force with improved rate of cutting.

References

1. Mkaddem, Ali; Huguet, Anne; Mansori, Mohamed EL: Recryatallisation of austenite grain when non-isothermal steel working: Effect of thermal kinetics and deformation-based mechanism, 'Materials and Design', vol. 31, no. 10, December 2010, 4808-4815.
2. Zhao, J; Jiang, Z; & Lee, C. Soo: Enhancing impact fracture toughness and tensile properties of a micro alloyed cast steel by hot forging and post-forging heat treatment processes, 'Materials and Design', vol. 47, May 2013, 227-233.
3. Huang, C; Chen, Z; Dean, TA; Loretto, MH: Effect of post-forging heat treatment on the microstructure and room temperature tensile properties in Ti-25 Al-10Nb-3v-1Mo (super α2), 'Materials Science and Engineering', vol. 174, no. 1, January 1994, 23-35.
4. Bin, Li: A review of tool wear estimation using theoretical analysis and numerical simulation technologies, SciVerse Science Direct: 'Int. journal of refractory Metals and Hard materials', vol. 35, November 2012, 143-151.
5. Leshchynsky, V; Ignatiev, M; Wiśniewska-Weinert, H; Borowski, J; Rybak, T; Dobrovnik, I: Forging tools modification with graphene-like solid lubricant nanoparticles, 'Journal of Achievements in Materials and Manufacturing Engineering', vol. 43, no. 1, 2010, 341-348.
6. Birosca, S; West, GD; Higginson, RL: Microstructural investigation of the oxide scale on low carbon steel, METAL 2005, 24.- 26.5.2005, Hradec nad Moravicí.
7. Astakhov, Victor P: The assessment of cutting tool wear, Science direct: 'International journal of Machine Tools & Manufacture' vol. 44, no. 6, 2004, 637-647 ◘