The Effect of Austenite Temperature on the Microstructure, Mechanical Behavior, Hardness, and Impact Toughness of AISI D2 Tool Steel

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ABSTRACT

For the wide use of AISI D2 tool steel in machine parts, molds and automotive industry it is worth to investigate the effect of heat treatment process of AISI D2 tool steel on its impact energy at room temperature, microstructure, mechanical characteristics and microhardness. AISI D2 tool steel specimens were machined using both CNC milling and turning machines to the recommended standard in order to conduct the tensile, impact test, microhardness test and microstructure test; all tests were performed before and after heat treatment process. Four regimes of austenite temperature namely: 980 ºC, 1010 ºC, 1040 ºC, and 1070 ºC were conducted. It was found that there is a prominent enhancement microhardness of 72.2 % at 1070ºC; also there is an enhancement on the impact energy of 75 % that achieved at the same temperature, finally the U.T.S was enhanced by 300.8% at 980 ºC.

Keywords: **AISI D2 tool steel, Microhardness, Mechanical characteristics, Microstructure, Toughness**.

1. INTRODUCTION

The benefits for the manufacture of components from hardened steel are substantial in terms of reduced machining costs and lead times compared to the more traditional machining route [1]. D2 tool steel is an air hardening, high-carbon, high-chromium tool steel possessing extremely high wear resisting properties. It is very deep hardening and is practically free from size change after proper treatment. This tool steel's high chromium content gives it mild corrosion resisting properties in the hardened condition. D2 tool steel is available in the form of DeCarb-Free (DCF) bars. DCF bars have been cold finished in the mill prior to shipment, eliminating the need for bark removal by the tool and die fabricator

[2]. Wear at elevated temperatures has been considered in detail for different metals and alloys. Pauschitz et al. [3] have reported recently a systematic survey of the current status and future trends of protection against high-temperaturewear,with specialemphasis on the mechanisms that explain the formation of glazed layers. The influence of oxide-forming alloying elements, such as Si and Al, on the tribological behavior of Fe alloys has been pointed out in the literature [3–5]. It is now widely accepted that improvement in WR by deep cryogenic treatment is considerably higher than that achieved by cold treatment [6–9, 10, 11, 12].

2. MATERIALS, EQUIPMENT AND PROCEDURES

2.1 Materials

AISI D2 tool steel was used through this study; it has characteristics like inability dimensional stability during hardening, good combination of hardness toughness and also tempering. It has high wear resistance and high compressive strength where. The chemical composition of AISI D_2 tool steel is(1.55 % C, 0.3 %Si, 0.4 %Mn, 11.8 % Cr, 0.8 %Mo, 0.8 %V and the balance is Fe).

2.2 Equipment and Tools

The following equipment and tools have been used in this study:
1- Engine lathe machine for turning preparation specimens (GAMET 600)

2- Milling machine (LAGUN FU.1100)
3- Grinding and polishing machine (struers Roto Force 4)
4- Electrical furnace for heat treatments of the specimen carbolit (1100 ºC)
5- Mineral oils for quenching heat treatments (Engine oil (40))
6 - Instron machine test (QUASAR 100)
7- Impact machine for the Charpy impact test (BROOKS CHARPY)
8- Digital micro hardness tester for measuring the Vickers micro hardness (HWDM-3) (HIGHWOOD)
9-Microscope used for the micro structure examinations (Nikon EPIPHOT200)

2.3 Experimental Procedure

2.3.1 Preparation of the specimens

Cylindrical of D_2 alloy steel were prepared with outside diameter equal to 16 mm. Alloy steel bar was cut into small pieces using band saw to produce the required dimensions. Specimen of 15 mm length and 16 mm diameter, 15 specimens used for impact test that prepared by milling machine. Alloy steel bar was machined using lathe machine to produce fifteen specimens for tensile test. These specimens were cut using cutting conditions as shown in Table 2.

Type of alloy steel	Vc (m/min)	F (mm/rev)	Depth of cut (mm)
AISI D_2 stee	640	0.2	1.5

Table2. Standard cutting conditions of D2 steel.

2.3.2 Heat treatment

Heat treatment is the process of heating and cooling a metal in its solid state in order to obtain the desired changes in its physical properties, changes in the structure and mechanical properties which commonly used for steels. The main heat treatments are hardening, tempering and annealing. However this study is more oriented towards hardening and tempering.

2.3.1.1 Hardening

The purpose of this process is to convert the phase of a metal to hard phase; this cycle involves three successive phases:

- Heating to temperature called austenitizing temperature.
- Maintaining this temperature to dissolve the carbides and obtain a homogenous solid solution austenite.
- Cooling by immersion in some medium which is oil sufficiently rapid to obtain the desired quenching components.

As mentioned previously D_2 was hardened in different temperatures. The process is done firstly by raising the temperature to 700ºC which is called preheating temperature, then increasing the temperatures as shown in Fig. 1.

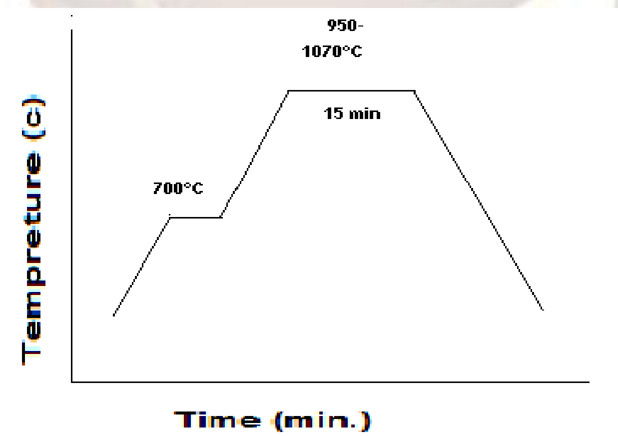


Fig.1: Hardening diagram of AISI D2 tool steel

All of the above specimens were maintained for 15 minutes at the recommended temperatures; finally it cooled in oil at 55 ˚C.

2.3.1.2 Tempering

The quenched metal is too fragile to be actually used therefore quenching is followed by tempering. The main purpose of this process is to remove the internal stresses caused by the hardening process; it also provides a combination of two contradictory requirements hardness and toughness. Unlike hardening the tempering process is done under the eutectoid transformation degree where no phase change occur and the cooling process is done on air so that the grains set in their position therefore no internal stresses are found and the toughness will increase.

1. The D2 steel specimens was entered to the furnace under 550 ˚C for two hours holding time, and then cooled to room temperature as shown in Fig.2.

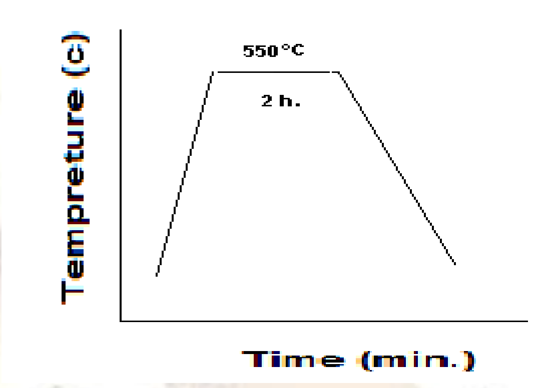


Fig.2: Tempering diagram of AISI D2 tool steel

The specimens after heat treatment process (Tensile, Impact) are shown in Fig.3.

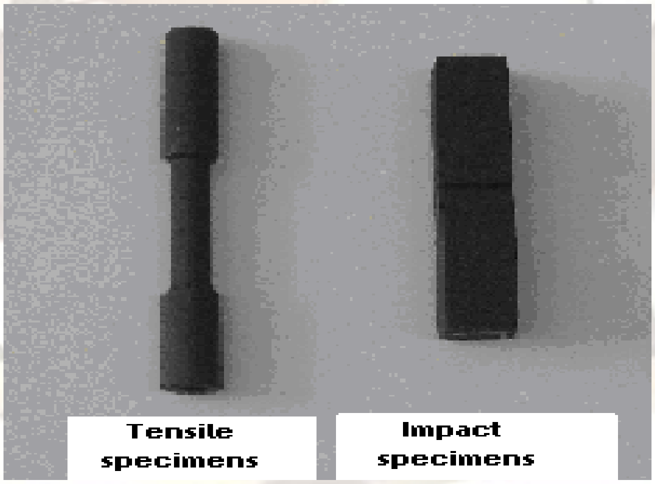


Fig.3: Tensile and impact AISI D2 tool steel specimens after heat treatment

2.3.2 Microstructure examination

Microstructure examination of used steels is an important analysis to be carried out; it is very useful since it can provide important information about grain size, material properties and reliability. It can show the surface cracks or other machining defects. Improper machining cause transformation of the microstructure. The microstructure examination was preformed on the flat surface as the follows:

1. The flat surface of the test pieces were ground by different grades of emery papers; (220, 320, 400, 600, 800, 1000 and 1200) using a disk grinder.

2. After polishing the test pieces using a rotary polishing machine with the aid of diamond paste achieving a surface like mirror.
3. The polished surfaces were etched by NITAL etching solution, nitric acid of percentage $2cm^3$ with $100cm^3$ of alcohol.
4. Finally photographs of the microstructure were taken using microscope type Nikon (EPIPHOT200).

2.3.3 Microhardness test

Micro hardness test was carried out on each specimen at 500 gmf, using micro hardness tester type (HIGHWOOD), five reading were taken then the average was calculated.

2.3.4 Impact test

The Charpy and Izod were designed and are still used to measure the impact energy; some times also termed notch toughness. The Charpy v-notch technique is most commonly used for Charpy and Izod the specimen, both have a thin shape of square cross section bar. The load is applied as an impact blow from weighted pendulum hammer that is released from a cocked position at a fixed height; the specimen is positioned at the base. Upon release, a knife edge mounted on pendulum strikes and fractures the specimens at the notch, which acts as a point of stress concentration for this high velocity impact blow. The pendulum continues its swing, rising to the maximum height, the energy absorption computed from the difference between both the heights.

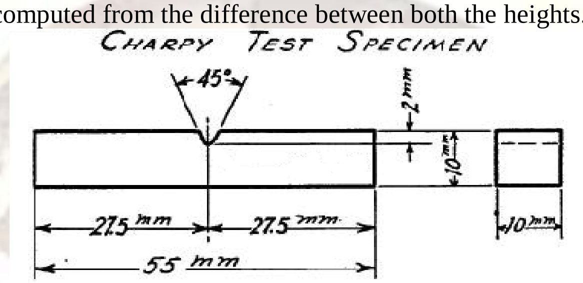


Fig. 4: Charpy test specimen dimension of AISI D2 tool steel

2.3.5 Tensile test

Tension test is probably the most fundamental type of mechanical test you can perform on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on the material, as the material is being pulled, you will find its strength along with how much it will elongate. A curve will result showing how it reacted to the forces being applied. The point of failure is of much interest and is typically called U.T.S on the chart. The test was carried out on work piece at strain rate $1*10^{-3}$, the load –deflection curve was obtained from which the true stress – strain diagram is obtained. The dimension of tensile specimen is shown in Fig.5.

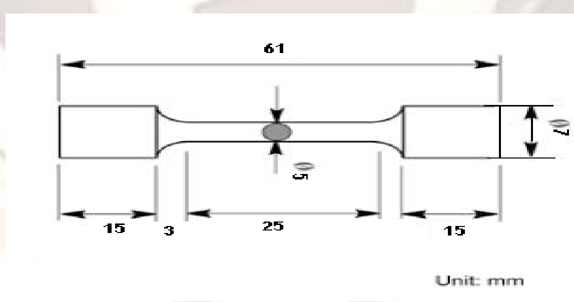
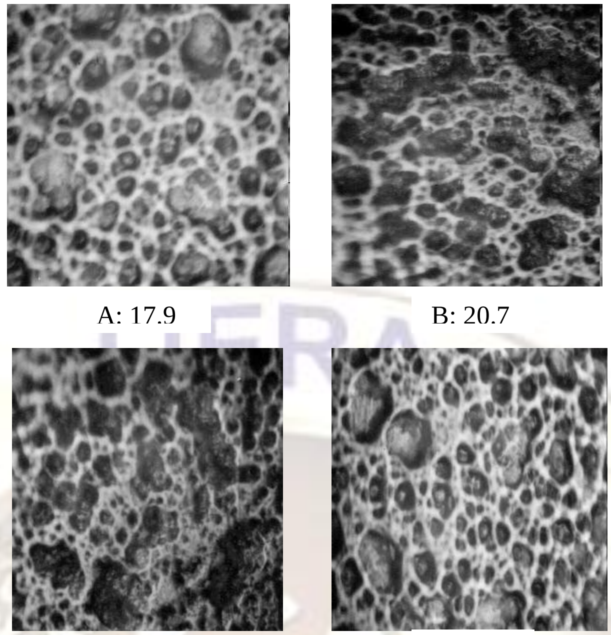


Fig. 5: Dimensions of tensile test specimen (ASTM-E8, 1975)

3. RESULTS AND DISCUSSION

3.1 Effect of Austenite Temperature on the Microstructure of AISI D2 tool steel

It can be seen from Fig.6 that the average grain size of D2 alloy steel varied as the austenite temperature increase the minimum average grain size was 14.8 µm that attained at 1070 ˚C; this can be attributed to high cooling rate at this temperature.



A: 17.9 B: 20.7

C: 14.9 D: 14.8

Fig.6: Micrographs of oil quenched D2 as received, microstructure is tempered martensite at 400x

3.2 Effect of Austenite Temperature on the average grain size of AISI D2 tool steel

It obviously shown from Fig.7 that the average grain size is increased as the austenite temperature increase, this caused by the faster cooling rate at 1070 ˚C, the maximum increase was 50 %.

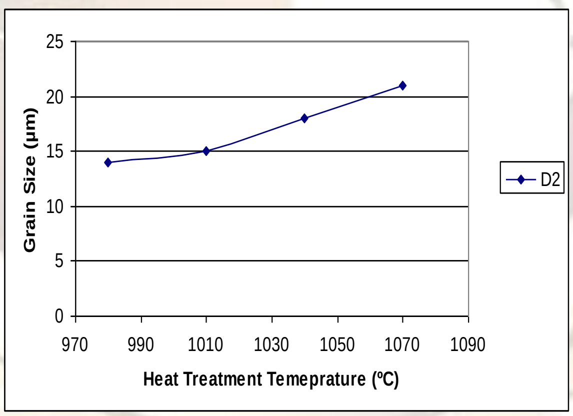


Fig.7: Effect of Heat Treatment Temperature on Grain Size of AISI D2 tool steel.

3.3 Effect of Austenite Temperature on the Microhardness of AISI D2 tool steel

It can be seen from Fig.8 that the microhardness increase as the austenite temperature increase, the maximum enhancement is 72.2 % that was attained at 1070 ˚C. This can be attributed to the large amount of martensite formed at 1070˚C compared to the other temperatures.

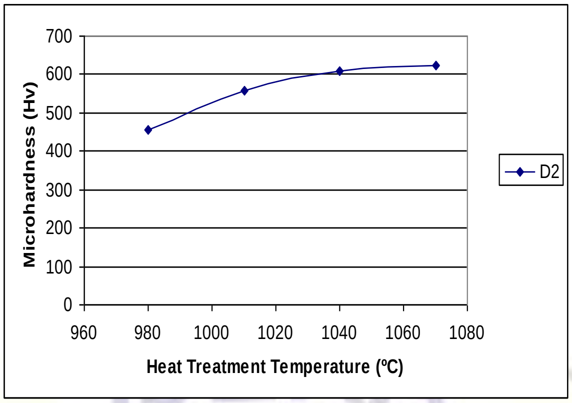


Fig. 8: Effect of Heat Treatment Temperature on Hardness of AISI D2 tool steel

3.4 Effect of Austenite Temperature on the Impact Energy of AISI D2 tool steel

It is obvious from Fig.9 that as the average grain size increase the impact energy decreased, the maximum was 35 J at 1070 ˚C compared to 20 J AT 980 ˚C, in most D2 steel application we compromise between the hardness and toughness according to the nature of application.

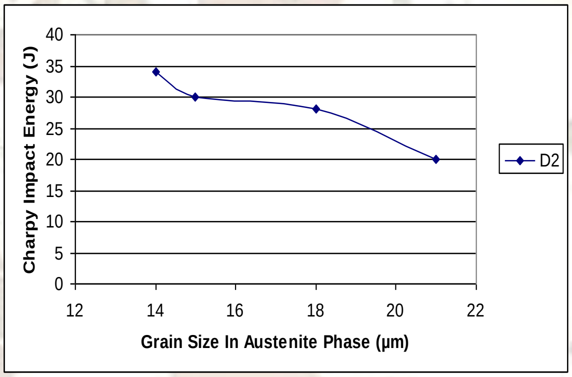


Fig.9: Effect of Grain Size on Charpy impact energy of AISI D2 tool steel

3.5 Effect of Austenite Temperature on the Ductility of AISI D2 tool steel

It can be seen from Fig. 10 the maximum elongation was 79.2 % for D2 before heat treatment but as the austenite temperature increase the maximum % elongation increase.

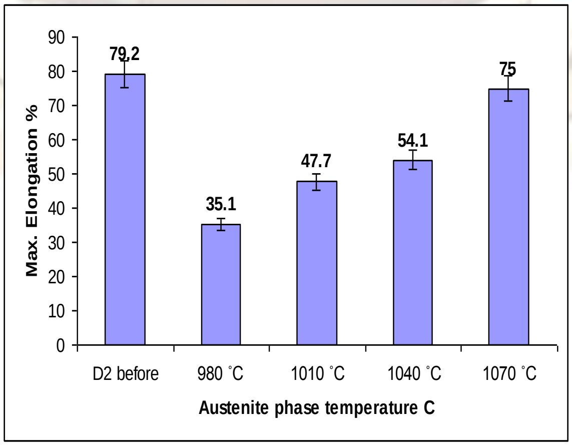


Fig. 10: Effect of Heat Treatment Temperature on the maximum elongation % AISI D2 tool steel

3.6 Effect of Austenite Temperature on the U.T.S of AISI D2 tool steel

From Fig. 11 it can be seen that there is prominent enhancement in the U.T.S at 980 ˚C, the enhancement was 300.8 %, which recommended for certain applications.

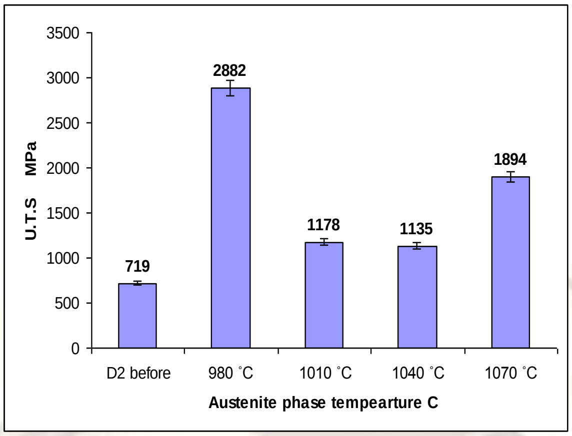


Fig. 11: Effect of austenite Temperature on U.T.S of AISI D2 tool steel

4. CONCLUSIONS

The following can be concluded:

- The average grain size is increased as the austenite temperature increase; the maximum increase was 50 % at 1070 ˚C.
- The microhardness increase as the austenite temperature increase, the maximum enhancement was 72.2 % that attained at 1070 ˚C.
- The maximum impact energy was 35 J that achieved at 1070 ˚C.
- There is prominent enhancement in the U.T.S at 980 ˚C, the enhancement was 300.8 %.

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