Effect of Heat Treatment on the Mechanical Properties, Microhardness, and Impact Energy of H_{13} Alloy Steel

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Abstract— AISI H_{13} tool steel is applied widely to produce many kinds of hot work dies, such as forging dies, extrusion dies, and die-casting dies. The hardness of AISI H_{13} tool steel varies with its application for different type of dies. For this type of alloy steel it is worth to investigate the effect of heat treatment process on its impact energy at room temperature, microhardness, microstructure, and mechanical characteristics. AISI H_{13} tool steel specimens were machined using CNC milling and lathe machines to the recommended standard in order to conduct the tensile, impact, microhardness and microstructure tests. All tests were performed before and after heat treatment process, where four regimes of austenite temperature namely; 980 ˚C, 1010 ˚C, 1040 ˚C and 1070 ˚C were conducted. After hardening and tempering it was found that the maximum enhancement in the U.T.S of about 277.6% at 1040 ˚C, it is also found that there is an enhancement in microhardness as the austenite temperature increased, and the maximum enhancement was 88.9 % that attained at 1070 ˚C, Furthermore, there is an enhancement on the impact energy of 117.6% that achieved at 980 ˚C.

Index Terms— Microhardness, Microstructure, Heat treatment, Impact Energy, H_{13} steel, Grain size, Ductility.

1 INTRODUCTION

AISI H_{13} steel is a hot-worked die steel that is widely applied in areas such as hot forging, hot extrusion and die-casting. Dies work at surface temperatures up to 550 ˚C which is very close to the tempering temperature of die steels. Operating at an elevated temperature inevitably leads to continuous evolution of the microstructure and will significantly affect various properties of dies [1]. Quenched and tempered H13 hot work tool steel is thus mainly used to make hot forging dies invirtue of its excellent properties: high hardness and mechanical strength, good toughness and significant resistance to shock,thermal fatigue and wear [2–5]. Heat treatment is a process to alter the metallurgical and mechanical properties for specific purposes that involves heating and cooling of the material. It is known that the hard-ness obtained from hardening process is greatly influenced by the available carbon content in steel during quench-ing [6]. The benefits for the manufacture of components from hardened steel substantial in terms of reduced machining costs and lead times compared to the more traditional machining route, [7]. AISI H_{13} tool steel is applied widely to produce many kinds of hot work dies, such as forging dies, extrusion dies, die-casting dies and so on. The hardness of AISI H13 tool steel varies with its application for the different type of dies. AISI H_{13} hardness recommended is at 43–52 HRC for extrusion dies, at 44–50 HRC for die-casting dies, at 40–55 for forging dies, [8]. Additionally,since hot-cracks mainly occur on the die surface, some surface treatment methods,for example, electric plating, nitriding and chemical plating, have been widely used, of these methods, laser cladding is considered as an out- standing process to bond the coating (with thickness of 0.3–2 mm) with asubstrate to achieve good metallurgical bonding by high power laser assisted melting [9-11]. Resently an investigation of the effect of heat treatment on the torsional aspects of H_{13} alloy steels was studied [12]. The main objective of this study is to investigate the effect of heat treatment quenching and temerping on the mechanical properties, microstructure and impact energy of H_{13} steel.

2 MATERIALS, EQUIPMET and EXPERIMENTAL PROCEADURS

2.1 Materials

In this paper alloy steel H_{13} were studied, according to (AISI), it has characteristics like inability, dimensional stability during hardening, good combination of hardness and toughness. The chemical composition of H_{13} alloy steel is shown in Table 1.

TABLE 1
CHEMICAL COMPOSITION OF H_{13} ALLOY STEEL

Element	C	Si	Cr	Mo	V	Fe
Wt.%	0.40	1.0	5.30	1.40	1.0	Bal.

2.2 Equipment

The following equipment and tools were used
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 carbo-

ISSN 2229-5518

lit (1100 °C).
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

Cylindrical bars of H_{13} alloy steel were prepared with outside diameter equal to 16 mm. Initially, alloy steel bars were cut into small pieces, using a band saw to produce the required dimensions. Specimens of 16 mm diameter and 150 mm length, 15 specimens were used for impact test that prepared using milling machine. Alloy steel bars were turned using single point carbide cutting tool by a conventional lathe machine to produce 15 specimens for tensile test with the standard cutting conditions as shown in Table 2.

TABLE 2
CUTTING CONDITIONS OF H_{13} STEEL

Type	Vc m/min	f mm/rev	Depth of cut mm	Type of tool chip
H13	350	0.3	1.5	P10c.c

2.4 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 structure and mechanical properties, most commonly used for steels. The main heat treatments are hardening, annealing and tempering. However this study is oriented towards hardening and tempering.

2.4.1 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 of H_{13} was hardened in different temperatures. The process is done firstly by raising the temperature to 650 °C which is called preheating temperature, then increasing the temperatures to 950-1070 °C, All of the above specimens are maintained for 15 minutes at required temperatures, finally it coold in oil of 55 °C.

2.4.2 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. The H_{13} steel specimens were entered to the furnace under 540 °C with one and half hours holding time, then cooled in air to room temperature.

The specimens after heat treatment process (Tensile, Impact and compression) are shown in Fig.1.

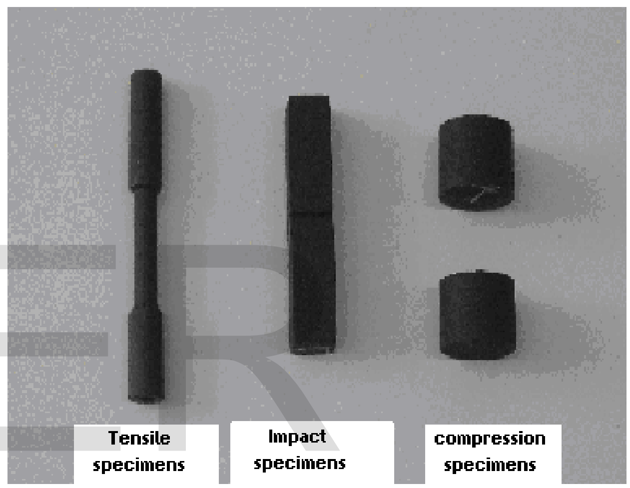


Fig. 1: Tensile, impact, and compression specimens after heat treatment

2.5 Microhardness test

Micro hardness test was carried out on each work piece of load (500gf), using micro hardness tester type (HIGHWOOD), five reading were taken then the average was calculated.

2.6 Impact test

Impact tests, 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. Dimension Charpy test specimen is shown in Fig.2.

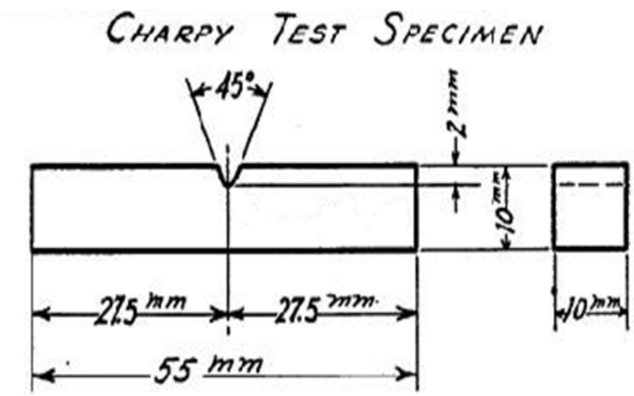
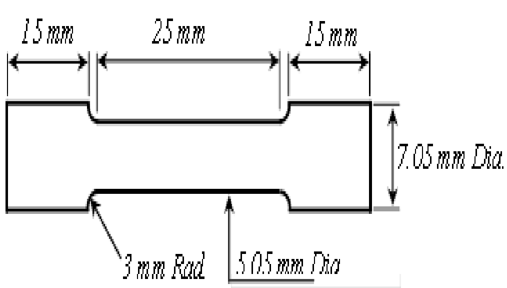


Fig.2: Dimension details of charpy test specimen

2.7 Tensile test

A tensile 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, you will very quickly determine how the material will react to forces being applied in tension. As the material is being pulled, you will find its strength along with how much it will elongate. As you continue to pull on the material until it breaks, you will obtain a good, complete tensile profile. 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 its Ultimate Strength or UTS 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 graphical for each alloy steel. Dimension tensile test specimen is shown in Fig.3.



3. Results and Discussions

3.1 Effect of heat treatment on grain size of H_{13} alloy steel

The effect of austinte temperature on the grain size was studied and the results of experiments are presented in Fig. 4. It can be ssen that as the austintic temperature increases the grain size is increased.

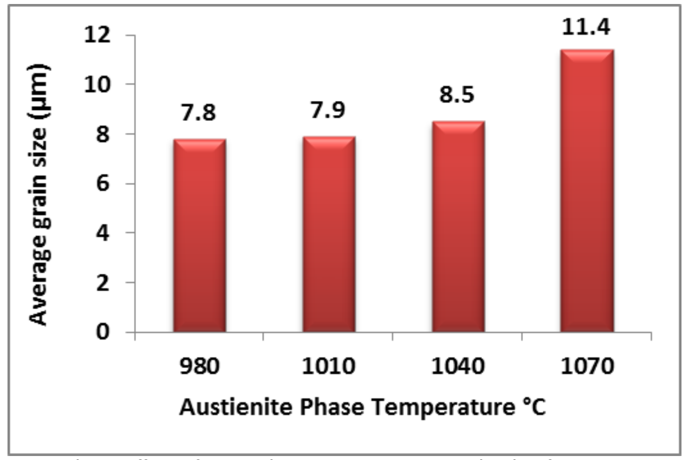


Fig.4: Effect of austenite temperature on grain size for H_{13}

3.2 Effect of heat treatment on the microstructure of H_{13} alloy steel

It can be seen from Fig.5 the smallest grain size is 7.8 µm that attained at 980 °C where it increased gradually as the austenite temperature increased. This microstructures were taken after oil quench followed by tempering operation.

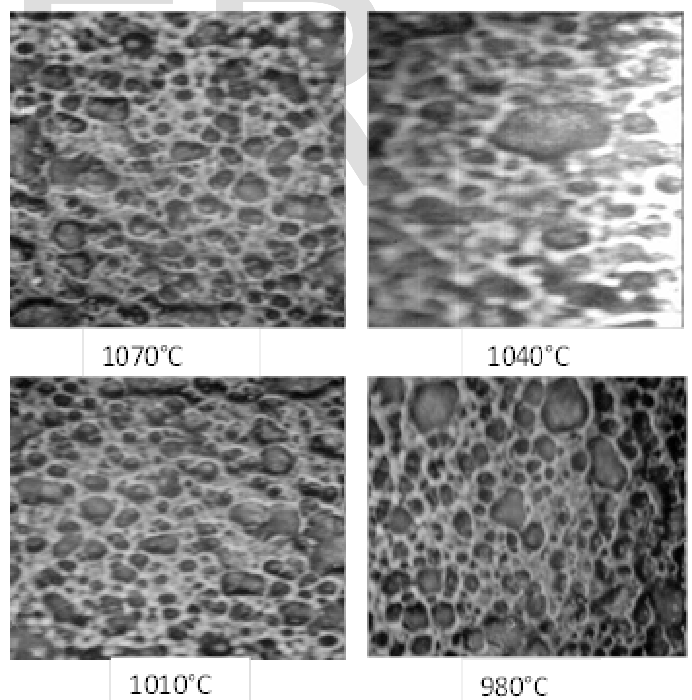


Fig.5: Micrograph of oil quenched H_{13} as received, microstructure is tempered martensite. Nital 3%, 400X.

3.2 Effect of heat treatment temperature on the micro hardness of H_{13} steels

FROM FIG. 6 IT CAN BE SEEN THAT THE MICROHARDNESS INCREASED AS THE TEPERATURE INCREASED, WHERE THE MAXIMUM INCREASE

ISSN 2229-5518

OCCURRED AT 1080 °C.

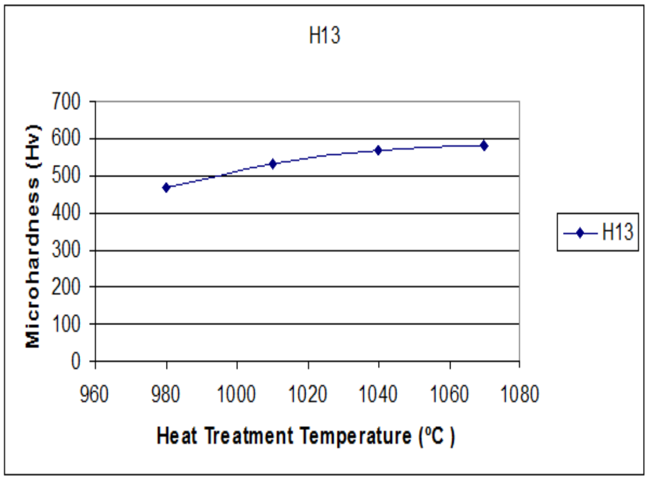


Fig.6: Effect of austenite temperature on Hardness for H_{13}

3.3 Effect of heat treatment temperature on the Toughness H_{13} alloy steel

Results of impact testing are determined by recording the amount of energy absorbed by the alloy steel specimens; they can be read directly from the testing machine in joules.

- Friction energy = 2.0 joule.
- Mass of hammer = 22.017 Kg.
- Length of pendulum = 0.7486 m.

The results of experiments are presented in Fig. 7, It is obvious that the impact energy decreases as the average grain size increase and the maximum was 200 J at 980 °C compared to 92 J at 1070 °C, however, it is required to compromise between the hardness and the toughness according to the work conditions of application.

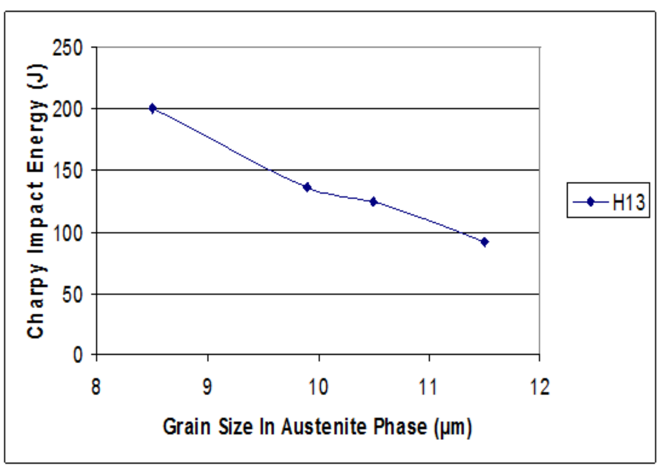


Fig. 7: Effect of grain size on charpy impact energy for H_{13}

3.4 Effect of heat treatment temperature on the Ductility of H_{13} alloy steel

It can be seen from the histogram of Fig.8 that the maximum reduction in area % was decreased for both austenite temperature 1070 °C and 1040 °C where it return back to increase at 1010 °C and then decreased at 980 °C. The maximum reduction in ductility was 33.8 occurred at 980 °C.

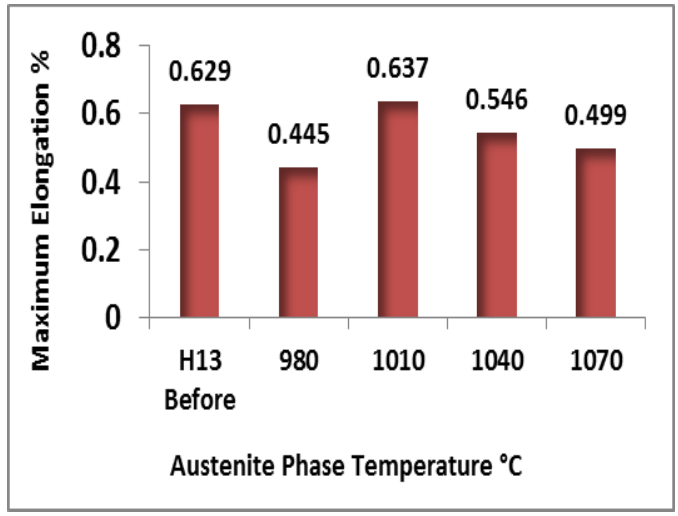


Fig. 8: Maximum elongation % of H_{13} steel alloy

3.5 Effect of heat treatment temperature on the U.T.S of H_{13} alloy steel.

From Fig. 9 it can be seen that in general there is an enhancement on the UTS at all austenite temperature where the maximum was at 1040 °C of about 277.7 %, which recommended for certain applications.

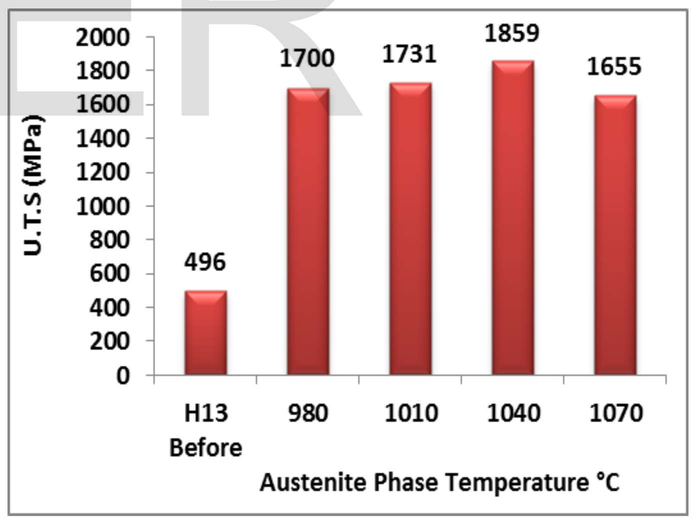


Fig. 9: U.T.S. for H_{13} steel alloy

3.6 Effect of heat treatment temperature on load deformation diagram of H_{13} alloy steel .

It obvious from Fig. 10 that the mechanical properties were enhanced for all austenite temperatures where the maximum was 225 % that attained at 980 °C.

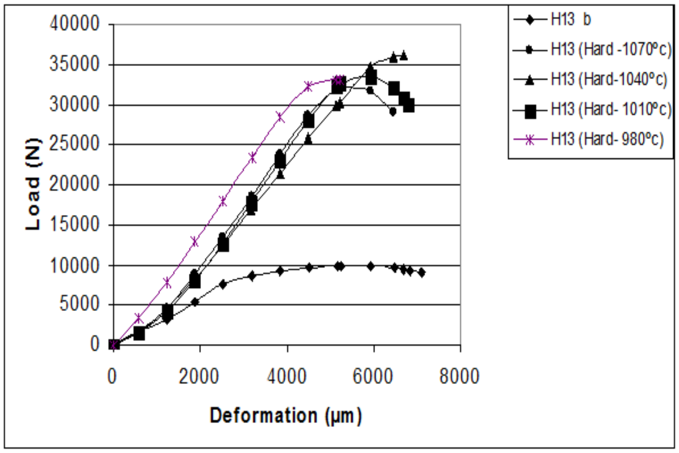


Fig. 10: Effect of austenite temperature on Temperature on Load deformation diagram for H_{13}

4. Conclusions

The following points can be concluded:

- The heat treatment temperature is the main factor in determining the grain size in austenite phase.
- It is possible to get different grain size for the same material using different heat treatment temperatures at relative variation .
- In austenite phase the grain size affects significantly on the hardness and toughness of heat treated H_{13} alloy steel, while the largest grain size gives highest hardness and lowest toughness.
- Grain size in austenite phase affects in direct relation on the mechanical behaviors of heat treated H_{13} alloy steel.
- There is an enhancement of UTS at 1040 °C of about 277.7 %.
- The mechanical properties was enhanced for all austenite temperatures where the maximum was 225 % that attained at 980 °C.
- The impact energy decreases as the average grain size increase and the maximum was 200 J at 980 °C compared to 92 J at 1070 °C.

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