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Experimental and FEM Investigation of Heat Treatment on the Torsional Aspects of D2 Alloy Steel

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Abstract : This study shows the effect of heat treatment on the torsion aspects of D2 alloy steel, in addition further analysis using ANSYS11 software was used in investigation. Test specimens were prepared using high accurate machines (CNC) however, hardening at different austenite temperature (during hardening) namely 1070, 1040, 1010 and 980ºC was studied followed by tempering process at 540ºC. It was found that there was a direct relation between the micro hardness magnitude and the austenite temperature, the maximum was 66.1% that achieved at 1070ºC. This finding was significant because there is a great enhancement in the ability of D2 alloy steel to sustain high torsion loads, where the maximum was 191.1% that achieved at 1070ºC.

Key words: FEM, heat treatment, maximum shear stress, microhardness, torsion

INTRODUCTION

The torsion test has not met with the wide acceptance and the use that have been given the tension test. However, it is useful in many engineering applications and also in theoretical studies of plastic flow Dieter (1988). Torsion tests are made on materials to determine such properties as the modulus of elasticity in shear, the torsional yield strength, and the modulus of rupture. Torsion tests also may be carried out on full-sized parts, such as shafts, axles, and twist drills, which are subjected to torsional loading in service. The torsion test has not been standardized to the same extent as the tension test and is rarely required in materials specifications Dieter (1988).

Most of the available fatigue properties today are for axial loading and little work on tortional data can be found. In addition, most of the tortional data available are for ductile materials. This is peculiar since there are many components in many industries that are primarily under tortional loading conditions McClaflin and Fatemi (2004). The D2 alloy steel which is called Orvar Surpreme containing a chromium-molybdenum-vanadium-alloyed steel where Sverker 21 is a high-carbon, high-chromium tool steel alloyed with molybdenum and vanadium which characterized by: High wear resistance, high compressive strength, good through-hardening properties, high stability in hardening, and good resistance to tempering-back. These materials can subject to cyclic shear stress and strain. Shear fatigue properties and behaviors of these high strength materials are often estimated from axial data using failure criteria such as Maximum Distortion-Energy Theory for ductile materials McClaflin and Fatemi (2004). Such theory is suitable for ductile materials that originated from the observation that ductile materials stressed hydrostatically exhibited yield strengths greatly in excess of values given by the simples tension test. The contention of the MDET is that any elastically stressed material undergoes a sight change in shape, volume, or both. The energy required to produce this change is stored in the material as elastic energy Joseph *et al.* (2008). But after heat treatment the structure become harder and brittle so the maximum normal stress theory is used. The successful employment of metal in engineering applications relies on the ability of the metal to meet design and services requirements and to be fabricated to the proper dimensions. The capability of a metal to meet these requirements is determined by the mechanical and physical properties of the metal, physical properties are those typically measured by methods not requiring the application of an external mechanical force. 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 which commonly used for steels. Modifies microstructure of the material by raising temperature of material, holding the temperature for a period of time, followed by specified controlled cooling schedule. Important manufacturing process that makes it possible to obtain better products with less expensive materials need to understand effects of carbon contents, of alloy additions, and temperature control alloying elements and heat treatments greatly affect a material strength hardness, ductility, toughness, fatigues resistance and wear resistance Joseph *et al.* (1999). Presence of high

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Table 1: Chemical composition of D2 and H13 alloy steels

Typical analysis	C	Si	Mn	Cr	Mo	V
	1,55	0,3	0,4	11,8	0,8	0,8
Standard specification			AISI D2,W.-Nr. 1.2379			
Delivery condition			Soft annealed to approx. 210HB			
Color code			Yellow/white			

carbon and high alloying elements in tool/die steels lower their characteristic temperatures of martensite start and martensite finish Roberts *et al.* (1998). Therefore, conventional hardening treatment of these steels fails to convert considerable amount of austenite into martensite often leading to unacceptable level of retained austenite in the as quenched structure of these steels Roberts *et al.* (1998). Transformation of austenite to martensite is associated with approximately 4 % volume expansion Reed-Hill and Abbaschian (1992). In conventional heat treatment, the amount of γR can be reduced by subjecting the hardened steel specimens to multiple tempering cycles at relatively higher temperature and/or for longer duration (Roberts *et al.*, 1998; Thelning, 1984). However, this process has inherent drawback as it leads to excessive softening of matrix and coarsening of carbides resulting into lower hardness and strength (Roberts *et al.*, 1998; Thelning, 1984; Reed-Hill and Abbaschian, 1992). Alternatively, γ_R content in tool/die steels can be reduced substantially by sub-zero treatment of conventionally quenched components (Roberts *et al.*, 1998; Thelning, 1984; Bowes, 1974; Das *et al.*, 2007; Carlson, 1990; Barron, 1982; Mohan, 2001; Gulyev, 1937; Popandopulo and Zhukova, 1980). The over all objective in this study is to investigate the effect of different heat treatment regimes on the micro hardness and the torsion aspects of D2 alloy steel.

MATERIALS AND METHODS

This study was conducted at Tafila Technical University in the 2nd semester of 2010 academic year.

Materials: In this study D2 alloy steel (Soft annealed to approx. 210 HB) was used, the chemical composition of D2 is shown in Table 1.

Equipment:
Different equipments were used in conducting the experimental work in namely:

- The WP 510 torsion testing unit
- Digital microhardness tester (model HWDM-3)
- Microscope type NIKON 108
- An electric resistance furnace (Carbolite) with 0-1100ºC
- Lathe machine (GAMET 600)
- Quenching oil SAE10W30
- Grinding and Polishing Machine NEBES
- Surface roughness tester (kosaka surfcorder SE3500)

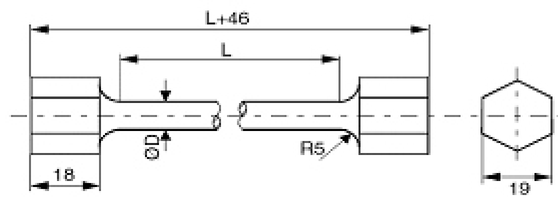

Fig. 1: Torsion specimen dimension

Procedures:
Preparation of work specimens: All test specimens were prepared by machining to the required dimensions using Lathe machine type (GAMET 600) then Grinding and Polishing Machine type (NEBES) was used for super finishing of test specimens, however, the surface roughness Ra = 0.4 µm based on cut off distance = 0.8 and ISO 13565 (Rk), The required dimensions of torsion specimen are shown in Fig. 1.

Heat treatment of D2 alloy steel: The main heat treatments are hardening, tempering, and annealing. However, this study is more oriented towards hardening and tempering treatments.

Hardening (quenching):
The quenching cycle involves three successive phases:

- Heating to temperature (T) called the austenitzing temperature.
- Maintaining this temperature (T) to dissolve the carbides and to obtain a homogenous solid solution of austenite. These two phases together form the austenisation phase.
- Cooling by immersion in some medium (water, oil and air) sufficiently rapid to obtain the desired quenching components.

Tempering: Quenched steel (Alloy steel) is too fragile to be actually used and therefore quenching is followed by tempering, Tempering provides a compromise between two contradictory requirements, hardness and toughness; it increases elongation, and above all toughness, but it reduces hardness, yield strength and ultimate tensile strength. In general, over the broad range of tempering temperatures, hardness decreases and toughness increases, as tempering temperature is increased. The hardening and tempering are shown in Fig. 2 and 3, respectively.

Microhardness test: Microhardness test was carried out using HWDM-3 microhardness tester at 500 g force on each D2 alloy steel.

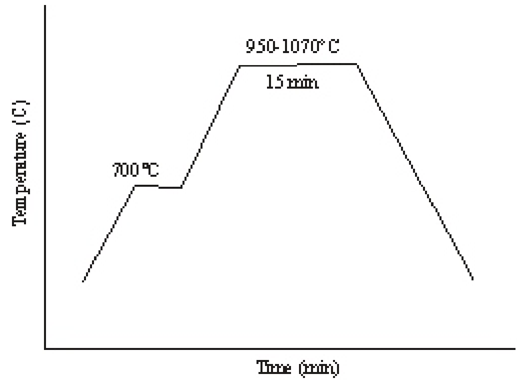

Fig. 2: Hardening diagram for steel D2

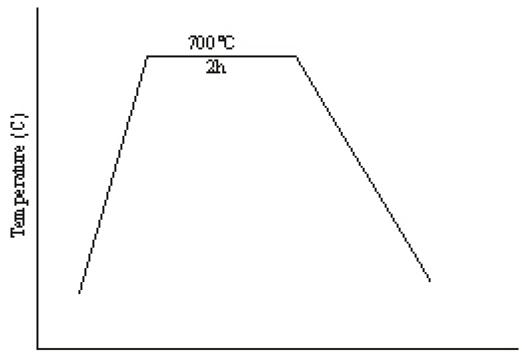

Fig. 3: Tempering diagram of D2 steel

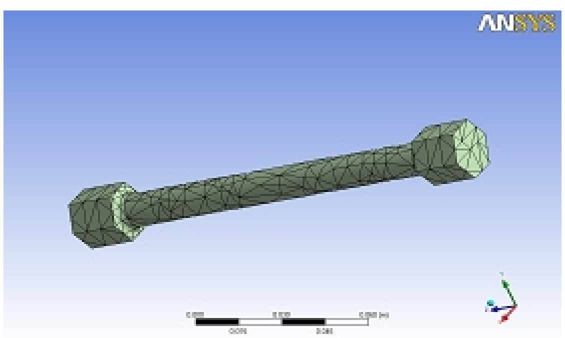

Fig. 4: Mesh diagram of torsion specimen

FEM based on ANSYS software: ANSYS software was used to analyse the workpies made of D2 alloy steel which subjected to torsion load of 200 N.m, the program divide the work piece into 593 element and 1355 node as shown in Fig. 4.

The torsion load was applied at the end of specimen of 200 N.m magnitudes where the other end was fixed, as shown in Fig. 5.

Torsion test: Torsion test is used to test the torsion of various types of materials. The testing moment is applied

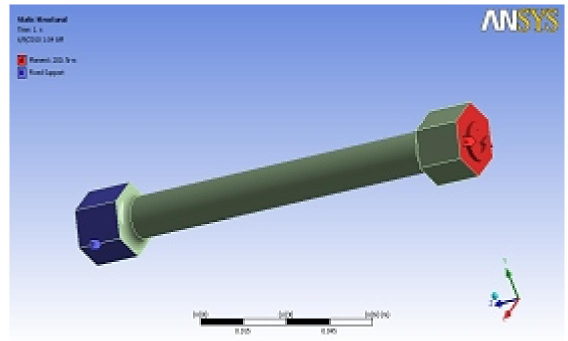

Fig. 5: Torsion load that applied at end specimen

Fig. 6: Torsion machine

with a highly reduced geared motor. The effective testing moment is measured electrically via a metering shaft which is equipped with a strain gauge. The angle of rotation is determined via an opto-electronic tongue sensor. Both values are shown digitally on a LCD display. It is also possible to set different deformation speeds. The unit is prepared for connection to a PC. Special software (included) can be used to create diagrams and evaluation, the torsion machine is shown in Fig. 6. Where the work piece before and after the torsion test are shown in Fig. 7.

RESULTS AND DISCUSSION

Effect of heat treatment on the microhardness of D2 alloy steels: It obvious from Fig. 8 that the microhardness was increased as the austenite temperature increased the maximum enhancement in microhardness was 66.1% that achieved at 1070ºC. This can attributed to rapid cooling rate that resulted in formation of high martensite quantity in the structure at room temperature.

The FEM results using ANSYS soft ware: The total deformation of the test specimen is shown in Fig. 9, the maximum is 1.59 mm.

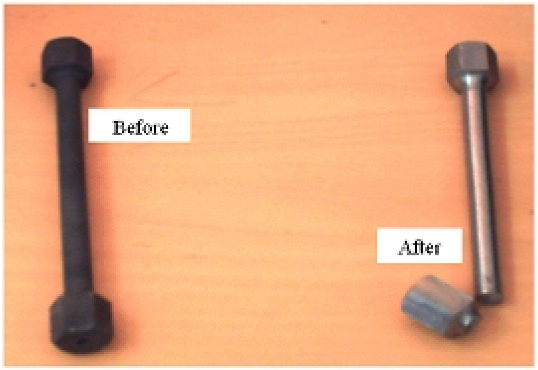

Fig. 7: Torsion test specimens before and after

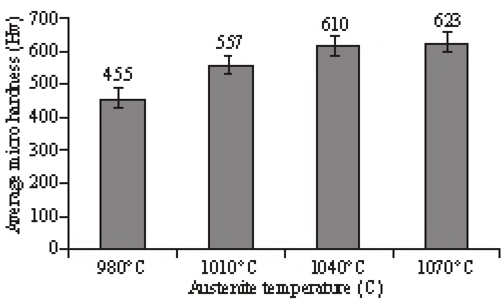

Fig. 8: Effect of austenite temperature on the microhardness of D2 alloy steel

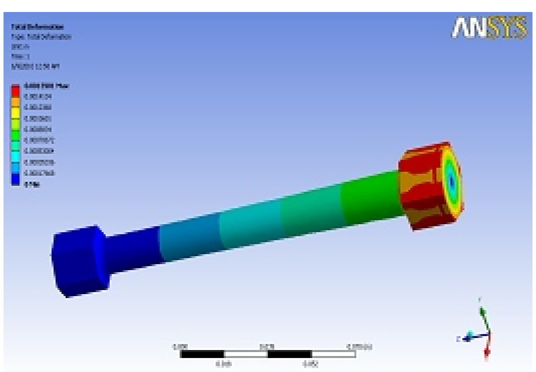

Fig. 9: The total deformation of test specimen

The maximum shear stress is shown in Fig. 10, it can be seen that the maximum shear stress is 627 MPa.

From Fig. 11, it can be seen that the shear elastic strain is 0.003 mm/mm that localized at the fillet of work piece, the poison which later on the fracture will happened.

Effect of heat treatment on the tortional aspects of D2 alloy steels: The effects of different austenite temperatures namely: 1070, 1040, 1010 and 980°C on the torsional aspects of D2 alloy steel will be presented and discussed.

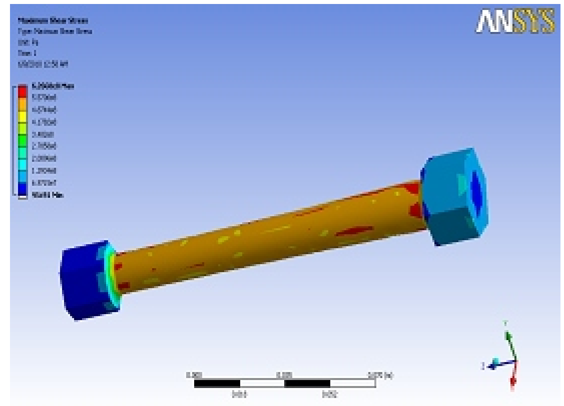

Fig.10: Maximum shear stress of D2 steel specimen

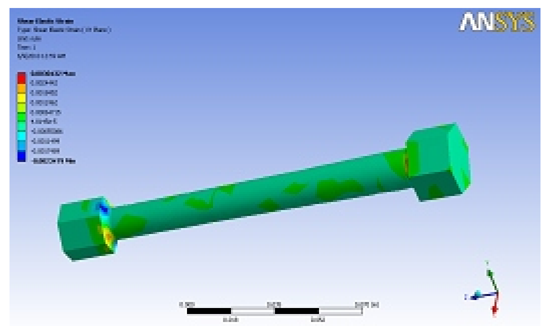

Fig.11: Shear elastic strain of D2 alloy steel

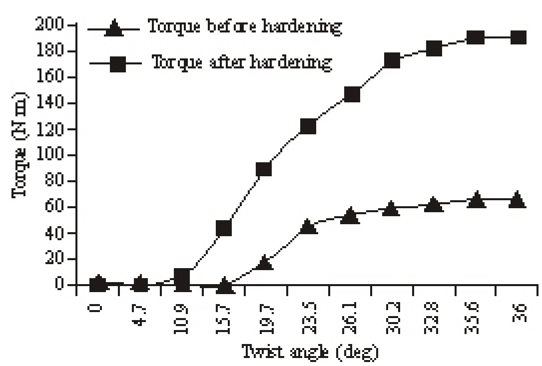

Fig. 12: Effect of heat treatment at 1070 °C torsion of D2alloy steel

Effect of heat treatment at 1070°C on the torsional aspects of D2 alloy steels: It can be seen from Fig. 12 that there was an enhancement in torque; the maximum improvement was 191.1 %. This attributed to the

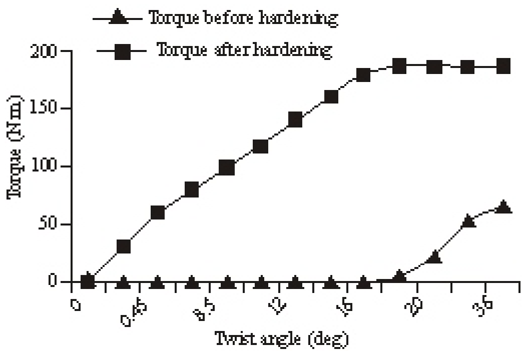

Fig.13: Effect of heat treatment at 1040ºC torsion of D2 alloy steel

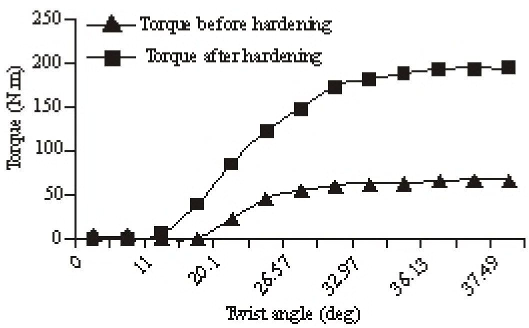

Fig.14: Effect of heat treatment at 1010ºC torsion of D2 alloy steel

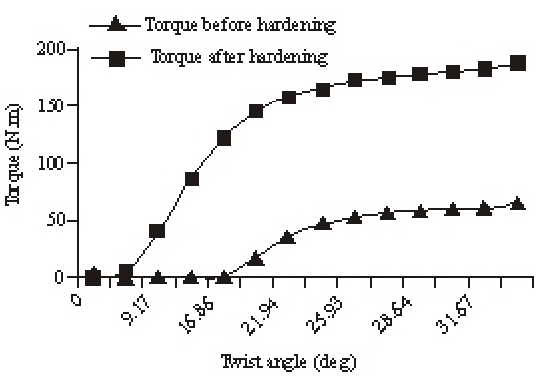

Fig.15: Effect of heat treatment at 980ºC torsion of D2 alloy steel

enhancement in mechanical properties that resulted after heat treatment of D2 steel.

Effect of heat treatment at 1040ºC on the microstructure of D2alloy steels: It can be seen from Fig. 13 that there was an enhancement in torque; the maximum improvement was 185.9 %. This attributed to the enhancement in mechanical properties that resulted after heat treatment of D2 steel.

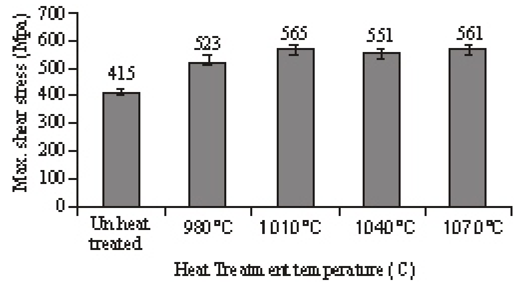

Fig. 16: Effect of austenite temperature on the maximum shear stress of D2 steel

Effect of heat treatment at 1010ºC on the microstructure of D2alloy steels: It can be seen from Fig. 14 that there was an enhancement in torque; the maximum improvement was 190.3 %. This attributed to the enhancement in mechanical properties that resulted after heat treatment of D2 steel.

Effect of heat treatment at 980ºC on the microstructure of D2alloy steels: It can be seen from Fig. 15 that there was an enhancement in torque; the maximum improvement was 187.2 %. This attributed to the enhancement in mechanical properties that resulted after heat treatment of D2 steel.

Effect of heat treatment temperature on the maximum shear stress of D2 alloy steel: From Fig. 16 it can be seen that the maximum shear stress increased as the austenite temperature increased, the best enhancement was 36.1% that achieved at 1010ºC.

CONCLUSION

The following can be concluded:

- There is a direct relation between the micro hardness magnitude and the austenite temperature, the maximum was 66.1% that achieved at 1070ºC.
- There is a great enhancement in the ability of D2 steel to sustain high torsion loads, where the maximum was191.1% that achieved at 1070ºC.
- The maximum shear stress was 565 MPa that achieved at 1010ºC.

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