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The effect of cyclic twist angle on mechanical properties for AISI 1038 medium carbon steel

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ABSTRACT

A group of 11 specimens AISI 1038 Medium carbon steel alloy fabricated according to ASTM standard D790-02 torsion test were twisted cyclically one in positive another to negative angle in range of angles (0^o-50^o), step 5 degrees for each specimen. The data from torsion test device help to get actual torques and shear stresses, later the specimens tested the tensile test to figure out the effects of cyclic angle of twist on mechanical properties for AISI 1038 Medium carbon steel. The results showed a good agreement between the theoretical and actual data (torque, shear stress) for specimens with positive angle of twist by the percentage: 98%, 91%, 96%, 93%, 91%, 89%, 88%, 85%, 82%, 81%, 80%. In other side the results for experimental tests showed a dangerous decrements in mechanical properties for cyclic or negative twist angles, the yield stress for reference specimen without twist angle is 490 Mpa, yield stress increased for angels (5^o,10^o,15^o) by 1%, 3%, 6%, then decreased for angels (20^o,25^o,30^o,35^o,40^o,45^o) by 3%, 5%, 13%, 18%, 24% and 35% Respectively and the final specimen with 50^o angle of twist had been broken torsional before tensile test as a result specimens groups consequent of the extrusion – intrusion defects concomitant from twisting load.

Keywords: AISI, Torsion machine, ASTM, Tensile Machine

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1. Introduction

One of the substances that play an essential and fundamental role in engineering applications is the iron-carbon alloys, Steel representing one of these alloys. Steel, as a necessary material in structural applications and modern engineering. Some applications that used steel are subjected to torsion load under twist angle. Torsion test is made on substances to determine some properties such as torsional yield strength and the modulus of elasticity in shear, Torsion tests may be carried out on different sized parts such as axles, shafts and twist drills [1-3]. In the last period, some researchers studied the behavior of medium carbon steel C45 under different conditions, Nicolas Ranc et al. investigated the thermal response and Stress-Number curves for C45 steel subjected to fatigue test [4]. Other researchers interest to enhance mechanical properties and develop the microstructure for processed nano-crystalline steel C45 via different high-pressure torsion loading procedures leading to ultrafine/nanoscale grain size [5]. Hani and his colleagues explained the effect of heat treatment with different temperatures on the torsion of steel. They found increase annealing, lead to reduce the hardness and consequently decrease torsion properties [1]. Other authors investigated the deformation of torsion and fatigue behavior of both thin-walled and solid tube of steel specimens, were also performed. Three-types of torsional-fatigue tests involving tensile mean stresses, and compressive mean stresses, as well as shear stress. They observed and discussed the fracture surfaces and Failure Modes[6-9]. Xiangru Wang and his friends studied the effect of torsion angle on multiaxial fretting fatigue behaviors of steel wires by using a tension-torsion multiaxial fretting fatigue test[10]. The objective of this work is to investigate the effect of the reverse angle of twist on the mechanical (yieldtorque, torsion and tensile) of medium carbon steel type AISI 1038.

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2. Material and experimental work

2.1. Material

The studied material for all specimens is AISI 1038 Medium carbon steel the steel [4]. The chemical composition is given in Table 1 as a weight %. Torsion-bar specimens were extracted from bars. Specimens were made according to ASTM standard [11]. Figure 1 shows the theoretical relationship between the twist angle and shear-strain [12], Figure 2 shows the final shape and geometry of specimen where, d = 6 mm represent the active diameter, total length *l* = 143 mm and active length *l* = 76.2 mm.

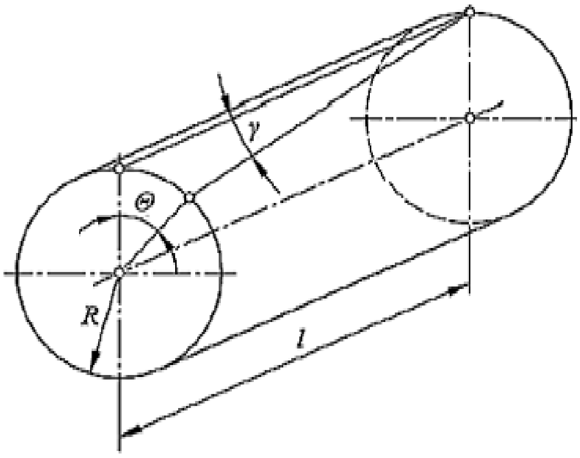


Figure 1. Twist angle (θ) and shear strain (γ)

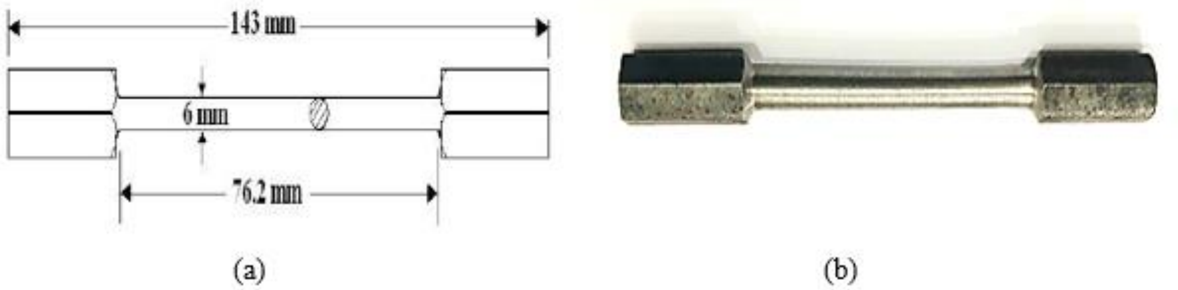


Figure 2. Torsional specimen (a) Graphical specimen (b) actual specimen

Table 1. Chemical composition of AISI 1038 steel

%Wt	Carbon	manganese	silicon	Nickel	Chromium	molybdenum	sulfur	potassium
Actual value	0.4	0.66	0.42	-	0.391	-	0.04	0.04
Standard value	(0.42-0.35)	(0.5-0.8)	0.4	-	0.4-0.6	-	0.035	0.025

2.2. Classification of specimens

After complete preparation of the specimen (cutting the bar, manufacturing process), they are categorized into eleven specimens as shown in Table 2 and Figure 3:

Table 2. Categorization of Specimens

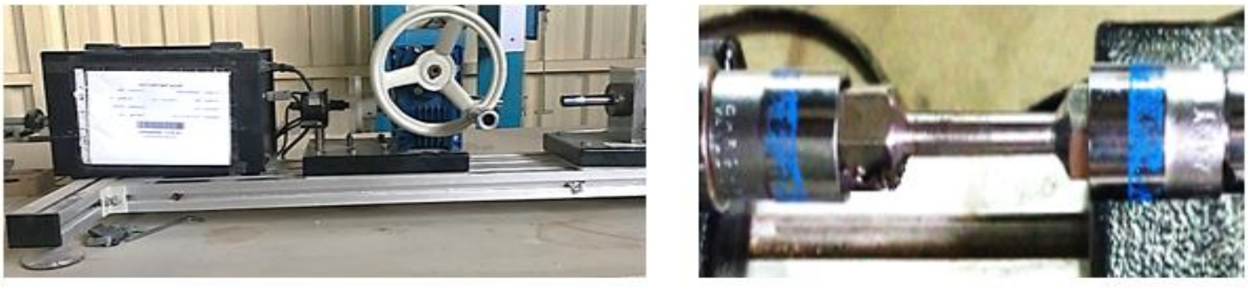
Specimen's symbol	State of Specimen	Specimen's symbol	State of Specimen
A	Reference specimen without twist angle	G	Twisted cyclically 30° forward and 30° backward
B	Twisted cyclically 5° forward and 5° backward	H	Twisted cyclically 35° forward and 35° backward

Specimen's symbol	State of Specimen	Specimen's symbol	State of Specimen
C	Twisted cyclically 10° forward and 10° backward	I	Twisted cyclically 40° forward and 40° backward
D	Twisted cyclically 15° forward and 15° backward	J	Twisted cyclically 45° forward and 45° backward
E	Twisted cyclically 20° forward and 20° backward	K	Twisted cyclically 50° forward and 50° backward
F	Twisted cyclically 25° forward and 25° backward		

Figure 3. Classification of Specimens

2.3. Torsion and Tensile work

Steel cross-section specimens that used in this paper were prepared according to ASTM standard [11] as mentioned before. The categorized specimens are explained in a Table 2 and figure (3) were positioned in the torsion equipment without any loading as illustrated in Figure (4 (a, b)). Firstly, use the twist control method to apply the twist angle to the specimen, rotate the handle counter-clockwise for the required degree of twist. The machine's one complete cycle will give 5° of twist angle. Then, the handle was rotated clockwise for reverse feeding at the same value of the twisted cycle. This procedure was repeated with all specimens by increasing value of twist torsion 5 degrees until failure with 50 angle. After applying clockwise and counterclockwise loads to the specimens (After applying the previous loads to test specimens, samples were taken to undergoes to the tensile test which is important to obtain yield stress that considers as an essential indication for the mechanical property of a specimen. All experiments were carried out on the Instron machines illustrated in the Figure 5. The test specimens were fixed in the Instron machine and applied the opposite load until fracture.



(a) (b)

Figure 4. Torsion test (a) Torsion machine (b) specimen after positioned

Figure 5. Tensile machine

3. Theoretical procedure

This part will explain the theoretical equations which used in calculate the theoretical results [13]:

$$\boldsymbol{T = F*r} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

T is the applied torque or twisting moment in (N.M), F is torsion force in (N) and r is the radius of the shaft in (mm)

From the torsion theory:

$$\boldsymbol{T/J = \tau /r} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

From equation (2) can obtained the elastic and plastic torque as explained in equations (3) and (4):

$$\boldsymbol{T_E = (\pi r^3 /2)*\tau_y} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$\boldsymbol{T_{FP} = (2\pi r^3 /3)*\tau_y} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Where:

T_E is elastic-torque, T_{FP} is fully-plastic torque and τ_y is the shear-yield-stress (shear stress at the elastic limit).

$$\boldsymbol{J= \pi d^4 / 32} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where:

J is the polar moment of inertia for circular rigid section.

d is the effective diameter in (mm)

Finally, the characteristic equation of shear stress (τ) can obtained from the torsion theory as following:

$$\boldsymbol{\tau = T*r / J} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

4. Results and discussion

4.1. Comparison between theoretical and experimental results for torque and shear stress

It can be clearly seen from Table 3 and Figures 6-7, a close agreement between theoretical and experimental results for torque and shear stress respectively, and the increment in torque and shear stress can be observed when increasing the cyclic angle of twist. Theoretically, it can be clearly observed at the same figurers, liner behavior between twist angle with torque and shear stress for angels (0° - 15°) and (0° - 10°) respectively. Then, sudden transition at the angles (15° - 20°) for torque and (10° - 15°) for shear due to the transmission from elastic region to plastic region. Experimentally, torque for positive angles behaved a non-liner path from angle of (15°), whilst torque for reverse angles behaved a close liner path with twist until reach angle of (30°) as illustrated in figure (6). Figure (7) showed non-liner attitude of shear stress for positive angles after (10°) angle, while liner behavior for reverse angles until angle of (30°) reached. This change in data can be noticed because of the graduate effect of torque from core to surface radius of material, in-fact while core in proceeding elastic range its obviously metal surface in plastic area, this disorganized in specimen substance led to deviation in results. From table (3) experimental results of torque for all ranged cyclic angles showed a rapprochement results for specimens with positive angle of twist by the percentage: 98%, 91%, 96%, 93%, 91%, 89%, 88%, 85%, 82%, 81%, 80%. Also, there are a closed agreement results for torque and shear stress in elastic region, however agreement results for plastic region.

The last specimen with cyclic angle (50°) of twist had been broken, where the torsional fracture occurs when the torque resulting from the contact between the instrument and canal wall exceeds the torsional strength of the instrument or when the instrument tip is locked in a canal while the rest continues to rotate[14]. The fracture in torsion for medium carbon materials generally occurs in the plane of maximum shear stress perpendicular to the longitudinal axis of the bar as illustrated in Figure 8.

Table 3. Theoretical and experimental results of torque and shear stress

T (*N.m*) Theoretical	τ (*Mpa*) Theoretical	θ	T(*N.m*) Actual	τ(*Mpa*) Actual	θ	T(*N.m*) Actual	τ(*Mpa*) Actual
0	0	0	0.3	7	0	1.2	28.3
5.584	131.7	5	5.7	134.4	5-	5.2	122.6
11.168	263.4	10	12.3	290.1	10-	10.8	254.7
18.6	395.1	15	17.5	412.8	15-	14.3	337.3
25.6	526.9	20	24	566	20-	18.6	438.7
28.1	658.6	25	25.4	599	25-	22.1	521.3
36.2	790.3	30	30.5	719.5	30-	26.2	618
41.7	922.1	35	32.6	769	35-	32.4	764.4
45.9	1053.8	40	36.4	858.6	40-	35.9	846.9
53.4	1185.5	45	40.8	962.4	45-	40.8	962.5
58.5	1297	50	44.2	1042.6	50-	43.2	1019

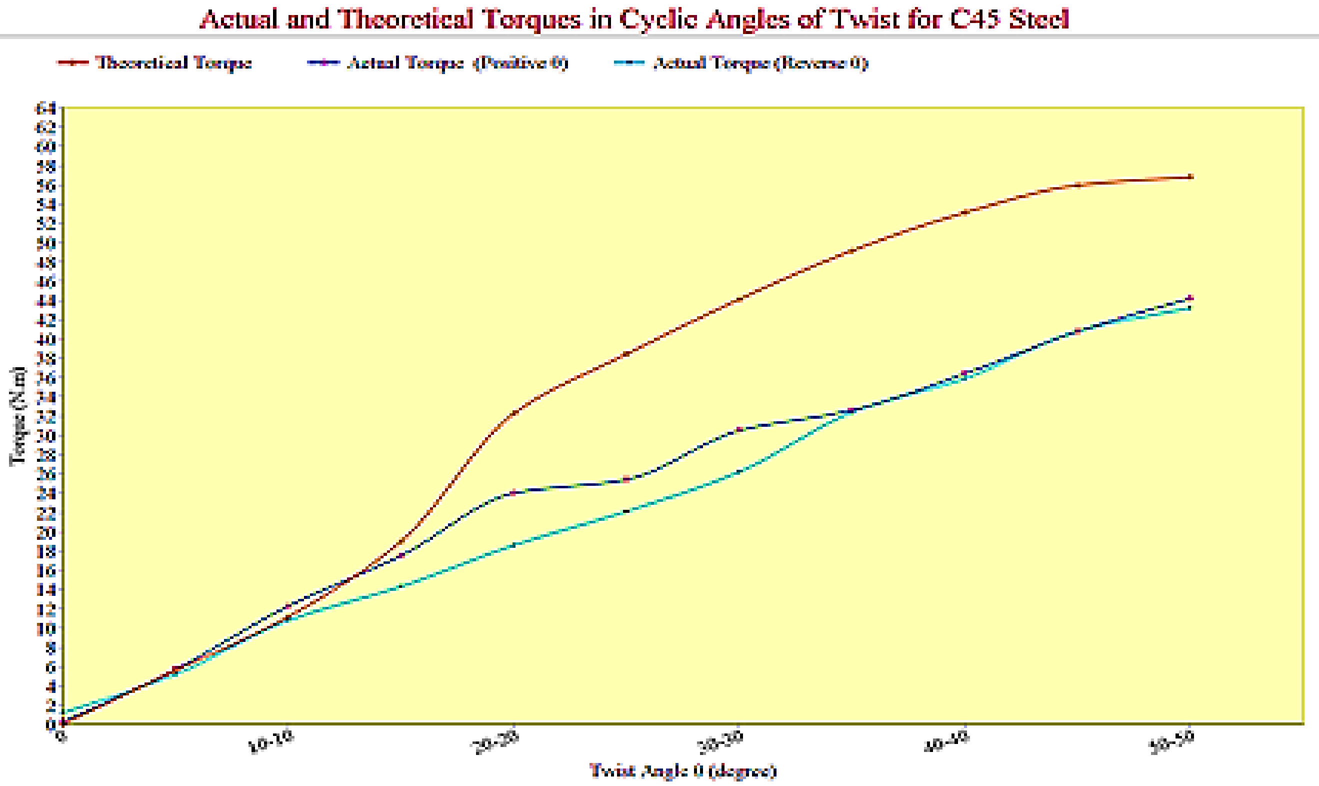


Figure 6. Theoretical and experimental torque

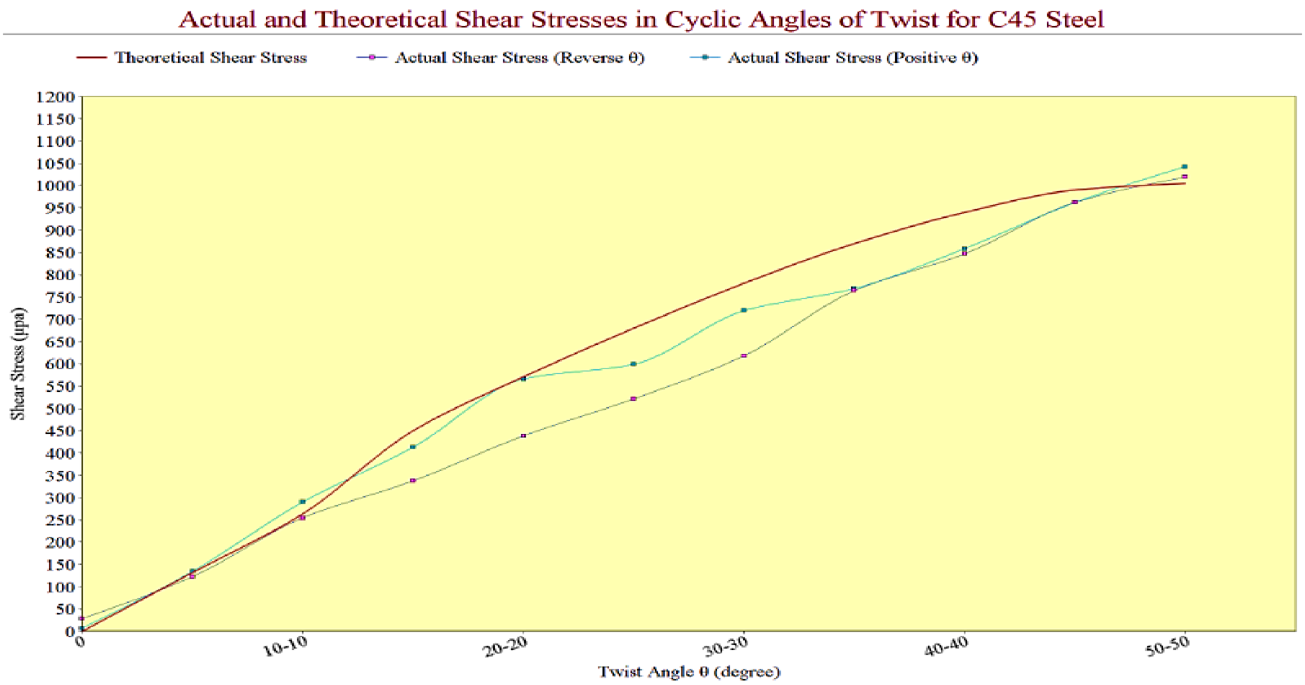


Figure 7. Theoretical and experimental shear stress

Figure 8. Specimen (50°-50°) after broken

4.2. Tensile part

The experimental results which obtained from tensile test will discussed in this part at Table 4 and Figure 9. At the beginning the value of yield stress for first specimen (without torsion test) was 490 Mpa, clearly seen there are increasing in the value of yield stress in samples with cyclic angles (5°, 10°, and 15°). These increments happened in elastic region, because of the effect of stress hardening. Then, directly showed decrement in yield stress value for other specimens, where increasing obtained in value of cyclic angles range (20°- 45°) led to decreasing in value of yield stress due to weakness between boundary lines in molecule micro-structure and the alloy start to behave as brittle material. Finally, the results showed an enhancement in the mechanical properties of the angles between (5°-15°) due to the phenomenon of strain hardening as explain in Figure 9.

Table 4. The value of actual yield stress

θ	zero	5-5	10-10	15-15	20-20	25-25	30-30	35-35	40-40	45-45	50-50
σy (*Mpa*)	490	493	505	520	475	468	430	405	375	320	Broken

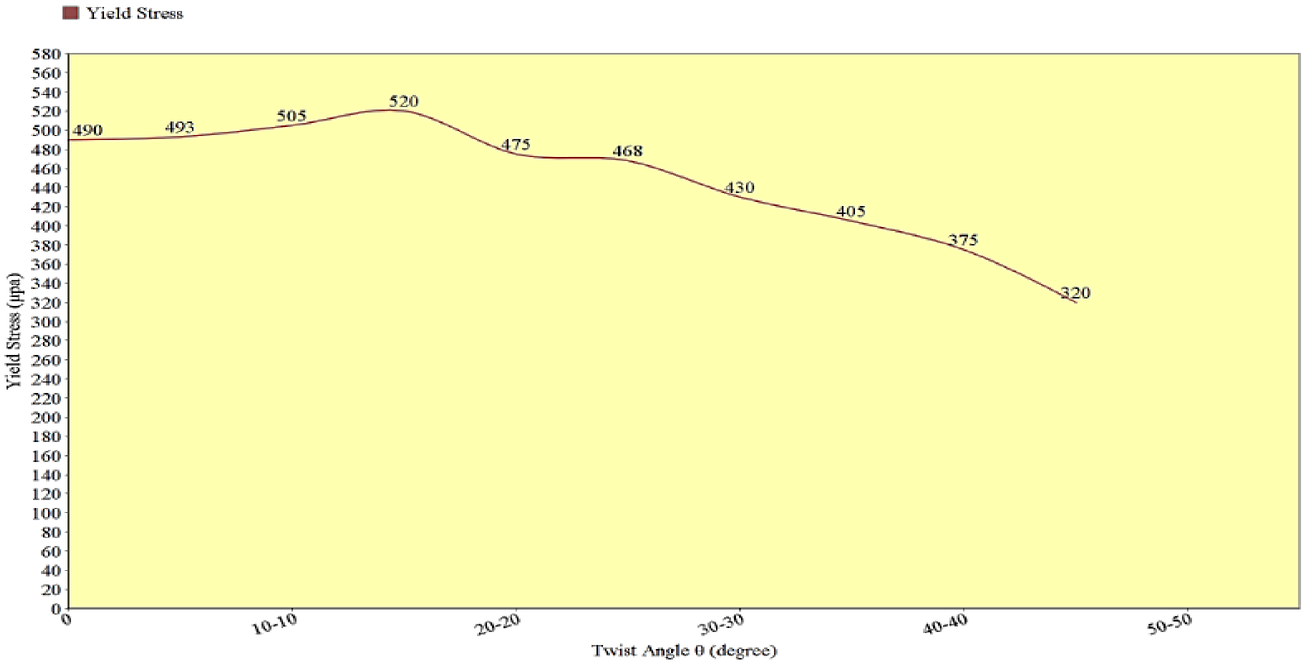


Figure 9. The yield stress

5. Conclusion

1- The results showed a good agreement between the theoretical and experimental results (Torque, Shear Stress) for specimens with a positive angle of twist.
2- The final specimen with a 50̊ angle of twist had been broken during torsional before the tensile test.
3- The results of yield stress for experimental tests showed a dangerous decrement in mechanical properties for cyclic or negative twist angles after 15̊.
4- The results showed an enhancement in the mechanical properties of the angles between (5̊-15̊).
5- Increasing in the value of yield stress in samples with cyclic angles (5̊, 10̊, and 15̊)

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