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Effects of Heat Treatment on the Mechanical Properties of Mild Steel

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Abstract: This research presents the effects of heat treatments on the mechanical properties of `mild steel. Sample of mild steel rods were subjected to the following heat treatment. Sample of these specimens were annealed at temperature of 100, 300 and 500°C while others were heated to 900°C and quenched in SAE 40 oil. Some of these specimens were retained as-quenched while others were tempered at temperature of 200, 400 and 600°C. The heat treated mild steel rod were then subjected to tensile, impact and torsional test the results of these tests show that stress and ultimate decreases as both annealing and tempering temperature increases. Also the percentage elongation increases as the annealing and tempering temperature increases. Moreover, the impact energy and the breaking torque increases as the tempering and the annealing temperature increases.

Key words: Mild steel, annealing, mechanical properties, quenched, tempered, elongation

INTRODUCTION

Steel is an alloy of iron containing a small but definite percentage of Carbon ranges from 0.15-1.5% (John, 1980). Mild steel are those containing 0.1-0.25% carbon, they are soft, malleable and ductile (Alawode, 2002). Mild steel are used for general engineering purposes. A research works carried out by Oyeleke and Ade (1998) found that heat treatment improves yield strength, ultimate strength, hardness of the low carbon steel but the ductility of the low carbon steel decreases (Adeyemi, 1994). The Korea research institute of chemical technology also investigated the effects of heat treatment on the bio-activity and mechanical properties of a poly E-Caprlactore/silica hybrid containing calcium. It was concluded from the research that the mechanical properties of a PCL/Silica hybrid could be improved by heat treatment. It was conjectured to be coursed by the reduction of the low molecular weight PCL phase and the intensification of silica network by heat treatment. The mechanical properties of the specimens heat treated at 150°C showed comparable value to those of canceller's bone and it mean that its likely to be used for a bio-active and degradable bone substitute (Hench *et al*., 1997).

However, the main objective of this paper is to evaluate the response of the mechanical properties of mild steel via hardness, impact strength, tensile and torsional properties to stress relief annealing and quenching and tempering. This is done by evaluating the mechanical properties before and after the heat treatment of mild steel rod of the same batch.

MATERIALS AND METHODS

Preparation: Mild steel rods of 12 mm in diameter of the same batch were obtained from iron and steel market in Lagos. The test specimens were of approximate chemical composition of 98.1% Fe, 0.25% C, 0.04% S and 0.04% P with others very low percentage impurities.

Experimental impact testing: Each of the impact test specimens after subjected to a predetermined annealing temperature was fixed in a charpy impact testing machine as a simple beam. The specimens were notched just at the middle and the notch face was fixed on the impact testing machine to receive fast moving hammer blow when released from a fixed position at a fixed height. Upon released, a knife edge mounted on the pendulum hammer strike and fractured the specimen at the notched face.

The energy absorbed at fracture was determined from the dial guage of the impact testing machine and the value

Table 1: Annealed specimens result for impact test

Temperature (°C)	Energy (Joules)
30.0	7.50
100.0	8.50
300.0	10.00
600.0	14.50

Table 2: Quenched and Tempered result for impact test

Temperature (°C)	Energy (Joules)
30.0	15.50
200.0	17.40
400.0	18.50
600.0	20.50

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Table 3: Quenched and tempered specimen results

Temperature (°C)	O.D (mm)	O.L (mm)L1	N.L (mm)L2	L2-L1	Y.L (KN)	U.L (KN)	U.S (MN m^{-2})	Y.S (MN m^{-2})	Elongation	StrainE
30.0	6.30	137.0	151.0	14.00	8.75	12.25	393.0	280.7	10.21	0.10
200.0	6.30	134.0	150.0	16.00	7.95	11.65	373.7	255.0	11.94	0.12
400.0	6.30	133.5	151.0	17.50	7.50	11.30	362.5	240.6	13.10	0.13
600.0	6.30	126.0	145.0	19.00	7.25	10.35	332.0	236.6	15.07	0.15

Table 4: Annealed specimen result

Temperature (°C)	O.D (mm)	O.L (mm)L1	N.L (mm)L2	L2-L1	Y.L (KN)	U.L (KN)	U.S (MN m^{-2})	Y.S (MN m^{-2})	Elongation	StrainE
30.0	6.30	135.0	145.0	10.00	13.75	9.50	441.0	304.8	7.40	0.07
100.0	6.30	139.0	153.0	14.00	13.05	9.25	418.7	296.8	10.07	0.10
300.0	6.30	134.0	152.0	18.00	12.00	8.25	384.9	264.7	13.43	0.13
500.0	6.30	140.0	160.0	20.00	11.15	8.00	354.5	256.7	14.28	0.14

indicated by the pointer was noted. The tests were repeated for the remaining specimens at different annealed temperature.

Table 1 and 2 shows the results for the impact tests for Annealed specimens and Quenched and Tempered specimens.

Experimental tensile testing: The tensile is used to evaluate the strength and ductility of a metal when subjected to tensile force. The specimens was mounted on a hounsfield tensometer with the aid of a chuck. The load on the specimen was varied and the strain in the specimen was transmitted to a precalibrated spring beam and this is proportional to the load applied. Each specimen at different annealing temperature was mounted and its corresponding value was measured by the movement of the mercutry in the glass tube until the specimen failed. Table 3 and 4 shows the results for the Quenched and Tempered specimen and Annealed Specimen.

RESULTS

Tensile test were carried out on the two sets of specimens: the quenched and tempered mild steel rod and the annealed mild steel rod. The following results were obtained from impact strength test.

Torsional test results: The results of the torsional tests on both annealled and quenched and tempered specimens are provided below at different temperature.

Table 5 shows the results at various temperatures of 30, 100, 300 and 500°C for annealed specimens and Table 6 for the results of quenched and tempered specimens at the temperatures of 30, 200, 400 and 600°C.

Graphs: The graph relating the various mechanical properties of the heat treated mild steel rods with temperature are presented using the results obtained from the test. Also there are graphs relating the breaking torque and the angle of test under torsional test.

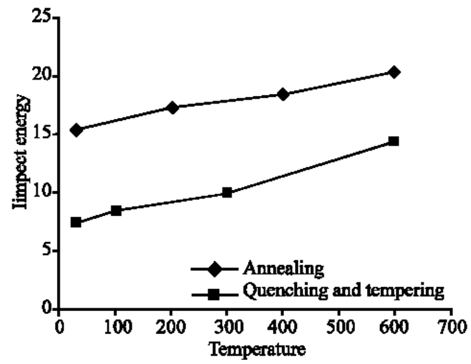

Fig. 1: Impact energy vs temperature

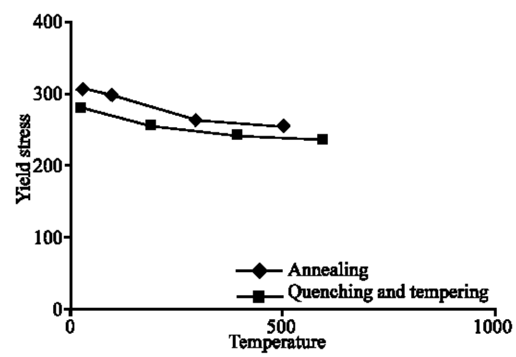

Fig. 2: Yield stress vs temperature

It could be inferred from the graphs for quenching and tempering (Fig. 1-5) that:

- The yield stress and ultimate stress decreases as the tempering temperature increases.
- The impact strength, torque and percentage elongation increases as the tempering increases.

It could also be inferred from the graphs for annealing (Fig. 6 and 7) that:

- The yield stress and ultimate stress decreases as the annealing temperature increases.

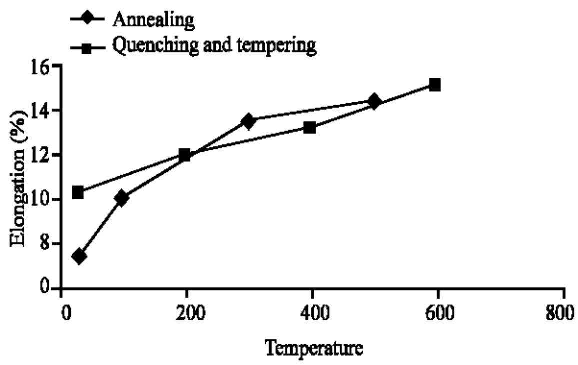

Fig. 3: Percentage elongation vs temperature

Table 5: At 30°C

No of revolution	Angle of twist θ in degree	Angle of twist in radians	Torque (Nm)
40.0	240.0	4.18	3.85
80.0	480.0	8.37	4.23
120.0	720.0	12.25	4.50
160.0	760.0	16.75	4.81
200.0	1200.0	20.94	4.95
240.0	1440.0	25.13	5.15
280.0	1680.0	29.32	5.39
320.0	1920.0	33.51	5.20
At 100°C			
40.0	240.0	4.18	4.25
80.0	480.0	8.37	4.39
120.0	720.0	12.25	4.65
160.0	760.0	16.75	4.94
200.0	1200.0	20.94	5.24
240.0	1440.0	25.13	5.78
280.0	1680.0	29.32	6.23
320.0	1920.0	33.51	6.65
360.0	2160.0	37.69	6.94
400.0	2400.0	41.88	6.22
At 300°C			
40.0	240.0	4.18	5.55
80.0	480.0	8.37	6.23
120.0	720.0	12.25	6.50
160.0	760.0	16.75	6.81
200.0	1200.0	20.94	6.95
240.0	1440.0	25.13	7.15
w280.0	1680.0	29.32	7.39
320.0	1920.0	33.51	7.50
360.0	2160.0	37.69	8.12
400.0	2400.0	41.38	8.74
440.0	2640.0	46.07	8.96
480.0	2880.0	50.26	8.21
At 500°C			
40.0	240.0	4.18	6.25
80.0	480.0	8.37	6.39
120.0	720.0	12.25	6.65
160.0	760.0	16.75	6.94
200.0	1200.0	20.94	7.24
240.0	1440.0	25.13	7.78
280.0	1680.0	29.32	8.23
320.0	1920.0	33.51	8.94
360.0	2160.0	37.69	9.26
400.0	2400.0	41.38	9.85
440.0	2640.0	46.07	10.24
480.0	2880.0	50.26	10.68
520.0	3120.0	54.45	11.31
560.0	3360.0	58.64	10.12
600.0	3600.0	62.84	10.55

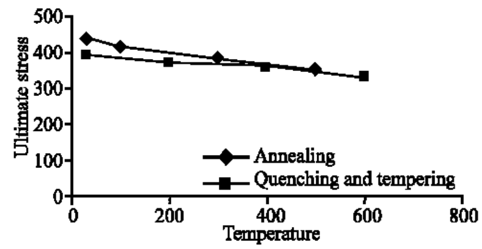

Fig. 4: Ultimate stress vs temperature

Table 6: Torsional test results fr quenched and tempered

No of Revolution	Angle of twist θ in degree	Angle of twist θ in radians	Torque (Nm)
At 30°C			
40.0	240	4.18	4.45
80.0	480	8.37	4.87
120.0	720	12.25	5.26
160.0	960	16.75	5.93
200.0	1200	20.94	6.38
240.0	1440	25.13	6.92
280.0	1680	29.32	6.21
At 200°C			
40.0	240.0	4.18	5.23
80.0	480.0	8.37	5.72
120.0	720.0	12.25	6.12
160.0	760.0	16.75	6.45
200.0	1200.0	20.94	7.32
240.0	1440.0	25.13	7.84
280.0	1680.0	29.32	8.21
320.0	1920.0	33.51	8.74
360.0	2160.0	37.69	7.22
At 400°C			
40.0	240.0	4.18	6.42
80.0	480.0	8.37	6.83
120.0	720.0	12.25	7.21
160.0	760.0	16.75	7.74
200.0	1200.0	20.94	8.23
240.0	1440.0	25.13	8.81
280.0	1680.0	29.32	9.21
320.0	1920.0	33.51	9.93
360.0	2160.0	37.69	10.22
400.0	2400.0	41.88	10.84
440.0	2640.0	46.07	11.12
480.0	2880.0	50.26	10.96
At 600°C			
40.0	240.0	4.18	7.54
80.0	480.0	8.37	7.56
120.0	720.0	12.25	8.21
160.0	760.0	16.75	8.86
200.0	1200.0	20.94	9.36
240.0	1440.0	25.13	9.89
280.0	1680.0	29.32	10.25
320.0	1920.0	33.51	10.8
360.0	2160.0	37.69	11.42
400.0	2400.0	41.38	11.42
440.0	2640.0	46.07	12.21
480.0	2880.0	50.26	12.84
520.0	3120.0	54.45	13.33
560.0	3360.0	58.64	12.98

- The impact strength, torque and percentage elongation increases as the annealing temperature increase.
- The torque increases as the angle of twist increases.

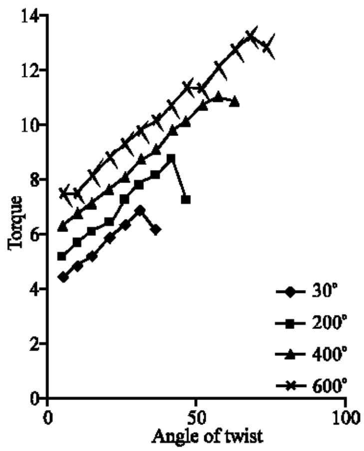

Fig. 5: torquevs angle of twist (quenching § tempering)

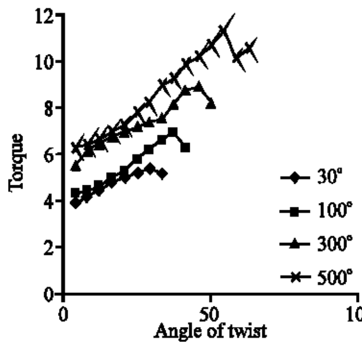

Fig. 6: Torque vs angle of twist (annealing)

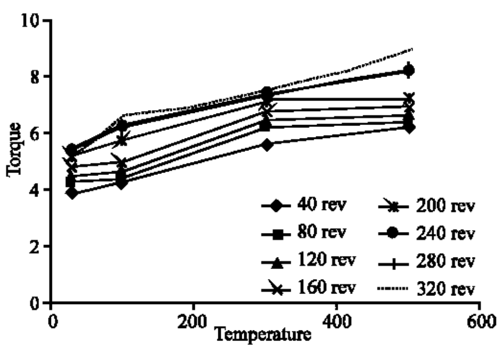

Fig. 7: Torque vs temperature (annealing)

DISCUSSION

The results from the experiment have actually shown the effects of heat treatment on the mechanical properties of the mild steel rods. Or can be inferred from the results that the ultimate stress decreases as both annealing and tempering temperature increases, they have the empirical relations of

$$\delta_{xa} = -0.178TA + 441.6$$
$$\delta_{nQ} = -0.102\ TQ + 396.6.$$

for annealing and tempering, respectively. Similarly, the yield stress decreases as both the annealing and tempering temperature increases, they have the empirical relations of

$$\delta ya = -0.108TA + 305.81$$
$$\delta_{nQ} = -0.082TQ + 277.5$$

for annealing and tempering, respectively. The percentage elongation which is a measure of the ductility of the mild steel increases as both annealing and temperature increases and the empirical relations of

$$EfA = 0.014TA + 8.026$$
$$Efq = 0.008TQ + 10.05$$

for annealing and tempering, respectively. More so, the impact strength of the mild steel increases as the temperature for annealing and tempering increases. The empirical relations for annealing and tempering are:

$$EA = 0.013TA + 6.92$$
$$EQ = 0.008TQ + 15.42$$

The torque and the angle of twist also increases as the tempering and annealing temperatures increases.

CONCLUSION

In this study, it can be inferred that the mechanical properties of mild steel can be altered through various heat treatment. The various mechanical properties are function of temperature. Also, the ultimate stress, yield stress, percentage elongation and impact energy of the mild steel can be predicted at various temperatures using their empirical relations obtained from the graphs.

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