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Effect of Tempering Temperatures on Mechanical Properties for Medium Carbon Steel

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ABSTRACT: In this research work the effect of tempering temperatures on mechanical properties for medium carbon steel has been studied. Steel AISI 1039 heated up to 950°C for 45 min in electric furnace and then quenched rapidly in engine oil as a quenching media. Tempering process has been performed for hardened samples. Hardness, tensile, and wear tests have been carried out for specimens after quenching. Also these tests were carried out for tempered samples.It was found that the wear rate for tempered medium carbon steel is higher than hardened alloy. Where the wear rate value for hardened steel was (1.8×10^{-8}) gm/cm. and the maximum value was (28.6×10^{-8}) gm/cm for steel that tempered at 600 °C. The Vickers hardness number for quenched steel in oil was (367.3Hv), while hardness value for tempered steel at 600C became (239.1Hv). Ductility and percentage of elongation of medium carbon steel increased with increasing the tempering temperatures. The lowest value of elongation was after quenching process in oil, it was recorded with value 9.5%. While the percentage of elongation for tempered alloy at 600 °C was 15%.

Keywords: tempering process, mechanical properties, and medium carbon steel.

I. INTRODUCTION

Medium carbon steel is easily available and relatively cheap having all material properties that are acceptable for many applications. Heat treatment on medium carbon steel is to improve ductility, to improve toughness, strength, hardness and tensile strength and to relive internal stress developed in the material. [1].The possible applications of medium carbon steel are very wide. Some popular uses of medium carbon steel for various engineering application are for Flywheel, Ball bearing, Railway wheels.Crankshaft,Bevel wheel , Hydraulic clutch on diesel engine for heavy vehicle etc. [2]. Quenching refers to the process of rapidly cooling metal parts from the austenitizing or solution treating temperature. Successful hardening usually means achieving the require microstructure, hardness, strength, or toughness while minimizing residual stress, distortion, and the possibility of cracking. The most common quenchant media are either liquids or gases. The liquid quenchants commonly used include Oil, Water and Aqueous polymer solutions.

Quenching effectiveness is dependent on the steel composition, type of quenchant, or the quenchant use conditions. Tampering of steel is a process in which previously hardened or normalized steel is usually heated to a temperature below the lower critical temperature and cooled at a suitable rate, primarily to increase ductility and toughness, but also to increase the grain size of the matrix. So the main purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel. Principal Variables associated with tempering that affect the microstructure and the mechanical properties of tempered steel include tempering temperature, time at temperature and cooling rate from the tempering temperature [3]. O.O. Daramola, et al, studied the effect of heat treatment on the mechanical properties of rolled medium carbon steel. The steel was heated to the austenizing temperature of 830°C and then quenching by water; it was reheated to the ferrite – austenite two phase regions at a temperature of 745°C below the effective Ac3 point. The steel was then rapidly quenched in water and tempered at 480°C to provide an alloy containing strong, tough, lath martensite (fibers) in a ductile soft ferrite matrix. The result shows that the steel developed has excellent combination of tensile strength, impact strength and ductility which is very attractive for structural use [4].

Hani Aziz Ameen, et al, Investigated the wear rate for different materials (Steel, Aluminum and brass) under the effect of sliding speed, time and different loads, where the apparatus pin on disc has been used to study the specification of the adhesion wear. A mathematical models have been made for all cases and from the results, It will showed that the rate of adhesion wear will be direct proportional with (time, sliding speed and load) , and the low carbon steel has less wear rate than the other materials [5]. Heat treatments like annealing, normalizing and tempering have been done for medium carbon steel. Two different grades of Steel (one with copper and another without copper) have been used in this study. The samples are tempered at 200°C, 400°C and 600°C for 1 hr.Heat treated samples were then mechanically tested for hardness (Rockwell) ,tensile properties (ultimate strength, ductility) and the microstructure. The results revealed that steel with copper has high hardness, ultimate tensile strength and low ductility [6].

Samples of medium carbon steel were examined after heating between 900ºC980ºC and soaked for 45 minutes in a muffle furnace before quenching in palm oil and water separately. The mechanical behavior of the samples was investigated using universal tensile testing machine for tensile test and Vickers pyramid method for hardness testing. The microstructure of the quenched samples was studied using optical microscope. The tensile strength and hardness values of the quenched samples were relatively higher than those of the as-cast samples. Samples quenched in palm oil displayed better properties compared with that of water-quenched samples. This behavior was traced to the fact that the carbon particles in palm oil quenched samples were more uniform and evenly distributed, indicating the formation of more pearlite structure, than those quenched in water and the as-received samples [7]. An investigation of suitability the adequate material properties and structure for agricultural industries. The En 8 is a medium carbon steel, En 19 and En 24 is a plain medium carbon low alloy steels containing molybdenum and chromium in different amount (up to 5% in total). The selected steels were heat treated and their mechanical and Tribological properties have been accessed for their suitability for agro machinery industries. The Tribological properties have been quantitatively estimated by three body abrasion test set-up which is Flex make as per standard specifications of American society of testing materials (ASTM), where the wear caused by abrasive trapped between the two moving surfaces [8]. The influence of heat treatment on mechanical behavior of AISI1040 has been investigated. Result shows that the ultimate tensile strength and the yield strength decrease while the elongation increases with an increase in tempering temperature and tempering time of different tempered specimen. The hardness of quenched/hardened specimen decreases with an increase in tempering temperature and tempering time. Furthermore, increasing temperature and lowering time produces approximately same result as decreasing temperature and increasing time [9].

The effect of heat treatments on microstructure and mechanical properties of EN 31 and EN-8 carbon steel have been studied. Further both the carbon steels are compared on the basis of their mechanical properties as well as the rate of corrosion, then the hardness of both the carbon steel are noted before and after the heat treatment processes. The heat treatment processes i.e. Annealing, Tempering & Oil quenching (hardening) are done. The mechanical properties such as the hardness and tensile strength among three processes, the oil quenching sample possess highest hardness and the annealed sample possesses highest elongation. That is how heat treatmentplays an important role in the mechanical properties and corrosion resistance of the experimental steel. [10]The mechanical properties of materials can be enhance by controlling the temperature of heating and cooling. Pardeep Singh Bains and Raman Kumaranalyzestudied the effect of different heat treatment processes such as annealing, normalizing, tempering and water quenching on hardness of material SAE 1040. The results revealed out that the optimum hardness was observed by tempering heat treatment process [11, 12]. The mechanical properties of a medium carbon steel of known composition after been subjected to various quenching media at various inter - critical temperatures were evaluated. Samples quenched in distilled water were noted to produce the highest mechanical properties such as high hardness value and strength possibly linked to the fact that it is free from impurities and minerals such as fluorides, calcium ions and magnesium ions which presence would have reduce the severity of quench, followed by those quenched in palm kernel oil due to it density which is higher than that of distilled water thereby producing a final sample with improved toughness and ductility, and water produces the least strength that could be attributed to internal stresses and transformation stresses developed after quenching as a result of rapid quenching. Hence palm kernel oil has been proven to be a suitable quenching medium which has been quantitatively assessed using microstructure, hardness value and tensile strength value [13].

Evaluation of palm kernel oil, cotton seed oil and olive oil as quenching media of 0.509Wt%C medium carbon steel was investigated .To compare the effectiveness of the oils, the samples were also quenched in water and SAE engine oil which are the commercial quenchants. The hardness of steel quenched in water was (1740.54 HBN), while the hardness of steel quenched in palm kernel oil was (740.34 HBN) which was recorded as the least in all samples quenched. As-received sample absorbed the highest amount of energy (183.10J) before fracture while sample quenched in water absorbs the least energy (28.50J). The microstructure of the samples quenched in the oils understudy revealed the formation of low proportions of martensite and in the case of olive oil, there was retained austenite. Hence, olive oil can be used where cooling severity less than that of water and SAE 40 engine oil is required for hardening of plain carbon steels [14, 15]. The Steel AISI 1039 quenched in different quenching media. These quenching media were cold water, water, oil and hot water. Hardness, tensile, impact and wear tests have been carried out for specimens after quenching in different media. It was found that the tensile strength and hardness increased with increasing the heating temperature values of heat treatment process. Also quenching in cold water has a great effect on tensile strength and hardness values. Where the heights value for tensile strength was (998.6N/mm^2) and the hardness was (360.4 Hv) for steel which quenching in cold water. The percentage of elongation decreased with increasing the temperature of heat treatment process. Also the lowest values of elongation were after quenching process in cold water. However, the impact toughness and wear rate values were high for alloy after stress relief and lower after quenching in different media. But the lowest values were recorded after quenching in cold water. It was found that the absorbed energy and the wear rate for the alloy quenched in cold water were (23.6) J and ($2x10^{-7}$gm/cm) respectively. While for steels treated with the stress relief process were (62.02) J and ($7x10^{-7}$gm/cm) respectively [16].

The hardness of medium carbon steel can be improved by quenching through different quenching mediums .Hardening was carried out for three different types of steel AISI 1040, 1050 and 4340 having varying carbon content. The quenching mediums like water, oil, brine and air have been used. Higher hardness values have been obtained when quenched in salt water (Brine) after 30 minutes of heat treatment at 750^{o}C.Also. The lowest hardness values have been obtained under normalizing condition. While the value of hardness decreases with retention of sample in the furnace for longer period [17]. Three types of heat treatments were performed, these are annealing, quenching and tempering. The fractured surfaces of the samples were also been examined by using Scanning Electron Microscope. The specimen with the highest hardness was found in samples quenched in water. Besides, the microstructure obtained after tempering provided a good combination of mechanical properties due to the process reduce brittleness by increasing ductility and toughness [18, 19].

II. EXPERIMENTAL WORK

medium carbon steel have been cut into three groups of small Cylindrical samples, samples in the first group have length (50 mm) and diameter (10mm), which used for wear test. While samples with second group have length (20 mm) and diameter (10 mm) were used for calculate the hardness values and microstructure examinations, while the third group of samples was made for tensile test to calculate the percentage of elongation. The chemical composition of the alloy is obtained by x-ray fluorescent. The chemical composition of AISI1039 is given in the table below:

Table (1): Chemical Composition of AISI1039

Element	C	Si	Mn	P	S	Mo	Ni	Al	Co	Cu	Fe
Weight%	0.39	0.173	0.796	0.009	0.022	0.168	0.069	0.023	0.008	0.095	Bal.

Samples are placed in Crucible made of silicon carbide and inserted into the Electric furnace. Heating temperature was 950 ^{o}C and socking time for 45 minutes in order to ensure the structure will be austenite. The cooling was carried out in engine oil as a quenching media. Tempering was performed for some samples at different temperatures 300^{o}C, 400^{o}C and 600^{o}C with socking time 45 minutes. Preparations of samples for hardness determination and the microstructure examination was done by using a grinding and polishing machines. All surface specimens were grounded by using 300,600 and 1000 Sic emery papers. Alumina slurry with particle size of 50μm and diamond paste with particle size of 1μm was used for polishing the samples. Finally samples were cleaned by water and alcohol and then dried. The samples were etched using Nital (nitric acid, ethanol), samples was observed and photographed at a magnification of X200. The tensile test was carried out by using WDW 2000 model No. M 353 Tensile device and Vickers hardness values were measured with 412A/413A INNOVA TEST Micro hardness device. The microstructure was examined by using an optical microscope .Wear rate calculations were done by using wear testing device (pin on disc) Fig (1) , Sensitive balance with an accuracy of 0.0001g It is used to determine the weight of the samples before and after the wear rate test.the wear rate was obtained by using the equation:-

$$\text{Wear rate} = \Delta W/\pi\, D.N.t$$

Where: - D= 10 cm the sliding circle, t =60 minutes the sliding time (min), N =256 rpm the steel disc speed and the applied load was (20) N.

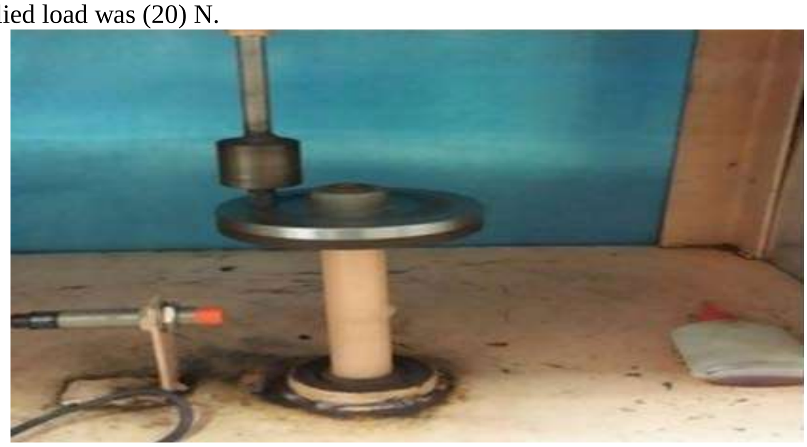


Figure (1): Wear testing device

III. RESULTS AND DISCUSSION

The effect of tempering temperatures on mechanical properties for medium carbon steel AISI 1039 has been studied, the conditions and the recorded results of this research work can be seen in table (2).

Table (2) Conditions and results of the experimental work

Sample No.	Heat treatment conditions	Wear rate (gm/cm)	Wear test Time (min)	Hardness (VHN)	% elongation
1	**Quenching in oil**	**1.8×10^{-8}**	**60**	**367.3**	**9.5**
2	**Quenching in oil + tempering at 600 °C**	**28.6×10^{-8}**	**60**	**239.1**	**15**
3	**Quenching in oil + tempering at 400 °C**	**11.2×10^{-8}**	**60**	**275.2**	**13**
	Quenching in oil + tempering at 300 °C	**3.5×10^{-8}**	**60**	**307.8**	**11**

From fig (3), it can be remarked the effect of tempering temperatures on wear rate for this steel . The sample subjected to quenching in oil followed by tempering process with 600 °C has a highest value of wear rate (28.6×10^{-8} gm/cm), while the lowest value was 3.5×10^{-8} (gm/cm) for tempered alloy with 300 °C . So it can be seen that the wear rate increased as the tempering temperatures increased. Also that the wear rate of metal after quenching was (1.8gm/cm). This is due to formation of martensite when the steel rapidly cooled by quenching. Martensite is a needle like structure; it is too hard, brittle and cannot be used directly after quench for any application. Martensite brittleness can be reduced by applying a post-heat treatment known as –tempering. Some hardness and strength is lost after tempering treatment. The microstructure of metal tempered at 600 °C is shows the formation of recrystallized ferrite grains with graphite flakes site in martensite matrix.

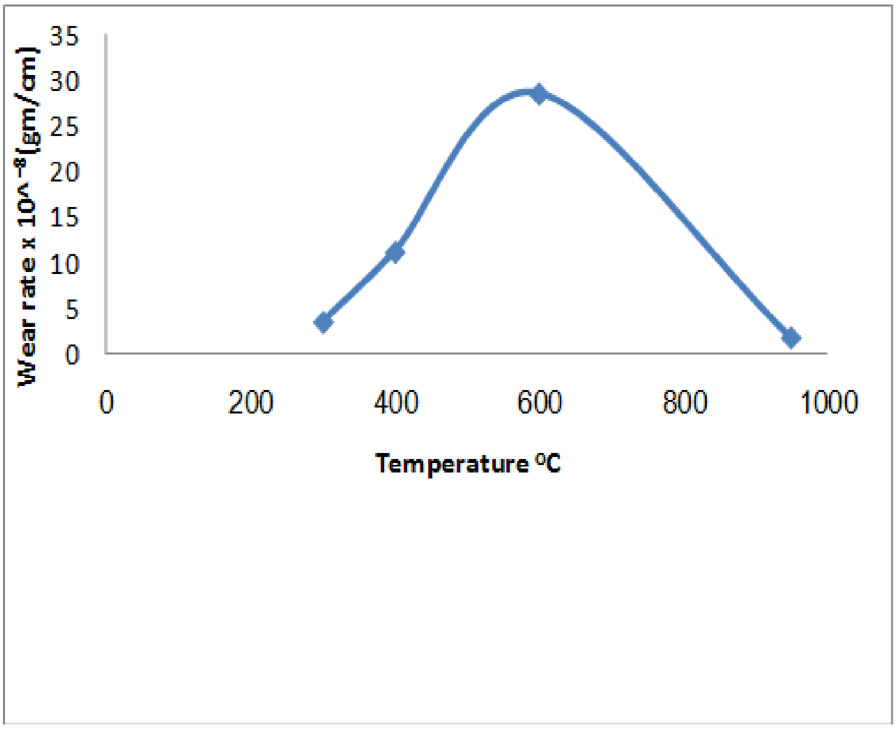


Fig (2): Effect of tempering temperatures on wear rate for medium carbon steel AISI 1039

However, the transformation of austenite to martensite by diffusionless shear type transformation in quenching is also responsible for higher hardness obtained and this property is due to the effectiveness of interstitial carbon in hindering the dislocation motion. The highest value of hardness after quenching the specimen in oil was (367.3 Hv) because the quenching is very fast. Hardness of steel decreased when samples subjected to tempering process, the lowest hardness value was (239.1 Hv) due to stress relief process and this process permit to dislocation motion in structure of steel. Also the brittleness of steel is reduced and ductility increased. So the percentage of elongation recorded as 15% after tempering the steel with 600°C Fig (4). Therefore, by increase in tempering temperature, the hard constituent of martensite is being transformed to comparatively soft troostite or also called as tempered martensite.

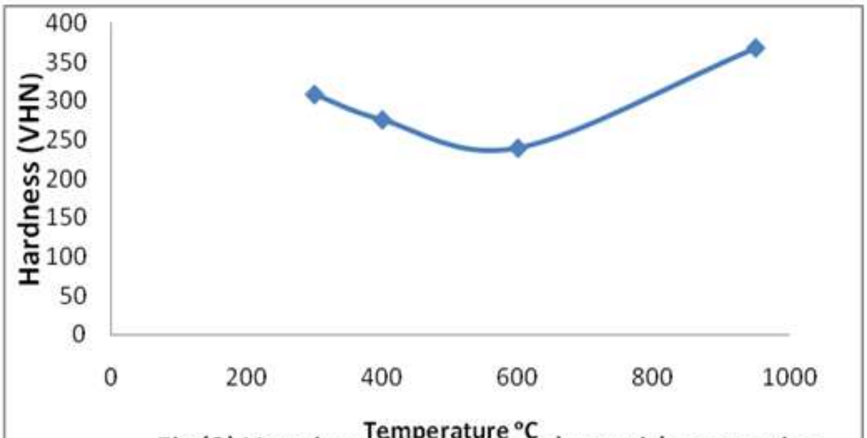


Fig (3) Varation of hardness values with tempering temperature for medium carbon steel AISI 1039 after quenching in oil at 950 °C

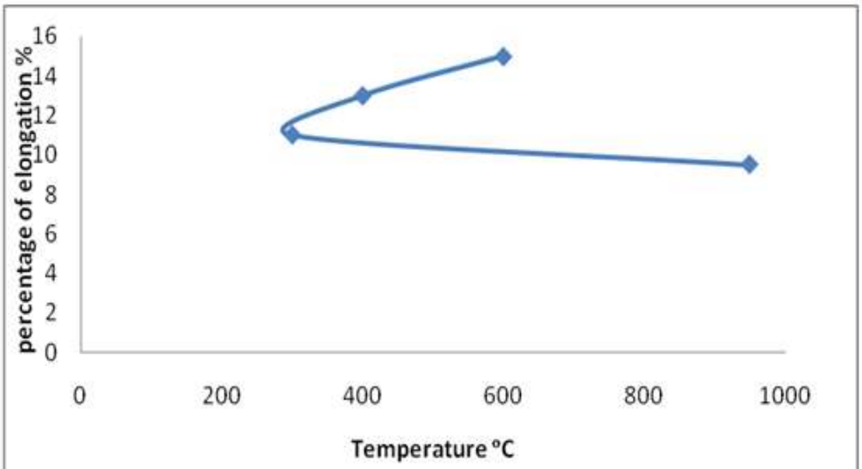
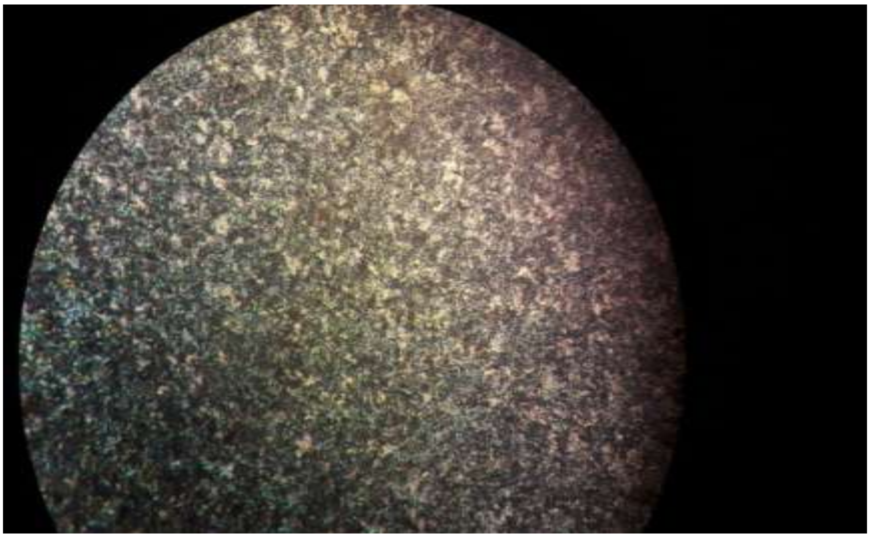


Fig (4) The change of % elongation with tempering temperature for medium carbon steel AISI 1039



Figure(5): The microstructure for medium carbon steel AISI 1039 after quenching in engine oil from 950°C , socking time 45min, magnification (200X)

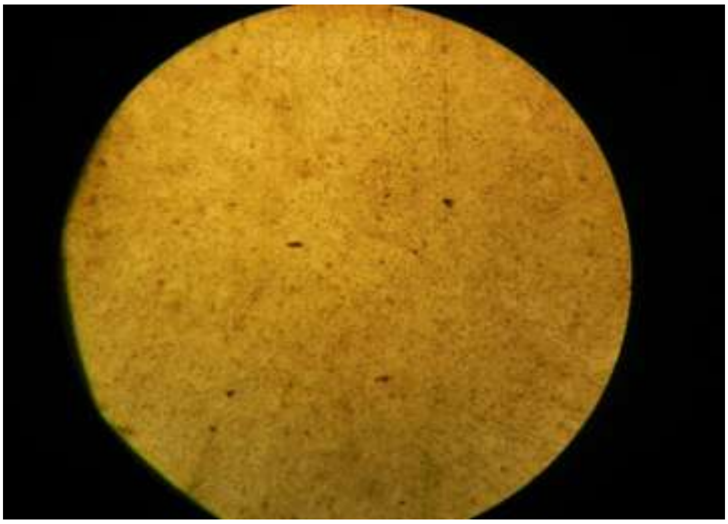


Figure (6): The microstructure for tempered medium carbon steel AISI 1039 after quenching in engine oil from 950°C , socking time 45min. Tempering temperature was 300°C magnification (200X)

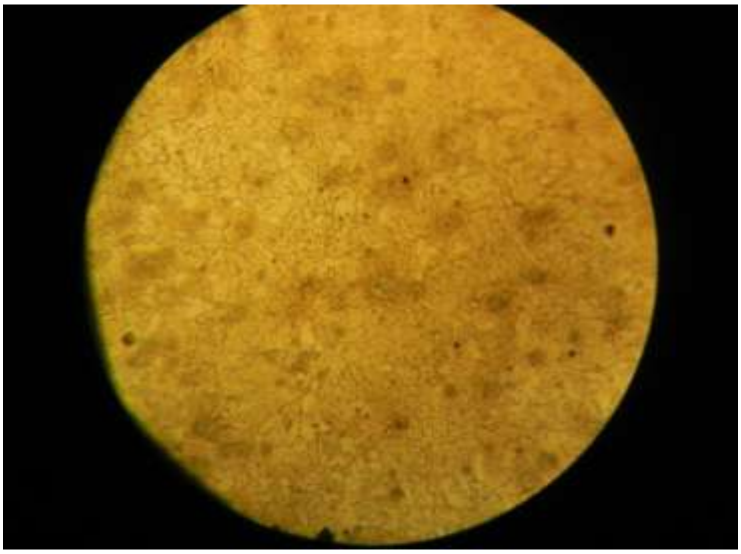
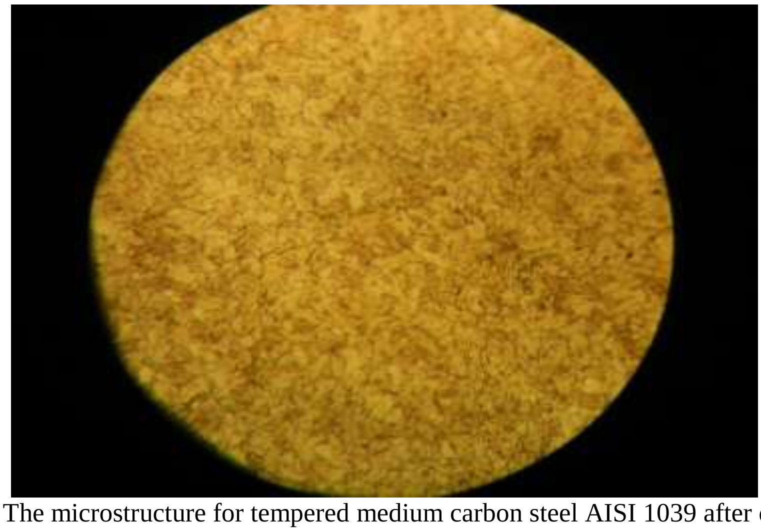


Figure (7): The microstructure for tempered medium carbon steel AISI 1039 after quenching in engine oil from 950°C, socking time 45min. Tempering temperature was 400°C magnification (200X)



Figure(8) The microstructure for tempered medium carbon steel AISI 1039 after quenching in engine oil from 950°C , socking time 45min. Tempering temperature was 600°C magnification (200X)

IV. CONCLUSION

In this research work, Investigation the effect of tempering temperatures on hardness, wear rate and tensile properties for hardened medium carbon steel AISI 1039, has been studied. The main results obtainedare as follows:

1. Wear rate for tempered medium carbon steel is higher than hardened alloy.
2. As tempering temperatures of steel increased the wear rate increased.
3. Hardness and brittleness of the medium carbon steel are decreased with increasing the tempering temperatures.
4. Ductility and percentage of elongation of medium carbon steel increased with increasing the tempering temperatures.

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