

Effect of Quenching Media on Mechanical Properties for Medium Carbon Steel

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ABSTRACT

In this research work the mechanical properties of medium carbon steel has been studied . 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/mm²) 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 was 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 (2x10⁻⁷gm/cm) respectively. While, for steels treated with the stress relief process were (62.02) J and (7x10⁻⁷gm/cm) respectively.

I. INTRODUCTION

Carbon is an effective, cheap, hardening element for iron and hence a large tonnage of commercial steels contains very little alloying element. They may be divided conveniently into low-carbon (<0.3% C), medium-carbon (0.3–0.7% C) and high-carbon (0.7–1.7% C) steels. Medium-carbon steels are capable of being quenched to form martensite and tempered to develop toughness with good strength. [1]Application for mid-carbon range include gears, shafts, axles, rods and a multitude of machine parts.[2]

The effect of heat treatment on the microstructure and mechanical properties of steel 45, steel 40CrNi and steel T8 was investigated. The result shows that hardness decreases with increase in tempering temperature. Quenched at different temperature, austenite may decompose into martensite, troosite with martensite, ferrite with cementite, and so on. Alloying elements can increase hardenability and tempering stability of steel. [3]

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.[4]

The effect of heat treatments on microstructure and mechanical properties of EN - 31 and EN-8 carbon steel are being 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 hardening temperature for EN-31 varies from 8200C - 8600C whereas the hardening temperature for EN-8 varies from 7500C - 9000 C. The mechanical properties such as the hardness and tensile strength among three process, the oil quenching sample possess highest hardness and the annealed sample possess highest elongation. That is how heat treatment plays an important role in the mechanical properties and corrosion resistance of the experimental steel.[5]

Investigations were carried out to study the effects of heat treatment on the mechanical properties of rolled medium carbon steel. The steel was heated to the austenizing temperature of 8300C and water quenched; It was reheated to the ferrite – austenite two phase region 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 (fibres) 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.[6]

The mechanical properties such as ductility, toughness, strength, hardness and tensile strength can easily be modified by heat treating the medium carbon steel to suit a particular design purpose. Tensile specimens were produced from medium carbon steel and were subjected to various forms of heat treatment processes like annealing, normalizing, hardening and tempering. The stiffness, ductility, ultimate tensile strength, yield strength and hardness of the heat treated samples were observed from their stress-strain curve. The value of the yield strength (σ_y) was observed to be higher for the tempered specimen possibly as a result of the grain re-arrangement, followed by the hardened, normalized and annealed specimens. The value of the ultimate tensile strength (σ_u) were also observed to be in the order; hardened > tempered > normalized > annealed. For high ductile and minimum toughness, annealing the medium carbon steel will give satisfactory results. Thus it is important to clearly specify the condition of the carbon steel as purchased so that tests can be conducted to ensure the material compositions before they are put to final use.[7]

The mechanical behavior of medium carbon steel Samples were examined after heating between 900°C - 980°C and soaked for 45 minutes in a muffle furnace before quenching in palm oil and water separately. Also, the microstructure of the quenched samples was studied. The tensile strength and hardness values of the quenched samples were relatively higher than those of the as-cast samples, suggesting improved mechanical properties. However, 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.[8]. The mechanical properties of materials can be enhanced by controlling the temperature of heating and cooling. Pardeep Singh Bains and Raman Kumar analyze the effect of different heat treatment processes such as annealing, normalizing, tempering and water quenching on hardness of material SAE 1040. The Rockwell hardness tester was used to measure the hardness of material and Muffle furnace was used to carry out the heating process. The results revealed out that the maximum hardness was observed by tempering heat treatment process.[9]

Sachin Kumar and et.al. studied the suitability of adequate material properties and structure for agricultural industries. The En 8 is a

plain medium carbon steel, En 19 and En 24 is a 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. [10]

Two different grades of medium carbon steel (one with copper and another without copper) have been studied and analyze result of mechanical testing performed on various heat treated samples for the two grades of steel. samples are subjected to different heat treatment sequences: annealing, normalizing, quenching and tempering at different temperatures 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 comparison of mechanical properties and microstructure of two grades of steel has also been studied. The results revealed that steel with copper has high hardness, ultimate tensile strength and low ductility.[11]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. The microstructures obtained were used to explain the results. 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 its 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.[12]

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 under study 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.[13]

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. The soaking time were 30, 60 and 90 minutes at 850°C. The hardness values under all the processes have been measured to show the comparison in this investigation. The results obtained that for all steels, higher hardness values have been obtained when quenched in salt water (Brine) after 30 minutes of heat treatment at 750°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. [14]

Three types of heat treatment were performed, these are annealing, quenching and tempering. During annealing process, the specimens were heated at 900°C and soaked for 1 hour in the furnace. The specimens were then quenched in a medium of water and open air, respectively. The treatment was followed by tempering processes which were done at 300°C, 450°C, and 600°C with a soaking time of 2 hours for each temperature. The results collected from the Rockwell hardness test and Charpy impact test on the samples after quenching and tempering were compared and analysed. 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.[15]

II. EXPERIMENTAL PROCEDURE

In this research work the medium carbon steel has been used. This plain carbon steel having 0.39% carbon in its composition. The chemical composition of the material is carried out at the specialized institute for engineering industries by x-ray fluorescent. The chemical composition of AISI1039 is given in the table below:-

Table1. 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.

The stress relief was carried out for alloy by using an electric furnace at 200°C for 4 hours. specimens of Twelve were prepared by conventional lathe (Harrison 600, M350, EWD700) and get the dimensions of tension specimen. Each group have three specimens. all groups were put it

in an electric furnace at different heating temperature and constant soaking time (one hour) it can be seen from the table below the conditions of the heat treatment and types of quenching media, that carried out in this research.

Table (2) Heat treatments conditions

No. of sample	Heating temperature	Soaking time	Quenching media
1,2,3,4	880°C	1 hour	Cold water (ice +water),water, oil, hot water (at 50°C)
5,6,7,8	920°C	1 hour	Cold water (ice +water),water, oil, hot water (at 50°C)
9,10,11,12	960°C	1 hour	Cold water (ice +water),water, oil, hot water (at 50°C)

In order to measure the hardness values and for a microstructure examinations a twelve specimen also prepared for this tests with these previous conditions. The tensile test was performed by using WDW 2000 model No. M 353 Tensile device and Vickers hardness values was measured with 412A/413A INNOVA TEST Micro hardness device. The microstructure was examined by using an optical microscope. For metallographic

examination, all surface specimens were grounded by using 250,500 and 1000 Sic emery papers. Primary and final polishing was performed using alumina slurry with particle size of 50µm and diamond paste with particle size of 1µm. Finally all polished samples were cleaned by water and alcohol and then dried. The samples were etched using Nital(nitric acid, ethanol). samples was then

observed and photographed at a magnification of X200.

After the heat treatment process completed, Izod impact test were performed. The results collected from Izod impact test on the samples after quenching and analyzed.

The pin-on-disc was used for measuring the wear rate after stress relief and quenching processes. Weight method was used to determine the wear rate of specimens. The specimens were weight before and after the wear test by sensitive balance with accuracy of 0.0001gm. the weight loss (ΔW) was divided by the sliding distance and the wear rate was obtained by using the equation:-
Wear rate = $\Delta W / \pi D.N.t$

Where :- D is the sliding circle , t is the sliding time (min) and N is the steel disc speed.

III. RESULTS AND DISCUSSION

The effect of heating temperature during the heat treatment processes and quenching media on the tensile strength , percentage of elongation , hardness, toughness and wear rate for medium carbon steel AISI1039 has been investigated. This effect can be seen in the Figures (1,2,3,4,5). Also the microstructure of the alloy after using the stress relief at 200°C for 4 hours can be remarked in figure(6) , while the microstructure for the alloy that quenching in different media at heating temperature 960°C can be seen in figures (7,8,9,10).

The tensile strength of treated specimen with stress relief was (755 N/mm²), Total percentage elongation (16%), Vickers hardness value (232Hv), toughness (62.02J) and the wear rate of (7×10^{-7} gm/cm).

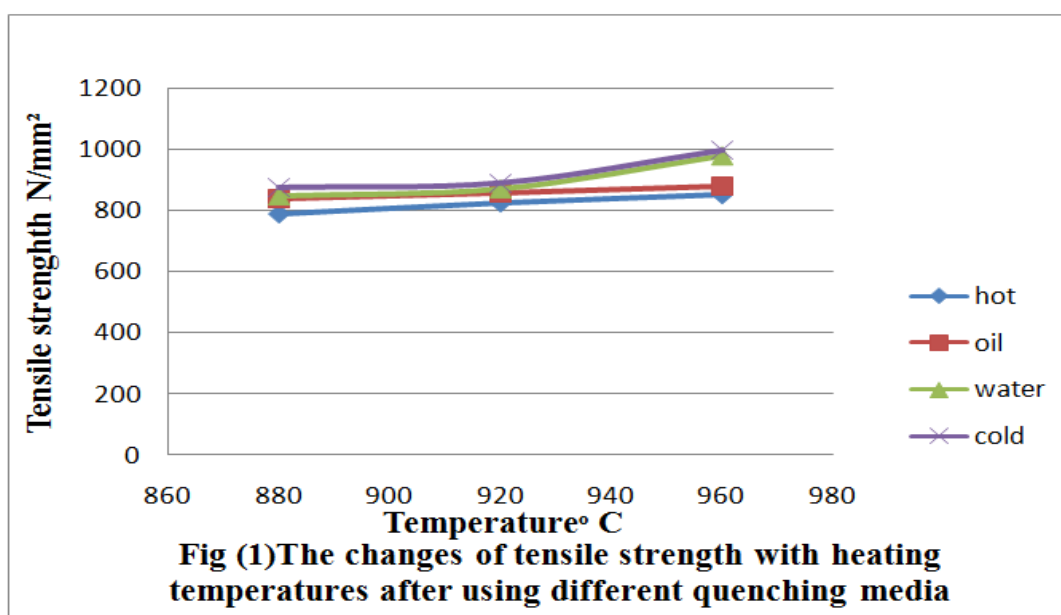


Fig (1) shows the effect of quenching media on tensile strength for medium carbon steel AISI1039 , it can be seen that the tensile strength increases with increase the heating temperature. The maximum tensile strength was 998.6 N/mm² at conditions of heating temperature 960°C , soaking time one hours and quenching rapidly in cold water (ice +water).

While the minimum value of tensile strength was 790.3N/mm² at conditions of heating temperature 880°C , soaking time one hours and quenching in hot water. So above the upper critical temperature the carbon present dispersed to form austenite structures. The quenched specimens would have their austenites transformed to martensites. These structures are fine needle-like structures which are very strong and hard, but very brittle. However the increase in tensile strength

and hardness can be attributed to the higher volume fraction of the harder martensite. So the hardness value reached to (360.4 Hv) when quenched the specimen in cold water (ice + water) from heating temperature of 960°C, due to very rapid cooling rate. Forever, 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. [16].The lowest hardness value was (232 Hv) due to stress relief process and this process permit to dislocation motion in structure of steel. The least value of hardness after quenching the specimen in hot water from 880°C was (252.3 Hv) because the quenching is not very fast.

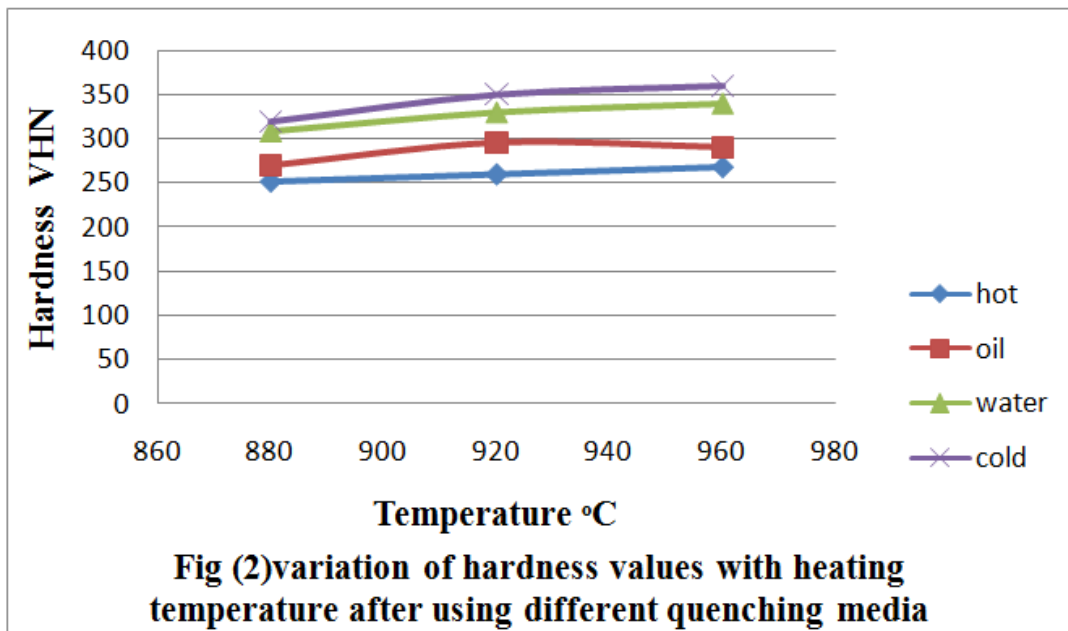


Fig (2)variation of hardness values with heating temperature after using different quenching media

However an increase in the heating temperature in austenite range , the grains begin to grow intensively, which means the coarsening of martensite grain [17]. So the quenching temperature of coarse-grained martensite should be higher than that for fine-grained martensite. The percentage of elongation is high (16%) for the specimen treated with stress relief due to the structure (pearlite +ferrite) which is soft Fig (6) ,while the structure of the steel after quenching from 960°C in cold water contains coarse-grained martensite and the percentage of elongation

reached to (7%) due to form this structure which is hard and brittle fig (2,3). The percentage of elongation of specimen quenching in water from the same temperature was (8%)because the structure is fine-grained martensite. While the percentage of elongation was (11%) after quenching the steel in oil from 960°C because the structure was troositeand martensite. However,The percentage of elongation was (12%) after quenching the steel in hot water from 960°C because the structure was also troosite and martensite.Figures (1,2,3,6,7,8,9,10).

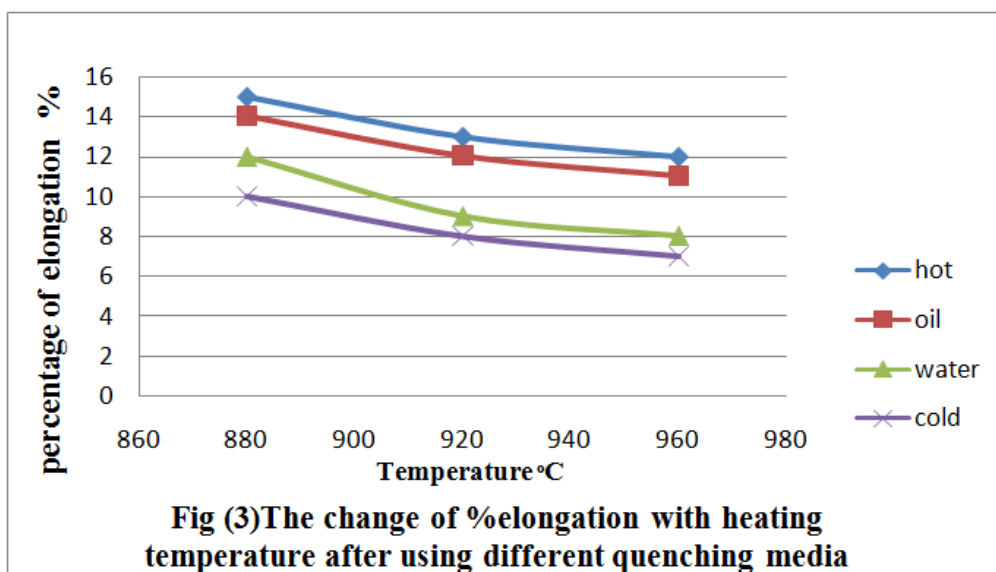
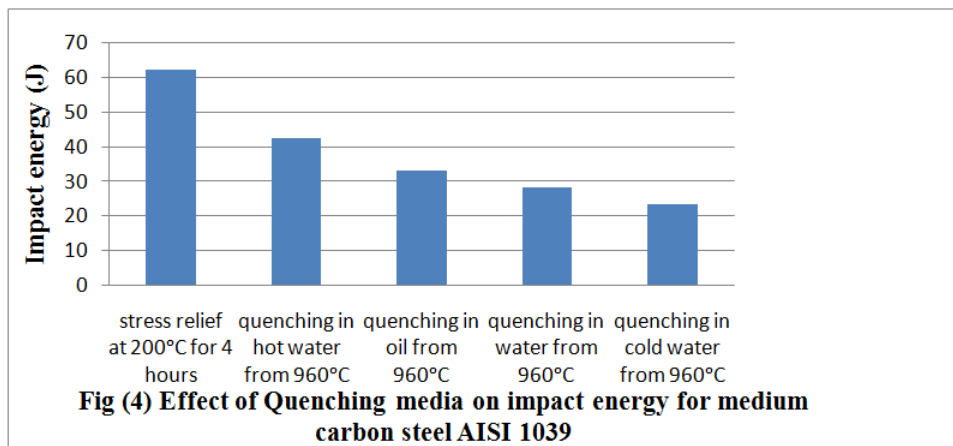


Fig (3)The change of %elongation with heating temperature after using different quenching media

The treated specimen with stress relief at 200C for four hours gave the heights impact strength value (62.02 J) and quenching in cold water from 960C gave the least impact strength

(23.6 J)the decreased in absorbed energy is due to the formation the martensite structure which is a brittle and hard.



It can be remarked that the quenching media has an effect on wear rate of medium carbon steel. From figure (6) it can be seen that the wear rate of the treated alloy with stress relief was (7×10^{-7} gm/cm) but the wear rate decreased when this alloy hardened by quenching from 960°C in

different quenching media. The wear rate value became (2×10^{-7} gm/cm) when the samples quenching in cold water from the same temperature, this is due to the formation of hard structure (martensite).

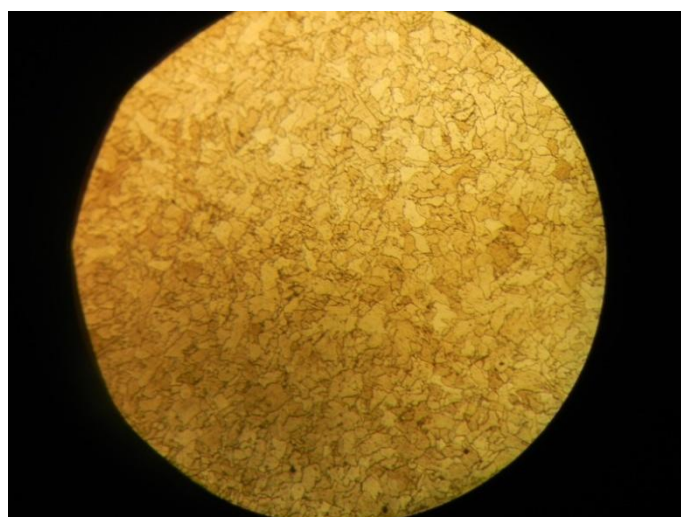
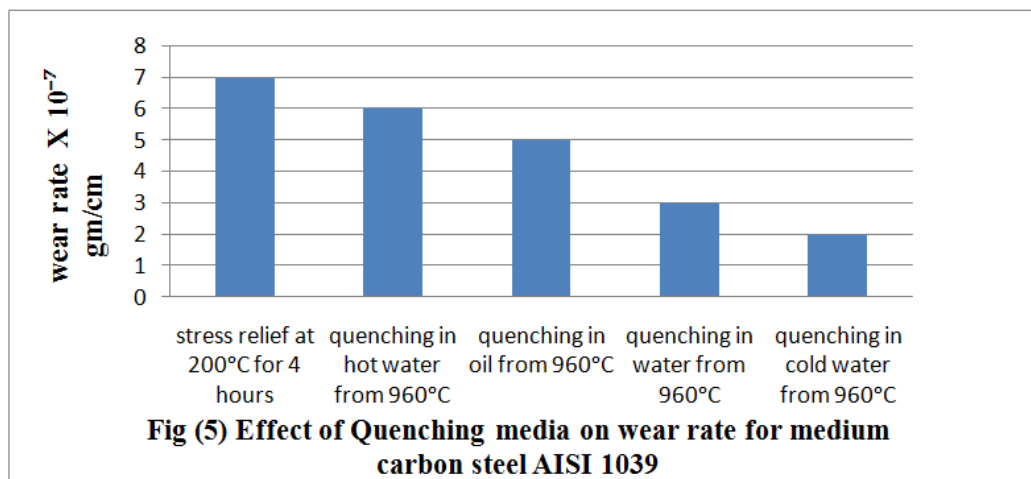


Fig (6) The microstructure for medium carbon steel AISI 1039 after stress relief at 200°C for 4 hours . magnification (200X) shows the ferrite and pearlite(dark regions) phases.

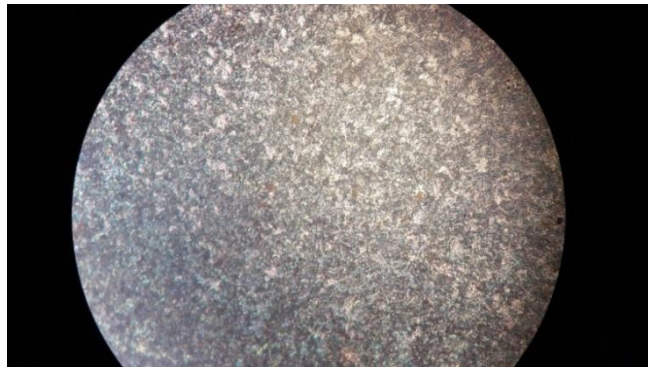


Fig (7) The microstructure for medium carbon steel AISI 1039 after quenching in cold water from 920°C ,
soaking time one hour . magnification (200X) .

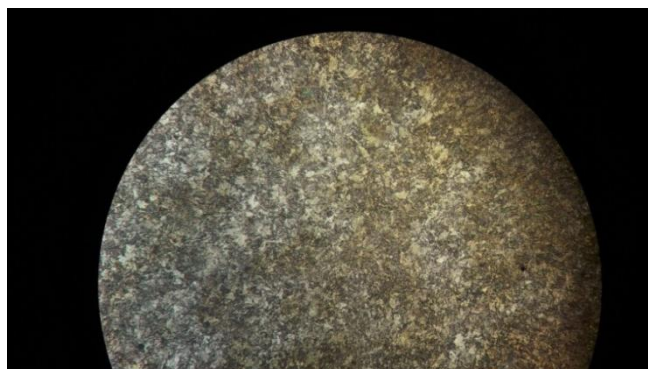


Fig (8) The microstructure for medium carbon steel AISI 1039 after quenching in engine oil from 920°C ,
soaking time one hour . magnification (200X) .

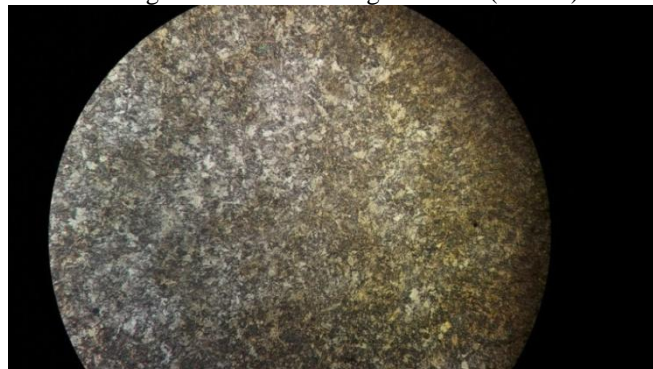


Fig (9) The microstructure for medium carbon steel AISI 1039 after quenching in water from 880°C , soaking
time one hour . magnification (200X) .

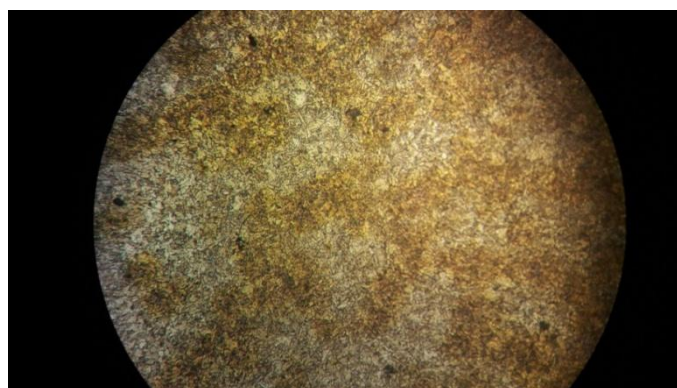


Fig (10) The microstructure for medium carbon steel AISI 1039 after quenching in hot water from 880°C ,
soaking time one hour . magnification (200X) .

IV. CONCLUSION

Investigating the mechanical properties of medium carbon steel AISI1039 by using different quenching media yielded the following conclusions:-

- 1- The tensile strength and hardness values of medium carbon steel AISI 1039 increased after quenching with increasing the temperature of heat treatment.
- 2- Medium carbon steel with Quenching in cold water has a height values of tensile strength and hardness than other quenching media.
- 3- Percentage of elongation decreased after quenching with increasing the temperature of heat treatment. Also the lowest values were recorded for this alloy when quenching in cold water and the heights values were obtained for the alloy after quenching in hot water.
- 4- The impact strength was higher after carry out the stress relief process. While the lowest value was recorded after quenching the alloy in cold water.
- 5- Wear rate for alloy which heat treated with stress relief process has higher than those treated with quenching and the lowest value was recorded after quenching the alloy in cold water.

REFERENCES

- [1]. R. E. Smallman and A. H.W. Ngan, "Physical Metallurgy and Advanced Materials", Seventh edition 2007.
- [2]. Peter A.Thornton, vito J. colangelo, "Fundamentals of Engineering materials", 1985.
- [3]. Song Zhen "Effect of Heat Treatment on the Microstructure and Mechanical Properties of Steel", University of Science and Technology Beijing, Dept.of M.S.E
- [4]. AshishVermaa, Pravin Kumar Singhb a,"Influence of Heat Treatment on Mechanical Properties of Aisi1040 Steel",IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),Volume 10, Issue 2 (Nov. - Dec. 2013), PP 32-38.
- [5]. KhushalKhera, Anmol Bhatia, Sanjay Kumar, Mehul Bhatia, "Investigation of the Effects of Various Heat Treatment Processes on Microstructure & Hardnesswith Respect to Corrosion Behavior for Carbon Steels",International Journal of Engineering and Advanced Technology (IJEAT)Volume-3 Issue-6, August 2014.
- [6]. O.O. Daramola, B.O. Adewuyi and I.O. Oladele, "Effects of Heat Treatment on the Mechanical Properties of Rolled Medium Carbon Steel",Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.8, pp.693-708, 2010
- [7]. T. Senthilkumar^{1,*} and T. K. Ajiboye², "Effect of Heat Treatment Processes on the Mechanical Properties of Medium Carbon Steel",Journal of Minerals & Materials Characterization & Engineering, Vol. 11, No.2 pp.143-152, 2012
- [8]. J. K. Odusote¹, T. K. Ajiboye², A. B. Rabi², "Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil",Journal of Minerals and Materials Characterization and Engineering, 2012, 11, 859-862.
- [9]. Pardeep Singh Bains¹, Raman Kumar², "Analysis of hardness on SAE 1040 using different heat treatment process",. International Conference on Emerging Trends in Science and Cutting Edge Technology (ICETSCET-2014).
- [10]. Sachin Kumar, Abhishek Jain , Pramod Singh, "Analysis of Abrasive Wear Characterization and its Correlation with Structure for Low and Medium Carbon Steels", International Journal of Emerging Technology and Advanced Engineering,Volume 2, Issue 12, December 2012.
- [11]. B.S. Motagi, Ramesh Bhosle,"Effect of Heat Treatment on Microstructure and Mechanical Properties of Medium Carbon Steel", International Journal of Engineering Research and Development, Volume 2, Issue 1 (July 2012), PP. 07-13.
- [12]. Joshua T.O, Alao O.A, OluyoriR.T,"Effects of Various Quenching Media on the Mechanical Properties of Inter – Critically Annealed 0.267%C - 0.83% Mn Steel", International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-3 Issue-6, August 2014
- [13]. M. Dauda¹, L. S. Kuburi², D. O. Obada^{3,*} and R. I. Mustapha⁴, "Effect of various quenching media on mechanical properties of annealed 0.509Wt%C – 0.178Wt%Mn Steel" ,Nigerian Journal of Technology (NIJOTECH) , Vol. 34 No. 3, July 2015, pp. 506 – 512.
- [14]. Saigeeta Priyadarshini¹, Sandeep K Anand², Omprakash Yadav³, "Effect of quenching medium on hardness of three grades of steel - AISI 1040, 1050 and 4340",International Journal for Research in Applied Science & Engineering Technology (IJRASET)Volume 4 Issue I, January 2016.

- [15]. Noor MazniIsmail,Nurul Aida Amir Khatif, MohamadAliffKamilAwangKecik, Mohd Ali Hanafiah Shahrudin1“The effect of heat treatment on the hardness and impact properties of medium carbon steel”,IOP Conf. Series: Materials Science and Engineering 114 (2016).
- [16]. Callister Jr. W.O , “Material science and Engineering An introduction”, John willey ,USA, 1987,pp 322-328.
- [17]. George E. Totten, “ Steel heat treatment : metallurgy and technology CRC Press”, Tayor&Francis group, 2006.163.