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COMPARATIVE STUDY OF CASE-HARDENING AND WATER-QUENCHING OF MILD STEEL ROD ON ITS MECHANICAL PROPERTIES

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ABSTRACT

Mild steel is easily available and affordable having all material properties that are acceptable for many applications. It has carbon content up to 0.15%. While case-hardening and water-quenching are carried out on mild steel to improve toughness, strength and hardness, ductility declines as a result of internal stress developed in the material. This research work evaluated the effect of case-hardening and water-quenching on the mechanical properties of mild steel rod. Fifteen samples of mild steel rod of diameter 50 mm were prepared and heat treated in all, 12 of which were tensile samples. The other materials used for the project work were; powdered charcoal (4.44 g), barium carbonate (250 g), venier caliper, optical microscope, heating furnace and the material testing equipment. The water-quenched specimens were heated to 950 oC and soaked for 40 minutes, after which the specimens were quenched in water. The case-hardened specimens were heated to 950 oC and for a period of 40 minutes and then quenched in salt solution. Various tests were carried out on the heated samples such as; tensile strength test, hardness test, microstructural analysis and chemical analysis were all carried out. The results showed that the case-hardened specimens had more ductility than the water-quenched. The hardness test revealed that the water-quenched samples were the hardest, followed by the case-hardened samples. The case-hardened specimens had higher value than water-quenched specimens for strain at break. Various microstructures which were product of austenite were got such as, martensite (BCT, fine grains), Bainites and Pearlites.

1.0 INTRODUCTION

Heat reatment is defined as the process of subjecting metals in the solid state to one or more temperature cycles to confer engineering properties which are induced in the process in the form of structural changes occurring during heating or cooling.[1]. The process which takes cognisance of time and temperature in determining the structure wanted in the material. The common heat treatment methods available are hardening, case hardening, tempering, aus-tempering, normalizing and annealing[2]. Hardening process is used to induce hardness (martensitic phase) property into the material. Case hardening is used to harden the surface of the material only without hardening the core of the material. The case-hardening types are nitriding, carbon-nitriding, cyaniding, and carburizing [3]. Tempering is used to soften and improve ductility in metal sequel to stress relief, to reduce brittleness and to make steel tough to resist shock and fatigue, after hardening had been conducted on it by heating the metal to a subcritical temperature [4-5]. Mild steel samples are carburized under two condition s such as: Carburisation in as received charcoal granules and $BaCO_3$ mixtures with a thick coating (2mm approx.) of a coal tar pitch on steel sample, Carburisation in used charcoal and $BaCO_3$ mixture with cold tar pitches coating on the steel sample. In both cases carburisation was carried out at a temperature of 930^0C for two hours (optimum)[6-7].All the quenched carburized steel samples were tempered at 150^0C for 15 minutes. As outlined by them, the nature and reactivity of carbon used greatly affect the mechanical properties and abrasion resistance of carburized mild steel specimens [8-9].

Failures (hogging and sagging) of mild steel in its applications ranging from reinforcement in buildings and bridges, production of burglary and in automobile section occasionally occurred. The failure which is due to its ductility at the expense of hardness made mild steel to fail (commonly sagging) causing the buildings and bridges to collapse[10-11]

Therefore, this research work focussed on comparative study of case-hardening and water-quenching on the mechanical properties of mild steel rod.

2.0 MATERIALS AND METHODS.

2.1 Materials

The mild steel samples were sourced locally. The samples were prepared in to cylindrical rod of 50.00 mm diameter and 44.0 mm height. Carburising materials are prepared from the mixture of charcoal and barium carbonate;60% of charcoal and 40% barium carbonate is to be used for the experiment;For charcoal:-60% of 1.11g = 0.666g of charcoal, For barium carbonate ($BaCO_3$):-40% of 250g = 100g of $BaCO_3$.

2.2 Methods

The water-quenching process was accomplished thus; cooling medium (water) was made available inside a metal bucket. The specimens (4 pieces) were placed inside the crucible. The crucible and with the specimens were placed in the furnace. The furnace was fired using oil as fuel. The specimens were heated to a temperature of 950^OC.The specimens were held at that temperature for 40 minutes known as soaking. Soaking at this temperature, 950^OC, for 40 minutes is for the desired micro-structure to be induced or simply homogenisation. The specimens were taken out and dropped in water for cooling, after that the furnace has been switched off. The cooling rate was rapid. Thus this rapid cooling in water is known as Quenching. Quenching can also be carried out in oil bath and by pressurised air. When the specimens and the cooling medium reached the ambient temperature, the specimens were taken out and cleanedup with napkin. Thus the processes of heating metals to a temperature above critical temperature and then cooled rapidly in water or oil- bath or by pressurised air are known as Quenching.

Case-hardening process is accomplished as follows; Stainless cup of 14cl in which the specimens are to be carburised was bought. The essence of placing the specimens in the stainless cup and not directly in the crucible was to prevent the crucible being carburised along with the specimens, should the carburising materials (barium carbonate and charcoal) were put directly, thereby reducing the carburising materials initially required to carburised the specimens. The charcoal and the barium carbonate (both powdered) were mixed in a plate. The stainless cup and its contents were placed in the crucible inside the furnace. The furnace was fired using oil as the fuel. The specimens were heat treated to a temperature of $950^{O}C$ above the critical temperature. The specimens were held at this temperature for 40 minutes i.e. soaked for 40 minutes, the furnace was switched off and the stainless cup and its contents were taken out of the furnace. The salt solution had already being prepared by adding salt to water. The specimens were cooled rapidly in the salt solution. The purpose of heating the metals in carbonaceous environment, such as charcoal is to increase the surface hardness of the metal with respect to the core. The hardness was due to carbon deposit on the outer surface on exposure the carbonaceous environment. Thus the heat treatment process in which the surface of the metal is hardening without hardening the core such as conserving a tough outer surface and ductile core is known as Case-hardening. There are different types of case-hardening: carburising, cyaniding, nitriding, carbon-nitriding.

Mechanical Properties Examination

The samples were examined for tensile, impact, hardness and microstructural properties.

3.0 RESULT AND DISCUSSION

3.1 Results

The results obtained are shown in tables 1 to 3

Table 1: Showed chemical analysis of mild steel

1	**C (%)**	**Si (%)**	**Mn (%)**	**P (%)**	**S (%)**	**Cr (%)**	**Ni (%)**	**Mo (%)**
	0.145	0.189	0.91	0.041	0.042	0.134	0.111	0.033
2	Al (%)	Cu (%)	Co (%)	Ti (%)	Nb (%)	V (%)	W (%)	Pb (%)
	<0.0001	>0.300	0.0076	0.0013	0.0083	0.0034	<0.0001	<0.0001
3	B (%)	Sn (%)	Zn (%)	As (%)	Bi (%)	Ca (%)	Ce (%)	Zr (%)
	0.0002	0.011	0.0021	<0.0001	0.0011	0.0004	0.0044	0.0005
4	La (%)	Fe (%)						
	0.0003	97.8						

The tensile strength tests were carried out 030.00 mm/min test speed of the machine for 12 tensile samples of the heat treated specimens and 3 tensile samples for the as-received specimens. From the results obtained, the water-quenched specimen had mean young modulus of 14.708 N/mm^2, mean elongation at break of 4.1990 mm, force at yield of 0 N, mean stress and strain at break of 1.6714 N/mm^2 and 9.543 % respectively, as shown in the table below.

Table 2: Water Quenched Specimens Tensile Strength Test Results.

Specimens Specification	Test Numbers.						
	1	2	3	Min.	Max.	Mean	S. D.
Diameter (mm)	50.000	50.000	50.000	50.000	50.000	50.000	0.000
Samples Length (mm)	0044.0	0044.0	0044.0	0	0	0	0
Test Speed (mm/min)	030.00	030.00	030.00	0	0	0	0
Force at Peak (N)	4983.0	2461.1	2401.5	2401.5	4983.0	3281.9	1473.5
Elongation at Peak (mm)	5.0070	2.9640	4.6260	2.9640	5.0070	4.1990	1.0864

Hardness Test Result

It can be shown from the table below that the annealed samples had the least hardness value of 25.0 HRF, followed by the as-received samples and the normalised samples of hardness values of, 33.2 HRF and 35.7 HRF respectively. The case-hardened specimens had hardness value of 51.94 HRF and the water-quenched had most hardness value of 54.97 HRF.

Table 3: Showed Rockwell Hardness values (HRF) of heat treated specimens and the as-received specimen.

S/N	Specimen Types	Rockwell Hardness values (HRF)
1	Case-Hardened	51.94
2	Water- Quenched Steel	54.97
3	As-received (Control Experiment)	33.2

3.2 Discussion

Water-Quenched Specimens

The water-quenched samples obtained by heat treating the specimens to austenite at 950^{O}C, soaked for 40 minutes and then cooled rapidly (quenched) in water. The water-quenched had Martensitic microstructure (BCT crystal structure) with fine grains. The martensitic transformation is a diffussionless transformation that involves a sudden reorientation in the structure of the steel (mild), making the atoms to precipitate out (precipitation hardening), thus responsible for the highest hardness property of water-quenched specimens. The hardness value for water-quenched specimen is 54.97 (HRF). As shown above, they were found to be the hardest of all the heat treated specimens but very brittle. The water-quenched specimen had force at yield of

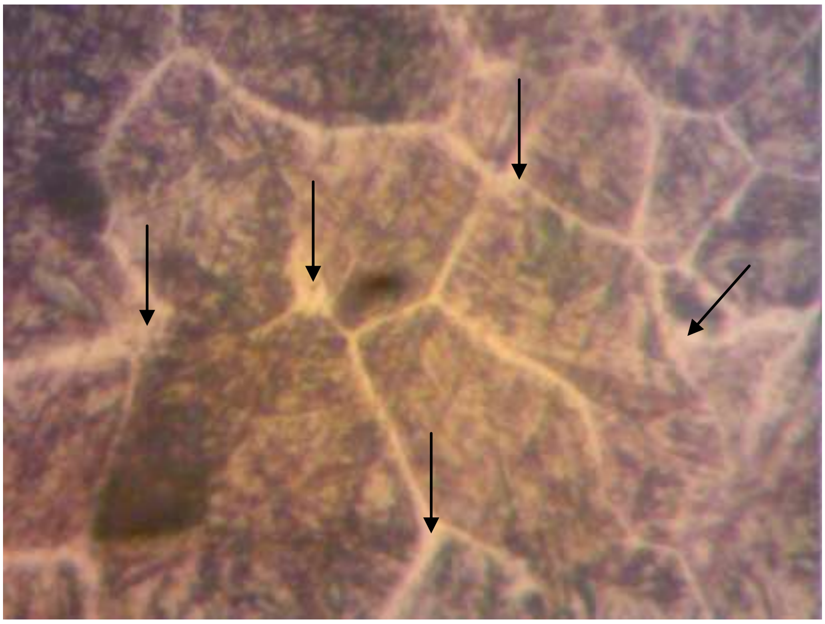
0(N) with mean young modulus of 14.708 N/mm^2. This result conforms to a previous work carried out[7,12-13], where they concluded that water-quenched at 910^{o}C soaked for 40 minutes had the highest hardness value but very brittle , also with martensitic microstructure.

Case-Hardened Specimens

The case-hardened samples were heat treated to austenite at 950^{o}C in a stainless cup of 14cl containing mixture of charcoal and barium carbonate for 40 minutes. The barium carbonate makes CO_2 available at the early stage of carburisation, thus it is called an energizer. The basic source of carbon for this type of carburisation (pack type) is the charcoal. The surfaces of the specimens absorb carbon at a faster rate and at a rate at which it can diffuse inside. The case-hardened specimens were cooled rapidly (quenched) in a salt solution. The microstructure produced was martensite with finer grains, which had resulted from the diffussionless transformation into Body-Cubic Tetragonal crystal structure. The case-hardened samples had higher hardness value of 51.94 (HRF) after the water-quenched samples in hardness and exhibit little ductility far more than the water-quenched. The increase in carbon content is 0.188. There is more carbon on the outer surface than the core. These results are in accordance with the work carried out by Sanjib in 2009, where he found out that the steel carburized for longer carburization cycle had greater case depth and surfaces hardness and high wear resistant.

Microstructural Analysis

Water-Quenched: The Product of Austenised Specimen (Mild Steel) At $950^{O}C$ Water-quenched heat (hardening) treatment method is the Body-cubic tetragonal, which is form when austenised steel is rapidly cooled such as quenching and this is known as Martensite. This martensite is the light area indicated by dark arrows distributed in the ferrite matrix (dark area).

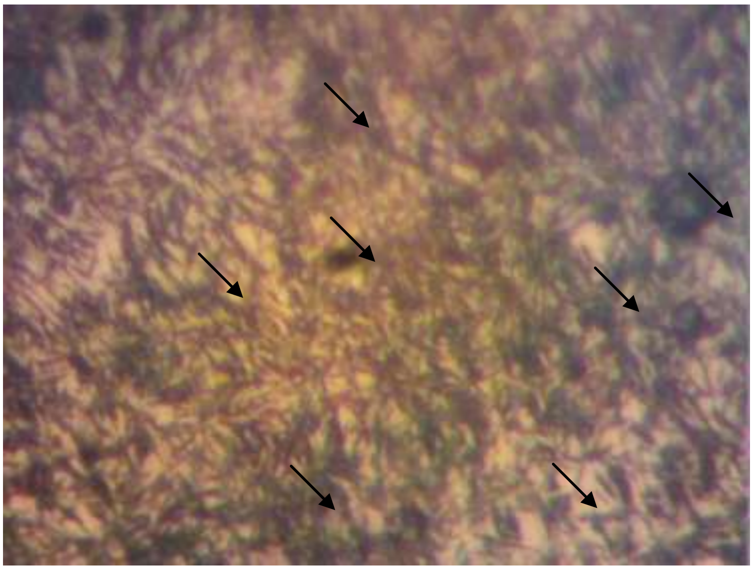


X400

Figure 1: Micro-structure of mild steel water-quenched at $950^{O}C$ Obtained through optical Microscope.

Case-Hardened:

Case-Hardening product of austenite specimen (mild steel) at $950^{O}C$ quenched in salt solution is Body cubic tetragonal known as martensite. The atom has limited time to diffused but trapped in the ferrite matrix. This consists of finer grains carbon atoms (dark arrows). Carbon is found in the elongated ferrite making its grains much finer than that of the hardening.



X400.

Figure 2: Micro-structure of case-hardening mild steel quenched in salt solution at 950^{O}C obtained through optical microscope.

As Received Samples (Control Experiments):

The as received specimen showed cementite (dark arrowed) in ferrite matrix that often form colonies and these colonies are oriented in the same direction. This kind of microstructure is known as Pearlite (fine).

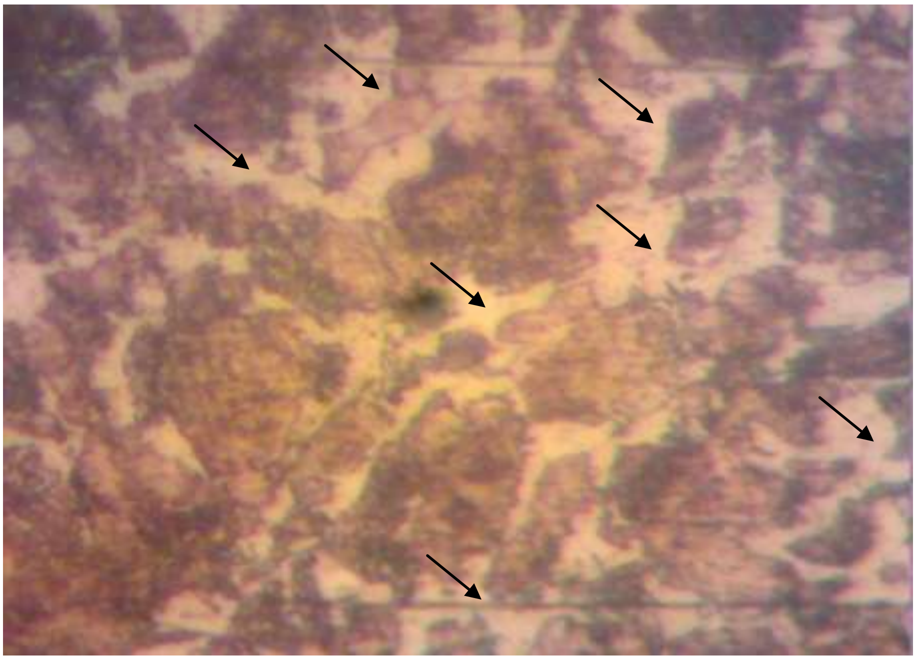


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Fig.3. Micro-structure of as-received sample obtained through optical microscope.

4.0 Conclusion

The following conclusions are drawn having completed the research work.

Heat treatment methods such as carburising and water quenching were carried out on mild steel rod which effect microstructures such as; pearlite (fine and coarse), bainite and martensite, which gives the heat treated specimens hardness property and tensile strength property that varied for the various heat treatment methods .

Effect of heat treatment on the mechanical properties of the mild steel such as tensile and hardness properties of both heat treated samples and untreated samples were carried out and comparison were made. And it was found that the annealed specimens were most ductile, followed by the as-received. Water-quenched come after case-hardened specimens in ductility.

The water-quenched specimens were the hardest in terms of hardness, followed by the case-hardened. The as-received specimens were harder than the annealed specimens.

References

[1] Adegbuyi P. A. O., 2003. “The Effect of Heat Treatment on Nigeria Construction Steel”. Engineering and Technology Research Journal (Lagos). 1(1).

[2] Adetunji O. R., Kuye S. I., Alao M. J., 2013. “Microstructure of Mild Steel Spring after Heat Treatment”. Pacific Journal of Science and Technology. 14(2): 11-15

[3] Adetunji O. R., Aiyedun P. O., Ismaila S. O., Alao M. J., 2012. “Effect of Normalizing and Hardening on Mechanical Properties of Springs”. Journal of Minerals and Materials Characterization and Engineering, 2012, 11, PP 832-835.s

[4] Avner S. H., 1974. “Introduction to Physical Metallurgy”. McGraw Hill, PP 305-313. Bartel G. E., 2006. “Steel Heat Treatment: Metallurgy and Technologies”. CRC Press: Boca Raton, F.L. 209.

[5] Dieter G. E., 1988. “Mechanical Metallurgy”. S.I Metric Edition, McGraw-Hill, ISBN 0-07-100406-8.

[6] Fadara D. A., Fadare T. G., Akanbi O.Y., 2011. “Effect of Heat Treatment on Mechanical Properties and Microstructure of NST 37- Steel”. Vol. 10, NO.3, PP.299-308.

[7] Fatai O. A., Simeon A. I., 2009. “Effect of carburization Time and Temperature on the Mechanical Properties of Carburize Mild Steel Using Activated Carbon as Carburizer”. Material Research, Vol. 12, No 4, 483-487.

[8] George E. B., 2006. “Steel Heat Treatment Metallurgy and Technologies”. CRC Press, Boca Raton, FL.

[9] Herring D. L., Jenko V., 2009. “Estimation of Fracture Toughness of Nitride Compound Layers on Tool Steel by Application of Vickers Indentation Method, Surface and Coating Technology 201. 182-188.

[10] Jokhio M. H., 1991. “Effect of Retained Austenite on Abrasive Wear Resistance of Carburized SAE 8822H Steel”. Thesis in Manufacturing Engineering and Technology, Jamshoro.

[11] Olagoke S. A., 2006. “Properties of Materials”, 3rd Edition. Kemiv Publication, Ibadan.

[12] Steel”. Journal of Achievements in Materials and Manufacturing Engineering. 35(2): 115-120.

[13] Sanjib Kumar Jaypuria. 2009. “Heat Treatment of Low Carbon Steel”. National Institute of Technology, Rourkela- 769008.p