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Charactarization of Nigerian Recycled Steel Austempered in 10 % Concentrated Brine Maintained at 300°C

Nuhu A. Ademoh

Department of Mechanical Engineering,
Federal University of Technology, P.M.B. 65, Minna, Nigeria

Abstract: Nigeria has not been able to complete and operate her indigenous steel plants for continuous production of needed assorted products for all sectors of her economy. Moreover steel scraps abound everywhere which some local companies recycle into rod, plate e. t. c. for use as structural reinforcement materials in construction industry without serious application for mechanical applications like in automobiles that critically require locally available replacement and completely knocked down parts. This study used austempering as one of the processes for enhancing the mechanical properties of steel to strengthen and toughen selected recycled steel scraps and characterised them for possible suitability for use shaft and gear production. Two steel samples; one with 0.16% carbon and another with 0.5% carbon were raised to temperatures of 800 - 950°C and austempered in baths containing 10% concentrated brine maintained at 300°C for varying periods of 30, 60, 90 and 120 minutes. Specimens were prepared and examined for metallographic and mechanical properties that included impact/tensile strength, hardness, endurance limits, percentage reduction in area and elongation. Result showed that sample with 0.16% carbon was only suitable by virtue of ultimate tensile strength. Steel sample with 0.50% carbon was found suitable for grades 1-4 shaft and gear production when austenized at 850-900°C and austempered in 10% concentrated brine maintained at 300°C for 60-120 minutes due to ultimate tensile strength, impact strength, endurance limit, percentage elongation and hardness. The steel sample austempered for 30 minutes was suitable for only grade 1 gear/shaft application in respect of above investigated properties.

Key words: Brine · Austempering · Quenchant · Holding time · Mechanical properties · Microstructure

INTRODUCTION

According to Rajan *et al.* [1], austempering is a specialized heat treatment process in which austenite at high temperature is transformed into bainite when a work piece is rapidly quenched into a medium maintained at an intermediary temperature between the austenite range and room temperature. Phase transformation happens during conventional heat treatment process that involves continuous cooling. The cooling rate and temperature of first quenching bath are the two parameters that control the process. Brandenberg *et al*. [2] described austempering as the isothermal transformation of ferrous alloy at a temperature below that of pearlite formation and above that of martensite formation to strengthen steel. Steels are austempered when heated within the range of 790°C to 870°C and then quenched in bath at constant temperature in a range of 260°C-400°C to toughen them for specialized applications like components for ships, aircrafts, automobiles, power plants e. t. c. They also specified characteristics of the salt used for austempering, quenching media for austempering applications e.t.c. Applied Process [3] observed that application of austempering process to steel provides the user with a tough, high-strength component that resists embrittlement.

The process was recommended to be appropriate for medium to high carbon stamping, forging, castings and fill density powdered metal parts needed in modern day high-tech industries. Common austempered automobile components include shock absorbers, transmission case, clutch housing, engine front cover, oil pan, steering column upper bracket, brake pedal brackets steering wheel cores, cylinder head covers, differential pinion, disc

Corresponding Author: Nuhu A. Ademoh, Department of Mechanical Engineering, Federal University of Technology, P.M.B. 65, Minna, Nigeria.

wheels, parking pawls e.t.c. [4]. In Nigeria, automotive industry is poorly developed due to non availability of locally produced standard component parts of high strength. The situation is so precarious that even when some of the original parts of imported vehicles that are common features on Nigerian roads fail, the owners have to resort to imported used replacement components whose reliability are uncertain. Incapability of local industries have not enabled them to key in to produce and supply required high quality completely knocked down parts required by local automotive assembly plants. This made actualization of local content initiative signed with multi nationals who imported automotive assembly plants to Nigeria difficult to implement.

Apart from needed compositional quality of automotive component production steel, the heat treatment to which steel was subjected could correct and greatly enhance its service properties and widen its range of application. Nigeria has not been able to produce her own steel of different grades for specialized industrial applications but also lacks technological capability to condition the steel recycled from scraps for standard component part production through well developed heat treatment processes. This research is therefore aimed at investigating the strengthening capability of brine of different concentrations as austempering quenchants for locally recycled steel for production of high quality automotive parts. The main objectives are to adopt known locally produced steel from recycled scrap, cut out samples from it, subject them to austempering heat treatment using salt solutions of varied concentrations maintained at elevated temperatures as quenchant; test treated specimens for mechanical property enhancement and microstructural changes and to compare the result with established standard so as to determine possible use of such treated steel for standard automobile component part production. The significance of this work when completed lies in the fact that it would make use of steel recycled from scraps in automotive parts production possible to reduce dependence on importation for service parts for vehicles, grow local industry, enable local content contribution to completely knocked down (CKD) part supply to Nigerian automobile assembly plants and generate more employment opportunities for technical professionals.

Property enhancement of steel by austempering is affected by important treatment factors like quench media, size of steel piece, type of steel used/nature of steel, cooling and holding rate and austempering temperature. It is an isothermal heat treatment that is applied to ferrous alloys, most notably steel and ductile iron mainly to improve mechanical properties Allen S.M. [5]. It produces lower bainite microstructure in steel, structure of acicular ferrite and high carbon stabilized austenite called ausferrite in cast iron. Austempered steel is used to produce high tensile, impact, fatigue strength and corrosion resistant part. Grossman and Bain [4] evaluated response of steel cooled rapidly from 788°C to intermittently high temperature, held for various times and reported that there was isothermal transformation which produced tempered steel of bainitic microstructure with 620N/m^2 tensile strength. It was found that the process resulted in low distortion of guns and that parts were tougher than quenched and tempered component that they replaced during the Second World War (www.appliedprocess.com/process) [3]. Nick [6] worked on factors affecting austempering heat treatment of some materials. He noted that amongst the most important factors that control the process are quenching media, quenching temperature and type of steel.

Kilicli V. Erdogan, [7] described austempering as method of hardening steel by quenching from high temperature into heat-extracting medium and suggested salt as heat-extracting medium. Brine that (common salt solution in water) when used as quenchant was found to reduce absorption of atmospheric gasses which in turn reduces amount of bubbles formed. Also, brine wets metal surface and cools it more rapidly than water [8]. In addition to rapid and uniform cooling, brine removes large percentage of scale that may be present [9]. Low-alloy and carbon steels could be quenched in brine. However, its rapid cooling rate is used to quench high speed and oil hardened steel to attain required hardness [10]. Austempered steel is cooled at sufficient rate to avoid nose of s-curve of temperature-time-transformation diagram (Figure 1) and hold just above the start of martensite transformation (Ms point) for complete transformation to bainitic structure at constant temperature to alleviate thermal stress that can cause cracking or distortion. Austempering involve less heat treatment time and preferred when fast turnaround is a prime consideration [11]. It can be applied to thin sections of certain medium or high carbon steel or alloy containing steels of thicker section.

Austempering requires high temperature quenching and holding usually in molten salt. It results in low distortion with tough structure that requires no tempering [6]. Austempered iron and steel offer engineers alternatives to conventional material combinations.

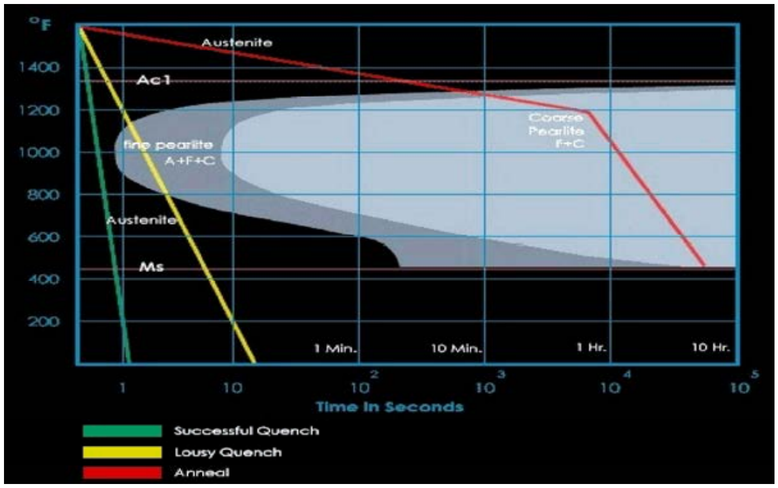

Fig. 1: Schematic I-T Diagram illustrating austempering, quench and tempering processes

Table 1: ASTM 897 Property table for steel used for production of gears and shafts

Grade	Tensile Strength (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)	Impact energy (Joules)	Hardness (No.)
1	850	550	10	100	269-321
2	1050	700	7	80	302-363
3	1200	850	4	60	341-444
4	1400	1100	1	35	366-477
5	1600	1300	N/A	N/A	444-555

Depending on materials and applications, austempering may provide benefit of ease of manufacturing, increased bending/contact fatigue strength, better wear resistance/enhanced dampening characteristics that result into lower noise. Table 1 shows some mechanical properties of gears and shafts Brandenberg *et al*. [2]; which are obtainable through austempering of steel. This was used for property control and comparison.

MATERIALS AND METHODS

Materials: Materials used for research work included plain carbon steel samples obtained from local commercial steel dealer in Kano and Jos, Nigeria; quantity of table salt (Dangote Company brand), distilled water, metallographic etching reagents and assorted grinding and polishing papers. The experimental equipment included steel basins, metal cutter, lathe machine, electric arc furnace, grinding machine, polishing machine, metallurgical microscope, izod impact machine; Hounsfield tensile test machine, digital hardness test machine and metal analyser. A most commonly used chemical etchant for iron-carbon steel, alloy steel and cast iron (i. e. natal) was used for the work. It was composed of 100ml ethanol (C_2 H_5OH) and 7ml nitric acid (HNO_3). Laboratory equipment was accessed in the laboratories of the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria and the Scientific Equipment Development Institute (SEDI), Minna, Nigeria.

Methods: The research experiments were grouped and conducted at different stages.

Steel Specimen Analysis: Two plain carbon steel samples of different carbon content were used. One was cylindrically shaped with a diameter of 4.3mm, labelled as sample A and the other was a plate of 6mm thick labelled as sample B. Experimental specimens were cut out based on the standard sample size required by type of test. A specimen was taken from each steel sample and prepared for elemental component analysis using metal analyser at Scientific Equipment Development Institute, Minna. Result 0f the analyses showing the main elemental chemical compositions are as presented in Tables 2 and 3.

Brine Solution Preparation: 10litres of distilled water was purchased from a pharmaceutical shop in Kaduna, Nigeria for use as solvent for salt and water solution. Appropriate weights of both the salt and distilled water were measured into separate containers and thereafter mixed for dissolution with water acting as solvent. A stainless steel vessel was used as container for the brine quenchant.

Table 2: Chemical composition of the experimental steel sample A (Low carbon steel)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Sn	Cu	V	Fe
Composition (%)	0.16	0.15	0.047	0.043	0.006	0.01	0.01	0.01	0.001	0.03	0.002	Balance

Table 3: Chemical composition of the experimental steel sample B (Medium carbon steel)

Element	%C	Ni	Co	Mo	P	Ti	Al	Si	Mn	S	Fe
Composition (%)	0.50	0.019	0.095	0.04	0.035	0.04	0.02	0.16	0.038	0.005	Balance

Test Specimen Preparation: The experimental steel sample A was cut into suitable pieces of 10mm long specimen each with power cutting machine and steel plate sample B was cut into 20mm X 20mm specimens. The samples were surface cleaned with grinding and polishing machines to remove surface oxide scales and grouped according to the schedule of tests prior to austempering treatment. In accordance with Vijendra Sigh [12], specimens from steel sample A were raised to a temperature of 900°C while those cut from high carbon steel, sample B were heated to a temperature of 800 - 850°C and held for 1 hour to soak and for proper homogenization in the electric arc furnace. The samples were quenched into different brine solution baths maintained at a temperature of 300°C and held at different time periods of 30, 60, 90, 120 minutes [13]. Thereafter, classified test pieces were withdrawn from hot brine bath and air cooled to room temperature. Samples were separated for preparation for metallographic examination and mechanical property tests that included reduction in area, elongation, hardness, yield, impact and tensile strength to ascertain effects of the heat treatment.

Specimen Testing: Austempered specimen meant for metallographic tests were selected, grouped and mounted on Bakelite. Grinding and polishing were done on water lubricated grinding machine with silicon carbide abrasive paper grades 120, 180, 240, 320, 400 and 600 grits. Final polishing was carried out using 0.3 microns particle size alumina to obtain mirror surface finish. Etching was done using 2% Nital for 10-20 seconds by handling with a pair of nickel crucible tongs. After etching specimens were washed with running water and dried by immersion into boiling ethanol [14]. They were withdrawn from ethanol after a few minutes and shaken to remove surplus as it dried almost instantaneously. Specimens were then examined under a metallurgical microscope at a magnification of X100 and microstructures recorded photographically. Each of untreated steel samples A and B were included in metallographic specimens for comparison with treated steel microstructures.

A universal digital hardness machine model LR300TD was used to determine hardness of specimens. Grouped Bakelite mounted and polished specimen were selected and subjected to hardness examination. Device operation panel was user-friendly. Test condition like loading speed and conversion scale were easily set using durable touch panel. Test piece was raised to within 8 mm of indenter and the START button pressed to begin test. Setting upper and lower limits were quickly done with help of convenient OK indicator. Hardness conversion scale displayed on operation panel was in compliance with ASTM (E-140) and SAE (J-417b). Automatic start loading feature measured major load instantly once minor load was set and results were tabulated as obtained. Impact toughness (Impact strength) of pieces under investigation was determined with izod machine which employed a bench clamp type technique to hold specimen. It made use of pendulum-testing machine. Specimen broke by single overload event due to pendulum impact and stop pointer recorded how far pendulum swung back up after fracturing specimen.

Impact toughness was determined by measuring the energy absorbed at fracture. This was obtained by noting the height at which pendulum was released and that to which it swung after it struck specimen. Height of pendulum multiplied by weight of pendulum gave the potential energy and the difference in potential energy of pendulum at start and end of test that equalled absorbed energy was instantaneously recorded. For tensile strength determination, Harrison M40 (model 16K20) precision tool room lathe was used for production of standard test specimen. Samples were grouped and austempered with other property test specimen. Austempered pieces were thoroughly cleaned to remove possible scale and then subjected to tensile strength test using universal strength testing machine. Each specimen was mounted and gripped on machine and tensile load gradually and continuously applied until necking and fracture occurred. Load at which necking and failure occurred was recorded and ultimate tensile/yield strength, impact strength; percentages of elongation and reduction were determined [15].

RESULTS

Figures 2 and 3 present the microstructures of mild steel samples A and B while Tables 4 and 5 show the basic mechanical property respectively. Figures 4, 5, 6, 7 show selected photomicrographs of specimens of plain carbon steel sample A austenized at a temperature of 900°C; austempered in 10% concentrated brine solution quenchant maintained at a temperature of 300°C for different holding period of 30, 60, 90 and 120 minutes respectively. Figures 8 and 10 show microstructures of specimens of steel sample B austenized at 800°C and austempered in 10% concentrated brine quenchant maintained at 300°C for 30 and 45 minutes. Figures 9 and 11 are microstructures of steel sample B raised to 800°C; austempered in 50% concentrated brine at 300°C for 30 and 45 minutes.

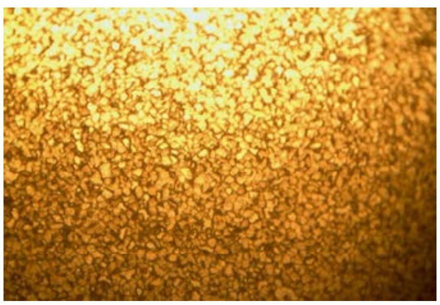

Fig. 2: Photomicrograph (magnification X100) of steel sample A before austempering

Fig. 3: Photomicrograph (magnification X100) of steel sample B before austempering

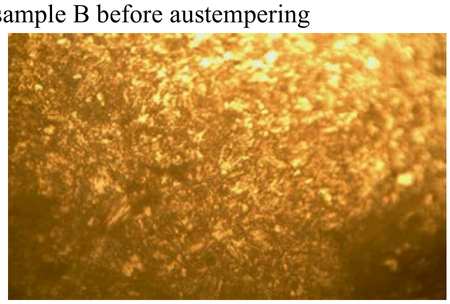

Fig. 4: Photomicrograph (Magnification X 100) of steel sample A austenized at 900°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 30 minutes

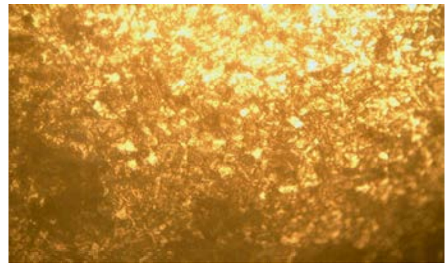

Fig. 5: Photomicrograph (Magnification X 100) of steel sample A austenized at 900°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 60 minutes

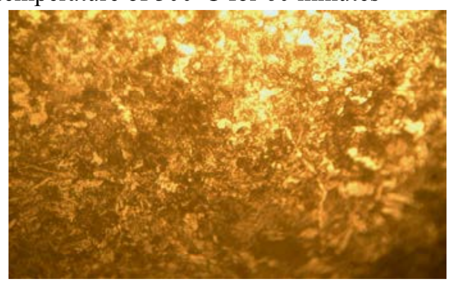

Fig. 6: Photomicrograph (Magnification X 100) of steel sample A austenized at 900°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 90 minutes

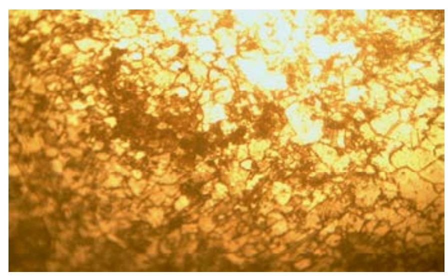

Fig. 7: Photomicrograph (Magnification X 100) of steel sample A austenized at 900°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 120 minutes.

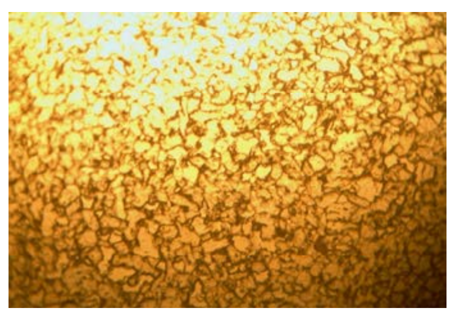

Fig. 8: Photomicrograph (Magnification X 100) of steel sample B austenized at 800°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 30 minutes

Table 4: Mechanical properties of the experimental steel sample A before austempering

Brinel Hardness (No)	Tensile strength (N/mm^2)	Impact strength (Joules)	Yield ((N/mm^2)
166.85	528.90	62.73	415.14

Table 5: Mechanical properties of the experimental steel sample B before austempering.

Brinel Hardness (No)	Tensile strength (N/mm^2)	Impact strength (Joules)	Yield ((N/mm^2)
201.38	576.38	69.33	465.76

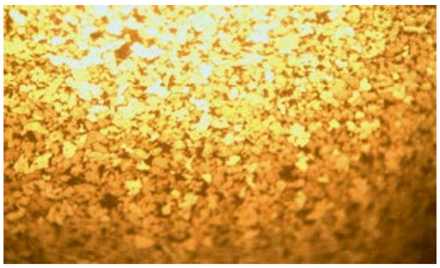

Fig. 9: Photomicrograph (Magnification X100) of steel sample B austenized at 800°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 60 minutes

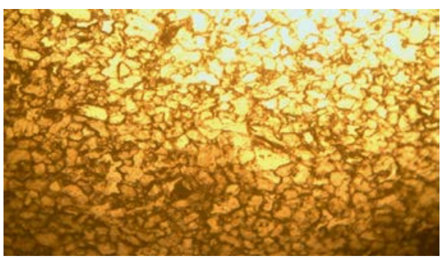

Fig. 10: Photomicrograph (Magnification X 100) of steel sample B austenized at 800°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 90 minutes

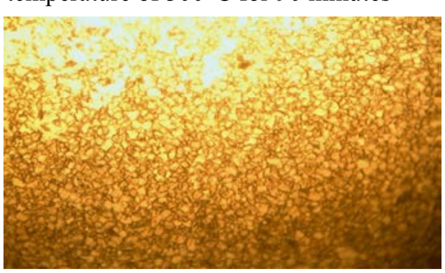

Fig. 11: Photomicrograph (Magnification X 100) of steel sample B austenized at 850°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 30 minutes.

Figure 12 is microstructure of steel sample B specimen quenched from 850°C in 10% brine maintained at 300°C for 30 minutes. Figures 13, 14, 15, 16 and 17 are graphical results of ultimate tensile strength, impact strength, reduction in area, hardness and percentage elongation respectively of specimens of sample A

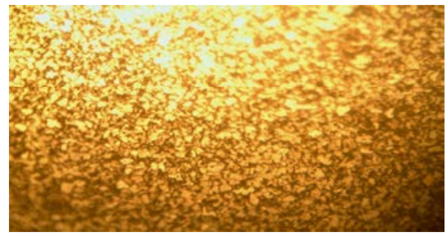

Fig. 12: Photomicrograph (Magnification X 100) of steel sample B austenized at 900°C and quenched in 10% concentrated brine maintained at a temperature of 300°C for 30 minutes

austenized at 900°C and austempered in 10% concentrated brine at 300°C for varying periods. Figures 18, 19, 20 and 21 show ultimate tensile strength, percentage elongation, hardness and endurance limits respectively of steel sample B austenized at temperatures of 750°C to 950°C; austempered in baths of 10% concentrated brine maintained at different holding times of 30, 60, 90 and 120 minutes.

DISCUSSION

Figures 2 and 3 presented the microstructures of steel samples A and B which are predominantly made of averagely fine grained pearlite distributed in ferritic matrix. The fine structure reflect the mechanical working that the samples went through to shape into the commercial forms in which it was sourced i. e. cylindrical rods. The results presented in Tables 4 and 5 for the properties of the as-received samples A and B respectively, show some elevated values of mechanical properties due to the same reason of the previous processing that samples had gone through when shaping billet into rod. The photomicrographs presented in Figures 4 to 7 showed that structural changes occurred to phases of specimens as a result of austempering treatment. While untreated samples had fine pearlite and ferrite structures, Figure 4 show a microstructure of coarse ferrite with pearlite and some dull structures of non-completely transformed bainite. Though induced mechanical stress observed in original test piece was relieved by austempering treatment, 30 minutes quenching wasn't sufficient for

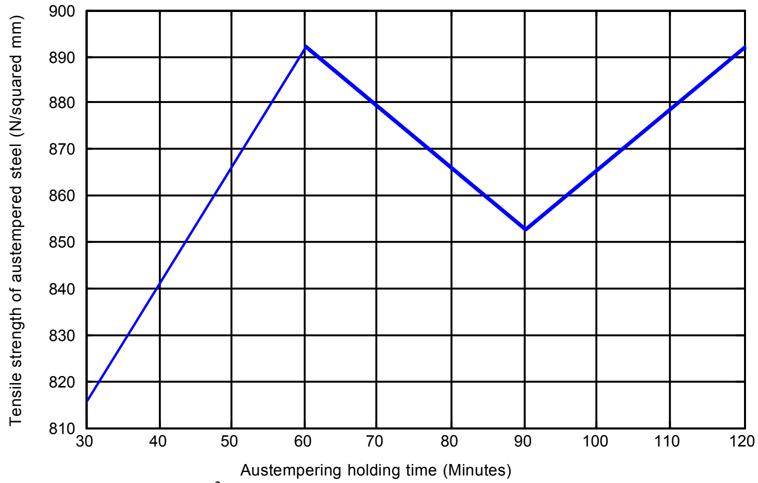

Fig. 13: Ultimate tensile strength (N/mm^2) of mild steel sample A heated to 900°C and austempered at 300°C in brine of 10% salt concentration against austempering quench holding time (Minutes)

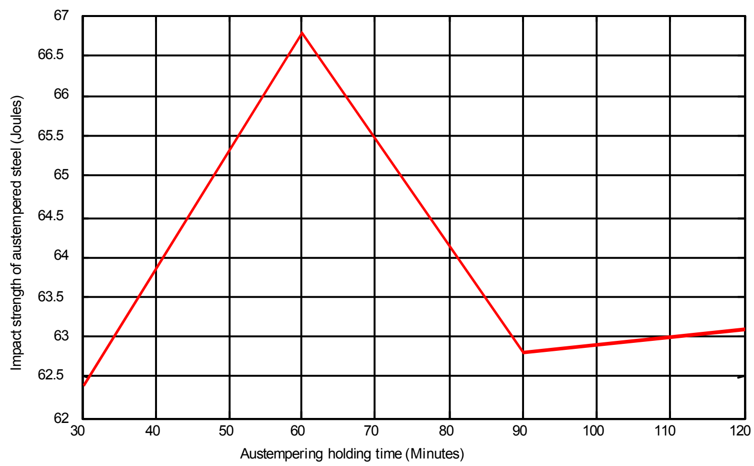

Fig. 14: Impact strength (Joules) of plain carbon steel sample A heated to 900°C and austempered at 300°C in brine of 10% salt concentration against austempering quench holding time (Minutes)

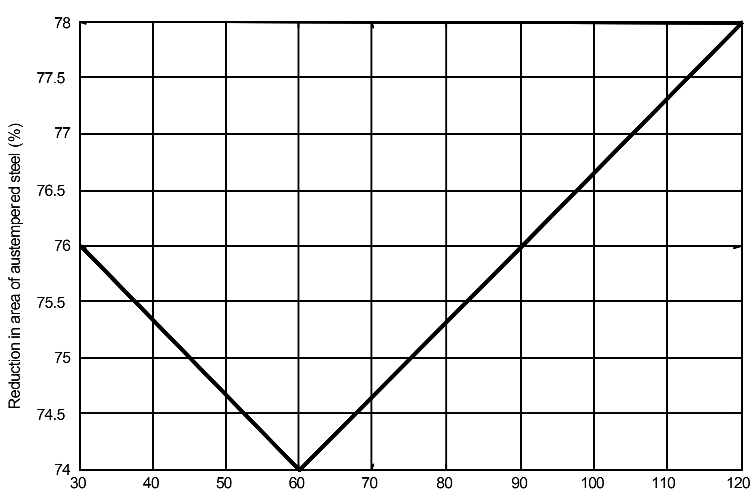

Fig. 15: Reduction in area (%) of mild steel sample A heated to 900°C and austempered at 300°C in brine of 10% salt concentration against austempering quench holding time (Minutes)

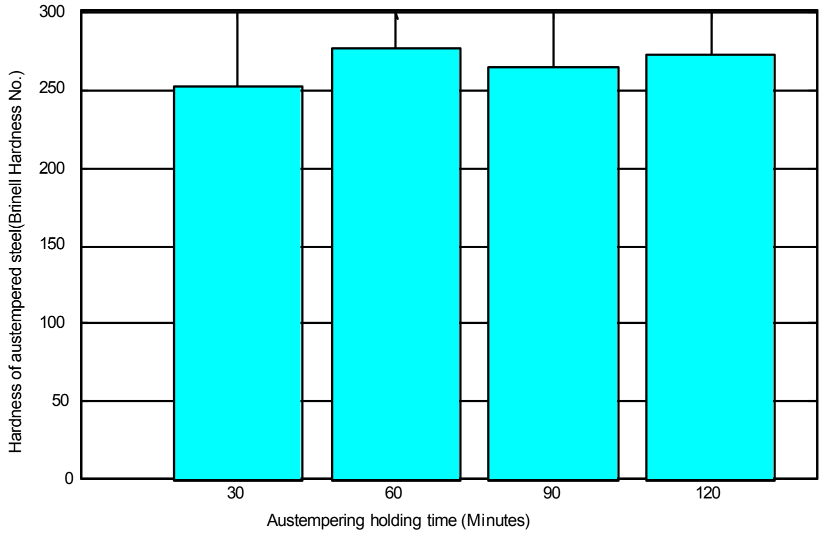

Fig. 16: Hardness (Brinell hardness No.) of mild steel sample A heated to 900°C and austempered at 300°C in brine of 10% salt concentration against austempering quench holding time (Minutes)

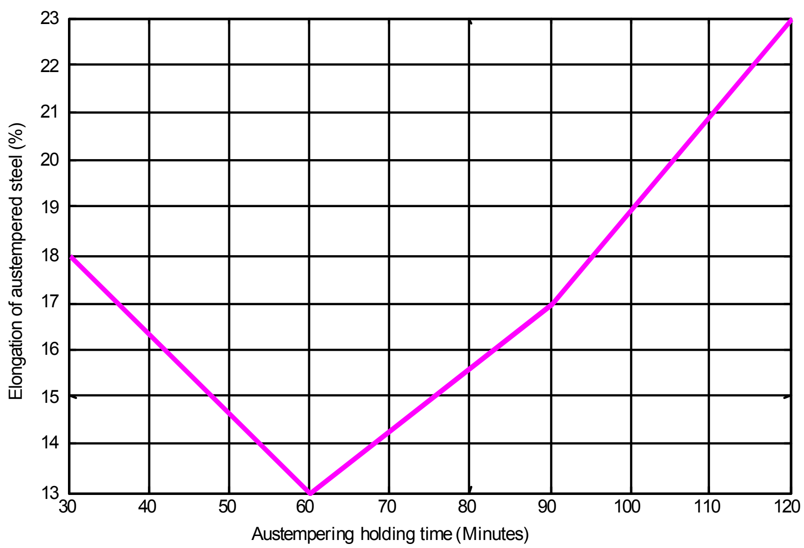

Fig. 17: Percentage elongation (%) of plain carbon steel sample A; heated to 900°C and austempered at 300°C in brine of 10% salt concentration against austempering quench holding time (Minutes)

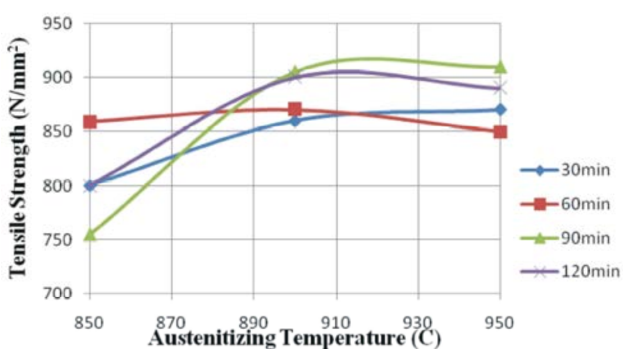

Fig. 18: Ultimate tensile strength (N/mm^2) of mild steel sample B heated to varied temperatures and quenched in 10% brine solution maintained at 300°C for different austempering holding periods (minutes)

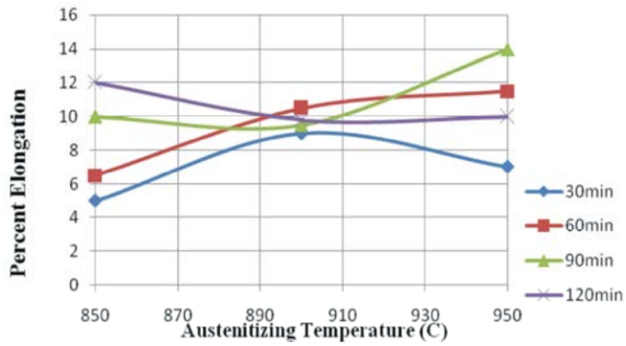

Fig. 19: Percentage elongation (%) of mild steel sample B heated to varied temperatures and quenched in 10% brine solution maintained at 300°C for different austempering holding periods (minutes)

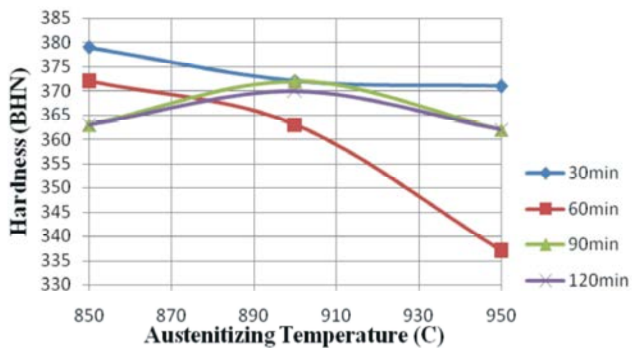

Fig. 20: Hardness (Brinell hardness No.) plain carbon steel sample B heated to varied temperatures and quenched in 10% brine solution maintained at 300°C for different austempering holding periods

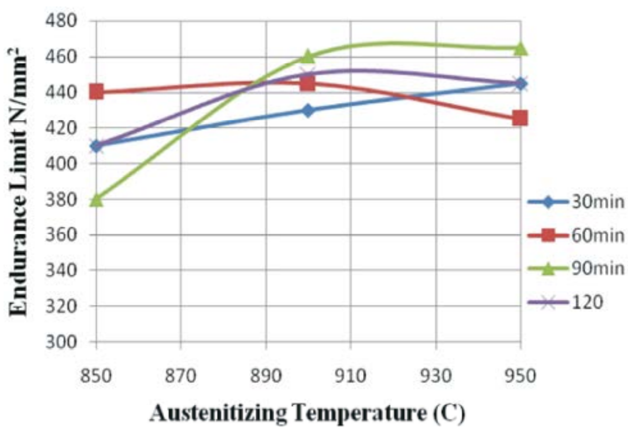

Fig. 21: Endurance limit (N/mm^2) of plain carbon steel sample B heated to varied temperatures and quenched in 10% brine solution maintained at 300°C for different austempering holding periods (minutes)

complete transformation of steel into bainite. In Figure 5 completely transformed bainite were seen distributed within ferrite matrix and fine pearlite grains. It showed that 60minutes retention period of specimen in 10% concentrated brine quenchant was sufficient for complete formation of tough bainitic phase from austenitic phase. As martensite formation was not readily stable at austempering temperature the high thermal conductivity of brine (about 89% higher than water) rapidly cooled steel from austenite to stable bainite before removal for air-cooling.

Photomicrographs in Figures 6 and 7 displayed similar microstructure phases of completely transformed bainite distributed within ferrite matrix and pearlite as those in Figure 5. The phase grains in Figure 6 are larger than those of Figure 5. Also grains in Figure 7 are larger than those in Figure 6. The steel specimen corresponding to the photomicrographs in Figures 6 and 7 had sufficient time to transform completely to bainite after austempering for 90 and 120 minutes respectively in brine quenchant maintained at 300°C. Grain size difference occurred due to length of time specimen spent in quenchant. Longer time enabled more time for grain growth that resulted to larger phase grain formation. Figures 8, 9 and 10 presented the microstructures of specimens of steel sample B raised to a temperature of 800°C; austempered in 10% concentrated brine maintained at 300°C for 30, 60 and 90 minutes respectively. In comparison with untreated steel sample B in Figure 4, it was observed that significant microstructural changes occurred. While Figure 4 showed a microstructure of fine grained pearlite distributed in ferrite matrix, Figures 8, 9 and 10 are microstructure of stress relieved ferrite, pearlite and noncompletely/ completely transformed bainite of bigger grains. Figure 8 showed some dull structure of non-completely formed bainite with the ferrite and pearlte. Bainite in this figure was dull lustred because 30 minutes holding time in quenchant wasn't sufficient for its complete formation before specimen was removed and air cooled.

In Figures 9 and 10, 60 and 90 minutes were sufficient for complete transformation of autenized steel to bainite. Because of higher carbon content in steel sample B, there is higher presence of carbon rich phases of bainite and pearlite in it microstructure than those corresponding specimens of steel sample A presented in Figures 4, 5, 6 and 7. However just like austempered specimens of steel sample A, longer period available for steel sample B held for 90 minutes had longer time for grain growth. Thus, its phase grains in photomicrograph of Figure 10 had larger grains than that of Figure 9 corresponding to specimen treated for 60 minutes. Figures 11 and 12 presented the photomicrographs of specimens of steel sample B raised to a temperature of 850°C and 900°C respectively; austempered in 10% concentrated brine held for 30 minutes. Both showed changes from the microstructure of untreated sample B (Figure 4). Induced mechanical stresses were relieved with some dull partially formed bainite which didn't exist in Figure 4 was observed to have been formed. Apart from insufficiency of the 30 minutes treatment period, excess heat in form of degree of superheating of specimen from 800°C to 850°C and 900°C created longer time for heat extraction for specimens after quenching in brine held at 300°C. Thus, the rapidity of cooling wasn't enough for complete transformation of austenized steel to fully formed bainite.

In Figure 13, tensile strength of austempered sample A specimens increased with holding time from 30 to 60 minutes, dropped at 90 minutes and again increased at 120 minutes. The trend showed quantities of smaller grains sizes and tough phases present in steel. When compared with properties of untreated steel, Table 2, it was observed that ultimate tensile strength was increased by an average of 46% due to the treatment. The result showed that in accordance with the standard presented in Table 1, sample A steel austempered for 90 to 12 minutes are suitable for grade 1 gears and shaft production. The result of impact strength of steel sample A in Figure 14 showed that austempering improved the property by 7-10% and steel is suitable for grade 3 shaft and gear production as compared to Table 1. The percentage reduction in area presented in Figure 15 showed high level of mechanical workability of steel sample A before fracture and thus a measure of the toughness of the material. Figure 16 presented hardness values for austempered sample a steel. Hardness was highest for steel austempered for 60 minutes followed by that of 120 minutes then 90 minutes and 30 minutes in that order. In comparison with untreated sample A steel, hardness was almost doubled by austempering. By standard in Table 1 steel specimen treated for 60 and 120 minutes possessed sufficient hardness for grade 1 shaft and gear production. The percentage elongation in length presented in Figure 17 showed that by comparison with the standard of Table 1, steel sample A was still quite ductile and unsuitable for shaft and gear production even after austempering treatment. This ductility as dictated also by high percentage reduction in area was caused by low content of carbon and other bainite/austenite stabilization elements in steel.

The ultimate tensile strength presented in Figure 18 showed that strength of specimens of austempered steel sample B generally increased with holding time in brine quenchant and austenizing temperature up to 850- 900°C before it dropped. In comparison with untreated steel sample B, there was an average improvement of about 44% in ultimate strength. When compared with Table 1, specimens austenized at 850-900°C and quenched for 60 - 120 minutes were suitable for production of grade 1 gears and shafts. In Figure 19, percentage elongation increased with increasing austenizing temperature from 850 - 900°C and then dropped for sample B autestempered in brine for 30 and 60 minutes. However it decreased gradually from 850 - 900°C and then increased for steel austempered for 90 and 120 minutes.

This is because bigger phase grains were formed with longer holding period in quenchant due grain growth. By Table 1 standard, specimens austenized at 850 - 900°C and austempered in brine for 30 and 60 minutes are suitable for grades 1and 2 shaft and gear production. Those austenized at 850 - 900°C; austempered in brine for 90 and 120 minutes are suitable for grade 1 gear and shaft production. Austempered Steel sample B hardness generally decreased with increasing austenizing temperature and retention period in brine quenchant as displayed in Figure 20. Increased austenizing temperature caused delayed cooling and grain enlargement that reduced hardness just like increased retention period in quenchant gave more time for phase grain enlargement. Hardness of treated sample B steel was observed to have increased by an average of 45% over that of untreated sample. In comparison with Table 1 the hardness of specimens austenized at 850 - 900°C; austempered for 30 120 minutes are suitable for grades 1- 4 shaft and gear production. The endurance limits which also depicts the toughness of steel sample B presented in Figure 21 show a general pattern of increase with increasing austempering period. The plots for specimens quenched for 30 and 60 minutes are almost straight lines due to short quenching period that didn't allow much variation. The values showed suitable results for grades 1- 3 gear and shaft production.

CONCLUSION

The study determined metallographical and mechanical properties of some local steel materials recycled in Nigeria for possible elevation from present uses as reinforcement material for structural constructions to mechanical plant/engineering applications like automobiles. Austempering was used as strengthening and toughening heat treatment was used to enhance properties since the country still lacks facilities for alloying; as process of improving the quality of steel. The result showed that austempering significantly improved the properties of the two locally sourced mild steel samples used but that better strengthening was achieved with sample with higher carbon content. In comparison with the for the alternative to in this work to strengthen locally produced Nigerian steel using neem seed oil as quenchant to ascertain its suitability for production of automotive shafts and gears. In comparison to the ASTM 897 mechanical property limits for production of automotive shafts and gears presented in Table 1, result of this study showed that the sample with 0.16% carbon is only suitable by virtue of its ultimate tensile strength. The steel sample with 0.50% carbon content was found suitable for grades 1-4 shaft and gear production when austenized at 850-900°C and austempered in 10% concentrated brine maintained at 300°C for 60-120 minutes due to ultimate tensile strength, impact strength/endurance limit, hardness and percentage elongation. Steel austempered for 30 minutes was suitable for only grade 1 application. Special alloying additives to the recycled steel may be investigated in extended works to expand suitability of such steel for production of all grades of parts of mechanical machines requiring high strength and toughness.

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