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RESEARCH ARTICLE

SUITABILITY OF LINEARALKYLBENZENE (LAB) AND TOLUENE AS STEEL QUENCHANTS

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ABSTRACT

Evaluation of toluene and linearalkylbenzene as quenching media for 0.49 and 1.14Wt%C carbon steel was investigated. The samples were quenched to room temperature in the quenching media (toluene, linear alkyl benzene and water). The machined specimen of the steel were heated at 840^0C and 880^0C then quenched in water, toluene and linear alkyl benzene. Tensile strength, hardness and impact energy were used to measure the quenching potentials of the various media. The microstructures and mechanical properties of the quenched samples were used to determine the quench severity of the petrochemical products. The test of the mechanical properties shows that the hardness of steel quenched in water was (50.0, 46.6 and 63.1, 64.2 HRC), while the hardness of steel quenched in toluene was (8.9, 17.0 and 40.4, 44.3 HRC) samples which was recorded as the least in all samples quenched. Samples quenched in toluene absorbed the highest amount of energy (57.4, 34.3 and 16.0, 12.5J) before fracture while samples quenched in water absorbs the least energy (13.7, 6.5 and 3.4, 2.7J). The microstructure of the samples quenched in the toluene under study revealed the formation of low proportions of martensite and in the case of linearalkylbenzene, there was retained austenite. Hence, linearalkylbenzene can be used where cooling severity less than that of water would be required for hardening of plain carbon steels.

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INTRODUCTION

Quenching is an essential process of developing the desired properties of both ferrous and non-ferrous metals. The main goal of heat treatment of steel is to achieve the desired combination of mechanical properties when subjected to controlled heat treatment. Quenching is one of the most important processes of heat treatment that can improve the performance of steel greatly, however, an important side effect of quenching is the formation of thermal and transformational stresses that cause changes in size and shape that may result in crack formation (Brooks, 1996). Therefore, the technical challenge of quenching is to select the quenching medium and process that will minimize the various stresses that develop within the part to reduce cracking and distortion while at the same time provide heat transfer rates sufficient to yield the desired as-quenched properties such as hardness (Krauss, 1990). Linearalkylbenzene is a clear colourless liquid with a characteristic odour. It is most widely used as the basic raw material for the manufacture of synthetic detergent. The linearalkylbenzene produced from the C10 – C13 or C11 – C14 Linear mono olefins are useful detergent intermediates and can be readily sulphonated to yield linearalkylbenzene sulphonates. These compounds constitute the "active" ingredients of many house hold detergents. They are surface active compounds (surfactants) which are combined with various binders (often inorganic salts) to make up a detergent formula (Honeycombe and Bhadeshia, 1996). Toluene from coal gas and light oil toluene or toluol is obtained from light oil by fractional distillation process (Roberts *et al.,* 1998). The light oil obtained by coal carbonization is recovered by cooling and scrubbing the by-product coke oven gas. The light oils (containing 12 to 20% Toluene), scrubbed from coke oven gas and distilled from tar, are combined and fractionally distilled in continuous or semi continuous units. 0.1 to 0.2 gal of toluene is obtained per gal of combined light oil distilled (Roberts *et al.,* 1998). Tap water and brine could be used to quench some grades of steels but do not produce good results with high carbon steels; the reason being that the rate of cooling is high in the temperature range of martensite formation. This exposes steels to simultaneous influences of transformational and thermal stresses. The combined effects of these stresses increase the risk of crack formation (Beddoes and Parr, 1999).

Over time, engine oil (SAE 40) has been found to be a suitable quenchant for high carbon steel (Chaves, 2001). When quenched in engine oil, high carbon steels could be hardened without cracking due to lower quenching rate than water or salt solution (Vander Voort, 1991). However, two of the major

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problems associated with quenching in engine oil are that engine oil is combustible and could only be used under controlled atmosphere either as the oxidation of the oil results in the formation of carboxylic acid and sludge which affects the induced hardness and colour of the work piece (Vander Voort, 1991). Molten salt bath is an expensive furnace and scarce in developing countries like Nigeria and in addition has the following shortcomings:

- The molten salt bath may cause explosion as a result of instrument failure.
- Salt bath heat treating is very hazardous especially during cleaning and in maintaining the bath at elevated temperature (Smith, 1990).

On the safety side, engine oil is hazardous to operate. Tools must be hard and capable of assuming sharp cutting edges and maintaining the sharp cutting edges under severe operating conditions. Tools and dies must be able to resist wear; and must be strong enough to resist fracture. Proper quenching with subsequent heat treatment will develop desirable properties in steels for tools and dies. Also in selecting the desirable properties, it is always necessary to make a compromise. Maximum hardness is usually accompanied by excessive brittleness. If a plain carbon steel is heat treated so as to obtain maximum hardness and strength, it may be so brittle that it will prove useless for a particular service. Increasing the rate of cooling during the full annealing of steel results in increasing fineness of the iron carbide and ferrite plates in the pearlite and these changes in structures result in somewhat higher hardness and strength values. Under such conditions the iron carbide or cementite particles become increasingly fine and are most uniformly distributed throughout the ferrite matrix (Offor *et al.,* 2010). Mineral oils have been used as quenchants for a long time since a wide range of quenching characteristics can be obtained through careful formulation and blending of the oils and additives (Higgins, 1998). Mineral oils can be any petroleum oil, as contrasted to animal or vegetable oils. Also a highly refined petroleum distillate, or white oil, used medicinally as a laxative. Mineral oils used in quenching are analogous to other petroleum products, including engine oils, spindle oils, and industrial lubricating oils such as gear lubricants. Nigeria is rich in these oils and fats that are mostly used in soaps, pharmaceuticals, candles and food industries.

The focus of this research is to develop quenchants that are cost effective, non-corrosive, and effective in inducing the required hardness without the problem of distortion and residual stresses.

Review of Related Literatures

Windergassen (1989) reported that quenching oils that contain substantial quantities of naphthenic derivatives usually exhibit inferior cooling characteristics, a greater deposit-forming tendency, and lower flash points than paraffinic oils. The lower flash points are particularly deleterious in heat-treating applications. Protsidim *et al.,* 1988 also showed that small changes in the compositions of the quench oils resulted in significant changes in quenching properties. Tensi (1985) had shown that the quench severity of a particular oil is directly related to its ability to wet a metal surface. Usually the particular additive or combined additive is added into the oil to accentuate the wettability of an oil, thus having a dramatic effect on oil properties including sludging, staining and so forth. The wettability of an oil can be quantified by measuring "rewetting" time or measuring the contact angle of the oil on that surface. According to Higgins (1998), heat treatment can be applied to steels and cast irons not only to harden but also to improve their strength, toughness and ductility. The types of heat treatment used will be governed by the carbon content of the alloy and its subsequent application. American Society of Metals (American Society for Metals, 1964), Rajan *et al.,* 1988 and Khanna (2002) pointed out that the purpose of any heat treatment process is to produce the desired changes in the structure and properties of an alloy by heating to a specified temperature, soak it at this temperature and subsequently cooling to room temperature. The factors that determine the outcome of heat treatment operations are the temperature at which it is cooled to room temperature, length of time the metal is held at elevated temperature and the cooling rate.

Mechanism of Quenching

Quenching is an operation whereby the surface of the work piece is cooled, thus, establishing a temperature gradient within the workpiece, which in turn allows heat to flow from the workpiece to the quenching medium. The moment a workpiece of steel at hardening temperature is placed in the quenching medium; its surface will be cooled. Immediately the heat will flow from the centre of the workpiece to the cooler surface where the temperature will tend to increase. This tendency is offset by the quenching medium which again cools the surface of the workpiece the action will continue with heat flowing from the centre of the workpiece to the surface until both the workpiece and the quenching medium attain the same temperature. The rate at which the heat can be abstracted from the steel is controlled by the thermal conductivity of steel and the specific heat of the quenching medium. If quenching medium is a liquid, the rate of heat dissipation will also be a function of latent heat of vaporisation. It can be seen that, there are physical limitations to the rate at which the heat can be removed under a given set of conditions. It is important that mass of the coolant be sufficiently large so that, during the quench the cooling medium temperature does not rise much (Offor *et al.,* 2010).

Quenching media under investigation

Toluene

Toluene is an aromatic hydrocarbon that is widely used as an industrial feedstock and as a solvent. Toluene occurs naturally at low levels in pine oil and is usually produced in the processes of gasoline via catalytic reformer, in an ethylene cracker or making coke from coal. Final separation, either via distillation or solvent extraction (Hogan, 2011).

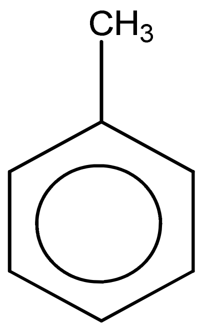


Fig. 1. Chemical structure of Tuolene

Table 1. Chemical composition of as-received medium carbon steel

Element	C	Si	Mn	S	P	Ni	Cr	Cu	N	Fe
Composition wt %	0.49	0.23	0.66	0.01	0.09	0.91	0.07	0.12	0.02	Balance

Table 2. Chemical composition of as-received high carbon steel

Element	C	Si	Mn	S	P	Ni	Cr	Cu	N	Fe
Composition wt %	1.14	0.25	0.33	0.01	0.06	0.14	0.12	0.09	0.01	Balance

Linearalkylbenzene (LAB)

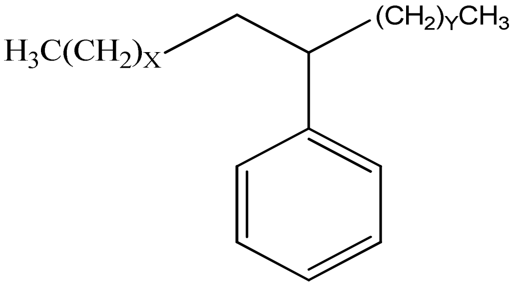


Fig. 2. Chemical structure of Linearalkylbenzene

The DETAL process involving dehydrogenation of n-paraffins to olefins, and subsequent reaction with Benzene using a fixed bead catalyst. This is new technology and has several of the stages depicted in the HF / n-paraffins process, but it is principally different in the Benzene alkylation step, during which a solid-state catalyst is employed. There is a developing transalklation (TA) stage to the Detal process wherein any higheralkylatedbenzene (HAB) are contacted with additional Benzene over a transalkylation catalyst (Thelning, 1984).

Factors affecting quenching

Several factors influence the effectiveness of a quenching medium in its ability to withdraw heat from a quenched part. These factors include: temperature of the medium, degree of agitation, surface conditions of the part, and the type of quenching medium (Grishin *et al.,* 1986). In addition, the configuration of the quenched part also plays a role in the rate of heat transfer during quenching (Kulikov, 1997).

MATERIALS, EQUIPMENT AND METHODS

Materials

The steel sample used for the research work was obtained commercially from Dana Steel Ltd, Katsina, toluene and linearalkylbenzene and its chemical composition were analysed at the Defence Industries Corporation of Nigeria (Research and Development Centre) Kaduna State.

Equipment

The equipment used includes

- Searchtech Sx-5-12 box-Resistance Furnaces controller box heat treatment furnace
- Impact Testing Machine, Hounsfield Balance Impact machine tensometer Ltd.
- Tensile Testing Machine Hounsfield Tensometer Serial number 4720 manufactured in England
- Hardness Testing Machine Indentec universal hardness testing machine Model 8187.5LKV (B)
- Grinding machine model 39-1471 GRIT 240 Handimet I made in USA by Buehled Ltd.
- Rotary Wheel polishing machine model 051932 Polimet Polisher.
- Etching reagent CA Solution of two percent Sodium hydroxide (2% NaOH) in water or 2% Nital Solution .
- Metallurgical microscope model number NJF-120A.
- Lathe machine Colchester/triumph.

RESEARCH METHODOLOGY

Samples were machined from medium and high carbon steels having carbon content of 0.49%C and 1.14%C respectively. One set of the machined samples was tested in the as-received composition. The samples were austenitized to attain sufficient soaking within a temperature range of 840^oC and 880^oC for 1 hour 20 minute in the furnace and quenched to room temperature in each of the investigated quenchants. The quenched samples were then removed, cleaned and subjected to micro hardness, tensile and impact tests respectively.

Sample preparation

The samples of medium and high carbon steels was taken to the machine shop for preparation into tensile, impact and hardness tests specimens, the specimens were prepared based on the ASTM standards.

Experiment procedure

The prepared medium and high carbon steels samples (charpy test standard for impact test, tensile and hardness test) were quenched in three (3) different quenching media, tap water, linearalkylbenzene and toluene by varying the solutionizing temperatures (840^0C and 880^0C) to determine the effects of these quenching media have on the mechanical properties of the both medium and high carbon steel (tensile strength, toughness and hardness). During the experiments the following operations were undertaken: heating operation, quenching process, testing of mechanical properties and micro-examinations.

Heat treatment operations

The heat treatment operations were carried out at the heat treatment laboratory of Metallurgical and Materials Engineering Department of Ahmadu Bello University, Zaria. A serachtech Sx-5-12 box-Resistance furnace was used to heat the prepared samples to the selected solutionizing temperature of 840^0C and 880^0C and holding time of 20 minutes. The sample were arranged in the furnace, so as to allow uniform circulation of hot air.

Quenching operations

The quenching media were weighed to be at uniform weight of 2kg. After heating both samples to the required austenitizing temperature, these samples were immediately quenched in linearalkybenzene, toluene and tap water respectively. The media were agitated in order to increase the rate of heat transfer through the quenching process. The samples were removed from the various media to perform mechanical tests.

Mechanical tests

Tensile test

Samples were machined to the standard dimensions prior to the heat treatment operations. The tensile test samples were machined to standard dimensions as specified in ASTM A370. The method adopted was ASTM E8. The specimen was mounted on the machine, the test was performed by applying a maximum uniaxial load 20KN to fracture the specimen. The maximum load that leads the specimen to failure and the corresponding dimensions were recorded. The effect of various heat treatment conditions on the tensile properties was studied. The yield and maximum loads were recorded directly from the machine. After fracture, the two broken end of the specimens were fitted together and final gauge length at the smallest diameter of the neck were measured.

Impact test

The impact test samples were machined to standard dimensions as specified in ASTM A370. The test method adopted was ASTM E23. The samples were machined to 8 mm diameter and 45 mm length with a 1 mm deep V- notch. The test specimen was then gripped vertically in a vice, the test was carried out by raising the hammer (pendulum) to a height of 1 meter and then released to strike at the specimen and the energy absorbed was registered in the pointer of the quadrant scale which indicated the energy absorbed in joule by the specimen. The energy absorbed in breaking the sample were recorded and repeated for other pieces.

Hardness test

Rockwell hardness tester was used for hardness measurement. The hardness test samples were prepared to standard dimensions as specified in ASTM A370. The test method adopted was ASTM E18. The test was done in two loading steps, one being primary and the other was the actual hardness test. The samples were placed respectively on the anvil which was raised manually until the sample contacted the penetrator. The upper part of the machine has a diamond cone indenter of 120 degrees then, the sample was raised slightly higher until a minor load or pre load of 10kg to dig slightly into the sample. After the minor load of 10kg was applied, the major load of 150kg was applied by actuating a handle on the front of the machine. As this major load was applied, the penetrator moved deeper into the sample. The hardness values were read directly off a scale on the machine displayed on the screen.

The Jominy end-quench test

The Jominy End–Quench test consists of selectively cooling a standard size bar of steel, the specimen consists of a cylindrical bar with a 25mm diameter and 100mm length. After the sample has been austenized, it was placed in a fixture, and a jet of water was quickly splashed onto one end of the specimen for 30minutes. Only one end of the specimen was actually quenched, and as a result, the transformation of austenite begins at the water-cooled end and progresses up the bar. The cooling rate decreases with increasing distance from the quenched end. After cooling, a flat surface is ground on the test bar and hardness measurements were made along the surface up to 75mm from the quenched end.

Determination of cooling curve

Cooling curves were obtained under unagitated conditions according to ASTM D6200-01. A K-type thermocouple was fitted in a hole drilled at the geometric centre of the test piece. The test sample was heated in a furnace to 880^0C, held for 1 hour, and then quenched in brine, toluene, linear alkyl benzene and water. On cooling, the drop in temperature and the corresponding time were recorded. The data obtained were used to plot the cooling curve for the medium.

Micro-examination operation

Prior to the micro-examination operation, samples (both untreated and heat-treated) were prepared for viewing under the microscope, the specimen were prepared by grinding, polishing and etching. Grinding was carried out on heat treated samples of the medium and high carbon steel using a hand grinding deck of abrasive papers of successively finer grades lubricated by a gentle flow of water on the abrasive papers of grade 220, 240, 320, 400, 600 and 1000, the operation was repeated for all the samples. The polishing was carried out on two 150mm rotating disc of a UNIFIELD universal polishing machine. Rough polishing was done with synthetic velvet polishing clothes impregnated with 1-micro alumina paste. Final polishing was carried out with 0.5-micro chronic oxide polishing powder. A solution of 2% Nital solution was prepared as etching solution. Etching was done by immersing the polished specimen surface into the etching reagent for 3 minutes and methylated spirit was used to clean the surface of medium and high carbon steel for 2 minutes and allowed to dry. The microscopic examinations were carried out on a wild X100 optical metallurgical microscope (the bench type) and the microstructural changes that took place in all the prepared samples were recorded with the aid of an in-built-camera.

RESULTS AND DISCUSSION

The following results were based on the tests carried out on each specimen made from the medium and high carbon steel, heated at 840^0C, 880^0C and quench in three media linearalkylbenzene, toluene and tap water.

Tensile test

The tensile test specimens were loaded to fracture on a tensile testing machine. From the data generated, yield strength (YS), percentage elongation (%) in area and the ultimate tensile strength (UTS) were calculated and the results presented in Table 3 and 4.

Impact test

The results obtained from the v-notch Charpy test are shown in Table 5 and 6;

Table 3. Results of Tensile Test for Medium Carbon Steel Quenched in Different Media

Quenching Media	Heat Temp. (^0C)	Solution time (minutes)	UTS N/mm^2	YS N/mm^2	Percentage /Elongation (%)
Water	840	20	1082.86	866.29	8.40
	880	20	1129.94	903.95	7.10
Toluene	840	20	881.06	704.85	15.50
	880	20	896.59	717.27	18.20
Linear Alky Benzene (LAB)	840	20	847.46	677.97	16.60
	880	20	820.17	656.14	19.20
Control Sample (AS-Received)	-	-	651.30	521.04	22.40

Table 4. Results of Tensile Test for High Carbon Steel Quenched in Different Media

Quenching Media	Heat Temp. (^0C)	Solution time (minuts)	UTS N/mm^2	YS N/mm^2	Percentage /Elongation (%)
Water	840	20	46.11	36.89	1.00
	880	20	68.93	55.14	0.75
Toluene	840	20	719.53	575.62	5.30
	880	20	109.51	87.61	1.25
Linear Alky Benzene (LAB)	840	20	249.62	199.69	2.50
	880	20	217.39	173.91	2.25
Control Sample (AS-Received)	-		597.16	477.73	0.25

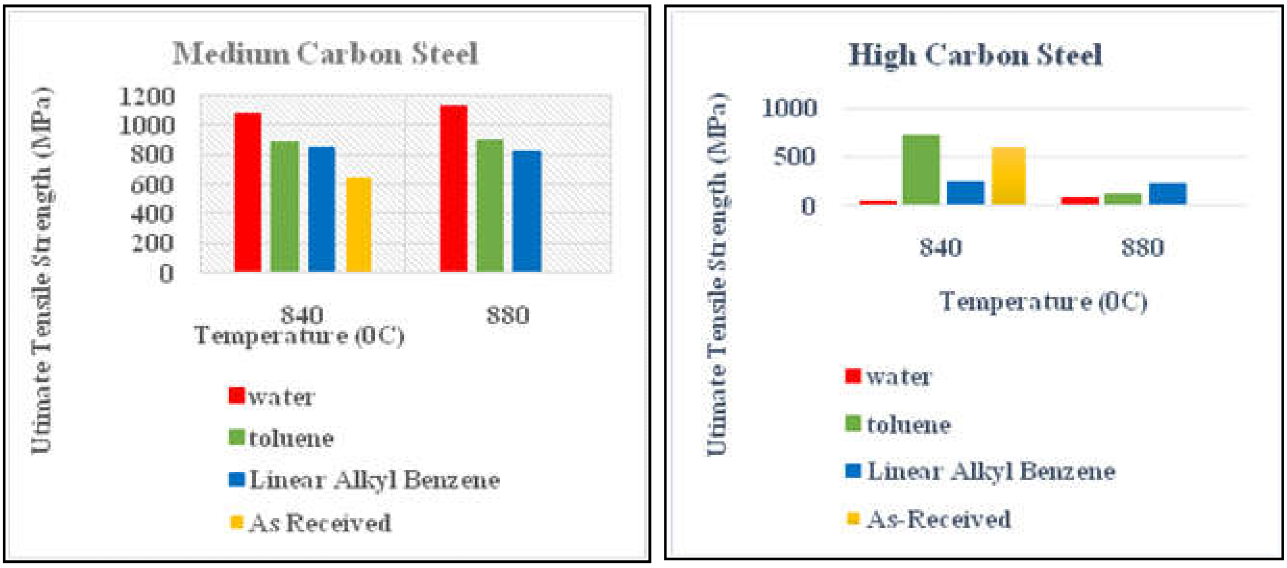


Figure 1. Variation of Ultimate Tensile Strength (MPa) within the Temperature range of 840 and 880 (^0C)

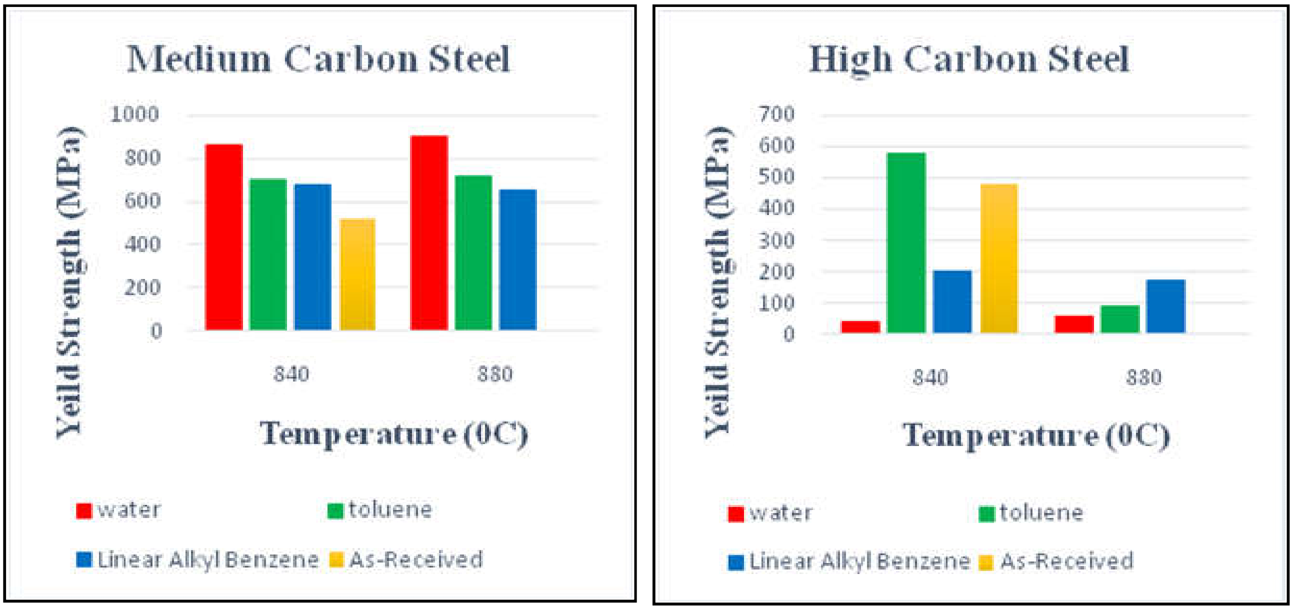


Figure 2. Variation of Yield Strength (MPa) within the Temperature range of 840 and 880 (^0C)

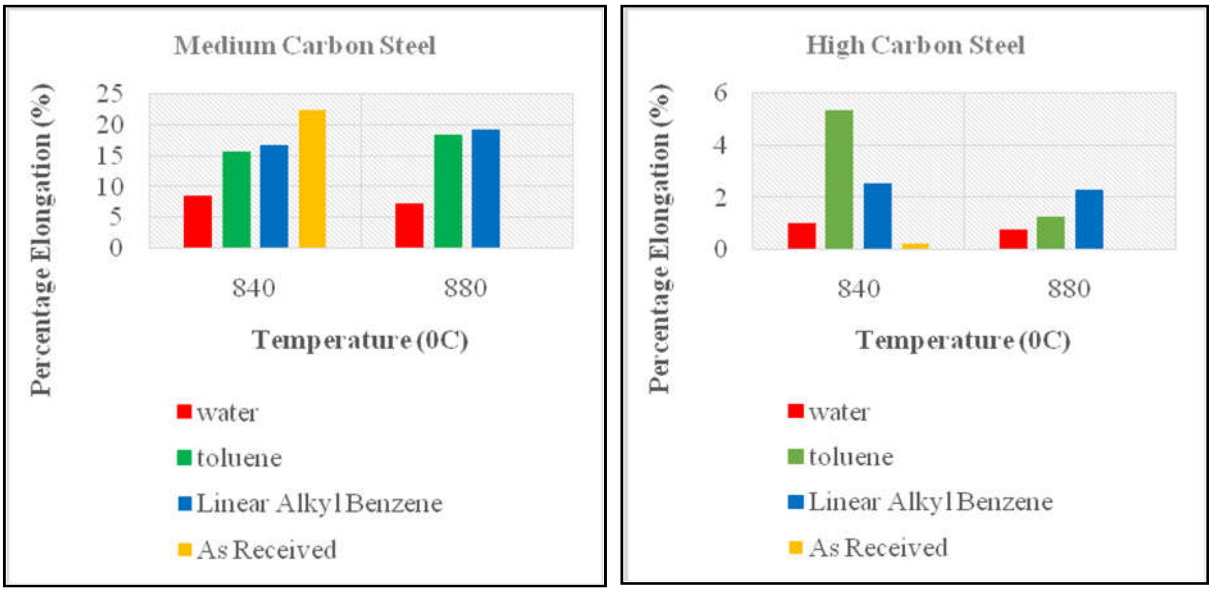


Figure 3. Variation of Percentage Elongation (%) within the Temperature range of 840 and 880 (^{0}C)

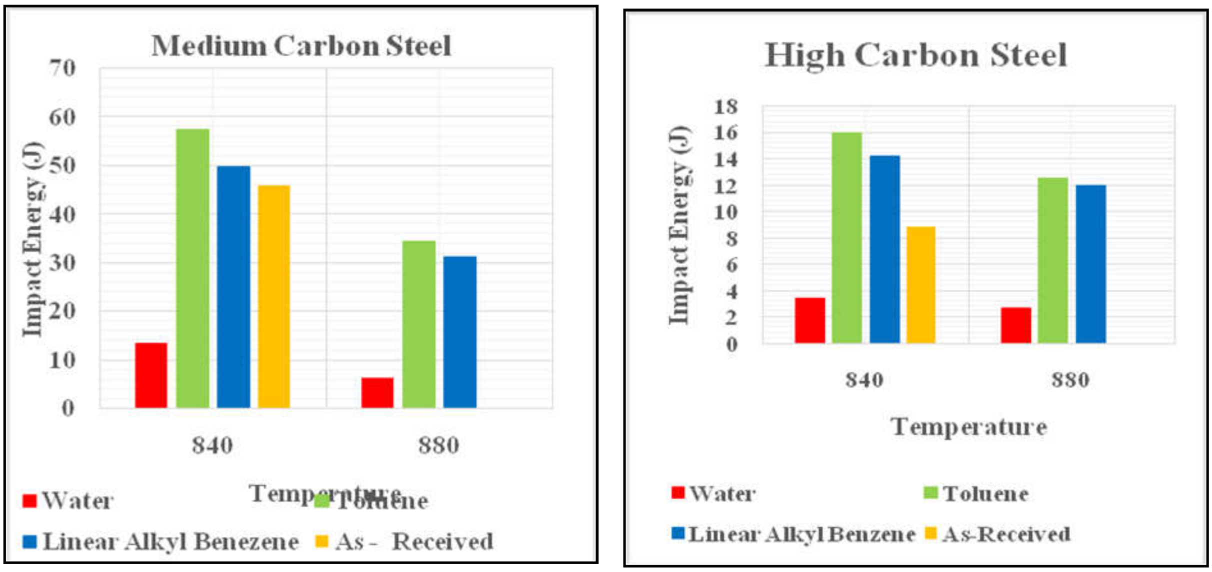


Figure 4. Variation of impact energy (J) within the Temperature range of 840 and 880 (^{0}C)

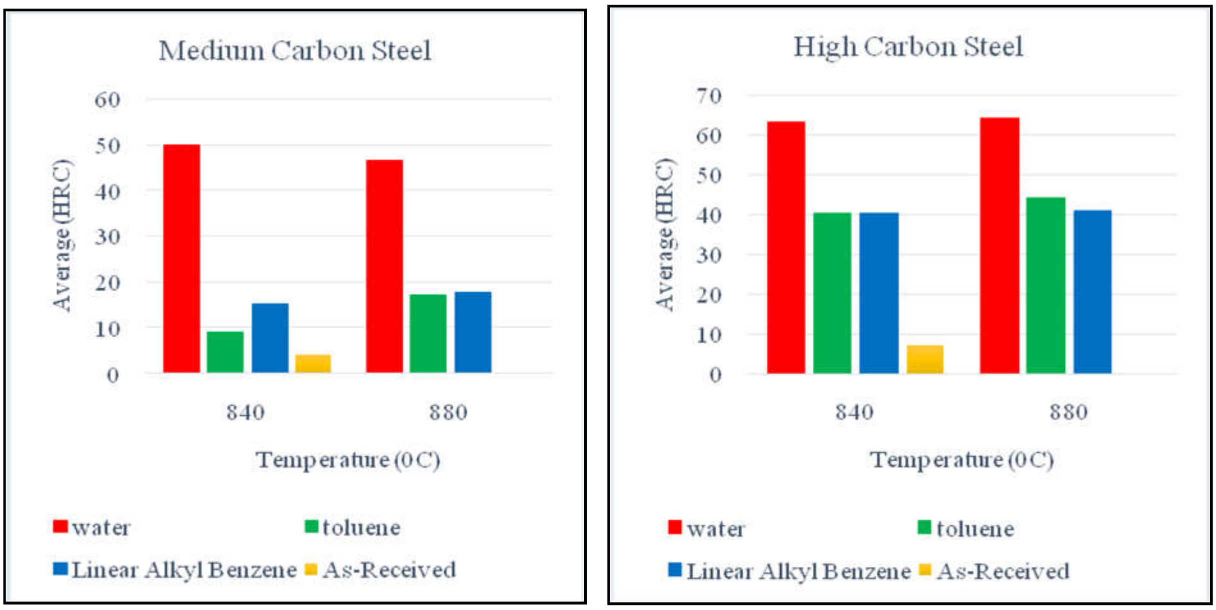


Figure 5. Variation of Average (HRC) within the Temperature range of 840 and 880 (^{0}C)

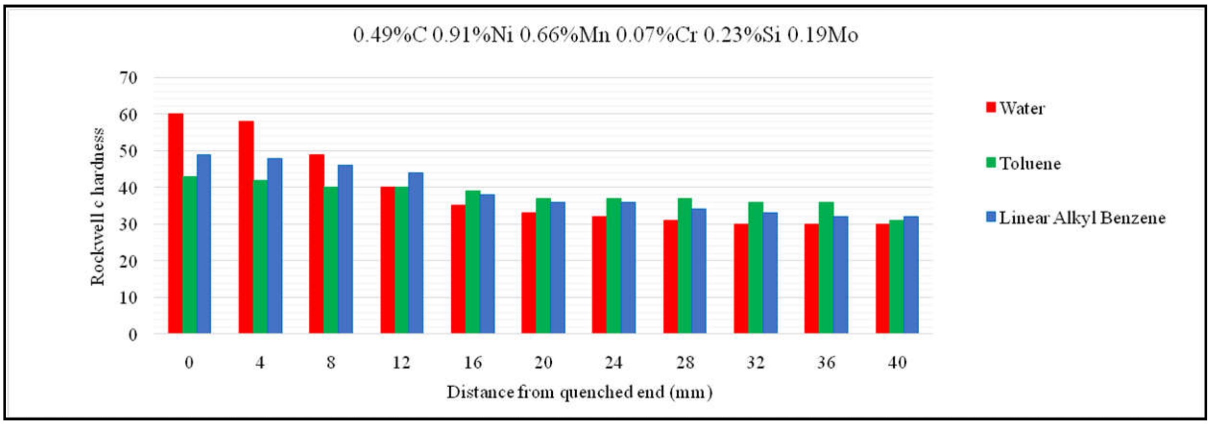


Figure 6. Jominy hardenability test for Medium Carbon Steel

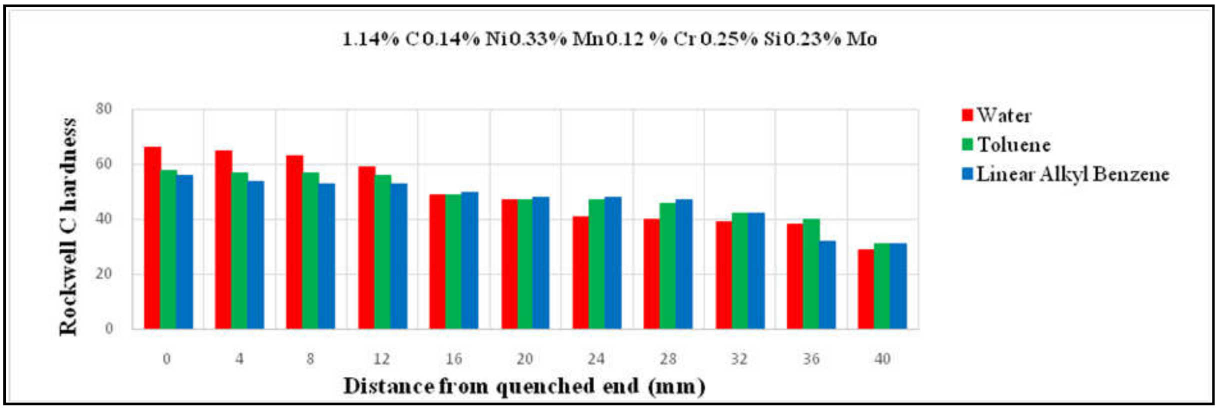


Figure 7. Jominy hardenability test for High Carbon Steel

Table 5. Charpy Impact Test Results Obtained from High Carbon Steel Quenched in Different Media

Quenching media	Temperature ^{0}C	Charpy impact value (J)
Water	840	3.4
	880	2.7
Toluene	840	16.0
	880	12.5
(LAB) Linear Alky Benzene	840	14.2
	880	12.0
Control Sample (AS-Received)	-	8.8

Table 6. Charpy Impact Test Results Obtained from Medium Carbon Steel Quenched in Different Media

Quenching media	Temperature ^{0}C	Charpy impact value (J)
Water	840	13.7
	880	6.5
Toluene	840	57.4
	880	34.3
Linear Alky Benzene (LAB)	840	49.8
	880	31.2
Control Sample (AS-Received)	-	46.1

Rockwell hardness test: Hardness test were conducted with the Rockwell hardness test method, three indentations were carried out on each specimen and average indentation was found. The results obtained are shown in Table 7 and 8.

DISCUSSION

Tensile Test

As revealed in figures 1 and 2 for both medium and high carbon steel were heated to 840^{0}C and 880^{0}C. The highest Ultimate Tensile Strength value for each medium carbon steel was 1129.94N/mm^2 (water quenched), 896.59N/mm^2 for toluene and 847.46 for linearalkylbenze, on the other hand the high carbon steel has the highest Ultimate Tensile Strength values of 719.53 N/mm^2 and 249.62 N/mm^2 for toluene and linearalkylbenzene respectively at temperature of 840^{0}C while that of water occurs at 880^{0}C, with a value of 68.93N/mm^2. Similarly, the highest yield strength obtained for medium carbon steel for water and toluene are 903.95 N/mm^2 and 717.27 N/mm^2 at 880^{0}C and that of linearalkylbenzene was 677.97 N/mm^2 at 840^{0}C, that of high carbon steel has its highest yield strength of 575.62 N/mm^2 and 199.69 N/mm^2 at 840^{0}C for toluene and linearalkylbenzene respectively.

The sample quenched in water has its highest at 880^{0}C with a value of 55.14 N/mm^2 when compared to the values of the control samples. However, the highest Ultimate Tensile strength of 1129.94N/mm^2 was obtained with sample heated to 880^{0}C and quenched in water. In contrast to the behaviour of the control sample, specimen for medium carbon steel quenched in toluene and water exhibited high values tensile strength at 880^{0}C at the same time maintaining low ductility. This means that the high strength produced was due to the effectiveness of the quenchants and their characteristics.

Impact test

The results for the impact test are shown in Table 3 and 4. the samples at 840^{0}C and 880^0 C quenched in linearalkylbenzene, toluene and water respectively showed a remarkable increase in the toughness of medium and high carbon steel in all cases, when compared with the value of 46.1 and 8.8 joules for the control sample. However, the medium carbon steel heated at 840^{0}C and quenched in Toluene has the highest value of 57.4 joules and that for high carbon steel has a value of 16.0 Joules.

Rockwell hardness

The hardness of high and medium carbon steel specimen quenched in water, toluene and linear alkyl benzene increased in this order. The highest hardness was at 880^{0}C for high carbon steel quenched in water with value of 64.2 HRC while toluene produced the next highest hardness value and linearalkylbenzene show a significant improvement in their hardness compared to control sample.

Jominy hardenability test

Water was found to have the greatest hardening power, but the relative differences in linearalkylbenzene and toluene were small. But out of the two media used linearalkylbenezene has a more tendency to harden than toluene.

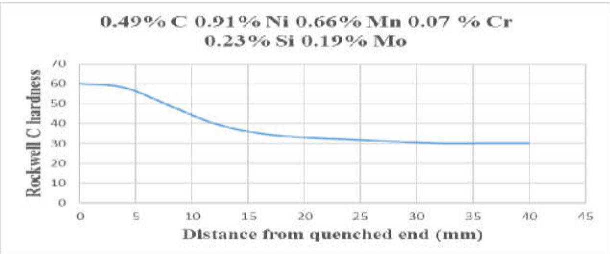


Figure 8. Jominy hardenability test for Medium Carbon Steel (Water)

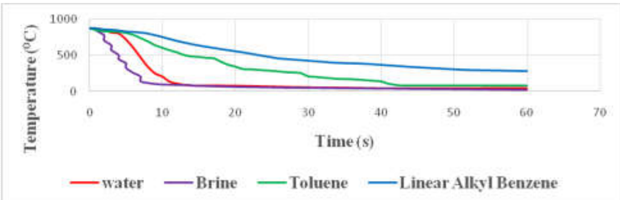


Figure 9. Cooling curves of different quenching media for medium carbon steel probe

Cooling curves

Figure 8 and 9 show the cooling curves of the various quenching media. The assumption was that the temperatures of the medium remain constant throughout the cooling operation. Brine proved to have the shortest stage I (vapour blanket stage): which is estimated to last in less than a second followed by water. Whereas stage II is estimated to last for 10 second. Linearalkylbenzene presents a prolonged vapour blanket and boiling stage; this is what makes it to have lower cooling rate than brine. The nucleate boiling stage for toluene is estimated to last 14 seconds; this is because of the fact that the heat extraction ability of this medium is relatively high.

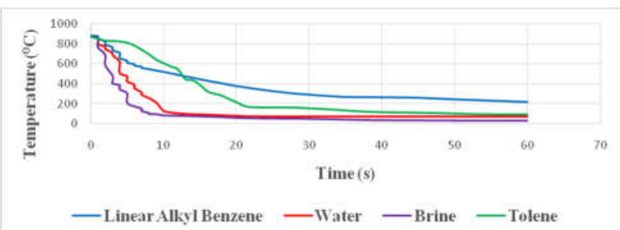
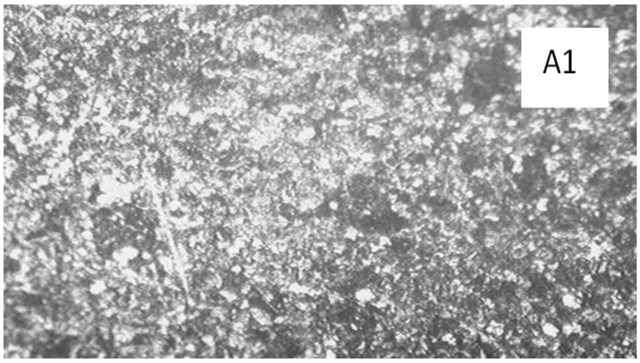


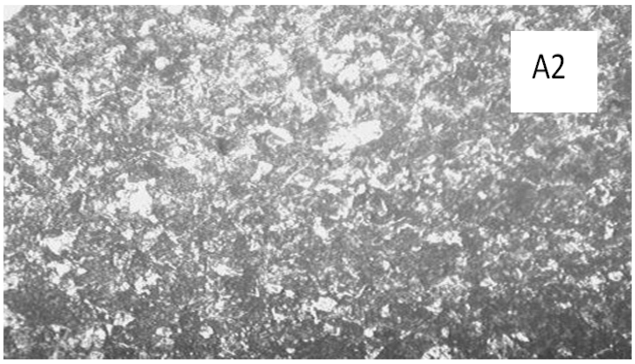
Figure 10. Cooling curves of different quenching media for high carbon steel probe

Micro structural examinations

The microstructure of the quenched samples of medium and high carbon steel as shown in plate i to vi, the as received structure of the test sample is shown in plate vii and viii; the structure consist of pearlite (dark) and ferrite (light) in plane from. The microstructures of medium carbon steel quenched in different media revealed the formation of martensitic in the matrix of pearlite. The results of micro structural examination of the specimens revealed that the specimens quenched in linear alkyl benzene and toluene at 840^{0}C (plate A1 and C1) possess higher values of impact test as shown in Table 4.1A, this is associated with large quantity of martensitic in evenly distributed in the matrix of pearlite some traces of ferrite is visible in the structure, which make the specimens to be tough and ductile as compare to other specimens which have a little coarse dispersion of precipitates.

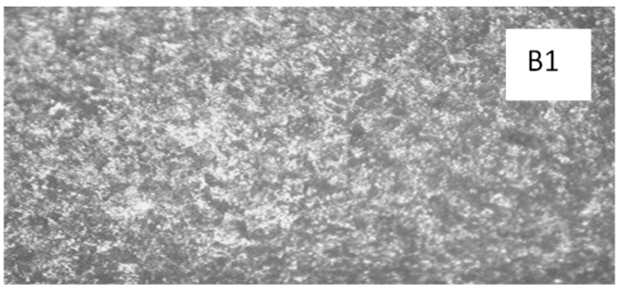


(A1) Microstructure of 0.49% carbon steel quenched in LinearAlkyl- Benzene; heated at 840^{o}C the structure consists of martensite (white) and pearlite (dark and grey) with unresolved ferrite



(A2) Martensite (white) is formed along with pearlite with some patches of ferrite. Samples austenitized at 880^{o}C. 2% Nital etch. Mag. X 100

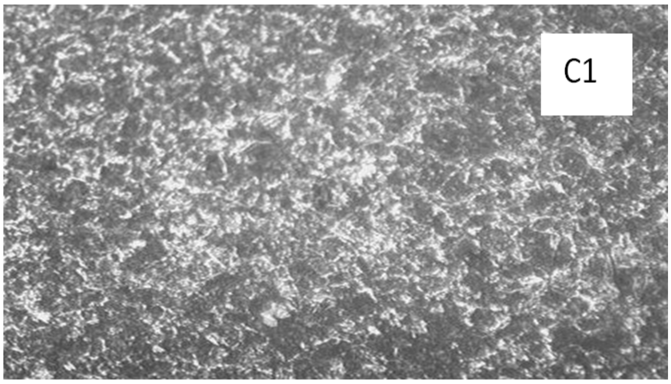
Plate I.



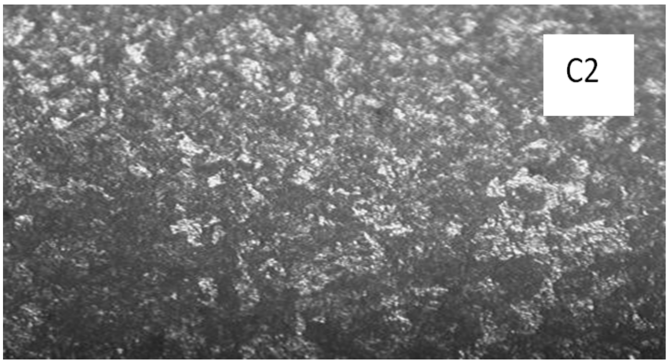
(B1) Microstructure of 1.14% carbon steel quenched in LinearAlkyl- Benzene; heated at 840^{o}C the structure consists of mainly bainite and pearlite

(B2) The structure is pearlite in predominantly martensitic matrix. Samples austenitized at 880°C. 2% Nital etch. Mag. X 100

Plate II.



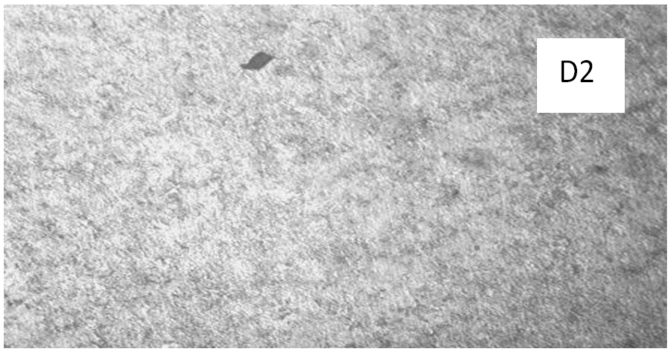
(C1) Microstructure of 0.49% carbon steel quenched in Toluene; heated at 840°C the structure consists of coarser martensite was evenly distributed and retained austenite



(C2) The structure consists of coarse structure of martensite formed in the matrix of pearlite. Samples austenitized at 880°C. 2% Nital etch. Mag. X 100

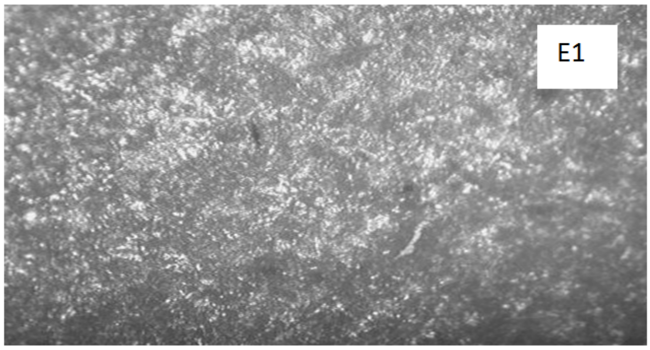
Plate III.

(D1) Microstructure of 1.14% carbon steel quenched Toluene; heated at 840°C the structure consists of martensite in coarse form and retained austenite

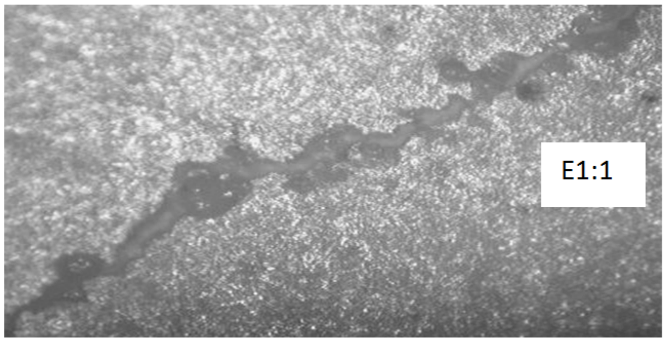


(D2) The structure is fine martensite. Samples austenitized at 880°C. 2% Nital etch. Mag. X 100

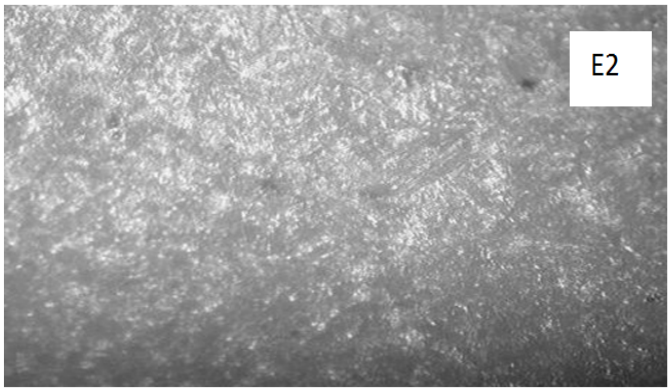
Plate IV.



(E1) Microstructure of 0.49% carbon steel quenched in water; heated at 840°C the structure consists of martensite (white) in the matrix of pearlite (dark)

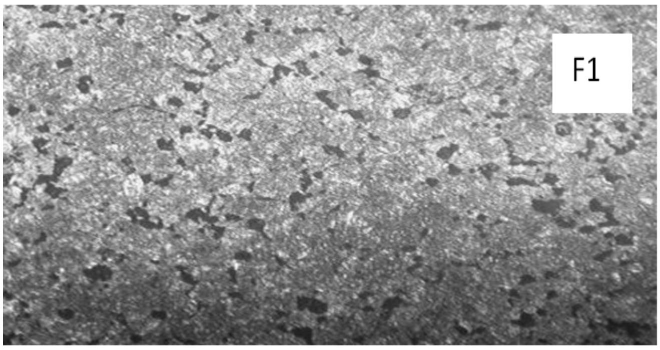


E1:1 shown a crack in a part of the steel due to thermal and transformational stress.

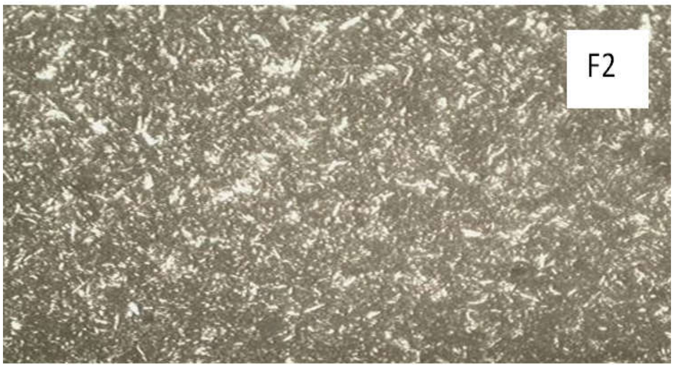


(E2) the structure reveals fine martensite in retained austenite. Samples austenitized at 880°C. 2% Nital etch. Mag. X 100

Plate V.



(F1) Microstructure of 1.14% carbon steel quenched water; heated at 840^{o}C the structure consists of martensite, unresolved cementite dotted and retained austenite



(F2) The structure consists of mixture of pearlite and martensite. Samples austenitized at 880^{o}C. 2% Nital etch. Mag. X 100.

Plate VI.

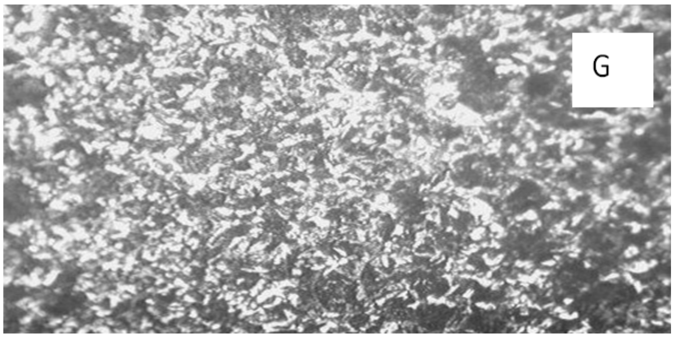


Plate VII. As received medium carbon steel coarse structure consists of pearlite (dark) and ferrite (light) and in plate forms

Plate VIII. As received high carbon steel the structure consists of tempered martensite

Conclusion

The potential of toluene and linearalkylbenzene as quenching media for medium and high carbon steel grades has been assessed using microstructure and mechanical properties. Based on the results obtained, the following conclusions were drawn:

- It has been established that toluene can be used as a quenching medium for medium carbon steel, since mechanical strength of some of the samples quenched with toluene improved when compared with those of the as-received sample.
- Quenching in water resulted in higher tensile strength and hardness due to formation of martensite after quenching.
- Linearalkylbenzene improves the ductility of the steel because of its lower cooling rate compared with toluene, brine and water. Thus, linearalkylbenzene will be a viable quenching medium, where improve elongation of the sample is critical.
- Toluene and linearalkylbenzene can be used to improve the toughness of these samples since they have higher impact energy values than those of water quenched specimen.

Recommendations

The following recommendations are made for further studies:

- The effect of temperature and agitations should be investigated within the range of 900^{0}C to 980^{0}C, for more improved properties of steel to be obtained;
- High speed camera should be used to study the cooling process distinctively for the three stages during quenching, because this enables a better capturing of the changes during the cooling process and gives better observation of what happens during the stages of cooling; and
- The two media should be further investigated for corrosion inhibitors.

REFERENCES

American Society for Metals, 1964. "Metals hand book".6thEdition.vol.2. Ohio, USA. pp.98-123.

Beddoes, J., and Parr, G. 1999. "Introduction to Stainless Steel, 3rd edition"., ASM International, Materials Park, OH.

Brooks, C. R. 1996. "Principles of the Heat Treatment of Plain Carbon and Alloy Steels", ASM International, Materials Park, OH.

Chaves, J.C. 2001. "The Effect of Surface Condition and High Temperature Oxidation on Quenching Performance of 4140 Steesl in Mineral Oil, in Manufacturing Engineering". Worcester Polytechnic Institute: Worcester. p. 8, 9.29.

Grishin, S.A. and Churyukin, Y.N. 1986. "Evaluation of the Cooling Capacity of Quenching Media Based on Water". *Metal Sci. Heat Treat.,* Vol. 28, Number 10, pp 744-5.

Hassan, S.B., and Aigbodion, V.S. 2013. "Evaluation of Khaya Seed Oil (Mahogany Oil) as Quenchant in the Hardening Process of Plain Carbon Steel". Pacific Journal of Science and Technology Vol 14, Number 1, pp19-30.

Higgins, R.A. 1998. "Engineering Metallurgy". First Edition Edward Arnold,London,UK. pp. 34 - 234, 239 - 370.

Hogan, C. 2011. "Sulfur is insoluble in water"National Council for Science and the Environment.

Honeycombe, R., and Bhadeshia, H. K. 1996. "Steels: Microstructures and Properties, 2nd ed.," Wily, New York.

Khanna, O.P. 2002. “Materials Science and Metallurgy”. Dhampat Rai publications Ltd. New Delhi. First Edition: pp. 98 – 342

Kulikov, A.I. 1997. “A New Quenching Medium for Metals and Alloys”. Metal Sci. Heat Treat. Vol 39, Number 11-12, pp 528-30.

Krauss, G. 1990. “Steels-Heat Treatment and Processing Principles”, ASM International, Materials Park, OH.

Offor, P. O., Daniel, C.C. and Obikwelu, D.O.N. 2010. “Effects of various Quenching Media on the Mechanical Properties of Intercritically Annealed 0.15Wt%C – 0.43Wt%MnSteel”. Nigerian Journal of Technology, Vol. 29 No 2, pp 76-81. [43]

Protsidim, P. S., Rudakova, N. Y and Sheremeta, B. K. 1988. “Metalloyed”. Term. Obrab. Met, p. 5-7.

Rajan, T.V. and Sharma, C. P. 1988. “Heat Treatment, Principles and Techniques”. Prentice–Hall of New Delhi.India.pp.20-150,236-380.

Roberts, G., Krauss, G and Kennedy, R. 1998. “Tool Steels, 10th edition”, ASM International, Materials Park, OH.

Smith, W.F. 1990. “Principles of Materials Science and Engineering”, McGraw-Hill.

Tensi, H.M., Steffen, E. 1985. “Measuring of the quenching effect of liquid hardening agents on the basis of synthetics”, Steel Research, vol. 56, p. 489-496

Thelning, K.E. 1984. “Steel and Its Heat Treatment”, 2nd ed. Butterworth, London, England, UK.

Vander Voort G.F. 1991. “Hardenability, in: Atlas of Time-Temperature Diagrams for Irons and Steels”, ASM International, Materials Park, OH, USA, pp. 73-77.

Windgassen, R. J. 1989. “Metalworking Fluid Today”, Society of Tribologists and Lubrication Engineers, 106.

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