Journal of Inventive Engineering and Technology (JIET) Vol 1 Issue 1 **September 2020**

Journal of Inventive Engineering and Technology (JIET)

ISSN: 2705-3865

Volume-1, Issue-1, September 2020

www.jiengtech.com

Research Paper Open Access

VIABILITY ASSESSMENT OF PALM KERNEL OIL-BITUMEN BLEND AS QUENCHING MEDIUM DURING AUSTEMPERING OF STEEL

[1](O. C. Okwonna, Department of Mechanical Engineering, Michael Okpara University of Agriculture Umudike, Nigeria) Corresponding Author:okwonnac@yahoo.com

[2](C. I. Nwoye, Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Nigeria

ABSTRACT: *Viability assessment of palm kernel oil-bitumen blend as quenching medium during austempering of steel was carried out. The samples were austenitized at various temperatures range; 850-9500C. Microstructural analysis and mechanical tests were carried out on the austempered steel to underscore the level of severity and viability of the quenchant. These tests include tensile test, impact test and hardness test. Results of measured hardness indicate that austempered 0.56%C and 0.76%C-steels posses higher hardness values; 502 and 513 HV compared to that of as-received same steel types (321 and 406 HV). This implies an improvement on the as-received sample as a result of formation of bainite structure and diffusion of carbon precipitates into the steel. A two-factorial empirical model expressed as;* $\xi = -0.0436ß^2 - 0.0135\vartheta^2 + 2.4173ß + 24.0915\vartheta - 10263.83$ *derived to interpolate and extrapolate the relationship between the quenched steel hardness and austempering temperature & time indicated a quadratic relationship. Comparative analysis of the correlations between the steel hardness and austempering temperature & time as obtained from experiment and derived model indicated that they were all > 0.99. The maximum deviation of the model-predicted steel hardness (from experimental results) was less than 3.5%. This translated into over 96% operational confidence for the derived model as well as over 0.96 reliability response coefficients of quenched steel hardness to the operational influence of the austempering temperature and time.*

KEYWORDS: *Viability Assessment, palm kernel oil-bitumen blend, quenching medium, austempering, steel*

Date of Submission: 07-09-2020 Date of acceptance: 19-10-2020

I. INTRODUCTION

Over the years, iron has been a vital engineering material for technological development. A decline in the use of other metals has prompted increase in the usage of steel for industrial and economic growth. It equally plays a vital role in engineering applications because of high range of physical and structural properties obtainable by changing in carbon content and heat treatment practice. It has found industrial application due to its low monetary value, high strength, and durability (Feng and Tahir, 2008). Some engineering components need higher hardness value so as to find application in components meant for heavy duty activities. This level of hardness involves heating the alloy to a particular temperature, holding at that temperature then cooling rapidly in a media (Hassan et.al, 2009). The hardness achieved due to the rapid cooling results from the phase transformation to austenite and low temperature transformation of austenite to martensite (Rajan et.al., 1988; Keenha, 2004).

Report (Hassan and Aigbodion, 2013) has shown that steel is an iron and iron carbide component (carbon ranging from 0.015% to 2.14%) with other alloying constituents such as manganese, silicon, sulphur, phosphorus.

There are several methods of making steel, the more important of which are the Bessemer process, the open hearth process, the electric arc furnaces process and the direct reduction process.

They are based on the same principle, which involves removing all the impurities from molten pig iron by oxidation and addition of known quantities of carbon and other elements to obtain desired composition. Pig iron, scrap iron and scrap steel are the raw material that is used for making steel (Osei, 2004).

The various types of steel include mild steel (0.15-0.30%C), medium carbon steel (0.35-0.65%C), high carbon steel (>0.65%C) and stainless steel.

Austempering is a hardenability process that includes austenitizing, followed by cooling to prevent formation of pearlite at a temperature above the martensite formation temperature and then holding until the desired microstructure is formed. Heat treatments can be applied to steel not only to harden it but also to improve its strength, toughness or ductility in order to change the original coarse grain structure of the steel. Austempering is one of the quench hardening methods applied to alloys so as to improve the mechanical properties of the alloy. The austempering media often used in the industries are molten bath, air, oil, brine e.t.c. Mineral oil and salt bath have been found to have the best cooling results, but they are expensive, toxic and non biodegradable.

A lot of researchers have carried out research on austempering of steel using various austempering media. Dauda et.al (2015) studied the effectiveness of the palm kernel oil, cotton seed oil and olive oil as quenching medium in the hardening process of steel. Results from the research show that palm kernel oil and olive oil gave a lower steel hardness value compared to as-received steel thereby rendering the quenchant undesirable for hardening.

The strength stability of medium carbon steel plays an important role in automobile industries. Medium and hard steels can be heat treated to produce steels with various degrees of hardness through heating of the steel to a hot region and cooling slowly. Palm kernel seed oil is an edible plant oil derived from the kernel of the oil palm (elaeis guineenis). Palm kernel seed oil is semi-solid at room temperature and more saturated than palm oil. It does not contain trans-fatty acids/cholesterol. The saponification value of palm kernel seed oil is 183.92mgKOH/g while the iodine value of kernel seed oil is 63.59mgl2/g.

Bitumen is a black/brown viscous liquid (thermoplastic in nature) consisting mainly of hydrocarbons and their derivatives, which can dissolve in carbon disulphide (Hassan and Aigbodion, 2009). The softening point of bitumen can help remove the bacteria in palm kernel seed oil thereby making palm kernel seed oil and bitumen blend a good austempering media. Furthermore, all other properties of bitumen can combine well with palm kernel seed oil.

Palm kernel oil esters have great potentials in the cosmetic and pharmaceutical industries due to the excellent wetting behavior of the esters without the oily feel. Bitumen will be added to palm kernel seed oil in order to eliminate the bacteria found in palm kernel seed oil so as to reduce distortion or decline in the life span of the material.

This research is to explore the potentials of using palm kernel seed oil-bitumen as a quenching media.

II. MATERIALS AND METHODS

Medium carbon steel was used as test samples to evaluate palm kernel seed oil-bitumen blend as austempering media. The chemical composition of the alloys is shown in Table 1. The equipment used during the experiment were: electrically heated furnace with temperature 12000C, medium sized kerosene stove and pot for heating the palm kernel seed oil-bitumen blend, struner's hot mounting press for mounting all metallographic samples, laboratory mercury thermometer, pendulum type Charpy impact testing machine (Denilson model), TEC-C- 100 tensile testing machine, Avery hardness machine, Heat treatment furnace, weighing balance, starter pH meter, H2SO4 and HCl, tensometer, lathe machine and, metallurgical microscope.

www.jiengtech.com. All Rights Reserved.

Table 1: Chemical composition of the steel and ductile cast iron

Element	C	Mn	Si	S	P	Fe
0.76%C	0.76	1.11	0.33	0.03	0.05	Fe
0.56%C	0.56	0.96	0.26	0.05	0.33	Fe

Palm kernel seeds were purchased from local palm processors in Ekwuluobia, Anambra state. Palm kernel oil was extracted from the palm kernel seeds using the traditional method of heating. Bitumen was purchased from C & O civil engineering laboratory Awka, Anambra state. Laboratory thermometer was placed into the steel pot containing the kernel seed oil-bitumen blend and heated to its boiling temperature. Bitumen was added in a small quantity to avoid under reaction or over reaction. The ratio of the addition was 8:1.

The alloys were machined to impact and tensile samples dimensions with their various specifications as 10 × 10 × 55 mm with a 2.5mm notch (for impact test) and 70 × 10 mm (for tensile strength).

One sample each from the alloys was taken from the samples and kept aside (as untreated) before heating the other ones. The remaining samples were given a normalizing heat treatment by heating the samples in an electrical furnace at various temperatures from 8500C to 9500C, soaked at various time intervals ranging from 5 mins to 2 hours, removed and cooled in air. One sample each were taken and kept aside as normalized sample. Normalized tensile and impact test samples of the two alloys were austempered. Normalized samples of 0.56%C-steel were placed in a crucible, loaded into the furnace, heated to 9000C, soaked for one hour and quenched in hot kernel seed oil-bitumen blend boiling at a temperature of 4200C. After some minutes, the first set of samples were removed from those quenching medium, cooled in air and washed in kerosene, then with soap solution. Another set of samples were removed after 5 minute, 30 minutes, 1 hour, and 2 hours, cooled in air, washed in kerosene and also in soap solution.

A. METALLOGRAPHIC SAMPLES PREPARATION FOR MICROSTRUCTURAL ANALYSIS

All the samples both untreated and heat treated involved in this experiment were subjected to thorough metallographic sample preparation processes highlighted thus

(a)Rough machine grinding of all samples successively on 60, 80, 120 and 180 gritts abrasive emery grinding papers.

(b)Fine machine grinding of all samples on 200, 400 and 600 gritts abrasive emery papers using wet type process.

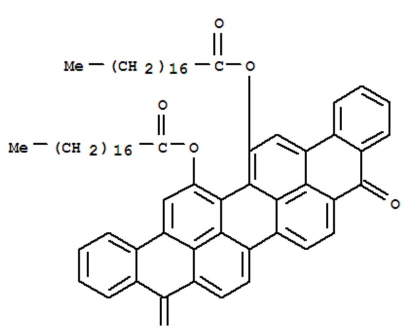
(c) Polishing all the ground samples on a polymet polishing machine.

(d) Testing polished samples for hardness at three different points on the same surface of metal sample and the average was taken.

(e) Re-polishing all samples after the hardness test and then etching them.

I. CHEMISTRY OF THE EQUATION

The chemistry of the equation is as follow as shown in Fig.1.



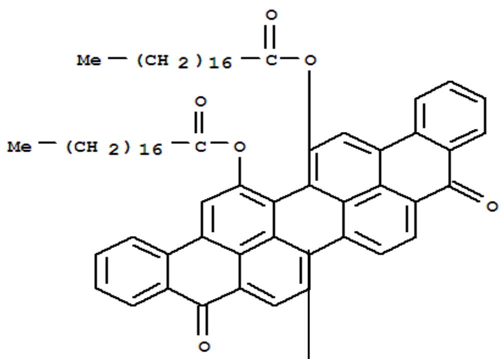
+

CH_2-OH + R-$COOH_2$ –COOR

CH_2-OH+R-COOHCH-COOR + 3H2O

CH_2-OH+R-COOHCH_2-COOR

$\xleftrightarrow[\textit{catalytic steel}]{}$



CH_2-OH + R-$COOH_2$ –COOR

Where R = CH_3 CH_2-OH+R-COOHCH-COOR $CO_2 + nH2O$

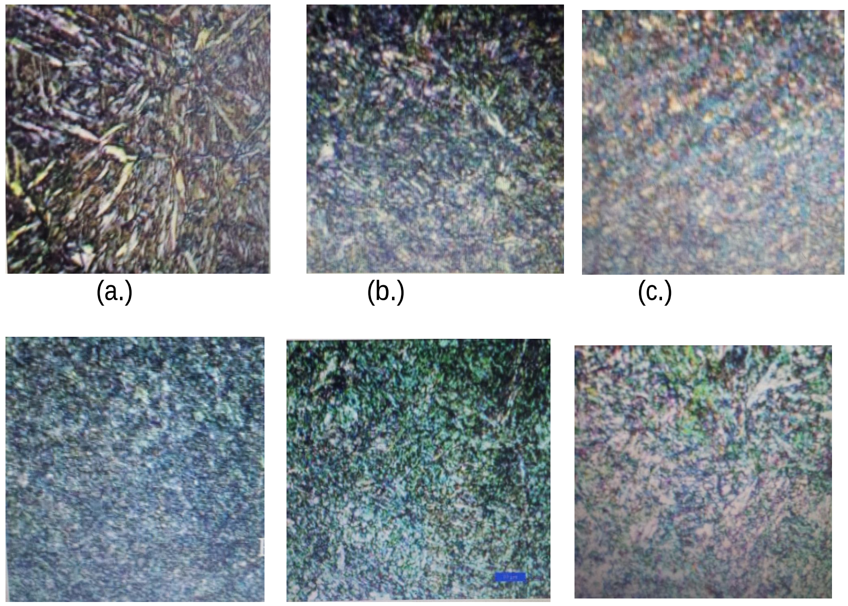
CH_2-OH+R-COOHCH_2-COOR

Fig. 1: The chemical equation of the reaction between palm kernel seed oil and bitumen

III. RESULTS AND DISCUSSIONS

A. MICROSTRUCTURE EXAMINATION

To evaluate the quenching strength, microstructural analysis of the as-received (untreated) and quenched (treated) specimen were carried out. Microscopic examination of the etched surface of various specimens was undertaken using a metallurgical microscope. The micrographs of the as-received 0.76%C-steel, 0.56%C-steel and the heat treated samples are shown in the micrograph (Fig. 2(a)-(f)). The structure shown in Fig. 2(a) indicates presence of ferrite in pearlite matrix of as-received 0.76%C-steel and 0.56%C-steel. Fig. 2 (b) shows microstructure of normalized 0.56%C and 0.76%C-steel. The normalized sample indicate that the size of the original austenite grains were influenced to a remarkable extent due to presence of pearlitic matrix; containing shorter graphite flakes compared to annealed sample. Fig. 2(c)-(f) shows that the microstructures of these steel types are martensitic when quenched in palm kernel seed oil–bitumen blend. Rapid quenching of this structure from its austenite temperature, leads to the austenite decomposition into a mixture of carbon martensite and fewer pearlite, and as a result, the microstructure formed will be hard and posses increased tensile strength and other mechanical properties. These micrographs (Fig. 2(c)-(f)) of samples quenched in bitumen-kernel seed oil blend from 5 minute to 2 hours show that in both steels, at the initial austempering time, combination of retained austenite and martensite was obtained but for high values of austempering times, and at various austenitizing temperatures, a mixture of retained austenite and bainite was also formed. It is suspected that the low distribution of martensite at lower soaking time was caused by the short heating times resulting in a non-homogeneous austenite. This shows complete diffusion of carbon into the austenite phase and a concentration gradient exists. With increasing austempering time, however, carbon diffusion is enhanced and a more homogeneous austenite evolves resulting in higher martensite transformation distribution upon quenching. The structures obtained from the practical microstructural investigation correlate with hardness predictions and are in agreement with findings in the introduction.This has also confirmed that the embarked heat treatment process is realistic and reliable for the development of structures with improved mechanical properties comparable to those of austempered samples.



(a.) (b.) (c.)

(d.) (e.) (f.)

Figs. 2(a) – (f): show the microstructure of as-received and quenched 0.56%C & 0.76%C-Steel; Fig. (a) shows the structure of unquenched 0.56%C & 0.76%C steel, (b) shows the structure of normalized 0.56%C & 0.76%C steel while Fig.s (c,)- (f) show the microstructure of 0.56%C & 0.76%C Steel quenched in palm kernel oil – bitumen blend.

Effect of Palm Kernel Oil-Bitumen Blend On the Mechanical Properties of Austempered Steel

Table 2: Hardness of 0.56%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	245	302	321
5 minutues	409	453	502
30 minutes	339	404	463
1 hour	298	383	417
2 hours	336	375	383

Table 3: Tensile strength of 0.56%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	550	553	675
5 minutes	659.2	656.4	789.7
30 minutes	613.6	612.1	741.5
1 hour	587.2	584.3	702.3
2 hours	616.6	615.6	745.6

Table 4: %Elongation of 0.56%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	38	41	67
5 minutes	57	73	83
30 minutes	46	66	76
1 hour	44	58	72
2 hours	50	66	80

Table 5: Impact strength of 0.56%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	11	10	7
5 minutes	15	14	8
30 minutes	22	17	9
1 hour	32	22	13
2 hours	32	24	16

Table 2 shows the value of the hardness on 0.56%C-Steel.
At all the transformation temperature, hardness values decreased as the holding time increased. The decrease was a result of the transformation of austenite to bainite.

Tables 3 and 4 show results of tensile strength and percentage elongation respectively of 0.56%C-Steel. The tables indicate that the tensile strength increased when the steel was quenched at 5 minutes and then decreased. This is attributed to the formation of austenite in the matrix of 0.56%C-Steel. The decrease in tensile strength indicates a migration from toughening stage to embrittlement.

Table 5 shows the impact test on 0.56%C-Steel. The impact toughness increased with increase in holding time because of the size of the austempered structure.

Table 6: Hardness of 0.76%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	348	435	406
5 minutues	468	566	513
30 minutes	399	526	474
1 hour	358	478	426
2 hours	391	444	393

Table 7: Tensile strength of 0.76%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	515	525	529
5 minutes	561	574	576
30 minutes	565	583	586
1 hour	574	589	593
2 hours	582	564	567

Table 8: %Elongation of 0.76%C-Steel austempered in palm kernel oil-bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	10	10	12
5 minutes	13	13	15
30 minutes	13	14	17
1 hour	16	16	19
2 hours	11	13	14

Table 9: Impact strength of 0.76%C-Steel austempered in palm kernel oil- bitumen blend

Austemper time	850^0C	900^0C	950^0C
As-received	8	6	4
5 minutes	10	7	4
30 minutes	15	11	4
1 hour	29	15	7
2 hours	27	24	10

Table 6 shows the hardness value on 0.76%C-Steel. The hardness of the quenched steel increased when the holding time was 5 minutes and after that, there was a decrease. The presence of the hard and brittle phase martensite is the main reason of the higher hardness values obtained. This was the same for all other transformation temperatures.

Tables 7 and 8 show the effect of the quenchant on the tensile strength of 0.76%C-Steel. The tensile strength increased with increased holding time. This was attributed to presence of less austenite to transform into martensite. Furthermore, bainite formation was enabled by presence of fine grain size and high carbon content.

Table 9 shows results of the impact test on 0.76%C-Steel. It was observed that at each austenitizing temperature, the impact strength increased with increase in holding time. This is attributed to the formation of bainite structure.

B. MODEL FORMULATION

Table 10: Variation of the hardness of 0.76C% steel (quenched in palm kernel oil-bitumen blend) with austermpering time and temperature

Hardness (HV)	**Time (mins.)**	**Temp. (^{0}C)**
468	5	850
503	20	880
526	30	900
476	45	925
426	60	950

Re-arrangement and computational analysis (using C-NIKBRAN: (Nwoye, 2008)) of results in Tables 6-9 gave Table 10 which indicates that

$$\xi = - K \S 2 - N\vartheta 2 + S\S + Z\vartheta - \text{ƀ} \qquad (1)$$

Substituting the values of K, N, S and ƀ into equation (1) reduces it to;

$$\xi = -0.0436\S 2 - 0.0135\vartheta 2 + 2.4173\S + 24.0915\vartheta - 10263.83 \qquad (2)$$

Where

K = 0.0436; N = 0.0135; S = 2.4173; Z = 24.0915

and ƀ = 10263.83 are equalizing constants

(determined using C-NIKBRAN (Nwoye, 2008))

(ξ) = Hardness of steel quenched in palm kernel oil-bitumen blend

(ϑ) = Time (mins.)

(ϑ) = Austempering Temperature (0C)

C. BOUNDARY AND INITIAL CONDITION

The ranges of hardness, austempering temperature and process time considered are 426 – 503 HV, 850 – 9500C and 5 – 60 mins. respectively.

D. GRAPHICAL ANALYSIS

Graphical analysis of Fig.s 3 and 4 show very close alignment of the curves and shapes dimensions from the experimental (ExD) and model-predicted (MoD) quenched steel hardness.

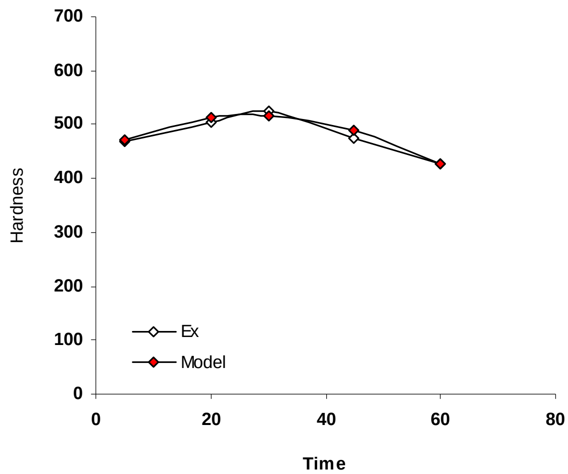


Fig. 3: Comparison of hardness (relative to autempering time) as obtained from experiment and derived model.

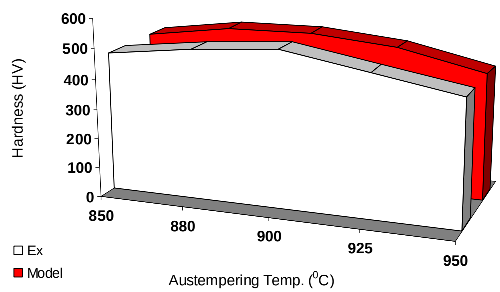


Fig. 4: Comparison of hardness (relative to autempering temperature) as obtained from experiment and derived model.

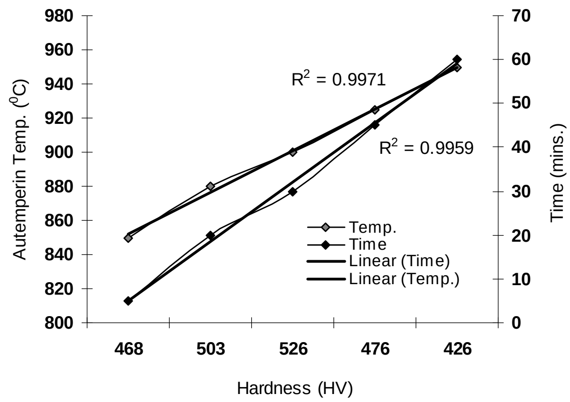


Fig. 5: Variation of hardness with austempering temperature and autempering time (showing their respective coefficients of determination) as determined from experiment.

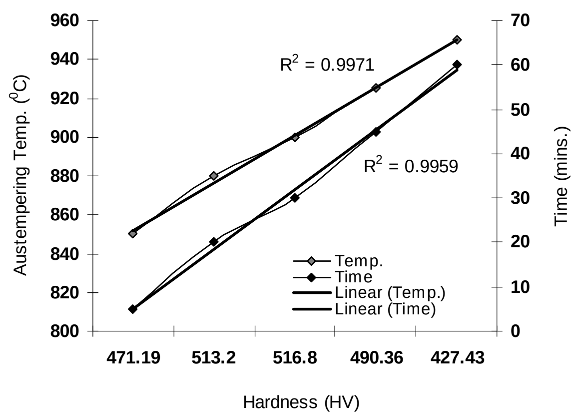


Fig. 6: Variation of model-predicted hardness with austempering temperature and autempering time; showing their respective coefficients of determination.

It is strongly believed that the degree of alignment of the curve in Fig. 1 and closeness of the shape dimension in Fig. 2 are indicative of the proximate agreement between both experimental and model-predicted values of the quenched steel hardness.

Fig..3 and 4 show significant variation between the quenched steel hardness, austempering temperature and time for the experimentally determined and model-predicted results respectively. These Figs indicate the same coefficients of determination (R^2 = 0.9971 and R^2 = 0.9959) with respect to austempering temperature and process time for both results from experiment and derived model respectively. This level of proximate agreement implies validity of the model. Furthermore, tthe calculated correlations (from Figs. 3 and 4) between the quenched steel hardness and austempering temperature & process time for both results obtained from experiment and derived model gave 0.9985 & 0.9979 respectively. These values are also in proximate agreement. Comparative analysis of these correlations were all > 0.99.

The deviation Dv, of model-predicted water absorption from the corresponding experimental result was given by

$$Dv = \left(\frac{\zeta_{MoD} - \zeta_{ExD}}{\zeta_{ExD}}\right) \times 100 \qquad (3)$$

Where

ζ_{ExD} and ζ_{MoD} are water absorptions obtained from experiment and derived model respectively.

Critical analysis of the quenched steel hardness obtained from experiment and derived model shows low deviations on the part of the model-predicted values relative to values obtained from the experiment. This was attributed to the fact that the surface properties of the and the physico-chemical interactions between the steel and the quenchant which played vital roles

during quenching process were not considered during the model formulation.
This necessitated the introduction of correction factor, to bring the model-predicted quenched steel hardness level to those of the corresponding experimental values

Table 11: Variation of model-predicted quenched steel hardness with its associated deviation and correction factor

Hardness (HV)	Dv (%)	Cv (%)
471.19	+ 0.68	- 0.68
513.20	+ 2.03	- 2.03
516.80	- 1.75	+ 1.75
490.36	+ 3.02	- 3.02
427.43	+ 0.34	- 0.34

Correction factor, Cf to the model-predicted results is given by

$$Cf = -\left(\frac{\zeta_{MoD} - \zeta_{ExD}}{\zeta_{ExD}}\right) x\ 100 \qquad (4)$$

Table 11 indicates that the evaluated correction factors are negative of the deviation as shown in equations (3) and (4). The correction factor took care of the negligence of operational contributions of the surface properties of the steel and the physico-chemical interactions between the steel and quenchant which actually played vital role during the quenching process. The model predicted results deviated from those of the experiment because these contributions were not considered during the model formulation. Introduction of the corresponding values of Cf from equation (4) into the model gives exactly the corresponding experimental values of the quenched steel hardness.

IV. CONCLUSIONS

Viability assessment of palm kernel oil-bitumen blend as quenching medium during austempering of steel was carried out. Austempered 0.56%C and 0.76%C-steels posses higher hardness values; 502 and 513 HV compared to that of as-received same steel types (321 and 406 HV). This implies an improvement on the un-treated sample as a result of formation of bainite structure and diffusion of carbon precipitates into the steel. A two-factorial empirical model; $\xi = -0.0436\gamma^2 - 0.0135\vartheta^2 + 2.4173\gamma + 24.0915\vartheta - 10263.83$ derived to interpolate and extrapolate the relationship between the quenched steel hardness and austempering temperature & time indicated a quadratic relationship. The correlations between the steel hardness and austempering temperature & time as obtained from experiment and derived model indicated that they were all > 0.99. The maximum deviation of the model-predicted steel hardness (from experimental results) was less than 3.5%. This translated into over 96% operational confidence for the derived model as well as over 0.96 reliability response coefficients of quenched steel hardness to the operational influence of the austempering temperature and time.

REFERENCES

[1] Feng, C and Tahir, I.K. (2008). The effect of quenching medium on the wear behavior of a Ti-6Al-4V Alloy. J-mater. Sci. 43(2): 788-92.

[2] Hassan, S. B, Balogun, S.O and Aigbodion V.S.(2009). hardening characteristics of medium carbon steel using fresh cassava liquid extract as quenchants, Journal of Metallurgy and Materials Engineering 4(2): 55-61.

[3] Rajan, T.V, Sharma, C.P; and Sharma, A. (1988). Heat treatment-principles and techniques, prentice-Hall of India private limited, New Delhi, India. pp 23-34.

[4] Keenha E. (2004). Effect of Microstructure on Mechanical properties of high strength steel weld metals, PhD thesis, Chalmers University of technology.

[5] Hassan, S.B and Aigbodian V.S, (2013). Evaluation of Khaya seed oil (mahogany oil) as quenchants in the hardening process of plain carbon steel. Pacific journal of science and technology. 14(1): 19-30.

[6] Osei Y.A. (2004). New School Chemistry for senior secondary school. Khana publishers, 3rd edition pp 445-448.

[7] Dauda M, Kuburi I.S, Obada D.O, Mustapha R. I. (2015). Effects of various quenching media on mechanical properties of annealed 0.509Wt%C-0.178Wt%Mn Steel, Nigerian Journal of Technology, 34(3): 506-512.

[8] Nwoye, C. I. (2008). Data Analytical Memory; C-NIKBRAN