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TENSILE STRENGTH AND MICRO-STRUCTURAL BEHAVIOUR OF MEDIUM CARBON STEEL QUENCHED IN SOME SELECTED MEDIA

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ABSTRACT

Quenching effect of pap water, coconut water and spent engine oil (SPE) on the strength and microstructural behavior of medium carbon steel was studied. Prepared samples were first heat-treated in a muffle furnace to temperature of 840 ℃ and normalized in order to reduce the stresses that might have been induced during machining operations. The prepared samples were later heated to 730 ℃, 760 ℃ and 790 ℃ and soaked for 30, 45 and 60 minutes, respectively using a muffle furnace and then quenched in different media. The control sample was only heated to 840 ℃ and normalized. A testometric M500-50AT model machine was used for the tensile test. M100 optical metallurgical microscope was used for the microstructural examination. An improved yield (YS) and ultimate tensile (UTS) strengths were observed in all the samples quenched in different media against the as-received samples. As-received samples tend to yield earlier at offset strain of about 0.07% which implies a drop in yield and ultimate tensile strength. SPE-quenched samples have better YS, UTS and percentage elongation than others. Quenched samples, irrespective of the heating temperature and soaking time has martensitic islands in matrix of ferrite phases. The quenching media proved effective in their application as quenching media.

Key words: Lamella morphology, Quenching media, Yield strength, Heat treatment, Soaking time, microstructure, ultimate tensile strength.

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1. INTRODUCTION

Heat treatment is a combination of timed heating and cooling operations applied to a metal or alloy in the solid state in such a way to produce certain microstructure and desired properties [1]. Quenching is one of the most important heat treatment processes that yields an improve performance of metals and alloys greatly. Quenching involves heating a metal or alloy to austenitizing temperature and soaking at this temperature for a specific time [2]. The heating process is immediately followed by an intense cooling in a suitable medium. Formation of bainites and martensites as against the pearlites and ferrites present in metals and alloys are usually achieved during quenching processes. Effective quenching depends on the cooling characteristics of the quenching medium and the response ability of metals. There are different types of quenching media [3], examples are; gas (N_2, H_2, Ar, and He), liquid immersion (water, oil and so on) and spray quenchants (gas + liquid). Ali and Majid [3] used water, dry air and compressed air to quench AISI4140 steel samples in their work. They reported that high hardening effect was obtained in water-quenched samples as a result of martensitic structures formation. Lower hardening depth was obtained with air-quenched samples. However, compressed air yielded better results compared to ordinary dry air. Vivek *et al.* [2] predicted quenching severity of various media based on hardness number and microstructure studies. They used brine solution, distilled water and oil as their quenching media and observed that in terms of hardness number and martensitic phase that evolved, severity can be arranged in descending order as brine is greater than water; while water is greater than oil (brine>water>oil). In another research work by Dauda *et al.* [4], effect of various quenching media on mechanical properties of annealed 0.509% wt C-0.178 wt% Mn steel; olive oil produced less cooling severity than water and engine oil. In Nigeria, conventional quenching media has become scarce and costly as a result of inflation in the prices of commodities; therefore, a need to assess wastes materials that possesses quenching ability becomes eminent. Coconut water (CW), pap water (PW) and spent engine oil (SPE) has largely been considered as wastes but these media could be harness for quenching of medium carbon steel [5 - 6]. Medium carbon steel is a vital engineering material in Nigeria, though the standard of production has been questioned by researchers [7 – 8]. Therefore, the present study will examine the quenching effect of coconut water, pap water and spent engine oil on the tensile strength and microstructure of medium carbon steel.

2. MATERIALS AND METHOD

2.1. Materials

Medium carbon steel and quenching media which include coconut water (CW), pap water (PW) and spent engine oil (SPE) were the major materials used in this study. The chemical composition of the medium carbon steel samples as obtained from optical emission spectrophotometer is given in Table 1.

Table 1 Chemical composition of the medium carbon steel

C	Si	Mn	S	Cr	Ni	Cu	Fe
0.389	0.182	0.980	0.030	0.111	0.135	0.368	97.805

2.2. Sample Preparation

Prepared samples were first heat-treated in a muffle furnace to temperature of 840 ℃ and normalized in order to reduce the stresses that might have been induced during machining operations. This was also done for structural and metallurgical readjustment, re-conditioning of the phases and induction of homogeneous structure in the samples. The prepared samples were later heated (HT) to 730 ℃, 760 ℃ and 790 ℃ and soaked (ST) for 30, 45 and 60 minutes respectively using a muffle furnace. After each heat treatment temperature has been reached, the samples were quickly removed from the furnace and quenched in the different media; which were coconut water, pap water and spent engine oil. However, the control sample was only heated to 840 ℃ and normalized. This methodology was adopted from the work of Ikubanni *et al.* [5].

2.3. Mechanical Test and Micro-Structural Examination

A Testometric M500-50AT model machine was used for the tensile test. Load and elongation curves were recorded during tensile test and were converted into stress-strain curves. Tensile strength, ultimate tensile strength and percentage elongation were recorded for the samples. M100 optical metallurgical microscope was used for the micro-structural examination.

3. RESULTS AND DISCUSSION

3.1. Yield and Ultimate tensile strength of samples quenched in different media

Medium carbon steel contains 0.29 to 0.6 wt% C [9] and the result obtained for the carbon content of the sample used in the present study is 0.39%wt which is within range. Table 2 shows the result of yield strength, ultimate tensile strength and percentage elongation for the samples. The stress-strain curves of the samples in different media, soaking time (ST) and heating temperatures (HT) with the as-received sample are shown in Figs. 1 - 9. Figs. 10 - 12 are the comparison made with yield strengths, ultimate tensile strengths and percentage elongations for different quenching media, soaking times and heating temperatures. The micrographs of the samples in different media, heating temperatures and soaking time are presented in Figs. 13 - 16. The stress-strain curves of the samples maintained a similar pattern for different media as they had no drop in yield strength as against the as-received sample. As-received samples tend to yield earlier at offset strain of about 0.07% (Figs. 1- 3). Sample quenched in CW for 60 minutes at 730^{o}C HT gave a drastic deformation both at elastic and plastic phases. With strain less than 0.1%, the yield (YS) and ultimate tensile strengths (UTS) were 89.6 N/mm^2 and 93.7 N/mm^2 respectively. These values were lower than the as-received sample that has 162.9 N/mm^2 and 171.1 N/mm^2 as YS and UTS respectively. SPE has better UTS and YS (Figs. 10 - 11). The percentage elongation of samples quenched is SPE is better than others and it is similar to the work of Smith and Hashemi [9]. The quenching velocity of oil is better than of CW and PW and this may be the reason for an improved strength of samples quenched in SPE over others. A similar result by Vivek *et al.* [2] was obtained in their work that showed that oil yields better than water in terms of strength. Generally from Figs. 4-9, it was observed that samples quenched in SPE are better in terms of YS and UTS than samples quenched in CW and PW. However, there were samples quenched in CW and PW that has better YS and UTS than the SPE-quenched samples and as-received sample.

Several researchers had previously established the influence of oil (various categories) as quenching media on medium carbon steel [2; 10 – 12]. They all reported an improved strength which was confirmed with usage of SPE in the present study. The other non-toxic, environmental friendly and cheap materials (CW and PW) used in the present study also improved the YS and UTS better than the as-received normalized sample. Except for sample quenched in SPE for 730^{o}C HT and 30 minutes ST with 66.4%, for all the quenching media and ST, percentage elongation tends to increase with increased HT. The result is similar to the work of Odusote *et al.* [10] that used water and oil at 900 -980^{o}C HT. Rapid cooling has been reported to have a negative effect on elongation [13] and the present study displayed a similar behavior with CW and PW (Fig. 12). For different HT and ST, SPE-quenched samples have better percentage elongation which implies that they will be more ductile than the PW and CW-quenched samples. When strength and ductility are the major criteria for material selection, all samples quenched in all the media will be effective, however, SPE-quenched samples will be preferred because they can withstand more loads. Adeleke and Odusote [14] recommended that for structural material such as medium carbon steel, a balance of both strength and ductility is important.

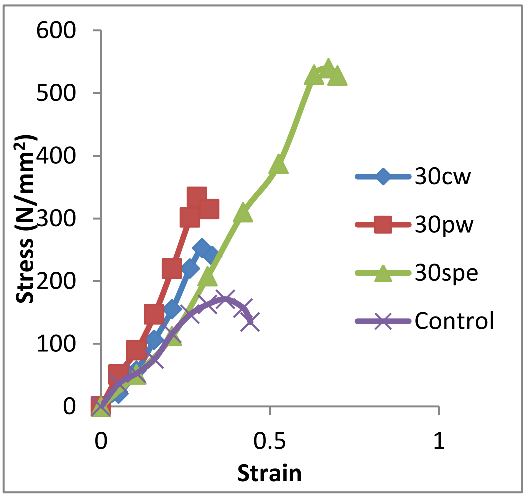

Figure 1. Stress-strain curves for samples in different for media 730°C HT and 30 min ST

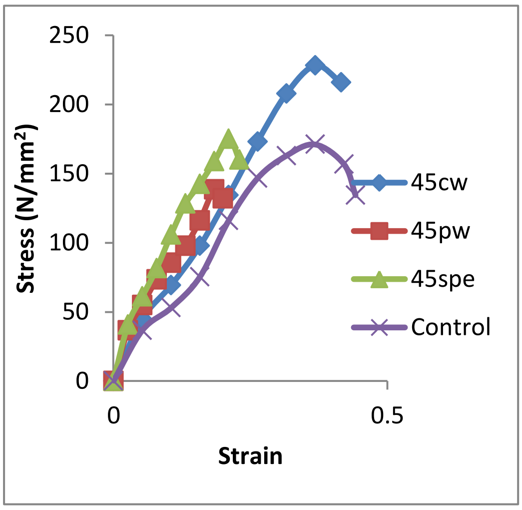

Figure 2. Stress-strain curves for samples in different media for 730°C HT and 45 min ST

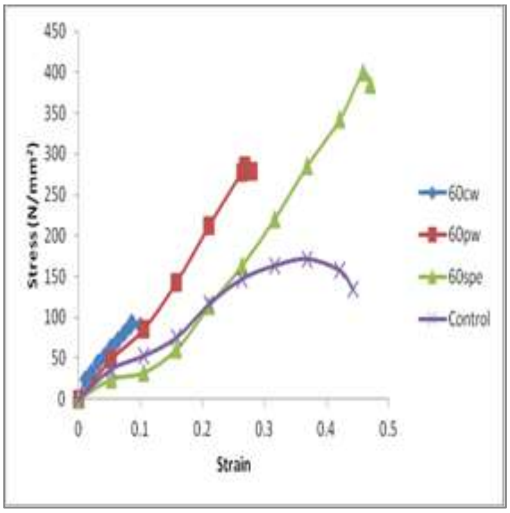

Figure 3 Stress-strain curves for samples in different media for 730°C HT and 60 mins ST

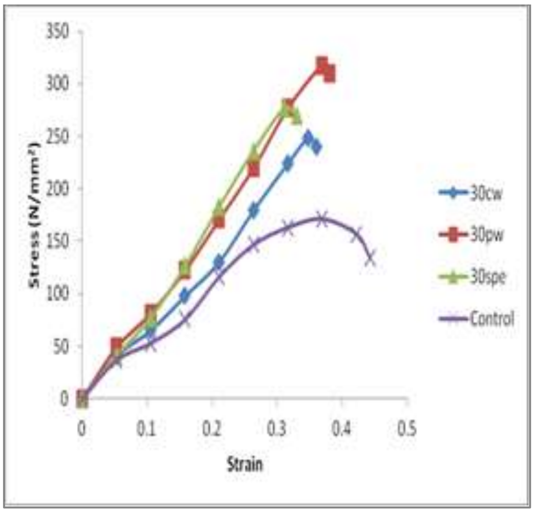

Figure 4 Stress-strain curves for samples in different media for 760°C HT and 30 mins ST

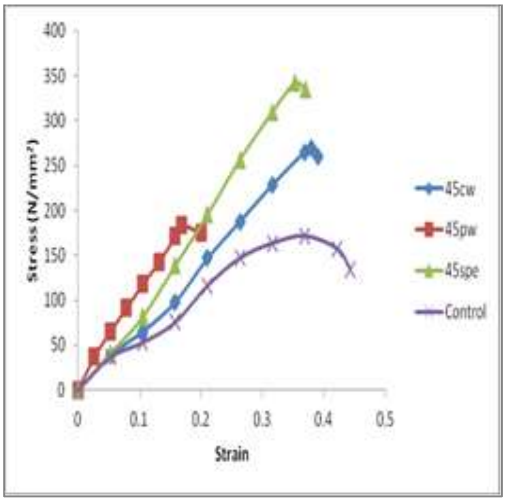

Figure 5 Stress-strain curves for samples in different media for 760°C HT and 45 mins ST

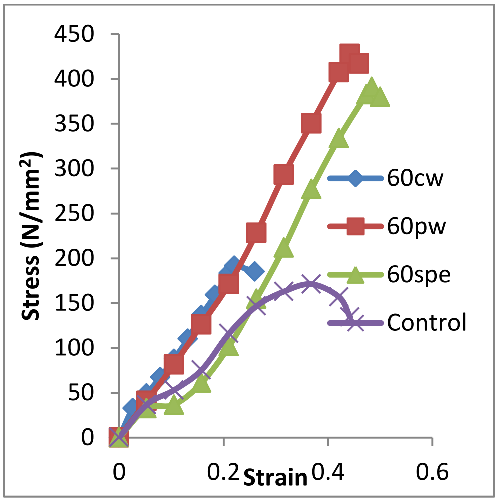

Figure 6 Stress-strain curves for samples in different media for 760°C HT and 60 mins ST

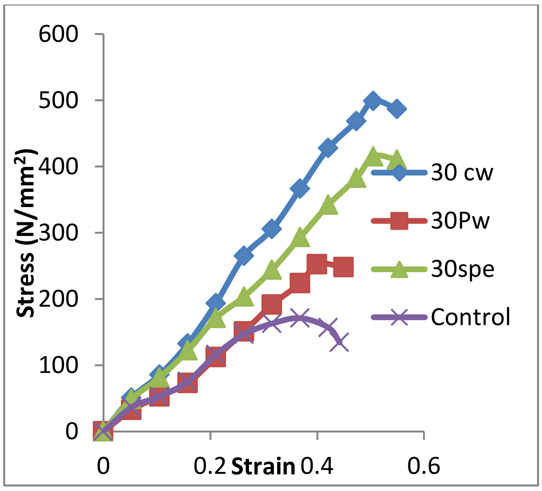

Figure 7. Stress-strain curves for samples in different different media for 790°C HT and 30 mins ST

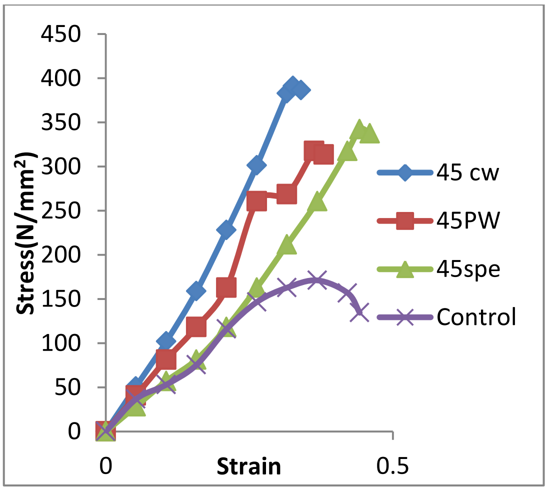

Figure 8. Stress-strain curves for samples in media for 790°C HT and 45 mins ST

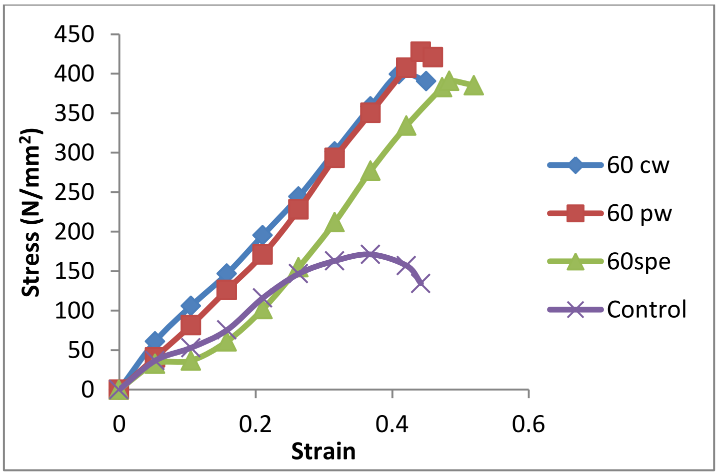

Figure 9 Stress-strain curves for samples in different media for 790°C HT and 60 minutes ST

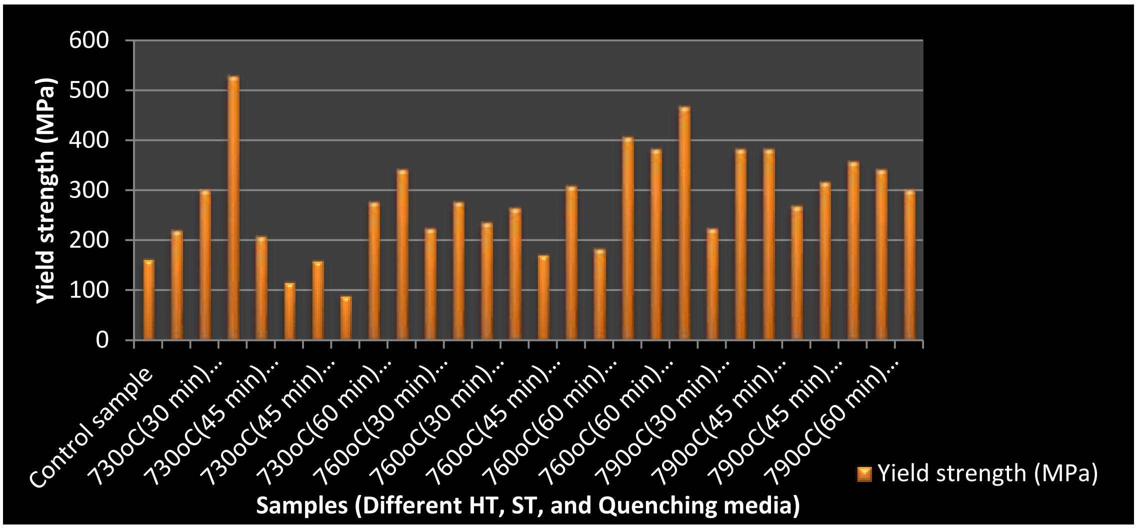

Figure 10 Yield strength of samples in different media, HT and ST

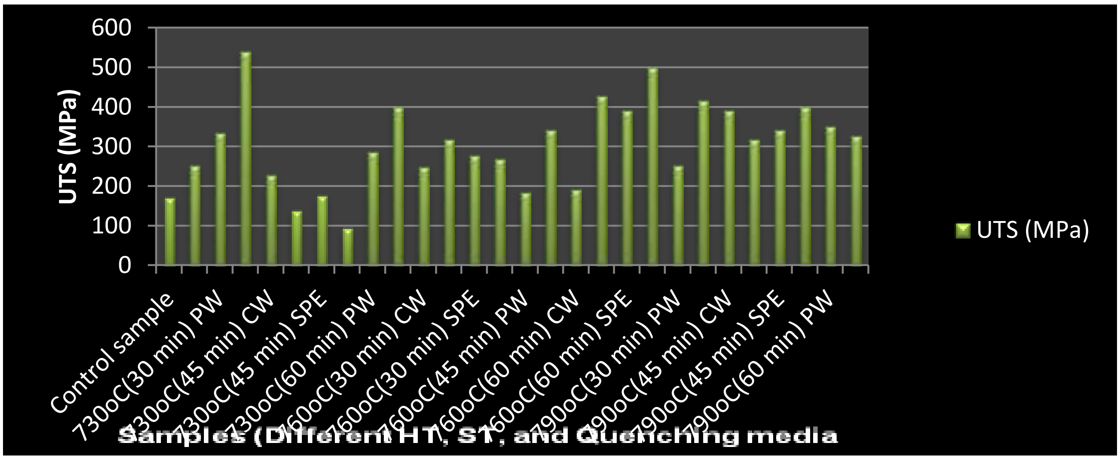

Figure 11 Ultimate tensile strength of samples in different media, HT and ST

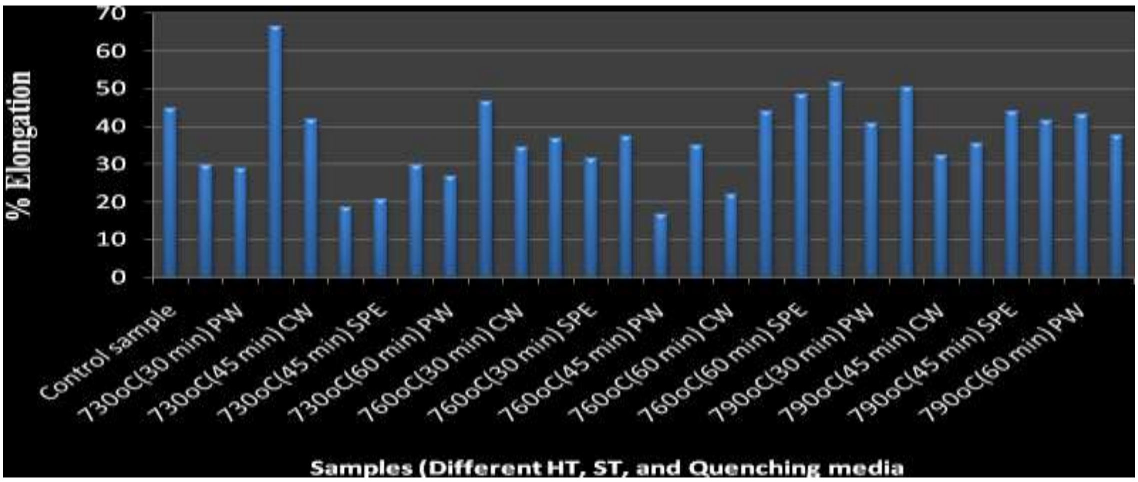

Figure 12 Percentage elongation of samples in different media, HT and ST

3.2. Microstructural Behaviour

Fig. 13 show the micrograph of as-receieved. The dark region, which is more on the micrograph is pearlite and the white region (not too many) is ferrite. It shows that the as-receieved samples contains pearlite lamella morphologhy that will lead to undesirable cold working mechanical properties in high stressed applications. As established in previous research [4], quenching causes formation of bainite, austenite and martensite in steel, the micrographs of samples quenched in CW and PW (Figs. 14 - 15) shows martensitic islands in matrix of ferrite phases irrespective of heating temperatures. However, samples quenched in SPE contains low proportion of martensitic structure in ferrite (Fig. 16). The transformation may be due to lower cooling rate of SPE. The dominant structure in samples quenched in PW and CW is martensite. Martensite tends to increase the hardness of steel rather than strengthen it [15]. The martensite in samples quenched in CW and PW is however in a matrix of ferrite phases (Figs. 14-15). This explains the balance in combination of strength and ductility.

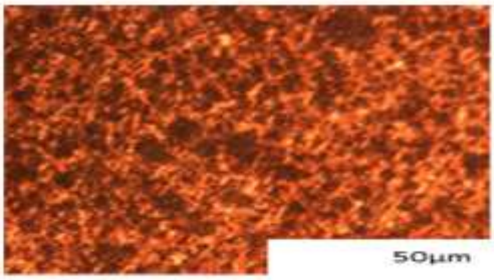

Figure 13 Micrograph of the control sample

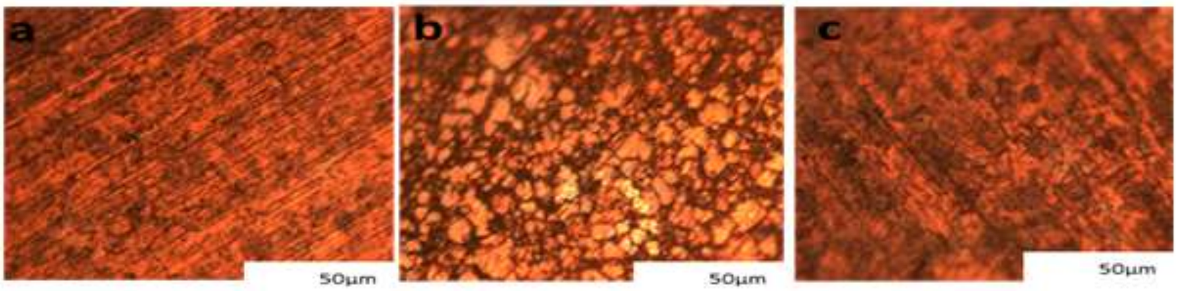

Figure 14 Micrographs of samples quenched in SPE (a) 730 ℃ HT, 30minutes ST (b) 730 ℃ HT, 60minutes ST (c) 790 ℃ HT, 45min ST

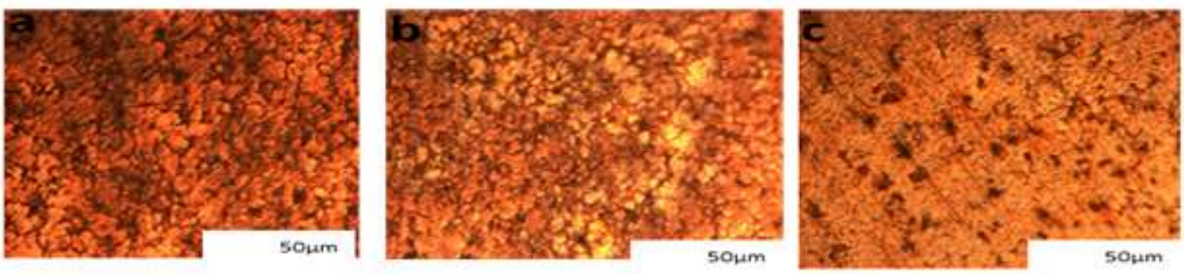

Figure 15 Micrographs of samples quenched in CW (a) 790 ℃ HT, 30minutes ST (b) 760 ℃ HT, 45minutes ST (c) 730 ℃ HT, 45min ST

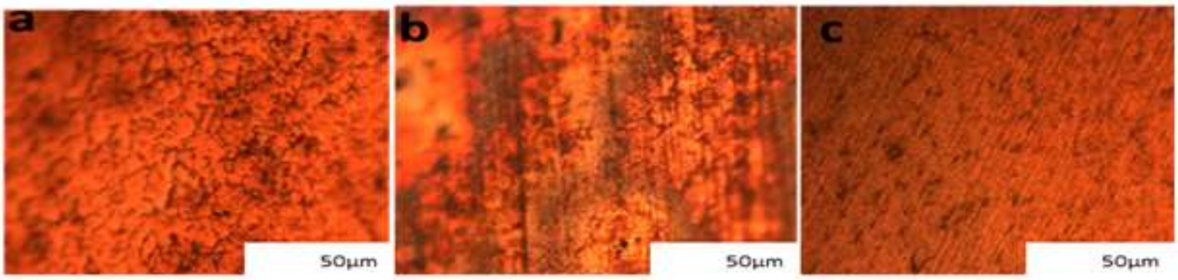

Figure 16 Micrographs of samples quenched in PW (a) 760 ℃ HT, 30minutes ST (b) 760 ℃ HT, 60 minutes ST (c) 790 ℃ HT, 45 min ST

Fig. 16-a shows low level of martensite in ferrite phase better than other samples quenched in SPE. This may account for higher YS, UTS and elongation tha other samples (529.6 N/mm^2, 539.8 N/mm^2 and 66.4% respectively). The media used in the present study compete favorably with the results of previous rsearchers. Therefore, instead of been considered as wastes, coconut water, pap water and spent engine oil can be viable alternatives for quenching processes.

4. CONCLUSIONS

From this present study, the yield and ultimate tensile strength of the quenched samples improves as compared with the as-received sample. The percentage elongation also improves. This implies that better ductility was achieved with the quenching used in the study. The martensitic island in ferrite phase in quenched sample depict a better microstructure over pearlite lamella morphology that leads to undesirable cold working mechanical properties in high stressed application. The three media used for the study can be effective in quenching operation and thereby turning waste to wealth.

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