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Evaluation of microstructural and structural characterization of rolled medium carbon steel quenched in different media

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Abstract
This paper studied the effect of quenching media on the mechanical properties of medium carbon steel at particular austenitic temperatures. All the samples except the as -received were heated to the austenitic temperatures of 870 ^{o}C, respectively, held for 45 minutes each and quenched in different media i.e. SAE 0 - 40 engine oil, Honey, palm Oil, water and freshly extracted cassava juice. Hardness tests, tensile tests, and microstructural examinations were used to evaluate the quenchants' effect on the properties of the steel. The results show that the as-quenched samples in oil and honey are fully bainitic structures. Simultaneously, samples quenched in water and cassava juice produced solely martensitic structure because of the sudden temperature change. These structures are unique and were responsible for the improved and favorable mechanical properties so observed.
Keywords: Steel, Hardening by quenching, quenching media

1 Introduction

Steel is the most commonly produced engineering material in the universe. The abundance of it is two primary constituents of iron and carbon, the comparatively low cost of production and impressive performance for infrastructural applications are responsible for its more extensive use [1-3]. Carbon steel usually contains less than 2.0% by weight and is commonly alloyed with chromium, cobalt, niobium, molybdenum, nickel, titanium, tungsten, vanadium or zirconium to impart addition or specific properties [4-6]. Steel properties can also be improved by heat treatment operations, which is done to alter mechanical properties such as hardness, strength, impact resistance, fracture toughness, and wear resistance. The principle of heat treatment, therefore, involves, (1) heating to a high temperature so as to course primary structural change, (2) holding at the elevated temperature for necessary structural transformation and chemical homogenization, and (3) cooling down to temperatures substantially below the pearlite transformation temperatures, so as to obtain desired structures and properties [7-9].

However, heat treatment designed to strengthen steel is based on the formation of bainite, a fine feathery microstructure consisting of ferrite and cementite. This can be formed by rapid cooling and holding time. Thus, a relatively low temperature could be form as a result of precipitation from the metastable martensite phase directly from the austenitic field [10]. Considerable work has been done in the past, on the possibility of replacing palm oil to mineral oil as quenchants, without aqueous solution of chemical substance and polymer [11-14]. More recently, the use of available cooking oils, which are relatively cheap, non-toxic, and environmentally friendly as quenching media, as begin to generate attention [14-20]. In the present study, evaluation of microstructure and mechanical properties of rolled medium carbon steel quenched in different

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media, such as Water, SAE 0 - 40 engine oil, Palm oil, honey, and Fresh cassava liquid extract will be conducted.

2. Methods and Materials

The materials used for this research include- medium carbon steel, which is the steel to be investigated, quenchants such as SAE 0 - 40 engine oil, Honey, Palm Oil, water, and freshly extracted cassava juice. The materials for metallographic specimen preparation, includes hacksaw with blade, silicon carbide, emery papers, 0.5% HCl etchants solution [7]. Hilger Analytical Direct Optical Light Emission Polyvac Spectrometer E980C was used to carry out the composition analysis of the steel sample through spark spectrometric analysis.

Six (6) tensile test specimens were machined to standard specification, (1) Normalizing: five (5) of the six (6) specimens already machined were normalized by heating it into the austenitic temperature, 850^{0}C, holding it at that temperature for 30 minutes for equal distribution of temperature and homogenization, and then allow it to cool in still air. The purpose of this normalizing treatment is to reduce internal stresses and also to restore back the microstructure changes that might have occurred in the steel during work hardening or rolling operation while the sixth (6) specimens was kept as the control. (2) Austenitizing process: Each of the five (5) normalized specimens were heated to temperature of 870^{0}C , held for 45 minutes, and then quenched in the following media:- Water, Palm oil, Honey, SAE 0 - 40 Engine Oil, and freshly collected Cassava Juice.

2.1 Tensile and hardness test

All the Six (6) tensile test specimens were subjected to tensile loads until fracture using a table top tensiometer. Hardness test samples were cut from the tensile test specimens after fracture. They were cut to 20mm length and 10 mm diameter from each cast and were subjected to grinding using grinding paper to ensure a smooth surface for accurate results. They were thereafter mounted on an anvil of the Brinnel Hardness Testing machine with 10mm indentor diameter ball in conjunction with 3000kg load. Two (2) hardness measurements were made per specimen after whom the average was recorded. Specimens for metallographic analysis were subjected to the normal sectioning, grinding, polishing and etching operations after which the microstructures were examined and micrographs were taken, using a metallurgical optical microscope. The micrographs are contained in plates 1 – 6.

3. Results and discussion

3.1. Chemical Analysis of As-received Medium Carbon Steel

From the table 1, the typical steel used for the research has 0.320% carbon and the alloying element of significant quantity is manganese for possible hardenability and toughness. It was observed that the as-received sample for this work contained 0.320% carbon and 97.98% iron while the remaining percentage were shared among the alloying elements present in the as-received sample. The significant alloying element in the sample is manganese with percentage 0.756% followed by copper having percentage 0.301%. Since manganese increases strength and hardness value, it makes it possible for the sample to be used for structural application [13, 21].

Table 1: The Spectrochemical analysis of as-received medium carbon steel

C	**Si**	**Mn**	**S**	**P**	**Cr**	**Ni**	**Cu**	**Nb**
0.3200	0.2010	0.7560	0.046	0.0480	0.1850	0.1220	0.3010	<0.0001
Al	**B**	**W**	**Mo**	**V**	**Ti**	**Fe**		
0.0370	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	97.9840		

3.2. Effect of the various quenching media on hardness and tensile strength properties of medium carbon steel

Figure 1 shows that as the specimens were heat treated and quenched in various quenching media, the hardness value was observed to increase from one quenching media to the other when compared to the as-received specimen. For instance, specimens heated to 870oC, quenched in SAE 0 - 40 engine oil, honey, palm oil, water, and freshly extracted cassava juice have their hardness values as 187.23HV, 241.18 HV, 320.58 HV, 340.93 HV, and 363.21 HV respectively while as-received was 171.3 HV. Fresh cassava juice quenching media provide a more significant hardening effect compare to other. Studies have established that the effect of different mediums on the strengthening characteristics is a result of chemoadsorption activities of the medium, which often oxides and impacts the microstructural evolution [12, 22].

The tensile strength was as well observed to have increased in certain quenching media as compared to the other and to the as-received specimen. For instance, the tensile strength of the specimen heated to 870^{o}C and quenched in engine oil, honey, palm oil, water, and cassava juice are 618 Mpa, 625 Mpa, 630 Mpa, 665 Mpa and 680 Mpa, respectively as compared to the as-received with 462 Mpa (see Figure 2). The nearly martensitic structures obtained in the samples quenched in water and cassava juice are likely to be responsible for the recorded high tensile strength and hardness values. While the bainitic structure obtained in the sample quenched in oil and honey is also responsible for the strong values and hardness values recorded.

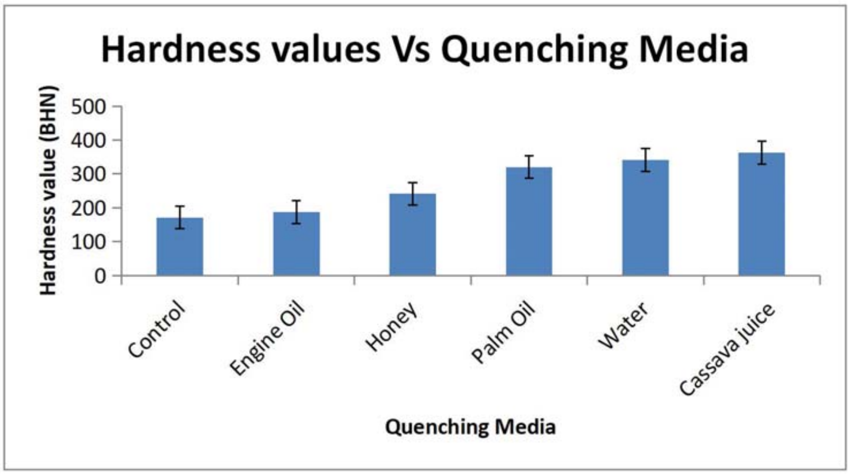

Figure 1: Brinnel Hardness Values (BHN) of samples quenched in different media from austenitizing temperature of 870^{o}C, after been soaked for 45 minutes

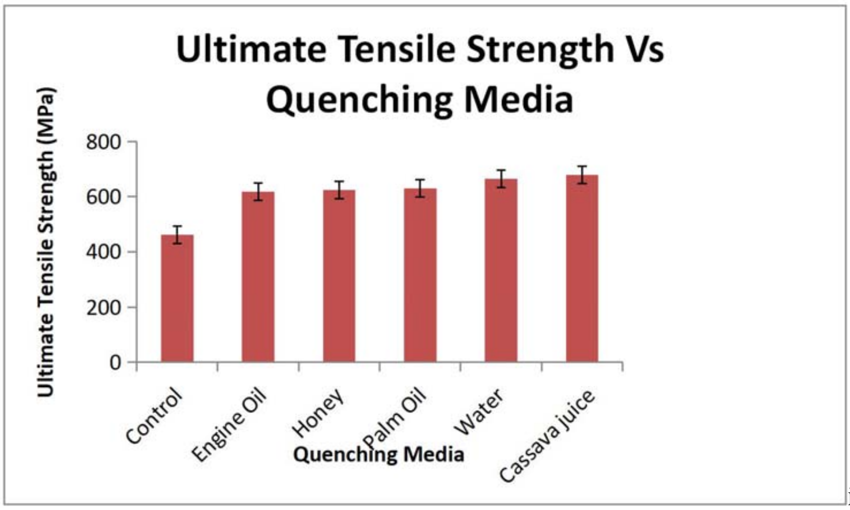

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Figure 2: Effect of various quenching media on the Ultimate Tensile Strength of medium carbon steel

3.3. Microstructural Analysis Results

After specimens of various quenching media had undergone a tensile and hardness test, a portion from each sample was cut for micro-examination where the samples' internal structure was revealed according to their view under a microscope. Internal structure with their magnification at various quenching media is shown in Figure 3a-f. The following transformation and properties were achieved as the samples were quenched in different media at the same austenitic temperature. From Fig 3a, the as-rolled medium carbon steel investigated has the microstructure of uniformly distributed pearlite regions in the ferrite matrix, which confirms that it was produced by hot rolling. Hence, this is a soft structure and confirms the level of mechanical properties and the high ductility expected of structural steels [6]. Figure 3b shows the cassava juice quenched sample. Due to the very rapid rate of cooling, carbon was forced to remain in solution, and austenite transforms to martensite from the as-quenched microstructures in brine. Figure 3c presented the Water quenched sample. Due to the very rapid rate of cooling, carbon was forced to remain in solution, and austenite transforms to martensite from the as-quenched microstructures in Water. Figure 3d shows the recrystallization of the Palm Oil quenched sample. Fine unresolved structure, was obtained when quenched from above A3 – points of 870oC from the hardness values, this matrix structure is likely to be lower bainite. Figure 3e shows the honey quenched sample morphology. The honey quenched sample was found not to result in martensite formation. Instead, bainite structures were presumed to be formed [8]. Thus, the level of carbon and other hardenability promoting alloying elements were not present in amounts required for martensite formation but enough for the formation of bainite. Figure 3f presents the SAE 0 - 40 Engine oil quenched sample. The evolution indicated that a quenched in engine oil, resulted in fine unresolved structure likely to be bainite.

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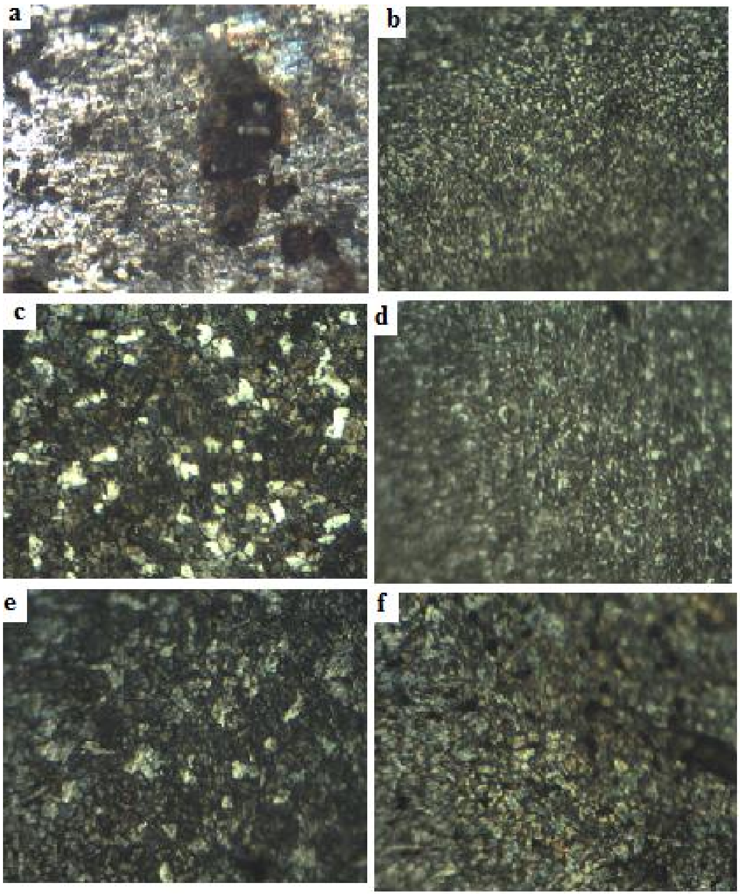

Figure 3: Microstructure of a} as-received medium carbon steel rod at x 20, b}Medium carbon steel rod heated to 870 ^{o}C held for 45 minute and later quenched in extracted cassava juice at x20, c} Medium carbon steel rod heated to 870 ^{o}C held for 45 minutes and later quenched in water at x 20, d} Medium carbon steel rod heated to 870 ^{o}C held for 45 minutes and later quenched in palm oil at x 20, e} Medium carbon steel rod heated to 870 ^{o}C held for 45 minute and later quenched in honey, f} Medium carbon steel rod heated to 870 ^{o}C held for 45 minute and later quenched in SAE 0 - 40 grade engine oil

Conclusions

After a successful study on the quenching processes, quenching media has a significant influence on engineering material in terms of its mechanical properties. Quenching media like palm oil, engine oil, and honey increased the strength and hardness of engineering materials, especially with applications related to machine parts. Quenching media like cassava juice extract and water produces a severe quenching effect which strengthening the materials and result into dispersive phases. Quenching media such as engine oil, honey, and palm oil in that order, respectively, as observed from their hardness values, were not as effective, especially where high durability and unique application are required.

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