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The Mechanical Properties of Low Carbon Steels Enhanced By Using Automotive Oil Quenchants (Environmental Impacts)

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Abstract This work aims to study the effect of utilizing oils of different categories as quenching medium to achieve different rapid cooling rates for low carbon steel samples. Rockwell hardness test was carried out on the 12 mmϕ and 14 mm low carbon steel samples before and after the heat treatment process.It was found that the positive effects on the mechanical properties are more pronounced in 12 mmϕ steel samples. The hardness increased by (Av. 58.5%), as compared with the untreated samples. The mechanical properties for 14 mm ϕ steel samples increased by (Av. 27.5%), as compared with untreated samples.The overall conclusion is that quenching oils affect the microstructures of the low carbon steels, and the effect varies depending on the type of employed oil. The used oils can have two important advantages. First, it is an affective quanchant to improve the steel hardness and thesecond is to save our environment against the used oil pollution. The prediction concerning the tensile strength from the Brinell hardness showed improvement in the mechanical properties for the (12& 14) mm ϕ low carbon steel.

Keywords: Low Carbon Steels, Automotive Oil, Heat Treatment, Mechanical Properties.

الخواص الميكانيكية للصلب المنخفض الكربون تتحسن باستخدام أنواع مختلفة من زيوت محركات السيارات كأوساط تبريد في المعالجة الحرارية

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الملخص الهدف من هذا المشروع هو دراسة تأثير أنواع مختلفة من زيوت محركات السيارات كأوساط تبريد في المعالجة الحرارية للصلب منخفض الكربون. استنادا الى نتائج اختبارات الصلادة ومقاطع الأطوار الداخلية للعينات لاحظنا أن التصلب في العينات المعالجة حراريا والمبردة في الزيوت المستعملة للسيارات (والذي يعتبر من أهم الخواص الميكانيكية للصلب) قد تحسن مقارنة بالعينات التي لم تعالج حراريا، والطور الداخلي المتكون هو باينيت (والذي يتميز بصلادة أعلى مقارنة بأطوار الفرايت أو البرليت). ونخلص من خلال هذه الدراسة أنه هناك فائدة مزدوجة للزيوت المستهلكة، حيث يمكن استعماها كمبردات فعالة في عمليات المعالجة الحرارية، وكذلك يمكن أن يساهماستعمالها كمبردات بشكل كبير في حماية البيئة من التلوث بالزيوت المستهلكة للسيارات.

الكليمات المفتاحية: فولاذ منخفض الكربون ، زيوت السيارات ، المعالجة الحرارية ، الخواص الميكانيكية.

1. Introduction

1.1. Waste (Used Oil): Used oil is defined as any oil that has been refined from crude oil, or any synthetic oil, that has been used and as a result, is contaminated by physical or chemical impurities[1].Waste lubricating oils have been contaminated with impurities in the course of usage and handing. They contain toxic and harmful substances such asbenzene, lead, cadmium, polycyclic aromatic hydrocarbons (PAHs), zinc, arsenic,polychlorinated biphenyls (PCBs)etc. These are hazardous and detrimental to the soil and the surrounding environment. Increase in demand for cars, heavy duty automobiles, generators etc. throughout the years led to increase in demand for lubricating oils, and this eventually resulted in the generation of large volumes of waste oils worldwide [2]. In our country, waste oil despite of the type and source of collection, is sometimes dumped on vacant plots, farm land etc., causing harmful or toxic materials to infiltrate through the soil, thus contaminating the soil and there by changing the physical and chemical properties. Used oil is also sometimes dumped down drain, sewers, disrupting the operations at waste water treatment plants.

1.2. Used Oil Specifications: Chemical composition of waste oil, along with the original ingredients of the base oils and additives, includes products of oxidation and degradation of base oils and additives as well as outer pollutants that have arisen during implementation. Waste oils, with much more serious impact on the environment compared to the effect that they have as unused lubricating automotive oils [1]. The following table shows the used oil constituents properties and their allowable on specification level.

Table 1. Used oil specifications [1]

Constituent/ Property	Allowable Specification Level	
Arsenic	5.00	ppm maximum
Cadmium	2.00	ppm maximum
Chromium	10.0	ppm maximum
Lead	100	ppm maximum
Total Halogens for Rebuttable Presumption	1000	ppm minimum
Total Halogens	4000	ppm maximum
Flash point	100	°F minimum

1.3. Plain Carbon Steels: Carbon steel is by far the most widely used kind of steel. The properties of carbon steel depend primarily on the amount of carbon it contains. Most carbon steel has a carbon content of less than1%. Carbon steel is made into a wide range of products, including structural beams, car bodies, kitchen appliances, and cans. In fact,there are 3 types of plaincarbon steeland they are low carbon steel, medium carbon steel,steel, high carbon steel. Indeed, it is good to precise that plain carbon steelis a type of steel having a maximum carbon content of 1.5% along with small percentages of silica, sulphur, phosphorus and manganese [3].
There are also other properties of plain carbon steel that needs to be considered and these physical properties are reported in ref. [3].

1.3. Heat Treatment: Steels can be heat treated to produce a great variety of microstructures and generally, heat treatment uses properties. Phase transformation during heating and change a microstructure in a solid state. In heat treatment, the cooling to processing is most often entirely thermal and modifies only structure. Thermo-mechanical treatments, which modify component shape and structure, and thermo-chemical treatments which modify surface chemistry and structure, are also important processing approaches which fall into the domainof heat treatment.

1.4. Quenching Oil: any components use quenching oil to achieve consistent and repeatable mechanical and metallurgical properties and predictable distortion patterns. The reason oil quenching is so popular is due to its excellent performance results and stability over a broad range of operating conditions. Oil quenching facilitates hardening of steel by controlling heat transfer during quenching, and it enhances wetting of steel during quenching to minimize the formation of undesirable thermal and transformational gradients which may lead to increase distortion and cracking [4].

2. Literature Survey: In 2013, Udonne J. D. , Onwuma H. O,Lagos State University have Studied of the effects of waste lubricating oil on the physical and chemical properties of soil and the possible remedies. The soil analysis showed that waste lubricating oil adversely alerted the physical and chemical properties of the soil. It resulted in increase in bulk density from1.10to 1.15 g/cm^3, organic carbon(2.15 to 3.05), moisture content and reduction in pH (6.0 to 6.5)[2].
In2014 T. Abdulla et al., studied the effect of different quenching medias including: (cold water, hot water, normal water, salt solution NaCl - 2.5%/L, salt solution- NaCl5%/L, salt solution NaCl- 10%/ L, benzene engine oil, used engine oil and vegetable oil) on the hardness of low carbon steel) [5]. According to results of Brinell hardness (HB), they found that the benzene engine oil and used oil have the highest Brinell hardness (HB) comparing with the other mentioned quenching medias, which they are 238 and 231 respectively. This approved that the used automotive oil as quenching media to improve the hardness of plain carbon steels can be one of the possible ways to protect our environment.
In 2014 O.O. Joseph et al., studied the effect of heat treatment at 850°C on the microstructure and mechanical properties of SAE1025 carbon steel. Annealing, normalizing and age-hardening heat-treatments at 850°C was used for the experimental work. Hardness tests, tensile tests and metallography were carried on the heat-treated and untreated samples.
The results were further analyzed using the obtained one-way ANOVA test. Results showed significant differences in the properties microstructure and mechanical of the different heat-treated samples.
The hardness profile determined using a Brinell ball indenter showed decrease in hardness of the heat treated samples when compared with the untreated ones which was possibly due to softening process [6].

3. Experimental Work

3.1. Data andPreparation of Plain Carbon Steel

Plain carbon steel samples were kindly provided by The Organization and Development of Administrative Centers, Sebha, Libya. The related dataincluding plain carbon steels chemical composition and tensile mechanicalpropertieswere also provided. The above mentioned data are illustrated in the following tables (2 and 3).

Table 2. Chemical compositions Data of Steel Used in this Work

Sample Diameter	**12 mm**		**14 mm**		Average of Element Composition
	Element Composition				
Sample's Symbol	I	II	I	II	
C	0.28	0.27	0.28	0.25	0.280
Si	0.14	0.13	0.14	0.13	0.140
Mn	0.54	0.54	0.53	0.53	0.539
S	0.03	0.04	0.04	0.03	0.040
P	0.01	0.0	0.0	0.0	0.015

Table 3. Dimensions and Mechanical Properties Data of 14 mm ∅ Steels Material used in this Work

Constituent / Property	Test		
Sample Shape	Deform Steel Bars		
As Received Diameter	14 mm		
Sample's Symbol	I	II	III
Yield Strength (N/mm²)	531	515	585
Tensile Strength(N/mm²)	666	632	699
Percentage Elongation (%)	17	15	15

The provided about one meter steel bars, were cut into several samples (6 specimens of 12 mm∅ steel bar and 6 samples of 14 mm ∅ steel bar) as shown on figures (1&2). After cutting the all required samples with required dimensions, grinding machine, silicon carbides sand papers (100, 120, 180, 220 and 320grit) and hand tool brush were used to prepare a samples surfaces to be ready for next steps.

Figure 1 - 12 mm ∅Steel Specimens

Figure 2 -14 mm ∅Steel Specimens

3.2. Experiment Quenching Oil: The characteristics of local lubricating and used oil are showed in tables (5 & 6) respectively [7]. The types of local oils used in this project are showed in figures (3&4).

Figure 5. Automotive Oil AL-THURIA 20 and AL-ZAHRA 40

Table 5. Lubricating Automotive Oil AL-THURIA 20

Density at 15°C	892 Kg / m³
Viscosity at 100°C	17.0 mm² / S
Flash Point	> 200 °C
SAE Grade	20 W 50

Table 6. Lubricating Automotive Oil AL-ZAHRA 40

Density at 15°C	898 Kg / m³
Viscosity at 100°C	14.5 mm² / S
Flash Point	> 200 °C
SAE Grade	40

3.4. Heat Treatment Process: Before entering the specimens in the furnace they were cleaned again using a chemical agent (Alcohol), followed by drying using dry rags. This procedure was done for all samples under investigation in order to remove any oxidation or contaminations.
The heat treatment furnace specification and data are sown in table (7).

Table 7. Furnace Specification and Operation

Type	SIB srl,26010 BangnoloCremasco - Italy
Maximum Capacity	1200 °C
Time Required to Reach Heat Treatment Temperature (950 °C)	$2\frac{1}{2}$ hrs

The heat treatment process in this project was carried out as the following:
* The temperature used for heat treat process was arranged to be **950°C**.
* The specimens were washed and dried immediately before inserting them in the furnace.
* All specimens were inserted in the furnace at **615°C**, and the temperature was increased gradually up to **950°C** and held for 40 minutes.
* All heat treated specimens were subjected to cleaning after heat treatment process.

4. Results and Discussions

4.1. Estimation the Hardness of Steel Specimens: The hardness test and the microstructure examination were carried out at the Technical Center, AbuSaleem, Tripoli, Libya. 5 hardness readings were recorded for each sample. 1 in the centre, 2 right and left of the sample surface and 2 up and down of sample surface.

The tables (8 & 9) shows the hardness reading results which represents the effect of used quenching media on the hardness of plain carbon steel (12mm ϕ and 14mm ϕ) specimens (with about 0.28 % C). There is a clear evidence that can be observed through the hardness readings of the heat treated samples (quenching in lubricating and used oil) and the non-heat treated sample, for instance, the highest increase in hardness can be seen in the heat treated 12mmϕ samples that were quenched in new (AL-THURIA 20). The average hardness increased from 23.32 to 60.52. This increase is higher by about 61%. Moreover, the hardness was also increased for other quenched samples, as compared with the untreated sample. However, there are minor differences between the hardness readings of those 12 mmϕ samples that were quenched in the other automotive oils including; used automotive oil (AL-THURIA 20), lubricating automotive oil (AL-ZAHRA 40), used automotive oil (AL-ZAHRA 40) and mixed automotive oil (AL-THURIA 20 + AL-AL-ZAHRA 40). The increases in hardness readings for these samples are 54.54, 54.08, 55.16 and 55.68 HB respectively. The enhancements in hardness are calculated to be as 57 %, 57 %, 58 % and 58 % respectively. This can be considered as an effective increase.

Another interesting advantage is that the hardness values in the center of all heat-treated samples conditions are almost the same as the hardness values in the edges. This means that the microstructure of each sample is uniform throughout. The homogenous microstructure can only result from equal transformation from austenite to bainite at relatively the same rate and speed. However, the hardness value of in the center of untreated sample is lower than that of edges of the same sample.

Table 8. Hardness (HB) Reading Results of 12mm Steel Samples of this Work.

Quenching Media	Centre Reading	Up Reading	Down Reading	Right Reading	Left Reading	Reading Average
Blank	17.6	27.8	26.3	17.1	27.8	23.3
THURIA 20	60.1	58.7	60.3	57.1	66.4	60.5
Used *THURIA 20*	54.8	50.3	60.3	53.4	53.9	54.5
ZAHRA 40	49.4	56.4	53.8	57.4	53.4	54.0
Used *ZAHRA 40*	50.7	54.3	56.8	57.8	56.2	55.1
Mixed *THURIA 20 + ZAHRA 40*	54.5	53.8	57.9	56.3	55.9	55.6

In case of 14 mm ϕ steel samples, there is clear evidence that can be observed through the hardness readings of the heat treated samples (quenching in lubricating and used oil) andthe untreated sample. The highest increase in hardness can be seen from the samples that were quenched in both new and used Al-ZAHRA 40 oil. The hardness readings increased from 21.36 (for untreated sample) to a value of 42.12 and 41.84 HB for the new and used oil respectively. Comparing the hardness values, the increases are estimated to be50 % in both cases.

Table 9 - Hardness (HB) Reading Results of 14mm *ϕ* Steel Samples of this Work

Quenching Media	Center Reading	Up Reading	Down Reading	Right Reading	Left Reading	Reading Average
Blank	19.8	20.7	20.5	22.0	23.8	21.3
THURIA 20	31.6	32.6	40.6	34.6	31.6	34.2
Used *THURIA 20*	25.6	30.0	28.2	31.1	28.8	28.7
ZAHRA 40	44.8	40.9	42.9	39.6	42.4	42.1
Used *ZAHRA 40*	40.1	42.4	41.0	43.1	42.6	41.8
Mixed *THURIA 20 + ZAHRA 40*	40.0	38.2	38.7	41.5	39.3	31.9

On other hand, there is a small differencein the hardness readings of 14 mm ϕ samples thatwere quenched in the other oil media. For instance, the hardness values were 34.20, 28.78 HB for specimen that were quenched in new and used (AL-THURIA 20) respectively. For samples quenched in the mixed automotive oil (AL-THURIA 20 + AL- AL-ZAHRA 40), the hardness reached 31.90. The enhancement in hardness for those conditions can be estimated as 38 %, 26 %, and 33 % respectively.The hardness readings for the untreated steel samples of the 12mmϕ and 14mmϕ are very close; they are23.322and21.36 respectively.Looking at the tables (8) and (9), it can be observed that the hardness values for the 12 mm ϕ steel samples are higher than those of 14 mm ϕ steel samples. The hardness values ranged from 54 to 60.5 for the quenched samples in different oil categories. As mentioned earlier, the highest hardness value was obtained from the samples that were quenched in lubricating automotive Oil (AL-THURIA 20) with valuesreaching 60.52. For the heat treatment in mixed automotive oil (AL-THURIA 20 + AL-ZAHRA 40), the enhancement in hardness reading in12mmϕsteel samples is again higher comparing with a 14 mm ϕ steel samples. The hardness readings are 55.68 and 31.90 respectively. The successful heat treating of steels to produce a uniform and stronger microstructure throughout the cross section depends mainly on three factors:the composition of the alloy, the type and character of the quenching medium and the size and shape of the sample [8]. Therefore, smaller samples, as is the case for 12 mm ϕ steel samples, are expected to undergo uniform heating during the heating process, which can allow the microstructure to be uniform since the entire sample can transform from austenite to bainite at relatively the same rate. Larger samples, on the other hand, are more likely to get non-uniform transformation and non-uniform cooling rate. In case of comparing between the hardness readings of lubricating oil and used oil for the same ϕ of steel samples, for the 12 mm ϕ steel samples, the hardness enhancement after heat treatment relatively has the same value in both types of automotive oil (AL-THURIA 20 & AL-ZAHRA 40). The average of hardness readings are 57.53 and 57.62 respectively.

For the 14 mm ϕ steel samples, the hardness enhancement after heat treatment is better in case of (AL-THURIA 20) automotive oil. The average of hardness readings are (31.00 and 41.98 respectively). When comparing between hardness readings of the pure and the mixing automotive oil in the same ϕ of steel samples, in case of 12 mm ϕ steel samples, there is no any observed changes occurred in hardness readings except for (AL-THURIA 20) which has slightly higher hardness reading comparing with the average of the others. The hardness readings are (55.68, 60.52 and the average is 54.59 respectively).

4.2. Estimation the Tensile Strength of Steel Specimens: In this part of the project, an estimation of the tensile strength of low carbon steel specimens were carried out using the resulted hardness readings. However, before the estimation can be done, the resulted Rockwell hardness readings in this work must be converted into Brinell hardness values. This was achieved by using a conversion method cited in reference[8].

Figure (6) shows the comparison between all Brinell hardness reading values resulted in this work. It is clear that the values of Brinell hardness for 12 mmϕsteel samples are much higher than those of 14 mmϕsteel samples. After conversion to Brinell hardness, it is possible to discuss the present data work using a modelling approach which links the hardness to the prediction of the tensile strength. This can be related to the fact that tensile strength is proportional to the hardness of the metal following the equation [8]:

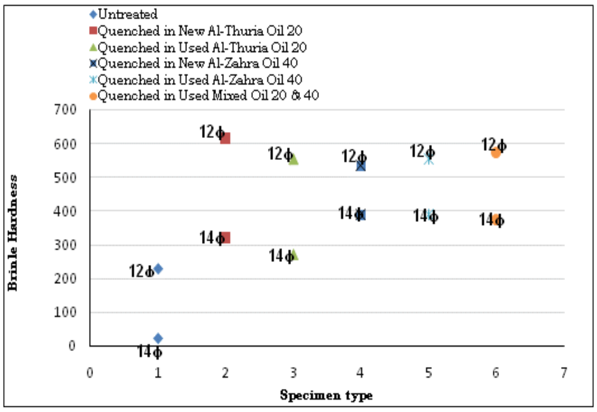

Figure 6 - Comparison between all Resulted Brinell Hardness Reading in this Work.

σ_{TS}=3.45 ×HB………………… (1)

This leads to the fact that any increases in hardness will certainly results with increasing in the tensile strength. So, the hardness data in this work was used for theprediction of the tensile strength of each specific specimen, using equation (1). The data for estimation the (UTS) of low carbon steel is shown in table (10) for 12 mmϕ steel samples and table(11) for 14 mmϕ steel samples respectively.

The analysis of the presented data shown in the tables (10 &11) reveals that the predictedtensile strength of heat-treated samples could increase dramatically ascompared with the untreated sample. The increase in the tensile strength is directly proportional with increasing of the hardness readings that were experimentally measured in this work. It is noticed that the positive effect on the mechanical properties are more pronounced in 12 mm ϕ steel samples.

The mechanical properties enhanced by 56 to 61 %, as compared with untreated samples. The enhancement in mechanical properties for 14 mm ϕ steel samples is relatively lower. The mechanical properties enhanced by 15 to 40 %, as compared with untreated samples. Since the size and volume of 12 mm ϕ steel samples are smaller than those of the 14 mm ϕ steel samples, therefore, the processes (phase transformation and diffusion of atoms) that are involved in the heating and quenching stages are more effective in a smaller sizes.

Table 10 - (UTS) Estimation Data of Low Carbon Steel for 12 mm ϕ Samples

Quenching Media	Rockwell H. (Av.)	Brinell H.	Estimated UTS	% UTS Increase
Blank	23.3	233	803.8	-
THURIA 20	60.52	613	2114.8	61
Used THURIA 20	54.5	552	1904	57
ZAHARA 40	54.1	534	1842	56
Used ZAHRA40	55.2	552	1904	57
THURIA 20 +ZAHRA 40	55.7	572	1973	59

Table 11 - (UTS) Estimation Data of Low Carbon Steel for 14 mm ϕ Samples.

Quenching Media	Rockwell H. (Av.)	Brinell H.	Estimated UTS	%UTS Increase
Blank	20.75	229	790	-
THURIA 20	34.85	322	1111	28
Used THURIA 20	28.7	271	935	15
ZAHARA 40	42.1	388	1338.6	40
Used ZAHARA40	41.6	388	1338.6	40
THURIA 20 +ZAHRA 40	39.6	373	1286.8	38

4.3. Metallographic Results and Discussion:

Metallographic procedures were carried out on all samples in preparation for optical microscope imaging and analysis. Optical micrograph reveals a three-dimensional scanning of the specimen surface. Our objectives of microscopic examination isto identify the changes of microstructures of the specimens after heat treatment, and also analyze the effect of the different quenching oil medias on microstructure formation during the cooling process. Unfortunately, XRD examination to study the possible phases that may be present in steel samples was not possible due to lack of equipment

Figures 7 and 8 show optical microscope images, which can reveal the possible changes in the microstructures, after the heat treatment process was carried out on steel samples.

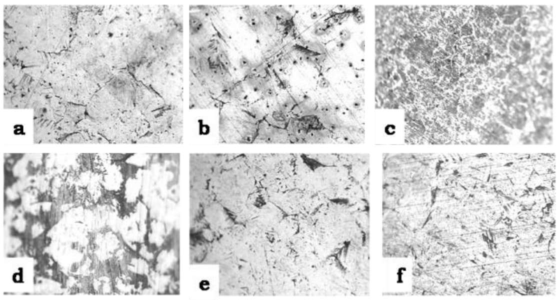

Figure 7 – Optical microscope images (400 X) showing microstructures of 12 mm steel samples of a) untreated sample, b) sample quenched in Thuria 20 oil, c) sample quenched in Used Thuria 20 oil, d) sample quenched in Zahra 40 oil, e) sample quenched in Used Zahra 40 oil, f) sample quenched in Mixed Thuria 20 & Zahra 40 oils.

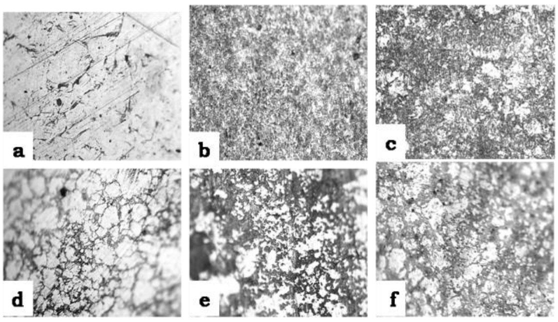

Figure 8 – Optical microscope images (400 X) showing microstructures of 14 mm steel samples of a) untreated sample, b) sample quenched in Thuria 20 oil, c) sample quenched in Used Thuria 20 oil, d) sample quenched in Zahra 40 oil, e) sample quenched in Used Zahra 40 oil, f) sample quenched in Mixed Thuria 20 & Zahra 40 oils.

As can be seen from both figures, some changes occurred to the microstructures of the heat treated steels. Possible precipitation of second phase particles and formation of new grains can be noticed. The increased hardness for specimens that were quenched in normal and used engine oil can be related to the fact that these oils contain chemical impurities, heavy metals, dirt and carbon elements [1, 9, 10]. Subjecting low carbon steel in carbon and other impurities environment (liquid) at elevated temperatures and for a certain amount of time may become a process similar to case hardening process. The final properties of heat-treated parts are directly linked with the microstructure that is produced during the heat-treatment process. The microstructure development is diffusion controlled since complex thermal cycles are involved.

5. Conclusions

In this work, Rockwell hardness test was carried out on 12 mm ϕ and 14 mm ϕ low carbon steel samples following to a heat treatments process. The heat treatment was carried out for 12 samples. After heating and holding the samples at a specific temperature (950ºC), a different quenching mediums were employed to obtain a specific microstructure. The used quanchants were a new automotive oil (AL-THURIA 20), used automotive oil (AL-THURIA 20) lubricating automotive oil (AL-ZAHRA 40), used automotive oil (AL-ZAHRA 40) and mixed automotive oil (AL-THURIA 20 + AL- AL-ZAHRA 40).

The aim of this work is mainly to apply different quenching oils for the heat-treated specimens. According to the experiments results in this work the overall conclusion is that the used quenching oils affected the microstructures of low carbon steels, and the effect varies depending on the type of the employed oil. In the present study, the resulted microstructure is expected to be a bainite, which is anticipated from the improved in hardness and strength of heat-treated samples. The improvements in mechanical properties may be attributed to a fast cooling rate during a heat treatment and a possible diffusion of carbon into the surfaces of the samples. Meanwhile it is noticed that the improvement in mechanical properties (HB and UTS) is more pronounced in 12 mmϕ steel samples. The mechanical properties were enhanced by (59.5% average), as compared with the untreated samples. The enhancement in the mechanical properties for 14 mm ϕ steel samples was relatively lower. The mechanical properties enhanced by just (27.5 % - average), as compared with the untreated specimens.

The evaluation concerning the tensile strength from the Brinell hardness showed some good agreement with data presented for steel. This is a good sign that data in this work are reliable and produced significant results.Finally, an important factor that can be considered in the present work is that environmental impact of recycling and reusing of the waste engine oils.

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