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The Effect of Quenching Media on the Hardness of Low Carbon Steel

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ABSTRACT

Steels with desired properties are essential and always required by many industries. This paper highlights some heat treatment operations with various cooling media to achieve different rapid cooling rates. This was carried out by heating samples of low carbon steel to a specific temperature and then cooling them rapidly in 8 different quenching media in order to obtain a specific microstructure of steel. These heat-treated samples were then tested mechanically using the Brinell hardness test (BH). The results show that the quenching mediums affect the mechanical properties and hence the microstructures of low carbon steels and the effect varies depending on the types of quanchants employed.

تأثيروسط التبريد السريع على خاصية الصلابة للصلب منخفض الكربون

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الملخص

الصلب مع الخواص الميكانيكية الجيدة مهم ودائما مطلوب من قبل العديد من الصناعات. تسلط هذه الورقة الضوء على بعض عمليات المعالجة الحرارية بمختلف وسائط التبريد السريع لتحقيق معدلات تبريد سريعة مختلفة. وقد تم ذلك عن طريق تسخين عينات من الصلب منخفض الكربون لدرجة حرارة معينة ثم التبريد بسرعة للحصول على بنية مجهرية محددة من الصلب، بعدها خضعت هذه العينات المعالجة بالحرارة إلى اختبار صلابة (برينل هاردنس) في وقت معين وتحميل. وأظهرت النتائج أن وسط التبريد يؤثر على مجهرية الصلب منخفض الكربون، ويختلف التأثير بناء على نوع الوسط التبريدي المستخدم.

الكلمات المفتاحية:
اختبار هاردنس
معالجة حرارية
صلب منخفض الكاربون
وسط نبريد

1. Introduction

Steel may be defined as an alloy of iron and carbon (with or without other alloying element) containing less than about 2.0 percent of carbon [1]. Additions of alloying elements to Fe-C system bring changes which depend on that particular element and its concentration. Almost all alloying elements causes the eutectoid concentration to decrease, and most of the alloying elements (e.g.: Ti, Mo, Si, W, Cr) causes the eutectoid temperature to increase while some other (e.g.: Ni, Mn) reduces the eutectoid temperature. Thus alloying additions alters the relative amount of pearlite and proeutectoid phase that form. [2]. The Fe_3 C (iron carbide or cementite) is a metastable intermetallic compound, it remains as indefinitely at room temperature, but decomposes (very slowly, within several years) into α- Fe and C (graphite) at 600 – 750 °C [3]. Low carbon steel is an iron/carbon alloy where the percentage of carbon is within the range of 0.05 % to 0.30 %. Low carbon steel is non-hardenable by heat treatment, and therefore is essentially unaffected by welding. This makes low carbon steel the ideal choice for general fabrication purposes where high strength is not a prime requirement, but ease of fabrication and welding are. [4]. Medium carbon steel contains carbon in the range of 0.30 % – 0.50 %. Medium carbon steels are hardenable, and exhibit improved mechanical properties over low carbon steel [4]. High carbon steel contains carbon in the range of 0.50%–1.70%. They are generally selected for use where hardness is a prime requirement [4]. Low carbon steel is considered to be ideally weldable as it is easy and cheap to weld. As the carbon content increases, hardenability increases. Therefore weldability decreases in medium and high carbon steels. This is the result of the formation of martensite, which is a brittle constituent

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that forms when steel containing more than 0.3 % carbon is cooled rapidly from elevated temperatures [4]. In all types of steel carbon is the principal component since the amount (%) present has a pronounced effect on the properties and the selection of suitable heat treatments to attain desired properties [5]. Critical temperatures for the start and completion of the transformation to austenite during heating are denoted, respectively, by Ac_1 and Ac_3 for hypo eutectoid steels and by Ac_1 and Ac_{cm} for hypereutectoid steels [6]. Heat treatment process is carried out to change the grain size, stress relieve, soften the metal and to modify the structure of material [6]. The heat treatment process controls in the two variables: the temperature and time [6]. This variable can be controlled to a large extent in the stages of transformation. For this, it is necessary to look at some of Fe-C equilibrium diagram like the eutectoid steel (carbon content 0.77 %) [6]. At temperature higher than eutectoid 727°C, this phase is called austenite, while below this temperature upon slow cooling the austenite transforms to cementite and ferrite and that known as pearlite [6]. On the other hand, fast cooling of austenite will produce various forms of ferrite products such as bainite or martensite which depends on the type of cooling rate. The types of heat treatment consist of annealing, normalizing, tempering and quenching [6]. Quenching is a process which starts with the heating of metal to a temperature over the upper critical point for the hypo-eutectoid steels. For the hypo-eutectoid steels, the heating is applied over the lower critical point and holding at this temperature for the suitable time and then quenched [7]. The quenching process is the rapid cooling of high temperature objects by exposure to a much cooler liquid. The behavior of quenching process is generally influenced by many parameters, such as the surface properties of the substance, thermal–hydraulic properties of the coolant, and temperatures of the substance and coolant [8]. Low-alloy, and tool steels, are quenched to produce controlled amounts of martensite in the microstructure. Successful hardening usually means achieving the required microstructure, hardness, strength, or toughness while minimizing residual stress, distortion, and the possibility of cracking. The selection of a quenchant medium depends on the hardenability of the particular alloy, the section thickness and shape involved, and the cooling rates needed to achieve the desired microstructure. The most common quenchant media are either liquids or gases [9]. Hardness so defined is not an intrinsic property of any material, (like density or melting point), it is rather a characteristic deriving from the composition, the thermal and mechanical history of the material, and essentially from the structure (or more properly the microstructure) of the specimen involved [10]. One of the most popular hardness testing methods, Brinell Hardness, it is most often applied on iron and steel castings where its usefulness is most advantageous as the results represents a sort of average surface hardness because these materials are not uniform on the microscopic scale [10].

2. Experimental Procedures

Low Carbon steel samples were kindly provided by The Organization for Development of Administrative Centers, Sebha, Libya. Chemical compositions as well as the tensile mechanical properties of these samples were also provided, see table 2.1 and 2.2. These data were carried out at the Industrial Research Centre, Department of Laboratories and Technical Development, Metallurgy and Surface Protection Section, Tripoli, Libya. Tests were approved by the Fessato.

Table 2.1 - Chemical Compositions for Different Steels Provided By the Company.

Sample diameter (mm)	**12**			**14**			**16**	
	A	B	C	A	B	C	A	B
Element	Percentage (%)							
C	0.278	0.279	0.177	0.284	0.259	0.153	0.273	0.261
Si	0.142	0.136	0.076	0.143	0.131	0.046	0.158	0.153

Table 2.2 - The Tensile Mechanical Properties of Steel Samples under Study.

Test	Result				
Sample Shape	Deformed Steel Bars				
As Received Diameter (mm)	14			16	
Sample's Symbol	A	B	C	A	B
Calculated Diameter (mm)	13.74	13.71	13.66	16.65	15.63
Yield Strength (N/mm2)	531	515	585	532	551
Tensile Strength (N/mm2)	666	632	699	668	676
Percentage Elongation (%)	17	15	15	15	14

2.1. As-Received Materials: The low carbon steel sample was received as rod of about 1 meter long. This rod was cut into several specimens, each with diameter of 14 mm and length of 15 mm, as shown in figure 2.1 below.

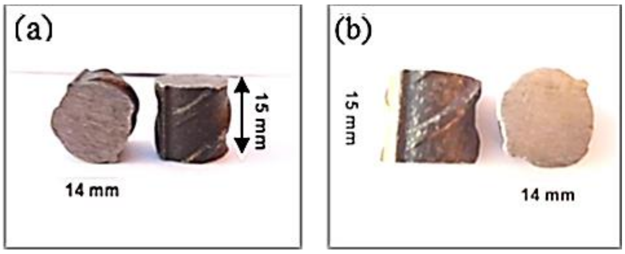

Fig. 2.1 - Two Different Views of Low Carbon Steel Specimens used in this Work, as they were cut from the Long Bar Provided by the Company.

The cutting of specimens was carried out using a lathe turning machining process. This operation is one of the most basic machining processes.

2.2. Sample Preparation: Several procedures were used to prepare the specimens for the hardness tests. In order to obtain a highly reflective surface that is free from scratches and deformation, the specimens must be carefully grinded and polished before they can be examined under the microscope. In this work, after cutting of the specimens all with the correct dimensions, as shown in figure 2.1 above, grinding was carried out for different stages to produce surfaces with high smoothness. This was achieved by using SiC papers ranging from 100, 120, 180, 220, and 320 grit.

The procedures for specimens' preparation including grinding were repeated before and after the heat treatment. This will help to achieve flat and smooth surfaces. Fig. 2.2 show different specimens after proper cleaning but before grinding process.

Fig 2.2 - Specimens Shown Before Grinding Down Using Sand Paper.

Fig. 2.3 shows the process of grinding during specimens preparation. Each stage of metallographic sample preparation must be carefully performed. This process is designed to produce a scratch free surface by employing a series of successively finer sandpapers. Failure to be careful in any stage will result in an unsatisfactory sample. The specimens were washed thoroughly before proceeding from one grinding operation to the next one. Finally, Fig. 2.3 (a) presents a number of steel specimens positioned vertically and (b) a magnified image of the top of one specimen to obtain close and clear view of the fine surfaces.

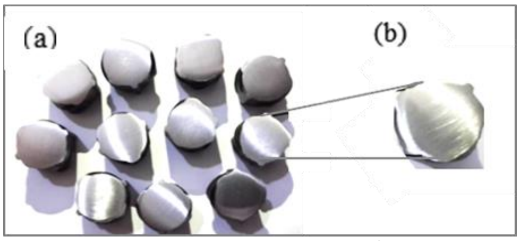

Fig 2.3 - (a) Low Carbon Steel Specimens after Grinding down to 320, with Smooth and Flat Surfaces, and (b) A Magnified Image of one Specimen to Show the Surface Details.

2.3. Layout of Experiments: The experiments in this work were designed according to the table 2.3 below. The specimens were divided into 8 types. The temperature used for heating (i.e. 950 C°) was obtained from the phase diagram and based on the carbon content of the specimens.

Table 2.3 - The Experiment Layout with all Details Used in This Work

Specimen No.	Heat Treatment (c°)	Holding Time (min)	Quenching Medium
1	950	30	Cold Water
2			Normal water
3			Salt solution 25% /L
4			Salt solution 50 %/L
5			Salt solution 100 %/L
6			Engine Oil
7			Used Engine Oil
8			Vegetables Oil

The salt solutions were prepared by mixing different amount of salts into 1 liter of water. For example, 25 grams of salt was mixed with 1 liter of water to produced 25%/L salt solution. For 50 %/L SS, 50 grams of salt was added to 1 liter of water, and likewise for 100 %/L SS where 100 grams of salt were mixed with 1 liter of water. Different percentages of salt concentrations were used to ensure that wide ranges of effects are explored. In the quenching of the steel: water, oil, aqueous polymer solutions and aqueous salt solutions (brine) can be used as quenchants that exhibit different characteristic on cooling mechanisms. For example: when water is used as the cooling media, a stable vapor film is formed around the hot component resulting in non-uniformity of surface heat transfer during the cooling process which is often responsible for distortion and cracking. Salt addition can reduce or inhibit this vapor film formation, enhancing the uniformity of heat transfer during the cooling [11].The oil quenchants used in this work were obtained in bottles of 1 liter. The used engine oil was obtained from a car workshop and amount of 1 liter was used for quenching. Some studies have estimated that less than 45% of used engine oil is being collected worldwide while the remaining 55% is thrown by the end user in the environment [12], so it is important that these oil wastes are exploited, a study reported that adding used engine oil to the fresh concrete mix resulted a concrete with greater resistance to freezing and thawing [13]. This means that enhancing some durability properties of concrete while serving is another technique of disposing the oil waste.

2.4. Heat Treatments: The heat treatment was carried out in different steps. The experiments started with turning the furnace on using the ON switch. The furnace has capacity from 200 to 1200 °C, and for this project the temperature of the furnace was set at 950 °C. Before placing the specimens into the furnace, clear marks were made on the top and the bottom of each specimen to show the difference. This to make sure that the top surface, which has been polished, is ready for cleaning, polishing and the hardness measurement. Table 2.4 shows the detail for experiments that were carried out in this section. After heating and holding the specimens for 30 minutes.

Table 2.4 - Summary for Heat Treatment Conditions Used in this Work

Specimen Type	Temperature (°C)	Holding Time (min)
Heat Treated	950	30

2.5. Hardness Tests: Hardness tests were carried out using Hydraulic Brinell Machine (model No. 47/4, type: OM150) which uses a tungsten carbide ball indenter. The indenter has a 5 mm diameter. The load used was 250 KPa, and the indent time is 30 seconds. All diameters of produced indents were measured with an ordinary Vernier caliper. This is a measuring instrument consisting of an L-shaped frame with a linear scale along its longer arm and an L-shaped sliding attachment with a vernier, used to read directly the dimension of an object represented by the separation between the inner or outer edges of the two shorter arms. After heat treatment and the rapid quench, all specimens were cleaned thoroughly with water and ground using 400 sand papers. A Special lubricant (diamond suspension) was used with water during grinding. This produced smooth surface ready for hardness tests. Fig. 2.4 shows the Brinell hardness tester used in this work, showing a step before and during loading the specimen into the hardness tester.

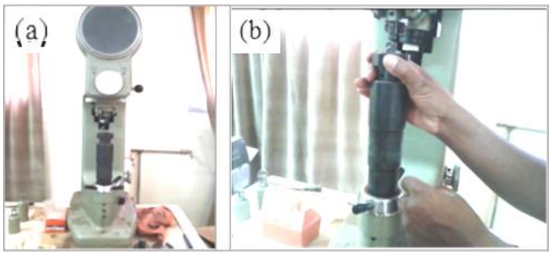

Fig. 2.4 - The Brinell Hardness Tester used in this Work, Showing a) before and b) during Loading the Specimen into the Hardness Tester.

The hardness measurements were taken at three different positions on the top of each specimen. The firs indent was made on the center and the other two were made on both edges (edge 1 and edge 2). Fig. 2.5 shows a schematic representation of where these measurements were undertaken.

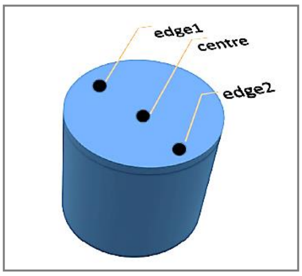

Fig. 2.5 - A Schematic Representation of How the Hardness Measurements were Taken on the Top of Each low Carbon (Heat Treated and Untreated) Specimen.

3. Results

Table 3.1 includes a summary of all hardness tests that were performed on each specimen. The summary also includes the three measurements taken for each specimen (2) at the edges and 1 in the center of the specimen).It can be seen that the hardness of the low carbon steel is affected by the different quenching media used. Using normal and cold water affect the hardness but in two different ways. The hardness increased for specimen that was quenched in normal water to 218 HB, and this is about 21 % increase in hardness as compared with the hardness of untreated specimen. On the other hand, the effect is different for specimen that was quenched in cold water. A reduction in hardness was recorded with average values of 136 HB. We interpret this behavior by the fact that during heating of this particular specimen, some grain coarsening took place due to high austenization temperature. As the specimen was quenched down rapidly the microstructure produced will have decreased hardness and increased ductility due to larger grains. This is because larger grains have less grain boundaries per unit volume to hinder the movement of dislocations, making the material more ductile. In smaller grains there exists large grain boundary area per unit volume and this result in lowering of ductility and increasing strength and hardness. The salt solutions with different concentration have shown different effects. The best performance was achieved by the salt solution containing 50 % salt. The hardness increased to 187HB; as compared with untreated specimen (average hardness of 180 BH was recorded). Some reduction in hardness was noticed for specimens that were quenched in salt solution containing 25 and 100 % salt. Hardness values recorded for those were 176 and 149 HB respectively. The idea of reducing the amount of air bubbles using salt solution is proved to be ineffective at low and high salt concentrations. There were noticeable increases in hardness for the specimens that were quenched in new and used engine oils. The average hardness increased to 238 HB for specimens quenched in new engine oil, while the one that was quenched in used engine oil recorded an average hardness of 231 HB.

These values compares favorably well with the average hardness of untreated specimen with average hardness of 180 HB. The percentage increase in hardness in both specimens is estimated to be 32 and 28 %. The effect of using vegetable oil showed negative effects. The hardness decreased to about 155 HB. Again there might be some softening in the steel specimen that led to this behavior.

4. Discussions

In most steels the microstructure consists of both (α) and (Fe_3C) phases. Upon cooling to room temperature, an alloy within this composition range must pass through the Y-phase field. The heat treated specimens in this work were all heated to 950 °C, and this temperature is chosen using the iron-carbon phase diagram. Conventional heat treatment procedures for producing martensitic steels ordinarily involve continuous and rapid cooling of an austenitized specimen in some type of quenching medium, such as water, oil, or air. The optimum properties of a steel that has been quenched and then tempered can be realized only if, during the quenching heat treatment, the specimen has been converted to a high content of martensite; the formation of any pearlite and/or bainite will result in other than the sample surface (2 edges and 1 at the center). Heating was carried out at 950° c, treatment time was 30 minutes.

Table 4.1 – Summary of Hardness Results for the Heat Treated and Untreated Specimens.

Specimen Type	Quenching Medium	Brinell Hardness Number (HB)			Brinell Hardness	Comments During Quenching
		Edge 1	Center	Edge 2	Average	
Untreated Sample	None	95	260	185	180	None
1	Cold water	95	218	95	136	Small air bubbles
2	Normal water	237	218	200	218	Small air bubbles
3	Salt solution 25% /L	84.9	237	107	143	More air bubbles than normal water
4	Salt solution 50 %/L	129	260	171	187	Increased amount of air bubbles than SS 25 %
5	Salt solution 100 %/L	185	171	89.7	149	Increased amount of air bubbles than SS 50 %
6	Engine Oil	218	260	237	238	Very small amount of air bubbles
7	Used Engine Oil	218	237	237	231	Largest air bubbles
8	Vegetables Oil	159	121	185	155	Air bubbles like turbulence

During the quenching treatment, it is impossible to cool the specimen at a uniform rate throughout. The surface will always cool more rapidly than interior regions. Therefore, the austenite will transform over a range of temperatures, yielding a possible variation of microstructure and properties with position within specimens [9]. In this work, there was a noticeable differences in hardness measured for each specimen. The hardness varies on the specimen edges and also on the center. As stated above, variations in microstructures lead to variations in mechanical properties in the same sample. The successful heat treating of steels to produce a predominantly martensitic microstructure throughout the cross section depends mainly on three factors: (1) the composition of the alloy, (2) the type and character of the quenching medium, and (3) the size and shape of the specimen [14]. In the present study, the microstructure obtained is expected to be Pearlite. This is because pearlite has a mechanical property that is intermediate between the soft, ductile ferrite and the hard, brittle cementite. It is well known that the microstructure of pearlite consists of alternating layers of ferrite (α) and cementite (Fe_3C). Fig. 4.2 below shows the SEM image of 0.38 wt% C steel having a microstructure consisting of pearlite and proeutectoid ferrite [15]. The layer thickness of each of the ferrite and cementite phases in the microstructure also influences the mechanical behavior of the material. Fine pearlite is harder and stronger than coarse pearlite. This is because the strong and rigid cementite phase severely restricts deformation of the softer ferrite phase in the regions adjacent to the boundary. In addition, phase boundaries serve as barriers to dislocation motion in much the same way as grain boundaries. For fine pearlite there are more boundaries through which a dislocation must pass during plastic deformation. Thus, the greater reinforcement and reaction restriction of dislocation motion in fine pearlite account for its greater hardness and strength.

Table 4.2 – All Hardness Results for the Heat Treated and Untreated Specimens.

Specimen Type	Quenching Medium	Diameter of Indent D (mm)			Brinell Hardness Number (HB)			Comments During Quenching
		Edge 1	Center	Edge 2	Edge 1	Center	Edge 2	
Untreated Sample	None	1.80	1.10	1.30	95	260	185	None
1	Cold water	1.80	1.20	1.80	95	218	95	Small air bubbles
2	Normal water	1.50	1.20	1.25	237	218	200	Small air bubbles
3	Salt Solution 25% /L	1.90	1.15	1.70	84.9	237	107	More air bubbles than normal water
4	Salt solution 50 %/L	1.55	1.10	1.35	129	260	171	Increased amount of air bubbles than SS 25 %
5	Salt solution 100 %/L	1.30	1.35	1.85	185	171	89.7	Increased amount of air bubbles than SS 50 %
6	Engine Oil	1.20	1.10	1.15	218	260	237	Very small amount of air bubbles
7	Used Engine Oil	1.20	1.15	1.15	218	237	237	Largest air bubbles
8	Vegetable Oil	1.40	1.60	1.30	159	121	185	Air bubbles like turbulence

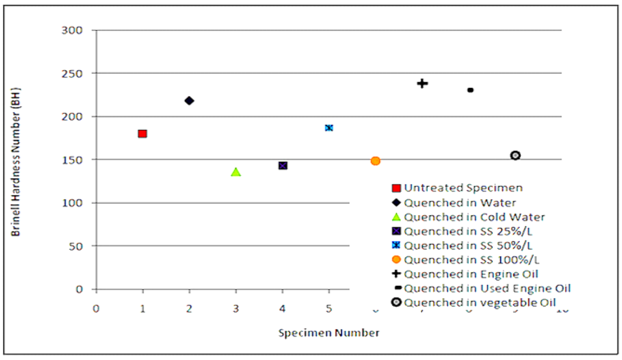

Fig 4.1 - The Effect of Quenching Medium on the Hardness of Low Carbon Steel Specimens used in the Present Work.

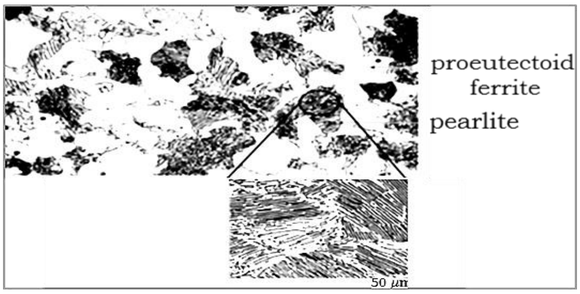

Fig 4.2 - SEM Image of 0.38 wt. % C Steel having a Micro Structure Consisting of Pearlite and Proeutectoid Ferrite [15].

Coarse pearlite is more ductile than fine pearlite. This behavior results from the greater restriction to plastic deformation of the fine pearlite [6 - 8]. The average hardness found for untreated specimen is 180 ± 82 HB. The hardness for specimen quenched in normal and cold water is equal to 218 ± 18 and 136 ± 71 HB respectively. The salt solution quenchants (25, 50 and 75 % SS/L) produced steel with average hardness of 176 ± 65, 187 ± 66 and 148 ± 51 HB respectively. The new and used engine automobile oil quenchants have the largest increase in hardness of low carbon steel, averaging at 238 ± 21 and 230 ± 11 HB. Note that the variation in hardness is the lowest in these specimens, indicating the better uniform microstructure. The vegetable oil yielded lower hardness, with average value of 155 ± 32 HB.

The increasing in hardness for specimens that were quenched in normal and used engine oil may attribute to the appropriate cooling rate achieved by theses used oils. Other possible reason is that subjecting low carbon steel to liquid containing carbon and other impurities at elevated temperatures and for a certain amount of time may become a process similar to case hardening [6,9]. For example, carburizing is a process used to case hardens steel with carbon content between 0.1 and 0.3 wt. % C., and then quenched. The carbon gets into the structure of the steel making it harder. Such processes are diffusion controlled, and so temperature and the time are the main variables. These observations should be confirmed by the use of optical microscope or scanning electron microscope. Unfortunately, it was not possible to perform these experiments due to limited equipment available and time constraints. Another way to discuss the present data work is to use an 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 [16].

$$\sigma_{UTS} = 3.45\, HB \qquad (4.1)$$

This leads to the fact that any increase in hardness will certainly results in increasing in the tensile strength. So, the hardness data in this work was used for the prediction of the tensile strength of each specific specimen, using Equation 4.1. The data for UTS of low carbon steel is shown in Table 4.3.

Table 4.3 also show the experimentally measured UTS for the low carbon steel as provided by the company and, for comparison, the predicted UTS for the same low carbon steel specimens after being subjected to heat treatment and quenching in a different media.

Table 4.3 – Ultimate Tensile Strength (UTS) of Low Carbon

Specimen	Quenching medium	Experimentally Measured UTS (MPa)	Predicted UTS (MPa)
Untreated	None	665 ± 33	621
1	Normal water		753
2	Cold Water		469
3	Salt solution 25% /L		608
4	Salt solution 50 %/L		644
5	Salt solution 100 %/L		512
6	Engine Oil		822
7	Used Engine Oil		796
8	Vegetables Oil		535

As can be seen, the predicted values of UTS are comparable to the experimentally measured UTS value. To find out whether the predicted tensile strengths are valid and fall within the range of existed and measured UTS for steels, the data is plotted on the figure (4.3) showing the relationships between hardness and tensile strength for steel, brass, and cast iron. It can be clearly shown that the hardness data from the present work is valid and can be used for the prediction of tensile strength of steels. The data for UTS for steel is shown to be in good agreement with the previous work

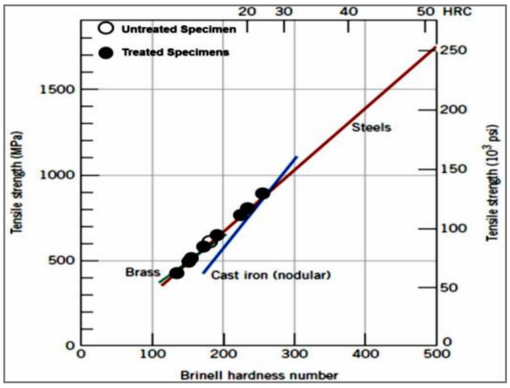

Fig 4.3 - Relationships Between Hardness and Tensile Strength for Steel, Brass, and Cast Iron. (The Black Circles Represents the Data of the Present Study for Comparison) [17].

Table 4.4 - (UTS) Estimation Data of Low Carbon Steel with Diameter (14 mm) [18].

Quenching Medium	Estimated UTS (M	Increasing UTS %
None	790	-
Used THURIA 20	935	15
Used ZAHRA420	1338.6	40

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The correlation between the Brinell hardness and the tensile strength predicted using equation 4.1 is effective and can be used for confirmation of other work of the same type.

Comparing with the previous research on the effect of different used and non-used engine oils on the ultimate tensile strength (UTS) [18], the results showed that quenching in used engine oil enhanced the UTS of low carbon steel as compared with the untreated one by about (15.0 % - 40.0 %) depends on the type of oil used, as shown on Table 4.3. Meanwhile in the present work the UTS of quenched low carbon steel in used oil as compared with the untreated one is enhanced by about (22.0 %) as shown on Table 4.3.

In the present study, the microstructure obtained is expected to be Pearlite and proeutectoid ferrite. This is because pearlite has a mechanical property that is intermediate between the soft, ductile ferrite and the hard, brittle cementite. It is well known that the microstructure of pearlite consists of alternating layers of ferrite (α) and cementite (Fe3C) [4 – 6]. It is also observed that the low carbon steel has a low response to the heat treatment, and this has been confirmed in other works. Some authors have previously concluded that iron-carbon alloys containing less than about 0.25 wt.% carbon are not normally heat treated to form martensite because very fast quenching rates are required. This might not be practical. Even though the holding time in this study was 30 minutes, It is recommended that the holding time may be made longer so that the specimens are held at the heating temperature long enough to have achieved a complete and homogeneous austenitic structure. For this project, this is to ensure fully austenite structure and to completely melt the original carbides to avoid grain coarsening.

5. Conclusions:

In this project, hardness tests were performed on low steel carbon specimens after being subjected to heat treatments. The heat treatment was carried out for 8 specimens. After heating and holding the specimens at the required temperature, different quenching medium were employed to obtain a range of microstructures. The quenchants used were normal water, cold water, 25 % SS, 50 % SS, 100 % SS, engine oil, used engine oil and finally vegetable oil. The aim of the project was mainly to applied different cooling rates by using different quenching mediums for the heat treated specimens. In the present work the highest values obtained for the hardness (an increase by 22 – 24 %) and predicted UTS (an increase by 22 %) were for the low carbon steel quenched in the new and used oil as compared with the untreated one. The overall conclusion is that the quenching medium affects the microstructures of low carbon steels, and the effect varies depending on the types of quenchants employed. 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.

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