Effect of Quenching Media on Mechanical Properties of Medium Carbon Steel 1030

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Abstract

This investigation aims to study the effect of quenching media (water, oil, Poly Vinyl Chloride PVC) on mechanical properties of 1030 steel. The applications of this steel include machinery parts where strength and hardness are requisites. The steel is heated to about 950 ℃ and soaked for 1hr in electrical furnace and then quenched in different quenching medium such as water, oil and poly vinyl chloride. After heat treatment by quenching, the specimens are tempered at 250 ℃ for 1hr and then cooling in air. The mechanical properties of the specimens are determined by using universal tensile testing machine for tensile test, Vickers hardness apparatus for hardness testing, measuring the grain size of the phases and examine the microstructure of the specimens before and after heat-treatment.

The results of this work showed that improving the mechanical properties of medium carbon 1030 steel, which is quenching by water gives the preferred results as the following: Quenching by water leads to increase σ_y, $\sigma_{u.t.s}$, K and hardness, but at the same time quenching by water leads to decrease E and n. Also the quenching by water and followed by tempering leads to improve the microstructure and decreasing (refining) of the grain size of ferrite and pearlite phases of the steel used in this work.

Key words: Heat treatment, Quenching media, Medium carbon steel, Mechanical properties.

الخلاصة

يهدف البحث الى دراسة تأثير أوساط التقسية (الماء، الزيت، بولي فنيل كلورايد) على الخواص الميكانيكية للفولاذ 1030. تتضمن تطبيقات هذا الفولاذ أجزاء المكائن التي تتطلب مقاومة وصلادة. يتم تسخين الفولاذ لدرجة حرارة 950 ℃ ولمدة ساعة في فرن كهربائي ومن ثم يقسى في الماء، الزيت، والبولي فنيل كلورايد. بعد المعاملة الحرارية بالتقسية تجرى عملية المراجعة للعينات عند درجة حرارة 250℃ في الهواء لمدة ساعة. تم تحديد الخواص الميكانيكية للعينات مثل خواص الشد والصلادة. كما تم قياس الحجم الحبيبي للأطوار وفحص البنية المجهرية للعينات قبل وبعد المعاملة الحرارية.

أظهرت نتائج هذا البحث تحسن الخواص الميكانيكية للفولاذ متوسط الكاربون 1030، حيث ان التقسية بالماء تعطي أفضل النتائج وكما يلي: التقسية بالماء تؤدي الى زيادة أجهاد الخضوع، مقاومة الشد القصوى، ثابت اللدونة والصلادة. لكن في نفس الوقت تؤدي الى نقصان معامل يونك ومعامل الأصلاد الأنفعالي. كذلك التقسية بالماء التي تتبعها عملية المراجعة تؤدي الى تحسين البنية المجهرية للفولاذ ونقصان (تنعيم) الحجم الحبيبي لأطوار الفرايت والبرلايت للفولاذ المستخدم في هذا البحث.

الكلمات المفتاحية: المعاملات الحرارية ، أوساط التقسية ، فولاذ متوسط كاربون ، الخواص الميكانيكية.

Nomenclature

$d_{ave.}$: average indenter diameter, mm.
F: applied load, Kgf.
K: strength coefficient.
n: strain hardening exponent.
σy: yield stress, (MPa).
σu.t.s: ultimate stress, (MPa).
ε: strain.
V.H.N: Vickers's hardness number, (Kgf / mm^2).

1. Introduction

Quenching of medium carbon steel can be done to transform the austenite to martensite, and then tempered to improve the mechanical properties such as strength and toughness. The main applications of medium carbon steel are in machine parts, rods, shaft, gears and axle, (**Ericsson , 1991**), industrially, quenching is one of conventional heat treatment, and this heat treatment has been carried out by using a suitable quenching media such as water, oil and polymer. (**Chandan and Ramesha, 2017)**, were studied the quenching in water may result in quenching cracks in the heavy sections, hence quenching in oil or polymers is used to avoid quench cracks created during water quenching. Furthermore quenching in oil exhibit good cooling capacity for alloy steel, mineral quenching oil is relativity toxic and expensive. The polymers as a quenching medium have an important advantage of less risk of cracking and low distortion, which in turn improving the mechanical properties compared with water and oil. (**Kadhim, 2016),** was studied the effect of different quenching media such as cold water, water, hot water and oil on the mechanical properties of steel AISI 1039. The results of this investigation show that the cold water has a great effect on tensile strength and hardness values, the value for tensile strength was 998.6 N/mm^2 and the hardness was 360.4 HV. When the elongation has the lowest value after quenching process in cold water.

(Verma and Kumar, 2013), investigated the effect of heat treatment on the mechanical behavior of medium carbon steel AISI 1040 steel. Heat treatment was done by quenching and tempering at 650 ^oC, 450^oC and 250^oC for 60, 90 and 120 minutes to alter the mechanical properties especially ultimate tensile strength, elongation and yield strength. The results of this work shows that the yield strength and the ultimate tensile strength decreases while the elongation increases with an increase in tempering temperature and tempering time, while (**Daramola *et.al.*,2010)**, were studied the effect of heat treatment by quenching on mechanical properties of rolled medium carbon steel. Quenching was performed by heating the specimens at austenizing temperature about 830^oC and water quenched. It was reheated to the ferrite- austenite two phase regions at temperature of 745^oC below the effective AC_3 point. The steel was then rapidly quenched in water and tempered at 480^oC to provide an alloy containing strong, tough, lath martensite in ductile soft ferrite matrix. The results showed that steel has an excellent combination of tensile strength, impact strength and ductility which is very attractive for structural use.(**Alabi *et.al.*, 2012),** the mechanical properties can be improved by using a suitable quenchant. However the suitable quenchant is regarded as the important factor of heat treatment by quenching. Water as quenching media lead to give higher tensile strength and hardness because of the formation of martensite phase after the quenching. Water as quenching media is suitable for medium carbon steel because of it is abundant, cheap, friend to environment and more safety than another quenchant**.**

(Tolstousov and Bannykh, 1981), were studied that the most important quenching media is mineral Oil which have the best cooling capacity for the alloying steels, at the same time there are many disadvantages because of its toxity, expensive and non-biodegradable. However and for that the disadvantages, this quenchant replacing with polymers as aqueous chemical solution to enhance the heat transferred during heat treatment by quenching..

There are many previous studies were done about this field, **(Ndliman, 2006**), was studied the effect of quenching media (Water and palm Oil) on mechanical properties of an AISI steel of grade C1035. The results of this study showed that the water as quenching media gives the best properties in strength and hardness, while the palm Oil gives the best property in impact strength.

Whilst (**Murugan and Mathews, 2013**), were studied the effects of heat treatment on the mechanical properties of medium carbon (C35Mn75) steel. The results of this study showed that an improvement in mechanical properties such as tensile strength, yield strength, toughness, elongation and hardness.

The aim of this investigation is to study two effects of different quenching media on the mechanical properties of medium carbon steel.

2. Experimental Procedure

2.1. Material Used

In this work the alloy used is 1030 steel. It is used in many industries, such as machinery parts with high strength and hardness. The chemical composition and mechanical properties of this alloy are given in **Table 1** and **Table 2** respectively, (**Funda, 2012**).

2.2. Preparing the Specimens

Before the hardening process, the specimens have been prepared for tensile test and hardness test by manufacturing them according to standard of ASTM E8/E8N for tensile test, ASTM E384 for hardness test and then all of the specimens have been grinded and polished mechanically. The grinding is made by emery paper (320, 500, 1000 µm) in size, while the polishing is made by using wool cloth and alumina (1µm) in size.

2.3. Conventional Heat Treatment

The heat treatment is done by heating the specimens of medium carbon steel 1030 in an electric furnace at austenizing temperature (950℃) for 1hr and quenched in three different quenching medium such water, oil and Poly Vinyl Chloride PVC. This heat treatment is done for all the specimens which have been prepared for different tests.

2.4. Tests and Examinations

To assess the mechanical properties, two main tests have been carried out for the specimens before and after quenching by three different quenching medium such as tensile test and macro Vicker's hardness test and measuring the grain size of the phases. Also microstructure examination is done for the same specimens as the following:

2.4.1. Tensile Test

Tensile test is done for the specimens before and after hardening process by using Instron universal tester (type Instron 1195 machine with full capacity 2.5 ton). Specimens for this test are manufactured according to ASTM E8N standard, (**Annula, 1988**). **Fig. 1** shows the specimen for tensile test.

Before hardening process, initial gauge length (L_o) and initial diameter (D_o) are measured. After that specimen testing is done for the specimen before and after hardening process. From tensile test machine, a graph paper can be obtained plotted for each specimen before and after the test. This graph paper displays the relation between applied load and the extension of the specimen. For graph paper, yield strength (σ_y), ultimate tensile strength ($\sigma_{u.t.s}$) and true strain can be calculated by using the following equations, (**Georg, 1986**).

$\sigma_y = F_y / A$ (1)
$\sigma_{u.t.s} = F_{max.} / A$ (2)
$\varepsilon = \ln L/L_o$ (3)

Whilst the coefficient of strain hardening (n) and the plasticity constant (k) for each specimen can be obtained by using the following formula, **(Georg, 1986**).

$\sigma = K (\varepsilon)^n$ (4)
$\text{Log } \sigma = \text{Log } k + n \text{ Log } \varepsilon$ (5)

2.4.2. Hardness Test

Macrohardness is carried out for each specimen before and after hardening process. The applied load is 10 Kgf for 15 second. Three readings are taken for each specimen, and the average of these readings is taken finally. Vickers's hardness number is calculated according to the following formula, **Bolton, 1988.**

$V.H.N = 1.8544 \times (F/d^2_{ave})$ (6)

2.4.3. Microstructure Examination

Microstructure Examination is done by using a computerized optical microscope to define the microstructure of all the specimens before and after heat treatment by hardening process. **Fig.2** shows the microstructure of the specimen before the quenching (as-received).

2.4.4. Grain Size Measurement

Grain size means the diameter of the grain of granular material. There are many methods are used to measure the grain size such as the plan metric and the grain intercepts,(**ASTM standard E112, 2004).**

In this work, the grain intercepts method is applicable to measure the average grain diameter by using a straight line at length (L) which intercepts number of many grains (n) and then calculating the grain diameter by the ratio of L/n.

Quenching heat treatment by using a suitable quenching medium leads to refining the gain size as shown in table (4).

3. Results and Discussion

To define the mechanical properties of the specimen quenched by different quenching medium, must be made a comparison between the obtained results of the specimen as-received with other specimens quenched by different quenching medium: (water, oil, PVC) as the following:

3.1 Analysis the Mechanical Properties

Table 3 shows the results of mechanical properties before and after heat treatment by quenching in PVC, oil and water respectively.

Table 3 shows the obtained values for the specimens before (as- received) and after heat treatment by quenching in three different quenching medium such as water, oil and PVC respectively. As shown in **Fig.3**, the tensile strength of specimen quenched by water is more than for oil and PVC, it is attributed to the fast cooling of water and highest free carbon in martensite. Martensite phase leads to detrimental effects on toughness, which is produced during quenching in water. Also the transformation temperature is decreased with increasing cooling rate and forming finer pearlite grains. Furthermore, presences of dispersion of small particles in ferrite, which in turn prevent the dislocation to move. At the same time the values of yield strength indicate that the specimen quenched in oil has the higher value comparing with those quenched in water and PVC. This means that the specimen quenched in oil withstand the increasing in loads. Whilst the highest hardness which obtained for the specimen quenched in water, is attributed to the hardness which increases with the increasing in percentage of carbon which dissolved in austenite before quenching. The specimens after quenching in selective quenching medium would have transformation of austenite to martensites. Martensite phase has a fine structure which is hard and very strong. The hardness for the specimen quenching in water has higher value than oil and PVC. This is due to higher amount of the harder martensite in the treated steel; the austenite is transformed to martensite by diffusionless transformation in quenching. It can be observed obviously that the variation of ultimate tensile strength has the same pattern as the variation in hardness. Also the results of tensile test show that the young modulus of elasticity has been decreased for the specimen quenched by water slightly than for oil and PVC quenching medium respectively for the same reasons as mentioned previously.

Finally the heat treatment in different quenching medium leads to increase in K as it is defined as the plasticity constant which is extremely depending on the type of steel and the percentage of carbon content. This value is the highest in water more than PVC and oil. Whilst the values of n reveal that the highest value for the quenching in PVC is more than quenching in oil and water respectively, as shown in **Fig.4** obviously. It is attributed to the same reasons mentioned in discussing the mechanical properties previously.

3.2. Analysis the Microstructure

As shown in **Fig.2**, the microstructure of the specimen as-received is composed of pearlite and the matrix of ferrite, while the microstructure of the specimen quenched in water is composed of martensite phase with the retained austenite. Whilst the microstructure of the specimen quenched in oil is composed of martensite phase only, and finally the microstructure of the specimen quenched in PVC is composed of little martensite phase with the ferrite phase as a matrix. It is showing that the quenching in water leads to obtain highest proportion of martensite phase with austenite as a retained phase. While the quenching in oil leads to transformation of the retained austenite and then the final microstructure is fully martensite. Also the quenching in PVC leads to obtain martensite phase with the ferrite as a matrix because of the ferrite phase cannot be precipated as a result of the transformation of retained austenite. **Fig.5** shows that obviously.

4. Conclusions

1- Quenching by water leads to increase $\sigma_{y,}$ $\sigma_{u.t.s,}$ K and hardness.
2- Quenching by water leads to decrease E and n.
3- Also the quenching by water and followed by tempering leads to improve the microstructure and decreasing (refining) of the grain size of ferrite and pearlite phases.

Table1. Chemical Composition of 1030 Steel Specimen in (wt%)

Element	Wt %	
	Standard Value (weight %)	Actual Value (weight %)
C	0.28-0.34	0.25-0.4
Mn	0.60-0.90	0.55-0.87
P	0.04 (max.)	0.031
S	0.05 (max.)	0.52

Table2. Mechanical Properties of 1030 Steel

Yield Strength (Mpa)	Tensile Strength (Mpa)	Modulus of Elasticity (Gpa)	Elongation %	Poisson's Ratio	Reduction in Area	Hardness HV (Kgf/mm^2)
341.3	463.7	190-210	31.2	0.27-0.3	57.9	132

Table3. Show the results of mechanical propertieof the specimen before and after quenching.

Specimen	σ_y (Mpa)	$\sigma_{u.t.s}$ (Mpa)	E (Gpa)	K (Mpa)	n	Hardness (HV) Kgf/mm^2
As- received	341.3	463.7	210	740	0.5	132
Quenching by PVC	397.1	502.3	190.7	792	0.41	156.5
Quenching by Oil	473.4	634.2	183.4	813	0.33	173.7
Quenching by Water	550.9	701.9	171.5	864	0.376	213.1

Table4. Show the grain size of the phases for the specimens treated by different quenching.

Number	Specimen State	Grain Size	Grain Size
		Ferrite (µm)	Pearlite (µm)
1	As- received	15.4	15.6
2	Treated by PVC	14.9	15.1
3	Treated by Oil	14.1	14.4
4	Treated by Water	13.2	13.8

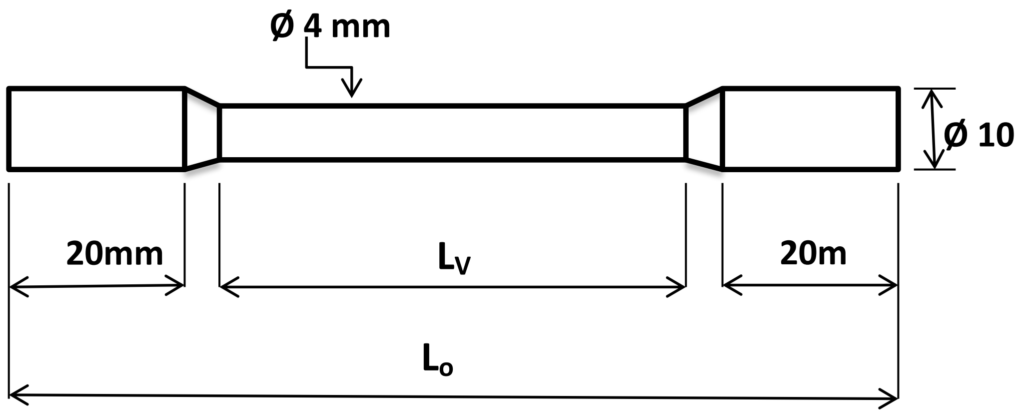

Figure1. The specimen of tensile test.

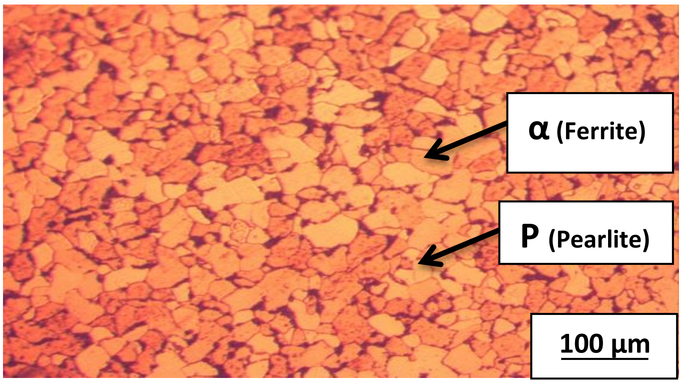

Figure2. Micrograph of the microstructure of 1030 steel (as-received).

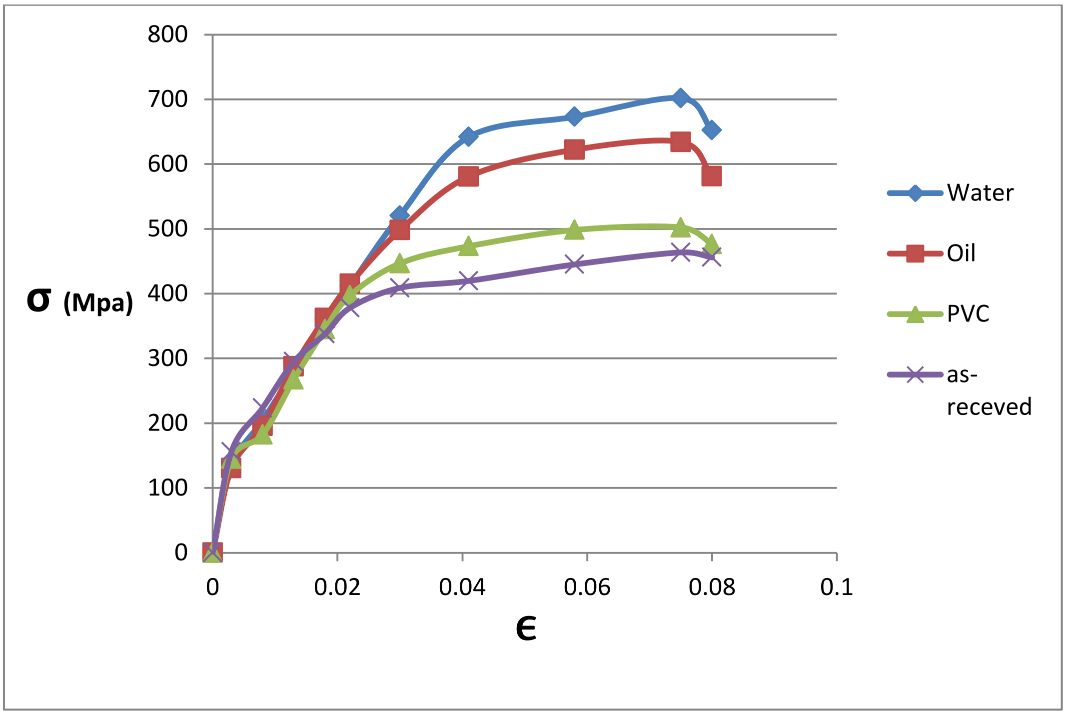

Figure3. Relationships between σ - ε for the specimens before and after quenching in three different quenchants.

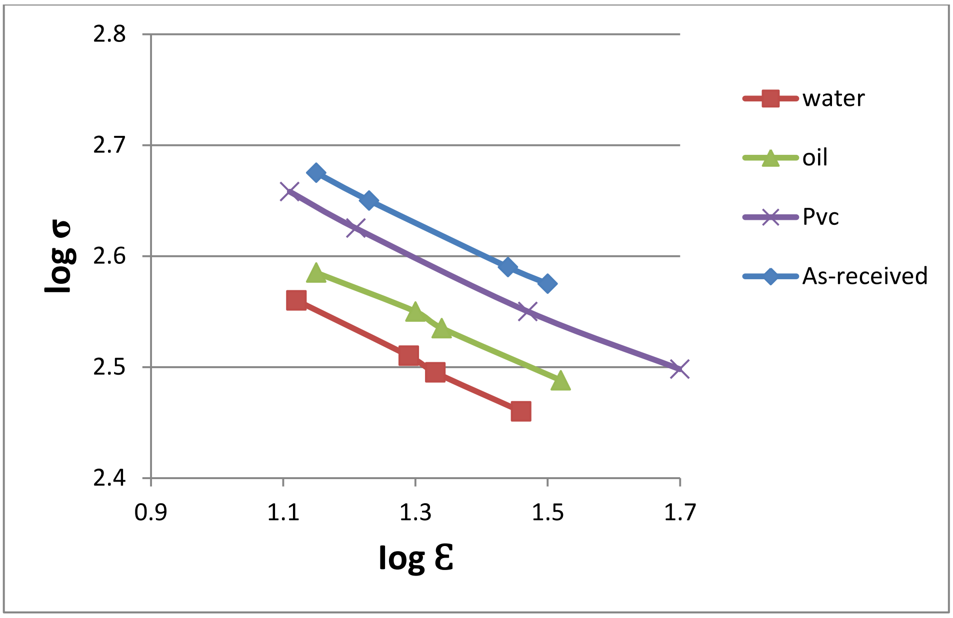

Figure4. Relationships between Log σ - Log ε for the specimens before and after quenching in three different quenchants.

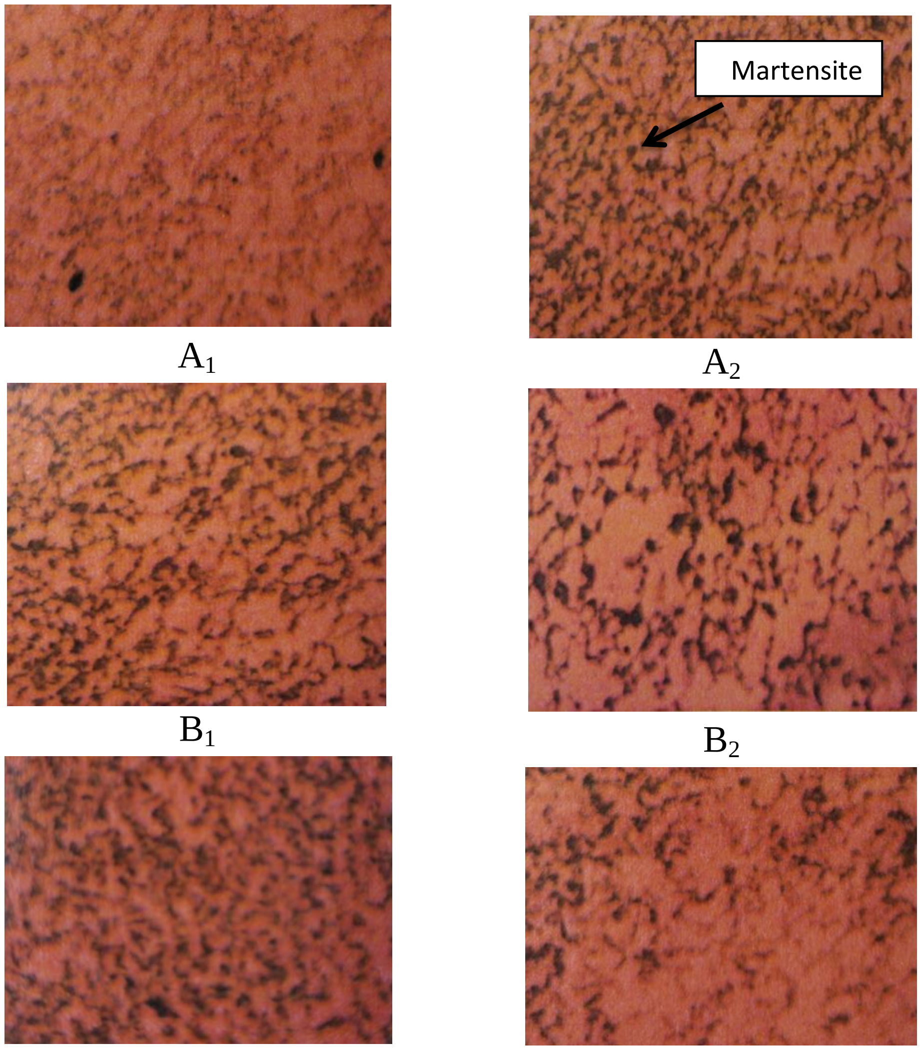

Figure 5. Photomicrographs of the specimens quenching in three different quenching media.

Where:

A: 1- quenching in PVC (250 x).

2- quenching and tempering in PVC (250 x).

B: 1- quenching in Oil (250 x).

2- quenching and tempering in Oil (250 x).

C: 1- quenching in Water (250 x).

2- quenching and tempering in Water (250 x).

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