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An investigation study using mixture proportion of polyethylene glycol-water as quenching medium and their effects on low carbon steel heat treatment process

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Abstract

Low carbon steels wide range using materials, chemical composition and physical properties controls by using heat treatment process that including heating and then cool by appropriate quenching mediums. The effects of polyethylene glycol diluted with water as quenching medium on the mechanical properties (hardness, compression) and microstructural properties of low carbon steel were investigated with the aim at improving their compatibility with polymer quenching. The tested samples were prepared and subjected to heat treatment process used electrical resistance furnace soaked for 1 hour and then quenched in polyethylene (PE) diluted with water in controlled percentages of PE% (25%, 35%,45%). Used digital microhardness and universal test machine resulted an enhancement in their mechanical properties, they though (PE) gives good cool rates. The dominant of martensitic phase in microstructures resulting in their enhancement of low carbon steel properties. The hardness improvement about 83.5% as illustrated with this paper, also the compressive strength improved about 23.3% with this work. Also, an enhancement of surface cracks was observed with increasing (PE) percentage. It is assumed that polyethylene solution will help to develop high performance of low carbon steel properties for industrial fields applications.

Keywords: Heat treatment; Polyethylene glycol; Microstructures; Quenching.

1. Introduction

Heat treatment process of steel is one of the most popular process of making it reliable in engineering application, this process includes heating and then cooling in appropriate mediums to achieve desired properties [1, 2].

The most common form of steel is low carbon steel because this material properties is acceptable to many applications [3, 4]. The factor affecting on low carbon steel performance in engineering application fields depend on mechanical properties and microstructures [5, 6].

For obtaining desired mechanical properties heat treatment process can be done to change the microstructures of steel to fit it in engineering applications [7].

Heat treatment processes like (Hardening, Annealing, Normalizing and Tempering) followed by cooling in appropriate quenching mediums after holding it in desired heat temperature to achieve desired mechanical properties [8, 9].

Normalizing technique including heating the steel and then cooling it on air to relief the residual stress while annealing involves cooling steel in furnace medium to produce good ductility, other techniques including quenching and tempering of steel.
To increase the hardness and strength of low carbon steel hardening process done by heating steel to austenitic region and then rapid cooling in appropriate mediums including water, brine and oil to obtain desired properties and desired engineering application fields. Polymer recently begun used as quenching medium in the few years. [10, 11].
Water is one of the oldest quenching medium that increases the strength and hardness, but it leads to cracking and alteration problem of steel, oil medium not lead to these problems but not have good cooling rates to obtain required mechanical properties, so that polymer solution discovered as substitution of conventional quenching mediums [12].
In recent years, more than researchers interested in studies the effects of polyethylene as quenching medium for heat treatment process of steels [13, 14]. The main goal of this paper is an investigation study the effect of different new controlling mixtures of PE-water on hardness, compressive stress and microstructures of low carbon steel and surface quality.

2. Materials and equipment's

The material used in this research was commercially low carbon steel. The chemical analysis of materials conducted in **heavy engineering equipment state Company /the quality control department/Baghdad**. The composition (weight %) of low carbon steel elements was shown in Table 1. Polyethylene glycol applied in different percentage with water used as quenching medium. Equepements used in this investication were electrical resistance furnace, digital microhardness for hardness measurments and metallurgical microscope for microstructures testing, universal testing machine for comperssion test. Also some assistant equipement like grinding device with emery papers and water as assistant agent, polishing with alumina (AL_2O_3) and Nital as developer agent.

Table 1. Chemical composion of 1023 low carbon steel.

Elements	C %	Mn %	Si %	P %	S %	Cr %
Composion	0.143	0.647	0.195	0.003	0.039	0.022
Elements	Mo %	Ni %	Al %	Co %	Cu %	V %
Composion	0.002	0.063	0.008	0.018	0.055	0.0005

3. Methods

3.1 Specimen's preparation

The commercial rod of low carbon steel from locally market used in this study, specimens were prepared as illustrated in Figure 1 according to (ASTM E92) for Vickers hardness testing and (ASTM E9) for compression testing [15]. After preparation of the samples and before heat treatment process carried out, the specimens normalize by heating to austenitic degree and then cooled in air for annul the mechanical history of the machined specimens [16]. Before heat treatment process of steel, hardness, compressive strength and microstructures measured and recorded to be able to compare later.

Figure 1. Specimen preparation.

3.2 Heat treatment and quenching process

Depending on the Fe-Fe_3C phase diagram and with [0.143% C], all samples were heated to austenitic zone using 1200 °C maximum electrical resistance furnace all samples heated at 910 °C soaking for 1 hour and then directly quenched in standard included vessels containing (25%, 35%, 45%) polyethylene percentage with water. After this all samples prepared for hardness, compression and microstructures investigation testing. Table 2 shows the heat treatment process.

Table 2. Heat treatment process of samples.

Samples	Temperature	Socking time	Quenching medium	Testing process
A	As-received Sample (Normalizing process only illustration in 3.1)			Hardness & compression
B	910 °C	1 Hour	25 % PE with water	Hardness & compression
C	910 °C	1 Hour	35 % PE with water	Hardness & compression
D	910 °C	1 Hour	45 % PE with water	Hardness & compression

3.3 Testing process

3.3.1 Hardness testing

Vickers's Hardness Indenter was used to measure the hardness of the samples. In Vickers's indentation technique, a diamond indenter is used to indent the substance. A load of 9.8 newtons with dwell time of 15 seconds were set for the measurements and then used the dimensions of the indentation mark (pyramid) the hardness was recorded.

3.3.2 Compression testing

The compression testing measures the compressive strength of the three specimens according to (ASTM E9) that quenched in different polyethylene percentage to show what happened in the compressive strength and what is the best percentage for reducing deformation in this investigation.

3.3.3 Microstructure testing

The Digital microstructure (Model: Tt 1715) was used for metallographic examination to study the microstructures of the specimens.

4. Results and discussions

4.1 Hardness measurements

The results of hardness measurement after completing all heat treatment criteria _ represents in Figure 2 that gives good impression what happened before and after using polymer quenching medium.

Hardness measurement process show that an enhancement about 83.2% comparing between sample A standard sample and sample B that quenching in 25% polyethylene that mean this process give reliable low carbon steel in application fields, also other samples (C and D) enhancing in their hardness comparing with standard sample A about 41.3% and 30.8% frequently. Because of the concentration of carbon in martensite phase component related that to the high cooling rate produces fine microstructures which enhance the hardness of the sample B, lower cooling rates resulted from the additional of PE reduced in hardness for other samples.

4.2 Compressive strength effect

The results of compressive strength after barreling of samples in universal testing machine with this work showed that when increasing the proportion of polyethylene in quenching medium the magnitude of compressive strength decrease, this is because of change in the microstructural grains of low carbon steel. But comparing with as-received carbon steel sample A that have the lowest magnitude of compressive strength (118.56 MPa) the 25% PE sample B have the best compressive strength (144.67 MPa) and (139.8 MPa) for 35% PE sample C and (128.3MPa) for 45% PE sample D, the reason for this back to the samples after quenching could be absorb the most energy comparing with standard sample A because of new microstructures that increasing compression ability, Figure 3 show the results for A, B, C and D samples of compressive strength testing.

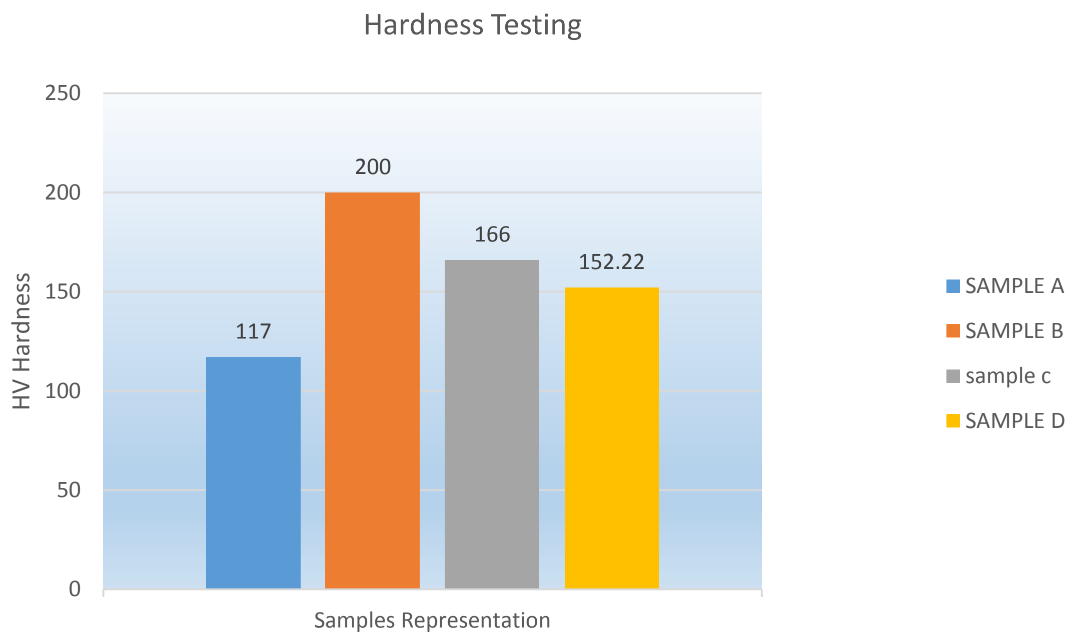


Figure 2. Hardness resulting of low carbon steel samples.

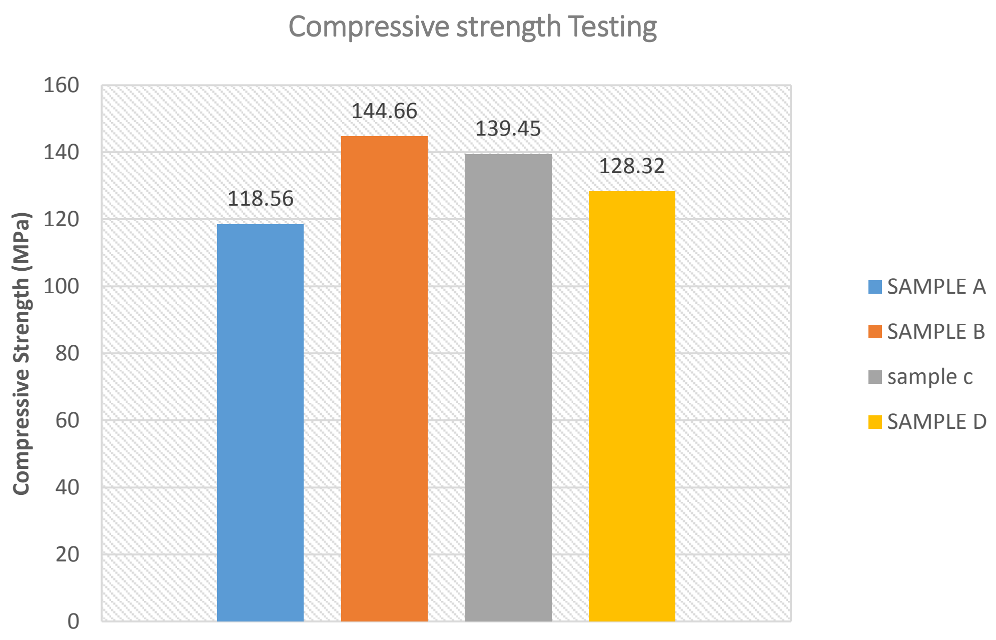
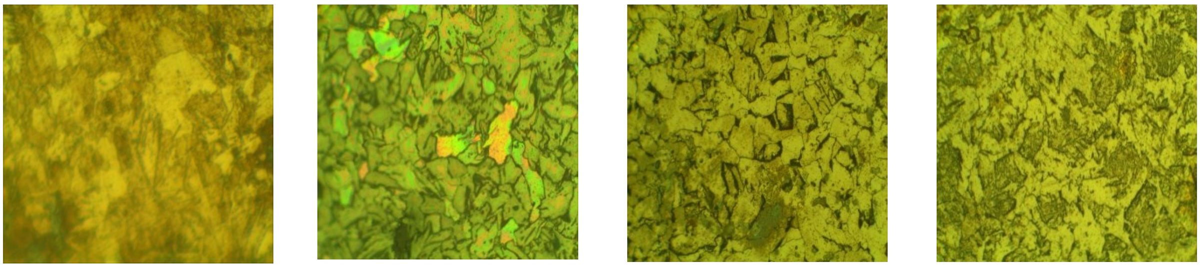


Figure 3. Compressive strength resulting of low carbon steel samples.

4.3 Microstructural effects

The microstructure of sample A (as-received) consist of ferrite with perlite as shown in Figure 4 while and after effected samples B, C and D by quenching process with different mixture of PE-water solution the microstructures of sample (B) convert austenite to martensite structures that more stable distributing with ferrite as illustrated in Figure 4. So that the martensite is responsible for the enhancement properties of 0.143 low carbon steel because of the high cooling rate produce fine microstructures and with additional PE result in reduces the cooling rate and produces relatively coarse grains microstructures. While ferrite keeping carbon steel ductile.



(a) (b) (c) (d)

Figure 4. Microstructural examination of (a) as-received sample (b) 25% PE (c) 35% PE (d) 45% PE (at 100x).

5. Conclusion

Low carbon steel one of the most material that used in many applications especially with improving mechanical properties. In this work, an investigation uses new mixture proportion of PE-water as quenching medium in heat treatment process of low carbon steel, the results show that:

1. The hardness and compressive strength increases after heat treatment process because of PE-water quenching medium create martensite phase in high proportion make mechanical properties better.
2. The higher the percentage of PE against water gives more moderated cooling rates.
3. Also with increasing the PE solution in quenching medium the ductility of low carbon steel enhances because it has good cooling rate comparing with water.

The less surface cracks can be obtained with increasing percentage of PE as observed in this investigation.

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