Effect of Different Quenching Media on Microstructure, Hardness, and Wear Behavior of Steel Used in Petroleum Industries

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Abstract

Medium carbon steel always used in most parts of the oil and gas industry, due to their cheap, simple manufacturing and easy deformation. However, as-rolled medium carbon steel usually does not meet the demands for many petroleum applications where high hardness and strength are needed; mainly because of their limitations in some mechanical features. Hence, many methods of thermal treatment techniques were adopted with a view to manipulate its structure and thus extend its scope of applications.This study focus on using a proper heat treatment to enhance medium carbon steel properties.

Quenching and tempering treatments are usually the end of any manufacturing process to production of a machine component. However, the internal and residual stresses which generate during the heat treatments due to the non-uniform the quenched layer depth lead to distortion or cracked the machine component result in deteriorate the properties. Thus, the selection of optimum parameters of the quenching process is very important to ensure the achievement of the desired properties of the machine component. The main aim of this study is to get the optimal conditions for heat treatment which brought the best combination of mechanical properties of medium carbon steel without tempering treatment. Thus, in current study, an investigation of effects of polymer solution media on the quenching process was carried out with samples made of medium carbon steel. The samples were quenched in four different concentrations (0, 10, 15, 20) % of polymer (polyalkylene glycol) solution and set of quenched samples were tempered at 400 ^{o}C for 1h. The resulting as-quenched and tempered microstructures were compared and evaluated. Mechanical properties (hardness and wear rate) of the samples were determined using suitable standards. The results show that the quenched samples in polymer solution with 10% polyalkylene glycol were brought the best combination of mechanical properties as compared with other quenched and tempered samples.

Keywords polymeric solution, quenching, wear rate, hardness value.

تأثير أوساط التقسية المختلفة على التركيب المجهري، الصلادة، وسلوك البلى للفولاذ المستخدم في الصناعات النفطية

الخلاصة

الفولاذ المتوسط الكاربون عادة مستخدم في اغلب الاجزاء في صناعة النفط والغاز نتيجة لرخص ثمنه، بساطة تصنيعه، وسهولة تشكيله. لكن، عادة الفولاذ المتوسط الكاربون بحالته المدرفلة لا يلبي احتياجات العديد من التطبيقات النفطية والتي تحتاج الى مقاومة وصلادة عالية وذلك بسبب محدداته ببعض الصفات الميكانيكية. لهذا فقد اعتمدت العديد من تقنيات التعامل الحراري بغية تعديل تركيب الفولاذ وبالتالي توسيع نطاق تطبيقاته. هذه الدراسة تركز على استخدام معاملة حرارية مناسبة لتعزيز خواص الفولاذ المتوسط الكاربون. معاملات التقسية والمراجعة تكون عادة هي الانهاء لأي عملية تصنيع لإنتاج أجزاء الماكنة. لكن الاجهادات الداخلية والمتبقية والتي تتكون خلال المعاملات الحرارية بسبب عدم انتظام عمق طبقة التصليد تؤدي الى تشوه وتشقق أجزاء المكائن وبالنتيجة انخفاض الخواص. لهذا، اختيار العناصر المثلى لعملية التقسية يكون جدا مهم لضمان الحصول على الخواص المرغوب بها لجزء الماكنة. الهدف الرئيس لهذه الدراسة هو الحصول على الظروف المثلى للمعاملة الحرارية التي من خلالها نحصل على أفضل مجموعة من الخواص الميكانيكية للفولاذ المتوسط الكاربون بدون عملية المراجعة. لهذا، في الدراسة الحالية، تم اجراء دراسة لتأثيرات أوساط المحاليل البوليميرية على عملية التقسية لعينات مصنوعة من الفولاذ المتوسط الكاربون. تم تقسية العينات في أربع تراكيز مختلفة (0، 10، 15، 20) % لمحلول (polyalkylene glycol) البوليميري وتم اجراء عملية مراجعة عند 400 ^{0}م لمدة ساعة واحدة لمجموعة من العينات المقساة. التراكيب المجهرية للعينات المقساة والمراجعة تم مقارنتها وتقييمها. الخواص الميكانيكية (الصلادة ومعدل البلى) للعينات تم تحديدها باستخدام مقاييس ملائمة. بينت النتائج ان العينات المقساة بالمحلول البوليميري 10 % (polyalkylene glycol) قد اعطت أفضل مجموعة للخواص الميكانيكية عند مقارنتها بالعينات الأخرى التي تم تقسيتها ومراجعتها.

الكلمات الدالة المحلول البوليميري، التقسية، معدل البلى، قيمة الصلادة

Introduction

Medium carbon steels have increased usage in petroleum industry. Their applications include flow lines, structural components, platforms, jackets, and pipelines. [1]. Medium carbon steels have excellent response for heat treatment. Therefore, thermal treatment is the effective tool which most widely used in improving the properties of medium carbon steel [2]. Among all thermal treatment techniques hardening treatment has the largest effect in enhancing the mechanical properties of medium carbon steels by quenching in appropriate medium.

The purpose of the most quenching treatments is to provide a fast cooling rate which is higher than the critical cooling rate in a specified depth of the component to obtain materials which exhibit increased hardness without distortion or cracking defects [3].

There are many quenchants which are used in industry. Water and oil were conventionally the most commonly used quenching media in the thermal treatment processes to harden steel alloy, especially for mild and medium carbon steels because they are readily quenchable [4, 5]. However, because of the water quenched steel needs to further treatment (tempering) to obtain the desired properties which means additional operation and production cost, and with arising the environmental, disposal, safety and toxicological concerns, there are grown interests in the potential use of alternative quenching technologies [6, 7]. One of the most commonly considered alternatives to quench water or oils are polymer solutions [8, 9]. Beside the supplying substantially higher safety with respect to fire and disposal, polymer solutions can supply more regular heat removal through quenching treatment leading to decreased thermal gradient and decreased distortion. In addition to, quenching in polymer solutions have another advantages in reducing the distortion and internal stress in quenched parts, minimize the cost, and quenched parts can be easy to clean. [10]

In this work, the polyalkylene glycol was used as polymer quenchant. The main aim of this study is to study the possibility of get a quenching media produces mechanical properties which is equivalent to those resulting from quenching in water with tempering. For this purpose, the effects of varying concentrations (0, 10, 15, 20) % of polymer in water on mechanical properties (hardness and wear rate) of medium carbon steel were investigated. Also, the optimal heat treatment conditions which brought the best combination of mechanical properties of medium carbon steel was determined.

Materials and methods

Sample material

Samples from medium carbon steel were used in this work. The chemical composition of used material is list in Table (1) polyalkylene glycol with density of 0.98 g/ml and viscosity of 32 cSt was used as quenchant to achieve the current work

Table (1) Chemical composition of selected metal

Element	C	Si	Mn	P	S	V	Pb	Fe
Medium carbon steel (%wt)	0.42	0.22	0.5	Max. 0.04	Max. 0.05	<0.05	<0.05	balanced

Heat Treatment

The prepared samples were heated to 810ºC and soaked for 30 minutes using a muffle furnace. The test samples were quickly taken out of the furnace after each of the heat treatment temperatures and quenched in four different quenching media; water, 10% polymer+90% water, 15% polymer+85% water, and 20% polymer+80% water separately. Then the samples were divided into two groups. One group was tempered at 400 ºC for 1 h and the other wasn't. Surface of all quenched samples were cleaned and prepared for subsequent tests.Table (2) illustrate different categories of used samples and Fig. (1) summarized the whole experimental procedure.

Table (2) Test samples classification

No.	Symbol	Heat treatment	Quenchant
1	$A_{\circ}$	As-received	....
2	A_1	Quenching	water
3	A_2	Quenching	10% polymer+90% water
4	A_3	Quenching	15% polymer+85% water
5	A_4	Quenching	20% polymer+80% water
6	A_{11}	Quenching and tempering	water
7	A_{22}	Quenching and tempering	10% polymer+90% water
8	A_{33}	Quenching and tempering	15% polymer+85% water
9	A_{44}	Quenching and tempering	20% polymer+80% water

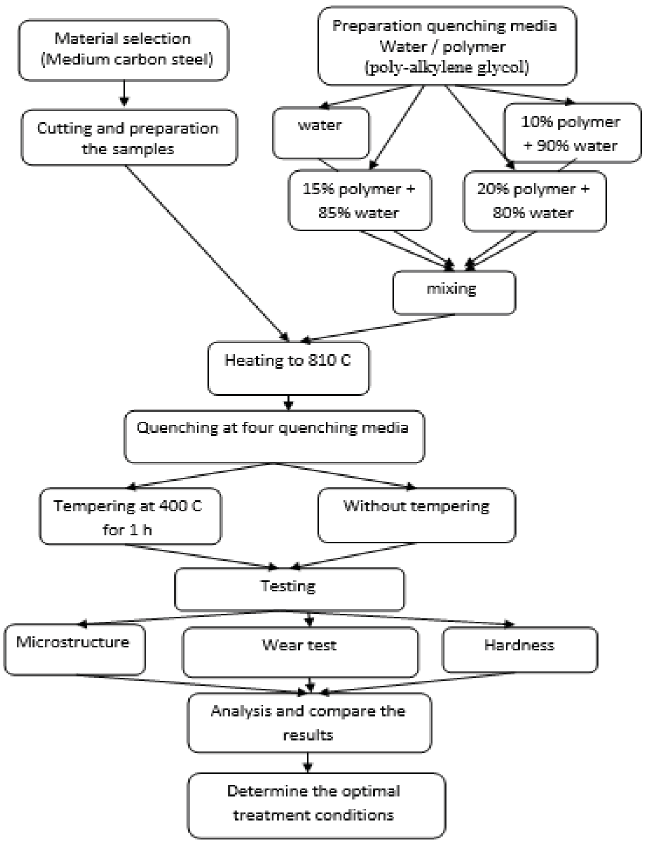

Fig. (1) Flow chart of experimental work.

Tests and Inspection

1- Microstructure test

The as-received and quenched samples will be prepared by mounting, grinding, polishing and then etched to analyze the microstructure, and observe the change in grain structure. The optical microscope was used to perform this test.

2- Hardness Measurement

The hardness of the specimens was measured with a Vickers hardness test instrument. The hardness tests were performed under an indentation load of 300 N for 15 s. In order to obtain a reliable statistical data, analysis points were spaced so as to eliminate the effect of neighboring indentations, and the hardness was evaluated by taking three indentations on each specimen and averaging hardness was calculated. Fig. (2) illustrate the hardness sample.

3- Wear rate test

Abrasive wear tests were performed on samples in according to the ASTM G99 using pin on-disc tester device with a continuously rotating alloy steel disc with hardness 55 HRC as a counter surface. The wear sample was cylindrical with 10 mm diameter and 20 mm height (Fig. 2). The wear test was done under constant load of 10 N, speed of 2 cm/s, and sliding distances of 50 m. After the end of each cycle of wear test, the mass of the worn out samples was determined by using a digital balance to obtain the weight lost. Weight lost from the tests was used to determine the wear rate W.R by using the following equation [11]:

$$\mathrm{W.R} = \frac{\Delta \mathrm{w}}{\mathrm{S}.\rho} \quad \ldots\ldots\ldots \quad \mathbf{1}$$

$$\Delta \mathrm{w} = w_1 - w_2 \quad \ldots\ldots\ldots \quad \mathbf{2}$$

Where: $\mathbf{W.R}$ is wear rate (cm^3/cm), $\Delta\mathbf{w}$ is weight loss in (mg), $\mathbf{S}$ is sliding distance in (cm), ρ is sample density (7.86 mg/cm^3), $\mathbf{w_1}, \mathbf{w_2}$ is sample weight before and after wear test (mg).

Fig. (2) Wear and hardness samples.

Results and discussion

1- Microstructure

the microstructure developed in the steel samples hardened in different quenching media were presented in Fig. (3).

It's clear from Fig. (3) the microstructure of as received sample was consisted of ferrite and pearlite, and the small dark dots were inclusions in steel. The water quenched sample showed predominantly martensitic structures and retained austenite with various morphologies of cementite, while the tempered water quenched sample exhibited mainly larger structure martensitic and retained austenite with smaller amount of cementite. In other hand, the samples treated with polymer solution exhibited more homogeneous structures of martensitic and retained austenite with disappear for any amount of cementite. It can be concluded from Fig. (3) that the developed microstructure was affected by the rates of cooling. The higher cooling rates for water quenching within the pearlite transformation temperature were fast enough to suppress diffusional processes. The variations in grain structures for quenched carbon steel were more pronounced at the edges than at the centers of the samples, owing to the varying cooling rates exhibited across the samples.

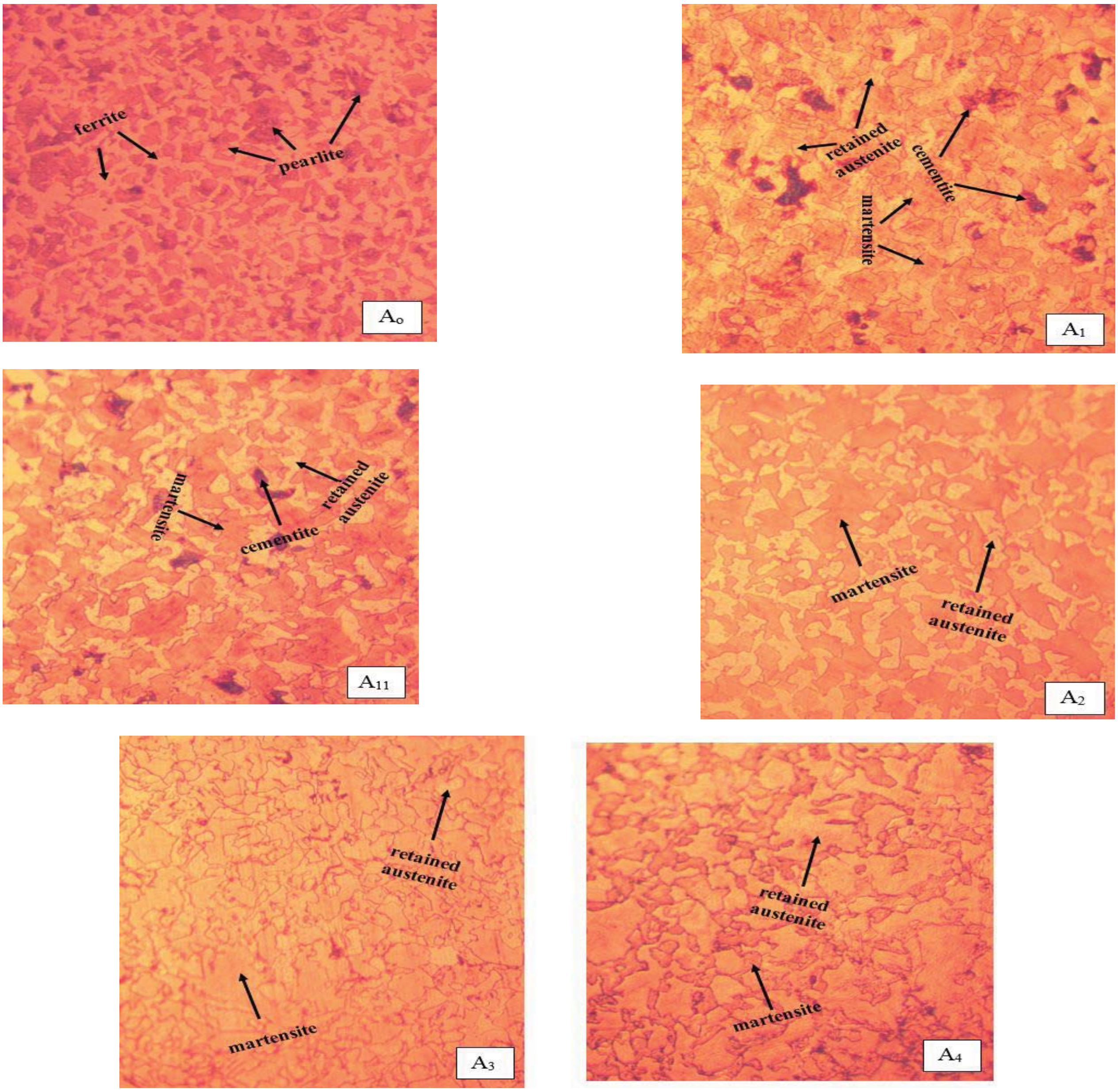

Fig. (3) Microstructure of steel samples hardened in different quenching media.

2- Hardness

The hardness of any materials is mainly associated with the properties of its ingredients, and it can be controlled by tailoring the chemical composition, microstructure, forming, and thermal treatments.

Fig. 4 presents the hardness results of the medium carbon steel and its significant enhancement after both quenching and/or tempering processes were performed. The as received samples were observed to possess the lowest hardness value thus indicating its unreliability in applications where high hardness values are required. The influence of the heat treatment was explicited in other samples as they all exhibited higher hardness values. It is clear from Fig. 4 that the water quenched samples have the highest hardness value compared to polymer quenched and tempered samples. This attributes to the faster cooling rate of water that leads to prevent any reaction or diffusion process may be taken place within the atoms of the metal during quenching treatment which results in highest free carbon in martensite. Moreover, the presence of small amount of cementite particles dispersion into the martensitic and retained austenite structure can be act as obstacle the dislocation movement, which may have contributed to the higher hardness value of the water quenched sample.

Also, Fig. (4) shows that the hardness values of quenched samples in polymer solution still have a large value relatively as compared with as-received samples. This is because the low viscosity of this polymer solution which leads to fast cooling rate. Fig. 4 indicates that the hardness value decreases with increasing the concentration of polyalkylene glycol in water. The hardness value was undergone decreasing in their values with using the tempering treatment in all cases. This can be explained by increasing the volume fraction of retained austenite in microstructure and reduces the amount of cementite particles as shown in Figure (3). The hardness value of tempered water quenched samples was very close to those 10% polymer solution quenched samples.

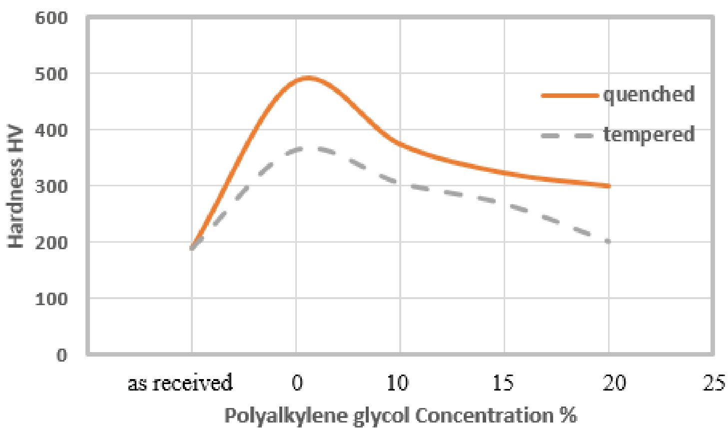

Fig. (4) The effect of varying quenching media on hardness (HV).

3- Wear rate

The wear rate values of the as received, quenched, and tempered samples are given in Figure 5. In general, wear rates for both quenched and tempered samples were reduced, this behavior coincides with the increasing in surface hardness which is attributed to the formation of hard martensite phase, this mind is correlated with AbdulKhaliq F. Hamood et. Al [12]. Also, Fly et. Al [13] reported that the wear resistance depends only on the skin properties. Wear rate of tempered samples marginally increases with respect to that of quenched samples due to decreasing of martensite phase and generation of more retained austenite in the microstructure. However, the tempered samples still possess much lower wear rate than the as-received samples due to presence of very soft phase of ferrite in the microstructure of as-received samples. The samples quenched in 10% polymer solution exhibit lowest value of wear rate as compared with other polymer quenched samples and this value was very close to those of tempered water quenched samples. This can be explained by the homogeneous distribution of martensite and refine the retained austenite in microstructure. In the water quenched sample, although it having the lowest value of wear rate, as a result of the increasing in martensite volume fraction and presence of cementite particles, but it still inapplicable in industry because the brittleness problems and must be tempered.

Overall, the wear rates were stable in the polymer solution quenched samples at all sliding distances. This is assumed to be due to the hard martensite phases were embedded in retained austenite structure, which reduce the risk of martensite cracking, that in turn contributed to the reduce of wear rate.

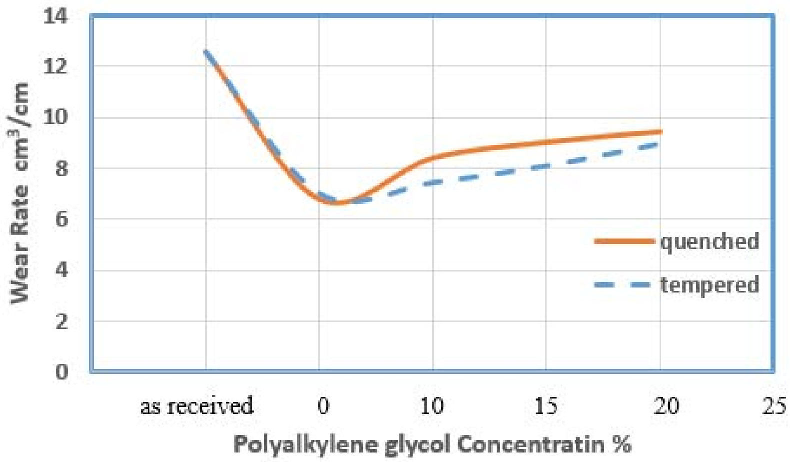

Fig. (5) The effect of varying quenching media on wear rate x 10^{-7} (cm^3/cm).

Conclusion

It can be concluded from the results that the best combination of hardness and wear resistance properties of medium carbon steel can be achieved by hardening in polymer solution with 10% polyalkylene. The overall mechanical properties of samples quenching in this solution were better than that quenching in water and tempered. Therefore, it can be improved the properties of medium carbon steel and reduces the time and cost of hardening treatment by using hardening in polymer solution with 10% polyalkylene instead of hardening in water and tempering.

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