EFFECT OF DOUBLE QUENCHING ON WEAR BEHAVIOR FOR LOW CARBON DUAL PHASE STEEL

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ABSTRACT:

In this paper the effect of double quenching heat treatment on microstructure and dry sliding wear behavior of low carbon dual phase steel with carbon concentration (0.0977% C) was investigated. The specimens were intercritically heat treated at different temperatures and then water-quenched. The martensite volume fraction in the double quenched specimens was higher than that of the single quenched specimens. Hardness test was conducted on low carbon steel specimens using Brinell hardness test. Optical microscopy was employed to examine the microstructure of the specimens.

Wear test were carried out on the single and double quenched specimens under dry sliding wear condition using a pin-on-disk machine at different loads with constant sliding time and speed, and at different sliding time with constant loads and speed. The experimental results showed that the wear rate effectively decreased in the double quenched specimen.

KEY WORDS: dual phase steel, low carbon steel, wear test, double quenching, intercritical heat treatment.

تاثير الاخماد الثنائي على سلوك البلى للصلب واطيء الكربون ثنائي الطور

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الخلاصة

في هذا البحث تم دراسة تاثير الاخماد الثنائي على البنية المجهرية والبلى الانزلاقي الجاف للصلب واطيء الكربون ثنائي الطور ذو تركيز كربون (0.0977%) .تم معاملة العينات بدرجات حرارة مختلفة واخمادها بالماء . لقد وجد ان مقدار الكسر الحجمي للمارتنسايت اكبر في العينات التي اجري لها اخماد ثنائي من العينات التي اجري لها اخماد مرة واحدة . كما تم اجراء اختبار صلادة برنيل لعينات الصلب الواطيء الكربون . ان اختبار البنية المجهرية تم باستخدام المجهر الضوئي .

اجري اختبار البلى الانزلاقي للعينات الاخماد الثنائي والعينات المخمدة مرة واحدة باستخدام تقنية المسمار على القرص باستعمال احمال مختلفة و زمن انزلاق وسرعة ثابتين ، كما تم الاختبار تحت ازمان انزلاق مختلفة مع تثبيت كل من الحمل والسرعة . النتائج العملية بينت ان معدل البلى قد قل بشكل واضح في العينات التي تم اجراءالاخماد الثنائي لها .

INTRODUCTION

In most cases, failures of material initiate from the surface, and are sensitive to microstructure and properties of the surface [1]. Wear is one of the important mechanical properties expected from steels in actual service condition for some of the aerospace and automobile parts [2], the best opportunities of the application for different elements of cars have the steels with a ferritic – martensitic structure. The DP-type (Dual Phase) steels have a structure of a ferritic matrix with islands of martensite [3]; the amount of martensite present in ferrite-martensite steel will depend on the intercritical annealing temperature in the ferrite plus austenite region. Further increasing the volume fraction of martensite increases the strength of the dual phase material. Unfortunately, increasing the martensite content might reduce ductility and toughness [4]; hence wear resistance increase with increasing ductility so the excess in martensite phase raises wear rate [5].

Adamczyk and Grajcar [3] investigated various routes of a heat treatment by using double quenching in order to obtain a DP-type structure with required fractions of ferrite and martensite and optimum mechanical properties of the investigated low-carbon steel and they concluded that various initial structure influences morphology of martensite in a final DP-type structure of the heat-treated steel. Also Güral et al. [5] studied the effect of double quenching on wear properties of atomized iron powder mixed with 0.3 % graphite and 1 % Ni powders, the mixed powders were cold pressed and sintered at 1200°C for 30 min under pure Ar gas atmosphere. They found that martensite volume fraction in the double quenched specimens was higher than that of the single quenched specimen and wear coefficient effectively decreased in the double quenched specimen.

Tekeli et al. [2] studied dry sliding wear behavior of Fe + 0.3% graphite powder metallurgy processed (PM) steels. After wear tests it was seen that the wear rate of the intercritically annealed specimens was very low in comparison to as-sintered specimen. The specimen intercritically annealed at 728 °C showed the lowest wear rate, despite its lower martensite volume fraction. Wang et al. [1] observed that the friction coefficient decreases and the wear resistance increases with the nanocrystalline (nc) surface layer. The improvement in friction and wear properties may be attributed to the harder nc surface layer which reduces the degree of plowing and micro-cutting under the lower load and the degree of plastic removal and surface fatigue fracture under the higher load, respectively.

The aim of this paper is to use double quenching heat treatment in order to obtain a DP-type structure with required fractions of martensite and optimum wear properties of the investigated low-carbon steel.

EXPERIMENTAL PROCEDURE

1. Material and Heat Treatment

The chemical composition of the investigated low-carbon steel was carried out at Alnaser Company for Mechanical Industry / Ministry of Industry and Minerals by using spectroscopy method **(Table 1)**.

The established heat treatment conditions are schematically shown in **(Table 2),** respectively all samples are tempered at temperature 200°C for one hour after heat treatment.

2. Microscopy Characteristics

The microstructure of the surface layer on the investigated low-carbon steel characterized by optical microscope, the specimens were grinded by using Aluminum oxide paper lubricated with water (600, 800, 1000, and 1200) grit, the samples polished by alumina suspension then etched with the 2% Nital solution. Mean linear intercept method was used for the calculation of martensite volume fraction according to the ASTM E562 [6].

3. Hardness Test

Hardness test was achieved by using Brinell hardness test. The specimens were grinded by using Aluminum oxide paper lubricated with water, ball diameter of the tester was 2.5 mm, and the applied load was 187.5 kgf. Hardness values were calculated using Brinell hardness equation [7].

4. Wear Test

Unlubricated wear experiment were performed under ambient laboratory conditions using a pin -on- disc wear tester, where the pin is loaded normally. The variables which are used for wear test can be presented by:

1- Study the effect of normal load on wear rate by using load (10, 20 and 30) N at both constant sliding time 20 min and constant speed.

2- Study the effect of the sliding time on wear rate by using times (10, 20 and 30) min at constant normal load 2N and constant speed .Wear rate can be calculating by using the followed equation:

$$wr = \frac{\Delta w}{2\pi r n t} \qquad (1)$$

Where:

Δw = weight difference of the sample (gm) , $\Delta w = w_1 - w_2$.

$2\pi\ rnt$ = sliding distance (cm).

r = radius from sample centre to the disc centre (cm) .

n = disc rotational speed = 500 r.p.m.

t = test time (min).

RESULTES & DISCUSSION

1. Microstructure Characteristics

The specimens have a ferritic matrix and the martensite is located on boundaries of α phase as a network **(Figs.3 & 4)** or as islands **(Figs. 1, 2, 5&6)**. The location of martensite is strongly dependent on a distribution of the austenite formed due to a carbon enrichment of the boundary-zones of ferrite connected with a decomposition of pearlite grains [3]. During the heat treatment of the investigated steel the privileged diffusion of carbon on the boundaries of the α phase is occurred, an increasing in heat treatment temperature leads to the increase of martensite volume fraction, keeping the distribution of this phase on grain boundaries of the α phase [3].

The diversity in morphology of the structure was the specimens quenched twice. In this case, during heating the steel the nucleation of austenite mainly occurs on the boundaries of martensite laths formed after primary quenching of the investigated steel from a temperature of 900°C [3]. The predominated martensite fraction occurs mainly as islands located in surroundings of grain boundaries of ferrite grains **(Figs. 1, 2,5and 6)**. Moreover, in surroundings of martensite, especially at a boundary zone of large grains of the α phase, small grains of the recrystallized ferrite can be identified. They are a result of plastic deformation connected with volume changes accompanying the martensite transformation [3].

Apart from the morphology differences after the heat treatment of steel according to the route 1 the difference in a grain size of ferrite is observed. The more fine-grained structure has steel heat-treated according to the route 1. This is due to the increased number of places convenient for the nucleation of ferrite and also a partially course of the recrystallization of the specimens with an initial structure of martensite [3].

Optical micrographs reveal that the coarse martensite was obtained with further increase in Martensite volume fraction for specimens of the investigated steel. The increasing in temperature of heat treatment leads in increasing of volume fraction of the martensite (MVF) [2, 3, and 8] as shown in **(Table 3)** .

2. Hardness Test

It appears from **(Table 4)** that hardness of the samples is increased as the temperature of heat treatment increase except the samples A_1 and A2.

An increase of the heat treatment temperature increases a fraction of martensite [2,3,8], the increase of martensite volume fraction increases the hardenability of steel[3]. But further increase in the MVF was to decrease the hardness; this result is agreed with the results obtained by Bello et.al. (2007)[4]. That is why hardness values of samples A1, A2 was less than the values of other samples.

Martensite enriched in carbon increases the hardenability of steel, when the quenching temperature increase the fraction of martensite increase [2,3,8], but at the lower carbon enrichment. It causes lowering the hardenability of steel (austenite depleted in carbon) and can lead to a transformation of the part of austenite to undesirable bainite [3] .

Clearly we can see that double quenching raises hardness values **(Fig.7)**. This is reported to be attributed to the fine grains of the recrystallized ferrite. They are a result of plastic deformation connected with volume changes accompanying the martensite transformation [3], Microstructural refinement is expected to enhance hardness [1, 9]. Beside that the increase of martensite volume fraction increases the hardenability of steel.

3. Wear Test

From **(Fig.8)** it has been noticed that wear rate is increased as sliding time increases until it reached highest sliding time. Increasing sliding time tends to raise surface temperature which causes cover of oxide on the surface of the sample. During sliding more and more oxide is produced, the metal–metal contact is reduced, thus lowering the wear rate, and leading to transition from severe to mild wear [10, 11].

In **(Fig.9)** when the load is lower than 20 N, wear loss mainly results from plowing and micro-cutting under the action of the abrasive particles and oxides fallen from the sample surface. When the load increases the abrasive particles indents more deeply into the surface; so the repetitive work-hardening in the surface layer will be severer under the repetitive sliding action. Eventually cracks propagating and growing induce spalling of the material in the surface layer. The dominant wear mechanism changes are plastic removal and surface fatigue fracture of the deformed layer when the load increases [1].

At the same time, wear rate caused by plowing and micro-cutting is less than that of the original sample under the lower load. As the load increases, the repetitive work-hardening caused by the reciprocated sliding action in the harder layer is smaller. Consequently the spalling loss of the treated sample is less than that of the original one too. In the harder surface layer of the treated samples, the depth that the abrasive particles indents is smaller, so that the force needed in the plastic deformation is diminished that the plastic removal in the harder surface layer is smaller, wear volume loss of the treated samples is less than that of the original sample under the higher load [1].

(Figs 8 and 9) show that double quenching process enhanced wear properties; this result is agreed with the results obtained by Gural et.al. (2007) [5], it is attributed to the higher hardness values are significantly associated with the finer distribution of martensite and ferrite composite microstructure gained from double quenching [4]. Microstructural refinement is expected to enhance hardness and then to result in an improvement in the adhesive wear resistance [1,2]. The higher hardness the lower wear rate [12], so the much enhanced wear resistance was of sample B1.

(Figs 1, 3 and 5) of the microstructure test reveal that the microstructures of the samples of route (1) consist from fine ferrite and martensite phases. Coarse martensite was obtained with further increase in volume fraction [4].In the case of specimen A1; further increasing in volume fraction of martensite increases the strength of the dual phase material. Unfortunately, increasing the martensite content might reduce ductility and toughness [4]. Wear resistance of dual phase steels affect their ductility. If dual phase steels have high ductility, they have high wear resistance as well, generally, dual phase steels having lower MVF have high ductility [2]. Therefore, as the samples had lower MVF, it can be expected to have higher ductility and thus high wear resistance [2].

Beside that an increasing of the quenching temperature increases the fraction of martensite, but at the lower carbon enrichment. During this process, martensite volume fraction increases while its hardness decreases as mentioned before, which results in a decrease in wear resistance of dual phase steels [2,3]. Martensite phase in a microstructure is easily cracked under loads and thus the weight loss from the surface is increased [2] therefore the wear rates of the samples being sever at high load as shown in **(Fig. 9)**.

CONCLUSION

1- Wear rate for the heat treated samples of low carbon dual phase steel shows improvement in comparison with the original one.

2- Double quenching showed enhancement in wear properties more than the single quenched samples.

3- Specimen double quenched from the temperature of 900°C and 850°C showed best wear resistance than the other samples.

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Table (1) Composition of the investigated low-carbon steel.

Elements **%**	**Cr**	**Ni**	**Mn**	**P**	**S**	**Si**	**C**
	0.16994	**0.13058**	**1.27698**	**0.06166**	**0.28942**	**0.01275**	**0.097796**
Elements %	**Co**	**Sn**	**Ti**	**W**	**Cu**	**V**	**Mo**
	0.01732	**0.02097**	**0.00079**	**0.00738**	**0.14820**	**0.00508**	**0.02835**
Elements %	**Fe**	**Zn**	**Ca**	**Zr**	**Nb**	**Pb**	**Al**
	97.7174	**0.00268**	**0.00002**	**0.0027**	**0.00142**	**0.00894**	**0.00035**

Table (2): Heat treatment of steel according to routes 1 and 2.

sample		Heat treatment
Rout 1 (double quenched)	A1	First quenched from temperature 900°C, second quenched from 870°C (booth quenched in water).
	B1	First quenched from temperature 900°C, second quenched from 850°C (booth quenched in water).
	C1	First quenched from temperature 900°C, second quenched from 810°C (booth quenched in water).
Rout 2 (singles quenched)	A2	quenched from temperature 870°C in water
	B2	quenched from temperature 850°C in water
	C2	quenched from temperature 810°C in water
D		Metal as received

Table (3) Martensite volume fraction %.

sample	Martensite volume fraction %
A1	36.71
A2	28.9
B1	31.24
B2	25
C1	21.09
C2	15.09

Table (4) hardness values.

Sample	Hardness kg/mm^2
A_1	168
A_2	166
B_1	179
B_2	173
C_1	170
C_2	161
D	159

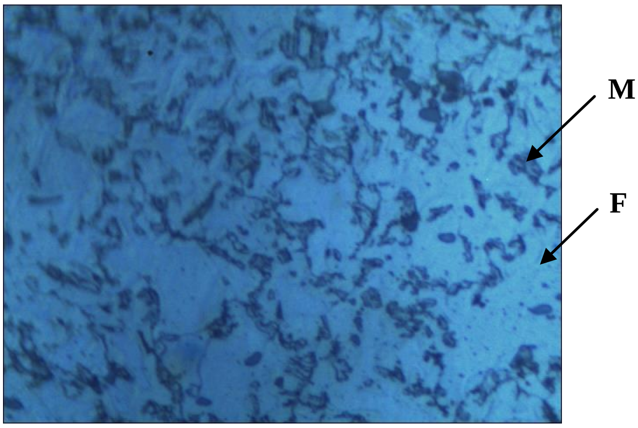

Fig.3: sample (B1) Ferritic – martensitic structure of steel double quenched from the temperature of 900°C and 850°C, (80X) (F: Ferrite, M: Martensite).

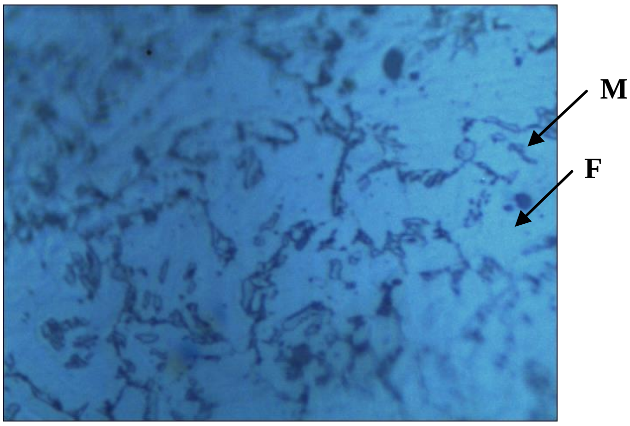

Fig.4: sample (B2) Ferritic – martensitic structure of steel quenched from the temperature of 850°C, (80X) (F: Ferrite, M: Martensite).

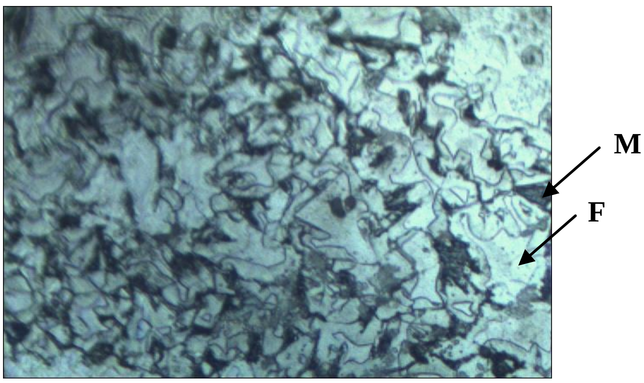

Fig.1: sample (A1) Ferritic – martensitic structure of steel double quenched from the temperature of 900°C and 870°C, (80X) (F: Ferrite, M: Martensite).

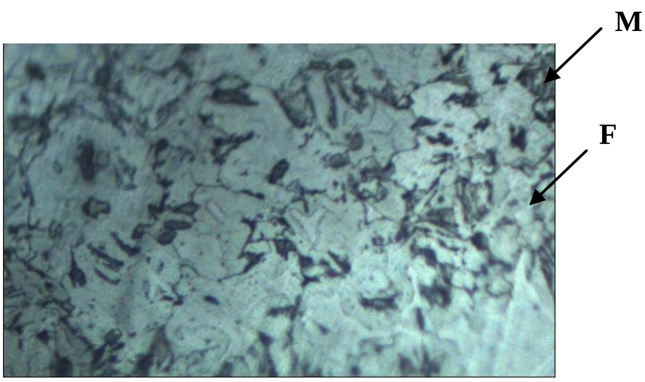

Fig.2: sample (A2) Ferritic – martensitic structure of steel quenched from the temperature of 870°C, (80X) (F: Ferrite, M: Martensite).

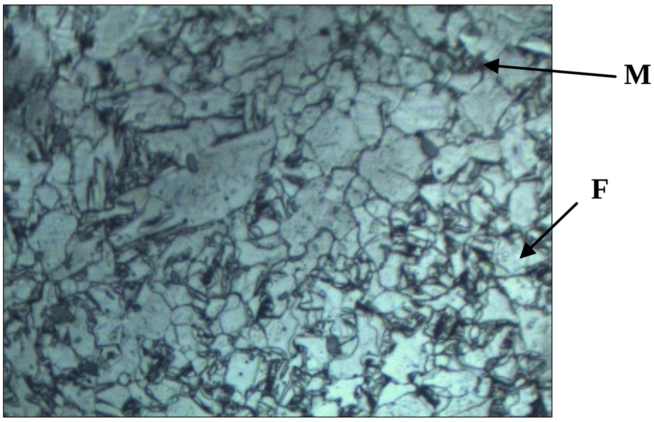

Fig.5: sample (C1) Ferritic – martensitic structure of steel double quenched from the temperature of 900°C and 810°C, (80X) (F: Ferrite, M: Martensite).

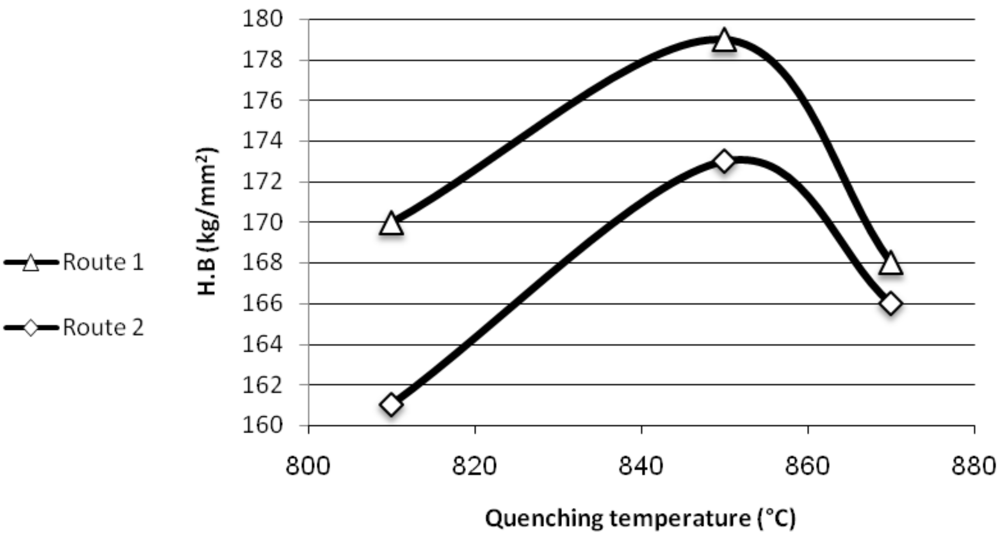

Fig .7: Relationship between quenching temperature and Brinell hardness.

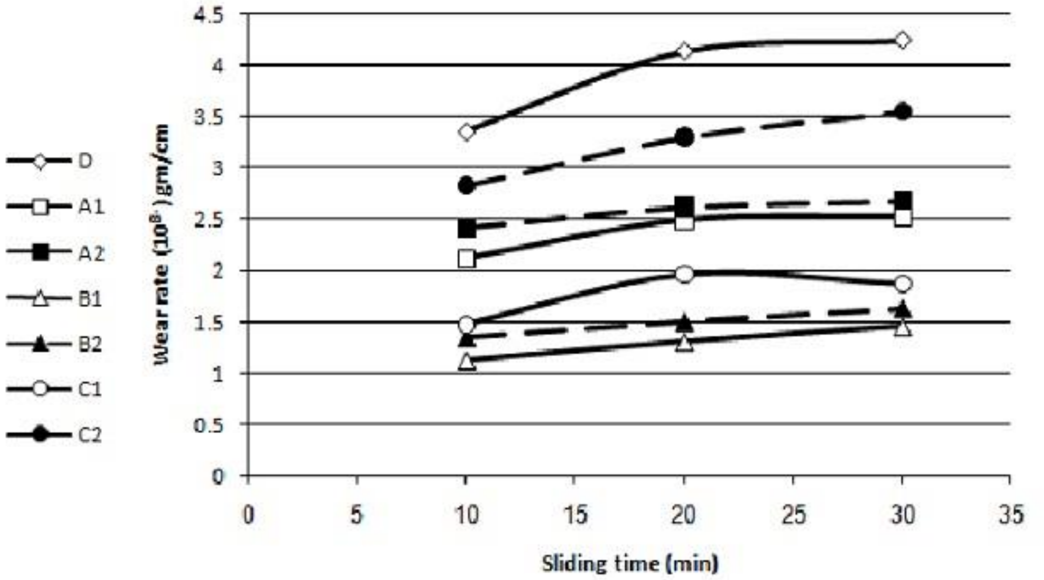

Fig.(8):Relationship between sliding time and wear rate.

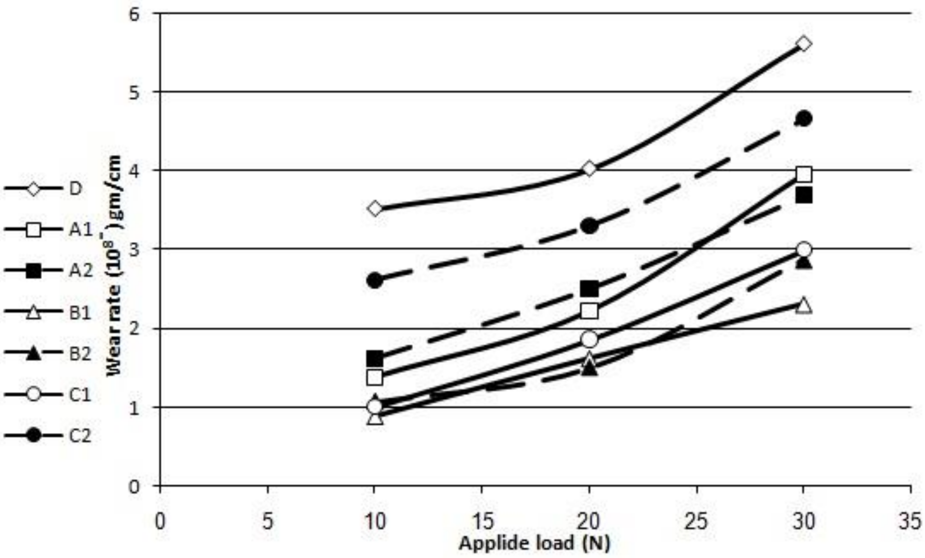

Fig. (9): Relationship between applied load and wear rate.