Wear Rate and Hardness of Boride Low Carbon Steel

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ABSTRACT

There are no single materials which can withstand all the extreme operating conditions in modern technology. Protection of the metals from hostile environments has therefore become a technical and economic necessity.
In this work, for enhancing their wear-resistance, boride layers were deposited on the surface of low carbon steel by a pack cementation method at 850 °C for (2, 4, and 6) h using vacuum furnace. The boronizing process was achieved using different concentration of boron source (20, 25, and 30) % wt. into coating mixture to optimize the best conditions which ensure the higher properties with lower time. The coating was characteristic by X ray diffraction (XRD), and it is confirmed the presence of (Fe_2B) and (FeB) in the coating. The wear rate, hardness and thickness of the boride layers were measured, and it was observed that they effected by concentration of boron and time holding of boronizing process. Experimental results show that the higher properties of coating layer were obtained with 30% wt. of boron concentration and 4 h time holding.
Keyword: boronizing, diffusion coating. Wear rate.

معدل البلى والصلادة للفولاذ الواطئ الكاربون المبورن

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الخلاصة

لا توجد مادة مفردة ممكن ان تتحمل ظروف التشغيل القاسية في التكنلوجيا الحديثة. لذلك, حماية المعدن من المحيط القاسي اصبح ضرورة تقنية واقتصادية. في هذا العمل، ولتحسين مقاومتها للبلى، تم ترسيب طبقات من البوريد على سطح الفولاذ المنخفض الكاربون باستخدام طريقة السمنتة الصلبة عند درجة حرارة 850ْم ولازمان (2، 4، و6) ساعات باستخدام فرن مفرغ. تم اجراء عملية البورنة باستخدام تراكيز مختلفة لمصدر البورون (20، 25، و30) % من الوزن داخل خليط الطلاء للحصول على أفضل القيم لأفضل ظروف للحصول على أعلى خواص بأقل زمن. تم توصيف الطلاء باستخدام حيود الاشعة السينية وقد اثبتت وجود طوري (Fe_2B) و(FeB) في الطلاء. تم قياس معدل البلى، الصلادة، وسمك طبقة البوريد، وقد لوحظ تأثرها بتركيز البورون وزمن الابقاء لعملية البورنة. اثبتت النتائج العملية ان افضل خواص ممكن الحصول عليها عند الطلاء ب 30 % من الوزن تركيز البورون مع زمن ابقاء 4 ساعات.

كلمات رئيسية: البورنة، الطلاءات الانتشارية، معدل البلى.

1. INTRODUCTION

Poor wear resistance still the main problem of steel alloys used in application involve aggressive conditions and elevated temperature like turbine and power plant applications.

In recent years, many studies on the enhancing of mechanical properties of materials have been carried out. From these researches, it was found that the large improvement in surface properties can be achieved by applied surface treatment on engineering materials, **Calika, et al, 2008**. Therefore, the use of surface coatings opens up the possibility for material designs in which the specific properties are located where they are most needed. A number of coating systems are known ranging from metallic or polymeric to oxide based ceramics. Among them diffusion based coatings (pack cementation) have additional advantages of high wear resistance, high temperature stability and superior mechanical, **Kayacan, et al, 2010.**

Boronizing is a thermochemical surface-hardening process. It's similar to other surface hardening treatments, such as carburization and nitriding. In boronizing treatment the surface of material was enriched by diffusing boron atoms into the surface at high temperatures, **Dong, et al, 2009**.

Industrial boronizing can be applied to most ferrous steels such as structural steels, tool steel, and carbon steel as well as to austenitic stainless steels. Thus, boronizing has long been used to improve the surface properties of valves, burner nozzle, etc. in the utility industry as boride layers have a high hardness, oxidation resistance, strong indicator of wear resistance and fracture strength.

Several researches were accomplished in this field. **Calika, et al, 2008**, investigated some mechanical properties of borided and unborided four types of steels. Boronizing of steels was performed by powder pack method at 1210°C. **Kayacan, et al, 2010**, investigated the diffusion mechanism of the boronizing process of AISI 1040. While, **Pazarlıoglu et al, 2012**, studied niobium boride layers deposited on the surface of AISI 1010 steel.

The most of the previous studies (**Gatea, and Abbas, 2009, and Al-Azawi, 2005**) carried out the diffusion coatings in pack process in the range of 1000-1200°C. It was found that the pack mass was sintered, and stuck to the samples so that it was very difficult to remove the contaminations from the pack. The samples were very much distorted and the grain size of the core increased due to high temperature and prolonged heat treatment.

In this study, the pack cementation process was achieved in relatively low temperature (850) $^{\circ}$C to avoid sintering of the pack and adhesion of material to the samples surface. The coating diffusion employed in this work was boronizing coating.

The aim of this research is to the optimum conditions which brought the higher surface properties (hardness and wear). The resultant coatings were characteristic by X-ray diffraction to identify the formed phases. The effects of boron concentration and holding time of boronizing process were also studied.

2. EXPERIMENTAL WORK

2.1 Material Selection and Sample preparation

The substrate material used in this study was low carbon steel. Low carbon steel is widely used in different areas of machine constructions. The chemical composition of material used in this work was given in **Table 1**. Before the boronizing, round samples were cut into proper

dimensions for each test, and ground up to 600 grid emery paper and then washed ultrasonically for 15 min in ethyl alcohol.

2.2 Coating Process

Boronizing process was performed using a fluoride-activated powder pack cementation method. The boronizing media were composed of different concentration of B_4C (20, 25, and 30) %wt., 5% wt.KBF4 and remaining was SiO_2. In this boronizing media, B_4C serves as the source of boron, SiO_2 as the diluent, and KBF4 as the active agent.

Simple steps was involved to achieve the boronizing process as following: all the media powders were mixed in a polyurethane jar for 6 h, using porcelain balls as the mixing medium; low carbon steel specimens were buried in the powders and packed into a rectangular stainless steel retort (25 cm length, 15 cm width and 8 cm), which was then placed in a horizontal tube vacuum furnace (**Fig. 1**) at 850°C. The heating rate for all runs was 10 °C/min. the varying soaking time (2, 4, and 6) h was used to get the lower time possible to achieve the higher properties. After treatment, the samples were cooled to room temperature in the furnace. Nine runs were repeated in each treatment condition. **Fig. 2(a & b)** illustrates the boronized and un-boronized samples respectively. All experimental work was carried out in metallurgy laboratory in material engineering department in university of technology.

2.3 Inspection and Testing

2.3.1 Characterization of boronizing coatings

After the boronizing treatment, the thickness of the resultant coating was measured by an eddy current based thickness measuring instrument with ND-2 type probe, suitable for ferrous and non-ferrous alloys.

Phase analysis of the boronizing coatings was identified utilizing X-ray diffraction analysis (Philips PLO1840 X-ray diffractometer in 2θ ranging between 20˚ to 90˚ using Cu Kα radiation).

2.3.2 Microhardness measurement

The hardness of the specimens was measured with a Vickers micro-hardometer model (HVS-1000). The hardness tests were performed under an indentation load of 100 N with a dwelling time of 20 s. In order to obtain reliable statistical data, analysis points were spaced so as to eliminate the effect of neighboring indentations, and the hardness was evaluated by taking five indentations on each specimen and averaging of only three middle values**.**

2.3.3 Wear test

Wear tests were performed according to the ASTM G99 for wear testing with a pin-on-disk apparatus. The wear rate of the materials were determine at a load of 10N, rotating speed of 2cm/sec, sliding distance of 50m using a pin-on-disk tribometer.

Specimens were weighed on an electrical balance with an accuracy of 0.1 mg before and after wear testing. Then, the wear rate expressed in (gm/cm) is calculated as follows:

$$W.R = \frac{\Delta w}{S} \quad (1)$$

Where: $W.R$: wear rate in (gm/cm), Δw: weight loss in (gm), S: sliding distance in (cm).

All of the tests were conducted at ambient atmospheric condition at room temperature (25)˚C. Lubrication is not applied to avoid the complication of terbo-chemical effects.

3. Results and Discussion

3.1 Thickness Measurement

Thickness of boride samples was in general increases with increasing the concentration of boron and time of treatment. The results presented in **Fig. 3**. Boronizing is diffusion process and obeyed the diffusion laws which are agreement with the result of increasing the thickness coating with increasing the exposure time to high temperatures.

Coating thickness of the boride specimens was in range of (0.25-0.135μm). Thinner layers of coating were favored in practical application because it can be helped to reduce the defects of the like porosity or micro-cracks.

3.2 X-ray Diffraction

The coating has been characterized by X-ray diffraction. It was observed that the main phases formed on the coating layers were Fe_2B, and only a small amount of FeB. The XRD patterns also reveal that the increasing of soaking time led to increase the amount of FeB.

Furthermore, the results indicates that the boron concentration has no much effect on the formed phases, only on intensity of Fe_2B peak, which become more intensive as boron concentration increases. The X-ray diffraction patterns for 30% B_4C boride samples treated at different time holding are shown in **Fig 4**.

3.3 Micro-hardness

The results of microhardness for un-boronized and boronized samples are shown in **Fig. 5**. It can be found from this Figure that the microhardness values of all boronizing coatings are much higher than that of the substrate, i.e. 151 HV.

It is also observed that the value of microhardness was enhanced strongly with increase the boron concentration and time of treatment. This improvement can be explained by the fact that the diffusion of boron atoms into substrate arise with increasing the period of exposing to higher temperature. These atoms produced in deformation of crystal lattice of substrate leading to generate of internal stresses. These stresses act as obstacle to motion the dislocation resulting in increasing the hardness values. However, during boronizing for longer than 4 h, the micro hardness shows to decrease slightly with increasing time. This phenomenon might be attributed to the formation of a great number of micro-cracks in the coatings when the treatment was carried out for long duration at high temperature. Also, this reduction in microhardness value may be caused by the phase transformation and changes in crystalline structure. Recrystallization, grain growth and change the microstructure make the metal softer. The similar observation was found by **Dong, et al, 2009**.

3.4 Wear Test

Fig. 6 illustrate the wear rate results. In order to find the differences in wear behavior, through their different wear mechanisms, the unboronized specimen was also examined. It is can be clearly observed that the wear rates of the boronized specimens were much lower compared with those of the unboronized specimen under the employed loads. Moreover, the wear resistance of the boronized layer increases with the increase of boron concentration from 20 to 30 % wt. The percentage of improvement in wear resistance of boronized samples varied depending on boron concentration and time of treatment.

The maximum improvement percentage was brought with boron concentration 30% and holding time 4 h. It is obvious that the wear resistance increases with the increase of the surface micro hardness. Hard and complex phases especially the phase (Fe_2B) is responsible for the excellent wear resistance property of the boronized samples.

The results of this study suggest that there is an inverse relationship between the hardness and wear rate. The harder materials revealed more wear resistance as shown in **Fig 7**. Although similar results have been reported by **Borgioli et al, 2005**,and **Hamood, Abd Al- khalaq F., 2012**, several studies have found no correlation between hardness and wear due to the complexity of wear process [**Seghi, et al, 1991, Yap, et al, 1997, Mandikos, et al, 2001, and Mair, et al, 1996**].

In other hand, the results can be explained according to wear mechanism. The wear mechanism for the un-boronized specimens takes place mainly through scratch and plastic deformation. On the contrast, the boronized specimens the wear mechanism are mainly characterized by scuffing and brittle micro-fracture.

4. CONCLUSION

The following conclusions may be drawn from the results obtained in this work:

- The boronizing coatings were successfully applied by a simple pack cementation process onto already prepared low carbon steel samples.
- The proposed coatings were applied at a relatively low temperature 850˚C, leading to less cost and energy consumption during application the coating.
- increasing the time soaking led to increase the amount of phase FeB formed in resultant coatings, while that the boron concentration has no much effect on the formed phases, only on intensity of Fe_2B peak.
- Boronizing coating improves the micro-hardness value and wear resistance of the resultant coatings in all cases.
- The optimum conditions which brought the higher enhancement of micro-hardness value and wear resistance were at 30% wt of B_4C with 4 h soaking time.

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Table 1 chemical composition of metal substrates.

Element	C	Mn	Fe	Si	Mo	Cu	Ti	V	P
Low carbon steel (wt%)	0.18	0.8	98.45	<0.05	0.4	<0.05	<0.05	<0.05	<0.05
Standard (DIN LW)	0.17-0.22	0.6-0.9	98.40	0.04-1	0.4-0.5	.....	.....	.....	<=0.035

Figure 1. Vacuum furnace

Figure 2. (a) Boronized and (b) un-boronized samples.

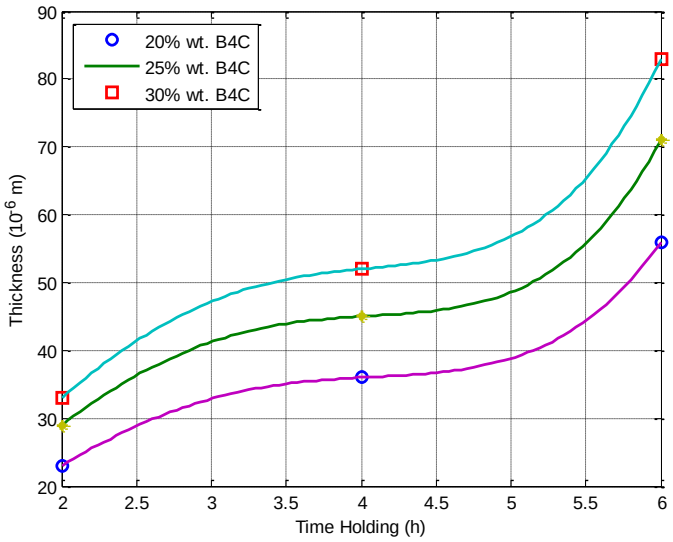

Figure 3. Variation of layer thickness as a function of boronizing time and B_4C concentration.

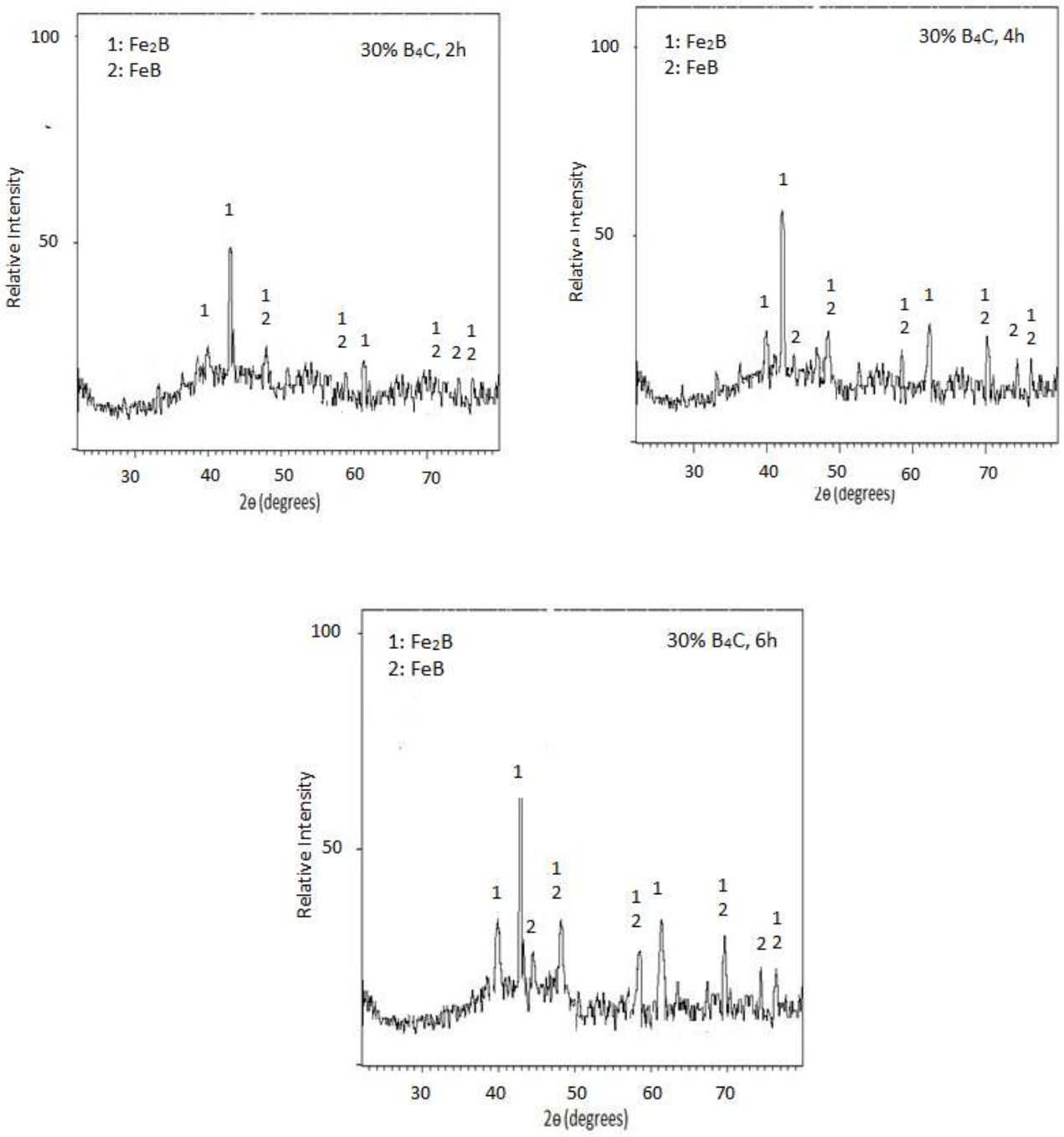

Figure 4. X-ray diffraction patterns of boronized samplesat 30% B_4C for different time treatment:2h,4h, and 6h.

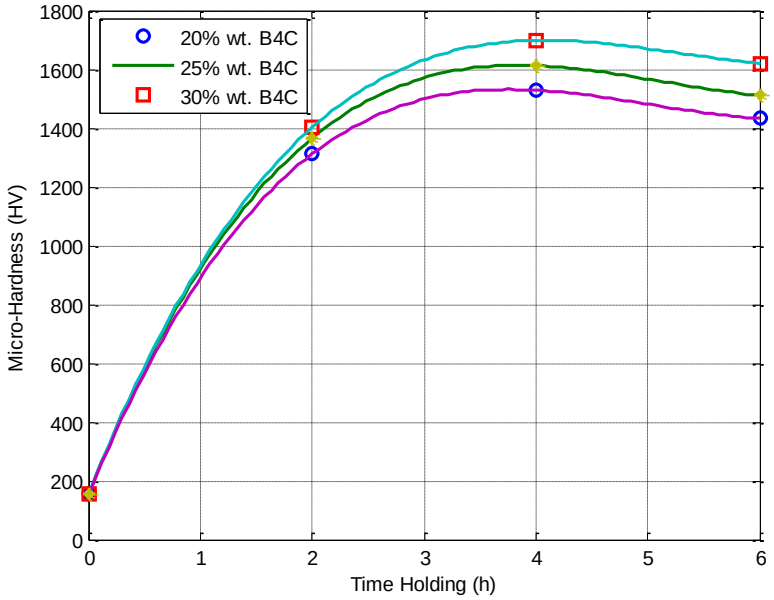

Figure 5. The micro-hardness variation of boronized samples at different time treatment and B_4C concentration.

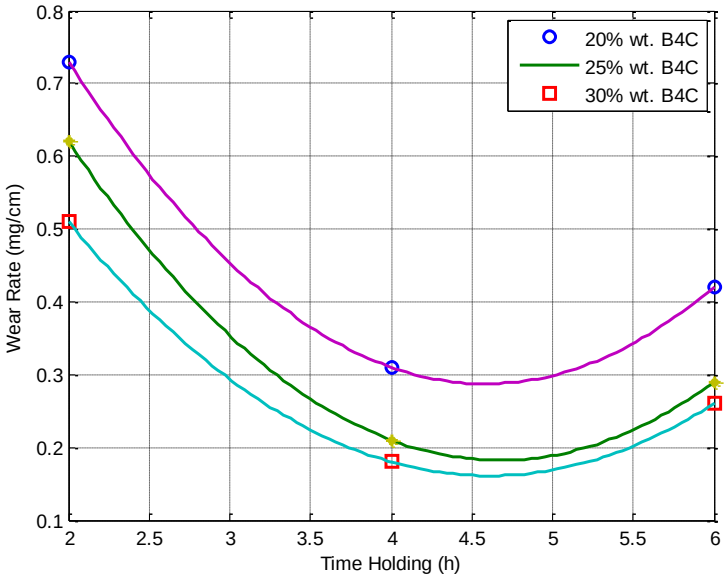

Figure 6. Variation of wear rate to time holding for the boronized samples at different B_4C concentration.

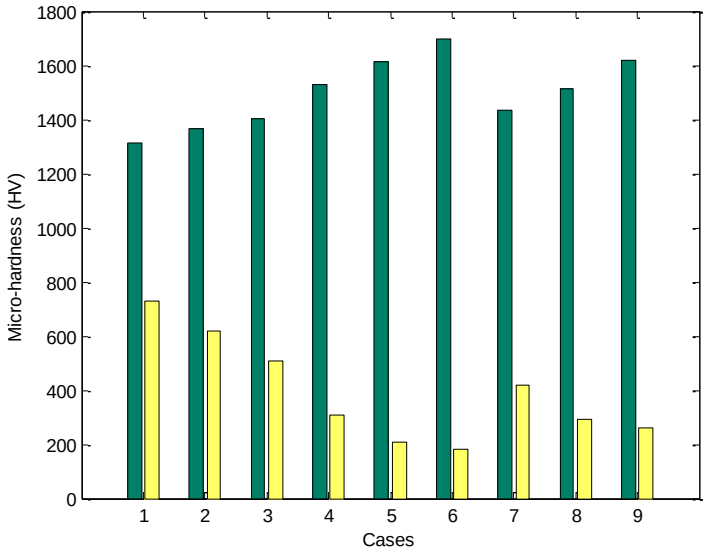

Figure 7. Microhardness (HV) and wear rate boronized samples.