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Abrasive wear behavior of boronized AISI 8620 steel

M. Tabur[a], M. Izciler[a,*], F. Gul[b], I. Karacan[c]

[a] Gazi University, Industrial Arts Education Faculty, Technology Education Department, Gölbaşı, Ankara, Turkey
[b] Gazi University, Tech. Education Faculty, Metal Education Department, Besevlerı, Ankara, Turkey
[c] Karabuk University, Tech. Education Faculty Manufacturing Education Department, Karabuk, Turkey

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ABSTRACT

In this study, AISI 8620 steel was boronized using the solid state boronizing technique. Processes were carried out at the temperatures of 850, 900 and 950 °C for 2, 4 and 6 h of treatment. Abrasive wear behavior of the samples boronized at different temperatures and treatment durations have been examined. Using boronized and unboronized samples, abrasive tests were conducted using pin on disc test apparatus. 80 and 120 mesh aluminum oxide (Al_2O_3) abrasive papers were used in the abrasion experiments and the samples were subjected to abrasion under 10, 20 and 30 N loads. Boronized steels exhibited an improvement in abrasive wear resistance reaching up to 500%. Microstructures and wear surfaces of the samples were inspected using SEM microscopy. SEM examinations revealed that the thickness of the boride layer on the steel surfaces changes with changing process durations and temperatures. The presence of boride formed in the borided layer at the surface of the steels were determined by XRD analysis and microhardness values of the iron borides (FeB, Fe_2B) formed on the steel surface were found to be over 1600 HV.

1. Introduction

Boronizing is one of the methods used on steels and iron to improve their surface properties [1]. Boronized steel parts exhibit excellent performance in various tribological applications in mechanical engineering and in the automotive sector [2]. In the past 40 years, boronizing has become an increasingly better surface protection method [3]. Boronizing of steels is used against adhesive, sliding and abrasive wear and is recognized as an effective method to combat these effects [1–13]. The most widely known boronizing procedure is forming iron borides on the steel surface [5]. Boronizing is one of the most widely used methods in many tribological applications where wear and friction control are paramount [14].

The boronizing process is a chemical heat treatment that aims to form borides with the substrate metal by diffusing the boron atoms into the sample surface [14]. Boron is a metal that can form many minerals and compounds [6]. Because it is a relatively small element, the process may be applied to many types of materials such as ferrous and non-ferrous metals [15], nickel and cobalt alloys, metal bound carbides, refractory alloys [13] and some super alloys [15]. Boronizing of ferrous products is usually conducted between 840 and 1050 °C [7,14]. There are several techniques available for surface boron enrichment process [8]. The process can be carried out employing any of the solid, liquid, gaseous state [7,14], plasma and ion implantation [16] environments [17]. Pack boronizing mixtures comprise 5% B_4C as the source, 5% KBF_4 as activator and 90% SiC as the diluting agent [7,9]. During the boronizing process, the sample is put inside a sealed container packed with powder mix and sealed. The container is heated up to desired temperature and kept at that temperature for the prescribed time, and finally cooled [7].

With the diffusion of boron into the steel, iron borides (FeB, Fe_2B) form and the thickness of the boride layer is determined by the process temperature and time [9,17]. The crystal structure of both layers exhibit columnar shapes oriented along the diffusion axis [18]. Generally, saw-tooth shaped single phase (Fe_2B) layer formation is preferred over a layer with both FeB and Fe_2B [7,9]. The boron-rich FeB phase that has approximately 16.23 wt% B is not preferred because it is more brittle compare to the Fe_2B phase that has 8.83 wt% B [19]. Boride layers adhere to the substrate material more strongly because of the saw-tooth morphology. Brittleness of the boronized layer increases with the layer thickness [1,20]. Also, since the FeB and Fe_2B phases have different thermal expansion constants (TEC; $\alpha_{FeB} = 23 \times 10^{-6}\,{}^\circ C^{-1}$, $\alpha_{Fe_2B} = 7.85 \times 10^{-6}\,{}^\circ C^{-1}$), crack formations are frequently found on the FeB/Fe_2B phase interfaces in two phase layers. These cracks frequently cause spalling and scaling under a mechanical load [19]. By controlling the boronizing parameters, that is the boronizing powder composition, temperature and process time, the pack boronizing method can reliably produce the Fe_2B phase [7].

Steels surface treated using boronizing heat treatment methods are widely used in industry. It is known that the boride layers can exhibit surface hardness over 2000 HV and provide good abrasive

* Corresponding author.
E-mail address: mizciler@gazi.edu.tr (M. Izciler).

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and adhesive wear resistance [21]. Comparison of steels used in industry treated with other surface hardening treatments such as carburizing and nitriding with boronizing shows that the boronized steels have superior tribological characteristics [22]. Boronized iron and steel surfaces exhibit high hardness, excellent wear and corrosion resistance and strong chemical stability [16]. Habig reports that the abrasive wear resistance of boronized steels is higher against alumina abrasives than against silicon carbide abrasives. Habig concludes that this is because of relative hardness of these materials. Richardson similarly reports that in case the hardness H value of the material subjected to wear is higher than the hardness H_a of the abrasive material or more appropriately in case $H > 0.8H_a$, wear resistance significantly decreases [23].

A very hard surface layer, a very low coefficient of friction, no requirement of heat treatment after the boronizing process and a very significant resistance against some acids, bases, metal solutions and high temperature oxidizing are among the advantages of boronizing over other surface hardening methods [24]. Hardness, shape and size or roughness of abrasive material, angle of contact, normal load applied, sliding speed and fracture toughness of the material are all among important factors in wear mechanisms [1].

One of the most important reasons for the machinery parts to suffer damage and fail is wear. Abrasive wear, most important type of wear for the industrial machine parts, is important as it may cause rapid failure in the system. Because of these, this study focuses on the effects of boronizing treatments carried out at different temperatures and with different process durations on abrasive wear resistance.

2. Details of the experiment

2.1. Test materials

Materials used in this study are AISI 8620 cementation steel samples. Chemical composition of the samples is given in Table 1. Test samples used were pin shaped with the flat surfaces sliding against the abrasive paper. Their nominal dimensions were 6 mm (diameter) × 50 mm (height).

Samples were ground using 500 mesh sandpaper before the treatment and 200, 400, 600, 800, 1000 and 1200 mesh sandpapers respectively and polished using 3 μm diamond paste before etching in 2% Nital solution after the treatment. Cross sections of the boronized steels were examined using a JEOL JSM-6060 LV brand scanning electron microscope.

2.2. Boronizing process

Boronizing was conducted using the solid-state pack boronizing method. All samples were treated using a micro-processor controlled electric resistance furnace with 1200 °C temperature limit, ±5 °C accuracy, a digital display and a volumetric capacity of 200 mm × 150 mm × 250 mm. All samples to be boronized in the treatment phase were packed inside stainless steel boxes with at least 10 mm of powder mix packing thickness. The stainless steel boxes were then securely sealed. Boronizing heat treatments were carried out at temperatures of 850, 900, and 950 °C for 2, 4 and 6 h using Ekabor-II, a mixture with high boronizing potential. Argon was used as the protective atmosphere. After boronizing, the samples were air cooled. The chemical composition of the Ekabor-II mixture was; 5% B_4C, 5% KBF_4 and 90% SiC. The mixture may be classified as high quality in regard to surface texture and is used in low allow steel and pig iron and spero casting procedures.

Table 1
Chemical composition of AISI 8620 steel (wt%).

C	Si	Mn	P	S	Cr	Mo	Ni
0.20	0.24	0.85	0.019	0.009	0.55	0.21	0.5

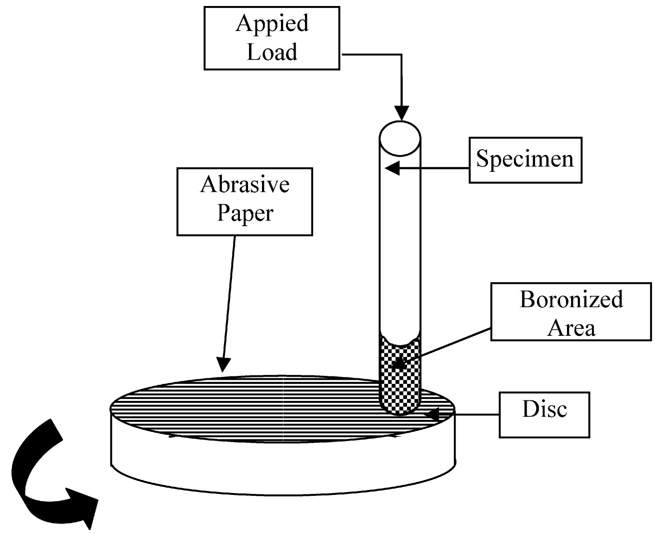

Fig. 1. Pin-on disc abrasive test apparatus [27].

2.3. Characterization and microhardness of specimen

Cross sections of the boronized steels were examined using a JEOL JSM-6060 LV brand scanning electron microscope. XRD analyses were performed in a Rigaku D/Max-2200/PC Model diffractometer, with 2θ varying from 20° to 100°, using Cu Kα radiation. Microhardness measurements of the samples were taken using a Shimadzu brand HMV Micro Hardness Tester model apparatus. Microhardness was measured using a load of 0.1 kgf and average of five reading was evaluated.

2.4. Abrasion testing procedure

Abrasion tests were conducted using a pin on disc apparatus under dry and grease-free sliding conditions at room temperature. Abrasive tests of the boronized and unboronized were carried out on the two-body pin on disc apparatus shown in Fig. 1 under 10, 20 and 30 N of load at the speed of 0.2 m/s using 80 and 120 mesh aluminum oxide (Al_2O_3) abrasive. Samples were moved in right angle with the abrasion axis on the abrasive paper so that the samples were constantly kept in contact with new abrasive surfaces. Total sliding distance of the samples on the abrasive surface was 10.25 m. Samples were weighed, before and after the test, using an electronic scale with a resolution of 10^{-4} g in order to determine wear losses as lost weight. Wear ratios of the samples with known lost weight were calculated using the formula below [25–27]. The abrasion tests were performed three times for each sample and the results were calculated using the mean values.

$$W_a = \frac{\Delta G}{dMS}\ \mathrm{mm^3/Nm}$$

where W_a is the abrasion rate, ΔG the mass loss, M the applied load (force × length), d the density and S is the sliding distance. The respective densities of FeB and Fe_2B are 6.75 and 7.43 g/cm^3.

3. Results and discussions

3.1. Microstructure

Scanning electron microscopy (SEM) on unboronized sample (AISI 8620) revealed that the ferrite and pearlite phases are homo-