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Research Article

Effect of boronizing process on wear properties of 16MnCr5 steels

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Abstract
In this study, boronizing processes with different parameters were applied to the cementation steels with a diameter of 11 mm. Microstructures were examined using optical and scanning electron microscopes (SEM). Wear and hardness tests were applied both to the untreated sample and to all boronized samples. As a result of boriding processes, a four-fold increase in hardness was observed in the sample boronized at 1000 °C and 16 hours compared to the sample without heat treatment. Although improvements were achieved in hardness and wear performance in the sample boronized at 900 °C and 8 hours, it was observed that the coating thickness was lower than the other samples.

Key Words
Boronizing, 16MnCr5, Wear

Borlama prosesinin 16MnCr5 çeliklerinin aşınma performansına etkisi

Öz
Bu çalışmada, 11 mm çapa sahip sementasyon çeliklerine farklı parametrelerde borlama işlemleri yapılmıştır. Optik mikroskop ve taramalı elektron mikroskopu (SEM) kullanılarak mikroyapılar incelenmiştir. Aşınma ve sertlik testleri hem ısıl işlemsiz numuneye hem de borlanmış numunelerin hepsine uygulanmıştır. Borlama işlemleri neticesinde 1000 °C ve 16 saat borlanmış numunede ısıl işlemsiz numuneye göre dört kat sertlik artışı gözlemlenmiştir. 900 °C ve 8 saat süreyle borlanmış numunede sertlik ve aşınma performansında gelişmeler sağlansa da kaplama kalınlığının diğer numunelere göre daha düşük olduğu gözlemlenmiştir.

Anahtar Kelimeler
Borlama, 16MnCr5, Aşınma

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1. Introduction

Machinery and equipment used in continuously operating systems must be durable, qualified, and have high mechanical and tribological properties. Wear mechanisms that can cause economic losses in many branches of the industry should be examined as an important issue. 16MnCr5 known as case-hardening steels are used in precision gears, cam rollers, and shafts which demand a harder and good surface with good core toughness properties in the industry [1–3]. This type of steel is mainly developed by heat treatment and thermomechanical surface hardening [4–6]. Surface hardening is an important subject to improve hardness and tribological performance [7]. In surface hardening techniques, the boronizing process can be widely preferred as a cost-effective method. Boron atoms have a small atomic size and diffuse to the surface of different metals and alloys (ferrous and nonferrous) [8]. Powder-pack boronizing due to its low cost and easy application can be more used among the boronizing techniques. This method contains boron source, diluent, and activator powders and directly affects the formation of the boride layer [9].

In this study, boronizing as a surface hardening mechanism was performed with different parameters on 16MnCr5 steels. Development of wear behavior of 16MnCr5 steels with the boronizing process was achieved with this report.

2. Experimental Studies

Boronizing process was applied to 16MnCr5 steel. The chemical composition of this alloy is presented in Table 1.

Table 1. Chemical composition of 16MnCr5 steel

C	Si	Mn	P	S	Cr
0,18	0,21	1,12	0,012	0,013	0,896

For the boronizing process, approximately 25 mm of Ekabor II powder was placed on the bottom of the high temperature resistant ceramic crucible. The samples were positioned in the ceramic crucible with a gap of 10 mm between themselves and the side surface of the crucible. The remaining part of the crucible was filled with powder, the lid was closed and placed in the furnace. The ceramic crucibles, in which the sample was placed, were placed in the furnace that reached the desired temperature and boronizing was performed. After the process, the crucible was taken out of the furnace and left to cool at room temperature. The parameters are given in Table 2. Also, some images belonging to the boronizing process are shown in Figure 1.

Table 2. Boronizing parameters of 16MnCr5

Sample No	Parameter
B1	900 °C- 8 hrs.
B2	900 °C- 16 hrs.
B3	1000 °C- 8 hrs.
B4	1000 °C- 16 hrs.

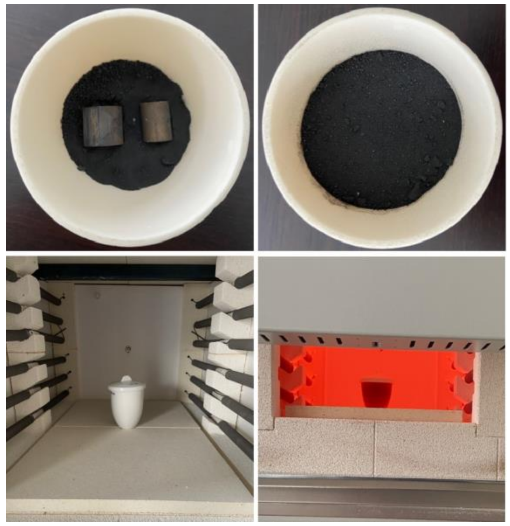

Figure 1. Images about the boronizing process

After the boronizing process, samples were prepared for microstructural and wear tests. Standard metallographic procedures were conducted using grinding and polishing of the surface. Optical microscope and SEM was used to see the formation of boride layer and to observe the coating thickness. Hardness was performed using Vickers Method and finally samples were cut into the suitable size without grinding and polishing for wear tests. Wear tests were applied in dry sliding conditions as Reciprocating. 5N and 10N loads were conducted.

3. Results and Discussion

Figure 2 and Figure 3 illustrate the optical microscope images of the samples boronized for 900 °C - 8 hrs. and 1000 °C - 16 hrs. respectively to see the lowest and highest boronizing parameters in the study. When the microstructure of the sample boronized at 900 °C - 8 hrs. were examined, it was understood that there were cracks and voids in the boronizing layer, and it had a saw-tooth-like appearance. Due to insufficient boronization time and temperature, boron atoms could not diffuse on the surface sufficiently and an average of 6-micron coating was obtained. In addition, this coating was irregular, and homogeneity could not be observed.

In the sample boronized at 1000 °C - 16 hrs., the coating was homogeneous and continuous. In addition, the coating thickness reached an average of 45 microns. This showed that sufficient time and temperature were provided for boronizing. At the same time, the presence of the transition zone in the sample was understood more clearly than in the other sample. SEM image of the same sample is given in Figure 4. The distribution of elements along the blue line between the matrix and the boride layer was examined by EDS analysis and when the transition to the coating zone was made, a decrease in the amount of carbon in the steel and a change in the peaks due to the compounds formed between iron and boron were detected.

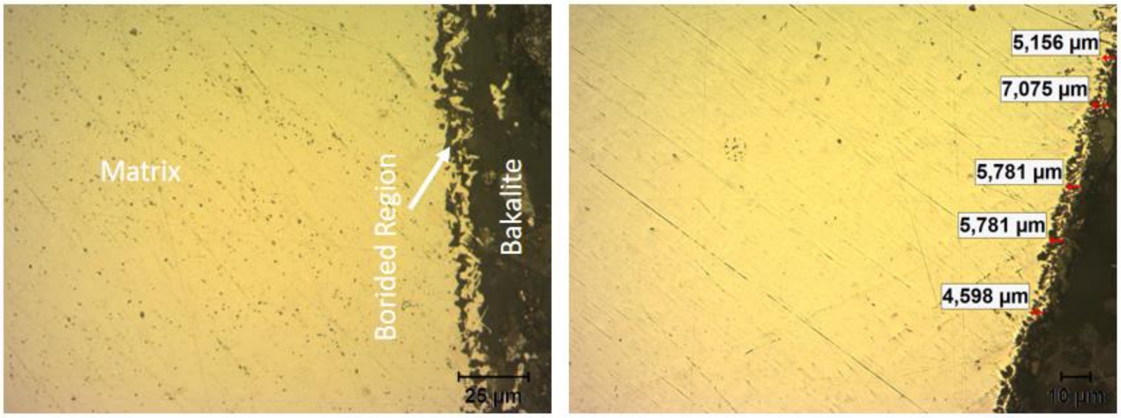

Figure 2. Optical microscope images of 900 °C- 8 hrs. sample

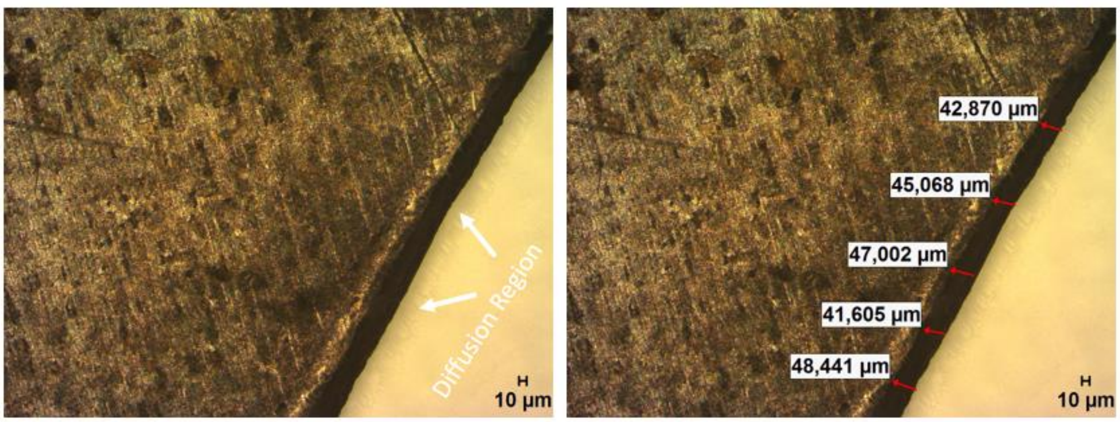

Figure 3. Optical microscope images of 1000 °C- 16 hrs. sample

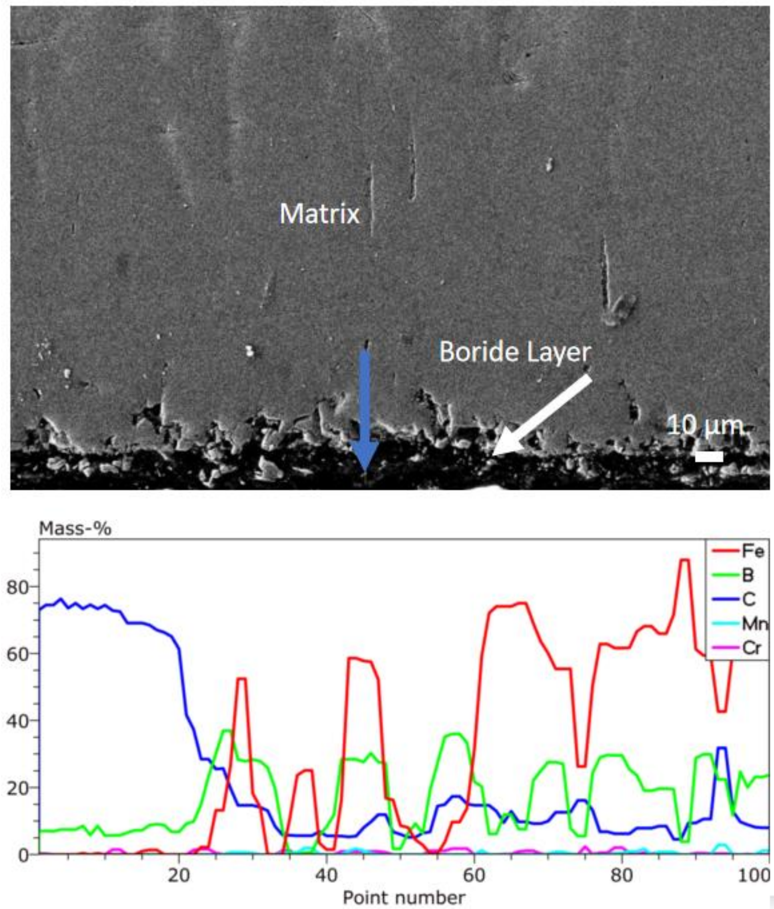

Figure 4. Line EDX results of 1000 °C- 16 hrs. boronized sample

Figure 5 shows the hardness test results of specimens. In the boronizing process, a hard layer is formed on the surface as a result of the boron atoms passing on the steel surface as intermediate atoms. Depending on the homogeneity and thickness of this layer, the hardness of the material increases. With the different boronizing parameter applied in this study, increases in hardness were obtained in the range of approximately 2 to 4 times.

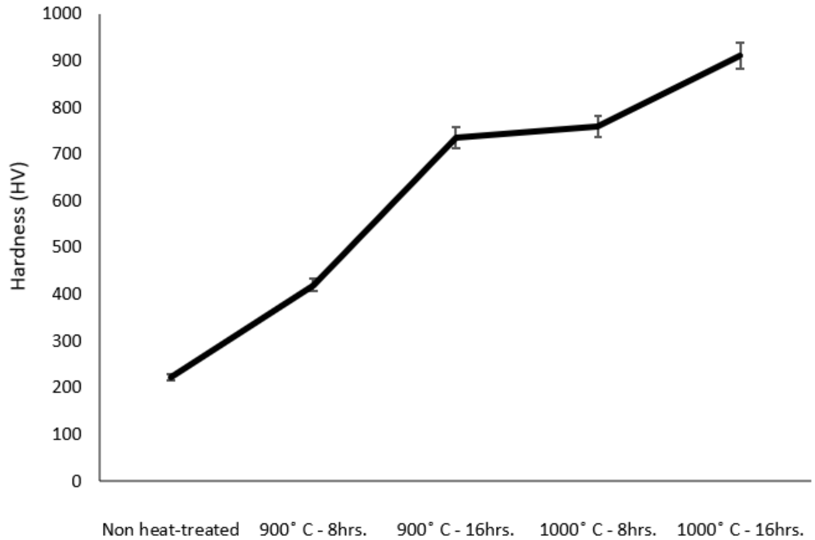

Figure 5. Hardness results of all samples

Figure 6 presents the wear rate graphs of all samples under two different loads. Wear rates were calculated from the volumetric loss along the sliding distance. Wear width, length and depth are considered, and this value (wear volume loss) is divided by slip distance. When the results are evaluated, three times improvement was achieved under 5N load by boronizing process. With the increase in boronizing temperature and time, the formation of the FeB phase (in addition to the Fe_2B phase) and the increase in its intensity make the surface harder. According to the Archard principle, the increase in hardness allows less wear on the material surface [10]. Therefore, with boronizing processes, the surface becomes harder and wear resistance increases. As the applied load increases, the coating thickness on the surface is removed in a shorter time, which causes more wear. In all samples, the wear rate increased with increasing load.

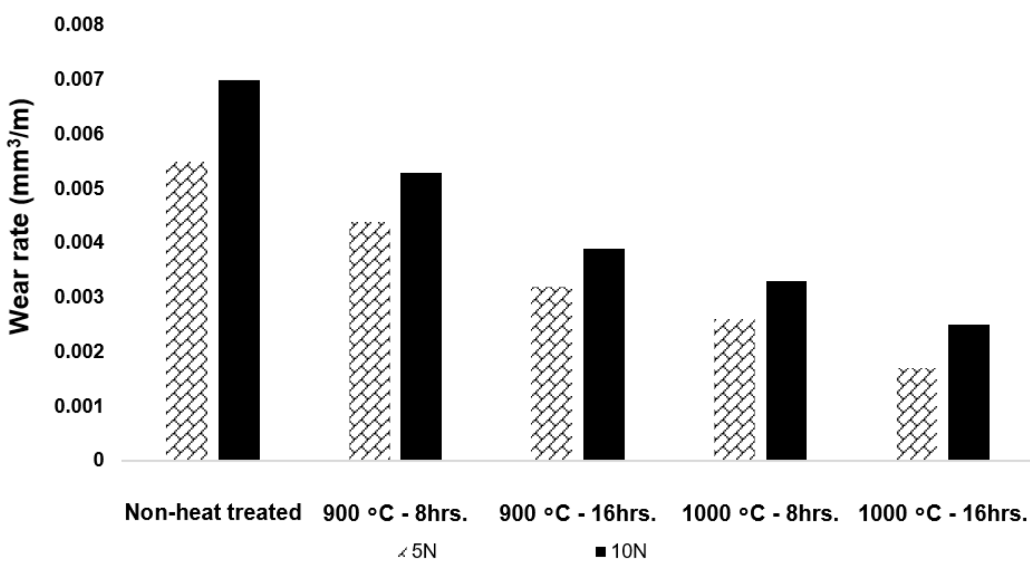

Figure 6. Wear rates of all specimens

4. Conclusions

In this study, 16MnCr5 steel was used and four different boronizing parameters based on time and temperature were applied successfully. Following results were obtained.

- As the boronizing temperature and time increased, the homogeneity of the boride layer and the coating thickness increased.
- As a result of all boronizing parameters, improvements were observed in hardness and wear performances.
- Coating thickness reached 45 microns for the 1000 °C-16 hrs. boronized sample.
- Hardness increases of up to 330% with the boronizing process was observed.
- The wear performance of the samples could be increased by three times with optimum boronizing process.

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