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JOURNAL OF ADVANCED APPLIED SCIENCES
e-ISSN: 2979-9759
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SHORT COMMUNICATION

Behaviour of 32 CrMoV12-10 Steel Towards Boronizing Variables

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ARTICLE INFO

Article History
Received: 29.11.2024
Accepted: 17.12.2024
First Published: 30.12.2024

Keywords
32 CrMoV12-10
Barrel steel
Boriding agent
Boriding
Boron compounds
Gun tube

ABSTRACT

During the shooting in gun barrels; there are many forces that affect each other such as external swelling caused by the explosion, excessive wear caused by the bullet core rubbing inside the barrel, high temperature caused by friction and gunpowder temperature, thermal expansion caused by temperature, chemical corrosion caused by gunpowder gases. It is expected that the barrel steel will show optimum resistance against all these effects. The most harmful of these is the wear force. The barrel, whose inner diameter expands due to wear, becomes unusable after a certain number of shots. In order to increase the effective number of shots, different hardening applications are made to the inner surfaces of the barrels of very different steel qualities. One of the commonly used barrel steels is 32CrMoV12-10 steel and hard chrome plating of the inner surface of the barrel. In this study, the boronizing behavior of 32CrMoV12-10 steel was investigated as an alternative coating technique. The changes in the type, layer thickness and hardness values of boron compounds formed on the surface as a function of temperature and time were investigated. Boriding processes were carried out with a holding time of 2, 4 and 6 hours by setting the boriding temperature to 900°C. Typical columnar structures were observed at depths of 73, 100 and 133 µm in SEM microscope images. XRD (X-Ray Diffraction) analysis revealed that these were FeB, Fe_2B, MnB and CrB compounds and that boride depth and hardness increased as the holding time increased. In microhardness tests conducted in this area, hardness values up to 2500 HV were obtained.

Please cite this paper as follows:

Sahin, S. (2024). Behaviour of 32 CrMoV12-10 steel towards boronizing variables. *Journal of Advanced Applied Sciences*, *3*(2), 85-90. https://doi.org/10.61326/jaasci.v3i2.316

1. Introduction

32CrMoV12-10, a type of alloyed carbon steel is used to manufacture automotive parts and gun tubes that require a high level of toughness and strength. Its original hardness value is not very high. High wear resistance is essential to extend ballistic gun barrel life. It was aimed to form hard boron compounds on the 32CrMoV12-10 steel surface. In current industrial practice, hard chromium coating is applied to the inner surface of gun tubes with the aim of extending their life. This is a very slow process that poses risks to the environment and occupational health due to the use of toxic chemicals. The term “surface boriding treatment” refers to the process of using thermochemical processes to create hard boron compounds on the steel surface in the form of a thin layer.

There are pack boriding studies concerning different types of steel. Zong et al. (2018) have detected FeB, Fe_2B and CrB compounds at 9.3-97.2 µm thickness on the surface of AISI 440C martensitic steel as a result of pack boriding. The hardness values taken from this surface measured between 393 and 1730-2080 $HV_{0.05}$. Campos-Silva et al. (2010) investigated the formation and kinetics of the FeB/Fe_2B layers on the surface of AISI 316 borided steel. Experiments were carried out at a temperature of 1000°C and holding times of 3 and 5 hours. An optimum 50-250 µm thick borided layer is formed in low-

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carbon and low-alloy steels, while the boride layer thickness range in high-alloyed steels was measured between 25-76 µm.

Kayali (2013) treated AISI 420, AISI 304 and AISI 304L stainless steel surfaces with Ekabor-II powder at temperatures of 850, 900 and 1000ºC for 2, 4 and 6 hours. 4.6-64 µm thick FeB, Fe_2B, CrB and NiB formations were detected on the surface. In their study titled "Low temperature boriding of high carbon steel", He et al. (2015) stated that two boride phases (FeB and Fe_2B) coexist in the borided layer at 780ºC. In his study, Taktak (2006) detected FeB, Fe_2B and CrB in the boronized layer as a result of the boronizing process applied to AISI H13 (X40CrMoV 5-1) steel at temperatures of 1073-1223 K for 5 hours and measured the hardness value as 1860 HV. Keddam et al. (2018) detected FeB, Fe_2B, CrB and Cr_2B in the boronized layer as a result of the boronizing process performed on AISI 440 C (X105CrMo17) steel at different temperatures and waiting times. Zuno-Silva et al. (2018) detected FeB-Fe_2B-CrB-Cr_2B-Ni_3B on the surface of AISI S1 (60WCrV 8) steel on which they applied boronizing process at 800-1050ºC.

Literatures reveal that after the boriding process, Fe-B compounds are formed on the steel surface and Cr, Ni, Mn-B compounds are formed on the boride layer depending on the alloying elements contained in the steel.

It is a common method to extend the wear and corrosion life of machine parts by coating the surface of a cheap material with an effective surface coating technique instead of using expensive materials. The process of boriding is a type of thermochemical diffusion process in which very high hardness values are able to be obtained (Keddam et al., 2017). It can be applied to steel, superalloys, non-ferrous metals and alloys (Anthymidis et al., 2002; Gencer, 2011; Litoria et al., 2020; Sista et al., 2015).

In order to obtain iron boron compounds, the boriding temperature applied to steel alloys ranges between 800 and 1000ºC. Although there are solid, liquid and gas boriding techniques, the most preferred method is pack boriding (Kulka, 2019).

It is a process that is similar in technique to pack carburizing. As a boron source, B_4C and its activator are usually found together in a box. B_4C and an activator are placed together with the part in a sealed box and kept in a furnace at a specified temperature and time. The box is removed from the oven and is left to cool.

2. Materials and Methods

In this study, 32CrMoV12-10 steel was used as the material to be coated. The chemical composition of the steel, and its mechanical properties are given in Table 1 and Table 2 respectively. It is widely preferred in the manufacture of gun barrels due to its high toughness along with its high strength value.

It has also a high carburizing and nitriding ability due to the alloying elements. The test pieces were machined on a cylindrical lathe with a diameter of 10 mm and a length of 20 mm. Prior to boronizing, the original hardness value of the steel measured at 300 HV.

Table 1. Chemical composition of 32CrMoV 12 10 steel.

	C	**Cr**	**Mo**	**V**	**Si**	**Mn**	**Ni**	**P**	**S**
Min	0.29	2.80	0.7	0.15	0.10	0.40	--	--	--
Max	0.36	3.30	1.2	0.35	0.40	0.70	0.30	0.001	0.001

Table 2. Mechanical properties of 32CrMoV 12 10 steel.

Yield Strength (MPa)	**Tensile Strenght (MPa)**	**Hardness (HV)**
800	940	300

2.1. Boronizing Method

Baybora-1 (Bayça, 2018) was used as a new boronizing agent in this study. Baybora-1 a new patented boronizing agent was used instead of EKABOR which is widely used as a boronizing agent. It contains boron compounds, activator and deoxidizer. The boriding process was carried out in a stainless-steel box fitted with a lid. To begin, the box was half-filled with Baybora-1 powder before placing samples in this powder. The other half of the box was then filled with deoxidant material and the lid of the box was securely closed. The box was placed in an electric chamber furnace and heated at 900ºC for 2, 4, and 6 hours. The samples were named as N2, N4 and N6 according to their waiting times in hour.

At the end of this period, the furnace was turned off and the sample was left in the furnace to cool. Cylindrical specimens, both original and boronized, were cut vertically and starting from 600 mesh, it was gradually ground with 1200 µm sandpaper. Nital solution was prepared using 4% nitric acid and 96% ethyl alcohol. The ground samples were immersed in the 4% nital solution and etched. The ethyl alcohol and nitric acid used were of analytical grade. SEM images of the etched samples were obtained. Vicker hardness was measured inward from the sample surface using a 100 g load and 20 µm spacing. After surface cleaning, XRD analysis was performed on the non-boronized and boronized samples.

The 2608 HV value obtained in the hardness measurements was evaluated as the success of the boronizing agent used, as it is the highest value seen in the literature.

3. Results and Discussion

As shown in Figure 1, the XRD diffraction peaks of N2, N4, and N6 were evaluated to determine the phase types. The formation of different phases on the boride layer can be used to define the hardness and mechanical properties of that layer. It was observed that the dual phase i.e., FeB and Fe_2B were formed on the boride layer rather than a single phase at 2θ = 82°. In addition, the chromium boride (CrB) phase was observed with FeB and Fe_2B at 2θ = 45°. Other elements of 32CrMoV12-10 steel, such as V and Mo, are generally known for forming solid solution phases with carbon. The diffraction peak that appeared at 2θ = 65° is imputed to the $Cr_{23}C_6$ phase.

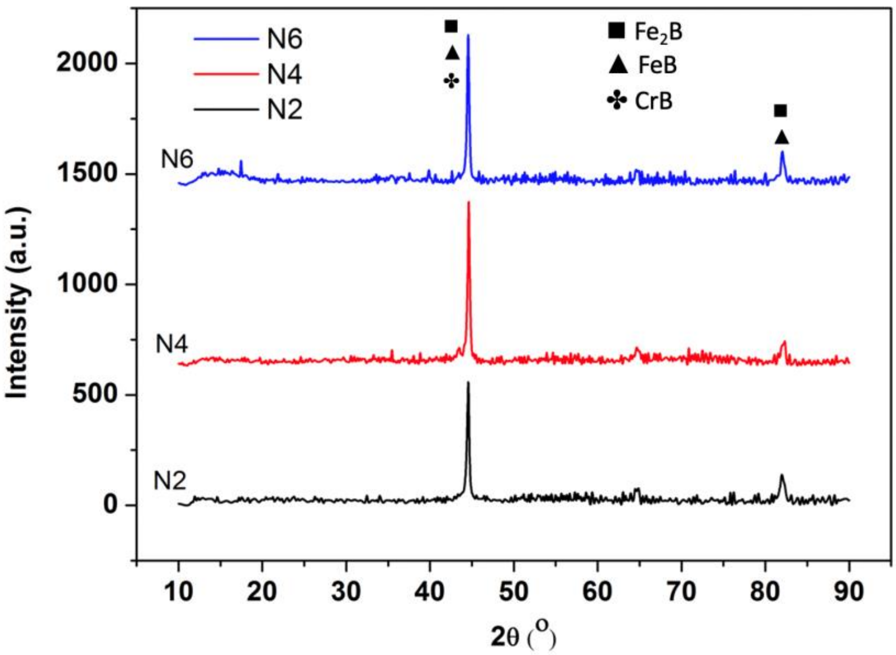

Figure 1. XRD result of N2, N4, and N6.

The microstructures of the boride layers on the surface of 32CrMoV12-10 steels were given for different times denoted as N2, N4, and N6. It was observed that the Cr monolayer formed on the surface of the boronized layers at a thickness of approximately 5 µm for N2, N4, and N6. The morphology of B_4C was observed as a columnar structure with 100 µm, 74 µm, and 133 µm thicknesses for N2, N4, and N6, respectively. The N6 sample that was boronized at 900°C for 6 hours demonstrated greater effectiveness on increasing the thicknesses of the boride layer. The types of formation phase i.e a single phase (Fe_2B) or dual phase (FeB and Fe_2B) is dependent on the temperature, time and chemical composition of the samples (Han et al., 2019; Salloom et al., 2020). Raghs et al. (2020) obtained both FeB and Fe_2B phases at temperatures 800°C and 900°C. Different types of boride phases such as Cr, Ni, V-B can be formed during the boriding process depending on the chemical composition of the 32CrMoV12-10 steel. The transition zone that which consists of the Fe_2B phase was clearly observed in each of the processing times. Figure 2 illustrates a typical borided structure on steel surface.

The EDX analysis of N6 is illustrated in Figure 3. Area 1 represents the boron-coated side and is selected by the base metal point 2. While no B signal is observed in Area 2, it can be seen that the composition of Area 1 contains B element at a concentration of 3.3% by weight. This result also established the presence of B in the coated area. EDX analyses of the areas are given on Table 3.

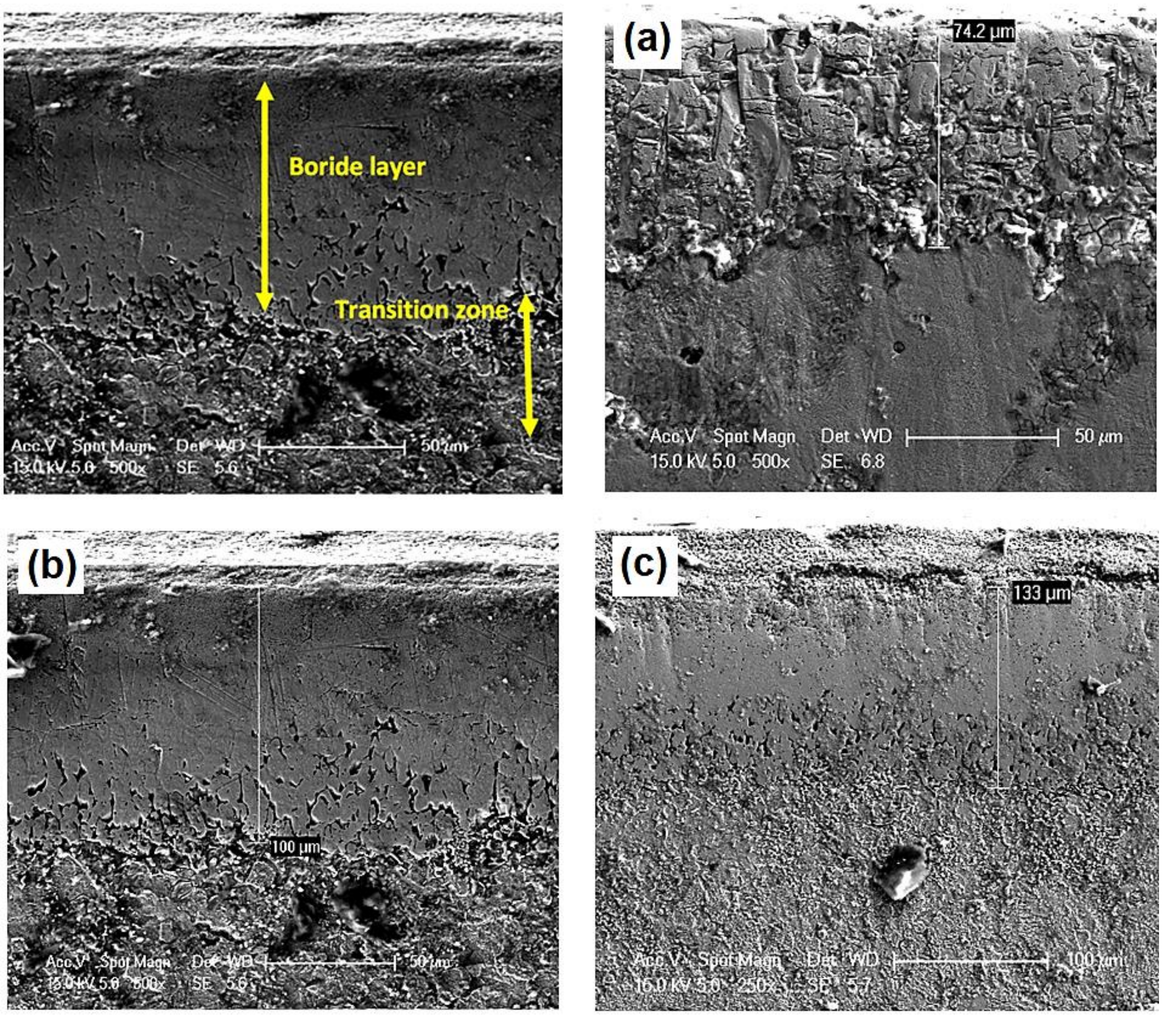

Figure 2. The SEM images of typical boride layers and (a) N2, (b) N4, and (c) N6.

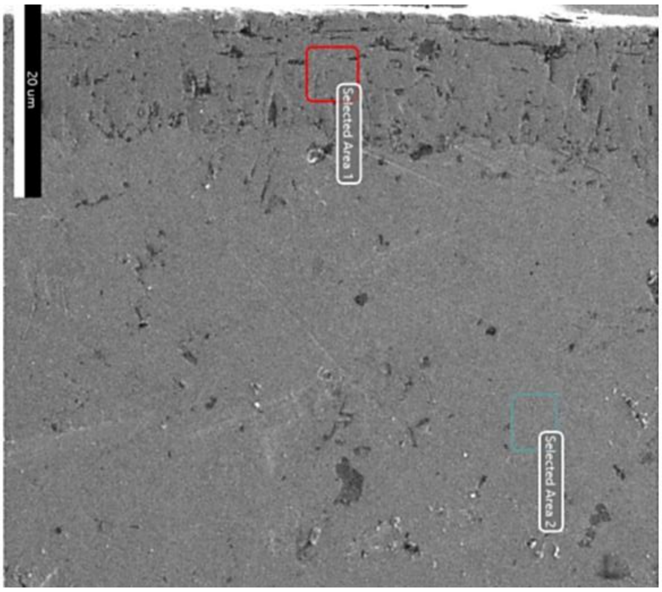

Figure 3. EDX analysis of N6 sample.

Table 3. EDX analyses of areas.

Elements	Area 1	Area 2
B	3.3	0
C	0.8	0.739
Al	0.85	1.02
Si	0.42	0.47
Mn	3.35	4.45
Mo	0.7	1.02
Fe	Remain	Remain

The surface hardness values of N2, N4, and N6 are displayed in Figure 4. The surface hardness values of the boronized layer were measured as 2200 HV, 2608 HV, and 1743 HV for N2, N4 and N6, respectively. The formation of hard FeB and Fe_2B phases resulted in a significant increase in hardness from bulk to boronized layer. N4 provided the layer with the highest hardness value. Due to the formation of the FeB phase in the boronized layer, the measured surface hardness of N4 increased by approximately 88% percent when compared to the bulk hardness. According to previous research, increasing the boronizing process time results in the increase in the formation of the Fe_2B phase, which has a lower hardness than the FeB phase (Campos-Silva et al., 2010; He et al., 2015; Zong et al., 2018). The decrease in N6's surface hardness can be attributed to the formation of the Fe_2B phase.

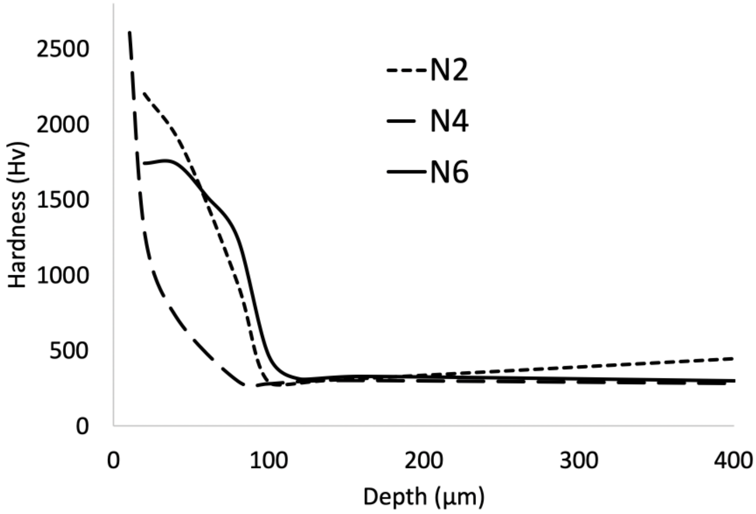

Figure 4. The surface hardness values of N2, N4, and N6.

4. Conclusion

In this study, the 32CrMoV12-10 steel was boronized and its coated layer morphology and hardness properties were investigated. The boronized layer was observed clearly in the SEM image and the presence of boron compounds were established through EDX characterization. The results indicate that as excess holding time increased, thickness of the borided layer increased but the hardness values of samples decreased because of Fe_2B formation on the surface. Baybora 1, a new and different boronizing agent, gave very good boronizing results.

Conflict of Interest

The author has no conflict of interest to declare.

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