Volume 13, Issue 2, Page 1-5, 2024 https://doi.org/10.46810/tdfd.1437681 Research Article

BİNGÖL UNIVERSITY

Türk Doğa ve Fen Dergisi
Turkish Journal of Nature and Science
www.dergipark.gov.tr/tdfd

The Effect of Boriding Temperature and Time on the Structural and Mechanical Properties of a High-speed Steel

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(Received: 15.02.2024, Accepted: 25.03.2024, Online Publication: 28.06.2024)

Keywords
Boriding,
Boriding temperature,
Boriding time,
M42 steel,
Mechanical properties

Abstract: In this study, the effect of boriding temperature and time on the structural and mechanical properties of M42 high speed steel were investigated. Samples placed in Ekabor II powder were exposed to pack boriding treatment at 900°C and 1000°C for 4 hour and at 950°C for 2, 4 and 6 hours. Scanning electron microscope (SEM) images indicate that boron diffuses into the samples and a sawtooth-like cross-sectional morphology is formed. The presence of boron has also been proven by Energy Dispersive X-ray spectrometry (EDX). In addition, it was determined that boron layer thickness increased with increasing boriding temperature. When the microhardness values were examined, it was observed that the sample borided at the highest temperature had the highest hardness value and the hardness values decrease with the decreasing of boriding temperature. Similar results were also obtained regarding the boriding time. The highest microhardness and layer thickness values were obtained after 6 hours of boriding. Additionally, it was observed that the hardness values of borided samples decreased as they moved from the surface to the inner parts.

Borlama Sıcaklığının ve Süresinin M42 Çeliğinin Yapısal ve Mekanik Özelliklerine Etkisi

Anahtar Kelimeler
Borlama,
Borlama sıcaklığı,
Borlama süresi,
M42 çeliği,
Mekanik özellikler

Öz: Bu çalışmada borlama sıcaklığının ve süresinin M42 yüksek hız çeliğinin yapısal ve mekanik özellikleri üzerine etkisi incelenmiştir. Ekabor II tozu içerisine yerleştirilen numuneler 900°C ve 1000°C derecede 4 saat; 950°C derecede 2, 4 ve 6 saat kutu borlama işlemine maruz bırakılmıştır. Taramalı elektron mikroskop (SEM) görüntüleri incelendiğinde borun numunlerin içerisine difuz ettiği ve testere dişlisine benzer kesit morfolojisi oluştuğu görülmektedir. Borun varlığı enerji dağılım x-ışını spektrometresi (EDX) ile de ispatlanmıştır. Bunun yanında, borlama sıcaklığın artmasıyla bor tabaka kalınlıklarının da arttığı tespit edilmiştir. Mikrosertlik değerleri incelendiğinde en yüksek sıcaklıkta borlanan numunenin en yüksek sertlik değerine sahip olduğu ve borlama sıcaklığının düşmesiyle beraber sertlik değerlerinin azaldığı tespit edilmiştir. Benzer sonuçlar borlama süresiyle ilgili olarak da görülmüştür. En yüksek mikrosertlik ve tabaka kalınlığı değerleri 6 saatlik borlama sonucunda elde edilmiştir. Ayrıca, borlanmış numunelerin yüzeyden iç kısımlara doğru gidildikçe sertlik değerlerinin düştüğü görülmüştür.

1. INTRODUCTION

Surface hardening is a primary method for enhancing certain mechanical properties of materials. Processes, such as carburizing, nitriding, and boriding, have been widely used to improve the materials' surface properties. In general, these processes are more cost-effective than replacing machinery components with ones made from pricier materials [1]. Boriding is a thermochemical reaction based on the diffusion of boron into the substrate material, forming a hard surface coating consisting of mixed boron compounds [2-5]. Due to its relatively small atomic radius, boron can easily diffuse into various materials such as steels, non-ferrous alloys, and some superalloys [6-8]. The boriding process of the samples is carried out by heating them in the temperature range of 973 K to 1323 K for 0.5 hours to 12 hours [9-11]. Depending on boriding parameters and the chemical composition of the material, the diffusion of boron atoms leads to the formation of iron and metallic borides in the material [12-14]. When it is sufficiently applied to the surface, high hardness values provide valuable wear, corrosion and heat resistance [15-17]. Boriding can be performed by various methods such as solid, liquid, gas, plasma, and past0 e[11, 12, 14, 18-20]. Among these, pack boriding is carried out using commercial boriding material containing BC_4 KBF_4 and SiC (Ekabor) [18]. This method is the most commonly used boriding method due to its simplicity and ease of applicability without requiring post process surface cleaning [15, 18, 20, 21]. Depending on the concentration of diffused boron atoms, the boride layer usually forms as tetragonal Fe_2B (8 wt% B) and/or orthorhombic FeB (16 wt% B) [20-22]. Generally, while the FeB phase has higher hardness, the Fe_2B phase exhibits better toughness [4, 20, 21].

High-speed steels are commonly used in milling cutters, reamers, taps, broaches, saw teeth, drill bits, strip saws, and guide production [23-25]. The selected M42 high-speed steel is known for its high toughness due to its 8% cobalt content. Additionally, due to the cobalt in its structure, it stands out as an ideal material in lathes used for processing aluminum and alloys, brasses, automatic steels, and drilling punches requiring high temperature and wear resistance [23-26]. In this study, the effect of boriding temperature and time on the structural and mechanical properties of M42 steel was investigated by boriding the steel at 900°C, 950°C, and 1000°C for 4 hours, and additionally at 950°C for 2, 4, and 6 hours.

2. MATERIAL AND METHOD

In this study, M42 steel, chemical composition of the steel is provided in Table 1, with dimensions of Ø12.5 x 10 mm was utilized. The surfaces of the test specimens were polished using SiC abrasive papers of 80, 150, 360, 500, 800, and 1200 grit sizes, respectively. The boriding process was carried out using commercial Ekabor II powder with the pack boriding method. The samples were placed in a cylindrical stainless-steel crucible containing Ekabor II powder. The furnace was heated to 900°C, 950°C, and 1000°C, respectively, before placing the crucible, and the samples were borided in a preheated furnace for 4 hours. Additionally, to determine the effect of boriding time, samples were borided at 950°C for 2, 4, and 6 hours. Subsequently, they were allowed to cool to room temperature. Thereafter, to determine the thickness of the boride layer, the borided samples were cut in half, polished using SiC papers followed by 3 µm and 1 µm diamond suspensions, and then etched in a 5% Nital solution after cleaning with alcohol. The etched samples were examined using a scanning electron microscope (SEM) (ZEISS EVO LS 10) to determine the thickness of the boride layer. Additionally, the elemental composition of the samples was determined using energy-dispersive X-ray spectroscopy (EDX) method. The phase structure of the borided samples was analyzed in the range of 30° to 90° using X-ray diffraction (XRD) (GNR Europe 600 XRD). XRD studies were performed with parameters of 40kV and 15mA. CuKα radiation with a wavelength of 1.542 Å was used to identify the phases. Microhardness measurements were conducted using the Vickers method under a load of 100 g and at intervals of 20 µm. At least 5 measurements were taken, and the average value was calculated.

3. RESULTS AND DISCUSSION

SEM images of the cross-sections of M42 steels subjected to boriding at 900°C, 950°C, and 1000°C for 4 hours are shown in Figure 1, while SEM images of the cross-sections of M42 steels subjected to boriding at 950°C for 2, 4, and 6 hours are provided in Figure 2. The EDX results of M42 steel borided for 2, 4, and 6 hours at 950°C are given in Table 2. The thickness of the boride layers which were determined by evaluating of SEM images, are presented in Table 3. Upon examining the thickness of the boride layers based on the boriding duration was found as 28.1 µm, 47.5 µm, and 52.5 µm for 2, 4, and 6 hours, respectively. Additionally, thickness of boride layer of M42 steel which was borided at 900°C, 950°C, and 1000°C for 4 hours, was measured as 29.7 µm, 47.5 µm, and 71.4 µm, respectively. It is observed that as the boriding temperature and time increase, the thicknesses of the boride layers also increase, with the highest thickness reached at 4 hours of boriding at 1000°C. Moreover, the boriding layers exhibit a morphology resembling sawtooth, which can be attributed to the diffusion of boron atoms into the base material. In addition, the EDX results that shows boron rates (weight %) increased from 8.72 to 10.77, confirm the diffusion of boron. As indicated, with increasing temperature and time, the diffusion rate increases, leading to an increase in boride layer thicknesses [2-6].

Table 1. Chemical composition of M42 steel

C	Mo	Co	Cr	W	V	Si	Mn
1.1	9.2	8	4	1.5	1.1	0.5	0.2

Table 2. EDX results obtained from the cross-sectional surface of M42 steel borided for 2, 4, and 6 hours at 950°C

Element	Weight %			Atomic %		
	2 h	4 h	6 h	2 h	4 h	6 h
B	8.72	9.98	10.77	27.88	29.46	31.82
C	11.74	10.32	9.2	31.18	27.45	26.48
V	1.46	1.31	1.3	0.91	0.89	0.82
Cr	3.5	3.32	3.54	2.15	2.04	2.29
Fe	47.73	52.73	54.09	27.27	30.15	32.6
Co	5.74	5.8	6.1	3.11	3.15	3.49
Mo	15.5	11.6	8.63	5.16	3.86	3.11
W	4.36	4.15	3.76	0.76	0.72	0.69

Table 3. The boride layer thickness values obtained from borided M42 steel at different temperature and time

Boriding temperature (°C)	Boriding time (hour)	Boride layer thickness (µm) (±1%)
900	4	29.7
950	2	28.1
950	4	47.5
950	6	52.5
1000	4	71.2

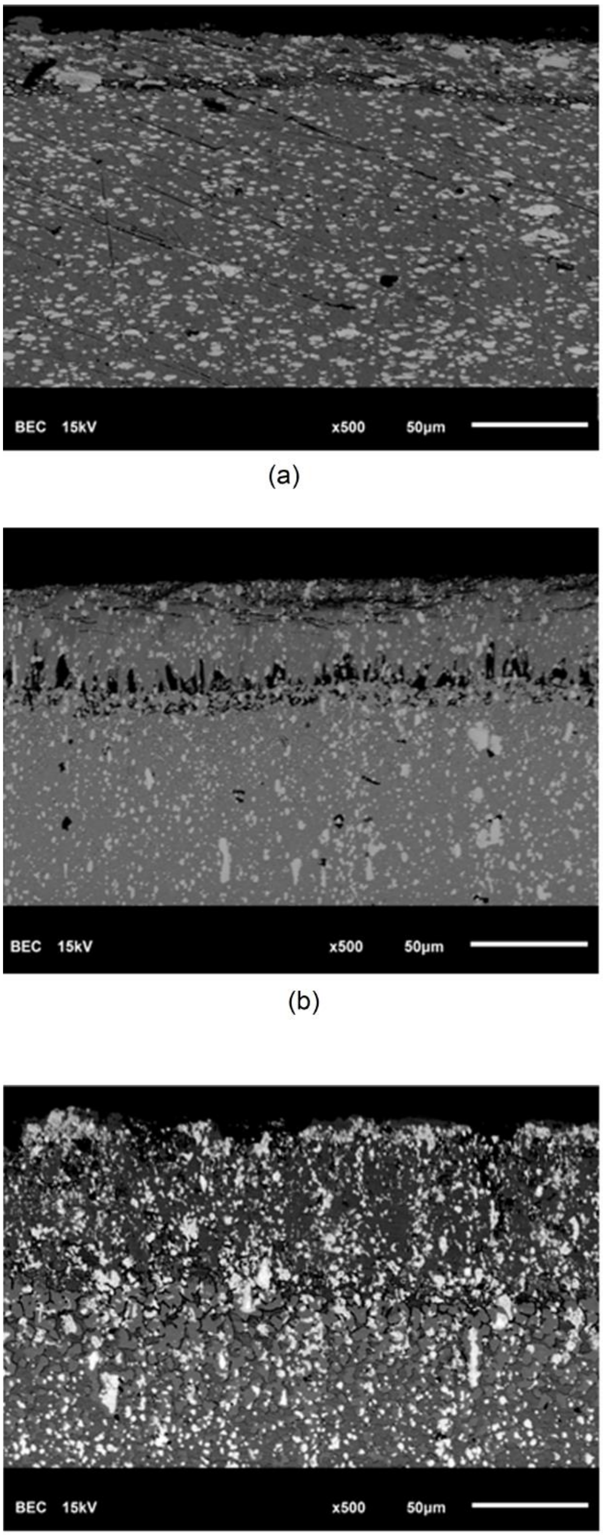

Figure 1. SEM images of M42 steel borided at (a) 900°C, (b) 950 °C and (c) 1000°C for 4 hours

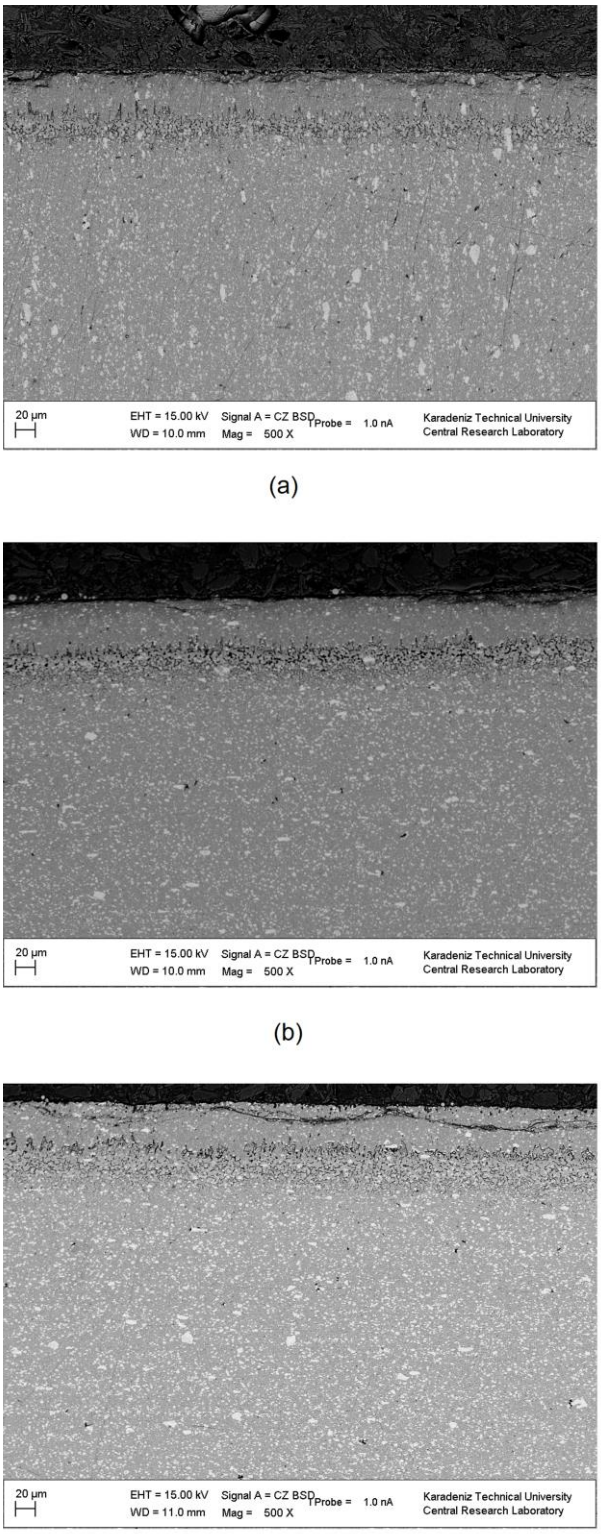

Figure 2. SEM images of M42 steel borided at (a) 2 hours, (b) 4 hours and (c) 6 hours at 950°C.

The XRD results of the untreated M42 steel and the M42 steel borided at 950°C for 4 hours are provided in Figure 3. The XRD indicates that the boride layers consist of FeB and Fe2B phases as shown in Figure 3b. Generally, while the FeB phase is harder than the Fe2B phase, it has lower toughness, making its presence undesirable. Since, it can deform more easily and lead to fracture and spalling under high loads due to its brittleness [2]. Furthermore, the presence of the FeB phase on the surface also reduces corrosion resistance [3]. To prevent the formation of FeB phase, the chemical composition of the boriding powder, boriding temperature and time should be selected appropriately for the material to be borided.

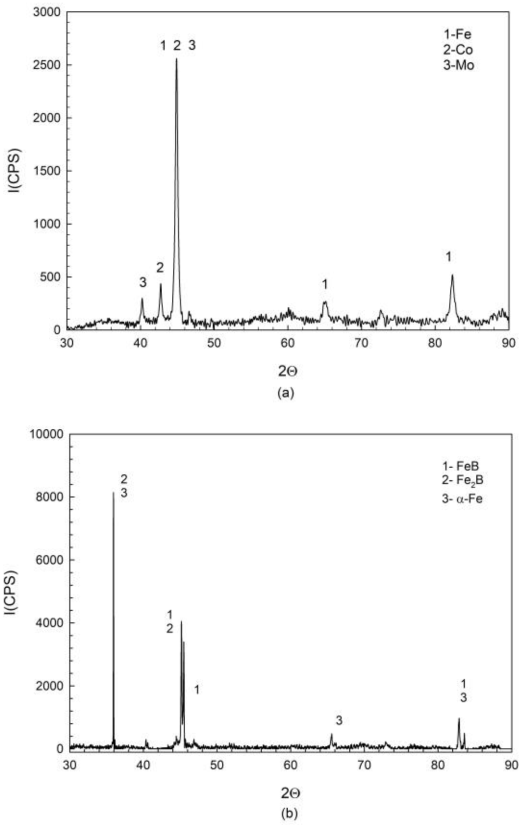

Figure 3. XRD results of M42 steel under conditions of (a) untreated and (b) borided at 950°C for 4 hours.

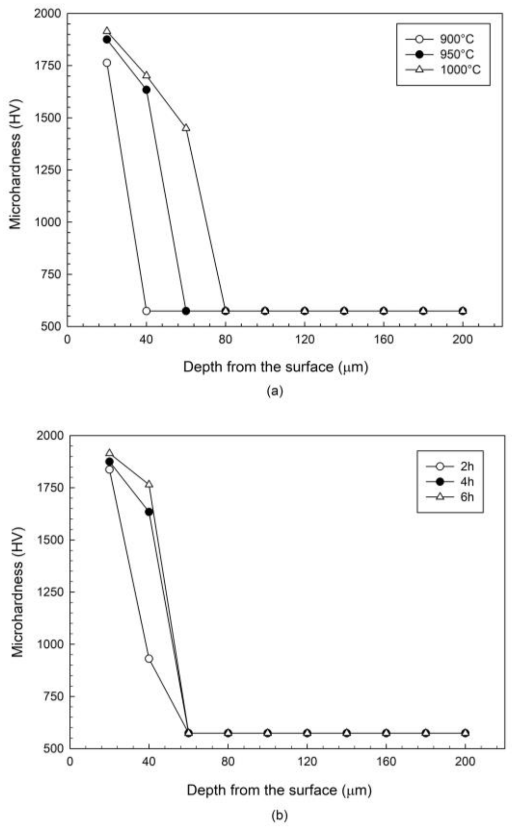

Figure 4 The cross-sectional microhardness values varying with the depth for M42 steel for (a) 4 hours at different temperatures and (b) 950° for different durations

The curves showing the variation of microhardness values, obtained from cross section of borided M42 steel, at different temperatures and time with depth are given in Figure 4. The hardness values of the borided layer range from 930 HV to 1914 HV. As can be seen in Figure 4, the hardness values of the borided samples decreased as depth increases from the surface towards the interior. Additionally, it is noted that the hardness of the boride layer formed on the surface increased with the increase of boriding temperature and time.

4. CONCLUSION

The phase structure, thickness boride layer, and microhardness values of M42 high-speed steel subjected to boriding at different temperatures for 4 hours and at varying time at a constant temperature were investigated. It was found that as the boriding temperature increased, the thickness of the layer increased from 29.7 µm to 71.2 µm, and as the boriding time increased, it increased from 28.1 µm to 52.5 µm. Additionally, in the EDX analysis of borided M42 steel at different times, the Boron element ratio increased from 8.72% to 10.77%. The structural analysis of the same sample also indicated the formation of FeB and Fe_2B phases as a result of the boriding process. It was concluded that boron diffused into the M42 steel, and the diffusion depth incresed with increasing temperature and time and as a result of this surface hardness increased.

Acknowledgement

This study was financially supported by the Scientific Research Projects Unit of Giresun University under project number FEN-BAP-A-240222-23.

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