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Research Article

Magnetic Properties of Borided Co-Cr-Mo Alloy

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Abstract

The magnetic properties of a borided Co-Cr-Mo alloy were studied in this work. The boron process was performed by the powder pack method with Ekabor HM and Ekabor III boron sources at 1123 and 1323 K for 9 h. The magnetic properties were characterized with a vibrating sample magnetometer (VSM). The results show that the non-magnetic Co-Cr-Mo alloy has a low magnetization with the boriding process. In addition, the saturation magnetization (Ms) varies with the boron source and temperature.

Keywords: Co-Cr-Mo alloy, saturation magnetization, magnetic behavior, boriding, boron source

Borlanmış Co-Cr-Mo Alaşımının Manyetik Özellikleri

Öz

Bu çalışmada borlanmış bir Co-Cr-Mo alaşımının manyetik özellikleri incelenmiştir. Bor işlemi, Ekabor HM ve Ekabor III bor kaynakları ile 1123 ve 1323 K'de 9 saat boyunca toz paket yöntemiyle gerçekleştirildi. Manyetik özellikler, titreşimli bir numune manyetometresi (VSM) ile karakterize edildi. Sonuçlar, manyetik olmayan Co-Cr-Mo alaşımının borlama işlemiyle düşük mıknatıslanmaya sahip olduğunu göstermektedir. Ayrıca manyetik doygunluk (Ms) bor kaynağına ve borlama sıcaklığa göre değişir.

Anahtar Kelimeler: Co-Cr-Mo alaşımı, manyetik saturasyon, manyetik davranış, borlama, bor kaynağı

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1. Introduction

Co-Cr-Mo alloy is widely used as orthopedic implant material because it has properties such as high impact and fatigue resistance [1,2]. Meanwhile, when used as an artificial joint implant material, this alloy shows low friction properties and low corrosion resistance due to corrosive body fluid and is subject to wear in a short time [3]. Therefore, a surface coating is applied to the Co-Cr-Mo alloy surface to improve corrosion and wear resistance. Regarding this, Cuao-Moreu et al. [4] showed that the wear resistance of the borided Co-Cr-Mo alloy is higher than that of the untreated Co-Cr-Mo alloy due to the high surface hardness of the boron compounds such as CoB and Co2B in the boride layer. In addition, it has been shown that the presence of CoB–Co2B and Co2B layers on the borided Co-Cr-Mo alloy increases bio-tribocorrosion resistance approximately 2.4 and 1.3 times compared to the unborided Co-Cr-Mo alloy, respectively [5].

An important issue is what kind of changes the increase in the mechanical and tribological properties of materials with the boriding process causes in the magnetic properties of the materials. Generally, studies on the magnetic properties of materials are focused on the effect of thermal properties on magnetic properties [6], the relationship between mechanical and magnetic properties [7], the magneto-structural characteristics of obtained magnetic nanoparticles [8], etc. These studies show that magnetic properties are strongly dependent on microstructure, particularly crystallite size, particle morphology, and structural defects. On the other hand, it has been observed that studies in the literature to investigate the effect of boriding on magnetic properties are limited. In a study conducted by Akkurt et al. [9] on AISI 316L austenitic stainless steel, they observed that boriding not only improved the shielding properties of AISI 316L austenitic stainless steel, but also increased the Ms of this steel. On the contrary, Ekinci [10] found that the boriding process decreased the magnetic saturation in Fe-Ni alloy due to the formation of boride and/or silicide phases with lower magnetic moments. In this study, it will be investigated whether Co-Cr-Mo alloy, which normally has non-magnetic properties, exhibits magnetic properties with the boriding process. Additionally, if it has magnetic behavior, the relationship of this behavior with the boron source and boriding temperature will be examined.

2. Materials and Methods

The chemical composition (wt.%) of the samples of commercially available Co-Cr-Mo alloy used in this study is Co (65%), Cr (30%) and Mo (5%). The solid boriding method was chosen for the boriding process, and Ekabor3 and Ekabor HM commercial powders were used as boron sources. The boriding process was carried out under a controlled atmosphere containing argon gas flow in two different temperature environments, 1123 and 1323 K, and in a furnace environment for 9 hours. Afterwards, the samples whose boriding process was completed were cooled in the oven under a controlled atmosphere. Before microstructural analysis, the polished samples were etched with macroetchant (30 mL HCl, 15 mL HNO3, 30 mL HF). Boride phases formed on the surfaces of borided samples were determined by SEM and XRD analyses. A vibrating sample magnetometer (VSM) was used to determine the magnetic properties of Co-Cr-MO alloy boronized with different time and boron sources. Measurements were made at room temperature and within a magnetic field range of ±7 Tesla. From the measured values, M-H graphs were drawn using the masses of the sample.

3. Results and Discussion

Co-Cr-Mo alloy is a non-magnetic material. For this reason, this alloy has a very low mass magnetic susceptibility of 7×4π·10−9m3/kg. [11] (The mass susceptibility yields the magnetic moment (or magnetization) per kilogram of material when multiplied by the magnetic field.) In this study, the curves of magnetization (M(H)) measurements due to the magnetic field of Co-Cr-Mo alloy borided with two different boron sources is given in Figure 1. When looking at this graph, the hysteresis loops obtained as a function of boriding source and temperature are clearly visible, as in ferromagnetic materials. However, a low maximum magnetization called saturation magnetization (Ms) was obtained (Fig.1).

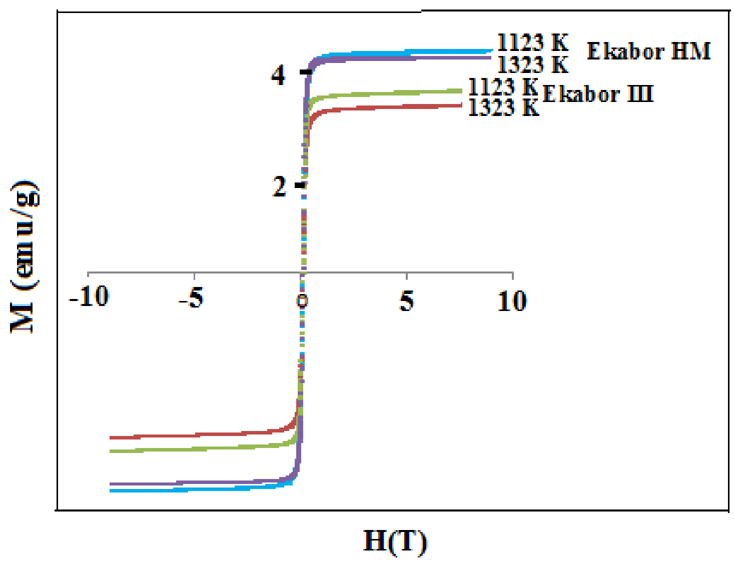

Figure 1. The magnetization of Co-Cr-Mo alloy after boriding process

We think that the M(H) curves seen in Figure 1, which are specific to ferromagnetic materials, are also observed in the non-magnetic Co-Cr-Mo alloy in this study (even if Ms is small), probably due to the boron phases (CoB and Co2B) formed by the boriding process. Co2B phase was formed predominantly in the boride layer. (Fig.2). In literature, it has been shown that the Co_2B phase has strong ferromagnetic behavior.

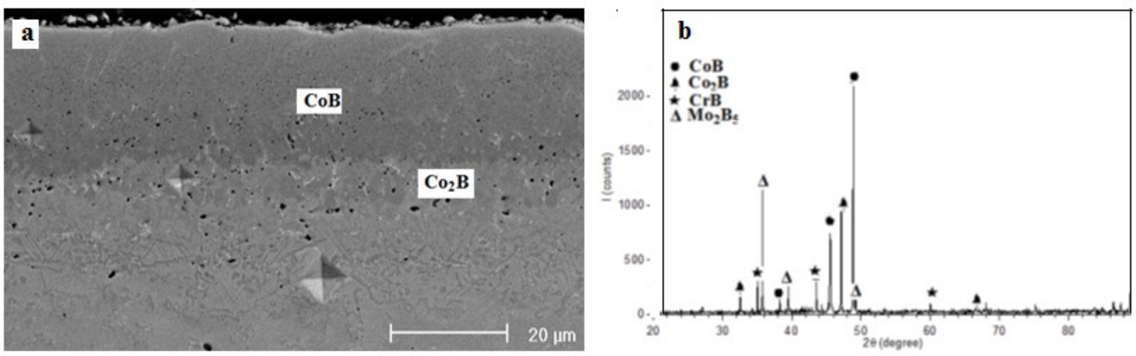

Figure 2. Microstructure of Co-Cr-Mo alloy borided at 1123 K for 9 h (a) and XRD patterns of Co-Cr-Mo alloy borided at 1323 K-9 h (b).

From Fig. 1, we see that the Ms of the Co-Cr-Mo alloy borided with ekabor HM is higher. The Ms attains its maximum value of 4.3 emu/g in Ekabor HM, after which decrease 3.4 emu/g for Ekabor III at 1123 K. The reason for this can be shown by the ferromagnetic Fe atoms in Ekabor

HM (Table 1). In addition, the biggest impact comes from particle size. In many studies, it has been pointed out that Ms values increase with decreasing particle size. In our study, the particle size of Ekabor HM was smaller than that of Ekabor III. These values are <100 µm and <1400 µm for Ekabor HM and Ekabor III, respectively [12].

Table 1. Chemical composition of Ekabor HM and Ekabor III (Weight%)

	B	O	N	Fe	Si	K	F	Ca
Ekabor HM	68.19	1.58	12.65	0.32	11.82	1.27	3.87	0.19
Ekabor III	57.49	7.51	--	--	31.70	0.90	2.42	--

Another important point on Figure 1 is that, while the boriding temperature of Co-Cr-Mo alloys borided with both Ekabor III and Ekabor HM increases, the Ms values decrease slightly. In the literature [10,13-15], it has been pointed out that Ms depends on composition as well as structural changes and the resulting phase. In the first stages of the boriding process (at low boriding temperatures), as mentioned in Ref. [16], the first product formed by B diffusion during boriding of the Co-Cr-Mo alloy is Co2B, which thermodynamically always has the lowest mole fraction. With increasing B diffusion on the Co2B surface, Co2B turns into CoB (Fig. 2.a). With increasing boriding temperature, the phases (CrB and Mo2B5) other than CoB and Co2B are formed, as seen in Fig. 2.b. We think that the movement of the magnetic domains is obstructed by these phases in the boride layer. Thus, Ms decreases with increasing boriding temperature. Another reason for the decrease in Ms is probably the strong interaction of internal forces and defects with the magnetic domain walls. It is well known that the most important microstructural changes are atomic displacements that cause defects and internal stresses in the later stages of the boriding process [17-19]. Corresponding to this, the relationship between B concentration and Ms is stated in a study by Luo et al. [20] on the Ni50Mn36.5Sb13.5xBx alloy. He showed in his detailed study that since the atomic radius of B is smaller, the increasing amount of B shortens the distance between Mn atoms in the structure. This strengthens the antiferromagnetic coupling between Mn atoms. Consequently, increasing B concentration reduces Ms.

4. Conclusion

In conclusion, while Co–Cr–Mo alloys have been used as superalloys in a broad spectrum of applications that require high strength, oxidation resistance, and wear resistance, this alloy exhibits a small amount of magnetization behavior with the boriding process. At the same time, this behavior seems to depend on the boron source and boriding temperature.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

Osman İyi: Designing the study, performing the calculations, evaluating the results
Adnan Çalık: Designing the study, performing the calculations, evaluating the results,
Nazım Uçar: Evaluating the results, writing the article.

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