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Effect of Oxidation Time on Wear Behaviour of Thermally Oxidized CoCrMo Alloy

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CoCrMo alloy,
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Thermal oxidation,
Process time

Abstract: CoCrMo alloy has been oxidized for 3 and 5h at the temperature of 850°C with 100% O_2 gas by thermal oxidation. The XRD, SEM, microhardness and ball-on-disc wear test devices were used to find out the structure, mechanical and wear properties of untreated and treated specimens. Outcomes showed wear resistance of oxidized specimens were became better than untreated CoCrMo alloy. Also, wear resistance of oxidized specimens improved with increased processing time (from 3h to 5h) increased.

Termal Olarak Oksitlenmiş CoCrMo Alaşımının Aşınma Davranışı Üzerine Oksidasyon Süresinin Etkisi

Anahtar Kelimeler
CoCrMo alloy,
Aşınma özellikleri,
Termal oksidasyon,
İşlem süresi

Özet: CoCrMo alaşımı, %100 O_2 gazı ortamında, 850°C'de, 3 ve 5 saat süre ile termal oksitlenmiştir. İşlemsiz ve işlem görmüş numunelerin yapısal, mekanik ve aşınma özelliklerin tespit edilmesi için XRD, SEM, mikro sertlik ve pim-disk aşınma test cihazları kullanılmıştır. Sonuçlar, oksitlenmiş numunelerin aşınma dirençlerinin, işlem görmemiş CoCrMo alaşımından daha iyi olduğunu göstermiştir. Ayrıca, oksitlenmiş numunelerin aşınma dirençleri, işlem süresi arttıkça (3 saatten 5 saate kadar) artmıştır.

1. Introduction

Biomaterials are used for various applications in a numerous of areas of the human body. Particularly, CoCrMo alloys are generally preferred for joint prosthesis [1, 2]. However, wear and corrosion in body fluid will create metal debris and ion release for CoCrMo alloy implants. This case can cause to some problems such as, inflammation, poisoning etc. Therefore, there are many surface treatments to minimize this effect. Thermal oxidation is one of these techniques and it has some advantages such as, require less expensive equipment and not need high skills person to operate this process [3, 4]. Therefore, the favourable advantages of thermal oxidation on wear and electrochemical feature of metallic biomaterials in the scientific literature was seen. Çimenoğlu et al. [5] indicated that thermal oxidation may considerably improve triblogical properties of Ti alloys. Kumar et al. [6] pointed out that thermal oxidation is useful method to improve corrosion resistance of titanium. Arslan et al. [7] demonstrated that tribological features of pure titanium increased as an oxide layer was created with thermal oxidation Shih et al. [8] investigated that influence of thermal oxidition method on corrosion properties of 316L stainless steel. They found that the treatments improved the corrosion resistance of specimens. Ayu et al. [9] reported that thermal oxidation method improved corrosion resistance in cobalt chromium molybdenum alloys. However, there are no enough works dealing influence of oxidation time on tribological features of CoCrMo Alloy in scientific literature. Hence, in our study we observed the effect of process time on wear behaviour of thermally oxidized CoCrMo alloy. The structural of untreated and oxidized CoCrMo Alloys were analyzed by X-ray diffractometer and Scanning Electron Microscopy. Tribological behaviour of untreated and oxidized specimens were carried out using pin on disk type tribo-tester.

2. Methodology

The materials used in this study were forged low carbon (LC) CoCrMo alloy. Its nominal chemical composition is 27.4 % Cr, 5.7% Mo, 0.62% Mn, 0.67% Si, 0.1% Ni, 0.17% Fe, 0.05 %C and balance (wt.%) Co. Specimens with 14-mm diameter and 6 mm thick were cut from this alloy bar. First, specimens were polished using SiC abrasive papers with 80–1000 followed by mirror polishing. Second, their surfaces

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were cleaned in ethanol. Thermal oxidation of the specimens was performed at the temperature of 850°C for 3h and 5h with 100% O_2 in a muffle furnace at normal atmospheric condition. X-ray diffractometer was operated with CuKa radiation for phase analysis. Thickness of oxide layers was observed by scanning electron microscope (SEM). The tribological experiments were examined on a ball-on-disc tester (Bruker UMT). 6 mm diameter Al_2O_3 balls were utilized as pin. Wear tests were investigated with a sliding distance of 141 m at 25°C and at normal load of 2 N. The wear volume values of specimens were calculated using Bruker Contour GT-K1 3D profilometer. Furthermore, afterwards the wear experiments the wear tracks were observed by SEM.

3. Results and Discussion

Figure1 displays phase structures of untreated and oxidized CoCrMo alloys as detected by XRD. Diffraction pattern of untreated specimens exhibits f_{cc} α-(CoCrMo) peaks.

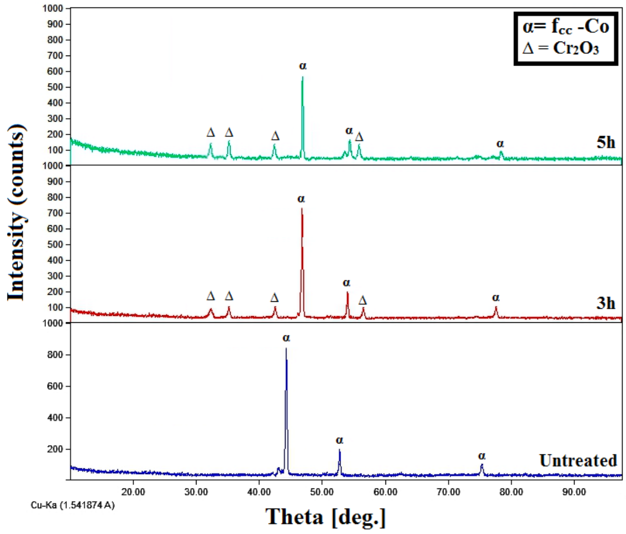

Figure 1. The XRD patterns of untreated and oxidized surfaces

After the oxidizing process, it was seen that the chromium oxide phases were dominant in the microstructure of specimens owing of the fact that chromium atoms have higher affinity to oxygen atoms than to cobalt atoms. At high time (5 hour), the required activation energy of atoms to form oxide is more than that at low time. Therefore, the intensity of oxide phases increased at the specimens that were treated for 5 hour. SEM micrograph of cross-section of oxidized CoCrMo alloys are illustrated in Figure 2.

According to Figure 2, while the lowest oxide layer thickness was obtained from the oxidized samples for 3h, the highest surface layer thickness was obtained from the oxidized samples for 5h. When the process time increased, film thickness also increased with increasing diffusion process (Table 1). The surface hardness values measured from the untreated and oxidized samples are given in Table 1. The microhardness of untreated CoCrMo alloy was measured as 430$HV_{0.1}$, while the highest hardness value was obtained from the samples oxidized for 5h as 1690 $HV_{0.1}$.

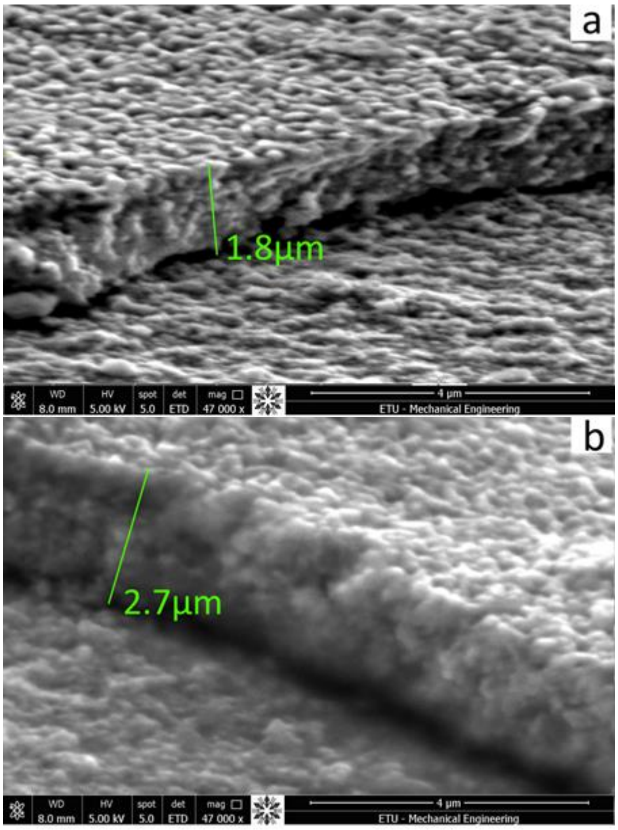

Figure 2. Cross-section SEM imagines of oxidized surfaces (a) 3h and (5)

Tablo 1. Surface hardness and layer thickness of untreated and thermally oxidized CoCrMo alloys

Treatment time (hour)	Layer thickness (µm)	Surface hardness $HV_{0.1}$
3	1.8	1250
5	2.1	1690
untreated	-	430

The increment in surface hardness was owing to formed Cr_2O_3 phase on the surface of CoCrMo alloys after thermal oxidation process. It was also seen that when the treatment time increased, the microhardness values increased due to more oxide phase intensity and thicker oxide layer thickness. The coefficients of friction (COF) of untreated and oxidized specimens are illustrated in Figure 3 for dry conditions.

According to Figure 3, the increment in COF values was observed at the initiation of the wear tests because of Hertzian contact, afterwards, these values were more balanced owing to reduction of roughness for all of specimens. It is seen that the COF value is about 0.71 for the untreated specimen in Figure 3. After thermal oxidation treatment under different process times, the COF of CoCrMo alloys diminished. This decrease is associated with hard oxide layer and oxide layer thickness. Because thick and hard oxide layer ensure preferable load bearing cases for preventive tools and the existence of hard oxide layer lead to increasing the abrasion resistance of surface and reducing plastic deformation in contact between two surfaces [10].

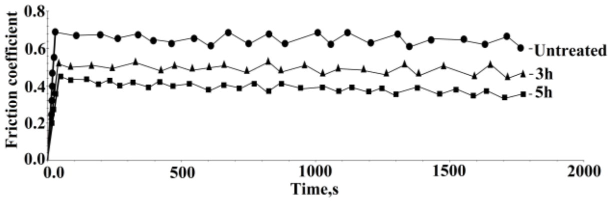

Figure 3. The coefficients of friction of untreated and of oxidized surfaces

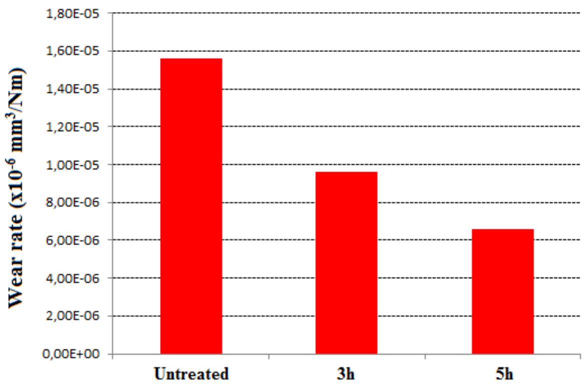

Figure.4 Wear rate of untreated and of oxidized surfaces

Figure 4 shows wear rates of untreated and oxidized specimens. According to results, the thermal oxidation process decreased the wear rate of CoCrMo alloy. Low wear rate of the all oxidized specimens can be ascribed to hard Cr_2O_3 phase, high surface hardness and low friction coefficients compared to untreated specimen. When the treatment time increased, growth of Cr_2O_3 peaks and increment in surface microhardness were observed and the wear rate of oxidized CoCrMo alloy diminished. In Figure 5 the SEM images of wear tracks of specimens are displayed. In Figure 5a, plate-like debris and excessive plastic deformation in the wear scars have been clearly approved that the untreated specimen have exhibited adhesive wear under dry condition. As the wear tracks of untreated and oxidized specimen are investigated, it may be seen that the width of wear tracks diminished after thermal oxidizing process. Also, the narrowest wear tracks were formed on oxidized specimens for 5h (Figure 5c). It is seen that width of the wear track decreased with increasing treatment time. Excellent wear resistance of the treated oxidized samples for 5h may be attributed to its hard Cr_2O_3 layer, film thickness and low coefficients of friction.

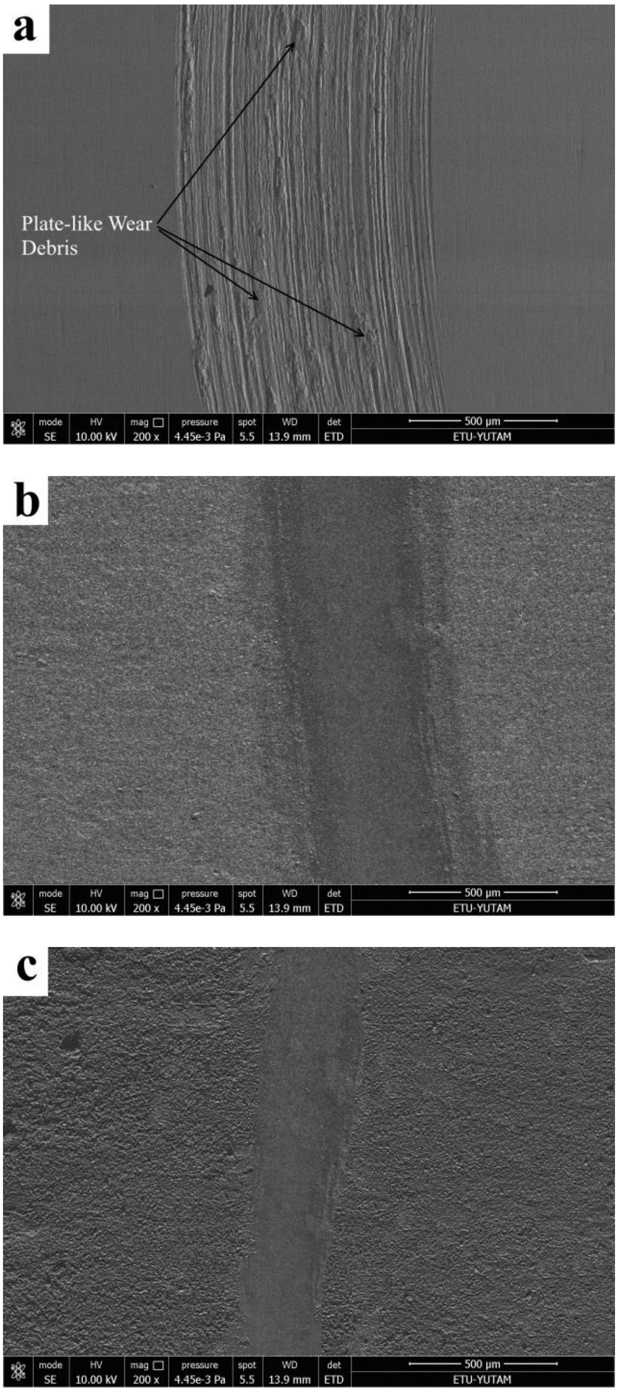

Figure.5 SEM images of wear tracks of (a) untreated and of oxidized surfaces (b) 3h and (c) 5h

4. Conclusion

Thermal oxidation was successfully was performed to CoCrMo alloy substrates at 850°C for 3h and 5h. The XRD results indicates that the Cr_2O_3 phases were observed from oxidized specimens. Also, intensity of the phases increased with increasing the treatment times. The applied surface process improved the surface microhardness of CoCrMo alloy. It was concluded the thickness and surface hardness of oxide films increased by increasing treatment time. Wear test results under dry conditions showed the improvement in wear resistance of thermal oxidated specimens in comparison with untreated specimens. Moreover, wear resistance of thermal oxidated

CoCrMo alloy specimens increased with increment of the treatment time.

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