

Article

Effect of Co-Coated Al_2O_3 Composite Powders on LPBF-Manufactured CoCrMo Alloy

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Abstract: In this study, we systematically examined the influence mechanisms of introduced cobalt coated alumina (Co-coated Al_2O_3) particles on the microstructure and properties of cobalt-chromium-molybdenum (CoCrMo) alloy printed by Laser Powder Bed Fusion (LPBF). The Co-coated Al_2O_3 composite powders with different density of cobalt coating were prepared by varying Al_2O_3 load from 1 g/150 mL to 2 g/150 mL during the electroless plating process. Then they were mixed with CoCrMo powders in the proportion of 1 wt.% and formed standard samples by LPBF technology. The results showed that the addition of Co-coated Al_2O_3 particles improved the friction performance of CoCrMo alloys significantly. The wear depth of CCM@2 Al_2O_3 was only 2.18 μm and the wear volume of it was about 10% of pure CoCrMo alloy. The CoCrMo alloy introduced the Co-coated Al_2O_3 particles with a 1 g/150 mL Al_2O_3 load formed metal-ceramic bonding interface, which solved the problem of poor wettability between Al_2O_3 and matrix in LPBF process. Such CoCrMo alloy exhibited excellent tensile properties and the mean microhardness of it reached $379.9 \pm 3.5 \text{ HV}_{0.5}$.

Keywords: alumina; cobalt-chromium-molybdenum alloy; electroless plating; friction performance; implants; Laser Powder Bed Fusion



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1. Introduction

In recent years, Additive Manufacturing (AM) has attracted significant attention as a type of novel and continuously expanding technology [1,2]. Laser Powder Bed Fusion (LPBF), an additive manufacturing process, is widely used to manufacture orthopedic implants [3,4]. The combination of CAD technology in LPBF makes the implants more accurate and easier to meet the requirements of personalized medicine [5–9]. It is generally known that the most-used metallic biomaterials in LPBF-manufactured implants are titanium alloys, Cobalt-chromium (CoCr) alloys, and stainless steel [10,11]. And CoCr alloys plays an irreplaceable role in orthopedic implants due to excellent mechanical properties and biocompatibility [12–16]. However, the service time of the artificial knee joints is limited because of the abrasion during movement, and the second operation is often required [17]. Additionally, more young and active patients are using artificial knee joints, and they have higher requirements for the wear resistance of implants [18].

Therefore, a great focus of researches have been put into improving the wear resistance of LPBF-processed CoCr alloys. Li et al. [19] carried out three kinds of heat treatments on CoCrMo alloys respectively, finding that the friction performance of aging-treated alloys at moderate temperatures (450 °C to 750 °C) had been improved. Balagna et al. [20] prepared the coating of tantalum carbide on the surface of CoCrMo alloys by molten salts, and the existence of the coating reduced the friction coefficient. However, this method did not control the thickness of the coating and was not suitable for personalized medicine. Isik et al. [21] used two premix raw powders (CoCrMo + 2 wt.% tricalcium phosphate and CoCrMo + 2 wt.% tricalcium phosphate + 4 wt.% Al_2O_3) to surface coat the CoCr alloy

via Laser Engineered Net Shaping. This method improved the wear resistance of CoCr alloys, but the inherent limitation of coatings was that they introduced discontinuities in mechanical properties at the interface of the alloy matrix.

Some scholars proposed to enhance the wear resistance of LPBF-processed CoCr alloys by improving the properties of powder feedstocks. Liu et al. [22] pointed out that it was a very effective method to improve the friction performance by adding high wear resistance powder to the matrix powder for parts fabricated by LPBF technology. The bioceramics such as Al_2O_3 , zirconium dioxide (ZrO_2) and silicon nitride (Si_3N_4) are usually used for the modification of metallic biomaterials [23–25]. Among them, Al_2O_3 is the preferred ceramic because of its excellent mechanical properties and wear resistance [26–30]. Gu et al. [31] prepared Al-based composites reinforced by Al_2O_3 particles using LPBF technology, which exhibited superior friction performance. However, insufficient wettability between Al and Al_2O_3 led to plenty of defects such as interfacial microcracks and interface separation [32]. Li et al. [33] proposed the method of producing MMC powder through electroless plating, successfully preparing Ni/ Al_2O_3 composite powder and the composite powder was suitable for LPBF forming. Cao et al. [34] prepared Ni- Al_2O_3 particles with a core-shell structure by electroless plating, and successfully fabricating CoCrMo alloys with different amounts of Ni- Al_2O_3 particles by LPBF process. They found that the increase of Ni- Al_2O_3 content helped to improve the wear resistance of the alloys. The composite containing 1 wt.% Ni- Al_2O_3 particles achieved the highest microhardness and the most stable coefficient of friction. However, the effect of Ni- Al_2O_3 powder prepared by different electroless plating processes on the properties of composite was not explored. Moreover, the introduction of Ni- Al_2O_3 particles increased nickel content in the CoCrMo alloys, which made the implants easier to release Ni ions during wear and tear. Nickel was a harmful element to humans because it could cause a biological allergy [35].

In order to improve the application of modified CoCrMo alloys in orthopedic implants, Al_2O_3 powder was coated with nontoxic cobalt layer using the electroless plating process. Moreover, the melting point of cobalt is close to that of CoCrMo alloy, so the cobalt layer helped the wetting of Al_2O_3 particles by matrix alloy. Importantly, the effect of Co-coated Al_2O_3 composite powders with different coating quality on the microstructure and properties of these CoCrMo alloys were explored.

2. Materials and Methods

2.1. Materials

Commercially available CoCrMo powders produced by Guangzhou Nalian Co., Ltd. (Guangzhou, China) were used in this study, and their chemical composition is listed in Table 1. The SEM micrograph, Figure 1a, shows the spherical morphology of the CoCrMo powder particles having uniform size. The average size of CoCrMo powders was 26 μm . The Al_2O_3 powders used in electroless plating were produced by Jiyuan Ceramic Material Co., Ltd. (Jiyuan, China). The smooth surface of as-received Al_2O_3 (Figure 1b) was conducive to coating the cobalt layer during electroless plating process. And Figure 2 shows the schematic representation of electroless Co plating and LPBF process.

Table 1. Chemical composition of CoCrMo powder (wt.%).

Co	Cr	Mo	Si	Fe	N	O	C
66.53	26.81	5.72	0.69	0.11	<0.1	<0.1	<0.01

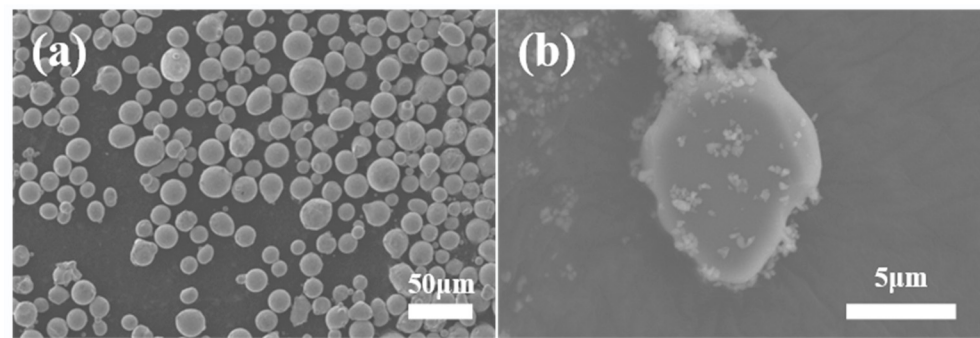


Figure 1. SEM images of powders: (a) CoCrMo powder; (b) Al₂O₃ powder.

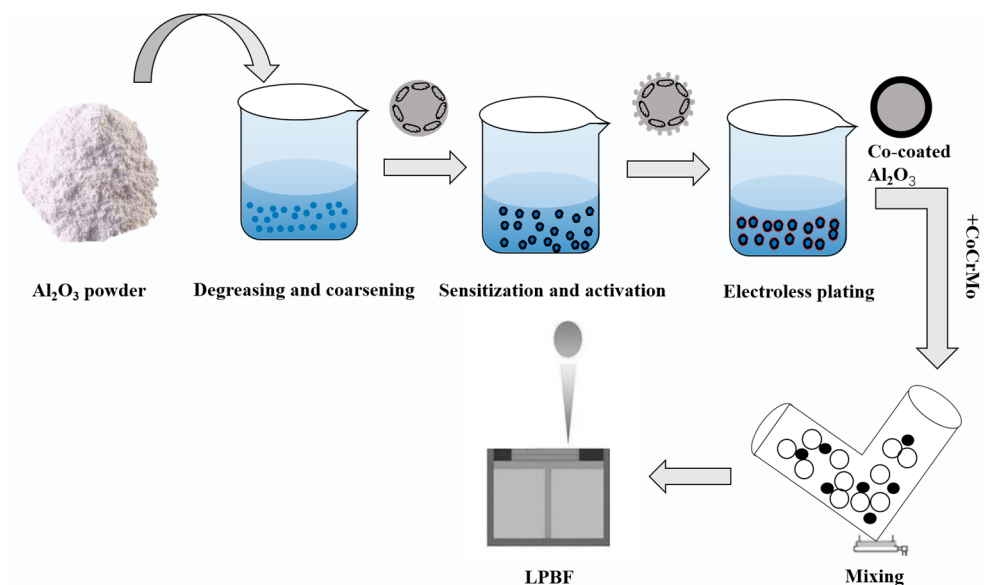


Figure 2. Schematic representation of electroless Co plating and LPBF process.

2.2. Fabrication Procedure

2.2.1. Electroless Plating

In the process of electroless plating, the Al₂O₃ powders were pretreated before putting into the plating solution. First of all, the raw powders were placed in 5 mol/L NaOH solution for degreasing, and then coarsened with HCl solution. The coarsened Al₂O₃ powders needed to be sensitized and activated successively. The sensitization solution was SnCl₂ solution (20 g/L), and the concentration of PdCl₂ activation solution was 0.5 g/L. The above four steps required magnetic stirring of the solution for 20 min.

The pretreated Al₂O₃ powders were placed in a plating beaker immersed in a 66 °C water bath and stirred for 30 min. The composition of the plating solution is listed in Table 2, consisting of the main salt (CoSO₄·7H₂O), reducing agent (N₂H₄·H₂O), stabilizer agent (C₄H₆O₆), complexing agent (EDTA), and pH regulating agent (NaOH). These chemicals were produced by Chengdu Colon Chemicals Co., Ltd. (Chengdu, China). This process was mainly the reaction of reducing agent and cobalt salt, and the equation of chemical reaction was shown in Equation (1). The plating solution and Al₂O₃ powders were separated by centrifugation, and subsequently the powders were dried in a vacuum for 2 h to get Co-coated Al₂O₃ composite powders.

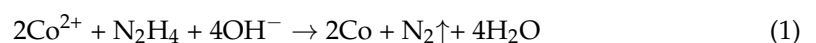


Table 2. Chemical composition of the plating solution.

$\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$ (g/L)	$\text{N}_2\text{H}_4 \cdot \text{H}_2\text{O}$ (ml/L)	$\text{C}_4\text{H}_6\text{O}_6$ (g/L)	EDTA (g/L)	NaOH (mol/L)
35	30	10	8	5

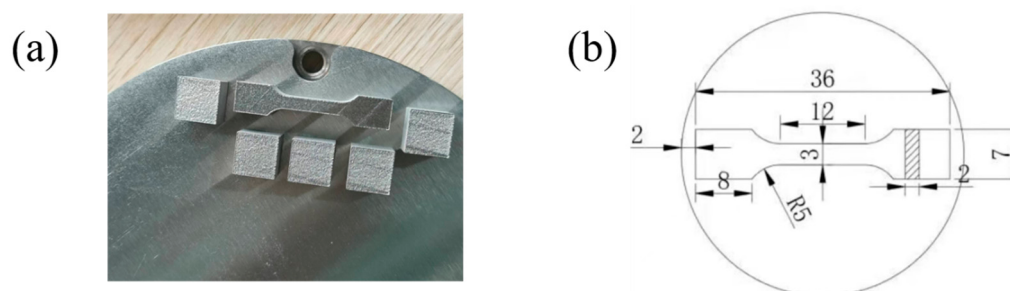
The powder load had an important influence on the properties of the coating during electroless plating [36]. There were more powder particles in the same volume of plating solution when the powder load was large, so the surface coating density of a single powder particle decreased. In this study, the powder load was expressed by the ratio of the Al_2O_3 weight to the volume of the plating solution. Co-coated Al_2O_3 composite powders with Al_2O_3 load of 1 g/150 mL, 1.5 g/150 mL and 2 g/150 mL were prepared respectively. The amount of Al_2O_3 added to CoCrMo alloy was selected as 1 wt.% according to previous studies [34], so the Co-coated Al_2O_3 composite powders were mixed with CoCrMo powders in a mass ratio of 1:99 by V-type mixer (WKA-100, Qingzhou Madsen Co., Ltd., Qingzhou, China). The mixer ran for 6 h at a speed of 200 RPM.

2.2.2. LPBF process

The pure CoCrMo alloy (CCM) and the CoCrMo alloys containing Co-coated Al_2O_3 particles were prepared by LPBF on an E-PLUS 150 machine (Beijing E-Plus 3D Tech. Co., Ltd., Beijing, China), and the process was carried out on the 316 L stainless steel baseplate at the deposition conditions in Table 3. 10 mm × 10 mm × 10 mm blocks (Figure 3a) were fabricated to analyze the microstructure and properties, which longitudinal section was parallel to the building direction. The tensile samples were formed according to the dimensions shown in Figure 3b. In this paper, the CoCrMo alloys containing Co-coated Al_2O_3 particles were named CCM@1 Al_2O_3 , CCM@1.5 Al_2O_3 and CCM@2 Al_2O_3 respectively, corresponding to the Al_2O_3 load of 1 g/150 mL, 1.5 g/150 mL and 2 g/150 mL during electroless plating process (these names were used in the following discussion).

Table 3. LPBF process parameters.

Laser Power	Scan Speed	Layer Thickness	Scan Spacing
120 W	760 mm/s	30 μm	80 μm

**Figure 3.** (a) LPBF-processed samples; (b) outline drawing of tensile samples.

Phase identification was conducted by X-ray diffraction (XRD) using the Dutch X'Pert high resolution three-dimensional diffraction system. Microstructure and energy spectrum analysis of Co-coated Al_2O_3 composite powders were carried out with a JSM-7900F scanning electron microscope (JEOL, Japan). The LPBF-processed samples used for SEM were cut, ground and polished according to standard procedures and etched with a solution consisting of HNO_3 (10 mL) and HCl (30 mL) for 10 s. Then, the longitudinal section of the samples was observed using a JSM-7900F scanning electron microscope. Prior to EBSD analysis, argon ion etching of the metallography surfaces was conducted to provide stress-free surfaces [37]. The Vickers hardness of samples was measured using

a microhardness tester (HV-1000B, Lanzhou Huayin Test Instrument Co., Ltd., Lanzhou, China) at a load of 4.9 N and an indentation time of 10 s. All samples were measured at 10 points in the cross section and final microhardness value was the average of these data. The tensile test was conducted at room temperature on a 3382 universal material testing machine (Instron, Norwood, MA, USA) at a tensile speed of 0.5 mm/min. The test process needed to measure the gauge length, thickness and width of the samples, and then clamped the samples to the machine. The friction and wear test were conducted with the HSR-2M reciprocating dry friction and wear testing machine (Lanzhou Zhongke Kaihua Technology Development Co., Ltd., Lanzhou, China) with a 3 mm silicon nitride friction pair. The machine applied a load of 5 N for 30 min at a speed of 500 RPM. Then the wear depth and wear volume of the samples were measured by the MT-500 probe type material surface abrasion tester (Lanzhou Zhongke Kaihua Technology Development Co., Ltd., Lanzhou, China).

3. Results

3.1. Co-Coated Al_2O_3 Composite Powder

3.1.1. Phase Analysis

Figure 4 shows XRD patterns of Co-coated Al_2O_3 composite powders. The main characteristic peaks were Al_2O_3 and Co in the patterns. The peaks of Co were detected at 41.68° , 44.76° and 47.57° respectively, which proved that Co was generated during electroless plating successfully. It was found that the diffraction peak height of Co was close to that of Al_2O_3 in the composite powder with 1 g/150 mL Al_2O_3 load, indicating that the Co phase accounted for a large proportion in the composite powder. However, the intensity of Co peak gradually decreased with an increase of Al_2O_3 load. Because the Al_2O_3 load went up, there were more Al_2O_3 particles in the same volume of plating solution, resulting in less Co deposited on each Al_2O_3 particle. Notably, the peak of Co_3O_4 appeared at 36.84° in the patterns. The reason was that a small amount of cobalt salt generated into $\text{Co}(\text{OH})_2$ under the joint action of the reducing agent and the complexing agent in the plating solution. $\text{Co}(\text{OH})_2$ decomposed into Co_3O_4 under the condition of rapid heat release during electroless plating process [38,39].

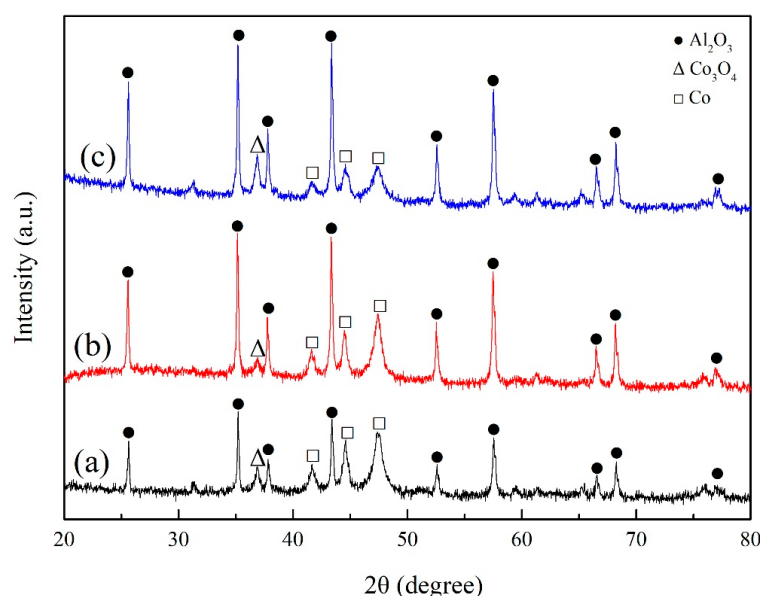


Figure 4. XRD patterns of Co-coated Al_2O_3 composite powders prepared by different Al_2O_3 load: (a) 1 g/150 mL, (b) 1.5 g/150 mL and (c) 2 g/150 mL.

3.1.2. Morphology Analysis

Figure 5 illustrates the morphological images of Co-coated Al_2O_3 composite powders. As shown in the low magnification maps (Figure 5(a1–c1)), the surface of the composite powders showed the flocculent coating compared with the raw Al_2O_3 powders, and all particles were coated successfully. The specific powder particles were selected for further observation (Figure 5(a2–c2)). The composite powder with Al_2O_3 load of 1 g/150 mL also had excess cobalt in addition to forming a cobalt coating, which was different from the other two powders. The cobalt coatings of different Co-coated Al_2O_3 particles were observed at higher magnification (Figure 5(a3–c3)). It was found that the Co-coated Al_2O_3 particle with 1 g/150 mL Al_2O_3 load presented a dense cobalt coating, while the cobalt coatings of the other two powders had pores. The porosity of cobalt coating increased with the enhancement of Al_2O_3 load. The reason was that less cobalt deposited on the surface of Al_2O_3 when the composite powder was prepared with a larger Al_2O_3 load, and it led to a decrease in the density of cobalt coating.

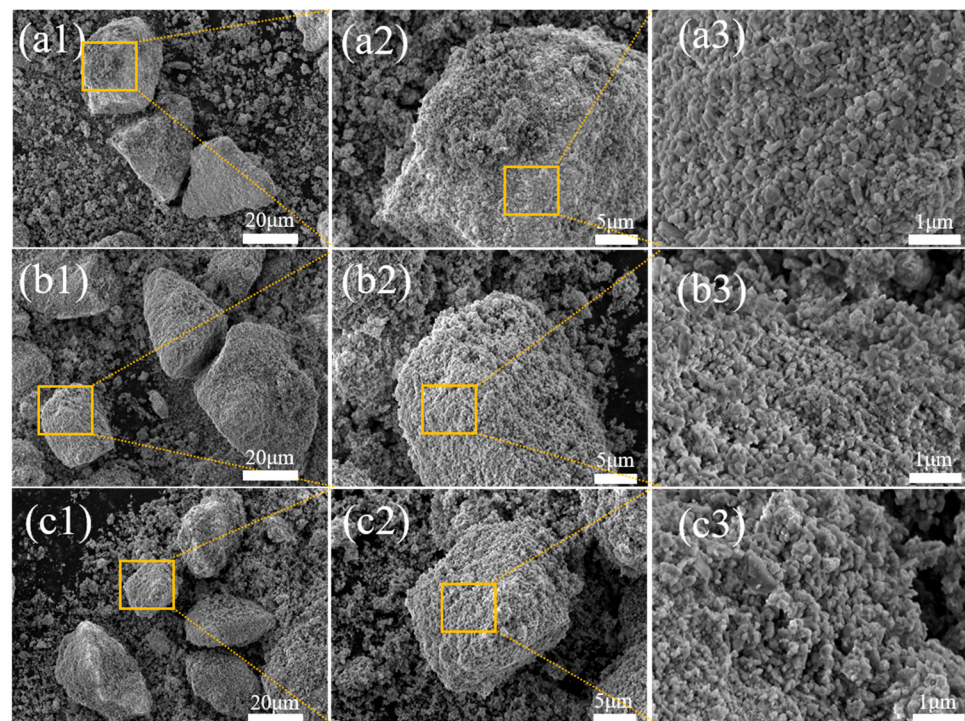


Figure 5. SEM images of Co-coated Al_2O_3 composite powders prepared by different Al_2O_3 load: (a1–a3) 1 g/150 mL, (b1–b3) 1.5 g/150 mL and (c1–c3) 2 g/150 mL.

Figure 6 shows the EDS results of Co-coated Al_2O_3 composite powders. It was found that the main elements detected in the powders were O, Al and Co, which proved that the flocculent coating of the composite powders was Co. The cobalt coating of Co-coated Al_2O_3 particle with 1 g/150 mL Al_2O_3 load was completely detected. And the content of Co decreased with the increase of Al_2O_3 load. The Co-coated Al_2O_3 particle with 2 g/150 mL Al_2O_3 load even had a partially missing of cobalt coating, because its cobalt coating was the loosest.

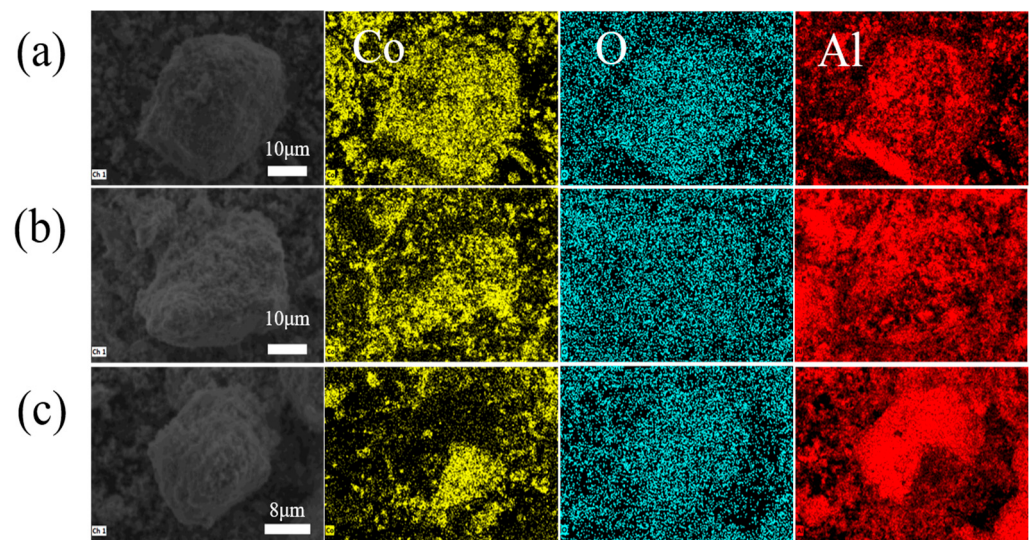


Figure 6. EDS of Co-coated Al_2O_3 composite powders prepared by different Al_2O_3 load: (a) 1 g/150 mL, (b) 1.5 g/150 mL and (c) 2 g/150 mL.

3.2. LPBF-Processed Parts

3.2.1. Microstructural Morphology

Figure 7 shows the cross-section microstructure of four CoCrMo alloys fabricated by LPBF. By observing the low magnification maps (Figure 7(a1–d1)), it was found that all samples were dense and no obvious pores appeared. The number of Co-coated Al_2O_3 particles increased in CoCrMo alloys with the enhancement of Al_2O_3 load. As can be seen from (Figure 7(a2–d2)), CoCrMo alloys exhibited a typical fish scale melting trajectory, and the lamellar semi-ellipse observed in the figure was the boundary of the molten pool [40]. Such molten pool morphology is typical of the longitudinal section for LPBF-processed parts [41]. All molten pools in the corresponding figure were measured and final molten pool depth of the alloy was the average of these data. The results showed that the molten pool depth of CCM, CCM@1 Al_2O_3 , CCM@1.5 Al_2O_3 and CCM@2 Al_2O_3 were 47.24 μm , 35.24 μm , 34.88 μm and 32.68 μm respectively. It was found that molten pool of the CoCrMo alloys containing Co-coated Al_2O_3 particles was shallower than CCM. Because the temperature exceeded 1500 $^\circ\text{C}$ during LPBF process [42]. The laser acted on the Al_2O_3 after melting the cobalt coating when it scanned the Co-coated Al_2O_3 particles. However, the absorptivity of Al_2O_3 is only 0.173 [43], which is far lower than that of CoCrMo [42]. The formed powders containing the Co-coated Al_2O_3 particles got less energy in LPBF process, so the molten pool depth of these CoCrMo alloys decreased.

Figure 7(a3–d3) presents the SEM images at higher magnification. It was found that the LPBF-processed parts showed conventional columnar and equiaxial dendrites. The metal-ceramic bonding interface was formed in CCM@1 Al_2O_3 , which may have a favorable effect on the alloy. But no similar phenomenon was observed in CCM@1.5 Al_2O_3 and CCM@2 Al_2O_3 , there were defects around the Al_2O_3 particles. Because thicker Co-coating of Al_2O_3 particles have helped particles wettability by the matrix alloy while when the Co content (thinner coatings) was low, the Al_2O_3 particles could not form strong bond with the matrix.

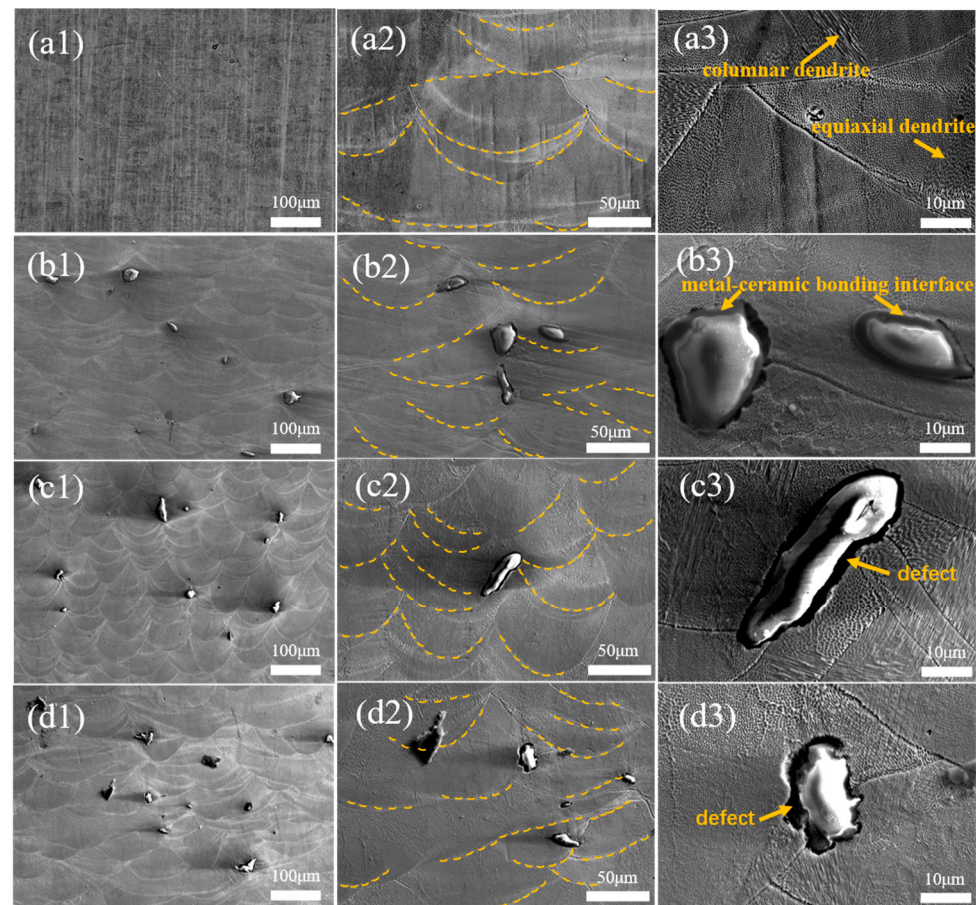


Figure 7. SEM images of longitudinal section for the LPBF-processed parts: (a1–a3) CCM, (b1–b3) CCM@1Al₂O₃, (c1–c3) CCM@1.5Al₂O₃ and (d1–d3) CCM@2Al₂O₃.

3.2.2. Phase Analysis

Figure 8 depicts the XRD patterns of the LPBF-processed parts obtained over a wide range of 2θ (40–100°). The diffraction peaks of ϵ (hcp)CoCrMo and γ (fcc)CoCrMo were identified clearly. However, the CoCrMo alloys containing Co-coated Al₂O₃ particles did not show the diffraction peaks of Al₂O₃, as the amount of Co-coated Al₂O₃ particles was only 1 wt.% in alloys. This phenomenon also occurred in other metal-matrix ceramic composites [44]. By comparing the relative intensity of peaks, it was found that the γ peaks strength of the CoCrMo alloys containing Co-coated Al₂O₃ particles were lower than that of CCM. The reason was that the addition of Al₂O₃ reduced the cooling rate of alloys [45]. The γ phase was stable at high temperatures, and the reduction of the cooling rate was conducive to the conversion of γ phase to ϵ phase [46]. The cooling rate of CCM@1Al₂O₃ was the fastest in three CoCrMo alloys containing Co-coated Al₂O₃ particles, because the metal-ceramic bonding interface played an auxiliary role in the heat conduction of Al₂O₃. And the other two alloys had relatively slow cooling rate, in which the heat transfer of Al₂O₃ depended on dissipation. The cooling rate of CCM@2Al₂O₃ was faster than that of CCM@1.5Al₂O₃, because the cobalt coating of Co-coated Al₂O₃ particles in CCM@2Al₂O₃ had more pores to dissipate heat. Finally, the intensity of the γ diffraction peaks of CCM@1.5Al₂O₃ was the weakest in them.

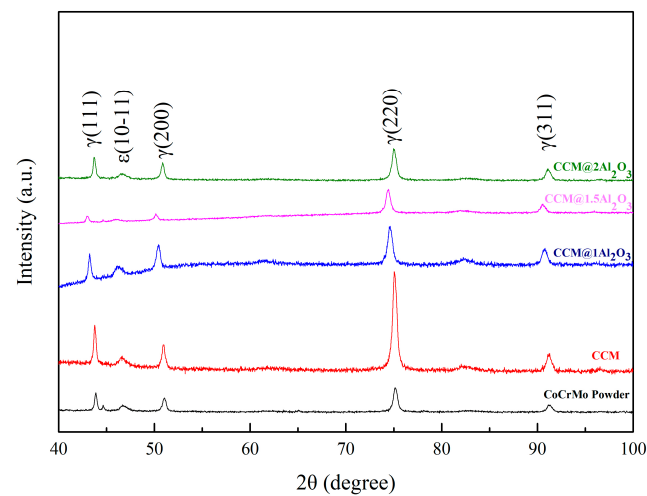


Figure 8. Phase analysis results measured by XRD.

3.2.3. Kernel Average Misorientation (KAM)

Figure 9 presents the KAM of longitudinal section for the LPBF-processed parts. The results showed that all samples retained large strain due to the very high cooling rate and repeated layer stacking during LPBF process. KAM analysis of the CoCrMo alloys containing Co-coated Al_2O_3 particles showed lower residual stresses, higher concentration of blue regions, than that of CCM, indicating that these samples had less stored energy [47]. Because they were formed at a relatively low cooling rate, more energy was consumed during the cooling process. At the same time, the KAM could reflect the dislocation density of alloys. And the KAM of CCM@1.5 Al_2O_3 was the lowest by comparing the intensity of the ribbon, revealing the lowest dislocation density in this sample.

3.2.4. Friction Performance

Figure 10 shows the wear tracks of the CoCrMo alloys. It was found that all samples exhibited similar shape of the wear tracks. The maximum wear depth and wear volume obtained in the test were analyzed statistically (Figure 11). The wear depth of CCM was the largest among all samples, reaching $9.2665\mu\text{m}$. The Co-coated Al_2O_3 particles significantly reduced the wear depth of the CoCrMo alloys. The wear depth of the CoCrMo alloys containing Co-coated Al_2O_3 particles decreased gradually with the increase of Al_2O_3 load. The wear volume was another important parameter reflecting wear resistance of materials. It was found that the wear volume showed a similar trend to the wear depth, and the wear volume of CCM@1 Al_2O_3 was only about 50% of CCM. These two groups of data showed that the addition of Al_2O_3 substantially enhanced the wear resistance of CoCrMo alloy fabricated by LPBF [21]. And CCM@2 Al_2O_3 showed the most excellent friction performance. Because the composite powder prepared using a large load contained a small proportion of cobalt in Co-coated Al_2O_3 particles. The density of Co is about 2.5 times larger than that of Al_2O_3 , so the average density of Co-coated Al_2O_3 composite powder with a large load was low. As 1 wt.% of composite powders were mixed with CoCrMo powders for all samples, the number of Co-coated Al_2O_3 particles in CoCrMo alloys increased with the enhancement of Al_2O_3 load.

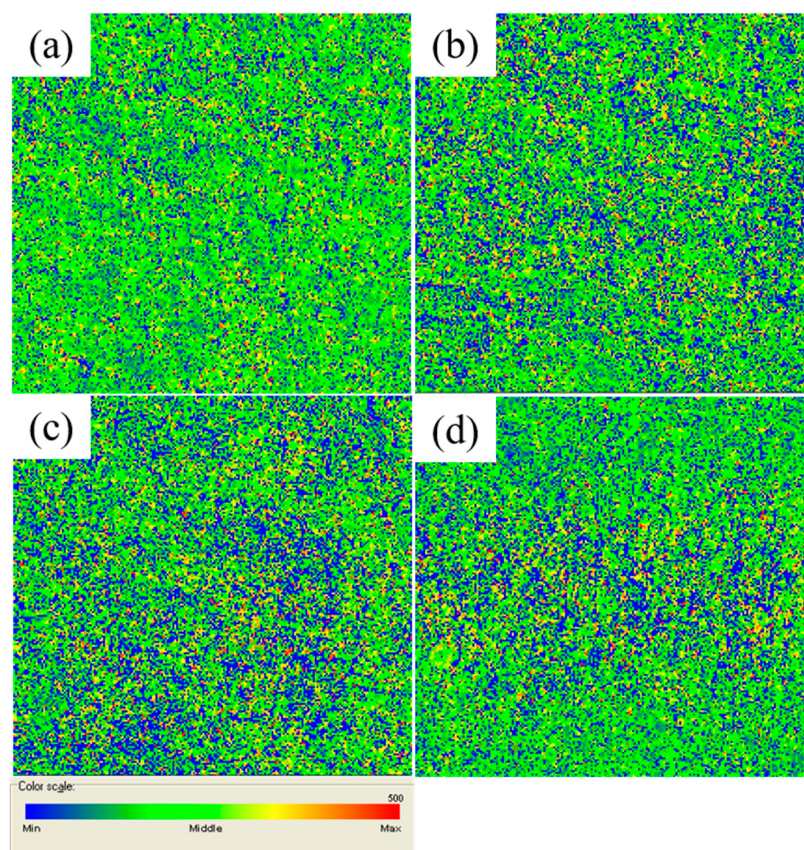


Figure 9. The KAM of longitudinal section for the LPBF-processed parts: (a) CCM, (b) CCM@1Al₂O₃, (c) CCM@1.5Al₂O₃ and (d) CCM@2Al₂O₃.

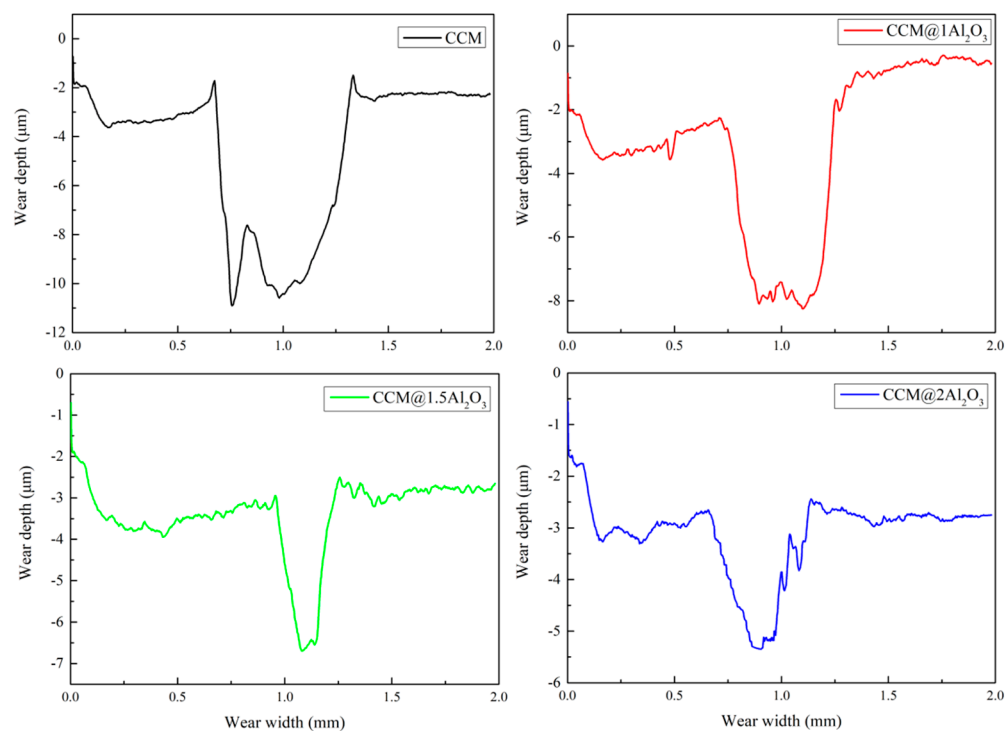


Figure 10. The wear tracks of the LPBF-processed parts.

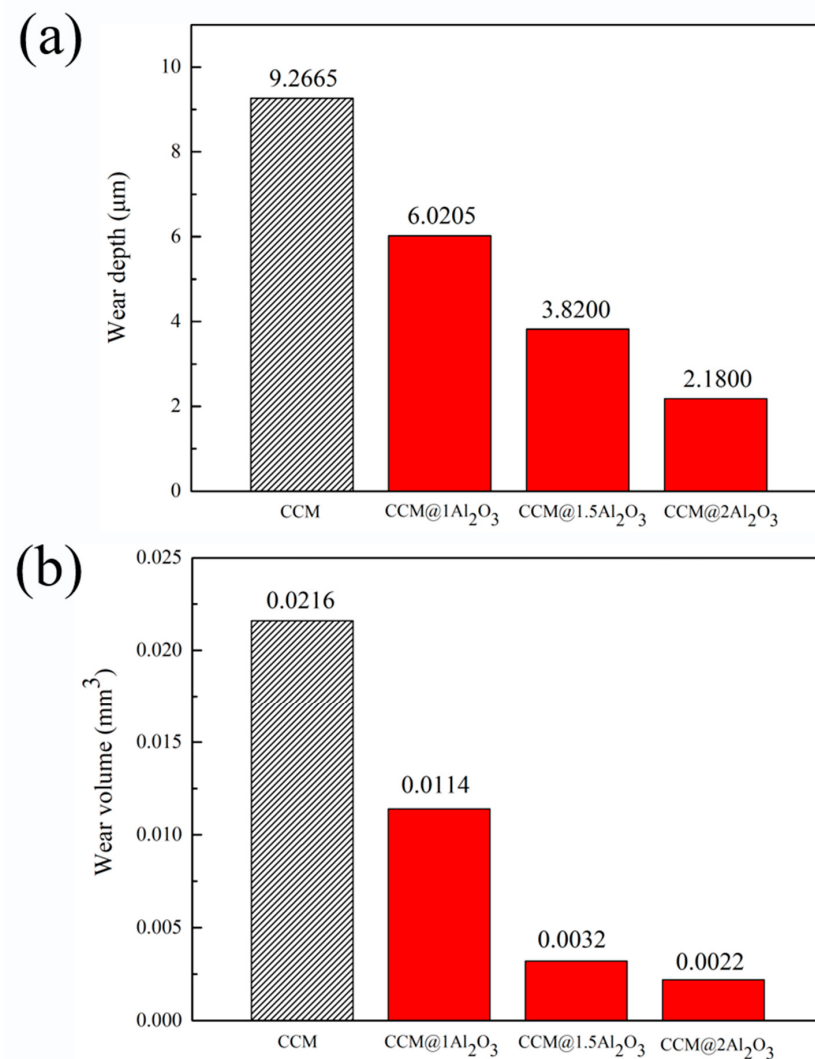


Figure 11. Friction data of the LPBF-processed parts: (a) wear depth; (b) wear volume.

3.2.5. Mechanical Property

Figure 12 shows the microhardness measured on LPBF-processed parts. The mean microhardness of CCM, CCM@1Al₂O₃, CCM@1.5Al₂O₃ and CCM@2Al₂O₃ were 358.5 ± 3.2 HV_{0.5}, 379.9 ± 3.5 HV_{0.5}, 373.1 ± 4.3 HV_{0.5} and 368.7 ± 3.7 HV_{0.5}, respectively. The high microhardness obtained at the CoCrMo alloys containing Co-coated Al₂O₃ particles indicated that the addition of Al₂O₃ enhanced the microhardness of CoCrMo alloys. On the one hand, Al₂O₃ existed in the CoCrMo alloys as the second phase particles, which had a dispersive strengthening effect on the alloys [48]. On the other hand, CoCrMo alloys containing Co-coated Al₂O₃ particles had more ϵ phase, contributing to the increase in microhardness [22]. The maximum mean microhardness was obtained at CCM@1Al₂O₃, due to the metal-ceramic bonding interface making the diffusion strengthening effect more significant. Although the XRD results showed that the content of ϵ phase in CCM@1Al₂O₃ was not the highest among all samples, the experiment indicated that the microhardness enhancement effect brought by the metal-ceramic bonding interface was stronger than the ϵ phase. However, the maximum average microhardness for the Al₂O₃ modified CoCr alloys was only 338.8 HV in the study of Hong [49], because the introduced Al₂O₃ particles were not treated by electroless plating.

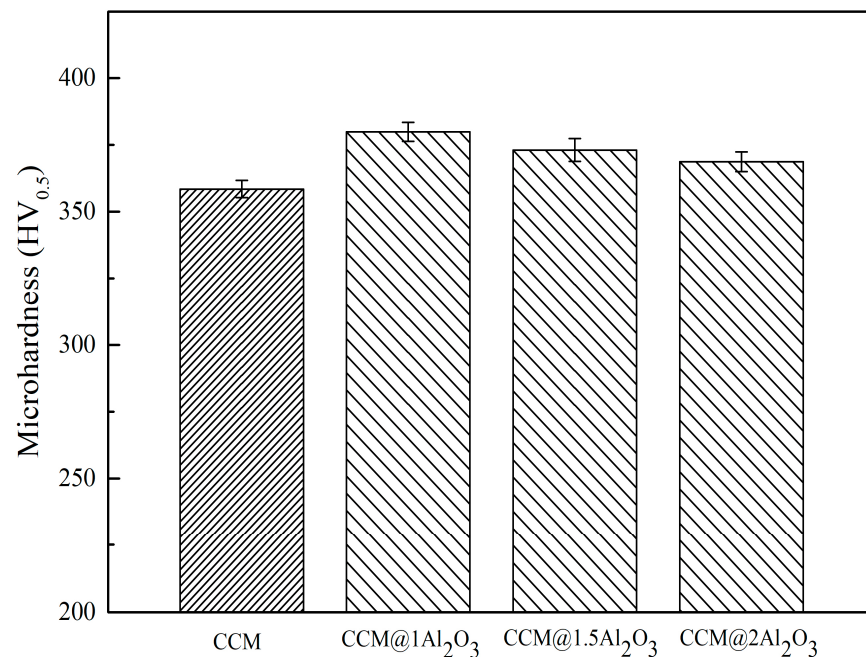


Figure 12. Microhardness of the LPBF-processed parts.

Figure 13 depicts the results of room-temperature tensile tests on the as-printed samples. The ultimate tensile strength (UTS) was directly measured by the standard tensile test, and the elongation was obtained by calculating the ratio of the displacement to the gauge length of the tensile samples (Table 4). It was found that the UTS of CoCrMo alloys containing Co-coated Al₂O₃ particles were lower than that of CCM, but all the values of UTS were higher than 665 MPa required in ISO 5832-4-2014. The decrease in strength of them was due to the relatively low dislocation density compared to CCM. It was well known that a high dislocation density can slow down the movement of the dislocation, which was beneficial to the strength. And the UTS of CCM@1.5Al₂O₃ was the minimum, because it showed the lowest dislocation density. In addition, defects also influenced the strength of composite materials [50]. The metal-ceramic bonding interface was formed in CCM@1Al₂O₃, which made it no defects around Al₂O₃ and contributed to the strength of the alloy. In terms of ductility, the increase of ϵ phase in CoCrMo alloys containing Co-coated Al₂O₃ particles led to the decrease of elongation, because the HCP structure of ϵ phase was not conducive to the crystal slip during the tensile process. The elongation of CCM@1Al₂O₃ was close to that of CCM, indicating the ductility of it was excellent.

Although comprehensive analysis showed that CCM@1Al₂O₃ were excellent in UTS and elongation, the values were still lower than that of CCM. Further researches were needed to improve the tensile properties of the LPBF-processed Al₂O₃ modified CoCrMo alloys.

Table 4. Tensile properties of the LPBF-processed parts.

Samples	UTS (MPa)	Elongation (%)
CCM	1191.46	41.01
CCM@1Al ₂ O ₃	1089.07	37.76
CCM@1.5Al ₂ O ₃	1050.07	25.47
CCM@2Al ₂ O ₃	1072.93	29.46

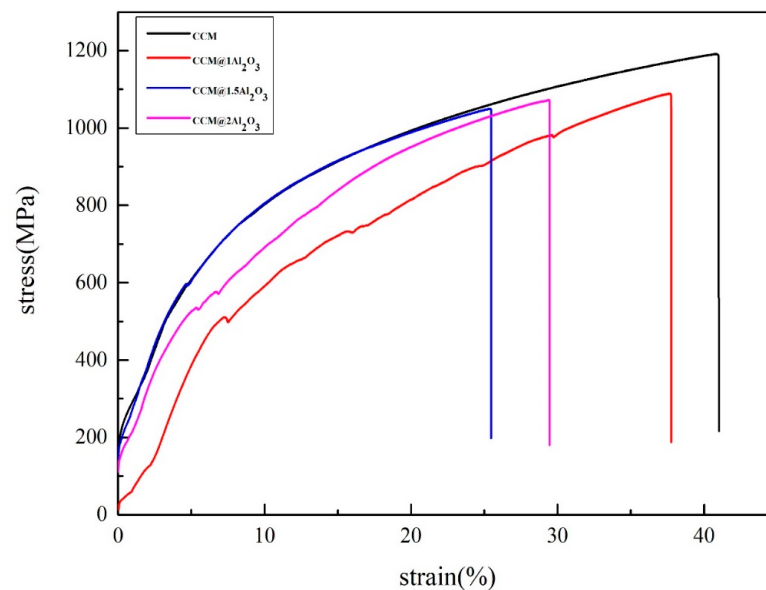


Figure 13. Stress-strain curves of the LPBF-processed parts.

4. Conclusions

To summarize, the effect of Co-coated Al_2O_3 composite powders prepared with different Al_2O_3 load on the microstructure and properties of LPBF-processed Al_2O_3 reinforced CoCrMo alloys were systematically investigated. According to SEM and EDS, the density of cobalt coating for the Co-coated Al_2O_3 composite powders decreased with the increase of the Al_2O_3 load in the electroless plating process. XRD patterns of LPBF-processed parts showed that the CoCrMo alloys containing Co-coated Al_2O_3 particles had more phase transitions from γ phase to ϵ phase. The ϵ phase was beneficial to microhardness of CoCrMo alloys but reduced the elongation of them. The wear depth of CCM@2 Al_2O_3 was only 2.18 μm and the wear volume of it was about 10% of CCM. The metal-ceramic bonding interface was formed in CCM@1 Al_2O_3 , which helped it maintaining excellent tensile properties. The mean microhardness of CCM@1 Al_2O_3 reached $379.9 \pm 3.5 \text{ HV}_{0.5}$, which was about 6% higher than CCM. However, more research is needed to optimize the friction and tensile properties of CoCrMo alloy at the same time in the future.

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