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Wear behaviors of HVOF sprayed WC-12Co coatings by laser remelting under lubricated condition

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ABSTRACT

A HVOF (high velocity oxygen fuel) sprayed WC-12Co coating was remelted with a CO_2 laser. The surface-interface morphologies and phases were analyzed by means of SEM (scanning electron microscopy), and XRD (X-ray diffraction), respectively. The friction and wear behaviors of WC-12Co coating under the dry and lubricated conditions were investigated with a wear test. The morphologies and distributions of chemical elements on worn scar were analyzed with a SEM, and its configured EDS (energy diffusive spectrometer), respectively, and the effects of lubricated condition on COFs (coefficient of friction) and wear performance were also discussed. The results show that the adhesion between the coating and the substrate is stronger after laser remetling (LR), in which mechanical bonding, accompanying with metallurgical bonding, was found. At the load of 80 N, the average COF under the dry and lubricated friction conditions is 0.069, and 0.052, respectively, the latter lowers by 23.3% than the former, and the wear rate under the lubricated condition decreases by 302.3% than that under the dry condition. The wear mechanism under the dry and lubrication conditions is primarily composed of abrasive wear, cracking, and fatigue failure.

1. Introduction

As one of the most widely used steel in the mold industry [1], H13 (i.e. 4Cr5MoSiV1) hot work mold steel has many advantages such as good toughness and thermal strength, thermal stability, antioxidant capacity and thermal fatigue, and etc., which is mainly used in the impact load of forging molds, hot extrusion mold, precision forging mold and pressure mold [2,3]. However, the H13 hot work mold steel is easily wore and failed during the usage [4,5], which is a research hotspot that how to improve wear resistance and prolong its service life [6,7]. Thermal sprayed WC-12Co coating has good wear resistance, high hardness and high temperature resistance [8,9], which has been widely used in many industrial fields. High velocity oxygen fuel (HVOF) has low flame flow temperature and high flame flow velocity characteristics [10–12], which reduces the decarburization and oxidation of sprayed WC powder particles, the coating-substrate combination after LR (laser remelting) was more closely [13,14]. However, researches on WC-12Co coating mainly focus on powder type [15,16], spraying process [17,18], microstructure [19], mechanical properties [20], and other fields, while the research on WC-12Co coating by LR is very little. Because the LR determines the distribution of surface-interface chemical elements and influences the wear resistance of the coating [21,22], the EDS analysis of chemical elements on the worn scars under the dry and lubricated conditions has not reported. In this study, a WC-12Co coating was sprayed on H13 hot work mold steel with a HVOF, and the obtained coating was processed with a LR. The morphologies of surface-interface and worn scar under the dry and lubricated conditions were analyzed by a SEM, and its configured EDS, respectively, which provided an experimental basis for the application of WC-12Co coating on the surface modification of H13 hot work mold steel.

2. Experimental

The substrate was H13 hot work mold steel with the mass fraction (mass, %) as follows: C 0.32–0.45, Si 0.80–1.20, Mn 0.20–0.50, Cr 4.75–5.50, Mo 1.10–1.75, V 0.80–1.20, S, P < 0.03 and the rest was Fe. Spraying powder was a DG type WC-12Co with the mass fraction (mass, %) as follows: WC 88, Co 12. Before spraying, the sample surface was washed with alcohol, and then was treated by 200 meshes brown corundum abrasive. The spraying was conducted on a XM-8000 type supersonic spraying system, using aviation kerosene as fuel, high pressure O_2 as combustion gases, and N_2 as the powder feed gas. Technological parameters: fuel pressure of 1.25 MPa, O_2 pressure of 1.58 MPa, water temperature of 40 °C, gun pressure of 0.95 MPa. The

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WC-12Co coating was remelted with a Zejin-8000 type CO_2 laser, the processing parameters as follows: of 800 W, scanning speed of 500 mm/min, and the size of the spot size was 15 mm×2 mm. The wear testes were conducted on a CFT-I type multifunctional surface performance tester, and the friction mode was reciprocating, and the wear counterpart was Si_3N_4 ceramic ball with the diameter of 5 mm. Load was 80 N, the wear time was 30 min; the number of reciprocating was 500 mm/min; and the reciprocating length was 2 mm.

After grinding and polishing, the surface-interface morphologies were observed with a JSUPRA55 type FESEM (field emission scanning electron microscope) and JSM-6363LA type SEM and, the coating microhardness was measured with a HV-1000 micro Vickers hardness tester, took five points in the coating with the load of 0.3 N, press head held time of 15 s, and the took the average of five points. After the wear test, the surface morphologies of worn scar were analyzed with a SEM and its configured EDS, and the phases of the coating was measured with a D/max2500PC type XRD (X-ray diffraction spectrometer).

3. Analysis and discussion

3.1. Surface-interface morphology

Fig. 1(a) shows the morphology of HVOF sprayed WC-12Co coating. The microstructure of WC-12Co coating was compact and the porosity was low. The porosity of the coating was influenced by the coating processing, the properties of the powder, and the cooling conditions, the coating with low porosity was the main technical advantage of HVOF spraying. During the HVOF spraying, the WC particle with high melting point (2867 °C) was uniformly distributed, the binder of Co with low melting point was melted and filled between the WC particles. The WC hard phase particles with clear edges and corners were clearly visible and the coating microhardness was 1100–1220 HV0.3 measured with a microhardness tester. The HVOF spraying time of the WC-12Co powders through the flame was short, only the binder of Co was melted, the ceramic phase of WC particles almost maintained in solid, presenting a semi molten state, and a handful of WC hard phase was spalled after cooling due to lacking of the Co binder. The cracks were caused by the solidification of Co in the process of cooling and solidification. The volume of Co decreased rapidly, the extrusion of WC solid was produced. After sandblast pretreatment, the substrate surface was uneven, prompting the substrate and sprayed coating formed a good “hooked to bite”, which helped to improve bonding strength of the coating and the substrate. Fig. 1(b) shows the interface morphology of WC-12Co coating with the thickness of about 200 μm, and the WC hard phase existed in the coating with a lamellar structure. The particles were finally presented in a semi molten state, and the substrate was impacted by the liquid/solid two phases, so that a large number of particles were embedded into the substrate, and the “interlocking” phenomenon appeared. The energy released during the impact occurred a part of chemical elements to diffuse. The combination between the coating and the substrate was primarily mechanical bonding, accompanied with a little metallurgical bonding. The sprayed particles enhanced bonding strength of the coating and substrate, playing a good role in the protection of the substrate.

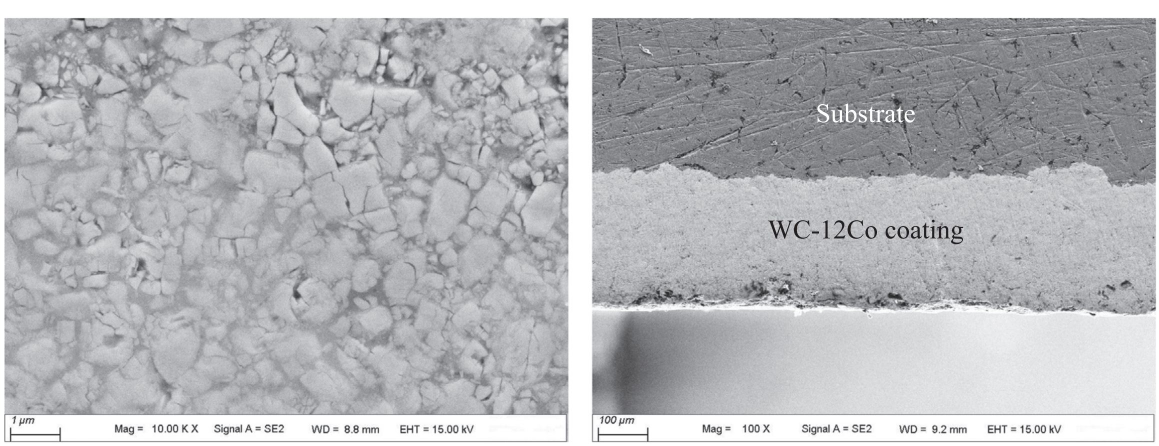
Fig. 2(a) shows the appearance of HVOF sprayed WC-12Co coating surface after LR. A part of the WC was decomposed into W and CO_2, and the Co was not filled in time, therefore, the particle distribution was more obvious in the molten state. Fig. 2(b) shows the morphology of laser remelted WC-12Co coating interface with the thickness of about 200 μm, the coating texture was compact, closely jointed with the substrate. The combination mode between the coating and substrate was primarily mechanical bonding, accompanied with a certain amount of metallurgical bonding. This was because that, the chemical elements of the coating and substrate were diffused during the LR, and a certain metallurgical bonding at the interface of the coating-substrate was produced.

3.2. XRD analysis

Fig. 3(a) shows the XRD spectrum of the HVOF sprayed WC-12Co coating, the diffraction peak of WC was very strong, the diffraction peak of Co was also strong, the coating was primarily composed of WC hard phase and a small amount of Co phase. Fig. 3(b) shows the XRD spectrum of the HVOF sprayed coating after LR, the diffraction peaks of WC at 31°, 37° and 48° were very strong, the other diffraction peaks were low, as a result, the coating composition was WC phase. The new phase of W_3O was not found before and after LR from the XRD analysis results, it can be seen that there was no obvious oxidation phenomenon of W elements in the coating. Both of which appeared a few new phase of W_2C, this was because that a small amount of WC appeared decarbonization reaction in the HVOF spraying, but the decarburization was not serious, showing that the component of the coating was WC and Co phases.

3.3. COFs

Fig. 4(a) shows the curve of WC-12Co coating COFs vs wear time under the dry and lubricated conditions. The average COF of the coating under the dry and lubricated conditions was 0.069, and 0.052, respectively. Under the lubricated condition, the COF decreased by 24%, which significantly decreased the COFs. The wear process was



(a) Surface (b) Interface

Fig. 1. Morphologies of HVOF sprayed WC-12Co coating surface-interface.