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Wear Mechanism of Plasma-Sprayed Coating in Mo- and Co-Based Alloy

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Abstrct—Wear and friction behavior of plasma-sprayed coatings in Mo- and Co-based alloy were studied for the application of piston-ring automobile engine. The plasma-sprayed coatings were varied with gun current density, gas flow, and distance. The surface roughness, microhardness, and wear volume were measured depending on the spray distances. The high temperature hardness value were also measured as a function of temperature. Ball-on-disc geometry configuration tribometer was utilized in air. The wear tests were performed in the temperature ranges from room temperature to 825°C to investigate the tribological trend of the piston-ring materials in the lack of lubricant. The cross sections of wear track were investigated, using microscopy.

Key words : Plasma Coating, Wear, Cobalt Alloy, Wear Mechanism

1. Introduction

Engine performance has improved higher output, smaller size, lighter weight, and longer life. Piston ring materials requires high wear resistance and high heat resistance. Hard chromium steel has been used as the piston ring materials. Recently surface coating was developed as the alternative remarkable technology. Plasma spray coatings have also been used for the various applications in the automotive, transportation, aerospace, and aircraft industries. The combinations of optimized plasma deposition parameters coupled with the properties of Co and Mo alloy material can provide significant wear resistance.

Present investigations have concentrated on determining the cause and effect relationships of various coating processes and coating attributes related to the general coating structure and wear performance. It has been reported the generally microcracks between the coating layers were produced and the wear of plasma spray coating layers due to the splat delamination [1-4]. Herman [5] suggested a model that gases among the splat layers were trapped and micropores were formed by connecting these gases trapped in the splat spacings. Plasma flame made the plasma spraying powders to be oxidized and to form the oxide deposition layers. These oxide layers among the splats have less binding energy and create cracks. These cracks are propagated into the splat layers in the contact sliding processes, and finally the splats were removed. This is called as burst-out damage [2]. Also Hartfield [6] suggested four different wear mechanisms for the plasma sprayed coating materials;

(1) effect of splat orientation and waviness, (2) effect of oxides, (3) effect of porosity, and (4) effect of resolidified particles.

The objectives of the present study is to find out wear mechanism and correlation between high temperature hardness and wear with microstructural features of plasma sprayed deposition as a function of different coating parameters.

2. Experimental Procedures

The powders used for the plasma spray coating were M64 and M66. The physical properties of the powders were shown in Table 1. M64 powder cosists of molybdenium. M66 powder consists of 62% cobalt and 28% molybdenium. These powders were manufactured by the METCO company. The purchased powders were analyzed with laser diffraction method to find out the size, shape, and density of particles. A plasma gun in this study was the METCO MBN gun with the maximum capacity of

Table 1. Character of powders used for plasma spray coating

POWDERS	COMPOSITION	SIZE DIST.	M. P (°C)	PRO. OF COATING LAYER		
				DPH_{300}	POROSITY	BONDING STRENGTH
M66	Co : 62% Cr : 8% Mo : 28% Si : 2%	-45μm +15μm	1230°C -1600°C	450±50 (DPH_{300})	<5%	7,000 psi
M64	Mo	-90 μm +44 μm	2610°C	460±70 (DHP_{300})	<2%	3,500 psi

40 kW. The operating gun gas were Ar and H_2. The operating parameters were varied to determine the optimal coating condition as functions of the amount of gas flow, the current density of gun, and the spraying distance from the gun to the specimen. The plasma spray gun was moved in the bi-axial mode of X-Y axis. The thickness of the sprayed coating thickness was tried to be approximately 300 μm in average. In this study the spray distances were varied.

The tribometers used at room temperature was Cameron Plint TE77, which has pin-on-disc reciprocal type configuration. The steel balls of 5 mm in diameter were used. The applied load was 20N. The sliding speed was 0.036 m/s. The sliding time was one hour. The wear volume was calculated by measuring the changes in weight loss prior to and post wear testing. The tribometer at the elevated temperatures up to 825°C was the reciprocal intermediate tribometer designed at the NIST NBD100 silicon nitride balls of 12.7 mm in diameter were used. The other wear testing conditions were as same as the room temperature testing conditions.

The microhardness were performed, using the NICON QM high temperature hardness tester. The indentation load was 10N. The indentation time was 10 seconds. The microhardness value was averaged with 10 indentations.

3. Results and Discussion

Fig. 1. shows the variation of wear volume at room temperature as a function of distance between plasma gun and substrate. The wear volume decreases with the spray distance below 100 mm above 100 mm the wear volume increases with the spray distance. It is found that the spray distance influences extremely on the wear properties. The

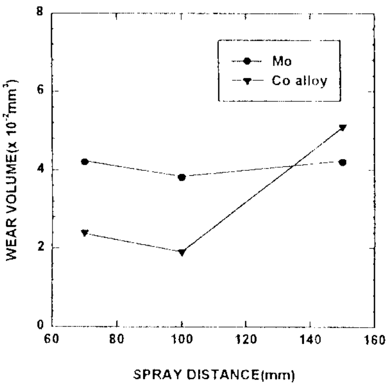

Fig. 1. Spray distance dependence of wear volume in Mo and Co alloy coating layers.

spray parameters changed the microstructure, which vary the hardness and surface roughness. The molten particles are heated by plasma flame and transported onto the cool sbustrate. The following molten particles are reheated by the particles contacted on the substrate. These particles are sintered each others in the diffusion process or contacted on the molten splat. This solidification phenomena cause variations in temperature depending on plasma spray distance. When the spray distance is short such as 75 mm, the molten particles can be overheated during colliding on the substrate. The viscosity of the splat is so low and rough splats form. However, the bonding between splats are strong. Moreover, the hardness properties are improved. When the spray distance is long such as 150 mm, the flying particles are overcooled and quenched. The flying speed is dropped. When the particles are collided on the substrate, the thermal and physical energy is not sufficient and maybe forms pores. Also the particles are resolidified and forms a unmelted spherical shape. This particle acts as a soft spot and poorly bonded. Hackett, etc. [7] reported that resolidified particles were commonly observed, which have the same appearance as unmelted particles. when the spary distance is in the middle of both extreme cases, the microstructure of the optimal surface roughness and microhardness can be obtained. This microstructure shows the highest wear resistance as shown in Fig. 1. The wear properties of plasma spray coatings are direct function of the unique microstructure, which apparently changes microhardness and surface roughness. These physical properties controls extremely the tribological behaviors particularly in the sliding contact of the plasma spray coating layers.

Fig. 2 shows the variation of microhardness values depending on spray distance. The hardness of cobalt alloy increases with increasing the spray distance, but that of molybdenium decreases with increasing the spray distance. Fig. 3 shows the variation of surface roughness depending on the spray distance. The surface roughness decreases with increasing the spray distance. In the case of the cobalt alloy, the wear resistance is low even with being the higher hardness value, which is associated with the higher surface roughness. Also the microstructure of the plasma spray coating layers mainly dominates the wear behavior during the sliding contact. When the surface is so rough, the edge fraction of coating layers may be easily broken in the initial sliding contact and the following abrasive contact sliding.

SEM microstructure of the spray coating layers

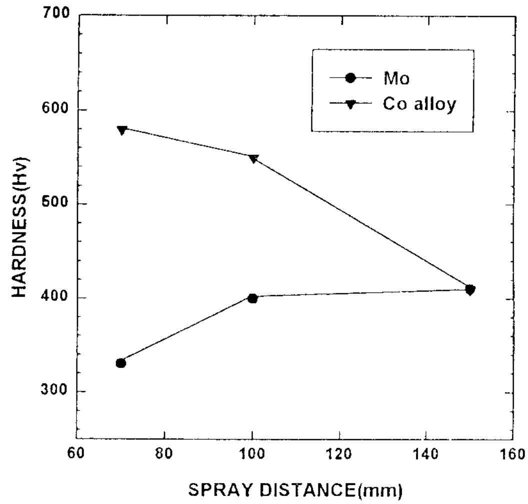

Fig. 2. Spary distance dependence of hardness in Mo and Co alloy coating layers.

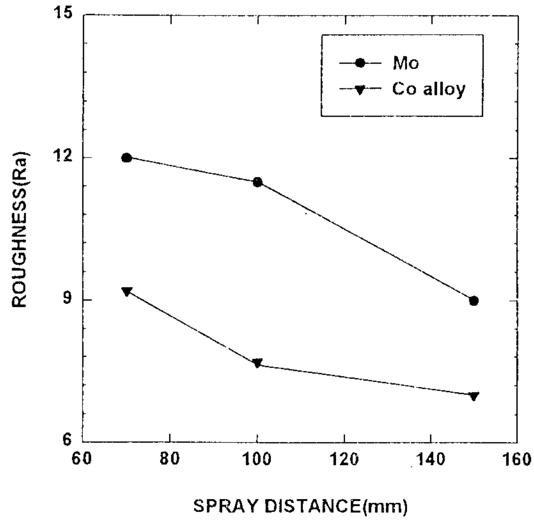

Fig. 3. Spary distance dependence of surface roughness in Mo and Co alloy coating layers.

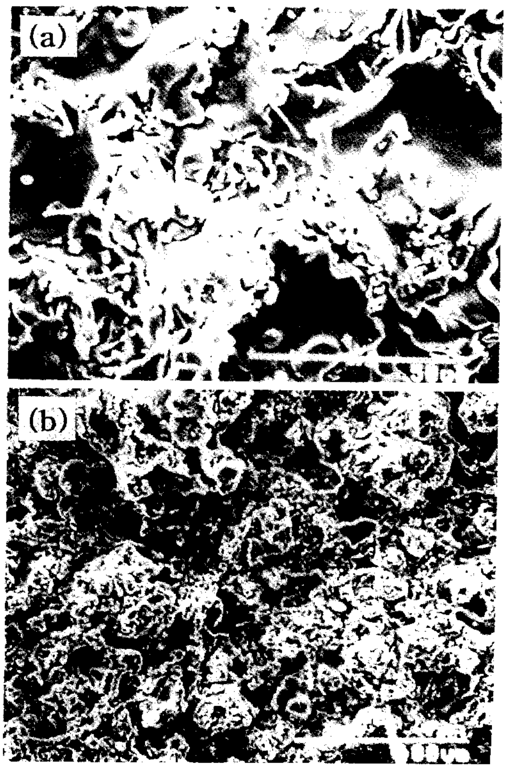

Fig. 4. SEM micrographs of Co-alloy coating layers sprayed with different spray distance: (a) 100 mm (b) 150 mm.

made by two different spray distances such as 100 mm and 150 mm are illustrated in Fig. 4. These are M66 cobalt based alloy. Fig. 4(a) indicated that the spray distance is 100 mm and the large splats are formed. Fig. 4(b) indicated that the spray distance is 150 mm and the spherical shape particles are generated.

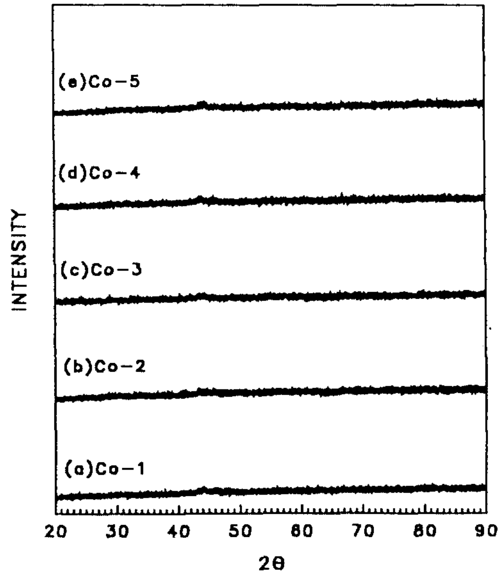

Fig. 5. X-ray diffraction patterns of Co alloy coating layers.

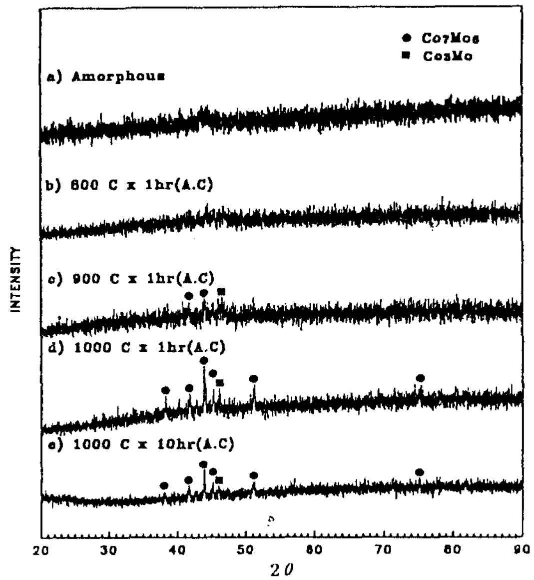

Fig. 6. X-ray diffraction patterns of heat treated Co alloy coating layers.

The x-ray diffraction patterns of the various plasma spray coating layers of cobalt alloys illustrate only amorphous phase as shown in Fig. 5. Similarly, Nertz and his coworkers [8] reported that the cobalt is in an amorphous state or is characteristics of microcrystalline materials when the cobalt was plasma sprayed. If these plasma sprayed cobalt layers are heated to a sufficient temperature, these would be recrystallized into various cobalt phases. Fig. 6 shows the x-ray patterns of cobalt alloy after heating from 800°C to 1000°C and cooling in air. Specimen heated at 800°C and 900°C still exhibit the typical amorphous state, but specimen heated at 1000°C displayed clearly the existence of crystalline phases. The peaks of Co_7Mo_6 and Co_3Mo were identified on the bases of JCPDS cards.

Fig. 7. shows the variation of wear volume for the cobalt alloy coated with the spray distance of 100 mm as a function of testing temperature. Up to 300°C the wear volume decreases with increasing temperature, and from 500°C to 700°C the wear resistance dose not change. However, from 700°C to 825°C the wear volume increases significantly. Below 300°C the moisture on the contact layers are removed and the dry sliding contact made the wear resistance to be poor with increasing temperature. In the temperature ranges from 300 to 700°C, the fine wear debris play a role of solid lubricant. It seems to be that the wear resistance is not changed, however, the frictional behavior can be strongly influcenced due to wear debris. At 820°C the mi-

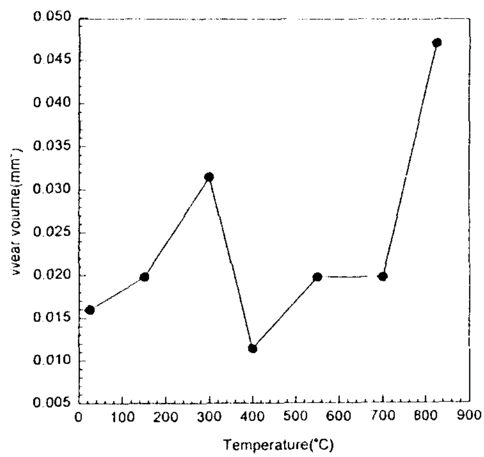

Fig. 7. Variation of wear volume for Co alloy as a function temperature.

crohardness of the cobalt alloy also decreases, which is associated with mainly the plastic deformation behavior of materials at the elevated temperature as well as the oxidation of the contact area. Fig. 8 shows the variation of microhardness of cobalts alloy as a function of temperature. Above 700°C, the hardness drops sharply which is well matched with the results of wear tested as shown in Fig. 7. The higher hardness value of the oxidized layers seems to be the lower frictional coefficient. These oxidation phenomena of the wear debris and the worn surface area were able to be determined, by using surface analytical tools such as EDX, micro-FTIR spectroscopy, Auger electron spectroscopy, and secondary ion mass spectroscopy (SIMS), and x-ray photon spectroscopy (XPS). These analysis have been reported in the plenty of previous works. Fig. 9 shows the comparison of the optical micrographs of cross section of specimen coated with the different spray distances of 100 mm (in Fig. 8(a)) and 150 mm (in Fig. 8(b)). Fig. 1 showed the higher wear volume in the case of the spray distance of 150 mm compared to that of 100 mm. Form these micrographs, it appears that the coating materials are removed by collapse around a pore and also the intersplats are broken. The splat delamination in the plasma sprayed coatings were not found. But it has been reported that generally microcracks between the coating layers were produces and the wear of plasma spray coating layers due to the splat delamination [1-4]. In the case of longer spray distance, porosity dominates an effect on materials removal. It is also possible that when the spray distance is long and the flying time is sufficient of plasma flame to make the unmelted particles to be oxidized and to form the oxide deposition layers. These oxide layers among the splats have less binding energy and enhanced the wear. The experimental results are matched partially as Harfield [3] suggested among four different wear mechanisms for the plasma sprayed coating materials. It is mainly due to effect of porosity.

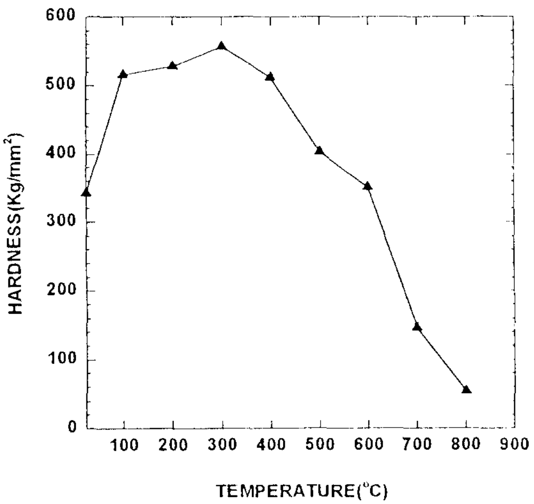

Fig. 8. Variation of hardness for Co alloy as a function of indentation temperature. The indentation load is 10 N.

(a)

(b)

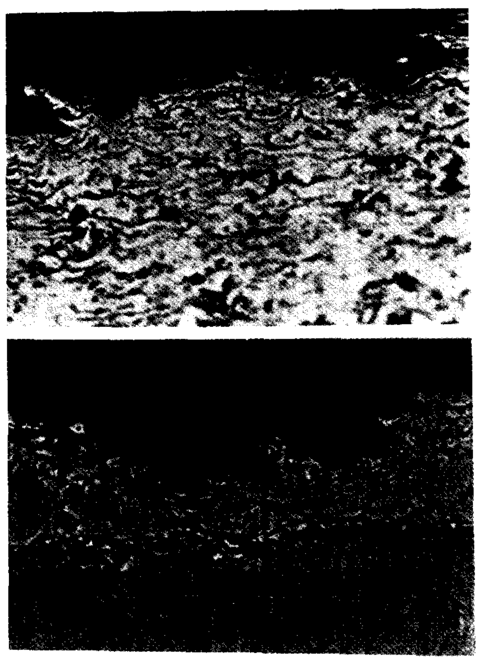

Fig. 8. Optical micrographs of cross section of the worn area of Co alloy depending on the spray distance : (a) 100 mm and (b) 150 mm.

4. Conclusions

Plasma spray coatings were made with varying the spray distance. The reciprocal sliding contact tests wear made to determine the wear properties depending on the costing parameters. In the specimen made with the longer distance the more pores among the splats form. In such case the porosity enhanced the materials removal.

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