Microstructural Characterization and Hot Erosion Behavior of Wc-12co Coated Stainless Steel Using HVOF Spray Process

M. Mruthunjaya[1] and K. I. Parashivamurthy[2]

1 Department of Mechanical Engineering, JSS Academy of Technical Education, Bangalore-560 060

2 Department of Mechanical Engineering, Government Engineering College, Chamarajanagar-571 313

Abstract

Erosion behavior of the High Velocity Oxygen Fuel (HVOF) deposited CrC-NiCr coating on stainless steel was evaluated. The solid particle erosion study was conducted using an air jet erosion test rig at a velocity 60m/sec and impingement angle 60^0 ,75^0 ·90^0, on HVOF spray coated steel at 600^oC. Microstructure, chemical composition, phases present in the coating on the steel substrate was studied by using Scanning Electron Microscope (SEM) and X-Ray Diffraction method. The Hardness is gradually increasing with increasing content of Cr_3C_2 particles in all three samples. The erosion mechanism of coatings was also discussed and erosion rate is maximum at impingement angle 75^0.

Keywords: *Chromium carbide, HVOF coatings, Scanning Electron Microscope, Hot erosion, Vickers hardness.*

1. Introduction

The HVOF spraying process is expanding its area of coating on hard facing engineering to reduce wear and erosion of metals in the hot erosion components in the fled of thermal and nuclear power plants [1-6]. Mainly coal crusher, coal handling units, coal burner, heat exchanger and fluidized bed combustor (FBC) boilers are the some of the example for hot erosion of metal [7-12]. HOVF method is proved carbide metal coating with required density, hardness, bond strength etc than any other coating technology using various types of carbides [5]. Rajasekaran and et.al [6] have conducted experiments on coatings using HOVF method for different applications. Similarly, Yourong Liu and et.al [7] developed a method of carbides coating technology using HOVF method and assess the microstructure, mechanical properties and abrasion behavior of the samples. Many investigators [12-18] investigate the adhesive and erosion behavior of WC coated specimens produced by HVOF technology. The results indicates that the WC carbides can be coated with required density, hardness, bond strength and other required properties than any other thermal spray technique. From last three decades, high chromium stainless steel is using for high strength and high temperature applications. The chromium more than 20% enhances the mechanical properties, weldability, and corrosion resistance at high operating temperature along with cold hardening properties.

WC carbide is approximately 1800 to 2200 Hv harness, melting point is around 2870^oC with a young's modulus of approximately 550 GPa and mainly using as cutting tools, abrasive and many more applications in modern industries. With combination of cobalt WC can be used as hard face reinforcements for wear and erosion resistant applications. Suresh babu et.al [1-3] demonstrated the wear behavior of WC-Co coated steel produced using HVOF method. Results indicate that wear rate increase with increasing hardness and wear resistance depends upon the erodent type. Many components continuously expose to wear and erosion at high temperature in particularly thermal and nuclear power stations. At high temperature, the strength of the metal will be reduce and reinforced carbide particles eroded along with matrix materials and surface of the steel cracked due to the thermal expansion mismatch of carbides with steel [4]. The purpose of this investigation is to investigate the hot erosion behavior of WC-Co coated steel specimen by varying mean grain size of WC from 40μm to 90μm and cobalt 12%.

2. Experimental procedure

The commercially available three different msh size 88%WC-12%Co powder was used for coating on steel substrate by using HOVF method. The three different mesh size available different mesh size. Stainless steel was used as a substrate. Series of WC-Co coated steel specimens of size 75*25*6 mm^3 were produced by using HOVF method using 80kW HVOF system at Spray Met Technologies at Bangalore. Specimens are initially grit blasted at a pressure of 3 kg/cm^2 using Al_2O_3 having grit size of 60 µm for the average roughness of the surface was 6.8µm. The standoff distance in shot blasting was kept between 120-150 mm. The average roughness of the substrates was 6.8 µm. The grit blasted specimens were cleaned with acetone in an ultrasonic cleaning unit. HVOF process carried out at operating power 80kW and current 550 A. The flow rate of fuel gas was 5.5 liter/minute, oxygen 2.90 liters/minute, spray distance 150 mm and standoff distance is 100 mm. Chemical analysis of base metal was determined by using vacuum emission spectrometer. Carbon of the base metal was analyzed by wet method. Chemical composition of WC-Co powder was analyzed using Energy Dispersive Spectroscopy (EDS). Chemical composition of base metal and WC-Co powder is tabulated in table 2.1 and table 2.2 respectively.

Table 2.1 Chemical composition (in weight %) of base metal

C	Mn	Si	P	S	Cr	Ni
0.08	2.00	1.00	0.04	0.03	20.0	10.5

Table 2.2 Chemical composition (in weight %) of WC-Co

Sample No.	Mesh size range in µm	C	W	Co	Ni	O
S_1	10-40	10.58	61.24	14.35	3.72	8.54
S_2	15-63	11.08	63.16	15.16	2.66	7.54
S_3	45-90	13.85	64.75	14.64	2.53	8.23

Microstructures of the surface coated specimens are taken using Scanning Electron Microscope (SEM) (Zissis) connected to Energy Dispersive X-ray analysis equipments (EDX). Secondary electron detector was used for surface imaging. SEM images were used for study the distribution of WC particles on the substrate.

XRD pattern was carried out using X-Ray diffract meter with CuK radiation using wavelength of 1,790 Å at operating voltage 40.0kV and current 30 mA. The 2 range scanned was 10 to 70 degree at the step size 0.02 degree and count time 0.60 seconds. computed. The micro-hardness measurements were made on carbide particles in the surface coating using ZWICK 3212 micro-hardness tester at a test load of 0.03 kgf and average of five different readings is Hot erosion tests were carried out using Air Jet Erosion Tester (TR470-600, DUCOM, Bangalore) at 800^{o}C using sample dimensions size 75*25*6 mm^3 as per ASTM G 76 standard. This test was carried out by forcing a stream of abrasive (Silica) partials gas

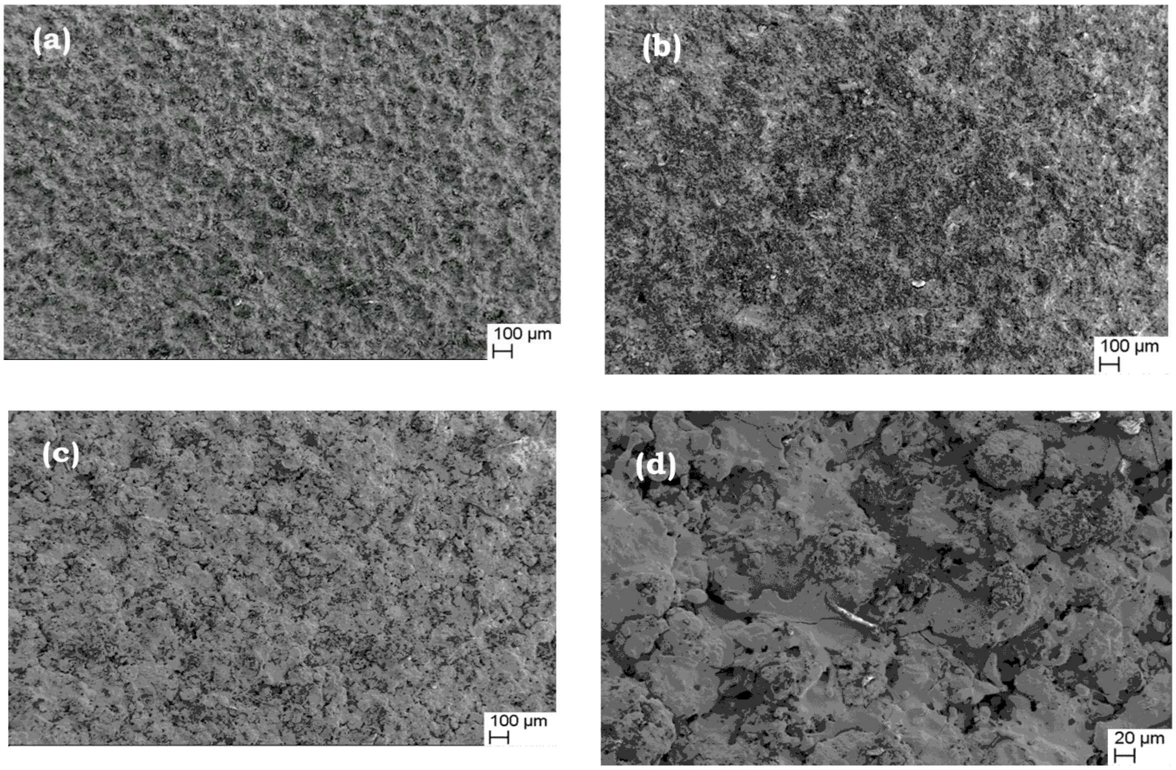

Figure 1. SEM structure of WC-Co coated specimens (a) 10-40 µm mesh size at 100X, (b) 15-63 µm mesh size at 100X, (c) 45-90 µm mesh size at 100X and (d) 45-90 µm mesh size at 500X

through a small nozzle of known orifice diameter towards the test sample. During the test, abrasive gas stream velocity maintained at 60 m/s for 10 minutes at known impact angle. Experiments were reputed for the impact angle 30, 45, 60, 75 and 90 degrees. Erosion of the specimens was calculated by measuring weight loss of the specimens.

3. Results and Discussion

The chemical composition of the base metal and WC-12Co carbides was determined using vacuum emission spectrometer. Carbon contents in the composites were analyzed by wet method and provided in table 1. The castings are designated as S_1, S_2, S_3, and $S_{4.}$

Fig. 1 (a) to (d) illustrate the surface SEM micrographs of samples prepared using HVOF method with varying mean grain size of WC varying from 30µm (sample 1) to 65µm (sample 3). As observed from the SEM structure the grain sizes are varied from sample S_1 to sample S_3. SEM micrographs confirm the WC-12%Co uniformly coated on the surface of the steel substrate. All the coating revealed uniform distribution of WC-12Co particles and good bonding existing between the metal matrix and reinforcements with varying grain sizes from sample S_1 to sample S_3. From the microstructure it was found that WC uniformly coated with thickness about 15 to 30µm on the surface of stainless steel. The Fig.1.d indicates SEM structure at higher magnification and clearly indicate porous of the samples. The SEM results indicate that the WC can be effectively coat on the steel surface at required thickness with varying grain sizes of WC with using HVOF method.

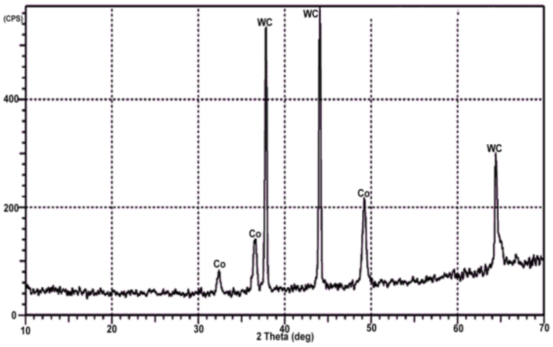

Fig. 2 XRD patterns of WC Coarse Mesh (45 to 90 µm)

Figure 2. illustrate the XRD pattern of the WC-12%Co coating on the steel surface. It is observed that the WC coating using HVOF consists of WC and Co and WC is dominating phase. During HVOF spraying the different phase transformations are taking place, notable quantity of binder phase is present in the coating.

The average micro hardness of the HVOF thermal sprayed coating is given in the Fig. 3. The coating with coarse mesh size exhibits highest hardness of 1682Hv compare to other two coatings, where as the minimum value of the micro hardness is shown by the coating with fine mesh sizes.

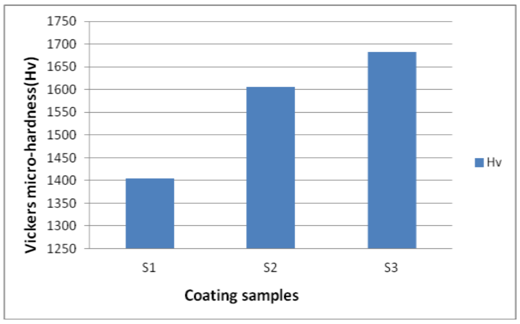

Fig. 3 Hardness VS Mesh Size

Erosion tests were conducted at impingement angles of 15^0, 30^0 45^0 60^0 and 75^o at 800^oC using silicon carbide particles as erodent. Erosion rate is gradually increases with increase in impingement angle from 30^0 to 60^0 then it is decreases as impingement angle increases and it is concluded that the erosion rate is maximum at impingement angle 60^0 and minimum at 15^0 and 75^0 impingement angles. In general, it is expected that the erosion rate should decrease with increase in hardness and decrease in porosity but WC-12%Co coating with fine mesh size (Sample S_1) as shown in Fig.4 highest erosion rate compared to the remaining two coatings.

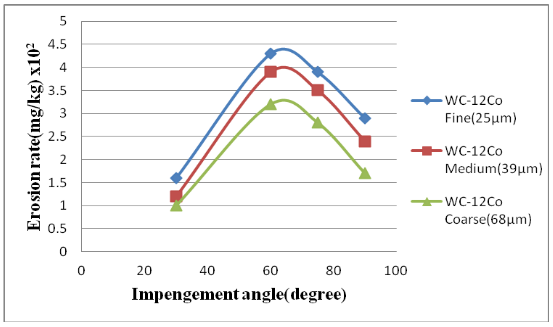

Fig. 4 Comparison of Erosion Rate Vs Different Impingement angle for three Mesh Sizes

In the case of hot erosion, scanning electron fractographic image of fine WC-12Co coated sample (Sample S_1) materials reveal that during erodent impact, material is deformed and smeared across the target surface. Little penetration of the surface by the erodent is observed. The wear of material occurs through surface deformation of the bulk solid followed by fracture and the loss of small volumes of the WC–12Co coatings. The specimen shows long, narrow grooves at the side of the softer phase fine surface and subsurface cracks occurred at the grain boundary during high incident angle erosion, induced by the resolved normal stress. Cracking therefore was one of the major mechanisms involved in repetitious erosion fracturing for all samples [19,20]. For the two-phase material, the grain boundary provides the cracking site during erosion impact it is found that the contact interfaces between the deposited particles had disappeared except the pores. The micro-pores could be generated in the healing of the incomplete interfaces.

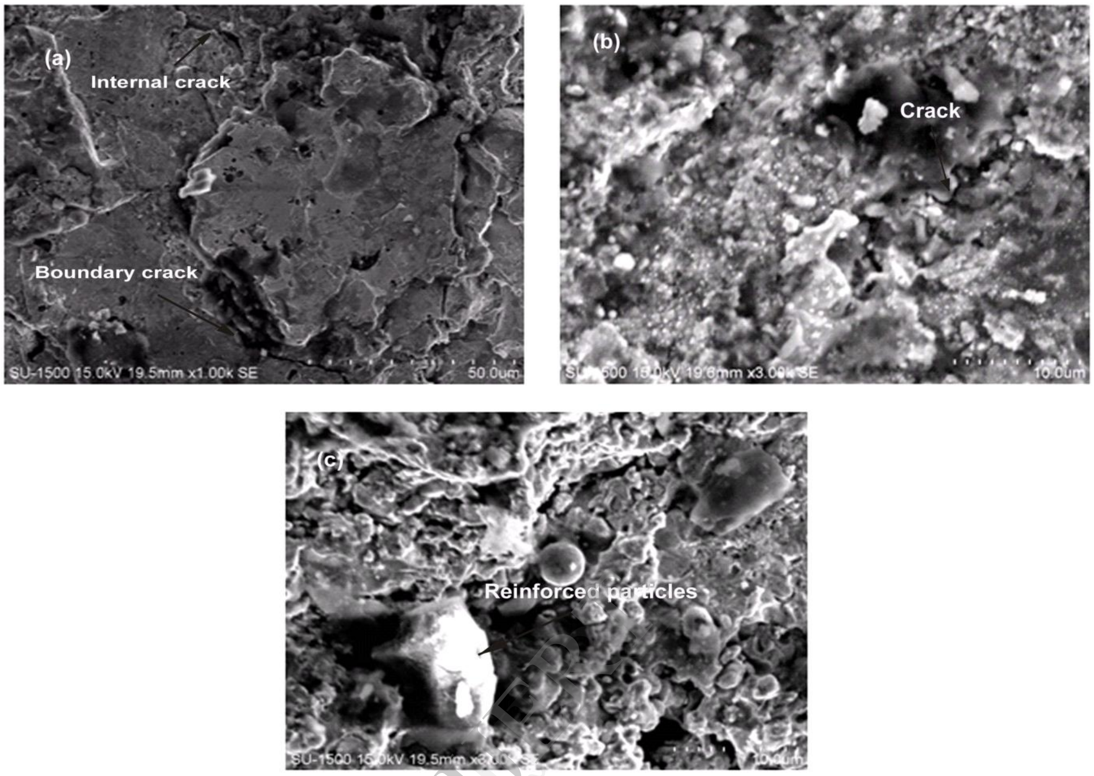

Fig.5 shows SEM fractographic of eroded sample at 60^0 impingement of WC-12Co coatings (a) Fine grain sixe, (b) Medium grain size and (c) Coarse grain size.

In the medium grain WC-12Co grain size, short groves are observed. The erodent material quartz created groves along with silica sand with round circular or irregular shaped structure. At high temperature the silica get solidified due to more thermal energy, so during solidification from molten state, they agglomerate to form splats flattened region [21]. Here very less amount of cavitations is observed. It states that, the material is removed in lumps from inter-splat boundaries and deeper groves are observed.

In the coarse size we may observe deformation, displacement and small cracking of particles of WC-12Co grains as well as the extrusion and preferential removal of the cobalt binder which is followed by the loss of single un-supported grains. The coarse-grained materials also behave in a predominantly brittle fashion in which transgranular fracture of the WC grains and intergranular fracture within the cobalt binder phase predominates [22]. In addition, the lips and ridges that formed during cutting or plastic deformation that provided important platelet mechanism sources. The eroded surface of bond coat WC-12Co and its interface to cermets coating, which reveals a dramatic delaminating at the interface between bond coat and cermets layer and the presence of many small cracks within the bond coat, Un melted particles and droplets can also be observed on the surface.

4. Conclusions

The result of the present study WC-12Co HVOF coatings can be summarized as follows.

- The three coatings exhibited better erosion resistance especially fine mesh size particle coating, which showed the better erosion resistance than the remaining two coatings.
- Erosion rate is increases with increase in impingement angle up to $60^{0,}$ then it is decreases as impingement angle increases it is concluded that the erosion rate is maximum at impingement angle 60^0 and minimum at 30^0 and 75^0.
- Among the WC-12Co HVOF coatings, the fine mesh size coating having fine structure

and the homogenous distribution of hard face particles as well as lower micro-hardness exhibited higher levels of resistance than coarse and medium mesh size coatings.

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