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Comparison and wear behavior evaluation of Cr_3C_2-25%NiCr composite coated on carbon steel by two different thermal spray techniques

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Abstract

Keywords:

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Plasma,
HVOF,
FESEM.

This study examined and compared the wear behavior of two different thermal spray-coating techniques. Plasma and high velocity oxygen fuel (HVOF) spraying are the most common types of thermal spray coating techniques that can be used to deposition different types of ceramic composites. Cr3C2-25%NiCr is well-known ceramic composite that can be used for extending the lifespan of products. The tribological and mechanical properties of them were investigated by tribometer (pin-on-disc) machine by applying different loads. The results show when the coated samples pushed against WC-6%Cr abrasive paper with maximum load, the rate of wear in the HVOF-coated sample is less than plasma-coated samples. However the average of wears and rate of weight loss in both of coated sample is not high. For this reason there is no big different between surface of samples before and after wear testing. Field emission scanning electron microscopy (FESEM) showed the distinctive microstructure of the HVOF and plasma coated samples before and after wear testing.

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1. Introduction

Thermal spray methods are cold spraying techniques that have a considerably less thermal stress, residual stress and other defects. Among different thermal spray coating techniques, high velocity oxygen fuel (HVOF) and plasma is the most commonly thermal spraying coating process to produce anti-wear and corrosion coatings with different types of materials such as metal, alloys, ceramic composite, etc [1-3]. Furthermore, HVOF and plasma thermally sprayed coating process induces microstructure heterogeneities, which increase the corrosion and wear resistance. The purpose of coating is to get a blend of unique properties with low cost, which is not possible from other manufacturing processes like welding, cladding and forging [4,5]. Because these methods each one has some defects. For example in welding method, there is some limitation for choosing materials, the material should be metal base. In addition to the high temperature of welding method causes to surface has a high thermal residual stress and possibility to create cracks. Also the temperature of this process causes the distortion occurs in the substrate, so it creates a limitation for the substrate thickness [6-9].

Cermet variety of coatings such as WC-Co and Cr3C2-NiCr are well known for their excellent wear behavior. Among these cermet variety of coatings, WC-Co and Cr3C2-NiCr coatings find application in a large variety of industrial usages [10].

Chromium carbide powder is a blend of chromium carbide and nickel-chromium powders used in HVOF and plasma coating. The nickel-chromium alloy serves as a matrix that improves overall coating integrity and corrosion resistance, while the chromium carbide constituent acts as a hard phase that assures wear resistance. Such coatings effectively combat solid particle erosion (SPE), high temperature wear (abrasion, erosion, fretting and cavitation) up to 870°C (1600°F) and hot corrosion [11-13].

A coating applied using the HVOF process is dense and very well bonded, with a more homogeneous structure. Also, coatings applied by plasma gun consume high energy, so the result is similar to HVOF coatings in terms of density and homogeneous structure; however, HVOF coatings have higher bond strength and more favorable residual coating stresses. The high temperature of coating up to 725°C (1340°F) for approximately 1 hour causes carbide dissolution into the matrix and increases coating microhardness [14-16]. Experts generally agree that micro structures, such as carbide content, carbide particle size and carbide distribution within splats, as well as porosity and so on, predominately influence the wear resistance of cermet coating [17, 18].

Coating applied by HVOF spraying is hard, dense and well bonded owing to the high thickness limit of over 0.63 mm (0.025 in), which is substantially greater than observed for standard chromium carbide coatings. This chemical composition can be used for many applications with no subsequent finishing as a result of its fine as-sprayed surface roughness. In addition, it produces thin, dense, hard and smooth coatings that are extremely resistant to wear and oxidation. Plasma spray coatings with this powder are very smooth and can often be used without post finishing [19-21]

In this research the surface of carbon steel is coated with Cr3C2-25%NiCr HVOF and plasma coating techniques. Then the wear properties of each coated samples was investigated at different loads.

2. Experimental procedures

2.1. Substrate and coating materials

The substrate material used is carbon steel, because it is one of the most popular materials used in oil piping production in both upstream and downstream domains.

Surface preparation is a very important step in thermal spraying. Grit blasting was carried out with a high efficiency sand blaster with Alumina grit (size 10-20 mesh), 8/10mm nozzle and operating at a blasting pressure of >0.5 MPa. The distance between substrate and nozzle was 150mm with a 30^0 angle. The grit blasting time was dependent on obtaining the required surface roughness. Upon grit blasting completion, ceramic composite powders were sprayed using HVOF and plasma gun systems. Table.1 and Table.2 show the parameters setting for HVOF and plasma methods respectively.

Table1: Parameters of Cr_3C_2-25NiCr powder for HVOF coating

Model: 9MP			DJ	
Nozzle			Standard	
Powder Port				
	Type		DJ2702	
	Injector		#3	
Gases		Pressure (psi)	Flow (FMR)	SCFH
	Oxygen	150	42	606
	Propylene	100	38	168
	Air	75	47	742
Spray Distance		150-200mm (6-8”)		
Spray Rate		38 g/min (5lb./hr)		

Table2: Parameters of Cr_3C_2-25NiCr powder for Plasma coating

Gun			9Miller	
Nozzle			9mm	
Powder Port				
	Type		2 used #1000450	
	Gauge		#6	
	Angle		90^{O}	
	Disc Rpm		23	
Suction and spreader			L/L	
Gases		Pressure (psi)	NLPM	SCFH
	Primary Gas (Ar)	75	100	228.3
	Air Jets (2used-Item #1000540)	58	47	18
	Carrier Gas (Ar)	49	2.4	5.5
Amperage	480A			
Voltage	111±3 V			
Spray Distance		120 ±3mm(4.75± 0.125”)		
Spray Rate		18 g/min (2.4 lb./hr)		

2.2 Surface Characterization

The coating morphology was observed through a high resolution FEI Quanta 200F field emission scanning electron microscope (FESEM).

2.3 Wear Tests

In this section, two different types of physical testing, roughness and bond strength were conducted, followed by wear testing under different loads.

Coating hardness was measured using an HMV-Shimadzu under a 300 g load for 15 s on the cross-section of the coatings. A total of 10 indentations were made on a coated sample. Microhardness was measured in air at room temperature. The roughness (R_a) of the coated samples was measured using an optical surface texture analyzer (Alicona 3D Infinity Focus) at a total of 100 R_a points on the coated sample. To measure the coating/substrate bond strength, ASTM C633 is used.

The wear tests were done using a pin-on-disc tester model TR-20LE. The wear tests for coated specimens were conducted under four normal loads of 5, 10, 15 and 20 N. The specimens were pushed against WC–6%Co paper with 200 rpm disc speed in dry condition. The track diameter D=40 mm and sliding speed v=1 m/s were kept constant during all tests.

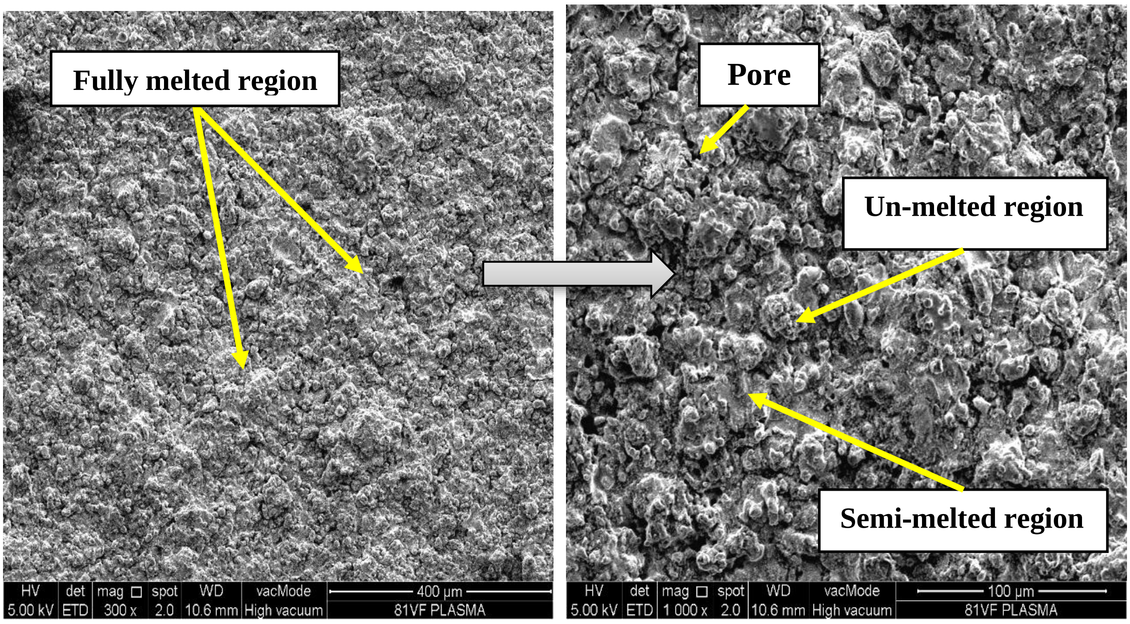
Wear testing was run for 60 minutes until the wear rate for coated samples stabilized so the total sliding distance for each sample was around 9048.96 m. Also, to increase the result reliability, each load was tested for five samples under the same condition. The mean scores of these tests are reported in Section 3.2. Afterwards, the samples were ultrasonically cleaned in ethanol and then dried. The weight, free from debris, was measured with a microbalance to an accuracy of 0.0001 gm. FESEM was used to study the wear tracks produced in the coating and the coating volume loss results were reported. The weight loss of the specimens was obtained from the standard method in accordance with ASTM G99-95a [19]. The worn surfaces and wear debris were observed by FESEM after wear testing.

3. Results and Discussion

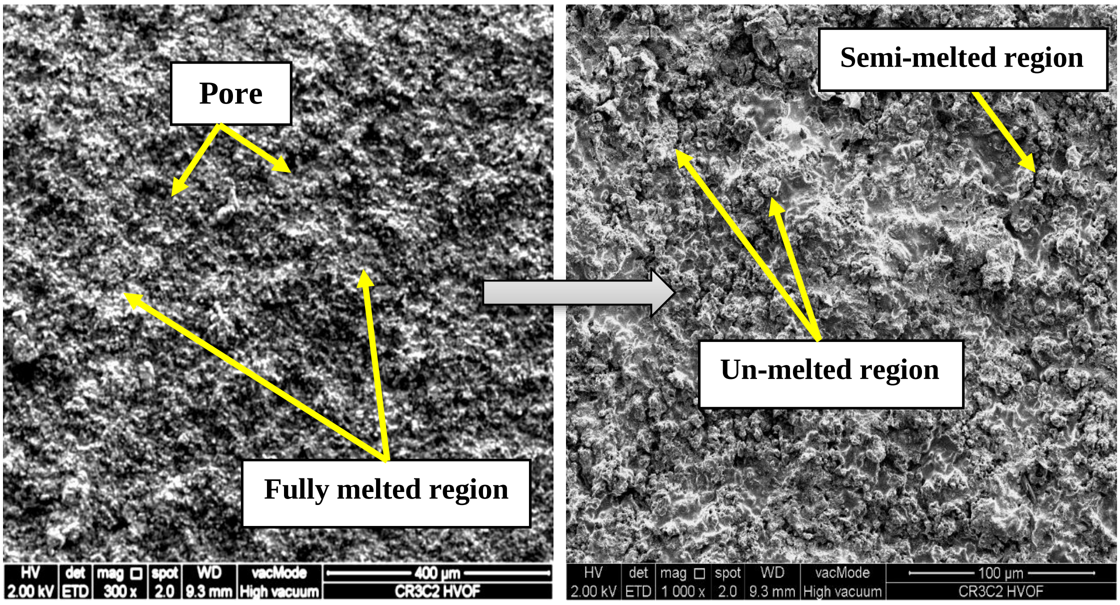
3.1 Microstructural analysis

Typical microstructures of plasma and HVOF-sprayed Cr_3C_2–25NiCr coatings are shown in Figure.2. This chemical composition powder was deposited on the carbon steel surface. The coating surface exhibited dense microstructure with high cohesion. However, a few pores appeared as black spots in the micrograph. It has been reported that these pores are due to the un-melted and semi-melted particles in the Cr_3C_2–NiCr coatings and are identified by their spherical morphology (Dent et al., 2000; Wang and Shui, 2002).

This is considered low porosity due to the high-impact velocity of the coating particles, which causes high density and high cohesive strength of individual splats [18]. Figure .2 shows the micrographs of this coating, which is uniform, homogeneous and free from surface cracks. A relatively homogenous coating without segregation is critical for improving the wear resistance of Cr_3C_2–25NiCr coating. According Figure 2(a) and (b), the amount of non-melted and semi-melted particles in plasma method is higher than HVOF coating techniques (Figure 2 (c) and (d)).



(a) Plasma (b) Plasma



(c) HVOF (d) HVOF

Fig.2: FESEM of Cr_3C_2–NiCr coated samples at different magnifications: (a), (c) 300X; (b), (d) 1000X

3.2 Wear behavior analysis

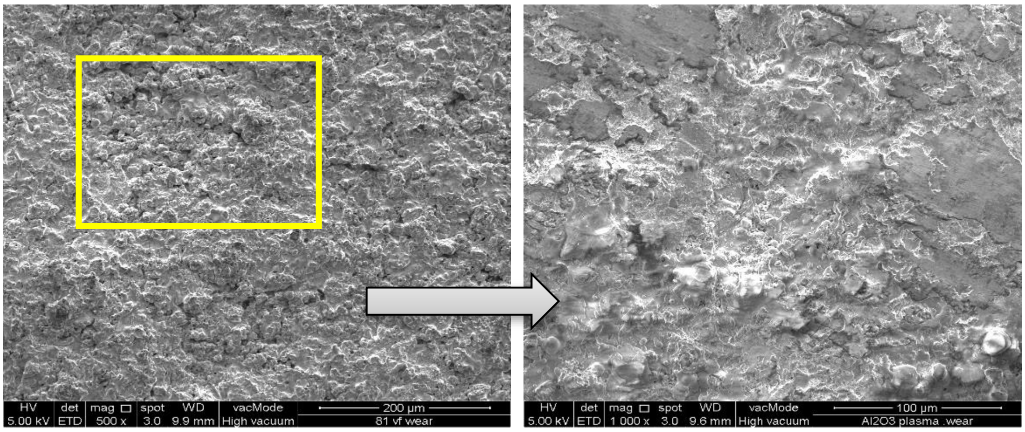
The coated sample roughness for plasma and HVOF is 6.2359 and 6.4166 µm respectively. As reported in previous studies, coating roughness plays a critical role in coating lifespan.

The average microhardness of samples coated by plasma and HVOF methods is 800-850 and 890-930 hV respectively. According to Scrivani et al. (2001) [20], the hardness of Cr_3C_2–NiCr coated using HVOF with propane fuel consistently has 950 hV hardness. Chatha et al. (2012) [21] reported that high volumes of carbides are well dispersed in the matrix. This factor might be responsible for higher microhardness and lower porosity values found in this type of coating.

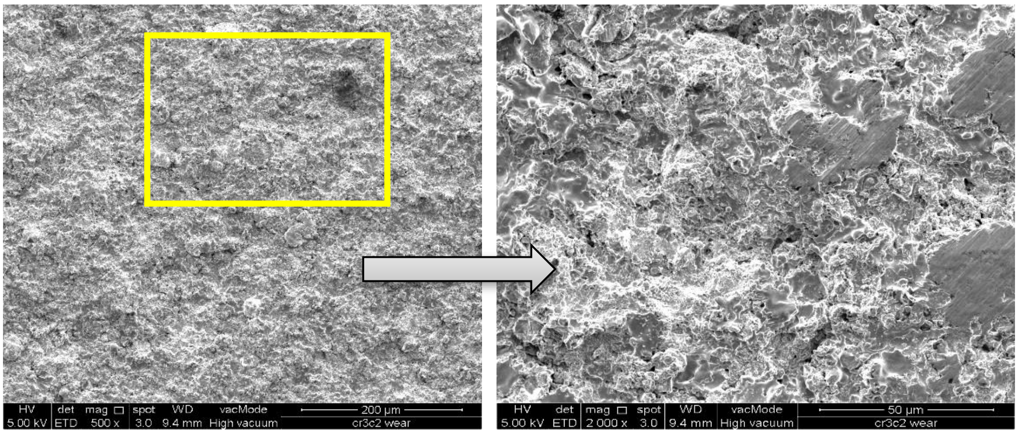
The regions of wear and coarse, worn debris from the coated samples at maximum load (20 N) of wear testing were investigated using FESEM.

In contrast, when maximum load was applied to the coated samples illustrated in Figure.3 no obvious difference was observed before the wear test. Moreover, no cracks or deformation formed at the edge of the samples after applying maximum load. Applying maximum load resulted in slight abrasion and wear in some sample surface regions, which were, however, smooth, as they were before testing (Figure. 2). As shown in Figures.3 (a), (b), the plasma-coated samples had bigger and rougher wear debris than the HVOF-coated samples (Figures. 3(c), (d)). In addition, within the tracks at maximum load (20 N) a little loose wear debris was found. On the surface of the coated sample exposed to wear testing, no cracks were detected. This was associated with the elevated bonding strength between the splats and component as well as the significant role that bond strength can play in splat propagation and resistance to crack initiation [22].

Generally, for Cr_3C_2–NiCr coating, NiCr alloy is a continuous matrix phase with chromium carbides as hard reinforcement phases. Because the microhardness of chromium carbides is much higher than that of the NiCr matrix, the carbides are more resistant to cutting or gouging than the matrix alloy phase [23]. Accordingly, the carbide phase, having higher wear resistance, would be removed at a lower rate, and the wearing off of NiCr alloy binder would occur more preferentially [24]. Consequently, the abrasive wear of the plasma and HVOF Cr_3C_2–NiCr coating in the pin-on-disc test occurred in two steps. The first step was the successive removal of the NiCr binder. Because the metallic Ni–Cr binder phase was deformed by the stress of compression produced by the sliding WC–6%Co plate, it exposed the carbide particles to the surface. Then the removal of carbide particles occurred by fracturing or loosening followed by subsequent pulling out by the abrasive particles [22]. Therefore, an improvement in the matrix alloy hardness and bonding strength between carbides and the matrix may enhance the coating's abrasive wear resistance.



(a) FESEM-500X (Plasma) (b) FESEM-1000X (Plasma)



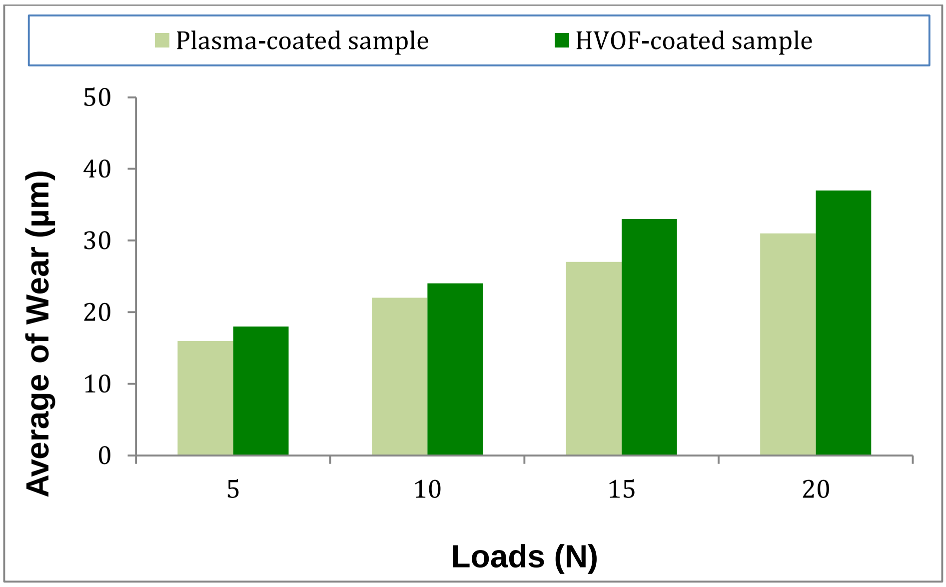
(c) FESEM-500X (HVOF) (d) FESEM-2000X (HVOF)

Fig. 3: FESEM of wear debris of Cr_3C_2-25NiCr coated samples under maximum load (20 N) for: (a), (b) plasma; (c), (d) HVOF coating

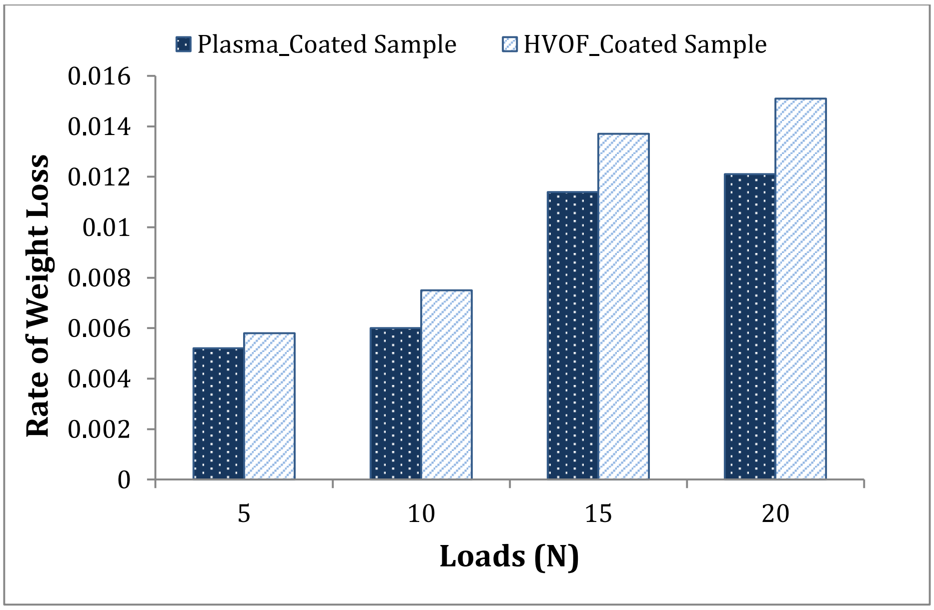
Figure 4 present the mean scores of weight loss as well as wear rate for both coating methods under varying loads. According to Figure. 4 (a), when different loads were applied on the different coated samples, the amount of wear for the HVOF-coated sample changed from 10 to 25 µm, while for the plasma-coated sample it changed from 12 to 30 µm. Thus, the average wear with the plasma method is slightly higher than the HVOF method. Figure. 4 (b) shows the maximum values of weight loss for the plasma samples, which were 0.0039, 0.0040, 0.0087 and 0.0115 g for loads of 5, 10, 15 and 20 N respectively. This confirms the wear rate trend of plasma-coated samples.

Different comparative studies on thermally sprayed coatings and hard chromium electroplating, suggest that the abrasive wear resistance of HVOF coatings could be 2–16 times higher than hard chromium coatings [25] Moreover, the wear rate is very sensitive to abrasive characteristics like chemical composition, shape, size and angularity.

Particle shape can significantly influence the wear mechanisms and determine if the particles will be able to roll or slide during three-body abrasion. Particles with angular shape can generate wear rates higher than rounded ones [26, 27]. Since finer, rounded particles produce less damage on both surfaces, finer carbide size coatings would exhibit a lower wear rate [22]. Furthermore, the smaller size of chromium carbide could involve a better distribution and cohesion of reinforced particles in the binder phase, which could decrease the pullout of the carbide particles during the sliding test and consequently produce a lower specific wear rate [21].



(a)



(b)

Fig. 4: Behavior of Cr_3C_2–25NiCrplasma and HVOF-coated samples under different loads: (a) average wear; (b) weight loss rate

4. Conclusion

Cr_3C_2-25NiCr chemical composition layer deposited by HVOF and plasma methods on the surface of carbon steel can significantly change the properties of carbon steel in terms of tribological performance. The tribological properties of HVOF-coated samples under different loads applied show more durability and the weight loss rate of this sample was very limited. However, there is a small difference between the wear rate of plasma and HVOF-coated samples.

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