Influence of deposition parameters on Tribological Performance of HVOF Coating: A review

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Abstract. Any mechanical component stationary or in relative motion is exposed to severe surface phenomena like corrosion, wear, abrasion etc. To address these issues various surface treatment processes are in industrial practice. In recent times, coatings techniques have been identified as cost effective alternative to other surface modification techniques. Thermal spray technique proves to be the prominent method to among a large variety of processes available. HVOF method owing to its capability to provide wear and corrosion resistant coatings with characteristics like high hardness, adhesion, density (porosity <1%) is widely accepted across industries. Process parameters seems to have significant influence on coating properties like porosity level, oxide content, micro hardness and tribological performance of coating. This paper intends to investigate the effect of above mentioned process deposition parameters on physical, mechanical, wear, erosion and corrosion properties of coating.

1. Introduction

A particular mechanical component can be subjected to different sorts of operating environments. Corrosion, wear, oxidation, abrasion, adhesion and radiation are regular phenomena that these components are regularly subjected to. The extent of deformation and wear depend on the surrounding media. When two or more parts are having a contact, the properties of both parts influence wear. Wear, friction and corrosion are surface phenomena and cause great damage to the parts. All industries including automobile, aerospace and biomedical receive the highest impact of these phenomena.

The wear and friction lead to a loss of about 2-4% of the GDP of an industrialized nation. Losses due to friction account for nearly 23% of the total worldwide consumption of energy [1]. The estimation of the severity of friction can be judged from the fact that near about 33.3% of fuel is wasted to limit friction in automobiles. A reduction in losses on account of friction can lead to savings upto 576,000 million Euros and 385,000 million litre of fuel. There is also a reduction of 960 million tons of CO2 emission from this [2]. The advent of corrosion can cause more severe failures than that by friction alone. The total monetary value of corrosion is near about 3.4% of world’s GDP [3].

The primary requirement of surface engineering is modification of surface properties through various processes e.g. Atomic Deposition, Particulate Deposition and Bulk Coatings. The characteristics of HVOF coatings are quiet superior. They include good bonding strength, dense and optimized structure and less number of pores. These coatings also possess great surface hardness. There are various spray methods e.g. by flame spraying, High Velocity Oxy-Fuel (HVOF) and plasma spray. Main aim of all these methods is to develop wear resistant and corrosion tolerant coatings.

There are various ways through which different class of materials like metals, ceramics, cermet and polymer materials can be deposited using HVOF method. The materials can take the powdered form, wired or rod form. They are inserted into a gun (torch). Inside the torch the material is heated...
near or slightly above the melting point. Material is converted to molten or semi-molten droplets. They are made to accelerate by the carrier gas. Their high velocity projects them upon the substrate. Upon striking, the droplets get converted into lamellar (thin) morphology. The heated droplets adhere to the surface. They keep on overlapping one over the other. They get interlocked during the process of solidification. A number of passes are required to produce a thick coating [4]. Table 1 shows the process attributes of various thermal spray methods.

The HVOF method is of great importance among these techniques. HVOF equipment of modern state of the art have gas speeds ranging up to 2000 m/s. The high speeds and medium temperatures allow very dense coatings to be developed with exceptional wear and corrosion behavior and excellent bond strengths [5]. Coatings sprayed by HVOF have found broad application in the maritime, aviation, automobile sectors and associated fields.

Thermal spraying with HVOF is a technique that melts and propels the powder material at high speed. It makes use of the oxygen and mixtures of the fuel gas, towards the substrate. Gases like H₂, C₃H₈, CH₄ propylene, acetylene, SPRAL 29 kerosene, ethylene, crylene, and LPG etc. helps in burning of fuel. The HVOF system is composed of a spray gun and three units. There are various units to feed powder, to measure and control the flow of the gases and to supply air and carrier gas. The powder feeder is made of a hopper, one vibrator for air, meter to monitor feed rate and controller. The material to be coated is injected from the feed unit via carrier gas and finally to the gun, where combustion takes place. By measuring feeding rate, the quantity of powder necessary for coating can be controlled. Based on the melt temperature and feed rate of the fuel, the powder material reaches the flame in the combustion zone. At this stage, it could be in molten or may be in semi-molten form. The HVOF cycle has a flame temperature of about 3000˚C [6]. At supersonic velocities, the molten or semi-molten particles are then pushed from nozzle of gun onto the target / substrate. The splat wise deposition takes place at the substrate. Basic principle of Gas fueled HVOF technique is shown in figure 1.

There is a high speed and high impact force of the accelerated particles of powder. The coatings developed by the HVOF technique have less number of pores. The oxy-fuel coatings have a higher bond strength than other methods of spraying by plasma, flame and electric arc [6]. The typical features of HVOF coatings like inter-lamellar splats, porosity, semi-molten top layer due to high velocity semi-molten particles are shown in figure 2.

The process parameters like spraying distance, fuel and oxygen flow rate, rate at which powder is fed, particle speed, flame temperature have significant influence on coating properties. The most important coating characteristics include porosity level, oxide content, micro hardness, bond strength and tribological performance. The intent of this paper is to review the influence of process deposition attributes on physical, mechanical, wear, erosion and corrosion properties of thermally sprayed coating.
2. Physical and mechanical properties of Coatings

The deformation was more pronounced in the liquid state as compared to the molten state. The coatings had a compact (dense) structure. The hardness of coating was because of high particle K.E. during HVOF technique. As a result, the droplets reacted with oxygen less frequently. All this happened during the flight time of the particles and their flattening. The diffusion mechanism allowed the process of oxidation to take place slowly. The high K.E. of the particles (plastic condition) allowed flattening by process of deformation. It resulted in the formation of dense and pore-free coating. The amount of oxygen in the coatings was low.

Micro size and nano size coatings of Tungsten Carbide-Cobalt (WC-12%Co) were thermally sprayed on carbon steel using both plasma and HVOF spray. The fuel rate was taken as 0.0063 L/S. The powder feed rate for the particles of micro and nano size was taken as 77 and 90 g/min respectively. Spray distance for HVOF process was taken as 381 mm while it was 127 mm for plasma spray [7]. For HVOF micro, the coatings were designated as H1 and for H2 as HVOF nano. All these parameters resulted in very dense HVOF coatings (porosity < 1.3%) and a very low (less than 1.69%) amount of oxide. These features are evident in figure 3.

It was observed that coating hardness produced by micro-sized powder spraying by HVOF when averaged was found to be 1066 HV (H1). While, for the nano-sized powder coatings produced by (H2) sprayed by HVOF method it was found to be 1367 HV. It was due to distribution of the nano-sized powders over large area. The finer distribution of nanostructured carbides in the matrix was also responsible for greater hardness of H2 coating.
Lekatou et al. [8] conducted a similar analysis. They studied the traditional and nano WC 12%Co HVOF coatings deposited on Al7075 T6. They investigated that the nano-sized powder coatings had considerably lower porosity. Their mechanical properties like micro-hardness and fracture-toughness were also better. But the degree of decarburization was higher, as compared to their traditional counterparts.

![Figure 3. Coatings of H1 showing voids and sharp edges in cross section mode [7]](image)

![Figure 4. SEM micrograph of Ni3Ti coating showing cross sectional thickness and lamellar microstructure [10].](image)

Researchers recorded Higher hardness and less porosity [9], in the three coatings (Cr$_3$C$_2$-self fusing alloy, Cr$_3$C$_2$-Ni-Cr-Al-Y, Cr$_3$C$_2$-Ni-Cr) deposited by HVOF spray. The deposition of Cr$_3$C$_2$-Ni-Cr-Al-Y coatings took place by Atmospheric Plasma Spray (APS), on nimonic discs. They discovered that APS deposited CRNY coatings were more porous (6-12%) than the coatings sprayed by HVOF (3-8%). The deposition parameters were oxygen flow (800, 870, 940 slpm), kerosene flow rate (20.8, 22.7, 24.6 litres per hour) and deposition distance (320, 350, 380 mm). They resulted in a higher hardness of HVOF coatings (1100-1300 HV0.1) compared to the plasma sprayed coatings (700-800 HV 0.1).

Katranidis et al. [10] investigated the effect of variable parameters e.g. spraying distance, angle of spray and traverse speed of gun on the complex geometry. There was a rotation of samples in front of the spraying gun. Results of WC-17 percent Co powders on steel substrates through HVOF revealed that in the short spray distance, micro-mechanical properties like compressive residual stresses, micro-hardness and porosity were higher. The particles appeared to hit at lower temperatures and elevated velocity. It resulted in high transfer of peening stress. Porosity value was unaffected when it was spray from very long distances from the gun at different angles. It was because peening stresses in the microstructure of the coating became less important. Gun traverse velocity did not impact the levels of porosity.

The production of Ni3Ti and Ni3Ti+(Cr3C2 + 20Ni-Cr) coatings by HVOF technique on AISI 420 stainless steel showed better mechanical properties. MDN 420 and ASTM B3265 titanium alloy (Ti-15) acted as the substrate. The microstructure of the coatings was concentrated. The layers reflecting the laminar structure [11] are shown in Figure 4. The coating micro-hardness was found to be higher than that of the substrate. It was due to the greater density, lower porosity and high micro-cohesion between the slosh of coating materials. Low porosity (1-3%) indicated that the HVOF technique produced sufficient deformation of the particles. They travelled at high velocity and had high temperature. It caused high cohesion of individual splats [11].

It was planned to increase the solid particle erosion resistance of WC 10Co 4Cr ceramic powder [12]. In this study, the influence of ceramic-reinforced (Yttrium and Zirconium) coating powders was investigated. The coatings were manufactured by HVOF technique on SS X2-Cr-Ni-Mo-17-12-2. The
fuel flow rate of LPG was 70 slpm. With the aid of the lab scale pot tester, tribological properties were tested. Coal ashes were used as the erodent (i.e., fly ash and bottom ash). In comparison with traditional WC-10Co4Cr cermet. Yttria enhanced WC-10Co4Cr coating showed superior tribological and mechanical properties like low porosity and high micro-hardness. In fly ash slurry, the zirconia reinforced WC-10Co4Cr coating had demonstrated excellent wear resistance.

3. Wear Resistance Properties

HVOF is among the versatile techniques of deposition of coating material. This method increases wear resistance. This is a process with no material constraint and has the ability to deposit coatings ranging from few micrometres to tens of millimetres. Wide variety of shapes and sizes are possible with HVOF. The carbide ceramic coatings HVOF are commonly used against tribo-corrosion in the petroleum industries. One such carbide coating (Cr3C2-NiCr) performed by the HVOF method on carbon steel [13] showed better tribological efficiency than the uncoated sample. A number of coating parameters such as the feed rate of powder (50-60 g / min), the flow rate of fuel (20-30 l / hr) and the spray distance (200 mm) were used. They played a major role in achieving a compact microstructure [13].

In industries such as mining and hydropower production, the coatings such as iron aluminides have proven to be protective for steel components. Amiriyan et al. [14] performed the HVOF sprayed Fe3Al / TiC coating wear test. They found that the mechanical and tribological performance of the alumina counter body coatings were improved. The spike in wear resistance of counter body coatings was because of the improvement in hardness. The development of TiC particle (in Fe3Al matrix) assisted in this process. Sliding and abrasive wear tests conducted by Bolelli et al. [15] on HVOF as well as HVAF-sprayed Cr3C2 25 wt. % Nickel Chromium coatings (hard metallic). They used two different particle sizes (fine and coarse). Their study showed that the fine feedstock powder provided coatings having higher wear resistance than the coatings produced by coarse feedstock powder. It was because of greater cohesion between matrix and carbide within the lamellae.

The surface of the substrate (Ti6Al4V) was treated with W-DLC, HVOF and Ion-Implantation techniques. The researchers used the coatings of CrN with a topcoat (C: H: W). The Cr3C2 was embedded in the Ni / Cr matrix and Low Pressure Nitriding [16] was used to improve the tribop- performance of Ti6Al4V in seawater. The Ti6Al4V substrate coated with W-DLC coating showed the minimum friction. The stability of friction was due to the formation of a transfer layer of less shear strength at interface. The coating of W-DLC and HVOF showed better tribo-corrosion efficiency under Open Circuit Potential (OCP) conditions. But the Ion implantation and the untreated Ti6Al4V substrate did not perform that well. It can be attributed to their enhanced friction and shallow depth of wear scars (Figure 5).

![Figure 5. Depth of wear scar on target surface treatments](image)

Carbon steel is another most used material in oil and gas industries. It is exposed to regular tribo-corrosion [12]. Tribological and mechanical properties of HVOF sprayed layers on carbon steel were
investigated in [17]. The coatings had the approximate formula Al₂O₃-40TiO₂ and Cr₃C₂-20NiCr. Both coatings were better in terms of thickness, porosity and substrate bonding. The highest wear resistance was that of the Cr₃C₂-20NiCr coating deposited by HVOF. The sample wear mechanism was based on the properties of the transferred layers. A variation in loads resulted in a change in the properties of these layers.

The effect of particle size on coating wear efficiency has been investigated [18]. The compact WC-10Co-4Cr coatings were deposited with average particle sizes of 0.6, 1.2 and 6.1 μm. All these three types of WC particles were deposited on steel substrates (ASTM 1045) for aircraft landing gear [18]. HVOF with process parameters such as kerosene (0.37 litre/min), powder feed speed (85 gram/min) and stand-off distance (380 milli-meter) was used in this study. The low size of the particles resulted in low porosity. The best abrasive wear resistance was demonstrated by 1.2 μm WC particles coating. The attributed like plasticity and homogeneity of coatings was found to be increased with the increment in the WC particle size. The micro-cutting wear mechanism was found to be primary wear mechanism. Researchers [13] investigated erosion and abrasion wear performance of HVOF deposited WC coatings. The coatings had an approximate chemical composition of WC₁₂Co, WC₁₀Co₄Cr and Cr₃C₂ 25NiCr. The substrate was 316 grade stainless steel. The erosion (solid particle) and abrasion testing were performed. The Cr₃C₂-25NiCr coating showed the maximum wear rate both tests (Figure 6). Cr₃C₂-25NiCr coating had the lowest coefficient of friction. The COF increased initially as surface asperities were ploughed and localized contact stress was found to be increased. Formation of tribo-oxide film resulted in lower COF (Figure 7).

Effect of particle velocity on coating performance was observed by Kumar et al. [14]. They used WC-CoCr hard coatings of composites on the steels used for hydro turbines using two different thermal spray techniques HVAF and HVOF. The parameters like spray particle velocities for HVAF were 1010 meter/s, 960 meter/s and 895 meter/s. HVOF used the particle speed of 680 meter/s. WC–CoCr coating sprayed at higher velocity by HVAF method exhibited comparatively better erosion resistance than others. It was true for all impact angles as well as jet velocity. HVAF samples performed better than HVOF coated ones. It was due to the better mechanical properties like adhesion, high density, increased hardness. The resistance to erosion was also found to be due to these attributes [14].

Another protective coating, Al₈Si₂₀BN was deposited via HVOF and plasma spray. The carbon steel substrate was investigated by researchers in [15] with respect to coating properties. The characterization of coatings was done to know about phase composition, micro-structure, micro-hardness and bond strength. Response to wear was investigated by applying 5N, 10N, 15N and 20N

**Figure 6.** Variation of abrasive wear volume with sliding distance at load of 20 N [13].

**Figure 7.** Variation in COF for at a load of 20 N [13].
loads on pin-on-disk machine. After which a comparison of the results was done. As per the findings, the durability of HVOF-coated models was greater than the plasma-coated samples. All these tests were performed under different loadings in the same environment [15].

In another study, WC 10Co4Cr powder, Cr$_2$C$_2$ 25NiCr powder and carbide powder WC 40Cr$_2$ 25NiCr, was deposited by HVOF method. The process parameters like Fuel flow rate 23.8 litre/h, standoff distance 380 mm and Feed rate of 70, 45 and 55 g/min were used by the researchers. They exhibited better mechanical and wear properties [16].

The process parameters were kept nearly constant at the values 0.46 and 0.38 l/min (Fuel flow rate), 45 g/min (Powder feed rate) and 356 mm (Standoff distance). The effect of coating powder material on the performance of the WC based HVOF coatings was assessed. Song et al. [17] reported the better performance of HVOF sprayed WC Co Cr coating under load of 96, 240 and 318 N. WC-Cr$_x$C$_y$-Ni coatings could not perform that well. The wear performance of the coating was determined by phase composition of phases and relative proportion of hardening carbides. The properties of binder and the interaction of carbide formation and matrix in WC-Cr$_x$C$_y$-Ni powder were responsible for its wear resistance.

WC coatings proved beneficial in conditions where cracking of coating is a normal occurrence. Tribological performances of such HVOF coated WC-12Co on steel sample were examined. The process parameters like Kerosene flow rate (22.7 l/h), powder feeding rate (65 gram/min) and spray distance (380 mm) were used. The researchers Tao Luo et al. [18] carried out rubber wheel abrasion test under dry condition and ball on disc wear tests in sliding module. The results showed that the coating exhibited poor wear resistance in abrasion due to crack propagation. However, the mass loss that occurred at the cracks was in the initial stages. As the time passed by, both the cracked and non-cracked HVOF coatings showed a similar wear rate. It was due to the ability of the cracks to store wear debris. The debris caused an abrasion of the surface of HVOF coating during sliding.

Optimum wear resistance and mechanical properties were obtained at different set of spray parameters. Co-Mo-Cr-Si super alloy coatings, prepared on Mar-M247 (Ni-based super alloy) by HVOF showed better fretting wear resistance. The coatings showed a dense (porosity < 0.8%) behavior. The process parameters like feed rate of powder (6.5 RPM), flow rate of fuel (6.0 GPH), O$_2$ flow rate (1950 SCFH) and spray distance (380 mm) were used. However, the effect of spraying parameters was less pronounced on hardness and wear tolerance of coatings [19].

4. Erosion and Corrosion Behaviour of Coatings

Effect of acid concentration on corrosion performance of HVOF deposited alumina coating was investigated. The AISI 4340 tool steel was used as substrate. Parameters like flow rate of fuel, feed rate of powder and spray distance were taken as 280 ml/min, 70 g/min and 50.8 cm respectively. The quantitative analysis of coated sample done by immersing in various media. They included HCl environment with concentrations of 5%, 10% and 15 vol.%. After 3 hours, it was found that the increment in acid concentration enhanced the corrosion rate. As a result, highly porous and deteriorated surfaces were obtained [20].

Aluminium and nickel industries face problems in pumps while transporting caustic liquor. Lima et al [21] used AISI 1020 carbon steel as substrate. Three powder materials of Cr$_x$C$_2$–25NiCr, WC–17Co and WC–12Co were used as feedstock in the HVOF method. Substrate was tested for slurry erosion testing. The erosive particles (400 gram/l) of Fe$_2$O$_3$ (HRC 40 to 50 and avg. dia. of 600 micron) were deployed as the erosive agent. Powder feed rate and Spray distance was taken in the range of 38-76 g/min and 250-350 mm respectively for three coatings. Impact angle was taken as 90. WC coated samples showed the highest micro hardness values. The WC–12Co coated layer (Figure 8) showed the highest wear under experiment conditions. The wear grew up with time.

WC–17Co coatings performed better in erosion test. It was owing to a unique combination of high micro hardness and low porosity. Poor corrosion behavior of Cr$_x$C$_2$–25Ni-Cr coating was due to
high roughness and porous nature. The destruction of the passivated layer lowered the corrosion performance [21].

Research work conducted by Peat et al. [22] [23] explored the tribo-corrosion behavior of HVOF coating. WC-Co-Cr, Cr$_3$C$_2$-Ni-Cr and Al$_2$O$_3$ surface coatings were formed on S355 steel specimen. The test was conducted under three conditions. They were erosive liquid impingement, slurry-erosion and dry jet-erosion. Fuel flow rate was taken as 681.5, 0.455 and 732 (l/min) for WC-Co-Cr, Cr$_3$C$_2$-Ni-Cr and Alumina (Al$_2$O$_3$) coatings respectively. Spraying distance was 229, 355 and 178 mm for above coatings, respectively. It was found that Al$_2$O$_3$ coatings provided comparably poor protection under E-C (erosive corrosive) medium. Despite Cr$_3$C$_2$-NiCr provided great corrosion resistance. But the coating failed poorly due to erosive wear under liquid impingement conditions. It led to highest loss of material out of all the investigated coatings. This wear behavior continued in erosion under dry as well as slurry conditions.

In another study, the Corrosion behavior of HVOF deposited WC-17Co, WC-10Co-4Cr and Cr$_3$C$_2$:25Ni-Cr coatings in solution of alkaline sulfide having S$^2-$, 0.2 milliliter/L, and pH value of 10 was evaluated. 18 days of immersion testing was conducted. The examination of corrosion rate showed that Cr$_3$C$_2$:Ni-Cr coating had less porosity. It was the reason for the best resistance to corrosion. In solutions of alkaline-sulphide (pH=10), the number of pores, formation of passive film and setting up of micro-galvanic potential between hard phase and binder phase played a great role in determining the corrosion behavior of HVOF coatings [24].

The prediction of erosion wear rate using an Artificial Neural Network (ANN) was done for hard coatings. The layers of coatings were deposited by different spray techniques including thermal. The division of coating was done in three groups of WC, CrC and metallic alloy coatings. Different microscopic characteristics that helped in controlling the mechanical properties and the tribo-performance of the 3 classes were analyzed. The results showed that the velocity of impact of the particles had a higher effect on the erosion behavior. But the angle of impact did not effect the erosion resistance much [25].

Zheng et al. [26] investigated commercial WC–10Co–4Cr coating deposited by using HVOF on the AISI 4140 substrate. ASTM G-73 standards were followed while conducting erosion testing. They revealed that resistance to erosive wear of the coating samples was remarkably improved. The wear performance was compared to that of un-coated material. At low angle of impact, the main erosive wear mechanism was micro-cutting as well as horizontal cracks failure (Figure 9). In a similar study [27], there was an analysis of erosive wear performance of WC–10Co–4Cr and Ni–20Cr$_2$O$_3$ coated SS 304 substrate samples. It was observed that WC–10Co–4Cr coated samples gave a better performance than Ni–20Cr$_2$O$_3$ [27].

The CaviTec powder in the atomized state was used to perform the HVOF coating. In this study, the C-E (cavitation erosion) testing of HVOF coatings was done. By milling the feed stock powder prior to deposition, the performance of the coatings was enhanced. A great improvement in the wear characteristics was obtained optimizing the deposition parameters. Damaged surface of Cavi-Tec coatings indicated that the defect sites acted as point of initiation for material loss and degradation of surface. Pores and the boundaries at the inter-splat regions were included in the defects (Figure 10) [28]. In a similar effort to reduce the wear of grinding rotors in high speed mill, WC-CoCr coating was deposited by HVOF technique. The process parameters like Ethylene (C$_2$H$_4$) (60 slpm) and spray distance (200 mm) were used. When tested for dry erosion, the coating had lowest weight loss than APS-sprayed Cr$_3$C$_2$:25NiCr and NiCrBSi coatings [29].

The slurry erosion-corrosion behavior of HVOF deposited WC-10Co-4Cr coatings (cermet) and the base SS 1Cr-18Ni-9Ti was examined by Hong et al. [30]. Spray of the feed stock powder took place at parameters like flow rate of kerosene (0.38 L/min), flow rate of O$_2$ (897 L/min) and nozzle spraying distance (300 mm). There was a rig with rotating disc apparatus. The rig also had circulating system facility. It was used to perform the coating. Slurry of water and NaCl (3.5 wt.%) were used in
the test. The results revealed higher slurry wear E-C (erosive-corrosive) resistance was found in case of WC-10Co-4Cr coating in comparison to the SS substrate in both media. Effect of porosity in relation to corrosion resistance was investigated in an another study [31]. The corrosion and erosion resistance (in the slurry environment) of HVOF deposited WC-10Co-4Cr coated samples was examined. The parameters like Feed rate (40 gm/min), rate of fuel flow (60 ltr/min) and spraying distance (200 mm) were used. The AISI 410 stainless steel (application in hydraulic turbines) was used as substrate. The Coatings had better wear performance during the slurry erosion test as compared to the uncoated steel substrate. In another study, it was found that the corrosion resistance was improved because of lower porosity. Presence of 5% TiO$_2$ in HVOF sprayed 80Ni-15Cr$_2$O$_3$ and 80Ni-15Al$_2$O$_3$ coating led to an increment in the resistance to erosive wear of mild steel pipeline. The process parameters like Kerosene flow rate (70 /min) and Spray distance (140 mm) were deployed. The application of this steel material is in mining and chemical sector. The prime purpose transportation of solids. Experimental results indicated that rotational speed played an important role in erosive wear of samples in given media, time duration of test and nature of eroding particles. Coating with composition of 80Ni-15Cr$_2$O$_3$–5TiO$_2$ performed better than 80Ni-15Al$_2$O$_3$–5TiO$_2$ coating [32].

![Figure 8](image1.png)

**Figure 8.** Eroded morphology of WC coating at low Impact angle (15°) [26].

![Figure 9](image2.png)

**Figure 9.** Cross sectional SEM image of coating after 2h of cavitation-erosion [28].

5. Conclusion
Wear resistance of HVOF coatings is better than other methods, except HVAF. They also have an excellent corrosion resistance. Their use is recommended for high temperature application also.

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