

Resistance of slurry erosion with HVOF coating: A review

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Abstract. Erosion - corrosion in various industrial applications causes considerable financial losses. Industry adopts many surface treatment methods to resolve these issues. Recent research suggests erosion-resistant coatings are economical than other surface modification methods. Surface modification techniques include thermal spraying, chemical vapor deposition, physical vapor deposition, chemical vapor deposition, laser surface modification, plasma nitriding and ion implantation. In order to prolong the life of industrial components exposed to wear and corrosion, thermal spray methods have been widely employed to apply coatings of different composition. Among the different coating's techniques, high velocity oxy-fuel spraying process is a novel and widely utilized thermal coating technology that produces a thick covering with a with porosity less than 1%. It is likely to achieve a coating thickness more than 1.5 mm by carefully controlling cooling to eliminate residual stresses. Increased durability, decreased porosity, and protection against erosion and corrosion are all results of using these spray procedures. The extensive utilization of HVOF coatings across various industries can be attributed to its notable characteristics. This review study analyzes how process deposition factors affect coatings physical, mechanical, wear, erosion, and corrosion properties.

1 Introduction

In order to address the issues of early degradation of components that are used in harsh conditions, coatings have been an essential tool for industries to combat these issues. Thermal spray procedures are a significant group of surface modification technologies that are experiencing rapid expansion. Particles that are either molten, semi molten, or solid can be deposited on a substrate by a method known as thermal spraying. Solid particles, wires, and suspensions make up the bulk of their feedstock materials, however they employ a vast array of other types. These materials include metals and alloys, hard metals, ceramics, and polymers. As a consequence of this, variations in thermal spray such as HVOF and atmospheric plasma spray methods are already well-accepted in the industrial space for the

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purpose of producing coatings that combat various types of surface degradation. Several thermal spray coating methods exist; selecting a suitable one depends on factors like functional needs, coating material compatibility, substrate size, shape, and metallurgy, adhesion levels, equipment availability, and budget. Thermal spray techniques include plasma spray, detonation gun spray, wire arc spraying, flame spray, high velocity oxyfuel coating, warm spraying, and cold spraying. The mechanical components were utilized in a diverse array of applications, effectively operating under challenging circumstances characterized by elevated loads, extreme temperature variations, and exposure to corrosive chemical environments. Erosion - corrosion and abrasion, either alone or in combination, are widely recognized as the primary factors leading to component degradation across various industries [1]. These parts need to be changed or fixed right away because it will increase costs, shorten the component's longevity, and reduce its effectiveness in functioning. Coatings are often applied because they protect the underlying metal from corrosive elements in the environment and enhance the practical lifespan of the parts. The hardness, porosity, and uniformity of the coating are significantly impacted by the consistency and quality of the powder used for HVOF spraying. There are many challenges that need to be overcome during HVOF coating process. This technique makes use of flammable gasses and high temperatures, which need cautious attention to avoid accidents or health risks. Oxidation of the coating or substrate during spraying might adversely impact the performance of materials that are sensitive to oxygen or high temperatures. High temperatures and rapid cooling rates in the HVOF process can cause thermal stresses in the substrate and coating, which may cause deformation, cracking of the coating. The quality and consistency of the powder used in HVOF spraying have a significant impact on the coating's performance, particularly in terms of hardness, porosity, and uniformity.

2 Thermal Spray Process

Thermal spraying is a popular method in several sectors for improving material surface characteristics. This procedure may be utilized to apply a specialized coating on various base materials. Figure 1 illustrates the schematic representation of thermal spray. It is possible to incorporate the coating material into the hot gas jet using a rod, powder, or wire. When droplets collide with a surface, they flatten and solidify, creating a coating. Whether these droplets are ejected from powders or created by atomizing wires or rods that are melting determines the extent to which they are melted. The particles, which are typically in powder form, melt during their flight and impact the substrate at high speeds, forming a dense, strong, and adherent coating. Factors such as the substrate's shape and roughness, surface chemistry, temperature control before, during, and after cooling, and particle impact parameters (size, velocity, temperature, and molten state) all contribute to the formation of microstructures in the coating. Other factors include the spraying pattern and the substrate's shape and roughness.

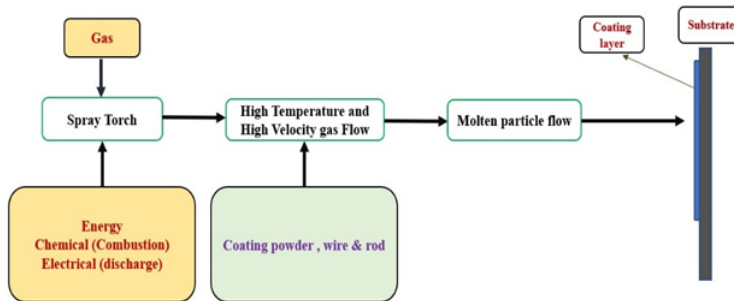


Fig. 1. Schematic representation of Thermal spray concept

3 Feedstock Powders

The adaptability of the thermal spraying method emerges from the fact that it may be used to any substance that can be melted without decomposing under the conditions of the technique. Thermal spraying can handle a wide variety of materials, including but not limited to metals, alloys, ceramics, cermet, composites, refractoriness, and mixes of these. Additionally, there are composite powders that combine the best qualities of their constituent elements to produce deposits with unique coating characteristics. Coatings with a broad variety of capabilities may be created using this variety of spray-grade materials, making them suitable for use in any operational environment. The thermal spray methods allow for the development of several types of coatings that are resistant to wear, corrosion, and oxidation. Additionally, coatings that act as heat barriers, electrical insulators/conductors, abrasable, and self-lubricating can be created. The usual coating choices are offered to resist the various types of wear. List of common coating powders are displayed in Table no.1. Coatings such as Al₂O₃, NiCrBSiC, WC-Co, TiC- Ni, nano-sized powders, and others are available for use in abrasive wear conditions. Materials such as NiCrBSiC, WC-Co, and Cr₃C₂-Ni Cr are employed for solid particle erosion. Powders such as Al-Bronze, Mo-NiCrBSi, and WC-Co are often chosen for adhesive wear. The best powders to use for dry sliding resistance to wear include WC- Co, Cr₂O₃, Cr₃C₂-NiCr, and NiCrBSi. It is observed that NiCrBSiC powder is best suitable for abrasive wear; cavitation erosion wears, for high amplitude fretting, solid particle erosion wear, adhesive and dry sliding wear condition.

Table 1. Commonly used Feedstock powder

Sl. No.	Powders	Application	Properties
1.	WC-CO, TiC, Cr ₃ C ₂ , Al ₂ O ₃ , Cr ₃ O ₃ , TiO ₂ , NiCr, NiAl	Jet Engine part, Seals, Pump Components, Automotive parts, bearing	Wear Resistance
2.	NiCrAl, NiCrAlY, CoCrAlY	Turbine Blade, Vanes, heating elements in chemical industries	Oxidation and Corrosion Resistance

3.	ZrO ₂ , Al ₂ O ₃	Combustion systems, Soldering equipment's	Thermal Barrier
4.	Ni-Graphite, Ni-Cu	Turbine seals	Abradable and self-lubrication

The high-velocity flow thermal spraying method may provide dense coatings that are extremely resistant to wear, corrosion, erosion, and low micro hardness, which has become more important in surface engineering [2,3]. The HVOF procedure is extensively utilized in several industrial sectors as a means of protecting components against the detrimental effects of corrosion [4,5]. The deposition of excellent quality coatings is a direct consequence of the substantial kinetic energy exhibited by particles of powder during the HVOF process. In comparison to other thermal sprayed treatments, HVOF coatings exhibit greater homogeneity and density. However, it is worth noting that residual oxides and porosity may still be present at the boundaries between individual splats [6]. Splat formation refers to the process by which small droplets or particles spread out when they impact a surface. Splat formation is a complicated instances that is impacted by various variables, including impact velocity, surface properties, fluid viscosity, and material characteristics. Powder material is propelled and melted with great force onto a specific surface using the HVOF thermal spray process, which employs a mixture of oxygen and fuel gas. The process makes use of oxygen (O₂) combined with various gaseous fuels like propane, methane, hydrogen etc. in order to facilitate combustion. Combustion takes place in the gun after the necessary powder has been transported there via the carrier gas. Coating powder quantities can be adjusted by means of the powder feed-rate meter. The powdered particle reaches the combustion region and, with respect to its degree of melting and feed rate, melts or becomes semi-molten. The HVOF method has a flame temperature of roughly 30000 C [7,8]. The material is deposited onto the intended target or substrate by means of the cannon's nozzle, which releases molten or partly molten particles at extremely high velocity. The coated substrate is hit with powder particles of sizes ranging from 10-63 μm, traveling at speeds of 300-800 m/s [9-11]. In comparison to other spraying processes, HVOF spraying results in coatings that are stronger at the bonding interface and have smaller pores [12-14]. The major criteria that set apart the various spraying procedures are the flame temperature, particle speed, and spraying environment. The gas pressure generated within the combustion chamber exhibits a direct correlation with speed and temperature of powdered particles when they make contact with the substrate surface. The HVOF spraying technique offers significant benefits, such as minimized porosity and a more refined spray surface, attributable to elevated impact velocities and lower particle dimensions. The wear resistance was enhanced due to the application of stronger and harder coverings (up to 1400 Hv), the development of dense and thick coatings resulting from reduced residual stresses, along with several additional advantages. In comparison to electroplating methods, HVOF has less of an impact on the environment, can be applied quickly, and results in denser coatings with fewer cracks and pores. The goal of this study is to find out how the deposition process affects the mechanical and physical properties of a coating that is sprayed by thermal spray, as well as its resistance to wear, erosion, and corrosion. Figure 2 depicts a simplified diagram of the HVOF spraying system. The chemical composition, microstructure, adhesion, and standoff distance are all investigated

by combining the thermal spraying parameters, which include the oxygen-fuel ratio, total gas flow, power feed rate, number of passes and particle morphology.

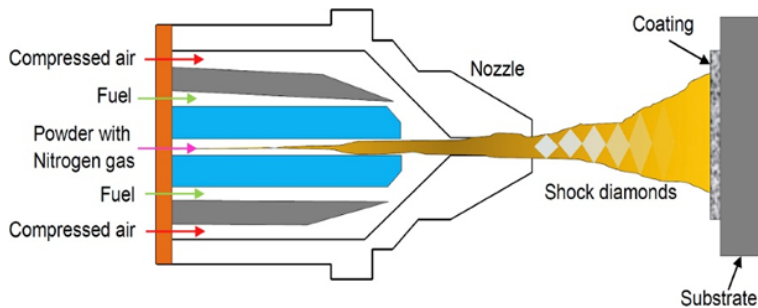


Fig. 2. Schematic layout of HVOF spraying system

4 Erosion and corrosion behaviour of the HVOF-sprayed coatings

HVOF thermal spraying is considered to be a highly effective technique for applying coating materials with the aim of enhancing wear resistance. Coatings with improved characteristics can be more easily produced with HVOF because of the thermal and kinetic energy it combines. The high velocity ensures strong adhesion and compact coating structures, whereas the thermal energy facilitates efficient melting and solidification of the powder particles. This phenomenon ultimately yields the formation of coatings that are characterized by high density and exceptional durability. Due to the slow diffusion process required for oxidation, less spray metal is oxidized in flight and flattening. Despite the plastic nature of the particles, their elevated kinetic energy enables them to undergo deformation, resulting in the creation of a compact and impermeable coating characterized by a deficient concentration of oxygen. To spray mechanically alloyed material, this aspect of the HVOF process is crucial [15-17]. After being deposited and resolidified, molten or partially molten powdered particles create coatings with distinctive splat-like, layered morphologies when they are sprayed using HVOF. In HVOF spray, powder particles typically have three distinct regions: a core of unmelted material, a molten surface, and a molten shell. Many researchers have demonstrated that various factors, including velocity and size of particles, gas temperature, trajectory through the gun, and type of gun have an impact on the relative proportion generated in a certain powder [18,19]. There is a common practice of using spray-fused coatings made of NiCrBSi alloys to increase the corrosion resistance of steels. Coatings made of NiCrBSi are very resistant to corrosion in alkaline solutions due to the surface's ability to self-passivate and produce protective films [20]. Coatings of Ni-Al-Ti and Ni-Cr-Ti were discovered to enhance the resistance of erosion wear of untreated SS-420. Coatings made of Ni-Cr-Ti are better than those made of Ni-Al-Ti. According to the findings, the most important component for both coatings was found to be the size of the particles [21]. Increasing the microhardness of the nanocomposite coatings while simultaneously lowering their porosity was accomplished by

the incorporation of YSZ nanoparticles into the WC-10Co-4Cr microparticles. WC-10Co-4Cr coating and substrate material are outperformed by ceramic nanocomposite coatings consisting of 95% (WC-10Co-4Cr) + 5% YSZ and 90% (WC-10Co-4Cr) + 10% YSZ in terms of erosion resistance. This results from the superior mechanical qualities of these coatings [22]. Several thermal spraying techniques, such as the detonation gun process [23], the plasma spray process [7] and various HVOF techniques [24] have been employed for the purpose of depositing a coating consisting of chromium carbide and nickel chromium. The HVOF approach is distinguished from other thermal spray methods due to its ability to deposit heat-sensitive materials at room temperature using a supersonic gas jet. The aforementioned advantages render HVOF a very promising and widely utilized method for the fabrication of cermet coatings with enhanced wear resistance. Tribological testing on NiCrBSi coatings shows that the HVOF spray coatings are better at microhardness and wear resistance than both the fused method and the plasma spraying method. Sliding wear resistance was lowest for plasma-sprayed NiCrBSi [25]. To better withstand high temperatures and prevent hot corrosion, possibility of depositing a 75Cr3C2-25NiCr coating using a HVOF technique on a T91 boiler tube steel substrate was also studied [26]. By manipulating the structure of Fe-based amorphous coatings and optimizing HVOF spraying conditions were able to create coatings with elevated hardness and reduced porosity [27]. A high-temperature air-jet erosion tester was employed to evaluate the corrosion characteristics of SS 304 boiler heat exchanger steel with an HVOF coated Co-based Stellite 6 coating under different situations, such as striking velocity, impacting angle, and time duration. In comparison to the other samples, the one coated with Stellite 6 on SS 304 showed the least amount of erosion [28]. Microstructure analysis of HVOF coated amorphous coatings was analysed by many researchers [29]. Researchers found that reducing porosity and the proportion of unmelted particles was achieved by raising the oxygen to fuel ratio. On the other side, higher powder input rates were linked to more porosity and a higher ratio of unmelted particles. In contrast, the characteristics of the oxide exhibited a negative correlation with the aforementioned factor.

5 The impact of deposition parameters on coating performance

Powder feed rate, fuel-to-oxygen ratio, and spraying distance are just a few of the factors that can drastically alter a coating's permeability and corrosion resistance. Particle velocity as well as temperature are increased as a result of rise in total gas flow rate, a drop-in powdered feed rate, and a decrease in spray distance. The sensitivity of particle velocity to spray settings is greater than that of particle temperature. According to the available literature, coating hardness increases with particle velocity and temperature while coating porosity decreases under the same circumstances [30-31]. At higher temperatures, particles of powder are more likely to become molten before colliding with the substrate surface. This makes them easier to flow, potentially making them better at filling the gaps that form along the perimeters of splats. As temperature rises, the majority of materials, including coatings, often exhibit increased softness. Heat induces increased molecular mobility inside the material, resulting in less stiffness and enhanced pliability or flexibility. Spraying variables have an impact on the attributes of HVOF NiAl intermetallic coatings were gas

blending ratio and particle size [32]. It has been discovered that coatings produced by molten particles with sufficient surface temperature and motion energy are thick and hard. Splat borders are enriched with metal oxides due to the oxidation of powder during HVOF spraying. Corrosion resistance and mechanical qualities of HVOF coatings will suffer from the presence of these oxides.

6 Conclusion

Based on the findings of various studies, it has been concluded by researchers that the HVOF technique exhibits significant potential due to its enhanced thickness capability, increased micro hardness, reduced porosity, compact coating, robust adhesion, and minimal environmental repercussions during the spraying process. HVOF coatings provide an ideal combination of durability, adaptability, and performance, rendering them a favoured option for many industrial applications. By developing coating components and deposition settings, these coatings may be customized to fulfill specific needs, guaranteeing enduring protection for components in the most challenging conditions. Despite many challenges, there are exciting opportunities and future directions for enhancing the tribological performance of HVOF coatings. Nanostructured coatings, hybrid materials, self-lubricating layers, and enhanced testing methods will advance HVOF coatings, making them more valuable in aerospace, automotive, renewable energy, and manufacturing.

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