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Study on oxidation and hot corrosion by HVOF in various AISI steels & superalloys: A Review

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***Abstract*—Cermet based coatings by HVOF may protect material components light weighted from wear while preserving fatigue strength when subjected to dynamical loads. It is possible to make personnel and production time savings. Spraying corrosion-resistant iron or nickel-based coatings using new HVOF guns that operates at higher combustion chamber pressures results in high deposition efficiency, high density, and low oxygen content. Spraying extremely reactive materials, such as titanium, under air conditions is also possible. The lack of appropriate characterization methods that allow for the determination of corrosion protective function is a key barrier to industrial usage of respective coatings. This review paper's objective is to present the most recent state-of-the-art on research that has been conducted by numerous academics to enhance the, mechanical, physical, erosion, wear & corrosion characteristics of AISI Steels and various super alloys using the HVOF Spray method by using various coating powders alone or in combination.**

Keywords— **Oxidation, Hot Corrosion, HVOF, AISI Steel, Superalloys**

1. INTRODUCTION

HVOF spraying is a subset of thermal spraying that was created in the 1980s. HVOF spraying works by combining fluid fuel and oxygen, which is then pumped into and fired in a combustion chamber. The resulting gas has an extraordinarily high temperature and pressure, and it is ejected at supersonic speeds through a nozzle. Powder is introduced into the high-velocity gas stream, which partially melts. The coated surface is in the path of the hot gas and powder stream. The thick covering that result has a low porosity and a high binding strength [1], providing a variety of advantages such as corrosion resistance. HVOF (properties or geometry). This surface engineering technology improves equipment life by boosting erosion and wear resistance, as well as corrosion resistance [2-5]. HVOF spraying has several advantages over other thermal spray methods, including a greater density (lower porosity) due to higher particle impact velocities, & increased coating quality. Lower oxide concentration due to decreased in-flight exposure time, stronger connection to the underlying substrate, and enhanced cohesive strength within the coating. Due to the shorter period spent at a given temperature, the chemistry of the powder is preserved. Higher impact velocities and smaller powder particles result in a smoother as-sprayed surface. Wear resistance is enhanced due to stronger, tougher coatings; hardness is improved due to less carbide phase degradation; and corrosion protection is improved due to less through thickness porosity [7-10].

2. LITERATURE REVIEW

HVOF materials in a semi-molten or molten condition. A number of alloys, metals, and ceramics can be employed for this sort of coating. In the HVOF process, four coating materials are most typically utilized. The following are the details: Aluminum bronze – thanks to coatings that demonstrate strength and high density, this is ideal for restoring worn-out components. Chromium carbide - where abrasive materials, hard surfaces, and fretting amplify the effects of wear and tear, chromium carbide's unique properties make it perfect. The dense coatings adhere well to the surface and are exceedingly hard, providing excellent protection. , Tungsten carbide-nickel super alloy – when compared to chrome plating, this super alloy offers several times the corrosion resistance [11-12]. Drilling components pump rotors, gate valves, ball valves, hydraulic rods, and other items are typically made of this material. Tungsten Carbide, this substance has the best low-temperature abrasive wear resistance of any of the HVOV coatings. This is the appropriate material in situations when abrasive wear is the predominant failure mechanism. Stainless Steel - Using HVOF to spray a substance Stainless steel delivers a dense, well-bonded coating at a reduced cost. These coatings are utilized in salvage and repair applications to defend against corrosion, cavitations, and low temperature particle erosion.

All thermal spraying techniques work by heating a feed stock material (powder or wire) to a high velocity and then letting the particle to strike the substrate surface. The particles will get deformed and stick to the substrate. In HVOF, which uses the combustion of gases or liquids, a thermal spray gun mechanism is used. Hydrogen and liquid fuels like kerosene are employed in the combustion process. Within the combustion area, oxygen and fuel combine and atomize under constraints that monitor the proper combustion mode and pressure required for coating [14].

High-pressure HVOF thermal spray equipment was used to spray 316 L stainless steel and Hastelloy C powders. Optical microscopy was used to investigate the microstructure and composition of the coatings that were created. The coatings' corrosion resistance was tested in an artificial seawater environment. The chemical makeup of the HVOF sprayed coat ings was nearly equal to that of the original powder, with the exception of an increase in oxygen concentration, which varies depending on spraying conditions. By increasing the combustion pressure to around 0.8MPa, the porosity of the stainless steel coatings may be lowered to slightly less than 1%. The porosity of Hastelloy C coating sprayed under conventional spray conditions, on the other hand, was less than 0.3vol percent, which was the porosimeter's detection limit. Even with the highest combustion pressure of 0.81MPa and the greatest thickness of 600m, the corrosion resistance of the as-sprayed stainless steel coatings decreased dramatically in a very short period of 3 days. Among the coating procedures by thermal spray, HVOF spray is one of the best options for hard, less porous and wear-resistant coatings [15]. This technique uses velocity more than 1000 m/s at relatively lower temperature, resulting in semi-molten particles engaging with one another and boosting the particle's cohesive strength. As a result of this method, low permeability and high bond strength are attained. HVOF spray coated substrates can have ten times the adherence of standard flame spraying processes. The HVOF spraying systems include a spray gun including a unit of powder supply, a flow metre, and an air and gas supply unit. In this process, oxygen and gas or liquid fuel are continually combined, inflamed, and combusted in a combustion chamber. As a result of combustion, hot gases are released at high pressure, and these gases travel through a nozzle before going through a nozzle. Hydrogen, acetylene, methane, kerosene, natural gas, and other fuels are examples. The gas jet exit from barrel's exceeds the speed of sound (>1000 m/s). After that, the powder feedstock is injected into a high-velocity gas stream and accelerated to 800 metres per second. The substrate on which the coating must be applied is also impacted by the accelerated powder. Because to high-speed impacts of powder grains with the base metal, the powder partially melts in the flow and partially melts on the deposited surface. Due to the heat generated when particles collide with the substrate, they become completely molten, resulting in superior coatings by HVOF. As a result, they've grown inextricably linked, resulting in high-quality coatings. HVOF coatings are excellent for usage in extreme temperatures, corrosive conditions, and erosive environments due to their high bond strength, greater density and lesser porosity that provide a material having high toughness, mechanical-strength, & hardness. Spray factors including spray distance, flow rate of compressed air, feed rate of powder and flow rate ratio of oxy-fuel have an impact on the properties & thickness of depositions by HVOF. Examine several study papers and determine the outcomes, as stated in table-I

Table I

Literature survey & its compression for various research papers [16-23]

Substrate material	Coating material	Coating method, parameters	Application	Testing Environment-Temp./Duration	Results	reference
IN738 superalloy	Commercially available shot peened nanostructured Ni-20Cr-10AlY powder having a particle size average of 52m bond coating	Cold spraying	Applications for advanced gas turbines include aircraft and electricity generating, as well as diesel engines..	Air atmosphere 900^0C & 1000^0C	During oxidation at 900^0C, a few oxide needles formed over the local coating surface, in addition to the -Al2O3 oxide that grew in a spherical shape, and little spherical -Al_2O_3 covered much of the shot peened covering. Al_2O_3 is the oxide that forms a spherical shape on the surface of coating & shot peened coatings at 1000^0C.	Qiang Zhang et al. (2007)
GH536 superalloy	NiCrAlY and NiCrAlY-Al_2O_3	Plasma sprayed Coating, laser remelted coating		1000^0C for 100h	In both NiCrAlY and NiCrAlY-Al_2O_3 coatings, laser remelted gained less weight than those that were plasma sprayed.	Y.N. Wu et al.(2000)
Low carbon non-alloyed steel	Deloro 30 Deloro 40	Plasma coating of (Fe-B-Cr)+Al based coatings and electric arc coating (Fe-Cr-B)+Al based coatings (laser treatment)			On a non-cooled substrate, LSM was followed by quick solidification of the molten layer, which produced a highly refined microstructure. Laser treatment can substantially improve the coating's strength and anticorrosion qualities.	Pokhmurska et al (2000)

Material of Turbine comopnent	Ni22Cr10A11Y(Amdry 962) and Ni31Cr11Al0.6Y(Amdry 964)	Plasma-sprayed NiCrAlYbond coatings (APS)	Turbine component	1000,1100 and 1200^0C for 50h and 100h	Amdry 962 coating has a higher isothermal oxidation resistance than Amdry 964 coating..	Hanshin Choi et al. (2001)
Stainless Substrate	NiCr coating (80%Ni,20% Cr)	HVOF	Gas Turbine Engines		A better density & cohesive strength of splats are present in NiCr coatings deposited by HVOF, which also improves micro hardness.	N.F. AK et.al(2003)
α+β Ti6Al4V	Mixture of Ni5Si2 and F.C.C. Ni in two phases	Magnetron sputtering from a Ni_3Si target	Gas Turbine Engines	Corrosion trials at 600^0C for 10 hours in an H_2O/ O_2 mixture with NaCl deposit on the specimens, and oxidation testing at 650^0C for 100 hours in ambient air.	The Ni-Si coatings outperformed Ti6Al4V in terms of resistance of oxidation at 650^0C in H_2O/NaCl & air induced resistance against corrosion at 600^0C, as well as eliminating the corrosion-induced fracture seen on the surface of untreated Ti-6Al-4V samples after 10 hours of corrosion at 600^0C.	Cunzhen Yu et.al.(2007)

9Cr-1Mo(ASME T91)	80Ni-20Cr Mass%(0.03C0.005P0.025S0.90Si0.92Mn19.7CrbalNi) and 50Ni-50Cr Mass%(0.05C0.005P0.012S0.7Si0.2Mn50CrbalNi)	HVOF	Boilers	Steam oxidation test at different temp. (600,650,700 and 750^0C)	For 600 and 650^0C, the 80Ni-20Cr coating demonstrated good steam oxidation resistance for 1000 hours of testing. In all of the conditions examined, the 50Ni-50Cr coatings performed admirably. At the coated surface of the 80/20 NiCr cladding steam oxidised at 750^0C/1000 hours, Mn segregation and Si enrichment were discovered. The elements segregated less to the coated surface in 50Ni-50Cr specimens steam oxidised at 750^0C/1000 hours.	T. Sundararajann et.al (2003)

3. STUDY ON HVOF

The purpose of this research is to coat the IS2062 to increase its surface hardness and wear resistance, with an emphasis on HVOF spray parameters including flow rate of oxygen, spray distance & thickness of coating. A thermal spray technique in which a oxygen & fuel are Combined, fed into a zone during combustion, and ignited is known as High-Velocity-Oxy-Fuel (HVOF) coating. The gas created in the combustion chamber has a very high temperature and pressure, and it is ejected at supersonic speeds through a nozzle. Powder is injected into a high-velocity gas stream and driven toward the coating substrate. The coating has a low porosity and a high binding strength to the substrate material, making it wear and corrosion resistant. The high velocity of the particles provides kinetic energy, which is more essential than temperature in the HVOF spraying process. One of the advantages of the HVOF spraying method is the ability to produce exceptionally dense and durable coatings at low temperatures. The HVOF procedure is depicted in Figure1 (a & b).

Fig.1. (a) Thermal Spray Gun

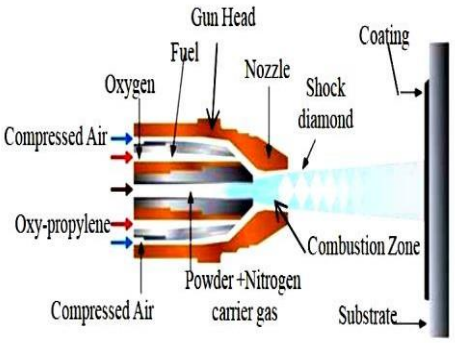

Fig1. (b) Schematic diagram of the HVOF process

4. SUMMERY AND CONCLUSION

According to the results of various studies, the HVOF process has enormous promise due to its ability to deposit coating thickness up to several millimetres (200-300 mm), lesser porosity (typically 1 percent), higher micro-hardness dense coating, and superior adhesive strength. Furthermore, Ni-Cr based coatings were shown to have extremely excellent hot corrosion resistance. Furthermore, the HVOF technique is frequently utilised in commercial applications because it creates coatings that are well-bonded, wear-resistant, and corrosion-resistant. Furthermore, applying HVOF coating to functioning components will extend their working life. Thermal spraying with HVOF is a sophisticated manufacturing technology for enhancing or enhancing component functioning. The HVOF technique effectively creates a supersonic flame in a dynamic environment under controlled settings & powder particles in partially melted state are deposited on component surfaces. The technique of spraying by HVOF is popular now a day and has advantages over traditional methods of thermal spraying for a variety of material coating applications, such as coatings for carbide cermets. Cermet layers (e.g. WC–CoCr & NiCr-Cr_3C_2) that has been successfully deposited using the HVOF technique are a feasible alternative to hard chromium and can assist to reduce the health hazards associated with hexavalent chromium solutions. According to the findings of the study, additional heat treatment (HT) improves the adhesive-strength & wear characteristics of claddings of carbide generated by HVOF. Following HVOF coating, HT is normally done to adjust & modify the phase's microstructure & composition. Heat treatment of as-sprayed coatings can also help to reduce stress. Remelting with highly radiant laser or electron beam as a surface modification technique has been reported to modify different types of HVOF coatings after HVOF deposition. Following these surface treatments, the cladding powder material can be mixed with the base metal to generate a new dense and durable coating with improved substrate/ coating adhesion. When new generations of HVOF and correctly selected post-spray processes develop, new application markets are expected to arise. End-users may benefit from innovative, more effective reduced friction solutions provided by nano-phased thermal spray coatings.

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