"HARDNESS AND WEAR ANALYSIS OF HIGH VELOCITY OXY FUEL SPRAY COATING ON AISI 1015 MILD STEEL SUBSTRATE" - A REVIEW

JOSHI YASH [1], MR. NAITIKBHAI PATEL [2]

[1]*Production Engineering (Mechanical Department), M.E.C, Mehsana- 384315, Gujarat, India*
[2]*Mechanical Engineering Department, M.E.C, Mehsana- 384315, Gujarat, India*

ABSTRACT

High velocity oxy fuel spray coating process is an effective surface engineering technique for its good thermal protectiveness, high hardness and wears resistance. The process covers a wide range of industrial applications including manufacturing, textile, and paper industries, and so on. To improve the micro hardness and wear resistance of mechanical components, high velocity oxy fuel coating has been applied to deposit of WC-17Co coating on low carbon AISI1015 substrate. The phase constituents and microstructure of the composite coating will investigate using optical microscope (metallurgical). Hardness at the coating cross section and wear rate measurement . Experimental data will be take according to orthogonal array to choose three process parameters and three levels. The experimental data will be optimizing by full factorial methodology, and give mathematical equation by regression analysis.

1 INTRODUCTION

The HVOF process efficiently combusts oxygen and a gaseous or liquid fuel to produce high kinetic energy with controlled heat input. The coating material, in powder form, is introduced into and uniformly heated by the hot gas stream to a molten or semi-molten condition. The flame and powder are accelerated by a converging / diverging nozzle (air cap) to produce supersonic gas and particle velocities, which propel the powder particles toward the substrate to be coated. The powder particles flatten plastically upon impact with the substrate; cooling and solidifying to form the coating. High particle velocities, uniform heating and low dwell time combine to produce coatings that are very dense and tightly bonded to the substrate. Coating chemistries are more predictable and coatings have fine, homogeneous microstructures[1].

Coating of Materials Choose from a wide variety of coating materials including pure metals, metallic

alloys, metallic blends, carbides and self-fluxing materials, tailored to gas or liquid fuel systems. Fuels like Gas-fueled systems can use hydrogen, ethylene, propane, propylene or natural gas. Liquid-fueled system scan use Jet-A or kerosene. Choose the fuel process that is suitable to your production requirements, economics and coating quality needed. System Options**.** Choose the system configuration that fits your budget and production requirements, with a choice of standard and customized part manipulators and gun manipulators [1].

HVOF is better than PVD because it has low capital cost , low temperature then pvd .it has high deposition rate .is is ideal for coating large size components .it has Higher density (lower porosity) due to greater particle impact velocities . Improved corrosion protection due to less through porosity. Higher hardness due to less degradation of carbide phases. Thermally sprayed WC–Co coatings, of the order of 200–400 mm thick[2], are widely used in many industries as they offer an effective and economic method of conferring wear resistance without compromising other

attributes of the component. High velocity oxy-fuel HVOF. Thermal spraying has shown itself to be one of the better methods for depositing WC–Co powders because the higher velocities and lower temperature experienced by the powder particles as compared to plasma and the results in higher quality, more wear-resistant coatings, with higher levels of retained WC and less porosity. However, the effects of powder morphology, type of HVOF spray system and spray parameters have all been shown to affect the coating microstructure and, in turn, the wear resistance . therefore, study whether the benefits of increased hardness and wear resistance, observed in sintered nano composite WC–Co cermets, can be readily realized when they are sprayed as coatings by the HVOF method.
Mild (low carbon AISI 1015) steel has a reasonable strength and hardness; it is easier to weld than stainless, and it is cheaper. An important property of mild steels that you lose with stainless steel is ductility, the ability of a material to withstand plastic deformation without breaking. Due to the large application of mild steal and its cheaper cost it is coated with wc based cermets and used instead of S.S[3]. Deposition Materials WC based cermets WC-17Co cermets coating due to the high-impact velocities and the relatively low spraying temperature. The hard WC particle in the coating leads to high coating hardness and high wear resistance, while the metal binder (Co or Co-Cr) supplies the necessary coating toughness Here we choose WC-17Co because comparably WC-12Co and WC-Co-Cr the wear rate in WC-17Co is very less.

2 LITERATURE REVIEW

R. Ahmed et al (2015)[4] carried out experiment on sliding wear investigation of suspension sprayed tungsten carbide and cobalt to nanocomposite coatings. They evaluated on High Velocity Oxy-Fuel and conventional HVOF a spraying. They performed experiment for Sliding wear tests on coatings using a balloon- flat test rig against steel, silicon nitride (Si3N4) ceramic and WC–6Co balls. Results indicated that nano sized particles inherited from the starting powder in S-HVOF spraying were retained in the resulting coatings. The sliding wear performance was dependent on the ball-coating test couple. Comparison of the total (ball and coating)wear rate indicated that for steel and ceramic balls, HVOF-JP coatings performed the best followed by the S-HVOF and HVOF-JK coatings. For the WC–Co ball tests, average performance of S-HVOF was better than that of HVOF-JK and HVOF-JP coatings. They observed that the total wear rate was dominated by the ball wear. A higher ball wear rate was generally observed with a relatively lower coating wear rate.

Sheng Hong et al (2015)[5] said that effect of ultrasonic cavitations erosion on electrochemical corrosion behavior of HVOF sprayed near-nanostructure WC–10Co–4Cr coating in 3.5 wt.% NaCl solution, was investigated using free corrosion potential, potentio dynamic polarization curves and electro chemical impedance spectroscopy (EIS) in comparison with stainless steel 1Cr18Ni9Ti. The results showed that cavitations erosion strongly enhanced the cathodic current density, shifted the free corrosion potential in the anodic direction, and reduced the magnitude of impedance of the coating. The impedance of the coating decreased more slowly under cavitation conditions than that of the stainless steel 1Cr18Ni9Ti, suggesting that corrosion behavior of the coating was less affected by cavitations erosion than that o the stainless steel.

Shan-Lin(2015)[6] said La0.8Sr0.2Ga0.8Mg0.2O3 (LSGM) is considered a promising electrolyte for intermediate-temperature solid oxide fuel cells due to its high ionic conductivity and stability under fuel cell operating conditions. Here we report our findings in investigating the feasibility of using a high velocity oxygen fuel flame (HVOF) spraying process for cost-effective fabrication of dense LSGM electrolyte membranes. The flame and in-flight particle behavior were simulated numerically to optimize the microstructure and phase compositions of the LSGM deposits. The measured gas leakage rate of an LSGM deposit is~7_10_7cm 4gf _1 s_1. The single cell assembled with 50e55 mm HVOF-sprayed LSGM electrolyte shows open circuit voltage (OCV) of 1.08 V at 800C, suggesting that the as-sprayed LSGM deposit is dense enough for direct application as SOFC electrolyte. At 800 _C, the ionic conductivity of the sprayed LSGM deposit is ~0.04 S cm_1, indicating that the HVOF spraying is a promising process for low-temperature fabrication of dense LSGM electrolyte membranes for IT-SOFCs.

Sheng Hong (2014)[7] et al conducted experiment on High-velocity oxygen-fuel spray to parameter optimization of nanostructure WC–10Co–4Cr coatings and sliding wear behavior of the optimized coating. They employed the Taguchi method to optimize the spray parameters like spray distance, oxygen flow and kerosene flow to achieve the highest hardness and, in turn, the best wear resistance. The optimal spray parameter (OSP) for the coating is obtained by optimizing hardness (330 mm for the spray distance, 2000 scfh for the oxygen flow and 6.0 gph for the kerosene flow). The coating deposited under the OSP with low porosity and high micro hardness consists predominately of WC and a certain amount of W2C phases. The coating deposited under the OSP exhibits bett er wear resistance compared with the cold work die steel Cr12MoV. The material removal of the coating is the extrusion of the ductile Co–Cr matrix followed by the crack and the removal of the hard WC particles.

Wu-Han Liu et al (2014)[8] conduct experiment on Fe-based alloy material is widely used in the corrosive environment of seawater. It is replacing expensive cobalt and nickel-based alloys. Amorphous iron-based (Fe-based) alloy coatings can be deposited on stainless steel by HVOF thermal spraying. Following spraying, coatings were heat-treated at 500,600, 700, 800, and 900 °C for up to three hours in a vacuum furnace. The microstructures of such coatings were analyzed herein using an optical microscope (OM) and scanning electron microscope (SEM) to monitor the morphologies of both powders and coatings of Fe-based alloy. Phase analysis was performed by X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS). The goal of this work on the modification of Fe-based alloy feedstock powder is to enhance the corrosion and wear properties of these coatings. The results of this investigation reveal that adding a cobalt material to Fe-based alloy yields coatings with enhanced corrosion nand tri biological characteristics.

O.P. Oladijo et al (2014)[9] , investigation had been conducted to determine the influence of residual stresses on the abrasive wear resistance of HVOF thermal sprayWC–17 wt.% Co coatings, as well as to derive stress relaxation after cutting by wire electric discharge machining (EDM). The abrasive wear properties of the coatings were characterized using anASTM-G65 three body abrasive wear machine with silica sand as the abrasive. The residual stress was measured by means of X-ray diffraction techniques, on the coated samples before and after the abrasive wear tests. Compressive residual stresses were observed in the surface layer of the large coated samples. However, stress relaxation results after cutting into small sizeswere distinctly different. There was strong correlation between residual stresses in the surface layer and abrasive wear resistance, as well as yield strength of a material.

Bo Sun et al 2013[10] all used to novel high pressure HVOF spraying system to deposit Stainless Steel 316L coatings. They compared with the conventional HVOF process, the high pressure HVOF has the characteristics of higher flame velocity and lower flame jet temperature. It was expected to deposit dense Stainless Steel 316L coatings with less oxidation. As a typicall conventional HVOF system, the JP-5000 (Praxair) used with kerosene and oxygen as the fuel and oxidant. Particle velocity increases significantly with the combustion chamber pressure and powder's average velocity of 675 m/s can be achieved at the combustion chamber pressure of 3.0 MPa. Particle temperature before impacting is determined by the oxygen/fuel ratio λ and spray distance. It is the dominant factor in determining the particle melting state, as well as the coating microstructure and deposition efficiency. Dense Stainless Steel 316L coatings composed of un molten or partially molten particles can be obtained at different oxygen/fuel ratios λ. It is possible to obtain high deposition efficiency of 90% with optimizing spray conditions

Sheng Hong et al (2013)[11] conducted experiment on NiCrBSiWFeCoC alloy coating was prepared by means of high-velocity oxygen-fuel (HVOF) thermal spraying process and analyzed with regard to their detailed microstructures and phase composition. Systematic characterization of the coating was carried out using X-ray diffraction (XRD), scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), differential scanning calorimeter (DSC) and high-resolution transmission electron microscope (HRTEM). Amorphous phase and nano clusters were obtained in the coating and the major crystalline phases were compounds Cr23C6, Cr7C3, Ni3B, WC, and solid solution c-Ni. It was found that micro twinning was highly localized within the Cr7C3 phase. The crystallization temperature of the amorphous phase was about 500 _C. The formation of the amorphous phase was attributed to the high cooling rates of molted droplets and the multi component alloy system of feedstock powder. The nanoclusters were formed by homogeneous nucleation.

A.J. Lopez et al (2013)[12] all investigated through to Influenced of high velocity oxygen-fuel spraying parameters on the wear resistance of Al–SiC composite coatings deposited on ZE41A magnesium alloy. They developed Pin-on-disc tests to characterize the tribological behavior of the different specimens. They achieved Composite coatings with thicknesses of 120 lm, reinforced with 10 wt% and with high adhesion to the substrate. The wear resistance of the substrates was increased and the wear rate decreased in two orders of magnitude respect to that of the bare Mg-alloy after the optimization of the spraying parameters.

Mingxiang Xiea (2013)[13] did work on , WC-17Co, WC-10Co-4Cr, WC-12Co and Cr3C2-25NiCr coatings were deposited on stainless steel using WOKAStar-640 HVOF spraying system. Three WC-based coatings were studied and compared with a chromium carbide-based coating. The microstructure, porosity, micro-hardness, indentation fracture toughness and adhesion strength of the coatings were investigated. The wear test was done by using silica grits as abrasive medium using a load of 20 N. The result shows that HVOF sprayed carbide based coating possesses low porosity, high micro-hardness and high adhesion strength. Three WC-based coatings have higher micro-hardness and indentation fracture toughness compared to the Cr3C2-25NiCrcoating. HVOF sprayed carbide coating has good wear resistance under 500 ◦C. The decarburization of WC-based coating has great effect on coating wear resistance. In addition, WC-17Co coating has best wear resistance.

Jifu Zhang (2013)[[14] conducted experiment on Erosion of sink rolls by molten zinc is one of the most prominent and persistent problems occurring in hot-dip galvanizing industry. MoB–CoCr as an alternative to WC–12Co for stainless steel protective coating resistance to molten zinc was deposited by high velocity oxygen fuel (HVOF).Microstructure and mechanical characterization of the coatings were carried out by SEM, XRD and micro-hardness test. Resistance to thermal shock and molten zinc corrosion of the coatings were also conducted. Results showed that MoB–CoCr coating exhibited a better resistance property to thermal shock than that ofWC–12Co. At the same time, the corrosion test showed that life time of samples with MoB–CoCr coatings in molten zinc appeared to be longer than that of WC coating. The corrosion resistance of MoB–CoCr coating may be ascribed to non-wet ability of MoB–CoCr in molten zinc, whichcan delay the molten zinc penetration into substrates along the micro-cracks of the coating.

Yuping Wu et al **2012[15]** conducted experiment through WC–Co–Cr coating by a high velocity oxy-fuel thermal spray (HVOF) onto a 1Cr18Ni9Ti stainless steel substrate to increase its cavitations erosion resistance. After the HVOF process, they revealed that the amorphous phase, nano-crystalline grains (Co–Cr) and several kinds of carbides, including Co3W3C, Co6W6C, WC, Cr23C6, and Cr3C2. The hardness of the coating was improved to be 11.3 GPa, about 6 times higher than that of the stainless steel substrate, 1.8 GPa. The micro-structural analysis of the coating after the cavitations erosion tests indicated that most of the corruptions took place at the interface between the un melted or half-melted particles and the matrix (Co–Cr), the edge of the pores in the coating, and the boundary of the twin and the grain in the stainless steel 1Cr18Ni9Ti.

D. Zois 2011[16]] said that stainless steel powder of a mixed amorphous and crystalline structure was HVOF sprayed in an effort to produce coatings with a large glass fraction. In the first part of this work, the microstructure and annealing behavior of powder and coatings are studied. The coatings consisted of a glassy part and a martensitic part, the latter with boride, boro-silicate and boro-carbide dispersions. The annealing behavior of powder rand coatings is characterized by glass crystallization and martensite tempering. Annealing of the powder leads to complete micro crystallization of the glassy part, whereas annealing of the coatings eventually leads to nano crystallization of the residual glass phase. In the second part, the effects of selected spraying parameters(oxygen-to-fuel ratio, powder feed rate, spraying distance and spraying stages) on characteristic coating properties are investigated by means of the Taguchi analysis. The oxygen-to-fuel ratio mostly affected the coating hardness and porosity. The powder feed rate had a significant effect on all the coating properties but mostly on the deposition rate and crack extension force. Spraying in stages significantly increased the deposition rate, whereas it promoted coating amorphicity. A spraying experiment under the optimum conditions determined by the Taguchi analysis, showed a good fit between the predicted and the attained property values.

Alessio Fossati 2010[17]] conducted experiment through Two CoNiCrAlY powders with similar chemical composition and granulometry, but with different starting reactivity toward oxygen, were sprayed by High Velocity Oxygen Fuel (HVOF) onto Hastelloy X super alloy substrates obtaining coatings of comparable thickness. After spraying, samples were maintained at 1000 °Cin air for different test periods up to 3000 h. Morphological, micro structural, compositional and electrochemical analyses were performed onto the powders and the coated samples in order to assess thehigh temperature oxidation resistance provided by the different powders. The powder with higher starting reactivity toward oxygen sensibly improves the oxidation resistance of the coated samples by producing thinner and more adherent thermally grown oxide layers in comparison with the other powders.

B. Rajasekaran et al 2010[18]all presented studied on to develop a Fe-based metal matrix composite (MMC) coating using high velocity oxy-fuel spraying (HVOF) process. A ledeburitic high alloyed cold work tool steel (X220CrVMo13-4) and NbC with an average size of 2 μm at different volume fractions have been considered as metal matrix and hard particles respectively. Metal matrix composite coatings has been deposited on austenitic stainless substrates and the coatings were subsequently densified by hot isostatic pressing (HIP) with and without encapsulation. They characterized Micro structural analysis of the as-sprayed and HIPed coatings by SEM and

XRD methods. They showed that the feedstock preparation involving fine NbC was an influencing factor on the coating deposition.
relatively homogeneous dispersion of fine NbC up to 30 vol. % in cold work tool steel matrix was possible using optimized HVOF spraying. Besides, HVOF spraying and its subsequent HIP treatment induced significant microstructural and phase changes in the MMC coatings. They showed the potential of HVOF spraying for the development of steel based MMC coatings and its subsequent densification can be achieved by HIP process with and without encapsulation.

Alfredo Valarezo 2010[19] said that in this paper, effective damage tolerance of a functionally graded coating deposited by HVOF spraying is observed. The thick FGC (≈1.2 mm) consists of 6 layers with a stepwise change in composition from 100 vol.% ductile AISI316 S.S to 100 vol.% hard WC–12Co deposited onto an AISI316 S.S substrate. Damage tolerance is observed via 1) an increase in compliance with depth, and 2) an increase in fracture resistance by containment, arrest and deflection of cracks. A smooth gradation in the composition and hardness through the coating thickness is found by scanning electron microscopy and depth-sensing micro indentation, respectively. The in-sit curvature measurement technique reveals that during the deposition of the FGC, compressive stresses exist inthe lower, metallic layers owing to peening effect of successive impact, and these gradually evolve to high tensile, in the top layers. Tensile stresses appear to be due to quenching alone; thermal stresses are low because of the gradation..The FGC structure shows the ability to reduce cracking with increased compliance in the top layer during static and dynamic normal contact loading, while retaining excellent sliding wear resistance. Results are discussed in comparison to the behavior and properties of coatings of similar individual compositions and thicknesses, as well as a thick monolithic WC–12Co sprayed coating. Further improvements in the processing are proposed to enhance the adhesion strength and avoid coating delamination under highload contact-fatigue conditions.

O. Culha 2009[20] conducted experiment through concerns the determination of mechanical properties such as hardness, elastic modulus and yield strength of WC-based cermet coatings for a roller cylinder. With this regard, Co and Ni containing WC-based coatings were sprayed on Ni–Al deposited 316 L S.S substrates by using HVOF . These HVOF sprayed coatings were analyzed by SEM with an EDS system attachment .Mechanical properties of the coatings were examined Shimadzu Dynamic Ultra-micro hardness test machine in order to determine the Young's modulus throughload–unload sensing analysis. In addition to mechanical investigation, hardness–depth and hardness–force curves of WC-based coating were investigated. Itwas found that both of these characteristics exhibit significant peak load dependency. Experimental indentation studies were carried out to determine load–unload curves of WC-Co and WC-Ni based coatings under 300mN, 350mN, 400mN and 450mNapplied peak load .Hardness and Young's modulus of WC-based coatings were calculated from experimental indentation test data of samples. It has been observed that the hardness and Young's modulus of the coating depends on the contact area and indentation size. The originality of this study is to determine the indentation size effect and contact area variations on mechanical properties of HVOF sprayed WC-based coatings.

Poh Koon Aw 2008[21] conducted experiment through WC-17Ni and WC-17Co coatings were deposited on mild steel and stainless steel substrates by High Velocity Oxy-Fuel (HVOF) spray process.WC-17Ni and WC-17Co coatings were obtained by the spray process and the porosity of these coatings was measured. Polarization and electrochemical impedance spectroscopy (EIS) were performed on both uncoated substrates and coated samples immersed in 3% NaCl solution. WC-17Ni coating with a lower porosity, serve as a better barrier and effectively prevented corrosion attack when it was deposited on mild steel substrate. The nickel binder in the WC-17Ni coating was found to have a better corrosion resistance than the cobalt binder in the WC-17Co coating.

A.K. Maiti 2007[22] conducted experiment through HVOF grade powders are now commercially available and being used in large scale for different components prone to abrasion/erosion. The literature on HVOF coatings based on WC–Co powder shows that there is a huge difference in hardness between the pure WC powder and WC–Co based HVOF coatings. The objective of this study was to improve the hardness of WC based HVOF coatings by adding pure WC powder tothe commercially available powder. The hardness data shows that 20% addition of WC powder will improve the hardness of HVOF coating from1106 to 1395 Hv0.3. Hardness increase is due to the embedding of tungsten carbide hard metal matrix. This HVOF coated sample was tested for dry sand abrasion and slurry erosion as per ASTM standards. These tests show that abrasion and erosion resistance of HVOF coated samples goes down with the addition of tungsten carbide powder even though coating hardness has gone up. To understand the negative trend, porosity and SEM studies were carried out. SEM studies show that the porosity of the

HVOF coating is higher than the conventional HVOF coating. With increase in WC content (30%), the porosity of the HVOF coating increased up to 10%. The higher porosity is believed to be the reason for poor abrasion and slurry erosion resistance.

C. Monticelli 2004[23] conducted experiment through the corrosion protection afforded to a carbon steel substrate by two cermet coatings (WC/12 wt.% Co and WC/17 wt.% Co; 0.05,0.01 and 0.2 mm coating thickness), applied by high velocity oxygen fuel (HVOF) technique, has been studied in 3.5% NaCl solutions. Potentio dynamic polarization curves of cermet constituents, substrate and coated samples, iron and cobalt dissolution kinetics under potentio static conditions and galvanic coupling tests have been carried out .Cermets layer hinders the anodic process and WC/17%Co is more protective than WC/12%Co, particularly at high coating thickness. It is likely that the increase in the matrix cobalt content changes the pore morphology, from interconnected to isolated pores with enhanced protective efficiency.

3. CONCLUSION

After studying the research papers, it found that mostly methods like PVD (Cathodic arc evaporation, magnetron sputtering), HVOF, Plasma and some others are used in the field of hard coatings and single material coatings like carbide, dual individual or composite layer coatings like Tungsten carbide, Titanium Nitride, etc. are mostly used in the specified methods. Going through all this valuable literature work on hard coatings, I observed that less work has been done on low carbon steel substrate using triad composite coating layers like WC-17Co as coating materials. WC-17Co because comparably WC-12Co and WC-Co-Cr the wear rate in WC-17Co is very less on S.S. material[13] .So investigation to study the wear behavior , hardness and micro structural properties of WC-17Co coatings films on low carbon substrate by full factorial optimization methods.

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