RELEVANCE OF HVOF SPRAY AND WAY TO COAT
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ABSTRACT
Currently High Velocity Oxy-fuel (HVOF) for hot spray is used in many industrial applications. HVOF coating techniques, processes, maps and applications are considered. The HVOF spraying mix is combined with other cover components. HVOF spraying is a combination of deposits for metal materials, metal systems and ceramic nanostructure powder. In coating generation, improvements in temperature and velocities because of preface of oxy-fuel dissolving in feedstock powder. To control the coating process, method and tool are described. Assembling the microstructure from the beginning of the splats until the construction of the final joint identified the microstructure. Coordinating and performing HVOF coating work is described.

Keywords: HVOF; Coating; Microstructure; APS.

INTRODUCTION
In many cases the technology of thermal spray coatings is used as rust and rust. Because of this, squat porosity and high adhesion are considered as important areas of integration. Extreme proximity processes - especially High velocity oxy-fuel (HVOF) spraying - are a popular method for optimizing combination production with squat porosity with maximum adhesion. In HVOF spraying technology, these combustible fuels are hydrogen, paraffin, propane, natural gas, ethylene, or acetylene which is heated or oxygen. Spraying is done with the help of a special design nozzle where a high speed aircraft is built. [1-4]

The thermal spraying coating process includes all methods of coating on or after melted or semi-melted drops. The material used in thermal spraying coating process is mainly in appearance of wire, powder and rod. The powder, wire or rod is then supplied into the flame of spray gun; the supplied material is then melts and converted into droplets which accelerate towards the substrate. The substrate is an object or part to be coated. The flame of spray gun can be formed either by an electrical control source or by combustion of mixture of fuel. On the basis of the energy sources, thermal spray coating methods can be classified into few groups: plasma spray methods, combustion flame spray methods (flame spray), and, the latest as, cold gas squirt methods (CGS). [1]

When the material is sprayed on the substrate, the coating on the substrate developed by packed down rapid solidified droplets in which the velocity plays a important position to obtain density of the lamella structured coating. Temperature plays a vital function in coating using various materials as the flame in this coating has a temperature range of about 3000 degree Celsius which gives strong effect on the appropriate materials to be sprayed. Some of the materials don’t require that much temperature like ceramic coatings, mainly coated by using atmospheric plasma spray method, whereas temperature sensitive materials, for example cermets, are further preferably sprayed by techniques with lower flame temperature. In Table 1 usual operation ranges for different coating technologies are presented.

Table 1 Operational ranges of different thermal spray coatings.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Coating</th>
<th>Velocity Range (m/s)</th>
<th>Flame Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>CGS</td>
<td>800-1200</td>
<td>300-1000</td>
</tr>
<tr>
<td>2.</td>
<td>HVOF</td>
<td>400-1000</td>
<td>3000</td>
</tr>
<tr>
<td>3.</td>
<td>D- GUN</td>
<td>500-1000</td>
<td>3000</td>
</tr>
<tr>
<td>4.</td>
<td>Combustion Flame Spray</td>
<td>40-100</td>
<td>3000</td>
</tr>
<tr>
<td>5.</td>
<td>Wire Arc</td>
<td>100-130</td>
<td>4000</td>
</tr>
<tr>
<td>6.</td>
<td>VPS/LPPS</td>
<td>150-600</td>
<td>12000</td>
</tr>
</tbody>
</table>
There are many HVOF spray coating systems present with little diverse structure and design of gun with varying capacity. Although all are based on the common basic principles of HVOF spray coating. The gun of HVOF spray coating is categorized into three levels, to be exact generation primary, secondary and tertiary. The primary and subsequent generation guns the speed of high temperature flame is nearly up to 2000 m/s and the only difference is designing of their nozzle. The combustion chamber of first generation HVOF spray system is comparatively large and the nozzle is straight by this design we can get utmost 1 Mach (sonic speed) velocity. Alternatively, the second generation is based upon de Laval nozzle, which gives over 1 Mach velocity. If the first generation system is working in standard spray environment, the system consume energy of about 100 kW and can spray up to 2–3 kg/h of WC-Co. [1] Although the third generation spray system consumes power from 100 to 300 kW and if the pressure of chamber is high i.e. 8 to 12 (up to 25 bars), can spray up to 10 kg/h. Table 2 summarize the main difference of generations in HVOF spray coating system.

**Table 2** The main difference of generations in HVOF spray coating system.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Nozzle Type</th>
<th>Power</th>
<th>Intensity (Output Heat)</th>
<th>Kg/h (WC-Co)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Generation</td>
<td>Straight</td>
<td>80 kW</td>
<td></td>
<td>2 to 6</td>
</tr>
<tr>
<td>2nd Generation</td>
<td>De-Laval</td>
<td>5 to 10 kW</td>
<td></td>
<td>2 to 10</td>
</tr>
<tr>
<td>3rd Generation</td>
<td>De-laval</td>
<td>8 to 12 (up to 25) kW</td>
<td></td>
<td>10 to 12</td>
</tr>
</tbody>
</table>

The main parameters which affect the coating are velocity of particles, temperature of flame and quality of substrate. These points gives information of built-up and properties of deposits. The velocity and temperature of the particles also influence the effectiveness and microstructure as well. The development of HVOF spray coating is towards high velocity of particles, low temperature and high gas pressure as shown in Table 3.

**Table 3** The trend in HVOF process development has been towards higher gas pressures, faster particle velocities and lower particle temperatures.

<table>
<thead>
<tr>
<th>FLAME TEMPERATURE (°C)</th>
<th>VELOCITY OF PARTICLES (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIRST GENERATION</td>
<td>1800 – 2000</td>
</tr>
<tr>
<td>SECOND GENERATION</td>
<td>1600 – 1850</td>
</tr>
<tr>
<td>THIRD GENERATION</td>
<td>950 – 1850</td>
</tr>
</tbody>
</table>

**HVOF Process and Mapping**

The progress of HVOF spraying is very composite, as this has a number of variables disturbing the deposit pattern and thus its properties. The powder is sprayed at a very high speed and temperature, the temperature is that much high up to the melting point of the powder particles. The high temperature might origin phase transformation, evaporate the powder mechanism and dissolve them. This complex nature of HVOF technique, give challenge to manage and optimize the process to attain coating with required property. To optimize and analyze, there are diverse ways in thermal spray processes and coat development. Statistical methods like, Taguchi and plan
of experiment, mathematical modelling and simulation, and Finite Element line of attack are incorporated to get desired result [1-5]. The example of Taguchi method, the test matrix is considerably reduced and the relative significance among variables can be indomitable satisfactorily. In this method the result is depends upon the plan and range of variables and the level of variables, therefore the result may be deceptive. To determine the consequence and influence of a large quantity of variables it is very complicated with the HVOF technique. This is applicable to diverse modeling measures as well.

High-quality coating with appropriate properties and performance for particular application is the goal of thermal coatings. Initial material, spray process and particle-substrate relations all influence the shape of coating with diverse microstructure which affects the performance and properties of coating. In last few years there are various sensors have been developed which affect the spray coating at very large scale and it seems very easy to measure various quantities like flux, temperature, velocity, and more without any difficulty and with accuracy. The concept of process mapping was first introduced by Professor Sanjay Sampath [7], and its use has increased since its introduction [8-11]. This section describes diagnostic aids and tools for the mapping process. Examples are shown of using process management maps and level design.

➢ Process measures

Spray coating process technique is taken care in presence of many sensors which measures various parameters like velocity of flame and temperature. Coating quality is examined with the help of splats analysis, melting state of the particles can be analysed. Such analysis gives the idea that how small NiCr particles, at high temperature undergo more oxidation [10].

Throughout the spraying process, it is increasingly possible that air packs are formed due to particle speeds, especially when the particles are not completely dissolved. NiCr of fully dissolved particles form smaller grain size splats as compared to particles in feedstock [10]. Examples of Al2O3 splats are presented in Figure 1, which show different melting regions of the sprayed particles from different spray parameters. Demonstration of composites performed by microscopic methods and examination of markings after spraying, thickness, thickness, lamellar formation with total or soluble particles, degradation rate, oxidation rate, bond, hardness, elastic modulus etc. It is revealed, and can be linked to changing processes. When coordination between process variables, coordinating committees and structures is made, recurrent reductions are also possible. Where a particular asset is a goal, it is possible to go back through the performance maps and identify the relevant process goals to achieve the desired asset.

The spraying process should be calibrated, so that measurement errors can be prohibited or measured. The use of feedback control in the process allows for this. Repeating certain conditions while performing the process mapping process shows data distribution and error, in the estimated temperature and speed ratios. Errors increase in input parameters (defects), metals, gas flow control and feed rate; effects of nozzle breakdown and injection wear [9]. This may have an effect on the obtained values of the velocity over the interval of the process, and therefore the calculation, re-calculation and adjustment of the spraying parameters are required throughout the spraying process.

An example of HVOF spraying of NiCr powder showed the impact of a flame containing oxygen, leading to high temperature and low velocity [11]. When excessive flame is used, the temperature drops (as the flame energy decreases), and the particle speed increases. Kinetic and thermal energy transferred to particles depends on the energy of the flames (enthalpy of used fuel, the population density, and the rate of oil in oxygen). The high energy of the flames yields the highest kinetic energy and energy available to the particles. Increased ambient air decreases the temperature and increases the particle speed by increasing the adsorption capacity of the particles and decreasing their residence time. Changes in the oxygen-oxygen ratio cause a powerful effect.
Food quality also plays a role in kinetic and thermal energy. The effect of the fire extinguisher was seen when the NiCr powder feed rate increased [11].

The oxide content of the coat is determined mainly by the reaction of the plane. The longer flame still protects the particles from oxidation by cutting off contact with the contiguous environment, and by burning oxygen inside the flame, a so-called protective effect. Therefore the fuel-consuming conditions produce metallic coatings with minimal oxidation [11]. Higher particle speed reduces particle overload, thereby preventing the oxidation and decarburization of carbides [14]. In contrast, the high temperature of the particles results in very high oxide content [11].

![Figure 1](image_url)

**Figure 1.** In SEM calculations of various soluble splats, HV2000 (Praxair) spraying and spraying of Al2O3-sprayed particles can be obtained [16].

➢ **Procedure Mapping**

Particle shape is influenced by the fuel gas fertilizer (fuel / oxygen ratio), total gas flow, and energy input, which affects particle temperature, velocity and therefore the combination of energy and properties. Structural-structural relationships can be made by process maps, which can serve as a computational tool for compiling. Process maps are the relation between the process variable and the output responses [13]. The process mapping tool has been broadly used in the plasma spraying process [13,15], but can be used successfully in the HVOF process also [11,16].

➢ **The concept of Process Mapping**

The process map methodology is developed for process control and to strengthen the functionality of structures. In the concept of process mapping, diagnostic tools are used to understand the basics of relationships in the thermal spraying process, from powder marking to spray spraying, deposit placement, cooling conditions, and finally to working conditions. A preliminary demonstration map of the process shows the associations stuck between the torch points and particles in the spray line, measured by the experts. The second-order process map represents the association between the basis of the sprinkler measured responses and the coordinate locations. Systematic evaluation of processes, which ultimately leads to the identification of functional binding properties and the process integrity assessment, can be done by constructing primary and subsequent order maps of a specific spraying process. A map of the third-order process, which links the micro structural microstructure and structures to the catalytic process, can also be developed.

➢ **First order map**
The mapping of the first orthogonal process relates the transition process to the particle shape (temperature and velocity). The results obtained by the diagnostic tools are plotted in the T-v diagram, which is called the initial planning process map. An example of a first-order (T-v) map is shown in Figure 2, which shows different temperatures and velocity ranges for two different combinations of HVOF sprinkled with Al2O3 [16]. The map of first-order process, Figure 1 for diverse process of thermal spraying introducing average temperatures and spray widths. From this figure it can be seen that the HVOF process has a higher average temperature and speed compared to other conventional body spraying processes. The first-order procedure map helps to understand how the particle shape has an impact on the formation of the adhesive microstructure.

![Figure 2 Preliminary order map of HVOF alumina, showing particle temperatures and the range of propylene-oxygen and hydrogen-oxygen ingredient mixes [16].](image)

➢ Map of second order process

The second order process map links the process with the deposit interaction. It describes the impact of microstructure on coating properties. To generate a second-order plan, a specific T-v window is selected for the first-order plan.

➢ Reliability through Performance Mechanism

Strong requirements for cover in a variety of applications improve process efficiency, reproducibility, reactivity and reliability (3 R's) of the piping process as a criterion [17]. However, dependence and reproducibility are a complex task as a result of the availability of related parameters that influence the sprinkler and dynamical process in the data structure. The complication of the process and the complexity of the material have made it difficult to understand the process-property-material relationships and industry/application-related characteristics, such as bending, placement and reliability [9]. Process performance is used to improve process through parameter development, tracking and retrieval, and thus optimizing inventory. Acquisition creation strategy can be achieved by careful use of process maps, since process parameters can be linked to markers and hence understanding of the process microstructure material relationship is possible [13]. Through the operation of the process it is possible to produce reliable and reproducible covers with optimized performance and operational predictability [16]. The concept of process mapping is therefore an excellent tool for analyzing and controlling the effects of spraying on parameters in fabric production. This method can be applied to any thermal spraying technology [11]. And structural efficiency (DE) can be improved, as well as the efficiency of the process.
Figure 3. SEM images of warm spraying panels represent different morphologies. a) Al2O3 / SiC mixed milling ball, Al2O3 / SiC; b) sprinkle dry Cr2O3; c) atomized gas Ni20Cr; and d) the use of Al2O3 and Al2O3 powder by Praxair.

➢ Monitoring of a In-Situ Deposition

Analysis of the cooling characteristics was performed mainly after the actual binding process. However, the complex deposit formation process is difficult to follow. In the material an in-situ coat sensor (ICP) material erstwhile prepared to keep an eye on the evolution of curvature and surface temperature under the spraying process [13]. Alignment measurements are possible by examining the submission of the downstream of the unaffected lasers. Temperature measurements are performed with multiple thermocouples attached to the back of the material during installation and cooling. With these statistics, it is probable to calculate residual stresses, CTE, and elastic modulus. The procedure and method of measurement are described in detail by Matejicek et al. [18].

The particle shape influences the pressure build-up during the spraying process and the residual stress mixture has an impact on the compaction properties. The residual pressure depends largely on the particle depth and the temperature of the particles [13]. Compressive pressures are formed on account of constipation in the upper particle surfaces. For example, in the curvature measurements of NiCr it has been make out that in the first movement, the shear stress is apparent due to the limited plasticity of the substrate [11]. Following the pass draws a lot of pressure due to the impact effect. The higher the speed, the higher the pressure builds up. The relative stability of the impact particles can be monitored while spraying with the in-situ curvature process. Its affinity can be attributed to microstructure, splats, residual pressure and hardness of deposits [11]. The difference in CTE’s (the coefficient of thermal expansion) between the composting and the vein material also creates pressure on the cooking. The emergence of compression and sub-surface...
temperatures are important considerations when considering the elasticity, compaction, and growth of residual stresses. [11].

Effect of Feedstock property on Coating

Powder quality and characteristics (e.g., particle, composition and size, Powder size and flow capacity, purity, phase content, agglomeration) depend on a detailed product design, namely, crushing and grinding, water and gas atomization, spray suspension, assembly and sintering [14]. Studies have shown the occurrence of a feed used for a given wrap, since particle characteristics are very different from the spraying process (e.g., temperature and velocity). When powders from the same material, but with different morphologies or different sizes, were sprinkled with the same temperature and velocity range, the resulting cover showed significant differences in several cases e.g., elul modulus [13]. Examples of different powder morphologies are presented in Figure 3. Feed characteristics (particle size, distribution size, density and chemical properties) have an effect on the deposit formation and the efficient process by changing the thickness of each pass, and other structures, such as hot flake, efficiency.

Applications of HVOF Coatings

Wear HVOF Coatings

Controlling wear is very important in many applications of spray paint. These applications include various related components such as rotation rolls and axels e.g., printing machines, paper and pulp machines, etc. Among the different methods of spraying with thermal high velocity oxy Fuel (HVOF) have been proven to be more suitable for low carbide and metal cover due to low flame temperatures and supersonic velocity of particles [17]. Under certain limits it can be used as well to produce high quality coverings for wear protection.

Wear Cermets

Common non-coated coating materials are used in cermets, that is, metal-ceramic layers, mainly consisting of various mixtures of metal matrix including cobalt (Co), chromium (Cr) and nickel (Ni), and tungsten carbide (WC) or chromium carbide (Cr3C2). The most common combination — WC-12 wt.% Co or WC-17 wt.% Co — is extensively used in application where high wear resistance is necessary. Ideally the composition matches up to 20% and 27% of cobalt in volume, but may vary depending on the spray conditions and WC decomposition during the spraying.

Comparison of APS with HVOF Wear Resistant Coatings

It is generally understood that the wear properties of HVOF coatings are higher than their APS counterparts. Li et al. [42] compared the coatings of the Cr3C2-25% NiCr coatings obtained by APS- and HVOF-weaves. They found that the wear resistance of Ni3r coatings of Cr3C2-25% under different impact conditions increased with the APS-Ar / H2, APS-Ar / He and HVOF orders. The HVOF hole sprayed Cr3C2-25% NiCr hole showed better wear resistance due to the denser structure and fewer problems because the Ni3r NiCr coating modes were influenced by the associated error such as level thickness, roughness and micro cracks in lamella, and therefore the control of these substances has a significant effect on the resistance to coating.

Turunen et al. [8] studied the spraying of nanostructure Al2O3 and Al2O3-Ni HVOF pipes with the cover materials incorporated there. It was found that by optimizing high quality generators with improved properties they are available. The introduction of nano-powders in the bonding process improved the hardness and purity of pure Al2O3-coating. The introduction of nickel alloying reduced the hardness and durability of the coating, but increased the hardness of the coatings by introducing small nickel particles into the alumina matrix and between the alumina splats. Addition of a small amount of nickel into alumina can thus be used to markedly modify the properties of the coating.
Summary and Conclusion

HVOF thermal spray technique has been reviewed in this particular review. In the last two and half decades HVOF spray techniques have considerably modified and improved. This technique have been commercialized or introduced very rapidly due to its characteristics and better results. The development of powder technology is also beneficial in the development of HVOF spray coating technology. It’s a matter of fact that to sustain there is need to focus upon the processes and their development. HVOF spray coating because of the high temperature increased the applications of coating through metals and ceramics. Although the deposition rate of HVOF coating is not the highest or fastest but the coating is much more improved as compare to all other techniques. Nowadays this technique has variety of applications in number of industries. The most common applications of HVOF spray coating are prevention from corrosion, wear, porosity, also a very essential tool in additive manufacturing, medical industry and many more.

References:


