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# Comparison of Solid Particle Erosive Wear Rate at Room Temperature of Flexicord Flame Sprayed Different Oxide Coatings

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**Abstract**

Flame spray technology is basic member of the thermal spray coating family. Higher cost-effective coatings can be produced at higher speeds with new flame spray equipments which developed in recent years. The Flexicord flame spray method developed in this direction offers many advantages. A wide variety of ceramic coatings can be deposited on metallic surfaces with this spray methods in the face of wear-induced problems. In this study, solid particle erosion rates and wear behaviors of different oxide ($Al_2O_3$, MgO-$Zr_2O_3$, $Al_2O_3$-MgO based coatings have been studied comparatively with respect to ASTM G76 standard. Spinel based coatings between the oxide based coatings exhibited superior wear resistance and significantly lower mass loss than the others. Due to the fragile nature of the ceramic coatings, the erosive wear rate is increased by crack growth formation related with the porosity of coating. Due to the accelerated solid particle impacting at high impact angles, wear rate is highest.

**Keywords:** Thermal spray, Flame spraying, Solid particle erosion, Microcracks.

## 1. Introduction

Metallic, ceramic and cermet based coatings can be effectively coated using different thermal spray coating methods (plasma spray, arc spray and flame spray techniques) depending on the spraying speed and temperature. Flame spray technology is one of the simplest and most practical methods among into thermal spray coating family. This coating method is used for repair, corrosion protection and wear resistance in many industrial applications. Depending on the oxygen-fuel ratio, the flame jet is sprayed onto the surface by feeding the coating materials in powder, wire or rod form. Spraying rate and melting capability of feedstock material determine the quality of the coatings. In recent years, high corrosion and wear resistant coatings can be produced by the special designed flexicord flame spray gun. Ceramic or metallic based powders filled into a polymeric flexible sheath can be sprayed at a homogeneous melting and high speed spraying since feeding to a high-energy flame jet (**Fig.1**). This spraying method is a more economical and practical coating method than the high-technology thermal spraying methods (APS, HVOF) which have high investment and operating tendency [1].

Due to the superior corrosion properties of stainless steel materials are used in many industrial applications. Erosive wear of stainless steel is a serious failure that occurs as a result of high-velocity impact of solid and hard particles on a surface in a fluid, corrosive environment. Wear resistant coatings are needed to increase the surface resistance of stainless steels. Ceramic based hard coatings with thermal spray methods can be used effectively in the production of wear resistant coatings. Thermal power plants, aircraft and land type gas turbine engine parts, pumps, mixers, conveyors, coal gasification facilities and ore or coal slurry pipelines are the most frequently encountered industrial applications of erosive wear [1-5]. In this study, wear rate and mechanisms are investigated of different type

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oxide (A:$Al_2O_3$, Z:MgO-$Zr_2O_3$, S:$Al_2O_3$-MgO) based ceramic coatings sprayed onto 321 grade stainless steel surface.

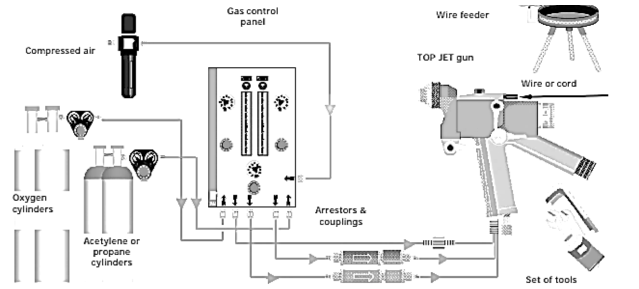



**Figure 1.** Schematic of flexicord flame spray coating process

## 2. Experimental Studies

### 2.1. Materials

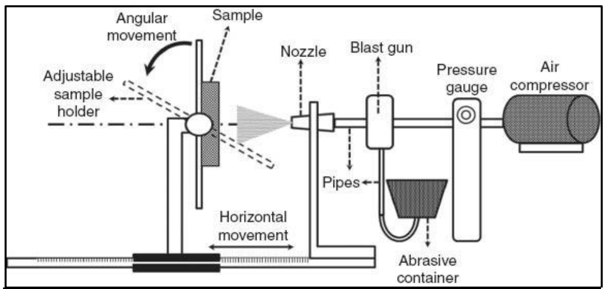
In the experimental study, AISI-321 grade austenitic stainless steel alloy was preferred as substrate material. Plates with dimensions of 50x25x4 mm were first cleaned into the ultrasonic bath and then sand blasted with $Al_2O_3$ (60-80 mesh) at 3 bar pressure, $75^o$ angle and 200 mm distance. The coating process was carried out in two stages and a bond layer was applied in a thickness of 70±25 µm (NiCr) to provide better adhesion with the substrate before the ceramic coating. A second step: different oxide-based ceramics are sprayed with optimum spray parameters (**Table 1**).

**Table 1.** flexicord flame spray gun parameters

| Coating Layer | $O_2$ | $C_2H_2$ | Air | Spray Distance | Deposit. Efficiency (%) |
|---|---|---|---|---|---|
| Bond layer | 4bar-60mm | 1.2bar - 70mm | 4.5bar | 100-120mm | 75-80 |
| Z | 4bar-60mm | 1.2bar - 70mm | 4 bar | 120mm | 60-65 |
| S | 4bar-60mm | 1.2bar - 75mm | 4-5bar | 110-120mm | 60-65 |
| A | 4bar-65mm | 1.2bar - 75mm | 4-4.5bar | 100-130mm | 50-55 |

### 2.2. Tests and Characterization Methods

The metallographic preparation to examine the microstructural section of the coatings was carried out by standard specimen preparation techniques (cold mounting, grinding: 500-800-1200 mesh, SiC; polishing: 9-3 µm diamond paste). The micrograph of the top surface and cross-section of the coating are examined with electron microscope (SEM). The micro hardness change of the coatings was measured by vicker method ($HV_{0,2}$). The solid particle wear behavior is tested by ASTM G76 standard (**Fig 2**). Erosion rate was determined as the ratio of weight loss of the material to the weight of eroding particles. Wear track profiles and surface roughness are analyzed with 3D profilometry.




| | |
|---|---|
| Eroder | $Al_2O_3$ |
| Eroder size | 400 mesh (38-45µm) |
| Impact angle | $30^0$ ,$45^0$ ,$90^0$ |
| Air pressure | 1.5 bar (const) |
| Eroder feed rate | 4 g/sec. |
| Nozzle diamater | 3 mm |
| Test duration | 10, 20 and 45 sec. |
| Distance to surface | 20 mm (const) |
| Humidty | 50% |

**Figure 2.** Schematic solid particle erosion test system and test parameters

## 3. Test Results And Discussion

### 3.1. Microstruture and coating properties

Coatings produced with flexicord flame spray represent the typical thermal spray coating microstructure. The lamellar coating structure has porosity and micro cracks between lamellar **(Figure 3).** The coating generally has a heterogeneous structure. The coating thickness is 180±15µm in total (70±10µm bond coat + 110±10µm top coat).

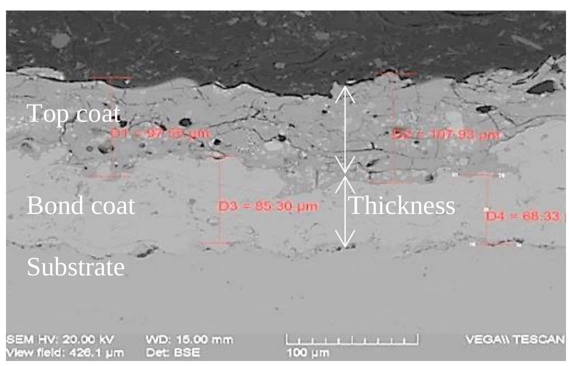


**Figure 3.** Cross section of the coating

**Table 2.** shows the chemical compositions, surface roughness and micro hardnesses of the coatings. Spinell which has the highest hardness and lowest roughness among the coatings.

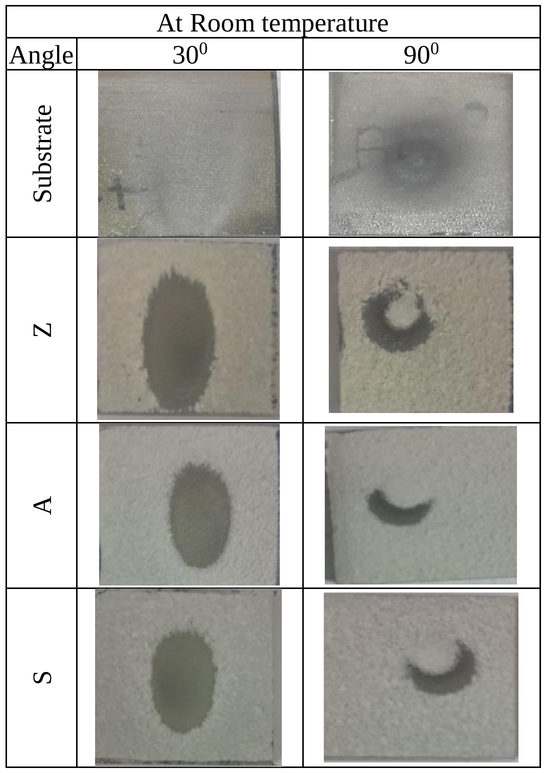
**Table 2.** Chemical compositions and technical properties of the coatings.

| Coating Layer | Composition (wt%) | Hardness (HV) | Roughness Ra (μm) |
|---|---|---|---|
| Bond coat | Ni-Cr %80,%20 | 280±35 | 6±2 |
| Zirconate-Z | $Zr_2O_3$-MgO-$Al_2O_3$ %75,%21,%4 | 720±45 | 12±2 |
| Spinel-S | $Al_2O_3$-MgO %70, %30 | 750±35 | 4±2 |
| Alumina-A | $Al_2O_3$ -Other %99,7, %0,3 | 740±45 | 10±2 |

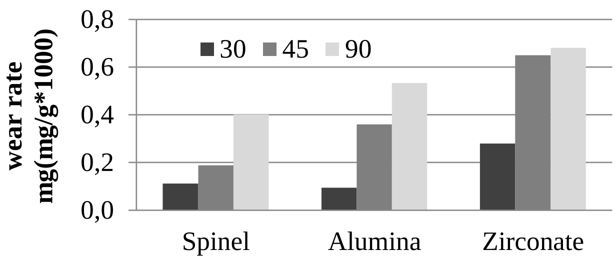
## 3.2. Solid Particle Erosive Wear Test Results

Table 3. shows the wear tracks after the wear test on coated samples. When the wear tracks images are examined, it is observed that the wear track geometry change depending on the impact angle of the solid particles on the surface. At low impact angle, the wear tracks are in an elliptical form, while it is circular at high angles. The wear track area on the ductile metallic substrate surface is larger elliptic at low impact angles as 30o. At high impact angles as 90o, it formed a circular and crater on the stainless steel surface. On the contrary, on the top surface of brittle ceramic coatings, the wear tracks were observed in the half-moon form at the high impact angles. It can be seen that the coatings are eroded in the effect of the rapidly impacting of solid particles and reaches the underlying bond layer. It is found that the coating thickness are to be an effective factor on wear. **Figure 4.** shows the comparison wear rate results of the coatings. It can be seen that the rate of wear due to the increase of the test duration increases. Especially at $90^o$, the wear is the highest.

**Table 3.** Wear tracks images of the coatings




When the wear mass losses of the coatings are compared in similar thicknesses and hardness, spinel and alumina coatings show more wear resistant than after zirconate based coating.



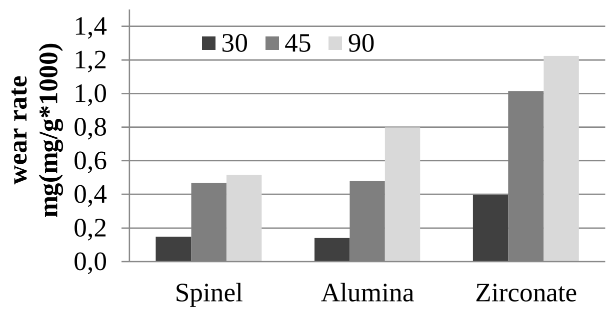




**Figure 4.** Wear rate comparison column graphics for 10 sec. (top) and 20 sec. (bottom)

It has been found that there are numerous micro- and macro-scale cracks on the top coating surface, as can be seen from the **Figure 5**. Besides, it is understood that some solid particles are embeded on the coating surface. The erosive wear mechanism of the coating is mostly the development of microcracks and then the formation of macro crack and fracture of the lamellar. As a result, the coating layers are spalling from the substrate.

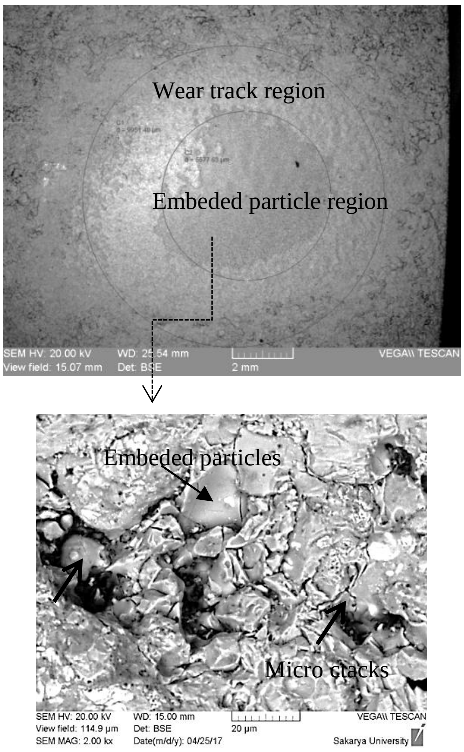



**Figure 5.**a.Top coating surface SEM micrograph after wear test ($90^0$,10 sec.) b. Higher magnification of embedded particle region in wear track.

**Figure 6**. shows the measurement results on the alumina coating sample with the 3D surface profilometry. The depth of wear track is very high at high impact angles. However, the depth of the track appears to decrease for lower impact angles.

## 4. Conclusion

From the study of microscophic invetigations on the oxide based thermal spray coatings it can be concluded that interior defects and porosity were main causes for the occurence of cracking in the coatings. The erosive wear mechanism, like in typical brittle materials, is caused by the cracking of the coating layer and the development of the crack and the spallation of the coating. During the erosive wear test these growing cracking paths and porosity lead to increased wear rate and to the coating being spalling. Good adhesion of the inter lamellar structure and low porosity plays an active role in showing resistance to the solid particle erosion of the coating. For this reason, coatings with optimum thickness and dense structure should be preferred. In this experimental study the spinel coating exhibited the best wear resistance performance among the other coatings. Aluminum oxide and spinel coatings on stainless steel surface can be used economically by flexicord flame spray method to increase erosive wear resistance.

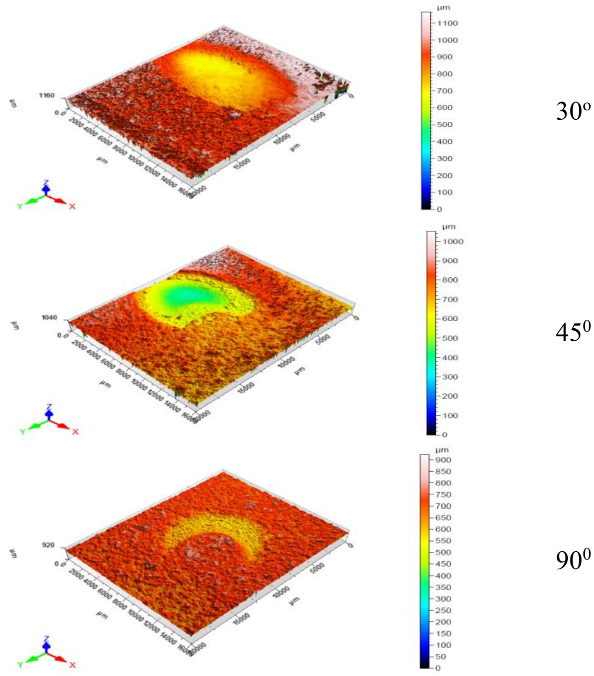



**Figure 6.** 3D profile of wear trackfor alumina coating after wear test (30,45, $90^0$, at 10 sec.)

## Acknowledgments

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