Solid Particle Erosion Performance of Multi-layered Carbide Coatings (WC-SiC-Cr_3C_2)

Kumar, Sharan  
Dept. of Mechanical Engineering, Sharanbasva University  

Akash  
Dept. of Mechanical Engineering, Sharanbasva University  

Anil K C  
Dept. of Industrial Engineering and Management, Siddaganga Institute of Technology  

J, Kumaraswamy  
Dept. of Mechanical, R L Jalappa Institute of Technology  

https://doi.org/10.5109/6792833
Solid Particle Erosion Performance of Multi-layered Carbide Coatings (WC-SiC-Cr3C2)

Sharan kumar1, Akash2, Anil K C3*, Kumara swamy J4
1,2Dept. of Mechanical Engineering, Sharana bsava University, Kalaburagi, India.  
3Dept. of Industrial Engineering and Management, Siddaganga Institute of Technology, Tumakuru, Karnataka, India.  
4Dept. of Mechanical. R L Jalappa Institute of Technology, Doddaballapura, Karnataka, India.

E-mail: anilkc@sit.ac.in

(Received March 31, 2023; Revised June 12, 2023; accepted June 14, 2023).

Abstract: A modern machine parts such as gas turbine blades and vanes are impacted by high temperature and high speed solid dust particles. As a result may leads to disastrous failure. In order to increase the performance multilayered (WC-SiC-Cr3C2) carbide coating was developed on AISI 304 steel using HVOF process. Erosion test as per ASTM G 76 standard were conducted at differently impingement angle (90°,75°,60°,45° and 30°) at room temperature. Micro structural, morphological and element analysis probed using SEM and EDAX. The changes in the resistance to erosion are due to high hardness and less porosity of the developed coating. The analysis showed a well-adhered and dense layer with a uniform distribution and presence of carbides and ability to withstand the erosive effects of solid dust particles.

Keywords: Multi-Layer, Coating, Solid particle, Turbine Erosion.

1. Introduction

Due to solid particle erosion at high pressure and temperature, the gas turbine blades deteriorated1-3. Hence, improving the resistance for the blades erosion could extend the working life. As an efficient and economic technology, coatings are designed to provide protective measures on the blades surface5. The thermal spray coating is considered as efficient and economic technique to provide protective measures on the surface of the blades3. To resolve the erosion issue, extensive studies have been conducted on factor that influences the erosion and mechanism of erosion6. Though, no researchers and scientists could forecast all circumstances of erosion and still it is a big challenge in surface engineering7-10. Due to the superior hardness, less porosity, good toughness and good resistance to erosion these WC, Cr Sic powder particles were used11. Hard WC provides high hardness and usage of Cr particles shows good toughness12-15. In previous paper, we have studied the solid particle erosion behaviour of multi-layered WC-SiC-Cr3C2 coated steel at different impingement time at room temperature. It was confirmed that, erosion rate was increases with increasing the impingement time16.

In an analysis of the erosion wear behaviour of coatings made of WC-12Co and WC-10Co-4Cr that were applied using HVOF thermal spraying, the WC-10Co-4Cr coating demonstrated greater erosive wear resistance than the WC-12Co coating under test conditions and displayed good microstructural characterization, erosion resistance rate and thickness residual stresses of the coatings17. Two different plasma spray coating systems were created, a microstructural analysis was done, mechanical properties were established and solid particle erosion was identified. An experiment revealed that the coatings had good density, adhesive strength, and hardness, and that volume erosion was more noticeable at 45° angle of impact18. Solid particle erosion resistance is increased by the existence of a ductile crystalline, fine carbide precipitates and embedded erodent particles19. The lower layer thickness displayed superior erosion resistance in resemblance to those with higher layer thickness20. According to laboratory particle erosion tests, the coated structure's lifetime has increased by up to four times compared to its uncoated equivalent21. The efficiency of the existing high velocity air fuel (HVAF) system for scattering tungsten carbide (WC-10Co4Cr) and chromium carbide based hard metal coatings spray method operated by gaseous state and liquid operated high velocity oxygen fuel (HVOF) spray method is compared. The HVAF sprayed coatings sustained impact resistance that had been nearly as high as the WC-10Co sintered material22-23.

In this manuscript, we present the deposition of multilayered coating of Wc-SiC-Cr3C2 on AISI 304 steel at thickness of 150 micrometer using HVOF process. Numbers of impingement angles were varied to analyses the erosion behaviour of samples with and without coatings. Microstructure and morphological studies were
conducted by using scanning electron microscope & EDAX. These coatings are useful for protecting surfaces against erosion by solid particles because they combine hardness, toughness, and thermal stability. Understanding the erosion behavior of multilayered carbide coatings is essential for optimizing their performance and expanding their practical applications where erosion is a critical concern.

2. Experimental Details

2.1 Substrate material

The AISI 304 stainless steel was received from reputed steel supplier in Bangalore. Due to good mechanical properties, this steel was chosen as the primary substrate material. The steel chemical composition is given in Table 1.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>0.07</td>
<td>19</td>
<td>2</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>1.1</td>
<td>Balance</td>
</tr>
</tbody>
</table>

2.2 Coating materials and deposition

Commercially existing tungsten carbide (WC), silicon carbide (SiC) and Chromium carbide (Cr$_3$C$_2$) metallic powders of nominal particle size of 45 µm were recognized as feedstock particles. Fig. 1 illustrates the particle morphology of the powder. The sharp-edged irregular morphology gives excellent fluidity and stability in the time of deposition$^{24-26}$. Wc-Sic-Cr$_3$C$_2$ multilayer coating was deposited on bare 304 steel plate of size 35x25x4mm utilizing high velocity oxy fuel (HVOF) deposition system with industrial standard parameters. Before spraying, substrates were degreasing using acetone and grit blasted. The Fig. 2 shows the deposition thickness of 250±30µm.

2.3 Characterization method of the coating

The measurement of surface roughness and porosity of coated and uncoated samples was carried out by employing a 3D laser scanning microscope$^{27-30}$. Additionally, the hardness of the interface between the coated and uncoated samples was assessed using a Vickers micro hardness tester. This testing method allowed for a precise measurement of the resistance to deformation and the hardness of the material at a microscopic level. By analyzing the hardness of the interface, it was possible to determine the effectiveness of the coating in terms of enhancing the mechanical properties of the substrate.

2.4 Testing for erosion

By following ASTM G76 standard, solid particle erosion test was conducted at room temperature by using 312 µm sized silica sand particles. The solid sand particles were loaded into a hopper which is in top of the test rig and introduced into high pressure gas stream. The stream passes through the nozzle which is made from silicon carbide and particles are directed towards the fixed substrates in sample holder of the test rig with high velocity at a present impingement angle (90° to 30°). During testing, the nozzle tip distance to specimen and time of impingement were kept constant. A precision balancer with accuracy of 0.0001 was used to determine how quickly the coated and uncoated specimens eroded.

3. Analysis of microphotograph and coatings of the mechanical properties

The SEM was used to analyze the surface morphology of the multilayer coated samples (before erosion experiment) as shown in Fig. 3. Micro photograph confirms the uniform distribution of the coated particles. EDAX spectrum technique was used to confirm the composition of the coated particles. EDAX spectra were showed in Fig.4 the coating thickness was measured between the interface of the coating and base substrate and it was achieved as 250±30 µm.
Erosion rate in mass of the bare 304 steel and multilayer coated and uncoated samples are presented in Fig. 6. And it has been confirmed that, multilayered Wc-Sic-Cr$_3$C$_2$ coatings shows improvement in erosion resistance compared to 304 steel that is uncoated.

Using the ASTM E-384 standard, the regular surface hardness of with and without coated samples was determined. The hardness values of the both with and without coating samples were shown in Fig. 5. From the results it has been confirmed that, excellent adhesion was obtained due to high surface roughness of the base substrate due to grit blasting and it leads to avoid the delaminating of the coatings from the substrate upon impingement of solid silica particles.

The solid particle eroded surfaces of the multilayered coated and uncoated samples were observed under SEM and are presented in Fig. 7(a-b-c) and Fig. 8(a-b-c). From the Fig. 8 (a) – Fig. 8 (c) coated substrates shows a representative plate like lamellar structure along with micro crack, voids. Fig. 7 and Fig. 8 show the increasing in weight loss of samples at different impingement angles. At 30$^\circ$ impact angles increasing in weight loss occurs in uncoated samples which were lower as compared to 60$^\circ$ and 90$^\circ$ the kinetic energy of solid particles increases and more effective than other angles and this leads to formation of grooves and lips in uncoated samples than the coated samples. The silica particles cause breaking ground and micro cutting on the uncoated samples at all impingement angles 31-33). At high impact angle 90$^\circ$ the multilayer coated samples surface was removed by forming the small cracks. At high impact angle, due to less contact area as compared to 30$^\circ$ less fracture has happened on both coated and un coated samples. According to the explanation above, multilayer coating is a crucial factor in improving the solid particle erosion behaviour of AISI 304 stain-free steel, in addition to the coated sample mechanical qualities 34-39).
4. Conclusion

When subjected to solid particle erosion at various impingement angles, the studied multi-layered coatings demonstrated evidence of withstanding plastic deformation. The multi-layered coatings that were developed are an excellent alternative for enhancing the erosion resistance of components, especially those used in turbine blade materials. The solid particle erosion resistance of the developed coatings increases as the impingement angle is increased up to 75°, but at 90° there is a decrease in erosion resistance due to less impact from the particles. The multi-layered coating with
a thickness of 250µm showed greater resistance to solid particle erosion at different impingement angles. The study demonstrated that multilayered carbide coatings composed of WC, SiC, and Cr₂C₃ exhibit good erosion resistance. The findings of these studies provide important insights into the design and optimization of multilayered carbide coatings.

References


37) Latha Shankar, B. Nagaraj, P. M. Anil, K. C. 
