HVOF Sprayed Coating’s (WC-Co Ni Cr Si) to Conduct the Erosion Test

Navinesh.BC1, Prathap.D2, Praveen.D2, Sanjay.S2, Veerendra Patel2, Dr.B.Somasundaram3

Department of Mechanical Engineering, SKIT, School of Mechanical, REVA University Bangalore, India

ABSTRACT: It is a well-known fact that materials that consist of both brittle and ductile constituents can show erosion behavior in either a ductile or a brittle manner. The high velocity oxy-fuel (HVOF) sprayed WC-CoNiCrSi coatings on GrA1 boiler tube steel exhibit composite ductile and brittle modes of erosion under angular silica sand erodent of size 125-180μm impacted at 40m/s. The HVOF spraying leads to a high retention of WC in the coating matrix accompanied with lower porosity. The as-sprayed as well as eroded coatings have been characterized using scanning electron microscope and optical profilometer.

KEYWORDS: HVOF process, erosion test, coating composition, and 306-SS

I. INTRODUCTION

Erosive wear is caused in the solid bodies by the action of sliding or impact of solids, liquids, gases or a combination of these [1]. Manifestations of solid particle erosion in service usually include thinning of components, a macroscopic scooping appearance following the gas particle flow field, surface roughening, lack of the directional grooving characteristic of abrasion and in some but not all cases, the formation of ripple patterns on metals [2]. Solid particle erosion is an important material degradation mechanism encountered in a number of engineering systems such as thermal power plants, aircraft gas turbine engines, pneumatic bulk transport systems, coal liquefaction/gasification plants and ore or coal slurry pipe lines [3,4].

Power plants are one of the major industries suffering from severe corrosion and erosion problems resulting in the substantial losses. Erosion results from impact of particulates, such as coal ash, dolomite and unburned carbon particles o the surface of heated boiler tubes. It is generally believed that the most erosive species in the fly ash are quartz, which is a crystalline from of SiO2 and mullite. More than one quarter of all the boiler tube failures worldwide are caused by fly ash erosion [5,6].

Generally speaking, coatings can be regarded as materials with greater resistance to the significant surface degradation process. Coatings provide of extending the limits of use of materials at the upper end of their performance capabilities, by allowing the mechanical properties of the substrate material to be maintained while protecting them against wear or corrosion. An advantage of coating is that are relatively cheap and they can be applied insitu. There are many coating deposition techniques intended, level of adhesion required (size, shape, and metallurgy of the substrate), and availability and cost of the equipment. In general, widely used techniques to obtain coatings on boiler tubes or weld
overly, diffusion coating, thermal spraying and laser cladding. The most important drawbacks of diffusing coatings are that they are thin and cannot be produced on sight or repaired. In comparison with diffusion coatings, thermal spray coatings do not require such a high temperature of the base metal that would impair the mechanical or micro structural properties in the case of weld overlies there is increase in corner that repeated weld overlay application to the same tube area may result in embrittlement of the old overlay and lead to cracks that could propagate into the overlaid tube. Because of the mentioned shortcomings in diffusion and weld overlay coatings, attention is increasingly being forced on thermal sprayed coatings.[1],[2],[3],[4],[5],[10].

II. HIGH VELOCITY OXY-FUEL PROCESS (HVOF)

2.1. Explanation on HVOF Process

- HVOF is a method of propelling molten particles on to work surfaces for each coating. As an essential feature of thermal spray coatings, sprayed particles – upon and after impact – deform so as to interlock with the impact surface’s profile. While the initial thermal spray technology focused on guaranteed deformation through excessive heating, a new method is introduced with the high velocity of HVOF.
- A small chamber is used to create supersonic velocity of exhaust. The focused exhaust stream receives the powder material at a velocity that the resultant impact forges adequate bonding. In fact, the impact from the kinetic energy is so great that most of the porosity is eliminated. As such, the less porous coating provides the best wear resistance and densest coatings available. The HVOF thermal spray process uses the combustion gases such as propane, propylene hydrogen or a liquid fuel such as a kerosene fuel and oxygen.[1],[2],[3],[5]

2.2. HVOF Process Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen flow rate</td>
<td>200 l/mm</td>
</tr>
<tr>
<td>Fuel (LPG) flow rate</td>
<td>50 l/mm</td>
</tr>
<tr>
<td>Air flow rate</td>
<td>750 l/mm</td>
</tr>
<tr>
<td>Spray distance</td>
<td>100mm</td>
</tr>
<tr>
<td>Powder feed rate</td>
<td>36g/min</td>
</tr>
<tr>
<td>Fuel pressure</td>
<td>500kpa</td>
</tr>
<tr>
<td>Oxygen pressure</td>
<td>750kpa</td>
</tr>
</tbody>
</table>

Fig 2.1 Block Diagram of HVOF Process.
2.2. Coating Compositions

<table>
<thead>
<tr>
<th></th>
<th>WC</th>
<th>Co</th>
<th>Ni</th>
<th>Cr</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>66.4</td>
<td>13.6</td>
<td>8.67</td>
<td>7.82</td>
<td>1.557</td>
</tr>
</tbody>
</table>

In this coating, 80% of coating contains WC Co and 20% of Ni Cr Fe Si. The percentage of WC - 66.4, Co - 13.6, Ni - 8.67, Cr - 9.82, and that of Si - 1.557.

III. EXPERIMENTAL PROCEDURE

3.1 Substrate material and development of coating

Low carbon steel ASTM-SA201 grade A1(GrA1) which is used as material for boiler tubes in some coal fired thermal power plants in northern part of India has been used as substrate in the study. The specimens with approximate dimensions of 30mm*30mm*5mm were cut from the tubes for erosion studies. Samples were grinded with SiC papers down to 180 grit and grit blasted with Al₂O₃ (grit45) before being HVOF sprayed to develop better adhesion between the substrate and the coating. [8],[9],[10]

The composite coating powder of 80%WC CO-NiCrFeSi was used to spray to deposit coatings using HVOF Process.

3.2 Erosion Test Equipment and Setup

Fig 3.1 Block Diagram of Erosion Test Equipment

Fig 3.2 Air Jet Erosion Test Machine
Erosion Test Procedure:
• Before conducting the test, the specimen surface was cleaned properly.
• The sample is clamped at the fixture. The required angle and standoff distance was adjusted.
• The air at required pressure is mixed with the erosive particle and is directed to a specimen for specified time duration.
• The initial mass and the mass of the specimen after erosion were found out using the weighing machine.
• The above steps are repeated for different parameters mentioned.

3.3 Erosion Test for Substrate (306-SS)

Its compositions are listed below:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent by Weight 306-SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.08</td>
</tr>
<tr>
<td>Manganese</td>
<td>2.00</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.75</td>
</tr>
<tr>
<td>Chromium</td>
<td>16.00</td>
</tr>
<tr>
<td></td>
<td>18.00</td>
</tr>
<tr>
<td>Nickel</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>14.00</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>3.00</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.045</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.030</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.10</td>
</tr>
<tr>
<td>Iron</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

1.6 Tables for Impingement Angles (30°, 60°, 90°)

30° Table

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>15.6445</td>
<td>15.6440</td>
</tr>
<tr>
<td>10</td>
<td>15.6440</td>
<td>15.6395</td>
</tr>
<tr>
<td>15</td>
<td>15.6395</td>
<td>15.6393</td>
</tr>
<tr>
<td>20</td>
<td>15.6393</td>
<td>15.6392</td>
</tr>
<tr>
<td>25</td>
<td>15.6392</td>
<td>15.6392</td>
</tr>
</tbody>
</table>

Fig 4.1 Erosion Test for 30°
60° Table

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>19.6329</td>
<td>19.6326</td>
</tr>
<tr>
<td>10</td>
<td>19.6326</td>
<td>19.6324</td>
</tr>
<tr>
<td>15</td>
<td>19.6324</td>
<td>19.6323</td>
</tr>
<tr>
<td>20</td>
<td>19.6323</td>
<td>19.6323</td>
</tr>
</tbody>
</table>

90° Table

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>19.6335</td>
<td>19.6332</td>
</tr>
<tr>
<td>10</td>
<td>19.6332</td>
<td>19.6330</td>
</tr>
<tr>
<td>15</td>
<td>19.6330</td>
<td>19.6329</td>
</tr>
<tr>
<td>20</td>
<td>19.6329</td>
<td>19.6329</td>
</tr>
</tbody>
</table>

3.4 Erosion Test for Coating Components (30°, 60°, 90°)

Coating Compositions – WC Co-NiCrSi (80%-20%)  
30° Table

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>16.2802</td>
<td>16.2773</td>
</tr>
<tr>
<td>10</td>
<td>16.2773</td>
<td>16.2760</td>
</tr>
<tr>
<td>15</td>
<td>16.2760</td>
<td>16.2743</td>
</tr>
<tr>
<td>20</td>
<td>16.2743</td>
<td>16.2736</td>
</tr>
<tr>
<td>25</td>
<td>16.2736</td>
<td>16.2730</td>
</tr>
<tr>
<td>30</td>
<td>16.2730</td>
<td>16.2730</td>
</tr>
</tbody>
</table>

60° Table

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>21.2661</td>
<td>21.2652</td>
</tr>
<tr>
<td>10</td>
<td>21.2652</td>
<td>21.2633</td>
</tr>
<tr>
<td>15</td>
<td>21.2633</td>
<td>21.2617</td>
</tr>
<tr>
<td>20</td>
<td>21.2617</td>
<td>21.261</td>
</tr>
<tr>
<td>30</td>
<td>21.260</td>
<td>21.260</td>
</tr>
</tbody>
</table>
IV. RESULT AND DISCUSSION

4.1 Comparison Between Substrate and Coating

4.1.1 Graph for Coating and Substrate at 30°, 60° and 90°

**Table:**

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>21.2723</td>
<td>21.2707</td>
</tr>
<tr>
<td>10</td>
<td>21.2707</td>
<td>21.2696</td>
</tr>
<tr>
<td>15</td>
<td>21.2696</td>
<td>21.2689</td>
</tr>
<tr>
<td>20</td>
<td>21.2689</td>
<td>21.2668</td>
</tr>
<tr>
<td>25</td>
<td>21.2668</td>
<td>21.2661</td>
</tr>
<tr>
<td>30</td>
<td>21.2661</td>
<td>21.2661</td>
</tr>
</tbody>
</table>

**Explanation:** From the above graph the erosion rate increased in coating compared to substrate at 60° and 90°.

**Fig 4.6 Erosion Test at 90°**

V. CONCLUSION

- High velocity oxy-fuel thermal spraying with oxygen and liquid petroleum gas as fuel gases has been used successfully to deposit WC-Co-NiCrSi alloy coatings on boiler tube steels. LPG fuel gaze is cheap and readily available as compared to other fuels used for HVOF spraying. Under the given spray parameters coating with average thickness 290microns and average porosity of 0.5% has been achieved coating deposited resulted in hardness value of 1223HV.
- WC Co-NiCrAlYSi coatings show retention of higher amount of WC in matrix with a minor amount of W2C brittle phase.
- The erosion resistance of WC Co-NiCrSi coating maybe attributed to composite ductile and brittle modes of material removal although brittle mode is dominant. The morphology of the eroded surface points out craters.
Substrate steel exhibit slower steady state volume erosion rate in comparison to HVOF sprayed WC Co-NiCrSi coatings under similar test conditions. The higher hardness ratio between silicon erodent particle and substrate steel might have caused the penetration of silica particles into the surface.

Erosion rate with respect to angle of impact is maximum at 30degree and minimum at 90degree. Erosion rate with respect to stand of distance is maximum at 100mm and lower for 200mm. This implies that lower the stand of distance greater is the rate of erosion.

Erosion rate with respect to Pressure increases as the rate of erosion increases.

From the predicted mechanism it is found that the erosion behavior is valid for ductile materials. Hence our observation also follows the same rule.

Having calculated the ideal angle of contact, force of impingement and the distance of fall for a Mild Steel, Aluminum, Stainless Steel, we would now be in a position to predict the condition that should be maintained to minimize wear.

REFERENCES