THE ROLE OF LASER TREATMENT HVOF COATING TO PREVENT HOT CORROSION ON INDUSTRIAL TURBINES

Dharamendra M*, Jegadeeswaran N, Somasundaram B
School of Mechanical Engineering, REVA University, Bengaluru, India

ABSTRACT

The major failure modes of high temperature application alloys are high temperature oxidation and hot corrosion of components in the hot sections of industrial gas turbines, boilers, industrial waste incinerators, metallurgical furnaces, petrochemical installations, etc. The present research work explores the possibility of use of HVOF sprayed cermet coatings on the material used in gas turbine systems followed by LASER heat treated on the coatings. The coated samples, before and after LASER heat treated will be investigated for their resistance to hot corrosion, under laboratory conditions.

Feed stock powder will be sprayed on Titanium alloy (Ti-15) used in turbine related applications. The microstructure and mechanical properties of the coatings will be characterized. It is followed by the investigation of their cyclic hot corrosion of the coating behavior before and after LASER heat treated is compared with the uncoated substrate alloy by thermogravimetric method. The reaction products of the corroded samples will be identified and gone through structural investigation made by means of X-ray diffractometer (XRD), and Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Analysis (EDAX) techniques.

Key words: HVOF, Hot corrosion, Thermogravimetric studies, Laser Heat Treatment.

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1. INTRODUCTION

Titanium alloys are considered as potential materials for aerospace engine structural components like compressor discs and blades, due to their superior specific strength compared to nickel based super alloys [1]. But the Ti alloys, when used for long time at elevated temperatures, undergo degradation in a service environment containing oxygen. Hence appropriate protective coatings must be developed in order to enhance the life of the component. Also, protective coating will allow the use of the alloy safely at elevated
temperatures, which will help in increasing the operating efficiency [2]. The use of protective coatings is the most practical, reliable, and economically viable method to resist the degradation due to the interaction with the salt environment. These composite systems perform better under extreme conditions. The base material provides the required mechanical strength and the coatings protect the component against wear, corrosion, erosion and oxidation. The coatings that are designed to resist high temperature, in a salt environment, should be capable of developing a surface oxide layer, which is thermodynamically stable, slow growing and adherent [3,4].

High-velocity oxy-fuel (HVOF) spraying is a new type of thermal spray coating and rapidly developing technology in combating high-temperature corrosion and is now challenging the vacuum plasma spraying technique (VPS), which is very expensive. HVOF coatings have very low porosity, high hardness, high abrasive resistance, and good wear resistance with a strong ability to resist high-temperature corrosion [5-7]. HVOF process produces a coating which is stronger and denser compared to other thermal spray processes like electric arc, plasma spray or flame spray processes [8-10].

2. EXPERIMENTAL PROCEDURE

2.1. Substrate Material and Coating Formulation

The titanium alloy Ti-15 is used as substrate material in this investigation. The substrate material is ASTM B265 Grade 2 and is supplied by M/s MIDHANI, Hyderabad, India. The specimen with dimensions of approximately 25mm X 25mm X 5mm were ground and subsequently grit blasted with alumina powders (Grit 45) to improve adhesion of the coating to the substrate. The specimens were prepared manually without any structural changes. Commercially available cermet powder, namely 25% (50%WC-Cr3C2) + 75% (80%Ni -20%Cr) is used as feedstock alloy for the HVOF spraying. The details of the feedstock alloy are given in the Table 1. Figure 1 shows morphology of the powder which is predominantly spherical in nature with varying particle size.

Table 1 Composition and particle size range of powder and substrate material used for HVOF coating

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
<th>Particle size range and shape (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating powder</td>
<td>25% (50% WC-Cr3C2) + 75% (80%Ni -20%Cr)</td>
<td>-45+15 (Spherical)</td>
</tr>
<tr>
<td>Ti-15 (ASTM B265 Grade 2)</td>
<td>C-.007, O-.1071 N-.007 H-.0013 Fe-.03 Ti-Bal</td>
<td>Rolled sheet</td>
</tr>
</tbody>
</table>

2.2. Coating Spraying

The coatings were sprayed at Spraymet India Ltd., Bengaluru, India, by using high-velocity oxy-fuel system. A Metco DJ2600 gun is used for powder spraying through HVOF method. Following spray parameters were used for HVOF process, Oxygen flow rate- 270 LPM; fuel (LPG) flow rate- 70 LPM; air flow rate- 700 LPM; spray distance- about 20 cm; powder feed rate- 50 g/min; fuel pressure- 7 kg/cm²; air pressure- 5.5 kg/cm²; oxygen pressure- 10 kg/cm²; nitrogen gas (powder carrying gas) pressure- 5 kg/cm². The specimen was cooled with compressed air jets during and after spraying.
2.3. LASER Heat Treatment on Coated Materials

The coatings were taken for LASER Heat Treatment at Geomatic LASER solutions, Nellore, Andhra Pradesh, INDIA by using Nd-YAG 2300 kuka robot heat treatment machine. Following spray parameters were used for LASER Heat Treatment, LASER power-400W; power density-38W/mm²; Scanning speed-600mm/min; overlap ratio-30%; spot laser irradiation-0.6sec. The samples were heat treated in a furnace at 150°C for 2 hours before and after laser heat treatment.

2.4. Hot Corrosion studies and Analysis

<table>
<thead>
<tr>
<th>SL. No</th>
<th>Macrograph of samples</th>
<th>Uncoated sample</th>
<th>Coated sample</th>
<th>Laser treated coated sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Before hot corrosion studies</td>
<td><img src="a" alt="Sample Image" /></td>
<td><img src="c" alt="Sample Image" /></td>
<td><img src="e" alt="Sample Image" /></td>
</tr>
<tr>
<td>2</td>
<td>After hot corrosion studies (50 cycles)</td>
<td><img src="b" alt="Sample Image" /></td>
<td><img src="d" alt="Sample Image" /></td>
<td><img src="f" alt="Sample Image" /></td>
</tr>
</tbody>
</table>

**Figure 1** Macrograph of Uncoated, Coated and Laser treated Samples subjected to hot corrosion studies after 50 cycles at 700°C.

Hot Corrosion studies were conducted in molten salt environment (50%Na₂SO₄ + V₂O₅) on uncoated, coated and laser treated coated material at 700°C for 50 cycles. Each cycle consisted of heating at 700°C for 1 hour followed by cooling in air for 20 minutes. The temperature was controlled to an accuracy of ±5°C. Weight of the sample, along with the boat and spilled scales, if any, was measured after each cycle by using an electronic balance, to an accuracy of 0.0001 grams. Weight change values were measured after each cycle with the aim to understand the kinetics of oxidation. Visual observation was made at the end of each cycle, with respect to colour, lustre or any other feature of the scale.

The macrographs of uncoated samples of Ti-15, which were subjected to hot corrosion in 50%Na₂SO₄ + V₂O₅ molten salt before and after 50 cycles at 700°C are shown in Fig.1 (a) and (b). After 3rd cycle the colour was changed to brown and slight removal of layer was occurred. The macrographs of coated samples of Ti-15, which were subjected to hot corrosion in 50%Na₂SO₄ + 50%V₂O₅ molten salt for before and after 50 cycles at 700°C are shown in
After 2\textsuperscript{nd} cycle a white layer is formed and after 17\textsuperscript{th} cycle light green colour obtained after cooling. The macrographs of laser treated coated samples of Ti-15, which were subjected to hot corrosion in 50\%Na\textsubscript{2}SO\textsubscript{4} + 50\%V\textsubscript{2}O\textsubscript{5} molten salt for before and after 50 cycles at 700\textdegreeC are shown in Fig.1(e) and (f).

3. RESULTS AND DISCUSSION

3.1. Thermogravimetric Studies

The plots of cumulative weight gain (mg/cm\textsuperscript{2}) as a function of time expressed in the number of cycles is shown in Fig.2. The weight gain at the end of 50 cycles subjected to cyclic hot corrosion at 700 °C for Ti-15 uncoated, coated and laser treated samples are found to be 38.6316 mg/cm\textsuperscript{2}, 3.6451mg/cm\textsuperscript{2}, and 2.9107 mg/cm\textsuperscript{2} respectively.

![Figure 2 Plot of weight gain/area versus number of cycles of samples Ti-15 subjected to cyclic hot corrosion at 700 °C.](image)

Further the weight gain square (mg\textsuperscript{2}/cm\textsuperscript{4}) data is plotted [11-15] as a function of time shown in Fig.3. The plot shows an observable deviation from the parabolic rate law for Ti-15 of uncoated, coated and laser treated samples. The Fig.3 Shows that deviation is more in uncoated sample as compared to coated sample & laser treated coated sample.

![Figure 3 Plot of square of weight gain (mg\textsuperscript{2}/cm\textsuperscript{4}) vs. number of cycles of samples Ti-15 subjected to cyclic hot corrosion at 700 °C.](image)
The parabolic rate constant can be determined by, \( K_p = (\text{Slope from graph}) \times (10^{-8}/36) \) g \( \cdot \) cm\(^2\) \cdot s\(^{-1}\). Where, \( K_p \) – Parabolic Rate Constant.

**Table 2** The parabolic rate constant and slope of hot corrosion for uncoated, coated and LHT

<table>
<thead>
<tr>
<th>Factor</th>
<th>Uncoated</th>
<th>Coated</th>
<th>Laser Heat Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parabolic Rate Constant ( (K_p) ) ( g^2 \cdot cm^{-4} \cdot s^{-1} ) ( \times 10^{-8} )</td>
<td>1.0587</td>
<td>0.0067666</td>
<td>0.0046036</td>
</tr>
</tbody>
</table>

**3.2. X-Ray Diffraction Analysis**

![X-ray diffraction patterns](image1)

**Figure 4** X-ray diffraction patterns for (a) Uncoated (b) Coated and (c) Laser treated coated material subjected to hot corrosion in Na\(_2\)SO\(_4\) – 50% V\(_2\)O\(_5\) for 50 cycles at 700°C

The X-ray diffraction patterns for uncoated sample after its exposure to salt environment at 700 °C for 50 cycles are shown in Fig. 4(a). The scale [14-16] on Ti-15 surface under study consisted of TiO\(_2\), V\(_7\)Ti\(_6\)O\(_{17}\), TiVO\(_4\) and AlVO\(_4\) as major phases and TiVO\(_4\) and AlV\(_2\)O\(_4\) as minor phases. The X-ray diffraction patterns for coated sample after its exposure to salt environment at 700°C for 50 cycle is shown in Fig.4(b). The scale [14-16] on Ti-15 surface with coated under study consisted of CrO\(_3\), and NiO as major phases. The samples also showed the presence of NiCr\(_2\)O\(_4\), Cr\(_2\)C\(_6\), and CrVO\(_4\) as minor phases. The X-ray diffraction
patterns for coated sample after its exposure to salt environment at 700 °C for 50 cycles are shown in Fig.4(c). The scale on Ti-15 surface with laser treated [14] coated under study consisted of Cr$_2$O$_3$, and NiO as major phases. The samples also showed the presence of NiCr$_2$O$_4$, Cr$_{23}$C$_6$ and CrVO$_4$ as a minor phase.

### 3.3. SEM Analysis

The SEM micrograph showing the morphology of oxidized scales along with EDX analysis for uncoated, coated and laser treated samples is shown in Figure 5. Figure 5(a) displaying the uncoated sample of Ti-15 shows TiO$_2$ (89.10%) and V$_2$O$_5$ (7.55%) as the main constituent of the surface layer [15]. Figure 5(b) displaying the coated sample of Ti-15 shows Cr$_2$O$_3$ (42.5%) and NiO(40.1%) as the main constituent of the surface layer [16] along with small quantities of V$_2$O$_5$ (12.15%), SiO$_2$(2.9%), Ta$_2$O$_5$(2.35%). Figure 5(c) displaying the Laser treated coated sample of Ti-15 shows Cr$_2$O$_3$ (48.8%) and NiO(42.2%) as the main constituent of the surface layer along with small quantities of V$_2$O$_5$ (7.5%), Ta$_2$O$_5$(1.5%).

![Figure 5 SEM micrograph of a Ti-15 material](image)

**Figure 5**: SEM micrograph of a Ti-15 material (a) Uncoated (b) Coated & (c) Laser treated subjected to hot corrosion at 700°C.

### 4. CONCLUSIONS

The Uncoated Ti-15 suffered higher corrosion rate and intense spalling of oxide scales (TiO$_2$; rutile) is observed.

The superior hot corrosion resistance of 25% (WC-Cr$_3$C$_2$) + 75% (NiCr) is attributed to the oxide scale containing a continuous film of NiO and Cr$_2$O$_3$ which has minimal solubility in highly acidic Na$_2$SO$_4$ –50% V$_2$O$_5$. 

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editor@iaeme.com
Based on the thermogravimetric studies, the laser treated sample showing more corrosion resistance comparing to coated and uncoated. The uncoated Ti-15 shows least corrosion resistance.

Laser Heat Treated > Coated > Uncoated

REFERENCES


