

# Hot Corrosion Resistance by HVOF Coating on Gas Turbine Superalloy Materials

Srikanth K<sup>1</sup>, Sowrabh R Shetty<sup>2</sup>, Vinit Paul<sup>3</sup>, Mohammed Ibrahim<sup>4</sup>, Guide: Dr. N Jegadeeswaran<sup>5</sup>

<sup>1,2,3,4,5</sup> Dept of Mechanical Engineering

<sup>1,2,3,4,5</sup> REVA University

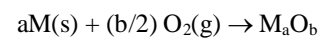
**Abstract-** In gas turbines, surface degradations such as Hot Corrosion occur at places like turbine blades, tubes etc. where the temperature is high. The turbines become less effective and noisy because of these defects. The present study is on High Velocity Oxy-Fuel coating on Superfer 800-H using a fused blend powder of NiCr with C. Hot Corrosion experiment was carried out on the coated and uncoated substrate in salt environment of V<sub>2</sub>O<sub>5</sub>+Na<sub>2</sub>SO<sub>4</sub> in 60:40 ratio at 600°C. In industries the turbines work during the day and are allowed to cool in the night, the same conditions are developed in laboratory using thermogravimetric analysis. In Thermogravimetric analysis, cycles of 1-hour heating and 20 minutes cooling were carried out. After each cycle, weight measurement was done. After conduction of 50 cycles, the samples were characterised using XRD and SEM/EDS. In XRD, X-Rays are projected on the specimens at 2θ angles and are reflected towards the receiver. A graph of intensity v/s diffraction angles are plotted to know the different phases of the elements. In SEM (Scanning Electrons Microscopy), an electron microscope is used to scan the surface of the specimen by focusing a beam of electrons. It was observed that the coated sample is more resistant to Hot Corrosion than the uncoated sample. Surface morphology from SEM/EDS indicated that the surface is rich in oxides. Thermogravimetric analysis indicated that the weight gain of the sample follows a parabolic relationship with time. The rate constant for the coated sample was much lesser compared to the uncoated sample.

**Keywords-** Hot Corrosion, High Velocity Oxy Fuel, Thermogravimetric Analysis, XRD, SEM.

## I. INTRODUCTION

There are, except for gold, no pure metals or alloys stable in air at room temperature. Oxidation of alloys is more complex than that of pure metals: no general theoretical treatment for high temperature oxidation mechanisms of ternary alloys is available (Reidar Haugsrud 2001). Metals tend to form oxides although in many instances the rate of reaction is very slow at low temperatures. Reaction rates increase rapidly with any increase in temperature, and at very

high temperatures most reactions are completed within a few minutes (Ivan Anzel 2000). Oxidation can be considered as a chemical reaction between a metal and oxygen gas to form the metal oxide. When a clean metal M reacts with oxygen gas, the oxide M<sub>a</sub>O<sub>b</sub> forms, it can be expressed as:



Alloys used commercially contain many alloying elements to achieve desirable mechanical properties. Such alloy components have different affinities for oxygen and diffusion rates differ in the oxide / alloy. Consequently, the scale and alloy compositions change in a complex way with time. The second component may enter the scale, affecting its structure, or may accumulate as metal or oxide beneath the main scale. If oxygen diffuses into the alloy, precipitation of the oxide of the less noble metal may take place as internal oxide.

Thermal spray coatings are coatings showing interesting and good cost/performance ratio. The ability to deposit coatings with thickness ranging from several micrometres to tenths of millimetres to improve resistance to surface degradation gives it its value. It is also suitable for a great variety of shapes and sizes and has the advantage of maintaining the substrate temperature relatively low. These coatings work at high temperatures developing a shielding oxide film on the metal surface to limit loss of metal by oxidation. Generally, these protective oxides (e.g. Al<sub>2</sub>O<sub>3</sub>, Cr<sub>2</sub>O<sub>3</sub>, etc.) decrease the penetration of gaseous or liquid corrosive mixture towards the substrate alloy/metal and prevent substrate elements diffusion towards the external surface where they could react with the coated elements to cause damage. Moreover, there should be minimum inter-diffusion phenomenon between coating and substrates to ensure no surface degradation takes place. (Mevrel 1989).

Amongst all the thermal spray coating techniques, HVOF process is the most promising due to its benefits. The kinetic energy and the output of a supersonic flow of burnt gases is used to soften and propel the spray powder, producing a dense, very low porosity, good inter-particle cohesion and well-bonded coatings. Combustion products come out under

high pressure from a confined combustion chamber. The products of combustion are then discharged through a cooled nozzle at high velocity. Powders to be deposited are fed into the combustion area by a carrier gas, where they are heated and carried by the gases. Molten or partially molten powder particles arrive at the substrate, on impact flatten and solidify rapidly. Coating thickness is normally in the range of 100 to 325  $\mu\text{m}$ . Depending upon the injection pressures of the fuel gases, jet velocities exiting the nozzle can be in the order of 700 m/s (Mohanty et al. 1996).

## II. EXPERIMENTAL SETUP

The substrate material used in the present investigation was Superfer 800-H. The substrate material was supplied by M/s Midhani, Hyderabad, India. The specimen of approximately 25mm x 25mm x 5mm were cut, ground and subsequently grit blasted with alumina powders. They were used as substrates for HVOF coating. Commercially available NiCr with C mixed powder was used for deposition. The details of the substrate used is given in Table 1

Table 1 Substrate Composition

Superfer 800-H	Fe	Ni	Cr	Ti	Al	Mn	Si	C	S
	Balance	30.8	19.5	0.44	0.34	1.0	0.6	0.10	.006

The coatings were sprayed at Spraymet India Ltd., Bangalore, using a Metco DJ 2600 (India) gun. The spray parameters were; oxygen flow rate: 250 litres per minute (LPM), fuel (LPG) flow rate: 60-70 LPM, air flow rate: 700 LPM, spray distance: 20-25 cm, powder feed rate: 30 - 50 g/min, fuel pressure: 7 kg/cm<sup>2</sup>, air pressure: 5.5 kg/cm<sup>2</sup>, oxygen pressure: 10 kg/cm<sup>2</sup>, nitrogen gas (powder carrying gas) pressure: 5 kg/cm<sup>2</sup>. Uncoated and HVOF coated specimens were subjected to Hot Corrosion test at 600°C ( $\pm 5^\circ\text{C}$ ) in salt environment of Na<sub>2</sub>SO<sub>4</sub>+V<sub>2</sub>O<sub>5</sub>. The samples were properly cleaned with acetone and dried before investigation. The physical dimensions of the samples were recorded before Hot Corrosion experiment. During Hot Corrosion, the specimen was kept in a ceramic boat and weight of the boat and the specimen was measured. The oxidation study was conducted under cyclic conditions. The tests were conducted for 50 cycles of which each cycle consisted of 1-hour heating at 600°C followed by 20 minutes cooling in room temperature. The weight change values were measured at the end of each cycle to check weight difference. Visual observations were made at the end of each cycle. The uncoated and HVOF coated materials after Hot Corrosion experiment were analysed by using X-Ray Diffraction method (XRD), Scanning Electron Microscopy (SEM) and Energy

Dispersive Spectroscopy (EDS) to reveal their morphological and microstructural features.

## III. RESULTS AND DISCUSSION

### 3.1 Visual Observations

In the case of Uncoated Superfer 800-H spalling was observed by the end of 3<sup>rd</sup> cycle. Light brown colour scales appeared on the surface which gradually turned dark black by the end of the study. This change of colour and surface texture was quite noticeable. By the end of the study the scales started falling off from the work pieces thereby exposing the base material. Apart from the scale formation no visible crack on the surface was observed during the entire experimental process.

On the coated substrate, the surface was brownish grey in colour at the starting and after subsequent cycles it turned into dark reddish brown and remained like that till the end of the study. This change of colour was quite noticeable but there was no appearance of visible surface crack. By the end of the study the surface remained crack free but small grains of brown colour formed on the surface. Scales formation on the surface was absent throughout the study. Samples after 50 thermal cycles are shown in Fig. 1.

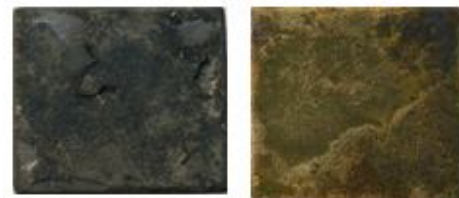


Fig. 1. Superfer 800-H Uncoated (Left) and Coated (Right) after Hot Corrosion

### 3.2 Thermogravimetric Analysis

The graph in Fig. 2(a) shows the variation of weight loss / area with respect to the number of cycles and the Fig. 2(b) shows the variation of (weight loss / area)<sup>2</sup> with respect to the number of cycles carried out the material during the course of the experiment. The above graphs illustrate the variation of weight loss by the material due to hot corrosion taking place due to the presence of V (Vanadium) and Na (Sodium) which reacts with the base material and atmospheric O (Oxygen) which in turn decreases the weight of the material. This corrosion happening due to this weakens the structural integrity of the boiler tube or turbine blades resulting in failure.

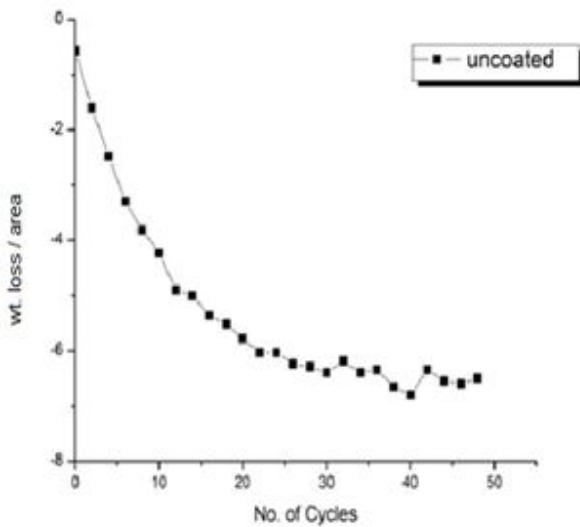


Fig. 2(a). Thermogravimetric data of uncoated Superfer 800-H subjected to Hot Corrosion, Weight gain per unit area versus number of cycles.

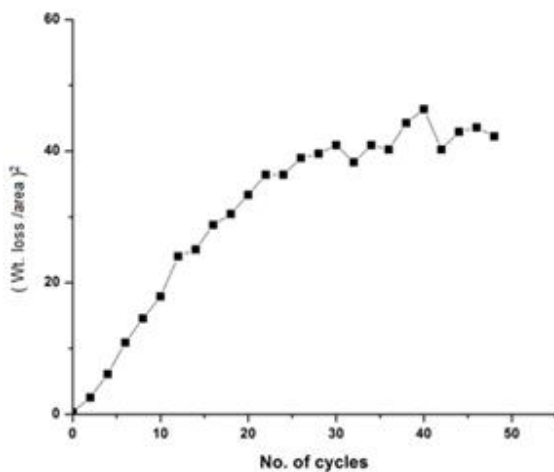


Fig. 2(b). Thermogravimetric data of uncoated Superfer 800-H subjected to Hot Corrosion, Square of weight gain per unit area versus number of cycles.

The Fig. 3(a) shows the variation of weight loss / area with respect to the number of thermogravimetric cycles and Fig. 3(b). Shows the variation of (weight loss / area)<sup>2</sup> with respect to the thermogravimetric cycles carried out the material during the course of the experiment. The above graphs illustrate the variation of weight loss by the material which is coated with NiCrC due to hot corrosion taking place on the surface of the material due to the presence of V and Na.

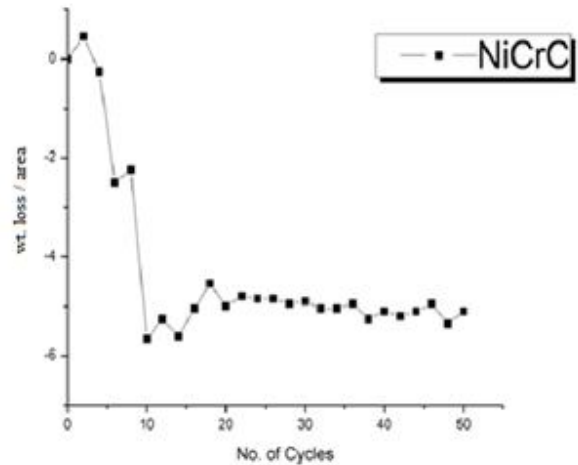


Fig. 3(a). Thermogravimetric data of coated Superfer 800-H subjected to Hot Corrosion, Weight gain per unit area versus number of cycles.

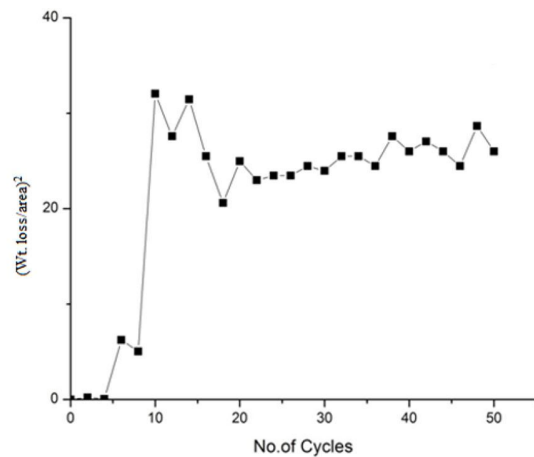


Fig. 3(b). Thermogravimetric data of coated Superfer 800-H subjected to Hot Corrosion, Square of weight gain per unit area versus number of cycles.

### 3.3 XRD Analysis

The XRD patterns of the hot corroded material is shown in Fig. 4. XRD patterns of the uncoated material reveals that the presence of Fe<sub>2</sub>O<sub>3</sub> and FeV<sub>2</sub>O<sub>4</sub> as the main phases. So, it is well established from both XRD analysis that Fe<sub>2</sub>O<sub>3</sub> is the main component present on the surface. Fe<sub>2</sub>O<sub>3</sub> is not a protective coating. The presence of Fe<sub>2</sub>O<sub>3</sub> weakens the material which ultimately leads to failure.

The XRD patterns of the hot corroded samples with NiCrC Coating after 50 cycles shown in Fig. 4. Revealed that the presence of NiO, Cr<sub>23</sub>C<sub>6</sub>, CrVO<sub>4</sub> and Cr<sub>2</sub>O<sub>3</sub> as the main phases. Weak phases belonging to Al<sub>2</sub>O<sub>3</sub>, FeVO<sub>4</sub> and MnO were not indexed. So, from the XRD study it is established

that the surface contains  $\text{Cr}_2\text{O}_3$  which makes a protective layer on the material. The presence of  $\text{Cr}_2\text{O}_3$  makes the material stronger as the corrosion stops after a few cycles

surface mostly consist of oxides of Cr, Fe, Ni, and some traces of V. From the SEM/EDX study it is found that  $\text{Fe}_2\text{O}_3$  is the most prominent oxide which is present on the surface.  $\text{Fe}_2\text{O}_3$  is not a protective coating. The presence of  $\text{Fe}_2\text{O}_3$  makes the material weaker. As the material weakens substantially over a period of time, the material eventually fails.

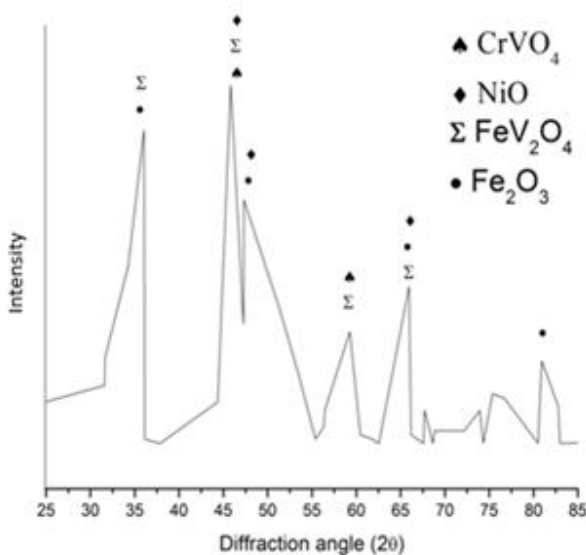


Fig. 4(a). XRD Graph of uncoated Superfer 800-H after Hot Corrosion

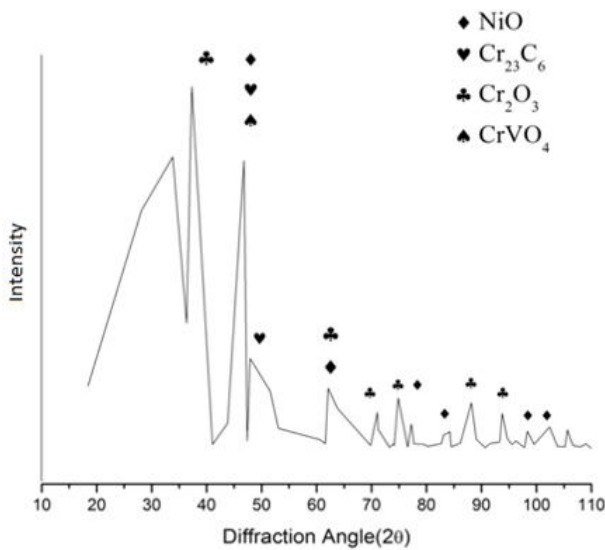


Fig. 4(b). XRD Graph of Superfer 800-H coated with NiCrC after Hot Corrosion

### 3.4 SEM Analysis

The Fig. 5(a) shows the SEM image Superfer 800-H subjected to hot corrosion at 600°C temperature after 50 cycles. SEM images of uncoated material reveal lots of needle like structures that are visible on the surface of the specimen. The SEM micrograph of the Superfer 800-H indicates lots of surface cracks and crystal formations. The scales on the

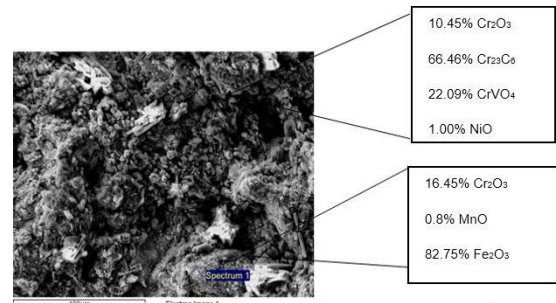


Fig. 5(a). Morphological investigation of uncoated Superfer 800-H after exposure to molten salt of  $\text{Na}_2\text{SO}_4$  and  $\text{V}_2\text{O}_5$  at 600 °C

SEM micrograph analysis of the hot corroded NiCrC coated super alloy are shown in Fig 5(b). In case of NiCrC coated material circular crystal-like structures can be seen on the surface as a result of hot corrosion which have taken place on the coating surface. The surface mostly consists of oxides of Cr, Fe, Ni, in the form of  $\text{CrVO}_4$ ,  $\text{Cr}_2\text{O}_3$ , NiO and also  $\text{Cr}_{23}\text{C}_6$ ,  $\text{Cr}_2\text{O}_3$  and NiO form the protective coating on the surface of the material thereby preventing further corrosion. From the analysis the surface mostly consists of  $\text{Cr}_2\text{O}_3$ .

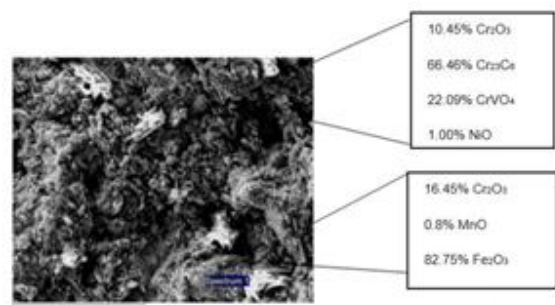


Fig 5(b): Morphological investigation of NiCrC coated Superfer 800-H after exposure to molten salt of  $\text{Na}_2\text{SO}_4$  and  $\text{V}_2\text{O}_5$  at 600 °C

### IV. CONCLUSIONS

In the present work, hot corrosion behaviour of uncoated and HVOF sprayed NiCrC and NiCrSi on Superfer 800-H alloy in an aggressive environment of  $\text{Na}_2\text{SO}_4 - \text{V}_2\text{O}_5$  at 600°C has been investigated and following conclusions are made.

- The HVOF spray process could be successfully to deposit the NiCrC and NiCrSi coating on the superalloy.
- Coating improved Hot Corrosion behaviour in aggressive environment of  $\text{Na}_2\text{SO}_4 - \text{V}_2\text{O}_5$  at  $600^\circ\text{C}$ .
- The uncoated superalloys have shown spalling and peeling of the scale and the mass lost was relatively more than the coated superalloys.
- The parabolic rate constant ( $K_p$ )/ slope of the NiCrC coated superalloy is much less than the uncoated one. It is also less than the NiCrSi coated material.
- The sequence of protection provided by the coating is NiCrC > NiCrSi > uncoated alloy.

### REFERENCES

- [1] I.G Wright, T.B Gibbons, Recent development in gas turbine materials and technology and their implications for syngas firing, Int. Journal of Hydrogen Energy Vol. 32, (2007), P.P 3610-3691
- [2] M. R. Khajavi, M. H. Sharait, Failure of First Stage gas turbine blades, Engineering Failure Analysis, Science direct vol. 9 (2004). P.P 3,4,6
- [3] T.S. Sidhu, S. Prakash and R. D. Aggarwal, Studies on the properties of HVOF thermal spray coating for Higher temperature application, Materials Science, Vol. 41, no. 6 (2005) P.P 2,3,6
- [4] H. Hamatani, Y. E. Chiyama and J. Kobayashi, Mechanical and thermal properties of HVOF sprayed Ni based alloys with carbide, Sci. Tech. Adv. Mater, 3, No. 4, (319-326) (2006)
- [5] T.S. Sidhu, S. Prakash and R. D. Aggarwal, Characterization of NiCr wire coating on Ni- and Fe-based superalloys by the HVOF process, Surf. Coat. Techno Vol. 201, no. 8 (2007) P.P 1602-1612
- [6] J. M. Guiemary, J. Fernandez, J.M Paco and De Sanchez, Corrosion resistance of HVOF WC-CO and TiC/Ni-Ti coatings sprayed on commercial steel., J. Surf. Eng.vol. 14 (133), (1998) P.P 3-7
- [7] A.W Batchelor, L.N Lam and M. Chandrashekhara, Discrete coatings, Material degradation and its control by surface engineering, 2<sup>nd</sup> Ed. Imperial College Press, (2003). P.P 124-129, 239-246.