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Combating Hot Corrosion Behaviour of Ni-Cr Superalloy for Turbine Applications

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Abstract – Hot corrosion is one of the major degradation mechanisms affecting the performance and life of gas turbine components operating at elevated temperatures. Nickel-Chromium (Ni-Cr) superalloys are extensively used in turbine blades, vanes, and combustion chambers because of their superior mechanical strength, oxidation resistance, and thermal stability. However, under aggressive environments containing molten salts such as sodium sulfate (Na_2SO_4) and vanadium pentoxide (V_2O_5), these alloys suffer severe hot corrosion damage. The present study investigates the hot corrosion behaviour of Ni-Cr superalloys and evaluates methods to combat degradation through alloy composition optimization, protective coatings, and HVOF thermal treatment techniques. Chromium-rich oxide layers improve oxidation resistance and reduce corrosion penetration. Thermal barrier coatings further enhance durability under cyclic thermal exposure. The study concludes that proper selection of alloying elements and surface engineering techniques significantly improves hot corrosion resistance, increasing operational efficiency and service life.

Keywords: Ni-Cr superalloy, hot corrosion, turbine application, oxidation resistance, thermal barrier coating, high-temperature corrosion.

I. OBJECTIVES OF THE STUDY

The key objectives of this study are as follows:

- To study the hot corrosion behaviour of Ni-Cr superalloys used in turbine applications.
- To analyze the influence of chromium content on oxidation resistance.
- To investigate the mechanisms responsible for hot corrosion degradation.
- To evaluate the effectiveness of protective coatings in reducing corrosion.
- To improve the service life and performance of turbine materials.

II. INTRODUCTION

Gas turbines are widely used in aerospace, thermal power plants, marine propulsion systems, and industrial power generation due to their high power-to-weight ratio and operational efficiency. Turbine components operate under extremely severe conditions involving high temperature, high pressure, cyclic thermal loading, and corrosive gases. The operating temperature of advanced turbines often exceeds 900°C, creating a challenging environment for structural materials.

Nickel-based superalloys containing chromium are among the most important materials used in turbine applications because of their exceptional resistance to creep, oxidation, and thermal fatigue. Chromium plays a significant role in improving oxidation resistance by forming a stable chromium oxide (Cr_2O_3) protective layer on the material surface.

Despite their superior high-temperature properties, Ni-Cr superalloys are vulnerable to hot corrosion in environments containing sulfur, sodium, and vanadium compounds. These contaminants originate from low-quality fuels, marine atmospheres, and industrial combustion gases. Hot corrosion accelerates material degradation by destroying the protective oxide layer, leading to rapid metal loss, crack initiation, and premature component failure.

The present research focuses on understanding the hot corrosion behaviour of Ni-Cr superalloys and identifying methods to improve corrosion resistance through material selection, alloy modification, and coating technologies.

III. MATERIAL SELECTION

3.1 Base Material: Ni-Cr Superalloy

The selected material for this study is Nickel-Chromium (Ni-Cr) superalloy, chosen for its proven performance in high-temperature environments. The chemical composition and key mechanical properties are presented in Table I and Table II respectively.

TABLE I. Typical Chemical Composition of Ni-Cr Superalloy

Element	Percentage (%)
Nickel (Ni)	70
Chromium (Cr)	20
Cobalt (Co)	5
Aluminum (Al)	2
Others	2

TABLE II. Mechanical and Physical Properties of Ni-Cr Superalloy

Property	Value
Density	8.2 g/cm³
Melting Point	1350°C
Tensile Strength	900 MPa
Hardness	350 HV
Thermal Conductivity	11 W/mK
Oxidation Resistance	Excellent

3.2 Hot Corrosion

Hot corrosion is a form of accelerated oxidation that occurs between 600°C and 900°C in the presence of deposited molten salts. It results from lower melting eutectic salt mixtures and causes severe localized attack on the alloy surface, destroying the protective oxide scale.

3.3 Chemical Reactions

The principal chemical reactions occurring during hot corrosion are as follows:

Formation of chromium oxide: $2Cr + 3O_2 \rightarrow 2Cr_2O_3$

Formation of nickel oxide: $2Ni + O_2 \rightarrow 2NiO$

Sulfidation reaction: $Na_2SO_4 + Ni \rightarrow NiS + Na_2O + O_2$

The protective oxide scale becomes unstable due to sulfur penetration into the alloy substrate, accelerating overall corrosion damage.

IV. EXPERIMENTAL METHODOLOGY

4.1 Sample Preparation

Ni-Cr alloy specimens were cut into standard dimensions suitable for high-temperature exposure testing. Surface polishing was performed using successive grades of emery paper to achieve a uniform surface finish. Samples were cleaned in acetone to remove surface contaminants, dried, and initial weight was recorded using a precision analytical balance.

4.2 Coating Process

Thermal barrier coatings were applied to specimens using the High-Velocity Oxy-Fuel (HVOF) thermal spray technique. The coating system comprised two distinct layers:

Bond Coat – NiCrAlY: A metallic NiCrAlY bond coat was deposited as the first layer to provide adhesion between the substrate and the ceramic top coat, and to offer additional oxidation resistance.

Ceramic Top Coat – YSZ: Yttria Stabilized Zirconia (YSZ) was applied as the ceramic top coat to act as a thermal insulator, reducing the temperature experienced by the metallic substrate.

4.3 Hot Corrosion Test

The hot corrosion test was conducted in a muffle furnace under controlled conditions. Samples were coated with a salt mixture of Na_2SO_4 and V_2O_5 and exposed cyclically. Post-exposure analysis was carried out using Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) to assess microstructural changes and phase transformations. Test conditions are given in Table III.

TABLE III. Hot Corrosion Test Conditions

Parameter	Value
Temperature	900°C
Exposure Time	50 hours
Salt Mixture	$Na_2SO_4 + V_2O_5$
Analysis	SEM and XRD

V. RESULTS AND DISCUSSION

5.1 Weight Gain Behaviour

The uncoated Ni-Cr alloy exhibited significantly higher weight gain throughout the exposure period due to continuous oxidation and scale formation. In contrast, coated specimens demonstrated markedly lower weight gain, confirming the effectiveness of the thermal barrier coating as both a thermal and chemical barrier against aggressive salt attack.

Key observations from the weight gain analysis:

- Uncoated sample: Higher corrosion rate due to direct salt-alloy contact.
- Coated sample: Substantially lower weight gain and reduced corrosion penetration.
- Higher chromium content alloys: Demonstrated improved oxidation resistance.

5.2 Oxide Layer Formation

A stable, adherent chromium oxide (Cr_2O_3) layer formed on the alloy surface at elevated temperatures. This oxide scale acted as a diffusion barrier, significantly reducing the rate of oxygen and sulfur penetration into the substrate. SEM analysis confirmed dense oxide layer formation in higher-chromium specimens compared to baseline alloys.

5.3 Effect of Thermal Barrier Coating

The application of TBC through the HVOF process resulted in substantial improvement in hot corrosion resistance. The YSZ top coat effectively reduced the thermal gradient across the alloy surface, while the NiCrAlY bond coat provided supplementary oxidation protection. Thermal barrier coatings significantly reduced:

- Oxidation rate and oxide scale spallation tendency.
- Sulfidation attack through molten salt infiltration.
- Thermal fatigue damage during cyclic heat exposure.

5.4 Failure Mechanism

Analysis of failed uncoated specimens revealed a multi-stage degradation sequence. In the initial stages, the protective Cr_2O_3 scale was destabilized by the molten salt mixture. Subsequent sulfur and vanadium penetration disrupted scale continuity leading to accelerated metal loss. The primary failure mechanisms identified were:

- Oxide scale spallation due to thermal cycling stresses.
- Crack propagation at the oxide-metal interface.
- Molten salt penetration dissolving the protective scale.
- Sulfur attack converting protective oxides to non-protective sulfides.

VI. CONCLUSION

The present study investigated the hot corrosion behaviour of Ni-Cr superalloys under turbine operating conditions involving aggressive molten salt environments at 900°C. The following conclusions are drawn:

1. The uncoated Ni-Cr superalloy exhibited significant weight gain and accelerated degradation due to the destabilization of the protective oxide scale in the presence of Na_2SO_4 and V_2O_5 salt mixtures.

2. Chromium-rich oxide layers (Cr_2O_3) formed on the alloy surface provided effective oxidation protection by acting as a diffusion barrier against oxygen and sulfur ingress.

3. Application of thermal barrier coatings using the HVOF technique with NiCrAlY bond coat and YSZ ceramic top coat significantly reduced the oxidation rate, sulfidation attack, and thermal fatigue damage.

4. Failure analysis confirmed that oxide scale spallation, crack propagation, and molten salt penetration were the primary mechanisms responsible for accelerated degradation in uncoated alloys.

5. Optimized alloy composition combined with HVOF-applied diffusion and thermal barrier coatings significantly enhanced hot corrosion resistance, improving operational efficiency and extending the service life of turbine components.

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REFERENCES

R. Rajendran, “Gas turbine coatings – An overview,” Engineering Failure Analysis, vol. 26, pp. 355–369, 2012.

S. Bose and J. DeMasi-Marcin, “Thermal barrier coating experience in gas turbine engines at Pratt & Whitney,” Journal of Thermal Spray Technology, vol. 6, pp. 99–104, 1997.

P. Kuppusamy and R. Krishnamurthy, “Hot corrosion behaviour of Ni-based superalloys in molten salt environment,” Surface and Coatings Technology, vol. 161, pp. 177–183, 2002.

A. S. Khanna, High Temperature Oxidation and Corrosion. Materials Park, OH: ASM International, 2002.

G. Mauer, R. Vaßen, and D. Stöver, “Comparison and applications of HVOF thermal spray coatings,” Journal of Thermal Spray Technology, vol. 20, pp. 233–241, 2011.

B. Rajasekaran, G. Mauer, and R. Vaßen, “Characterization of NiCrAlY bond coats deposited by HVOF for thermal barrier coating applications,” Journal of Thermal Spray Technology, vol. 20, pp. 1209–1216, 2011.

N. Birks, G. H. Meier, and F. S. Pettit, Introduction to the High Temperature Oxidation of Metals, 2nd ed. Cambridge: Cambridge University Press, 2006.