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Research Article

Hot Corrosion Behaviour of Detonation Gun Sprayed Al_2O_3-40TiO_2 Coating on Nickel Based Superalloys at 900°C

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Hot corrosion is the major degradation mechanism of failure of boiler and gas turbine components. These failures occur because of the usage of wide range of fuels such as, coal and oil at the elevated temperatures. Nickel based superalloys having excellent mechanical strength and creep resistance at elevated temperature are used under such environment but they lack resistance to hot corrosion at high temperature. To overcome these problems hot corrosion resistant coatings are deposited on these materials. In the current investigation Al_2O_3-40%TiO_2 powder has been deposited on Superni 718 and AE 435 superalloys by Detonation Gun method. The hot corrosion performance of Al_2O_3-40%TiO_2 coated as well as uncoated Superni 718 and AE 435 alloys has been evaluated in aggressive environment Na_2SO_4-82%$Fe_2(SO_4)_3$ under cyclic conditions at an elevated temperature of 900°C. The kinetics of the corrosion is approximated by weight change measurements made after each cycle for total duration of 50 cycles. Scanning electron microscopy was used to characterize the hot corrosion products. The coated samples imparted better hot corrosion resistance than the uncoated ones. The AE 435 superalloy performed better than Superni 718 for hot corrosion in a given environment.

1. Introduction

Many important engineering systems operating at high temperature fail due to hot corrosion which is the main failure modes of components in the hot sections of gas turbines, boilers, and so forth [1, 2]. Hot corrosion is basically the result of attack by fuel and/or ash compounds of Na, V, S, and Cl that are present in the coal or in fuel oil used for combustion in the applications such as boilers, IC engines, gas turbines, fluidized bed combustion, and industrial waste incinerators. In some situations, these impurities may be ingested from the service environment. The operating temperatures in gas turbines are relatively high and are expected to increase further with the advances in materials development and cooling schemes for the new generation gas turbine engines. The combination of such high temperatures with an aircraft environment that contains contaminants such as sodium, sulphur, vanadium, and various halides requires special attention to the phenomena of hot corrosion [3]. Superalloys find their largest application in the gas turbine industry, constituting over 50% of the gas turbine weight. Superalloys exposed to high temperature tend to suffer degradation due to hot corrosion during service. In utility gas turbine, contaminants in the fuel and air can cause serious hot corrosion problem [4–6]. One of the solutions to this problem is applying a thin layer of antiwear and antioxidation coating [6–8]. Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Coatings are used in wide range of applications including automotive systems, boiler components, power generation equipment, chemical process equipment, aircraft engines, pulp and paper processing equipment, bridges, rollers and concrete reinforcement, orthopaedics and dental, land based and marine turbine, and ships [9]. Among the commercially available thermal spray coating techniques, Detonation Gun Spray and High Velocity Oxy Fuel (HVOF) spray are the best choices to get hard, dense and wear resistant coating as desired [10]. Detonation Gun (D-Gun) Spraying is one of the thermal spray processes, which gives an extremely good adhesive strength, low porosity, and coating

Table 1: Chemical compositions of Superni 718 and AE 435 superalloys Midhani grade chemical composition (wt.%).

Materials	C	Mn	Si	S	P	Cu	Cr	Fe	Ti	Al	Ni
Superni 718	0.0047	0.01	0.02	0.002	—	0.010	17.78	19.56	—	—	Bal
AE 435	0.08	0.03	0.03	>0.005	>0.005	>0.01	20.19	0.10	0.30	0.12	Bal

Table 2: Characteristics of Al_2O_3-40TiO_2 coating powder.

Powder	Make and commercial code	Chemical composition (wt%)	Morphology	Particle shape	Powder size
Al_2O_3-40TiO_2 coating	H.C. Starck Amperit 745.001	SiO_2 maximum 0.1% Fe_2O_3 maximum 0.3% Na_2O maximum 0.3% Al_2O_3 balance	Fused	Regular and angular block	45/22 μm

surface with compressive residual stress [11]. Detonation Gun (D-Gun) offers highest velocity (800–1200 m s^{-1}) for the sprayed powders that are unattainable by the plasma and HVOF condition. The higher particle velocity during deposition of coating results in desirable characteristics such as lower porosity and higher hardness of the coating [12]. In thermal spray industry Al_2O_3 alloy with TiO_2 ceramics are known for easy spray and environmental compatibility [13, 14]. Al_2O_3 alloy with TiO_2 ceramics are popular in thermal spray industry due to easy spray and environment compatibility [15]. The presence of TiO_2 in the Al_2O_3 powders contributes to lower porosity in the coating [13, 16]. The microhardness of Al_2O_3-TiO_2 composite coating depends essentially on its composition. The objective of the present work is to investigate the role of Detonation Gun Sprayed coating in enhancing the properties of surface of substrate to counter the problem of hot corrosion. Al_2O_3-40TiO_2 coating is deposited on Superni 718 and AE 435 superalloys using the Detonation Gun Spray process. Hot corrosion test of specimens is carried out in the molten salt environment Na_2SO_4-82%$Fe_2(SO_4)_3$ at 900°C for 50 cycles of one hour duration. Thermogravimetric technique was used to approximate the hot corrosion kinetics of Al_2O_3-40TiO_2 coating and bare superalloy substrates. SEM is used to characterize the hot corrosion product of the coated and bare samples.

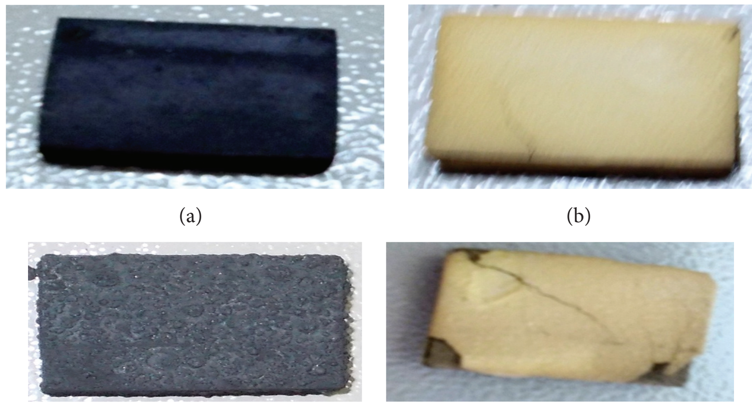
2. Experimental Procedure

2.1. Materials and Coating Formulation. Two nickel based superalloys, namely, Superni 718 and AE 435, are selected as substrate materials procured from M/S Mishra Dhatu Nigam Limited, Hyderabad, India, in the rolled sheet form. The chemical compositions of Superni 718 and AE 435 are given in Table 1. Each specimen measuring approximately 20 mm × 15 mm × 5 mm was cut from the rolled sheet and polished by using 180, 220, 320, 400, and 600 grades SiC emery papers. The specimens were blasted using alumina stones (grit 20) prior to coating. Commercially available Al_2O_3-40TiO_2 powder (H.C. Starck, Amperit 745.001) with its particle size 22–45 μm was used to coat the superalloys by Detonation Gun Spray process. The Characteristics of Al_2O_3-40TiO_2 coating powders is given in Table 2. D-Gun was used to apply Al_2O_3-40TiO_2 coating on the superalloy substrates at SVX Powder M Surface Engineering Pvt Ltd, Greater Noida (India). All the process parameters, including the spray distance, were kept constant throughout coating process. The process parameters are given in Table 3.

Table 3: Parameter used in Detonation Gun Spray.

Parameters	Al_2O_3-40TiO_2 coating
Oxygen flow rate (O_2)	4,800 SLPH
Pressure	0.2 MPa
Acetylene flow rate (C_2H_2)	1920 SLPH
Pressure	0.14 MPa
Nitrogen flow rate (N_2)	800 SLPH
Pressure	0.4 MPa
Spray angle	90°
Spray distance	200 mm
Power	450 VA
Wire rate	1–10 Hz
Coating thickness (average)	250 μm

2.2. Hot Corrosion Text. Hot corrosion studies were performed in a molten salt Na_2SO_4-82%$Fe_2(SO_4)_3$ for 50 cycles under cyclic conditions. Each cycle consisted of 1 hour heating at 900°C in a Kanthol wire tube furnace followed by 20 minutes cooling at room temperature. The samples were washed in acetone for removing dirt, grease, and oil. The specimens were heated in an oven to about 250°C before applying the salt layer. A salt of Na_2SO_4-82%$Fe_2(SO_4)_3$ thoroughly mixed with distilled water was applied uniformly on the warm polished specimens with the help of a camel hair brush. The amount of salt coating was kept in the range of 4.0-5.0 mg/cm^2. The salt coated specimens inside the alumina boats were then kept in the oven for 3-4 hours at 100°C. They were again weighed before exposure to hot corrosion tests in the Kanthol wire tube furnace. During hot corrosion runs, the weight of boats and specimens was measured together at the end of each cycle with the help of electronic weighing balance with an accuracy of 1 mg. The spalled scale was also included at the time of measurements of weight change to determine total rate of corrosion. The corrosion rate was calculated using the weight change measurements of the bare



(a) (b)

(c) (d)

Figure 1: Surface macrographs for (a) Superni 718, (b) coated Superni 718, (c) AE 435, and (d) coated AE 435 after 50 cycles exposure to molten salt Na_2SO_4-82%$Fe_2(SO_4)_3$ environment at 900°C.

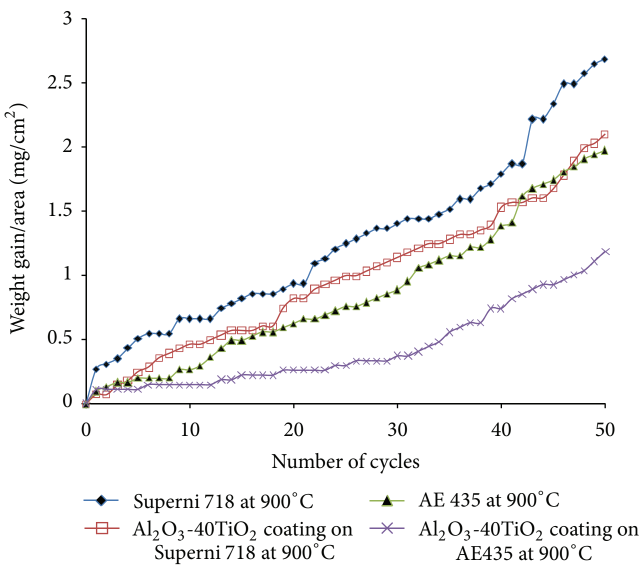


Figure 2: Weight gain/area versus number of cycles plot for Al_2O_3-40TiO_2 coated and bare superalloys subjected to Na_2SO_4-82%$Fe_2(SO_4)_3$ at 900°C for 50 cycles.

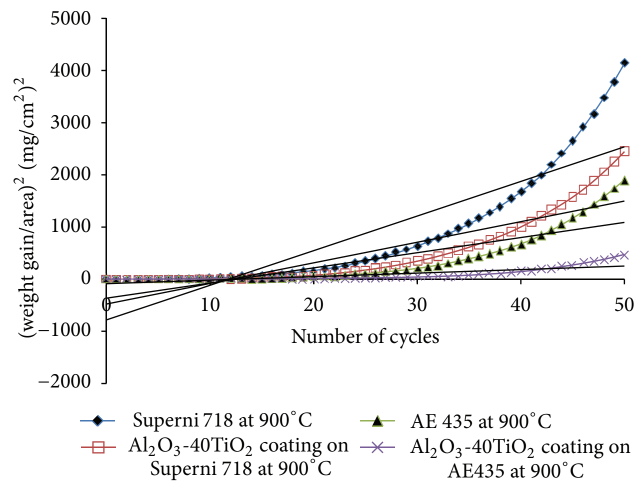


Figure 3: (Cumulative weight gain/area)^2 vs. number of cycles for bare and Al_2O_3-40TiO_2 coated superalloys subjected to Na_2SO_4-82%$Fe_2(SO_4)_3$ at 900°C for 50 cycles.

and coated samples. The surface of all the samples after corrosion tests was analysed using SEM.

3. Results and Discussions

In case of Superni 718 superalloy (Figure 1(a)), spalling was observed after the completion of the 8th cycle. The colour of Superni 718 was blackish upto the 6th cycle. The colour of AE 435 superalloy was light blackish upto the 4th cycle and for subsequent cycles the colour was dark blackish. The colour of coated Superni 718 and AE 435 was light blackish colour upto the 5th cycle and for further cycles they showed yellowish colour.

Figure 2 shows the weight gain/unit area for the bare as well as coated superalloys in the presence of molten salt Na_2SO_4-82%$Fe_2(SO_4)_3$ environment under cyclic conditions. Figure 2 indicates that the weight gains of the coated superalloys are lower when compared to those of bare superalloys in the molten salt environment. Al_2O_3-40TiO_2 coated Superni 718 has shown a slightly higher weight gain when compared to Al_2O_3-40TiO_2 coated AE 435 superalloy. The weight gain data indicate that the bare superalloys are prone to hot corrosion attack, whereas the Detonation Gun Sprayed Al_2O_3-40TiO_2 coating on AE 435 superalloy provided a better protection to the superalloys from the hot corrosion to a considerable extent.

The weight gain square (mg^2/cm^4) versus time (number of cycles) plots are plotted in Figure 3 to establish the rate law for the hot corrosion. It is observed from the graph that the coating follows a nearly parabolic rate law. The parabolic rate (Figure 3) constant K_p was calculated by a linear least-square algorithm to a function in the form of $(W/A)^2 = K_p t$,

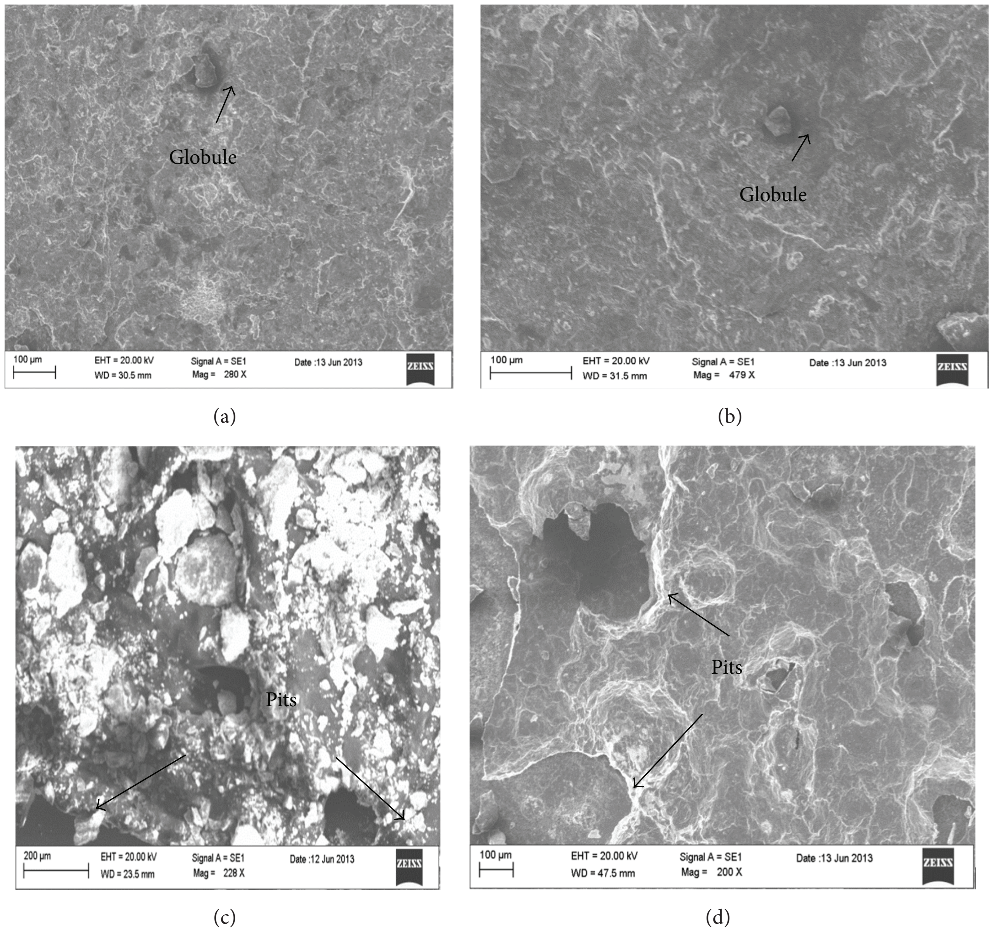


Figure 4: SEM micrographs of (a) Al_2O_3-40TiO_2 coated Superni 718 (b) Al_2O_3-40TiO_2 coated AE 435 (c) Superni 718 (d) AE 435 superalloys subjected to Na_2SO_4-82%$Fe_2(SO_4)_3$ at 900°C for 50 cycles.

Table 4: Parabolic rate constant (K_p) for the Al_2O_3-40TiO_2 coated and uncoated Superni 718 and AE 435 superalloys.

Substrate	K_p Values ($\times 10^{-10}$ g^2 cm^{-4} s^{-1})
Superni 718	66.376
Coated Superni 718	39.443
AE 435	28.995
Coated AE 435	6.7245

where W/A is the weight gain per unit surface area (mg/cm^2) and t indicates the number of cycles, representing the time of exposure [14]. The parabolic rate constant K_p for both superalloys is given in Table 4.

The SEM micrographs of Al_2O_3-40TiO_2 coating and uncoated superalloys after exposure to hot corrosion environment are shown in Figure 4. The surface morphology of both the coated substrates is almost similer with some globular like structure on the surface as seen from Figures 4(a) and 4(b). The surface of Superni 718 is rough as seen from Figure 4(c). Some pits are also visible in Figures 4(c) and 4(d). This may be due to spalling behaviour of the scale. Similar results have been reported by Sidhu et al. [17]. According to them, the presence of different phases in the superalloy might impose severe strain on the surface thin layer during cooling period which may result in cracking and exfoliation of the scale.

4. Conclusions

In the present work, hot corrosion behaviour of detonation gun sprayed Al_2O_3-40TiO_2 coated on Superni 718 and AE 435 superalloys in aggressive environment of Na_2SO_4 + 82%$Fe_2(SO_4)_3$ at 900°C has been investigated and the following conclusions are made.

(1) The bare superalloys have shown some spalling and peeling of scale and mass gain was relatively more.

(2) The parabolic rate constants of Al_2O_3-40TiO_2 coated superalloys are lower than the bare superalloys subjected to cyclic hot corrosion in molten salt environment. The values of parabolic rate constant K_p for coated Superni 718 were obtained to be 39.443 mg^2/cm^4 and for coated AE 435 were obtained to be 6.7245 mg^2/cm^4.

(3) The hot corrosion resistance of Al_2O_3-40TiO_2 coating on AE 435 was better when compared to that Superni 718 superalloy in the given molten salt environment.

(4) Al_2O_3-40TiO_2 coating is successfully deposited using Detonation Gun Sprayed on Superni 718 and AE 435 superalloys. The Detonation Gun Sprayed Al_2O_3-40TiO_2 coating improved the hot corrosion behaviour in aggressive environment of Na_2SO_4-82%$Fe_2(SO_4)_3$ at 900°C by 14.8% and 36.8% for Superni 718 and AE 435, respectively.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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