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Effect of Salt Coatings on Low Cycle Fatigue Behavior of Nickel -base Superalloy GTM-SU-718

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Abstract

Nickel-base superalloys are used as components of gas turbines both of jet engines as well as marine engines. Since these components are subjected to high temperature and oxidizing environment, their performance is drastically affected by the environmental conditions. Marine environment further aggravates the situation due to presence of salt (NaCl) particles in air. This salt along with sulphur and vanadium present in the fuel oil, leads to formation of compounds like sodium sulfate (Na_2SO_4) and vanadium pentaoxide (V_2O_5) during combustion and causes hot corrosion and stress corrosion cracking of engine components. Strain controlled low cycle fatigue tests were conducted on the nickel base superalloy GTM-SU-718 in air, at room temperature on unexposed, exposed at 550°C for 25h, exposed at 650°C for 25 h as well as on the specimens coated with layers of NaCl, 25wt.%NaCl+75wt.%Na_2SO_4 and 90wt.%Na_2SO_4+5wt.%NaCl+5wt.%V_2O_5 salt/salt mixtures separately and exposed at elevated temperatures for 25 h. While the NaCl coated sample was exposed at 550°C, those coated with other two salt mixtures were exposed at 650°C. It was observed that fatigue life of the NaCl coated sample, exposed at 550°C for 25 h was reduced, however, there was little effect on fatigue life of the other specimens referred to above, including even those coated with salt mixtures and exposed at 650°C.

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Keywords: Low-cycle fatigue; super alloy GTM-SU-718; salt coating; fatigue life; hot corrosion

1. Introduction

The effect of environment on low cycle fatigue (LCF) behavior of superalloys at elevated temperature is known to be severe. Many combustion turbines in power generation units operate in peaking mode, often involving daily start-stop cycles. Therefore, LCF resistance of the materials becomes an important consideration in the design of turbines.

Extensive research work and nearly all the manufacturer's information on mechanical properties, including LCF resistance of metals and alloys, have been based on the tests conducted in air. However, high temperature industrial components, such as turbine blades and vanes, usually operate in hot corrosive environments which

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are associated with deposits of Na_2SO_4 and NaCl salts on to their surfaces. Hot corrosion in a marine environment causes degradation of materials at a faster rate and leads to premature and catastrophic failure. It has been shown that hot corrosion is more detrimental than oxidation at elevated temperature [1-11].

2. Experimental

LCF tests were conducted on the nickel base superalloy GTM-SU-718, supplied by the GTRE-Bangalore, India, in solution annealed condition, in the form of 15mm diameter rods. The chemical composition of the alloy is presented in Table-1. Blanks of 110mm length were subjected to double-aging heat treatment (720 +/- 5˚C for 8 hours, furnace cooling at the rate of 55˚C/h to 620˚C, holding at 620 +/- 5˚C for 8 hours, followed by forced air cooling). The heat treated blanks were machined to cylindrical fatigue specimens with gage length of 14mm, gage diameter 4.5mm and threaded ends of 30mm and 12mm diameter. LCF specimens were cleaned with distilled water, followed by acetone. Some of the specimens were heated to temperature of 130-160˚C, exposing over a hot plate, and were coated in their gauge sections with three different salt composition: NaCl, 75wt.%Na_2SO_4+25wt.%NaCl and 90wt.%Na_2SO_4 + 5wt.%NaCl + 5wt.%V_2O_5.. The salts were coated uniformly, spraying water slurry of the above salt compositions, over gage sections of the specimens, with the help of an air brush kit, and rotating the specimens by a motor. The weight of coatings varied between 2-5 mg/cm^2. The specimens coated with NaCl were thermally exposed to 550°C and those coated with the other two salt mixtures at 650°C ,for a period of 25hrs, before the LCF tests. LCF tests were carried out on a completely computer-controlled Servo Hydraulic MTS (Model-810) of 50kN capacity, with FlexTest40 digital controller interface. Fully reversed (R = -1) LCF tests were performed in air under total axial strain control. All the tests were carried out at room temperature and at total strain amplitude of ±1.0%, at a frequency of 0.3Hz. Strain measurement during LCF tests was accomplished by means of an MTS extensometer (Model 632.130-20), mounted in gage section of the specimen. After testing, cyclic stress response curves and the fatigue life under different corrosive environments were established. Tensile tests were also conducted for all the different conditions. The fracture surfaces were examined under scanning electron microscope (SEM).

Table 1. The chemical composition of the superalloy GTM-SU-718 bars (wt. %).

Ni	Cr	Nb	Nb+ Ta	Mo	Ti	Al	Co	Si	Fe
53.5	17.91	5.22	5.22	3.1	1.02	0.54	<0.05	0.03	Bal

3. Results and discussion

3.1. Low cycle fatigue

Cyclic stress response of the different specimens tested at constant total strain amplitude of +_1.0% is shown in Fig 1. It may be seen from the stress response curves that there is difference in stress response of the different specimens. In general, there is softening in all the cases, in cyclic stress response preceding hardening during the initial few (<4) cycles. However, there are some distinct differences. Stress level of the specimens, unexposed, or exposed at 550°C, is higher than of those exposed at 650C. This may be attributed to relatively lower temperature (550°C) of exposure, in that set of specimens, prior to LCF testing. It is relevant to mention here that the final temperature of age hardening had been 620°C therefore further exposure of the material at higher temperature of 650C would lead to its softening. Further, it may be seen that both, the degree as well as the rate of softening of the specimens exposed to 650°C is much lower than of those exposed at 650°C, during the initial cycles, from 2-4 to~30 cycles. It is known that cyclic hardening/ softening of metallic materials depends upo initial condition of the material. In general, initially soft materials with UTS/YS ratio >1.4 exhibit cyclic hardening whereas initially strong materials with UTS/YS ratio of<1.2 undergo softening. Cyclic stress response of age hardening alloys, like that in the present investigation, is controlled by dislocation- precipitate interaction.

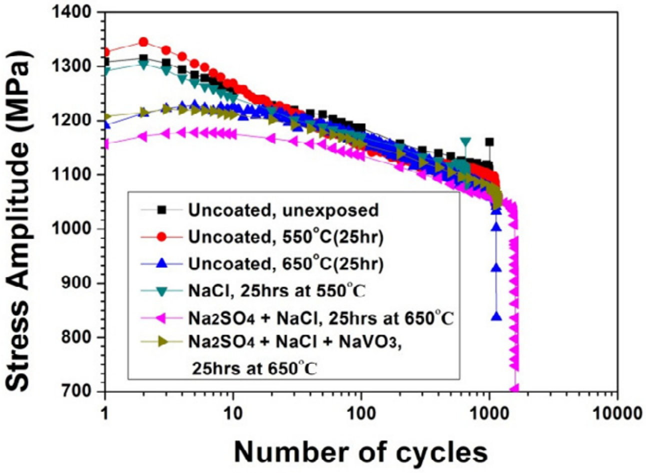


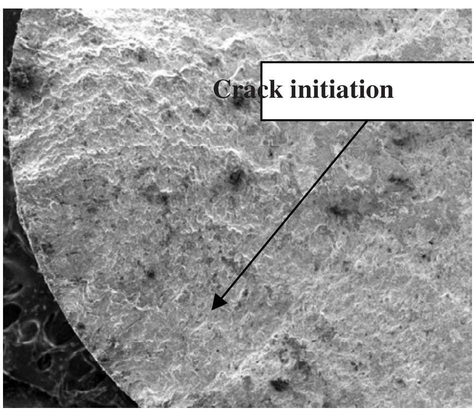
Fig. 1. Cyclic stress response for the superalloy GTM-SU-718 at room temperature.

It is obvious from Table 2 and from Fig 1 that fatigue life of the specimen coated with NaCl and exposed at 550°C is lowest among all the specimens and life of the other specimens is more or less comparable. It is known that fatigue life consists of two components e.g. cycles to crack initiation and cycles to crack propagation. In the present case, there is more likelihood of decrement in cycles to crack initiation, because of the coating at the surface and exposure of the coated specimen at 550°C. Exposure of the specimen with salt coating is likely to cause localized pitting at the surface of the specimen. Such pits at the surface, resulting from hot corrosion become the potential sites for crack initiation because of stress concentration in those regions. Detrimental role of NaCl coating on fatigue crack propagation is unlikely because the exposure with salt coating was given at a high temperature of 550°C and the LCF test was carried out at room temperature. Figure 2 shows cyclic stress response curves for all the specimens tested at room temperature. An initial hardening followed by cyclic softening was observed in all the cases. Fatigue lives of the specimens, exposed in air at 550°C and at 650°C as well as of those coated with the other two salt mixtures, exposed at 650° C for 25hrs, are not reduced and remain unaffected. It implies that surfaces of these specimens are not adversely affected like that of the NaCl coated sample exposed at 550°C.

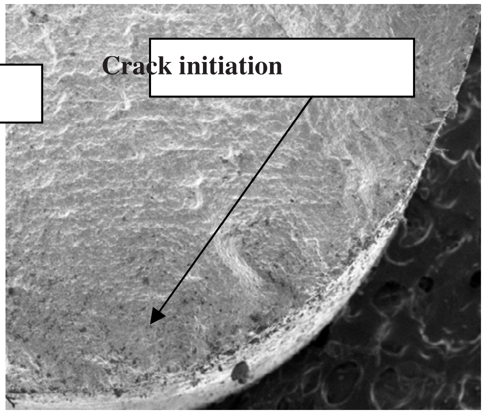
Table 2. LCF data at room temperature.

Condition	Exposure time and temperature	Cycles to failure (Nf)
Uncoated	No exposure	1002
Uncoated	25hrs at 550°C	1119
Uncoated	25hrs at 650°C	1132
3.5wt.%NaCl	25hrs at 550°C	651
75wt.%Na2SO4+25wt.%NaCl	25hrs at 650°C	1594
90wt.%Na2SO4+5wt.%NaCl+5wt.%V2O5	25hrs at 650°C	1136

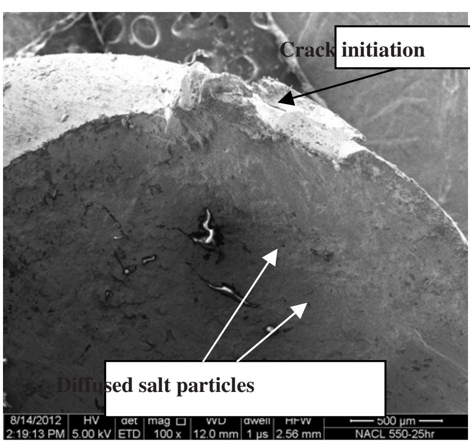
The crack initiation sites on the different samples, tested in fatigue, are shown by scanning electron micrographs in Fig 2. Relatively higher degree of roughness at crack initiation site, in the specimen coated with NaCl and exposed at 550C, is quite obvious (Fig 2c). Tensile properties of the material in different treated conditions are recorded in Table 3.

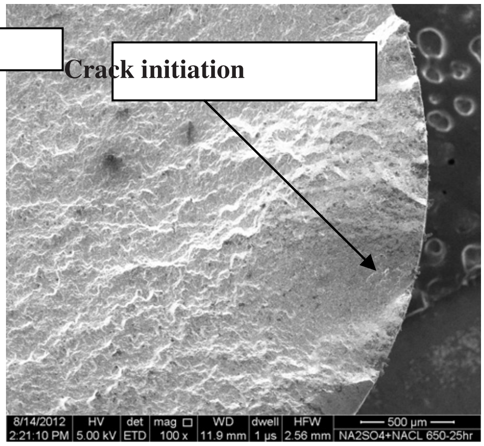


(a) Uncoated and exposed at 550°C for25hr.

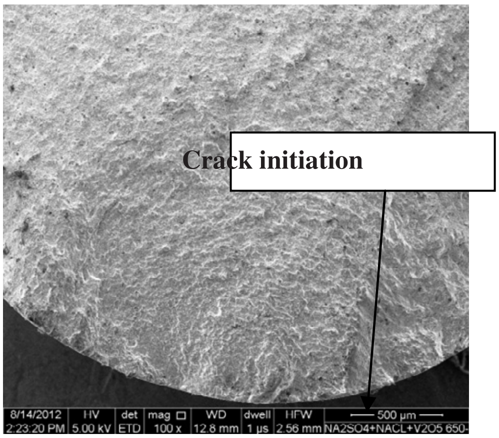


(b) Uncoated and exposed at 650°C for25hr





(c) NaCl coated and exposed at 550°C for 25hrs(d) Na_2SO_4+NaCl coated and exposed at 650°C for 25 hrs



(e) Na_2SO_4+NaCl+V_2O_5 coated and exposed at 650°C for25 hrs

Fig. 2.(a-e). Fractured surfaces of LCF tested specimens showing crack initiation sites.

Table 3. Tensile properties at room temperature.

Condition	Exposure time and temperature	Tensile properties		
		UTS (MPa)	YS (MPa)	El. (%)
Uncoated	No exposure	1507	1294	17
Uncoated	25hrs at 550°C	1445	1186	28
Uncoated	25hrs at 650°C	1414	1214	30
3.5wt.%NaCl	25hrs at 550°C	1429	1186	22
75wt.%Na2SO4+25wt.%NaCl	25hrs at 650°C	1374	1140	22
90wt.%Na2SO4+5wt.%NaCl+5wt.%V2O5	25hrs at 650°C	1399	1155	24

4. Conclusions

- Fatigue life of the superalloy GTM-SU-718 is severely affected by coating of sodium chloride salt and exposure at 550°C. It is due to reduction in cycles for crack initiation from pits, resulting from exposure at elevated temperature.
- Thermal exposure of 25hrs at 550° and 650°C in air does not cause any reduction in fatigue life.
- Fatigue life of the superalloy GTM-SU-718 is not affected by coatings of the other two salt mixtures, even from exposure at 650°C for 25 hours.

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