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LCF Behavior of IN718 with NaCl Salt Coating at 550°c

Mukesh Kumar[1*], G. S. Mahobia[2] ,
Vakil Singh[2] , Rohit Sahu[1], Vijay Yadav[1]

[1]Department of Mechanical Engineering, GLBITM Greater Noida, India*
[2]Department of Metallurgical Engineering IIT (BHU), Varanasi, India

ABSTRACT

Alloy IN718 is a precipitation - hardenable nickel-iron base alloy. Some of the critical parts of marine gas turbine engine like shaft, disc, turbine casing and stator blades are made of super alloy IN718 Performance of these components is affected by environmental conditions such as presence of sodium chloride salt (NaCl) in marine environment and sulphur and vanadium as impurities in fuel oil. During the process of combustion process in gas turbine, sulphur and vanadium get oxidised as SO_2 and V_2O_5. Further, sulphur oxides react with NaCl to form Na_2SO_4. These salts cause hot corrosion and stress corrosion cracking of engine components of gas turbine. The effect of environment on low cycle fatigue (LCF) behaviour of super alloys at elevated temperature is known to be severe. Therefore, it was essential to simulate environmental conditions in which marine gas turbines are operated and study the behaviour of this material under such operative conditions. The present investigation was undertaken to examine the effect of NaCl salt on LCF behaviour of the alloy IN718 at 550^0C.

Keywords –Alloy IN718, LCF Test, NaCl Coating, Strain Amplitude, Super alloys

I INTRODUCTION

It was highly essential to develop alloys with high temperature strength as well as high resistance against oxidation, fatigue, and creep along with surface degradation by hot corrosion. Super alloys were developed for use in turbo superchargers and aircraft turbines requiring high temperature applications. Super alloys have elements like Fe, Ni, Co and Cr as major alloying elements, as well as lesser amount of W, M, Ta, Nb, Ti, and Al. They are classified as Fe-Ni based Ni-based and Co-based super alloys. Super-alloys are now widely used in various applications at temperatures ranging from 658^0C to 1100^0C in aggressive atmosphere such as the combustion products of fuel and air, high temperature catalytic reactors [1, 2].In the very beginning in 1940s super alloys were processed as equiaxed castings, then as directionally solidified (DS) materials during the 1960s and finally as single crystals (SC) in the 1970s. Although super-alloys retain considerable strength at elevated temperatures, they tend to be susceptible to environment attack like oxidation, hot corrosion and thermal fatigue. This is because of the presence of some alloying elements which provide super-alloy its high temperature strength. Most of the current alloys are coated for use at high service temperature but the coating are consumed eventually, both by their slow reaction with the atmosphere at surface and by diffusion with substrate (usually to the detriment of substrate properties) [3]. Super alloys are used as discs, bolts, shafts, cases, blades, vanes, burner cans, afterburners and thrust reversers in aircraft and industrial gas turbines; stock gas re-heaters, in steam turbines, power plant turbo chargers, exhaust valves, hot plugs, pre combustion plugs and valve seats inserts in devices, aerodynamic heat skins and rocket engine parts in space vehicles, trays, conveyors and fixtures in heat treating equipment's; and control rod drive mechanisms valve steam and ducts in nuclear power plants.

II . EXPERIMENTATION

2.1 Material

The material used in the present investigation was super alloy IN718, procured from M/s MIDHANI (India) in the form of rods of 15 mm diameter in solution annealed at 980^0C, holding at this temperature for 1½ hours and then air cooled condition.

2.2 Heat treatment of IN718

The alloy IN718 was obtained in solution treated condition. It was subjected to double-aging heat treatment for720±5^0C-8hrs, furnace cooling @ 55^0C/hr to 620^0C, holding at 620 ± 5^0C8hrs, and forced air cooling to room temperature.

2.3 Salt Coating

The LCF samples were coated using spray technique. A number of dummy LCF samples was taken and after polishing with alumina powder these samples were cleaned with acetone. Then samples were weighted to know the initial weight. Adopters were used to eliminate salt deposition on the radial and threaded portion of LCF samples during salt coating. The use of adopters avoids completely the process of post cleaning of threaded ends of LCF specimen, fig. 1.

Fig.1: Adopters used for covering the radial and threaded portion of the LCF sample

2.4 Mechanical Testing

2.4.1 Low cycle fatigue testing

For conducting LCF tests a cylindrical sample with threaded ends of 30 mm length and 12mm diameter, gauge section of 14mm length and 4.5mm diameter, and shoulder radii of 17mm, were machined from the heat-treated blanks. Schematic diagram of the LCF sample and a LCF coated sample prior to LCF test are shown in fig. 2 & fig. 3.

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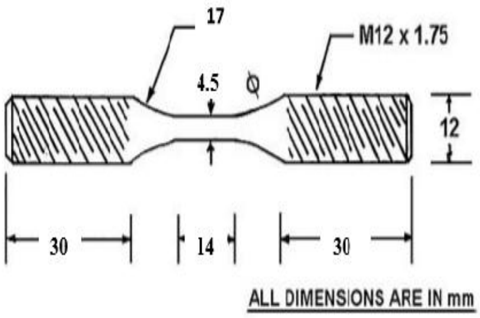

Fig 2: Schematic view of LCF sample **Fig 3: NaCl salt coated LCF sample**

LCF tests were performed using a completely computer controlled Servo Hydraulic MTS testing Machine fully reversed (R= -1) LCF tests were carried out in air under total strain control mode on the samples with and without salt coating. Tests were carried out at 550^{0}C, at two different strain amplitudes of 0.50%, and 0.70% at a constant frequency of 0.3Hz. Strain was controlled by means of a high temperature MTS extensometer which was mounted in gauge section of the LCF sample. After failure of the fatigue samples their Fracture surface, cylindrical surface of gauge section and longitudinal section were examined under scanning electron microscope (SEM) and optical microscope.

III RESULT AND DISCUSSION

3.1 Adherence of salt mixtures

The adherence checking of salt coating is necessary to ensure that the salt coating will not spall during the LCF testing at high temperature. The dummy LCF sample was coated by NaCl salt mixture. The weight of sample was measured prior to the coating and after the coating to ensure that the required amount (2.5mg/cm^2 to 5 mg/cm^2) of coating on the gauge section of LCF specimen. The weight increase should be 4.95 mg to 9.90 mg. The area of gauge section of LCF sample was 1.98 cm$^{2.}$ The Table 1 shows the weight observations before and after the salt coating.

Table 1: Weight of LCF sample before and after NaCl salt coating

Salt type	Wt. before salt coating (mg)	Wt. after salt coating (mg)	Increase in wt. (mg)	Amount of salt coating (mg/cm^2)
100wt.% NaCl	64762.9	64769.5	6.6	3.33

3.2 Fatigue behaviour

Fatigue behaviour of uncoated and salt 100wt. % NaCl coated samples were studied at the temperature 550^{0}C at ($\Delta\varepsilon_t/2$): ±0.5% and ±0.7% strain amplitudes at frequency 0.3 Hz. The results are discussed below in terms of fatigue life, fractured and optical microscopy.

Table 2 and 3 summarized the half-life plastic strain & stress amplitude for uncoated and NaCl coated samples.

Table 2: LCF test data of the alloy IN718 of uncoated samples, at 550^{0}C

Sr. No.	$\Delta\varepsilon_t/2$ (%)	$\Delta\varepsilon_p/2$(at half life) (%)	$\Delta\sigma/2$(at half life) (MPa)	Fatigue life (N_f) (cycles)
1	±0.50	0.0006	769	Test interrupted at 10^5
2	±0.70	0.0023	797	2090

Table 3: LCF test data of the alloy IN718 with NaCl salt coated samples, at 550^{0}C

Sr. No.	$\Delta\varepsilon_t/2$ (%)	$\Delta\varepsilon_p/2$ (at half life) (%)	$\Delta\sigma/2$ (at half life) (MPa)	Fatigue life (N_f) (cycles)
1	±0.50	0.0008	816	17700
2	±0.70	0.0023	792	2115

The degree of softening is more in case of coated sample than that of uncoated sample at high stress regime. However at low strain amplitude the stress required for the same strain was higher in case of coated sample than that of uncoated sample.

3.2.1 Coffin-Manson Analysis

The variation of low cycle fatigue life for different strain amplitude imposed was analysed by Coffin-Manson relationship [4].

$$\Delta\varepsilon_p/2 = \varepsilon'_f\,(2N_f)^{\,c} \qquad \text{...............} \quad (1)$$

Where, ε'_f = fatigue ductility coefficient defined by the strain intercept at $2N_f$ =1
c = fatigue ductility exponent, determined by the slope of the log $\Delta\varepsilon_p/2$ versus log ($2N_f$) plot. C-M plot for the uncoated and salt coated conditions are shown on log-log scale in Fig 4a and 4b Fatigue life was found to decrease with increase in strain amplitude. It is important to mention that at low strain amplitude of 0.5% was not failed up to 10^5 cycles in uncoated sample. The low cycle fatigue parameters ε'_f & c determined from the linear fit of the data between $\Delta\varepsilon_p/2$ & ($2N_f$) are shown in the Table 6. Data at ±0.4%, ±0.6%, ±0.8%, and ±1.0%

strain amplitude were used from Mahobia et al [5] to confirm dual slope behaviour for uncoated sample and single slope for coated sample in C-M plot results.

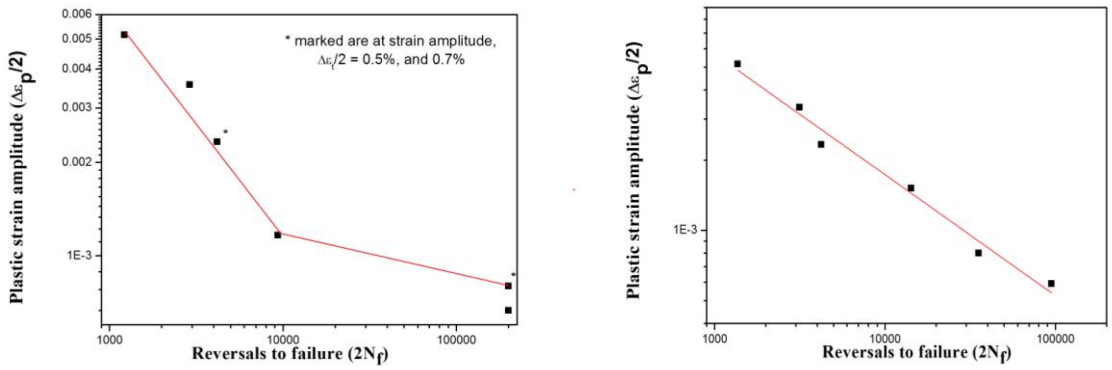

Fig 4: C-M plot (a) for uncoated sample at 550^{0}C (b) for NaCl coated sample at 500^{0}C [4]

Table 4: Low cycle fatigue parameters

Without salt coating				
LCF test condition	Low strain amplitude region		High strain amplitude region	
	ε'_f	c	ε'_f	c
Uncoated, 550^{0}C	0.003	-0.13	1.10	-0.74
With salt coating				
LCF test condition	ε'_f		c	
NaCl coated, 550^{0}C	0.21		-0.51	

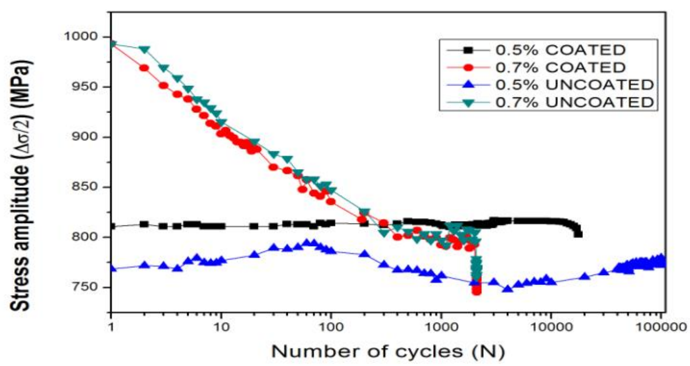

Fig 5: Cyclic stress response curves of alloy IN718 at 550^{0}C for coated and uncoated samples

It is clear from the data in Tables 4 and Fig. 5 that fatigue life was reduced significantly at lower strain amplitude but there was a little difference in the life at high strain amplitude between uncoated and coated sample. It may be seen that there was bilinear behaviour in C-M plot for the uncoated alloy 718 with 'c' values of -0.74 and -0.1 in the region of high and low plastic strain amplitudes respectively. On the other hand there was only single slope in C-M plot of the salt coated sample with 'c' value of -0.51 for NaCl coated sample.

IV OPTICAL MICROSCOPY

Fig. 6 shows optical images of the cylindrical surface of the NaCl coated and uncoated LCF samples tested at different strain amplitudes. It was found that the surfaces of NaCl salt coated samples were rougher than that of uncoated sample. The uncoated LCF specimen which was not fail up to 100000 cycles was also examined under optical microscope. There was found to be no sign of surface cracking (Fig.6).

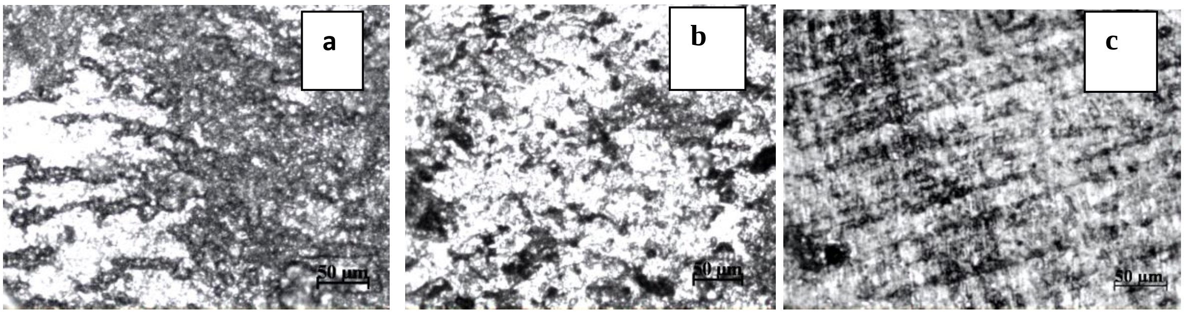

Fig 6: Optical micrographs from cylindrical surface of LCF samples tested at 550^{0}C, (a & b) NaCl coated samples, (c) uncoated sample.

Optical image in Fig. 7 show surface cracks along the edge in longitudinal cross-section of the uncoated and NaCl salt coated samples .It is known that cyclic hardening or softening of metallic materials depends upon initial condition of the material. Smith et al [6] and Manson [7] observed that when the ratio of UTS to 0.2%YS is≥ 1.4, cyclic hardening occurs and when this ratio is less than 1.2, cyclic softening results. Softening of this type of age-hardened alloys may be attributed by dislocation-precipitate interaction [8]. The resistance of aged material against softening at low strain amplitude is higher than at high strain amplitude, results lower slope in C-M plot.

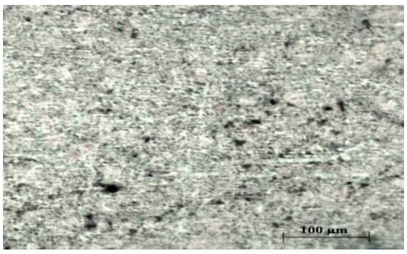

Fig. 7: Optical image of cylindrical surface of the LCF uncoated sample tested at 550^{0}C, (>10^5 cycles)

V CONCLUSION

Results of present investigation showed that fatigue life of the alloy IN718 was severely affected due to NaCl coating at low strain amplitude at temperature 550^{0}C. The reduction in life was resulted in shortening the number of cycles for crack initiation through formation of pits from hot corrosion by NaCl.

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