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Effect of Heat Treatment on the Corrosion Behaviour of GTM-SU-718 Superalloy in NaCl, HCl and H_2SO_4 environments

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Abstract : Nickel-based superalloys are extensively used in marine gas turbine applications. One such superalloy namely, GTM-SU-718 is designed to resist a wide range of severely corrosive environments. This alloy can be double-aged for hardening by precipitation. But the corrosion properties of the alloy may then get effected. This paper is aimed at evaluating the effect of heat treatment on the corrosion behaviour of GTM-SU-718. These studies were carried out with the potentiodynamic polarization techniques at ambient temperature in various environments viz. NaCl, HCl and H_2SO_4 solutions with different concentrations.

1. Introduction

Superalloys are heat-resisting alloys based on nickel, nickel-iron or cobalt which exhibit several key characteristics like excellent mechanical strength, resistance to thermal creep deformation, resistance to corrosion and good surface stability. Nickel-based superalloys are widely used in gas turbines and aircraft engines requiring excellent corrosion resistance. [1][2] The steady increase in the availability and applications of gas turbines led to the new developments of nickel-base superalloys like GTM-SU-718. By double ageing treatments, different sizes and types of precipitates are developed. The principal strengthening precipitates are ϒ' (Ni_3Al or Ni_3Al,Ti) or ϒ" (Ni_3Nb). These form according to the nickel and aluminium contents present in the nickel-based superalloys and alter the corrosion rate of the material. So, it is required to analyse the corrosion resistance of GTM-SU-718 before and after double ageing so that it can be used in gas turbine applications effectively.

2. Materials and Methods

2.1 Material

The chemical composition of GTM-SU-718 supplied by Midhani Steels, Hyderabad is shown in Table 1. GTM-SU-718 material is obtained in sheet form.

Table 1. Composition of GTM-SU-718 superalloy (in wt%)

Superalloy	Ni	Cr	Fe	Mo	Nb	Ti	Ta	Al	Si	Mg	Co
GTM-SU-718	50	20	19	3.1	3.01	2.5	1.3	0.54	0.3	0.2	0.05

2.2 Heat Treatment

The superalloy GTM-SU-718 was received in a sheet form which was solutionized at 1000°C for 2 hours. Then it was double aged at 720° C for 8 hours followed by furnace cooling and held at 620° C for a total ageing time of 18 hours.[3]

2.3 Test Environment

The experimental solutions have been prepared from reagent grade chemicals and de-ionized water. The specimens were tested in 0.5N, 1N, 2N NaCl and 0.1N, 0.5N, 1N HCl and 0.1N, 0.5N, 1N H_2SO_4 solutions[4].

2.4 Preparation of Test Samples

The test specimens, both before and after heat treatment have been characterized by Optical Microscopy. Both the specimens were machined and polished using a series of emery papers to a smooth surface and then etched in Glyceregia [5] (5ml HNO_3 , 10ml glycerol and 15ml HCl) for about 30 seconds.

2.4 Experimental Apparatus

A conventional three-electrode glass corrosion cell with a capacity of 300ml was used to obtain Tafel plots. An Ag/AgCl electrode saturated with KCl was used as reference electrode and a platinum foil was used as counter electrode. Alloy specimens having exposed area of 1cm^2, placed inside the corrosion cell to serve as the working electrode. All electrochemical measurements were performed using Electrochemical work station (PARSTAT 4000, Princeton applied research) controlled by VersaStudio software.

2.5 Experimental Procedure

All electrochemical experiments were conducted at room temperature. Tafel plots have been recorded at a scan rate of 1.5 mV.s^{-1} with in range of - 250 to 250 mV versus the open circuit potential (i.e., OCP) to determine corrosion current density (I_{corr}) and corrosion potentials (E_{corr}).

3. Results and Discussion

3.1 Characterization

Fig.2 and Fig.3 indicate the optical microstructure of GTM-SU-718 superalloy in as received condition and after double ageing, respectively. The micrograph after double ageing confirms the formation of precipitates by which more number of galvanic couples are formed.

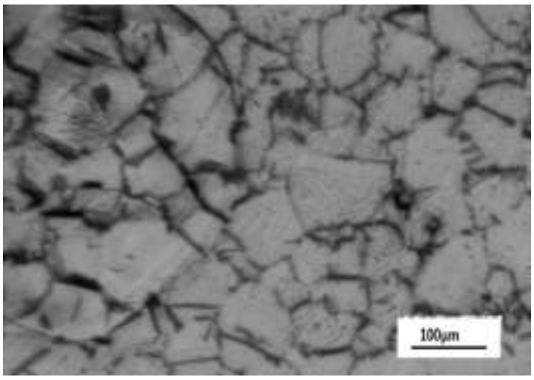

Fig. 2 : Optical microstructure of GTM-SU-718 in received condition

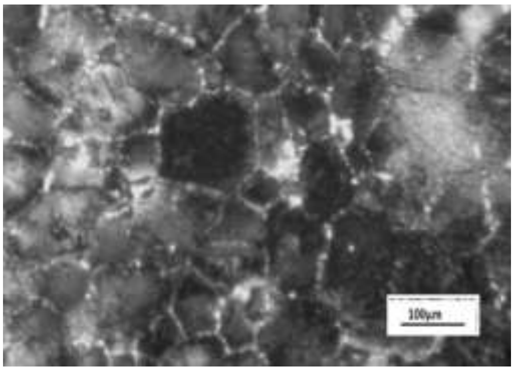

Fig. 3 : Optical microstructure of GTM-SU-718 after double ageing

3.2 Potentiodynamic Polarization Studies

Potentiodynamic studies have been carried out for GTM-SU-718 superalloy in three corrosive environments viz., NaCl, HCl and H_2SO_4 solutions with different concentrations. The corrosion parameters are shown in Table 2 to Table 4.

Table 2 : Effect of NaCl conc. on GTM-SU-718, GTM-SU-718 (Double aged) corrosion behaviour

Alloy	Conc.	E_{corr} (V)	i_{corr} (μA)	B_c (mV/dec)	B_a (mV/dec)	Corrosion Rate (mpy)
GTM-SU-718	0.5N	-0.17	0.119	-118.673	173.937	0.041
	1N	-0.19	0.146	-193.107	228.134	0.05
	2N	-0.21	0.345	-157.84	371.854	0.119
GTM-SU-718 (Double aged)	0.5N	-0.32	0.367	-182.735	194.874	0.127
	1N	-0.348	0.402	-155.051	386.294	0.139
	2N	-0.353	0.497	-101.82	348.392	0.171

Table 3 : Effect of HCl conc. on GTM-SU-718, GTM-SU-718 (Double aged) corrosion behaviour

Alloy	Conc.	E_{corr} (V)	i_{corr} (μA)	B_c (mV/dec)	B_a (mV/dec)	Corrosion Rate (mpy)
GTM-SU-718	0.1N	-0.145	0.561	-168.775	106.357	0.194
	0.5N	-0.15	1.476	-118.984	160.406	0.509
	1N	-0.161	11.595	-240.567	245.678	3.99
GTM-SU-718 (Double aged)	0.1N	-0.3	2.775	-297.567	116.551	0.957
	0.5N	-0.325	12.455	-101.362	160.309	4.296
	1N	-0.328	25.346	-138.825	164.207	8.743

The polarization test data for GTM-SU-718 indicate that there is significant increase in corrosion rate in HCl solution than NaCl solution and increases with increase in concentration of solution. This is due to the formation of oxide layer on the surface as the concentration increases, but when the oxidizing potential is further increased, the dissolution of metal oxide layer takes place and the corrosion rate is further increased[6].

Table 4 : Effect of H_2SO_4 conc. on GTM-SU-718, GTM-SU-718 (Double aged) corrosion behaviour

Alloy	Conc.	E_{corr} (V)	i_{corr} (μA)	B_c (mV/dec)	B_a (mV/dec)	Corrosion Rate (mpy)
GTM-SU-718	0.1N	-0.12	3.089	-229.09	219.007	1.065
	0.5N	-0.13	7.619	-130.967	311.266	2.628
	1N	-0.14	18.747	-260.622	153.124	6.466
GTM-SU-718 (Double aged)	0.1N	-0.31	5.882	-114.89	219.587	2.029
	0.5N	-0.33	18.309	-142.71	268.97	6.315
	1N	-0.34	49.585	-391.23	149.64	17.103

Tafel plots for different environments are shown in Fig.4 to Fig.9. The corrosion rate is higher in the case of H_2SO_4 than in HCl solution. The SO_4^{2-} ions are more corrosive when compared to Cl^- ions[7].

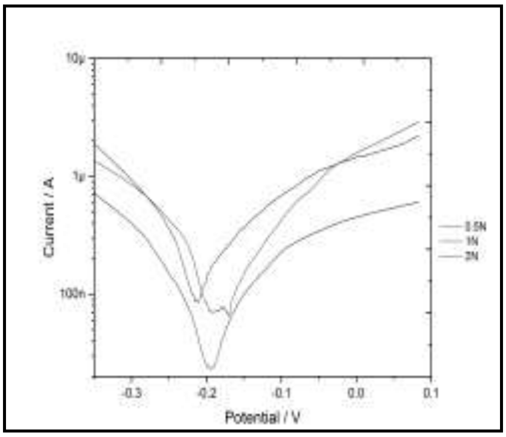

Fig. 4 : Potentiodynamic polarization curve received GTM-SU-718 in NaCl

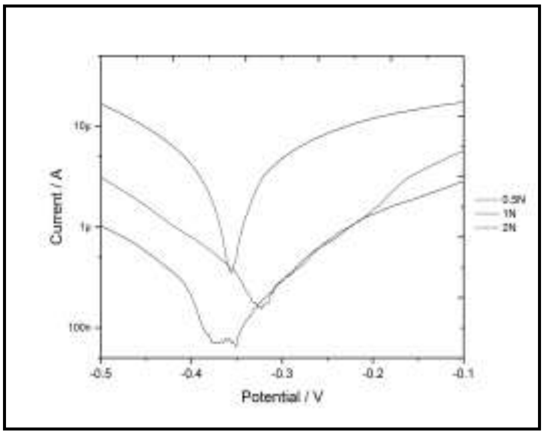

Fig. 5 : Potentiodynamic polarization curve of as-of double aged GTM-SU-718 in NaCl

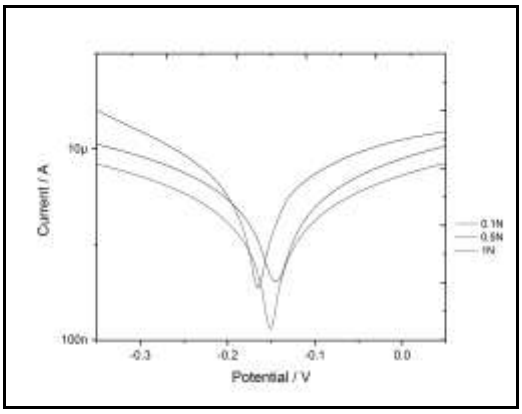

Fig. 6 : Potentiodynamic polarization curve of as-received GTM-SU-718 in HCl

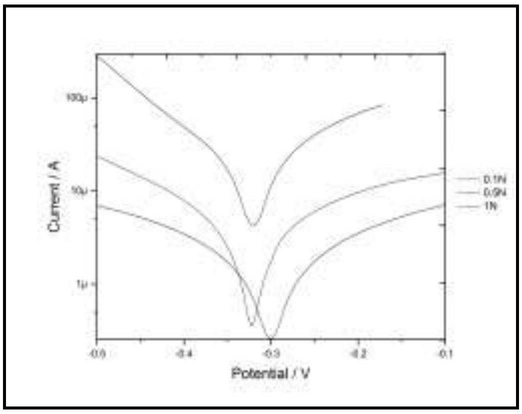

Fig. 7 : Potentiodynamic polarization curve of double aged GTM-SU-718 in HCl

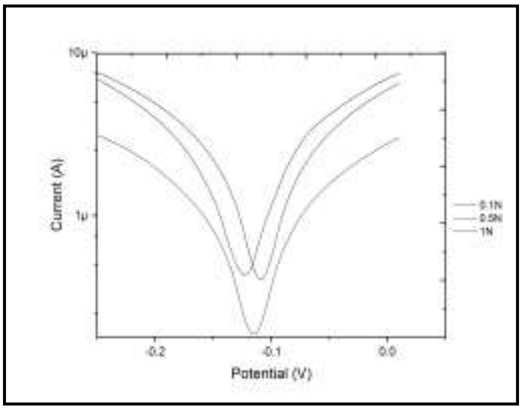

Fig. 8 : Potentiodynamic polarization curve of as-received GTM-SU-718 in H_2SO_4

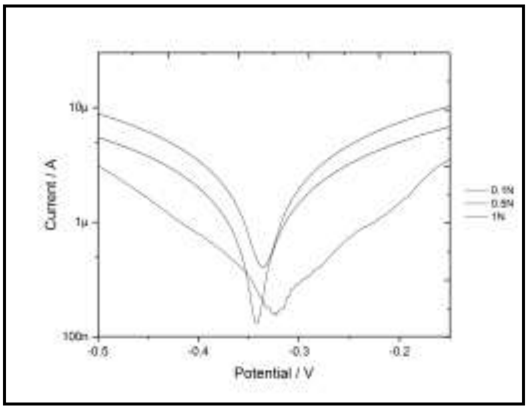

Fig. 9 : Potentiodynamic polarization curve of double aged GTM-SU-718 in H_2SO_4

4. Conclusions

1. From the potentiodynamic polarization studies, it can be concluded that corrosion rate has been increased with increase in concentration of solutions for GTM-SU-718
2. Corrosion rate is higher in the double aged condition of GTM-SU-718 superalloy.

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