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The Study on Failure Behavior and Low Cycle Fatigue Life of Hot Gas Casing for Gas Turbine

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Abstract. In this study, failure behavior of hot gas casing for gas turbine was investigated. The microstructure and damage mechanism of serviced hot gas casing were examined. Also low cycle fatigue tests of the Inconel 617 super alloy is used for structural material of hot gas casing were performed. To predict the low cycle fatigue life, Coffin-Manson and strain energy density methods were used.

Introduction

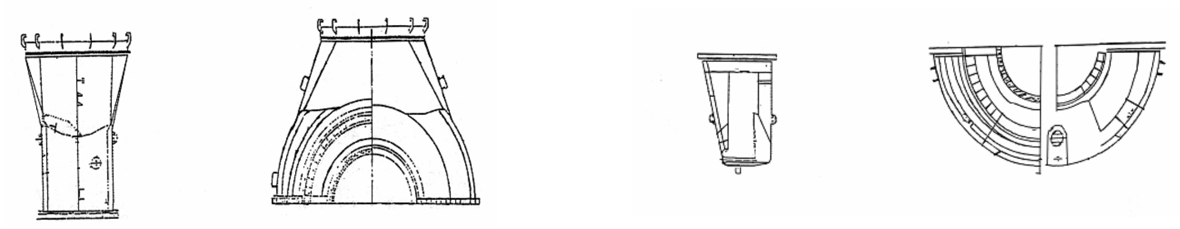
The hot gas casing is one of main components of the gas turbine system for electricity generation and is exposure to the high temperature and pressure. In general, failure of hot gas casing is caused by creep, thermal fatigue and erosion etc. Cracks are easily observed at the welded region of hot gas casing due to accumulated creep damage. Thermal gradient due to a thick wall results in the thermal stress. In addition, high cycle vibration at the steam inlet leads to the initiation and propagation of cracks [1].

In this study, the failure behavior of hot gas casing for gas turbine was examined. The microstructure of serviced hot gas casing material was investigated and damage mechanism was described. And low cycle fatigue tests of base and welded materials and heat treated material after welding of Inconel 617 superalloy for hot gas casing were carried out. In order to predict the low cycle fatigue life, Coffin-Manson, plastic and total strain energy methods were used.

Damage Mechanism of Hot Gas Casing

Based on the maintenance documents, damage mechanism of hot gas casing was investigated. Fig. 1 showed the schematic configurations of hot gas casing. In the top half of inner housing, the detachment of hot gas casing was not found but several cracks were observed for every shutdown. In case of bottom half of inner housing, the detachment was not found equally but cracks at welded zone less occurred compared to any other components. Fig. 2 shows the typical failure configuration of hot gas casing. As can be seen in Fig. 2, cracks occurred at upper region near cooling holes. This is because of thermal stress caused by steam internal pressure, shutdown and loading variations etc.

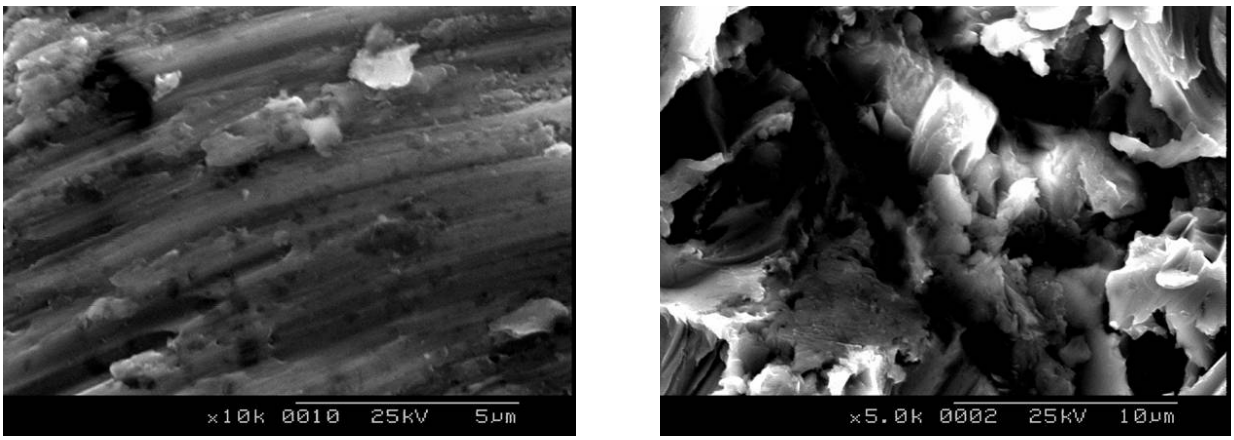
To verify the damage mechanism and strength degradation, microstructure and mechanical strength were evaluated. Fig. 3 shows the SEM images for serviced material of hot gas casing. As can be seen in Fig. 3 (a), striation as typical fatigue characteristic was observed. On the other hand, cavern cavity as typical creep characteristic in Fig. 3 (b) was also found. From the tensile test, tensile strength of serviced materials was measured as 460 MPa. It decreased about 44% compared to Inconel 617 base material. Based on above results, it can be concluded that the major failure mechanisms of hot gas casing are creep, low cycle fatigue and their combined effects etc.



(a) Top half of inner housing (b) Bottom half of inner housing

Fig. 1 Schematic configurations of hot gas casings

Fig. 2 Failure configurations of hot gas casing



(a) Fatigue fracture (b) Creep fracture

Fig. 3 Fracture appearances of serviced hot gas casing material

Low Cycle Fatigue Life of Inconel 617

Test Method. Test materials were base material (B.M.), welded material (W.M.) and heat treated material after welding (H.T.M.) of Inconel 617 super alloy. The mechanical properties of test materials are shown in Table 1.

Table 1 Mechanical properties for testing materials

	B.M.	W.M.	H.T.M
Young's modulus (GPa)	220.3	200.4	176.9
Yield strength (MPa)	270.0	257.2	429.2
Ultimate strength (MPa)	813.3	777.0	805.1
Elongation (%)	71.2	41.9	30.6
Hardness (HRB)	86.7	92.1	114.6

Low cycle fatigue specimens were manufactured to uniform gauge type in accordance with ASTM E 606 [2]. The low cycle fatigue tests were performed with electro hydraulic servo-controlled fatigue testing machine (model: MTS 810) under strain control. Stress ratio of all experiments was held on R=-1. And, total strain amplitude was 0.4-1.0%. Since test materials is so tough, fatigue life was defined that maximum tensile load drop to 98.1N (10kgf) and below. Also, fractured specimens were observed by scanning electron microscope.

Results and Discussion.

The curves of low cycle fatigue of Inconel 617 superalloys are given in Fig. 4. The low cycle fatigue life of B.M. was relatively higher compared to those of W.M. and H.T.M. This is because welding process decreases the fatigue strength. The strain amplitude versus number of reversals to failure curves are plotted on log-log scale in Fig. 5. Coffin-Manson parameters for test materials are also represented in Fig. 5.

A relationship between the plastic strain energy density (ΔW_p) and the cycles-to-failure (N_f) is expressed in Eq. 1 and a relationship between total strain energy density (ΔW_t) and cycles-to-failure is expressed in Eq. 2, where, A, χ , m and α are experimental constants [3-6].

$$\Delta W_p = A(N_f)^m \quad (1)$$

$$\Delta W_t = \chi(N_f)^\alpha \quad (2)$$

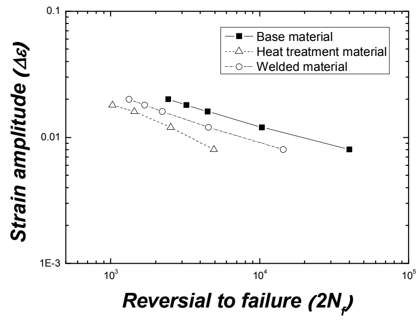
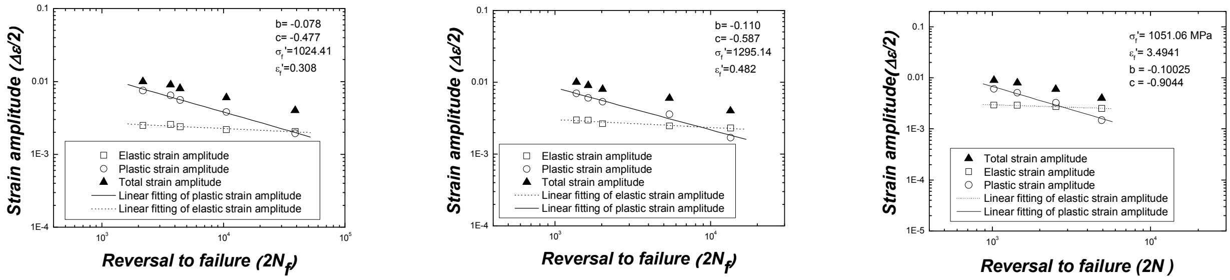


Fig. 4 Strain amplitude and life curves

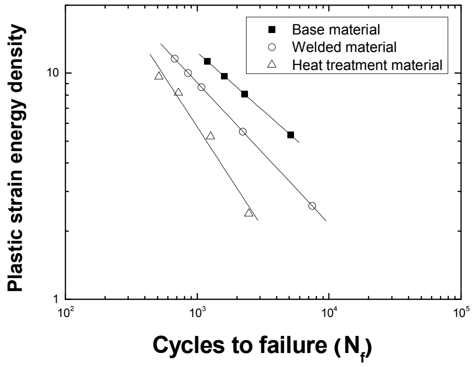


(a) B.M. (b) W.M. (c) H.T.M.

Fig. 5 Strain amplitude and reversal to failure curves

Table 2 The predicted equations of low cycle fatigue life calculated by using strain energy method

	Plastic strain energy method	Total strain energy method
B.M.	$\Delta W_p = 439.04(N_f)^{-0.517}$	$\Delta W_t = 351.81(N_f)^{-0.479}$
W.M.	$\Delta W_p = 675.41(N_f)^{-0.624}$	$\Delta W_p = 502.99(N_f)^{-0.570}$
H.T.M	$\Delta W_p = 5373.53(N_f)^{-0.899}$	$\Delta W_p = 12843.10(N_f)^{-1.031}$



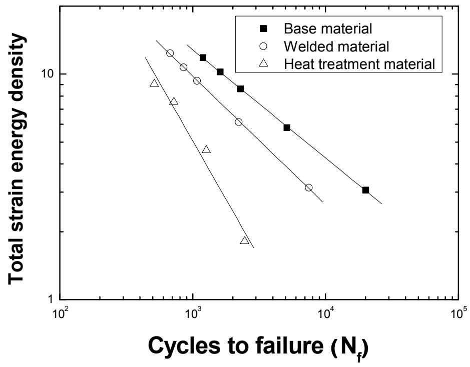


Fig. 6 Plastic strain energy density versus cycles to failure of Inconel 617

Fig. 7 Total strain energy density versus cycles to failure of Inconel 617

The predicted equations of low cycle fatigue life obtained by strain energy method are presented in Table 2, Fig. 6 and Fig. 7. All predicted life using strain energy density agreed well with experimental data. Hence, it can be concluded that it may be possible to estimate the low cycle fatigue life by the calculation of strain energy density.

Conclusions

(1) The damage mechanism for hot gas casing was investigated. The major failure mechanisms of hot gas casing were creep, low cycle fatigue and their combined effects etc.
(2) The low cycle fatigue life of the base material of Inconel 617 superalloy is relatively higher compared to lives of welded material and heat treated material after welding.
(3) The LCF lives predicted by the strain energy density coincided with experimental data and results obtained from the Coffin-Manson method.

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