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LOW CYCLE FATIGUE LIFE PREDICTION OF INCONEL 617 IN ELEVATED TEMPERATURE FOR POSSIBLE USE IN GAS TURBINE COMBUSTION CHAMBER LINERS

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Abstract

Design of Turbo machinery is complex and efficiency is directly related to material performance, material selection is of prime importance. Temperature limitations are the most crucial limiting factors to gas turbine efficiencies. The problems at various components are of different magnitudes. As a result, the materials selection for individual components is based on varying criteria in gas turbines. Also materials and alloys for high temperatures application are very costly. The LCF tests were conducted under various strain ranges based on gas turbine operating conditions. The paper will focus light on above issues and each plays an important role within the Gas Turbine Material literature and ultimately influences on planning and development practices. It is expected that this comprehensive contribution will be very beneficial to everyone involved or interested in Gas Turbines.

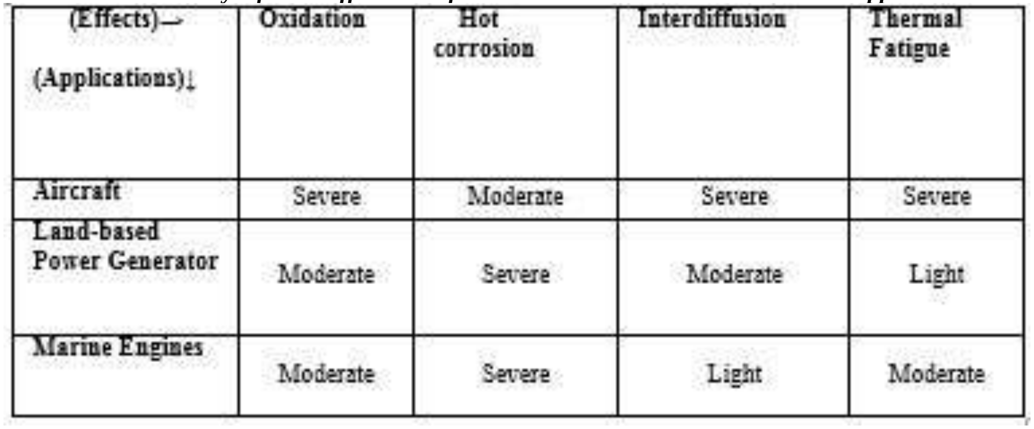
Introduction

INCONEL 617, which is a solid solution nickel-based alloy, has been widely used in the high temperature application because of its excellent oxidation resistance, superior mechanical properties and high temperature phase stability. Alloy 617 is a candidate material for next generation very high temperature gas turbine combustion chamber liner. The fatigue behaviour of Alloy 617 in the temperature range of 650–1100 0C is superior. The exceptional fatigue strength at temperatures above 650 0C were attributed to solution strengthening by the molybdenum and cobalt additions. Presence of 1 wt% aluminium also strengthens the matrix by forming Ni_3Al type intermetallic compound which marginally improves the mechanical properties at 650–760 0C. However, the major role of aluminium and chromium additions is to improve the oxidation and carburization resistance at high temperatures.

The alloy is considered superior to INCONEL 625 since it does not form any embrittling phases after long-time exposure at elevated temperatures [1].Introduction of a tensile hold period led to reduced creep-fatigue life at both strain ranges in all environments. Decarburization occurred in specimens tested in vacuum and purified air, but not in air. Although fatigue lives were longer in the inert environments than in air for most test conditions, quantitative assessment of the differences was not possible because cracking frequently did not occur before test termination due to load drop for tests in inert environment. [2]

The combustor experiences the highest gas temperatures in a gas turbine and is subject to a combination of creep, pressure loading, high cycle and Low Cycle fatigue. The materials used presently are generally wrought, sheet formed nickel-based super alloys. These provide good thermo mechanical fatigue, creep and oxidation resistance for static parts and are formable to fairly complex shapes such as combustor barrels and transition ducts,liners.This effects are shown on table-I [3]

Table-I Severity Of The Different Surface-Related Problems For Gas Turbine Applications



(Effects)→ (Applications)↓	Oxidation	Hot corrosion	Interdiffusion	Thermal Fatigue
Aircraft	Severe	Moderate	Severe	Severe
Land-based Power Generator	Moderate	Severe	Moderate	Light
Marine Engines	Moderate	Severe	Light	Moderate

In the past, the low-cycle fatigue (LCF) test and the Manson– Coffin equation were widely used to evaluate the reliability of the substrates of Liners. However, the LCF test, which only can simulate fatigue conditions under high isothermal temperatures, can not model actual operating conditions. For that reason, Low Cycle fatigue (LMF) tests, which can simulate both mechanical fatigue and thermal fatigue simultaneously, are preferred. LCF tests are the most appropriate for simulating actual combined loading conditions during service. It is very important to evaluate the LCF characteristics [4].In this paper, LCF test for the life prediction of INCONEL-617 were carried out using the furnace.

Failure modes in gas turbine

Predominant failure mechanisms and commonly affected Components:[6]

- Low cycle fatigue-compressor and turbine disks.
- High cycle fatigue-compressor and turbine blades, disks, compressor stator vanes.
- Thermal fatigue-nozzles, combustor components.
- Environmental attack (oxidation, sulphidation, hot corrosion, standby corrosion)-hot section blades and stators, transition pieces, and combustors.
- Creep damage-hot section nozzles and blades.
- Erosion and wear.
- Impact overload damage (due to foreign object damage (FOD), domestic object damage (DOD) or clash/clang of compressor blades due to surge).
- Thermal aging.
- Combined effect

Components of Combustion chamber are as given in the figure below-

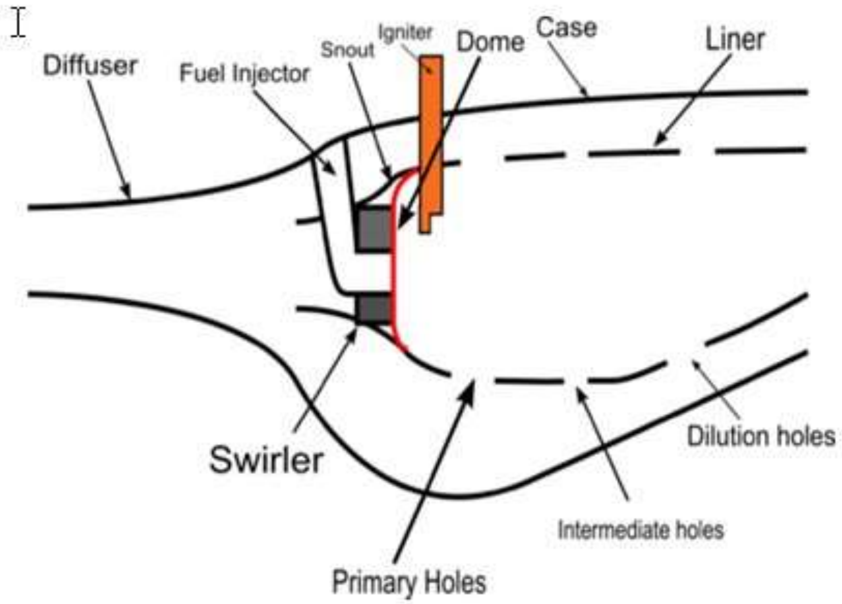


Fig.1.Overview of Combustion Chamber

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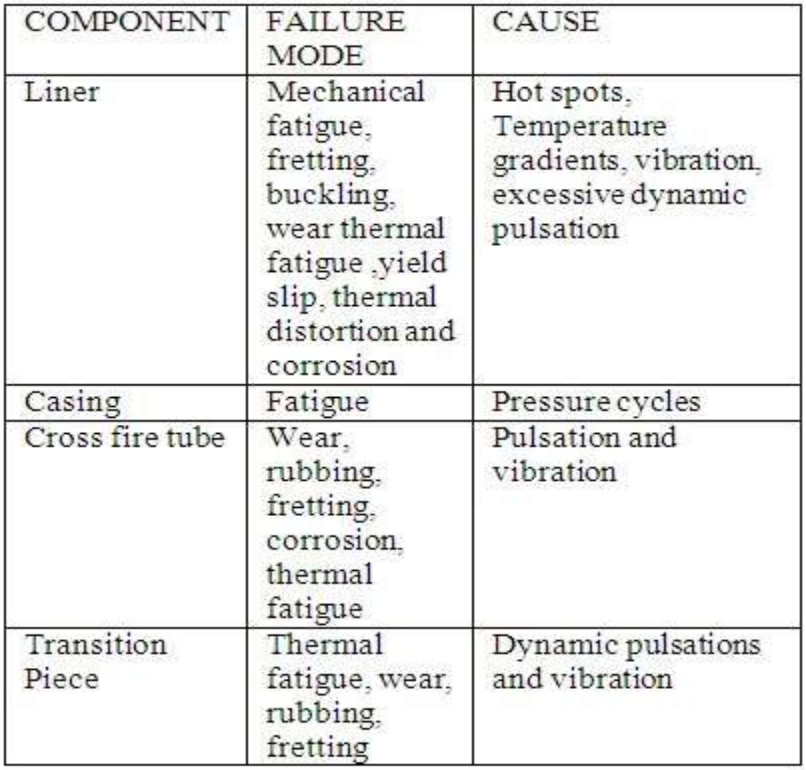
Table-ii

Failure mode of combustor is shown on table [5]



COMPONENT	FAILURE MODE	CAUSE
Liner	Mechanical fatigue, fretting, buckling, wear thermal fatigue ,yield slip, thermal distortion and corrosion	Hot spots, Temperature gradients, vibration, excessive dynamic pulsation
Casing	Fatigue	Pressure cycles
Cross fire tube	Wear, rubbing, fretting, corrosion, thermal fatigue	Pulsation and vibration
Transition Piece	Thermal fatigue, wear, rubbing, fretting	Dynamic pulsations and vibration

A. Fatigue

Fatigue accounts for a significant number of turbine and Combustion chamber liners failures and is promoted by repeated application of fluctuating stresses. Stress levels are typically much lower than the tensile stress of the material. Common cause of vibration in combustion liners explosion include passing frequency wakes, but also under hostile conditions of high temperature, corrosion, creep, and thermomechanical fatigue occurs.

B. Low Cycle Fatigue

Low cycle fatigue (LCF) occurs as a result of turbine start/stop cycles and is predominant in the combustion chamber liner, casing. It is typically a problem associated with machines that have been in operation for several years. In this situation, minute flaws grow into cracks that, upon attaining critical size, rupture. Cracks also develop in it. To some extent, this is to be expected under normal operation and cycling service.

Test equipment and methods

A. Specimen

In this paper, tensile tests, LCF test was conducted to evaluate the mechanical characteristics of INCONEL-617. The specimens used in this study were made from the INCONEL-617, which is can be used in commercial gas turbine combustion chamber liners. The chemical components of INCONEL-617 are as follows-

Nickel-	44.5 min.
Chromium-	20.0-24.0
Cobalt-	10.0-15.0
Molybdenum -	8.0-10.0
Aluminium -	0.8-1.5
Carbon -	0.05-0.15
Iron-	3.0 max.
Manganese -	1.0 max.
Silicon -	1.0 max.
Sulphur -	0.015 max.
Titanium -	0.6 max.
Copper-	0.5 max.
Boron -	0.006 max

Following figures of specimens are used for testing:

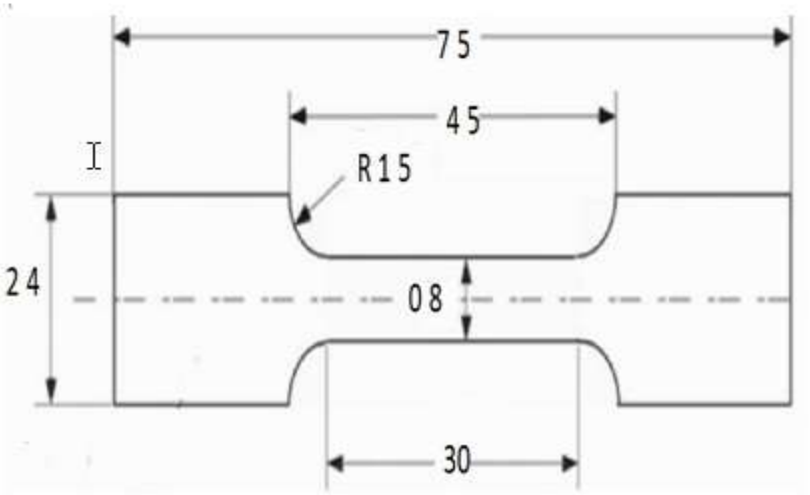


Fig.2.Specimen for Tensile Test
ASTM E8-04
(All dimensions are in mm)

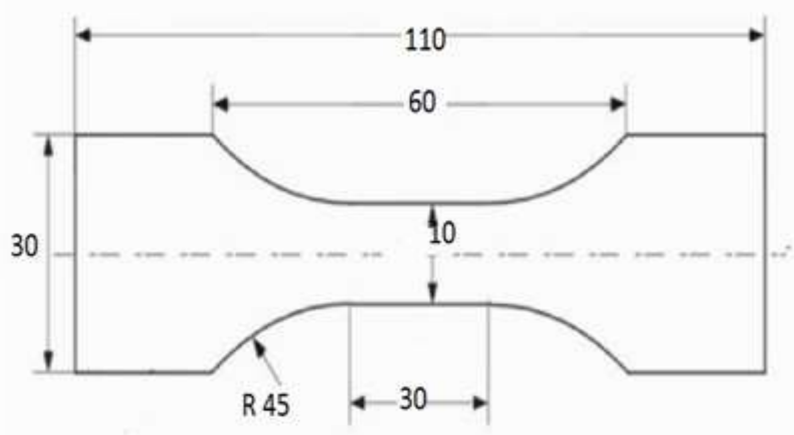


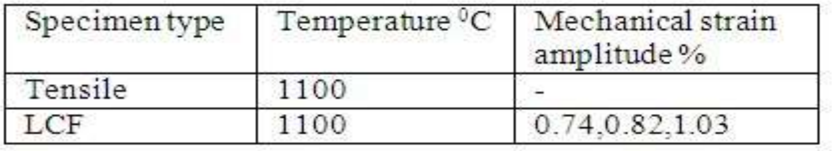
Fig.3.Specimen for Low Cycle Fatigue Test
ASTM E-466
(All dimensions are in mm)

B.Test equipment and method

In this study, tensile, LCF was performed using an electric furnace. Tensile tests were conducted at 11000C. A hydraulic test machine was used to apply a strain rate of 0.0167 mm/sec in accordance with ASTM E8-04[7]. In the high-temperature tensile test, the specimen was maintained at 1100 0C for 1 h to prevent the formation of a temperature gradient. By using the mechanical properties obtained from the tensile tests, the amplitude of the total strain to be used as input for LCF test. The time at which the specimen completely separates was considered to be the time of fracture.

LCF tests were performed under strain control conditions at 11000C. The test frequency was set to 0.4 Hz and the strain ratio was -1 (R = -1) for a strain of constant amplitude as based on ASTM E-466[8]. Strain was measured by a longitudinal extensometer with rods spanning a gauge length of 30 mm. Temperature was controlled by an N-type thermocouple located at the mid length of the specimen. Total strain amplitudes (Total strain amplitude and mechanical strain amplitude is same at LCF test) of 0.74%, 0.82% and 1.03% were applied.

Table-III shows the conditions for each test



Specimen type	Temperature ^{0}C	Mechanical strain amplitude %
Tensile	1100	-
LCF	1100	0.74,0.82,1.03

Test result and discussion

Fig. 4 shows the results of tensile tests at room temperature and 11000C . The tensile test at room temperature was performed once and the tensile tests at 11000C were performed twice. The tensile strength of the tested specimen was 1,115 MPa at room temperature and 720 MPa at 11000C. Yielding occurred at 933 MPa at room temperature and at 687MPa at 1000 0C. When the temperature was increased, the yielding strength decreased and strain increased . These results indicate that INCONEL 617 became ductile. This tendency was also confirmed by the LCF test.

The Young's modulus given by the LCF test were higher than that given by the high temperature tensile test. This means that the material was hardened by fatigue.

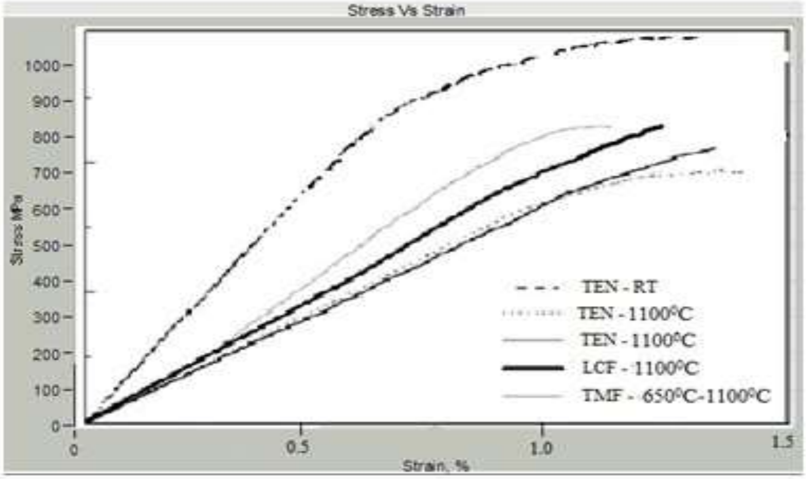


Fig.4. Result of Tensile Test

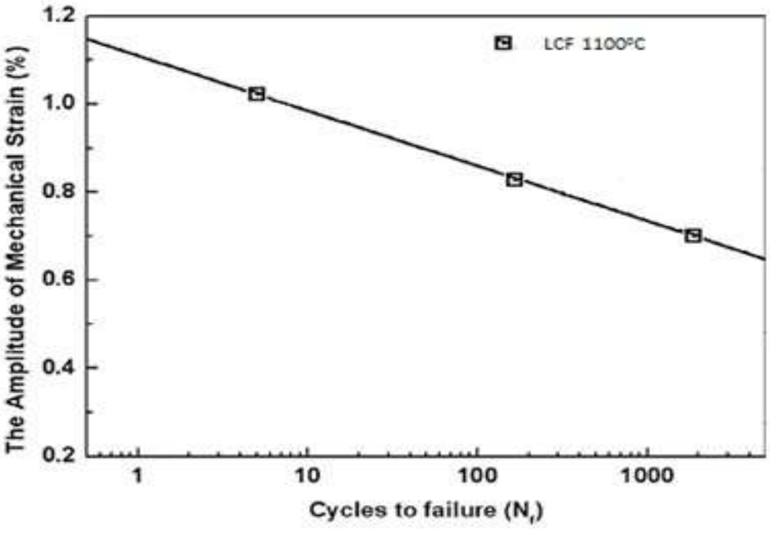
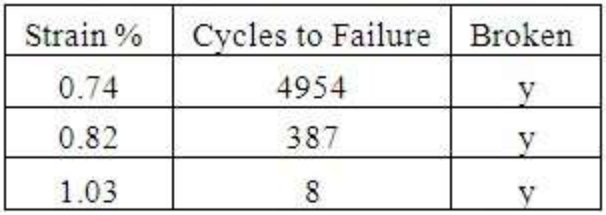


Fig.5. Life Prediction of Low cycle Fatigue Test

TABLE-IV

LIFE PREDICTION OF LCF TEST



Strain %	Cycles to Failure	Broken
0.74	4954	y
0.82	387	y
1.03	8	y

Fig.5. shows the results of the LCF Test. Table no.–IV represents the relationship between strain and no. of cycles to failure for LCF.

It is thought that high temperature creep influenced the life of the material. It can be estimated that the influence of creep would increase under real operating conditions because gas turbines generally operate for long periods.

Conclusion

a. High temperature deformation behaviour of Alloy 617 at11000C showed decrease in elongation with increase in the temperature and serrated flow at slower strain rates.
b. The secondary cyclic strain hardening occurred in INCONEL 617 at elevated temperature is attributed to the dislocation multiplication, which leads to the exhaustion of local plasticity and the formation of stress concentration. This consequently causes fatigue damage or crack initiation.
c. The INCONEL 617showed the superlative yield Strength, Ultimate tensile strength and total elongation compared with the other alloys
d. In the tensile, LCF test, INCONEL 617 became ductile at high temperatures. This indicates that the material is softened by high temperatures.
e. Young’s modulus given by the LCF test were higher than that given by the high temperature tensile test. This meant that the material was hardened by fatigue.

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