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LOW CYCLE FATIGUE LIFE PREDICTION OF GTD 111 SUPERALLOY FOR USE IN GAS TURBINE BLADES

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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. This paper presents the life of GTD 111 applied to gas turbine blade based on High temperature tensile test and LCF test results. 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

Blade failures have plagued designers and operators since the inception of turbo machinery. Turbine Blades are subjected to significant rotational and gas bending stresses at extremely high temperature, as well as severe thermo mechanical loading cycles as a consequence of normal start-up and shutdown operation and unexpected trips. The most difficult and challenging point is the one located at the turbine inlet because there are several difficulties associated to it like extreme temperature, high pressure, high rotational speed, vibration, small circulation area and so on. These effects produced in the blades are shown on the Table I [1].

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

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In order to overcome those barriers, gas turbine blades are made using advanced materials and modern alloys (super alloys) that contains up to ten significant alloying elements, but its microstructure is very simple, consisted of rectangular blocks of stone stacked in a regular array with narrow bands of cement to hold them together. This material(cement) has been changed because in the past,intermetallic form of titanium was used in it, but now a days, it has been replaced by titanium[2].The change gave improved high temperature strength and also improved oxidation resistance.

However, the biggest change has occurred in the nickel, where high levels of tungsten and rhenium are present. These elements are very effective in solution strengthening [2].An important recent contribution has come from the alignment of the alloy grain in the single crystal blade, which has allowed the elastic properties of the material to be controlled more closely. These properties in turn control the natural vibration frequencies of the blade [1].To achieve increased creep strength, successively higher levels of alloying additions (Al, Ti, Ta, Re, W) have been used to increase the levels of precipitate and substitution strengthening. However, as the level of alloying has increased the chromium additions have had to be significantly reduced to offset the increased tendency to reduce the limit ductility and reduced strength. Reduced chromium levels also significantly reduce the corrosion resistance of the alloys.

The low-cycle fatigue (LCF) test and the Manson–Coffin equation were widely used to evaluate the reliability of the substrates of gas turbine blades. The LCF test can simulate fatigue conditions under high isothermal temperatures. In this study, High temperature tensile test and LCF tests are carried out in Specimen with specified ASTM values for the life prediction of Ni-base superalloy.

Failure modes in gas turbine blading

Predominant failure mechanisms and commonly affected components are:

• Low cycle fatigue-compressor and turbine blades and 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.

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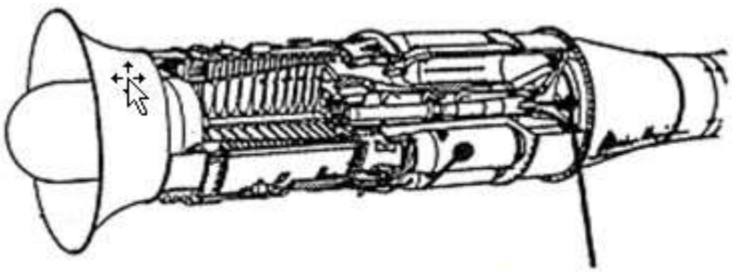

Fig1.Pictorial overview of turbine blades section.[4]

Table ii
Failure modes and causes of different parts of a turbine section. [4]

Component	Failure Mode	Cause
Turbine Rotor Blades	Low cycle and High cycle fatigue,creep ,corrosion,sulphidation , erosion	Centrifugal and temperature stress, vibratory stress, environmental, fuel problems, excessive temperature spreads, cooling problems
Turbine Stator Blades	Creep rupture corrosion,sulphidation, bowing,fatigue,thermal fatigue	Cooling problems, Improper temperature profile
Turbine Rotor Disc	Creep-rupture, low cycle fatigue	Improper wheel space cooling, Thermal stresses

A. Fatigue

Fatigue accounts for a significant number of turbine and compressor blade failures and is promoted by repeated application of fluctuating stresses. Stress levels are typically much lower than the tensile stress of the material. Common causes of vibration in compressor blades include stator passing frequency wakes, rotating stall, surge, choke, inlet distortion, and blade flutter. In the turbine section, airfoils have to function not only in a severe vibratory environment, but also under hostile conditions of high temperature, corrosion, creep, and thermomechanical fatigue.Ewins (1976) provides a detailed treatment of blade vibration.

B. **Low Cycle Fatigue**

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Low cycle fatigue (LCF) occurs as a result of turbine start/stop cycles and is predominant in the bores and bolt hole areas of compressor and turbine disks that operate under centrifugal stresses. 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 the nozzle sections. To some extent, this is to be expected under normal operation and cycling service.

C. Thermomechanical Fatigue

Thermomechanical fatigue (TMF) is associated with thermal stresses, e.g., differential expansion of hot section components during startup and shutdown, and is particularly severe during rapid starts and full load emergency trips. The stress levels induced may initiate cracks, if they exceed the material yield stress. Temperature variations as high as 360°F (200°C) per minute are often experienced in hot section blading. This is the reason why full load trips are so detrimental in terms of life reduction, consuming as much as 200 equivalent hours per trip.

Material and experimental procedure

A. Specimen

The alloy used for testing was GTD111.This nickel-based super alloy composed of approximately of following elements as shown in Table III.

Component	Ni	Co	Cr	W	Mo
wt (%)	Bal.	10	13.5	4	4.5
Component	Ti	Al	C	B	Ta
wt (%)	5	3	0.1	0.01	3

Table III Nominal compositions OF GTD 111 (wt %)

In this study, tensile tests at room temperature and tensile test at 9000 C, LCF tests were conducted to evaluate the mechanical characteristics of Ni-base superalloys.The specimens used in this study were cylindrical, in accordance with ASTM E604 [7] for LCF test and ASTM E8–01 [6] for high temperature tensile test. Fig. 2 and Fig.3 shows the shapes of the specimens used in the tests.

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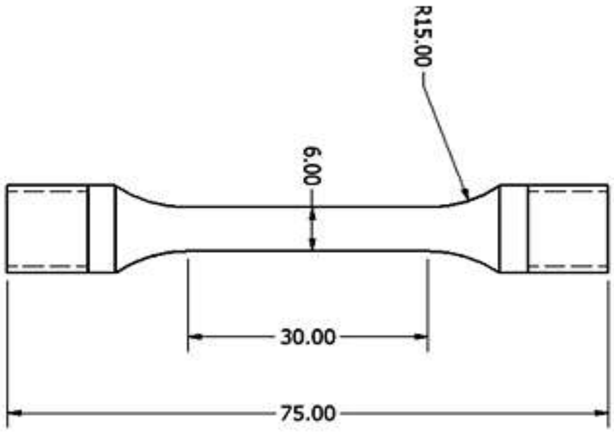

Fig.2 Tensile test specimen
(All Dimensions are in mm)

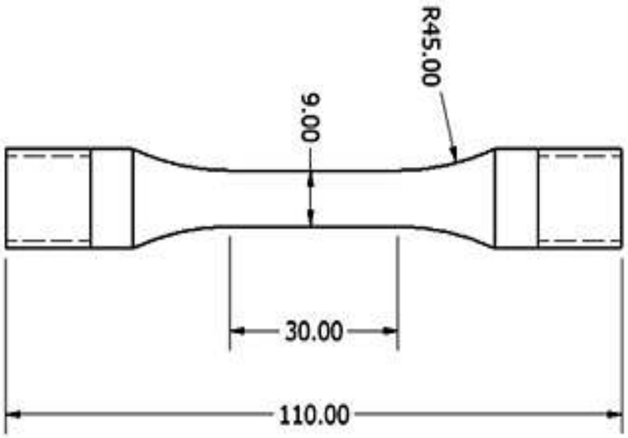

Fig.3 LCF test specimen
(All Dimensions are in mm)

A. Test equipment and method

An electric furnace is used to perform the tensile, low cycle fatigue (LCF).The tensile tests were conducted at room temperature and at 9000 C.A hydraulic test machine was used to apply strain rate 0.0167 mm/sec in accordance with ASTM E8-M

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[6].In high temperature tensile test, the specimen was maintained at 9000C for 1 hour to prevent a temperature gradient. The time at which the specimen completely separates was considered the time of fracture.

LCF tests were performed under the strain control condition at 9000C.The test frequency was set to 0.4 Hz and strain amplitudes 0.78 %.0.85% and 1 % were applied.Table IV shows conditions of Temperature and strain amplitudes for High temperature tensile test and LCF test.

Table IV.
Conditions Of Temperature And Strain Amplitude

Specimen Type	Temperature (^{0}C)	Strain Amplitude (%)
Tensile	RT, 900	--
LCF	900	0.78, 0.85, 1

Test results and discussion

Fig. 4 shows the results of tensile tests at room temperature and 9000C.The tensile test at room temperature was performed once and the tensile tests at 9000C were performed twice. The tensile strength of the tested specimen was 1,130 MPa at room temperature and 860 MPa at 9000C. Yielding occurred at 980 MPa at room temperature and at 710 MPa at 900 0C. When the temperature was increased, the yielding strength decreased by about 20%, and strain increased by about 30%. These results indicate that GTD-111 became ductile. This tendency was also confirmed by the LCF and High temperature tensile test. Fig. 5 shows the results of the LCF life prediction test.

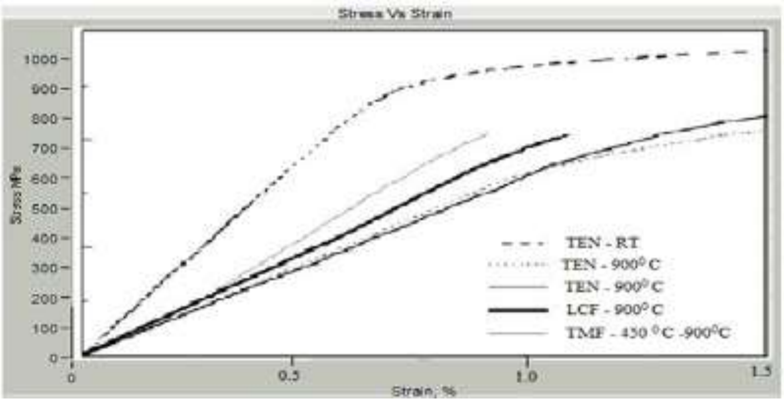

Fig.4 Results of Tensile test of GTD 111

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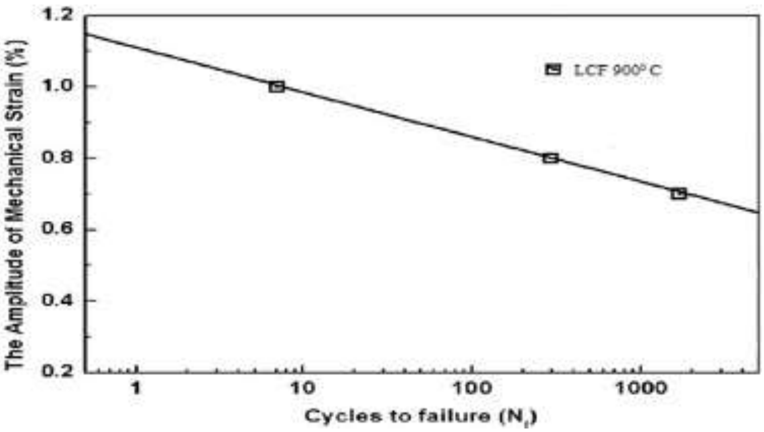

Fig.5 Life Variation of LCF test

Life variation of GTD 111 at different strain amplitudes in LCF test in tabulated form is presented in Table V.

TABLE V Life variation of lcf test

Strain %	Cycles to Failure	Broken
0.78	4523	y
0.85	537	y
1	9	y

Conclusions

This investigation of low cycle fatigue (LCF) test and high temperature tensile test of GTD111 at temperature range 900◦C leads to the following conclusions:

1. The result of Tensile, LCF and High temperature tensile test of GTD111 shows favorable properties at elevated temperature and is better among the material under option for gas turbine blades.

2. GTD111 hardens by fatigue at elevated temperature as it is evident from the fact that the Young's modulus given by the LCF was higher than that given by the high temperature tensile test.

3 .The GTD 111 showed the superlative yield Strength, Ultimate tensile strength and total elongation compared with the other alloys.

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4. High temperature deformation behaviour of GTD 111 at 9000C showed decrease in elongation with increase in the temperature and serrated flow at slower strain rates.

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