Engineering Failure Analysis 17 (2010) 848–856

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis in after shell section of gas turbine combustion liner under base-load operation

Kyung Min Kim, Namgeon Yun, Yun Heung Jeon, Dong Hyun Lee, Hyung Hee Cho *

Department of Mechanical Engineering, Yonsei University, 134, Sinchon-dong, Seodaemun-gu, Seoul 120-749, Republic of Korea

A R T I C L E I N F O

Article history:
Received 13 July 2009
Accepted 11 October 2009
Available online 16 December 2009

Keywords:
Failure analysis
Gas turbine failures
High temperature fatigue
Thermal stress

A B S T R A C T

The present study investigates the failure analysis and the lifetime prediction in the after shell section of gas turbine combustion liner with internal cooling passages called C-channel. To calculate distributions of temperature and stresses, 3D-numerical simulations using FVM and FEM commercial codes are performed. As a result, the discrepancy in thermal expansion between hot and coolant side walls induces high thermal stresses in the welding region and above the divider of the C-channel. Thus, these two regions are much weaker than the other regions. The locations match well to those of thermal cracks in actual gas turbine combustors in service.

1. Introduction

In gas turbine systems, the achievement of high thermal efficiency is strongly related to the increase in the turbine inlet temperature, which is accompanied by the excess thermal load in the hot components of gas turbine. Thus, various cooling techniques [1–3] have been used to protect the main hot parts of the gas turbines. If unsuitable cooling method is used, the local thermal crack and structural failure are yielded due to the thermal stress and the reduction of the material strength in high temperature. Therefore, the failure analyses as well as the thermal analyses for temperature, deformation and stress are required for the effective thermal design and the lifetime prediction of hot components. It is noted that the failure analysis was investigated only in material point of view, but rarely with thermal analysis, by many researchers [4–8].

Furthermore, the temperature gradient in each hot component increases with the turbine inlet temperature increasing, and it generates thermal damages by high thermal stresses. It is necessary to estimate the temperature distributions in the materials of the system in an appropriate thermal environment to predict the life and safety of hot components such as combustors, vanes, and blades. In recent years, several investigators [9–12] have attempted a thermal analysis in hot components of gas turbines and the thermal damages were predicted. It has been shown that the computational results are useful for inspecting the thermal environment of the gas turbine and defining the factors that contribute to advanced maintenance and operation.

In this paper, we can find the locations of high stresses under the steady state operation and the base-load operation using the thermal analysis of the after section of combustor liners. However, it is hard to decide whether the high stresses will cause fatigues induced by the transient operations such as unit start-up and shut-down. Therefore, the objective of the present research is to find major causes of thermal damages affecting the creep lifetime induced by the temperature and thermal stress distributions. As an example, we calculated the lifetime and the distributions of temperature and thermal stress which have often yielded the axial and weld cracks in an actual combustion liner in service as shown in Fig. 1, and then we find the causes of these cracks from the analysis results.

* Corresponding author. Tel.: +82 2 2123 2828; fax: +82 2 312 2159.
E-mail address: hhcho@yonsei.ac.kr (H.H. Cho).

1350-6307/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engfailanal.2009.10.018

Nomenclature

D	hole diameter
E	Young's modulus
h	heat transfer coefficients, $q/(T_w - T_m)$
K	thermal conductivity
t	the lifetime in hours
T_2	coolant flow temperature
T_w	wall temperature
T_m	main flow temperature
q	heat flux per unit area
UTS	ultimate tensile stress
YS	yield stress

Greek symbols

α	thermal expansion coefficient
v	Poisson's ratio
σ_v	von-Mises stress
σ_n	de-bonding stress or stress in the direction normal to the TBC bonded surface
σ_c	initial creep stress

2. Research methods

The combustion liner [13] is divided into three parts such as forward shell section, center shell section, and after shell section as shown in Fig. 2a. Each section has different cooling methods. In other words, the forward shell, the center shell, and the after shell sections are cooled by rib-roughened passage, impingement jet, and C-channel, respectively. Among these sections, the after shell section is cooled using an internal passage cooling method because this section is inserted into transition piece. It is called C-channel and is invented by Intile et al. [14]. The C-channel consists of cooling holes, divider walls, hot side wall, coolant side wall, and spring seals as described in Fig. 2b.

In the present study, one hole segment of the 88 cooling holes of which diameter (D) is 2.6 mm in this section is considered for analysis because the shape has a symmetric behavior as shown in Fig. 3a. The calculations of fluid flow and heat transfer are conducted using a computational fluid dynamics (CFD) code, CFX v11. The Reynold-averaged Navier–Stokes equations and the transport equations of the turbulent quantities are solved by the pressure correction algorithm SIMPLE. The fluid is considered to be compressible and fluid properties are assumed as a function of flow temperature. The turbulence model is the SST k–ω model. The grid consists of approximately 1.5 million cells including flow and solid domains with TBC, of which thickness is 1.0 mm as shown in Fig. 3b. The external boundary conditions were set to constants in Table 1.

A stress analysis was conducted using the calculated temperature data to find the causes of the thermal damage in the aforementioned geometries. The numerical stress analysis was performed using a finite element analysis (FEA) code, ANSYS v11. In the numerical calculations, the boundary conditions used the temperature and the heat transfer data calculated from the CFD analysis. To calculate the thermal stresses, symmetric conditions in both the side regions and constant forces of 1500 N into reverse z-axis direction at locations of spring seal were imposed. Constraints are very important because most stresses are caused by settlements of constraints and thermal effects (arising from temperature changes and differences). In other words, the thermal stress for structural materials is proportional to the material property, thermal expansion coeffi-

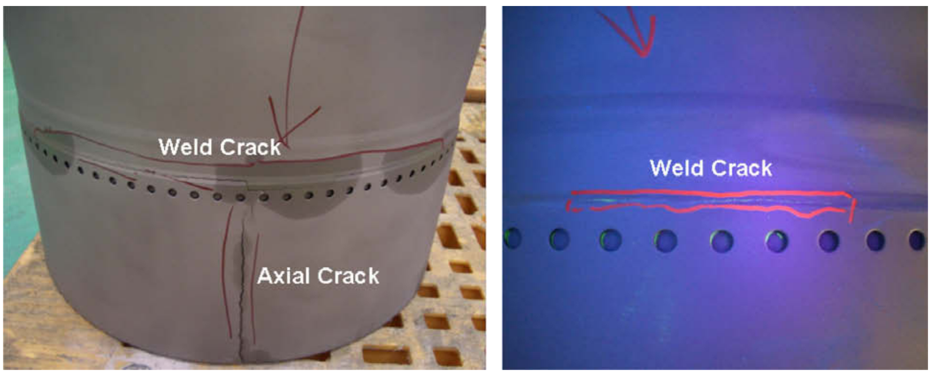

Fig. 1. Thermal damages observed in service.