Biaxial fatigue life evaluation method of DS superalloy for 1300˚C class gas turbine blades and development of simplified blade life assessment program

Background

CRIEPI developed the detailed temperature and stress analysis program for first row blades in 1300˚C class gas turbine based on a finite element method. It was found that surface of the first row blade is subjected to in-plane biaxial tension stress in blade height and normal to blade height direction resulting in biaxial fatigue due to start-stop operation *1. It is necessary to clarify biaxial fatigue life property of the blade material and develop life assessment method based on the experiment to predict crack initiation life of the first row blade under the biaxial fatigue loading. However, no experimental study on high temperature in-plane biaxial fatigue of the blade material has been made due to difficulty of the in-plane biaxial fatigue test at high temperature using a highly equipped testing machine. Furthermore there is strong demand to develop simplified life assessment program of the first row blade by utilities.

Objectives

To propose biaxial fatigue life evaluation method of a Ni base directionally solidified (DS) superalloy based on the biaxial fatigue property, and to develop a simplified blade life assessment program which incorporates the biaxial fatigue life evaluation method.

Principal Results

1. Development of biaxial fatigue life evaluation method of DS superalloys

Biaxial fatigue tests on a DS superalloy at 870˚C were conducted by using the previously developed high temperature in-plane biaxial fatigue testing machine (Fig.1(a)). ϕ was defined as a ration of x directional strain to y directional strain where x directional strain coincides with solidified direction.

(1) Fatigue life decreases with increasing ϕ and fatigue life in x-directional loading with ϕ = 0 is shorter than that in y-directional loading with ϕ = 0 (Fig.1(b)). Due to such an anisotropic failure property of the DS superalloy, biaxial fatigue lives were not correlated with Mises equivalent strain range which is commonly used in design.

(2) Considering dependency of the biaxial fatigue life property on ϕ and the solidified direction, an iso-fatigue life curve was derived on the E-plane *2 (Fig.2(a)). A new fatigue life criterion, “equivalent normal strain range” was formulated based on the iso-fatigue life curve. The biaxial fatigue lives of the DS superalloy were correlated with “equivalent normal strain range” independent on ϕ (Fig.2(b)).

2. Development of a simplified blade life assessment program

(1) A simplified blade life assessment program which can assess crack initiation life of 1300˚C class gas turbine blade was developed incorporating above mentioned biaxial fatigue life evaluation method. It was confirmed that error of life prediction by the simplified program was within 10% of the detailed program based on the finite element method.

(2) Damages in a first row blade under following four different conditions were compared by the simplified program (Fig.4). [Case 1]: normal DSS operation, [Case 2]: 10% output reduction from Case 1, [Case 3]: inserting partial loading in Case 1, [Case 4]: longer start up duration than Case 1. It was found that although difference between Case 1 and Case3, Case 4 is not significant, fatigue damage in Case 2 is less than in Case 1 due to lower combustion temperature. Calculation period of several months by the detailed program can be reduced to a few hours by the simplified model. Therefore the simplified blade life assessment program is effectively applied to determine operation condition that reduces damage in a blade.

Future Developments

The simplified blade life assessment program developed in this study will be applied to remaining life assessment of 1300˚C class gas turbine blades and/or determination of operation condition which reduces damage of the blades.

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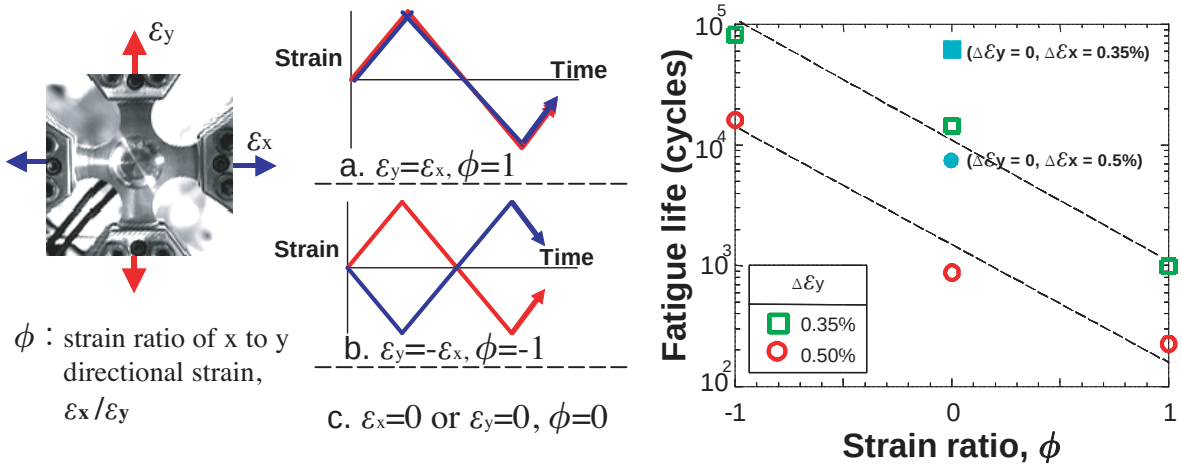
Reference

T. Ogata, et. al., 2006, “Development of high temperature biaxial fatigue life evaluation method for Ni base conventional casting and directionally solidified superalloys use for gas turbine blade,” CRIEPI Report Q06004 (in Japanese)

*1 : T. Sakai et al., CRIEPI Report, Q04013 (2004).

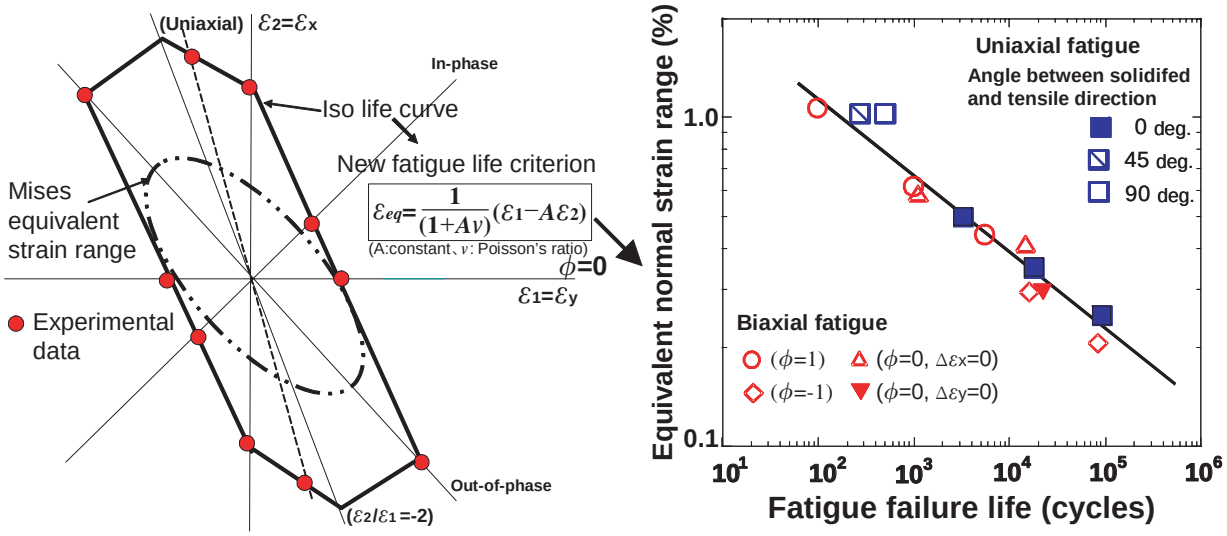
*2 : A strain plane having solidified direction on y axis and normal to solidified direction on x axis.



(a) Biaxial fatigue test condition

(b) Biaxial fatigue life property of DS superalloy

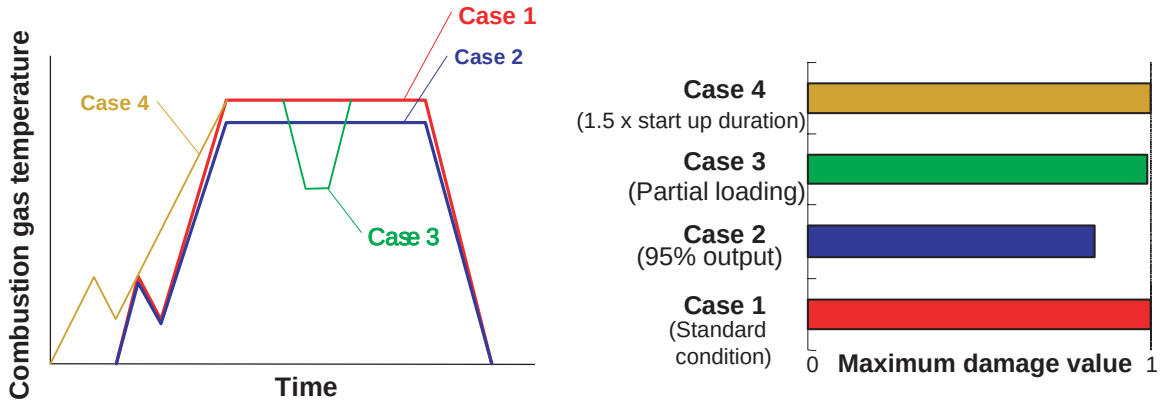
Fig.1 High temperature biaxial fatigue test condition and test results of DS superalloy



(a) Biaxial fatigue failure life criterion

(b) Relationship between equivalent normal strain range and fatigue life

Fig.2 Biaxial fatigue life correlated with equivalent normal strain range formulated in this study



(a) Schematics representation of operation pattern

(b) Comparison of damage between different conditions

Fig.3 Comparison of damage on blade surface between different operating conditions