Engineering Fracture Mechanics 123 (2014) 211–222

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

Creep damage assessment for notched bar specimens of a low alloy steel considering stress multiaxiality

Nobuhiro Isobe [a,*], Kenji Yashirodai [b], Ken'ichi Murata [b]

[a] Research & Development Center, Mitsubishi Hitachi Power Systems, Ltd., 3-1-1, Saiwai, Hitachi, Ibaraki, 317-0073, Japan
[b] Steam Turbine Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd., Japan

ARTICLE INFO

Article history:
Available online 13 March 2014

Keywords:
Creep
Damage
Multiaxial stress
Inelastic analysis
Low alloy steel

ABSTRACT

Creep damage assessment methods considering the effect of stress multiaxiality are discussed in order to evaluate creep crack initiation from stress concentrating fields. Creep tests using notched bar specimens were conducted and damaging features around the notch root were investigated. Micro damages such as small creep cracks were mainly observed around several hundred micro-meters below the surface. Creep damage assessment methods based on inelastic analyses considering the primary and secondary creep were discussed. Creep damages evaluated from creep strains taking the ductility reduction in multiaxial stress states into account were in good agreement with experimental results.

1. Introduction

Reliability against creep is an important factor in the design and life management of turbine components such as rotors and blades in high temperature stages. Uniaxial creep data is typically used when designing these components. One of the most severe portions in turbines from the viewpoint of material strength is the stress concentrating area around the joint between the rotor and blades. Creep behaviors in stress concentrating area are not same with the uniaxial condition because a multiaxial stress state generates at the stress concentrating area and it constraints creep deformation.

Creep damage or life assessment methods for stress concentrating fields have been studied for a long time [1–8]. Notched specimens were often employed in these studies and notch strengthening and weakening behaviors in comparison with smooth bar specimens have been discussed. There are a lot of factors affecting the creep strength of notched specimens, such as ductility of the material, temperature, shape and dimension of notches, size of the specimen. Further, it also varies with testing time whether the material shows notch strengthening or weakening behavior. In longer life region, the ratio of rupture strength of the notched specimen to that of the smooth bar specimen generally reduces. This behavior would relate to the notch sensitivity of creep ductility [9]. It is, therefore, difficult to give a standardized criterion for judging the notch strengthening or weakening behavior. It usually confirms in the manufacturing of actual components that the employed material shows the notch strengthening property in the service condition.

Materials used for turbine components usually have the notch strengthening property in actual conditions [10]. Design based on uniaxial creep data, therefore, is a reasonable approach because it gives conservative evaluations. However, improving the accuracy of life evaluation methods for these components is important in terms of rationalizing the design and life management of plants. Stress states at the stress concentrating fields are usually biaxial or triaxial tensile conditions.

* Corresponding author. Tel.: +81 294 55 8197; fax: +81 294 55 9969.
E-mail address: nobuhiro_isobe@mhps.com (N. Isobe).

http://dx.doi.org/10.1016/j.engfracmech.2014.01.017
0013-7944/

Nomenclature

D_c	creep damage
R	notch radius
TF	triaxiality factor
t_R	creep rupture time
ε_c	total creep strain
ε_f	creep ductility
ε_{f0}	creep ductility under the uniaxial stress condition
$\dot{\varepsilon}_m$	steady creep rate
σ_1	maximum principal stress
σ_{eq}	von Mises equivalent stress
σ_H	hydrostatic stress
σ_n	nominal stress at the minimum cross section (in the specimen)
σ_n'	nominal stress at each cross section

Creep rates reduce in such stress fields of high multiaxiality and it would affect the notch strengthening behaviors of materials. The effect of stress multiaxiality is also important in the assessment of creep damage in weldment [9]. Several studies have been conducted to establish creep damage or life assessment techniques for weldment taking the stress multiaxiality into account by using inelastic analyses [11–15]. Moreover, assessment methods for creep crack growth are also discussed in relation to the stress multiaxiality because high multiaxial states appear around the crack tip [12,16]. A rational assessment would be achieved by evaluating creep damaging behaviors of materials under the condition of high stress multiaxiality.

In this study, we performed creep tests and inelastic analyses of circumferentially notched bar specimens of a CrMoV steel for turbine rotors. Features of creep cracks were investigated and compared with stress and strain state obtained by inelastic analyses. Evaluation methods of creep damage are also discussed by taking the stress multiaxiality into account.

2. Experimental procedures

2.1. Material and specimen

The material employed in this study is a forged CrMoV steel for the turbine rotors. The main chemical components of the steel are Cr: 1.10, Mo: 1.30, V: 0.25, C: 0.30, Mn: 0.75 in weight percent. Mechanical properties at room temperature are 757 MPa of tensile strength, 585 MPa of proof strength and 14% of elongation.

The shape and dimensions of the circumferentially notched bar specimens are shown in Fig. 1. Four notches are introduced to the specimen. Diameters at the notch root are changed in order to investigate damaging features at each root. The minimum diameter is 8 mm and is increased by 0.05 mm so that the maximum diameter is 8.15 mm. The radii of the curvatures at the notch root, R, are 1.0 mm and 0.5 mm, as shown in Fig. 1, and stress concentration factors are 2.3 and 3.1 respectively.

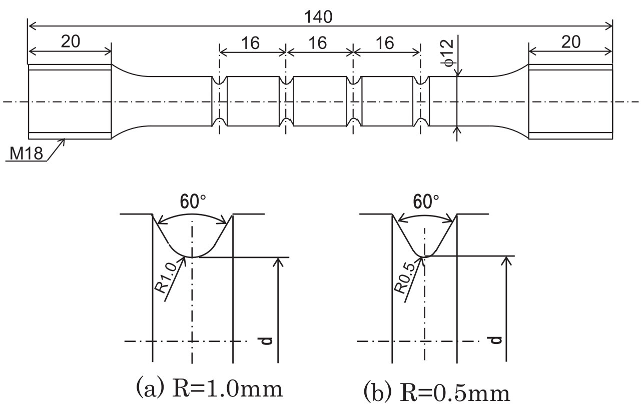

Fig. 1. Shape and dimension of notched bar specimens.