Engineering Fracture Mechanics 123 (2014) 197–210

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

A multiaxial creep-damage model for creep crack growth considering cavity growth and microcrack interaction

Jian-Feng Wen, Shan-Tung Tu *

Key Laboratory of Pressure Systems and Safety (Ministry of Education), School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, PR China

ARTICLE INFO

Article history:
Available online 14 March 2014

Keywords:
Creep damage
Crack growth
Cavity growth
Multiaxial fracture
Finite element analysis

ABSTRACT

This article presents a concise multiaxial creep-damage model for creep crack growth considering the cavity growth and microcrack interaction. Special emphasis is put on developing and validating the multiaxial creep ductility factor (MCDF) based on power-law creep controlled cavity growth theory. Good agreements with the theoretical and experimental data prove the effectiveness of the proposed MCDF. The application of the proposed creep-damage model through finite element simulation of the creep deformation and crack growth in C-Shaped Tension and Compact Tension specimens of 316H tested at 550 °C confirms the predictive capability of the proposed model.

1. Introduction

A number of metallic components inevitably containing defects are subjected to high temperatures in various industrial fields. For safety reasons, it is imperative to assess the integrity of such components operating in the creep regime. The analysis of creep crack growth based upon Continuum Damage Mechanics (CDM), which offers complementary possibilities to the Fracture Mechanics (FM), has received considerable attention in recent years. Within this approach, the whole process of initiation and propagation of creep crack may be directly related to the build-up of creep damage in the vicinity of the crack tip. When the damage variable, ω, reaches a critical value, failure of material ahead of the crack tip is considered to occur, and thus crack growth can be characterized by a completely damaged zone. Following the pioneering work of Kachanov [1] and Rabotnov [2], dozens of creep-damage models have been presented according to the multifarious definitions of damage, with a single [3–10], double [11–13], triple [14–16] or even quadruple [17] damage variables. Damage evolution models in the abovementioned studies are generally stress-based, which can represent the creep damage process to some extent. However, many material parameters in these models need to be calibrated with caution before use. In many cases, obviously, the complex calibrations cannot be realistic for an engineering assessment.

If the critical-strain criterion [18] is employed as a local criterion at the crack tip under creep conditions, the number of undetermined material parameters in the damage models can be considerably reduced. As delineated in Fig. 1, the units of length increments in the area ahead of a creeping crack are compared to uniaxial specimens used in conventional creep tests [19]. The crack is assumed to propagate when the local accumulated creep strain at the crack tip reaches the critical creep ductility. And at the same time, the damage parameter approaches unity. In this sense, the damage evolution law can be given by

* Corresponding author. Tel.: +86 21 64253425; fax: +86 21 64253513.
E-mail address: stu@ecust.edu.cn (S.-T. Tu).

http://dx.doi.org/10.1016/j.engfracmech.2014.03.001
0013-7944/

Nomenclature

a	crack length
A	coefficient in the creep strain rate expression
d	grain size
d'	average diameter of cavitating grain boundary facets/micro-cracks
f_c	area fraction of the cavities at which linkage occurs
f_h	area fraction of holes on the grain boundary
f_i	initial area fraction of the cavities
f_w	area fraction entering the bound calculation in the cavity growth theory
G	stress–state parameter used in the cavity growth theory
l	half distance between voids
L	diameter and height of the cylindrical cell containing a cavitating facet
m	time exponents in the time-hardening creep law
n	stress exponent in the creep strain rate expression
N	number of cavitating grain boundary facets/micro-cracks per unit volume
P	applied load
P_y/P_x	biaxial stress ratio
r_h	radius of growing void
t	time
t_c	time to coalescence of cavities
t_{c0}	time to coalescence of cavities in the case of simple tension
T	triaxial stress superimposed on the axial stress
V	volume of the cylinder
w	a distance entering the bound calculation in the cavity growth theory
α	stress–state parameter used in the cavity growth theory
α_0	stress–state parameter used in the case of simple tension
ε^c, $\dot{\varepsilon}^c$	creep strain and creep stain rate, respectively
$\dot{\varepsilon}_a$, $\dot{\varepsilon}_r$	axial and radial creep strain rate of the cylinder, respectively
ε^c_{ij}, $\dot{\varepsilon}^c_{ij}$	creep strain tensor and creep stain rate tensor, respectively
ε_f, ε^*_f	uniaxial and multiaxial creep failure strain, respectively
$\dot{\varepsilon}_{ss}$	steady creep rate in absence of voids
ρ	micro-crack damage parameter
σ_a	axial stress
σ_{ij}, s_{ij}	stress tensor and deviatoric stress tensor, respectively
σ_{eq}, σ_m	equivalent (von Mises) and hydrostatic stress, respectively
ω, $\dot{\omega}$	damage variable and damage rate, respectively
CDM	Continuum Damage Mechanics
C(T)	Compact Tension
CS(T)	C-Shaped Tension [Enter Key]
FE	finite element
FM	Fracture Mechanics
MCDF	multiaxial creep ductility factor, defined as $\varepsilon^*_f/\varepsilon_f$

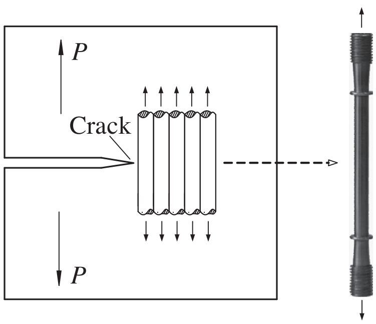

Fig. 1. Schematic diagram of the creep crack growth model in which the crack tip area is described by a series of pseudo uniaxial specimens.