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Fracture Mechanics, Creep and Fatigue Analysis

edited by
C. Becht IV
S. K. Bhandari
B. Tomkins

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FOREWORD

The primary objective of the Design and Analysis Committee of ASME Pressure Vessels and Piping Division is to provide a forum for the dissemination of information and the advancement of current theories and practices in the design and analysis of pressure vessels, piping systems and related components. This is achieved largely through presentations and discussions at the annual PVP Division conference, as well as through encouragement and sponsorship for publication of the technical literature.

This publication is comprised of technical papers on various topics of interest to the pressure vessels and piping industries and includes international contributions by authors from Canada, the People's Republic of China, France, the Federal Republic of Germany, the United Kingdom, and the United States of America.

All the papers in this volume were prepared for presentation in technical sessions developed under the auspices of the Design and Analysis Committee for the 1988 ASME Pressure Vessels and Piping Division Conference in Pittsburgh, Pennsylvania.

This volume, "Fracture Mechanics, Creep and Fatigue Analysis" is presented in three chapters:

Creep and Fatigue Analysis
Fracture Mechanics
Flaw Evaluation in Fast Breeder Reactors

The first chapter contains: An approximate technique for assessing multiaxial stress-relaxation using uniaxial behavior corrected with multiaxiality correction factors, an evaluation of high cycle fatigue service of piping fillet weld joints using piping code stress intensification factors and endurance limits, and a case study in which six years of pressure fluctuation data from two chemical plant towers were used to derive a pressure amplitude spectrum which was applied to a CCT speciman to determine crack growth rate under representative variable-amplitude loading.

The second chapter contains: Development of a three-dimensional failure assessment diagram which uses crack extension as a third independent variable, a fatigue crack growth analysis of a 45 lateral to evaluate the margin to fatigue failure based on a postulated defect and a 40 year service life, extension of net section plastic collapse evaluation of flawed pipe to permit evaluation of arbitrarily shaped cracks, and an elastic-plastic evaluation of a prototype metal-matrix fuel waste disposal container subjected to water pressure in a 1000 meter deep vault.

The third chapter presents developments in the European Fast Breeder Reactor Program to establish the leak-before-break concept for application to austenitic stainless steel piping and vessels in liquid sodium service.

C. Becht IV

CONTENTS

ESTIMATION OF MULTIAXIAL STRESS RELAXATION USING ISOCHRONOUS CURVES

R. Seshadri
Industrial Systems Engineering
University of Regina
Regina, Saskatchewan, Canada

ABSTRACT

The state of stress in pressure components is usually multiaxial. In evaluating component damage and associated inelastic deformations for elevated temperature service, it is essential to understand how the stresses relax with time. Most of the available stress-relaxation data are based on relaxation tests that use a one-dimensional configuration in which the strain is held fixed, and the decrease of the initial stress is measured as a function of time. It is therefore useful to relate the multiaxial relaxation behavior of a pressure component to the uniaxial relaxation behavior so that the available relaxation data can be used effectively. This paper discusses a simple approximate technique for assessing multiaxial stress-relaxation by utilizing the isochronous curves in conjunction with "multiaxiality correction factors".

NOMENCLATURE

A = material constant for time-hardening creep relationship

B = material constant for steady-state creep relationship

E = modulus of elasticity

m = material constant

n = material constant

α = stress-ratio (σ_2/σ_1)

β = stress-ratio (σ_3/σ_1)

$\bar{\varepsilon}$ = equivalent-strain

ε_{ti} = total-strain in the i-direction (i = 1,2,3)

ε_{ei} = elastic-strain in the i-direction (i = 1,2,3)

ε_{pi} = plastic-strain in the i-direction (i = 1,2,3)

ε'_{ci} = creep-strain in the i-direction (i = 1,2,3) first stage of creep

ε''_{ci} = creep-strain in the i-direction (i = 1,2,3) second stage of creep

$\bar{\sigma}$ = equivalent stress

$\sigma^{(i)}$ = initial stress before relaxation occurs

$\sigma_1, \sigma_2, \sigma_3$ = principal stresses

τ = time

τ_{1d} = time-scale (uniaxial)

τ_{id} = time-scale (multiaxial), i = 2, or 3

$\bar{\lambda}_i$ = multiaxiality parameter, i = 2 for two-dimensional constraint and i = 3 for three-dimensional constraint.

ν = Poisson's ratio

1. INTRODUCTION

Proper estimation of the amount of creep-damage incurred during elevated temperature operation of pressure components requires an understanding of the stress-relaxation behaviour. Relaxation is the decay and redistribution of stresses in a component operating at elevated temperatures when the total strain in one or more directions is held fixed. The accumulated creep deformations are essentially counterbalanced by equivalent changes in elastic strains. Some practical examples of multiaxial

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