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Identification of inelastic material parameters for modified 9Cr–1Mo steel applicable to the plastic and viscoplastic constitutive equations

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ABSTRACT

In this paper, the material parameters of plastic and viscoplastic constitutive equations for modified 9Cr–1Mo steel are developed for various isothermal conditions to support inelastic analysis for a sodium-cooled fast reactor. To do this, the material parameters related with the elastoplastic behaviour are identified with uniaxial cyclic test data by performing computer simulations, which use the combined Chaboche model including the kinematic hardening rule and the isotropic softening rule. The viscous parameters are identified from uniaxial stress relaxation test data through computer simulations with the pre-determined elastoplastic material parameters. Sensitivity studies are performed for the material parameters to investigate cyclic inelastic behaviour and stress relaxation during a hold time. From the comparison between the tests and the simulations, it is expected that the identified material parameters of the plastic and viscoplastic constitutive equations can accurately express the material characteristics of modified 9Cr–1Mo steel sufficiently well to be used for inelastic analysis.

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1. Introduction

Recently, many countries have been making efforts to substantiate new concepts for nuclear power plants, i.e., Generation IV reactor systems, such as the sodium-cooled fast reactor, high temperature gas-cooled reactor, and lead-cooled reactor. In most Gen-IV reactor designs, the operating temperature is over 500 °C and the design lifetime is 60 years. The structural damage issues for these high temperature and long life reactors are significantly related to time-dependent creep rupture, excessive creep deformation, cyclic creep ratcheting, creep-fatigue, creep crack growth, and creep buckling.

There are many codes and standards to provide rules or guidelines for the elevated temperature design of the nuclear power plants, such as ASME-NH [1], RCC-MR [2], Monju design guide [3], and R5 [4]. However, all of these provide basic elastic approach with excessive safety margins to cover possible uncertainties in inelastic material behaviour. Actually, the inelastic material behaviour of metals is complicated at elevated temperature and may significantly affect the accumulation of creep ratchet strain and creep-fatigue damage. Especially, modified 9Cr–1Mo steel, which is considered as a primary candidate material for some main components of Gen-IV reactors, exhibits significant viscosity and cyclic softening at high temperatures [5,6]. These are different from the behaviour of austenitic stainless steels and carbon steels. Therefore, it is difficult to consider all types of inelastic behaviour with the elastic rules of the codes and standards. To resolve these issues, many researchers are focusing on the development of inelastic analysis methods with plastic and viscoplastic constitutive equations [7–10]. However, although a few studies have been published on inelastic material parameter identification [11–14], studies on the material parameter identifications for modified 9Cr–1Mo steel have been rarely published yet [10,14].

The main purpose of this paper is to develop inelastic material parameters for the plastic and viscoplastic constitutive equations of Chaboche's model [7–9] for modified 9Cr–1Mo steel. These can be used for the inelastic analysis of actual components. To do this, specimen tests such as strain-controlled cyclic hysteresis loop test, cyclic softening tests, monotonic tensile tests, and stress relaxation tests are carried out for various isothermal conditions.

Methods for identifying the constitutive parameters have been developed by many researchers [11–13]. In this paper, based on the stabilized hysteresis loop test results, the kinematic hardening parameters are identified by a simple method [11] with computer simulation of the elastoplastic Chaboche's three decomposed model. And the isotropic softening parameters are identified by computer simulations with the combined Chaboche constitutive equations based on strain-controlled fully cyclic hysteresis loop test data. Finally, the viscosity parameters are identified with stress relaxation test data through sensitivity studies by computer

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