

# Aging effect on the thermal transient behavior of the fuel cladding of a sodium-cooled fast reactor



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## HIGHLIGHTS

- Transient tests has been performed at 0.56, 5.6, and 20 °C/sec.
- Mechanical properties reduced during aging process at 650 °C.
- Aging effect on transient behavior of HT9 cladding have been estimated.
- Failure temperature reduced at the same hoop stress after aging at 650 °C.

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## ABSTRACT

The transient behavior of the fuel cladding of a sodium-cooled fast reactor (SFR) is one of the main design issues concerning the safety of a reactor. The safety margin of the cladding during transient events has been widely studied in the past. However, previously, the transient testing was conducted using as-received specimens (and not aged specimens). For ensuring safety margin of the fuel rod of an SFR, the effect of aging on the transient behavior of the fuel cladding should be considered. This study examines this effect on the transient behavior of HT9 cladding by correlating between the UTS and the result of the ramp test and proposes a modified Dorn parameter that reflects the aging effect. At 100 MPa of the hoop stress, the modified Dorn parameter, which reflects an aging effect, is  $7.7266 \times 10^{-14}$  and the Dorn parameter of as-received specimen is  $1.749 \times 10^{-12}$ . This results in the enhanced safety during transient event by considering aging effect.

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## 1. Introduction

Detailed knowledge of the behavior of a fuel cladding of a reactor during reactor transients is required for the core design and safety analysis of both transient overpower (TOP) and loss-of-flow (LOF) events [1]. A TOP accident is assumed to be initiated owing to the control rod withdrawal caused by the failure of the drive motor. LOF implies a loss of the cooling capability of the core due to the failure of primary pumps. The imbalance between the reactor power and primary flow rate is the main safety concern in an LOF [2].

The design and safety analyses of liquid metal reactors (LMRs) require understanding the fuel pin responses to a wide range of off-normal events. During an LOF or a TOP, the temperature of the cladding rapidly increases above its steady-state service temperature. Modeling the fuel pin transient behavior requires a knowledge

of the mechanical behavior of the cladding under the stress and thermal conditions encountered in the transient events [3]. Designed transient tests have been performed on sections of a fuel pin cladding, and a large data base has been established for austenitic stainless steels [4–7] and ferritic/martensitic steels [1,3,8,9].

The ferritic/martensitic stainless steel, HT9, is widely being investigated as a cladding and duct material in LMRs. It is a promising alloy because of its high resistance to swelling, good resistance to irradiation creep, and low-thermal expansion [3].

In previous studies, the designed transient tests for HT9 were performed using as-received type specimen. It is widely known, ferritic/martensitic steels exhibit a degradation of the mechanical properties with aging time above 500 °C [10–13]. In sodium-cooled fast reactors (SFRs), a fuel rod operates in the core of the reactor for 5 years at the designed temperature that is mostly greater than 500 °C. Therefore, the cladding tube is irradiated as well as thermally aged so that the aging effect on the mechanical property of HT9 is taken into account.

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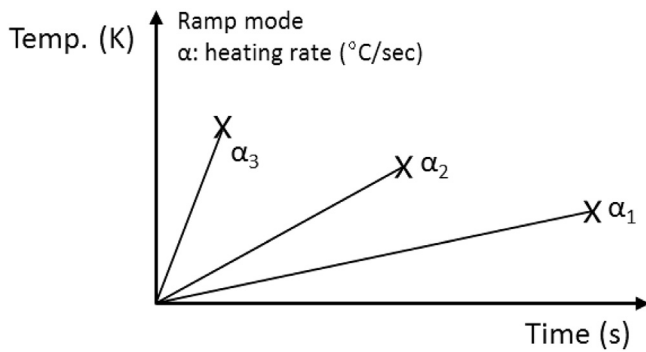


Fig. 1. Typical ramp test mode of a transient test.

The objective of this study is to evaluate the effect of thermal aging on the transient behavior of an HT9 cladding tube aged at 650 °C. Because the peak temperature of the cladding tube is 650 °C in a normal SFR system, previously, aging experiments have been conducted at 650 °C for 7000 h and tensile and rupture tests using the aged specimens have been performed at 650 °C [13]. In this study, the thermal aging and transient behavior are correlated using previously reported experimental data, and the transient behavior of the cladding tube after 7000 h of aging is estimated.

Furthermore, a modified Dorn parameter, which is used for calculating the failure time, is proposed for ensuring the safety margin of the reactor.

## 2. Experimental

For thermal transient events such as TOP and LOF, the designed transient tests were performed and a schematic of the test mode is shown in Fig. 1. A designed TOP test is referred to as a ramp test mode in which the temperature is increased until failure occurs. It considers various heating rates under a constant hoop stress. In KAERI, research regarding the FCCI and the ramp test and ramp & hold test is now individually carried out. The FCCI study is actively carried out [14] since we adopt a metallic fuel form such as U-10Zr. Also a part of combined test (FCCI-transient test) is carried out [15]. Depending only on the temperature profile, the ramp test is designed to simulate the TOP event in this study.

A schematic of the experimental set up of the designed transient test is shown in Fig. 2 (a). The experimental system consists of mainly two parts, namely, temperature and pressure control parts. The temperature is controlled by eight radiant heaters that are located around the specimen. A duralumin mirror in the outermost region of the heating system reflects and concentrates the heat onto the specimen. Three points of the spot-welded K-type

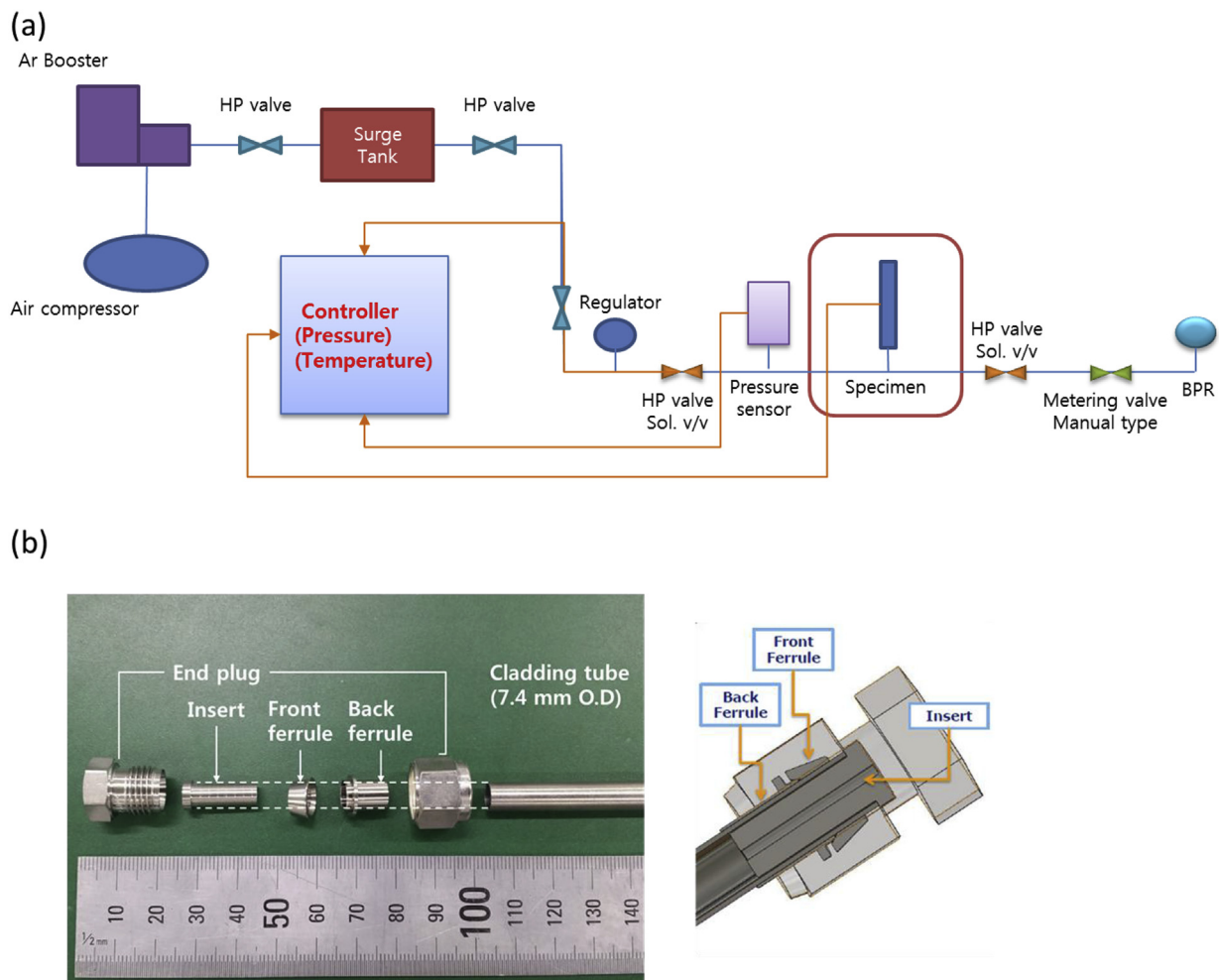


Fig. 2. (a) Schematic of the designed transient experimental system. The experimental system consists of mainly two parts, namely, temperature and pressure control parts. The temperature is controlled by eight radiant heaters that are located around the specimen. The internal pressure of the specimen is controlled by a solenoid valve, pressure sensor, and back pressure regulator. (b) The joining technique between the cladding tube and the end plug is shown. The insert, front and back ferrule is manufactured by an order production.

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