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Original Article

Influence of Dynamic Strain Aging on Tensile Deformation Behavior Of Alloy 617

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ABSTRACT

To investigate the dynamic strain aging (DSA) behavior of Alloy 617, high-temperature tensile tests were carried out with strain rates variations of 10^{-3}/s, 10^{-4}/s, and 10^{-5}/s from 24°C to 950°C. Five flow relationships, Hollomon, Ludwik, Swift, Ludwigson, and Voce, were applied to describe the tensile true stress–strain curves, and the DSA region was defined. In describing the tensile curves, Ludwigson's equation was superior to the other equations, and the DSA region was adequately defined by this equation as plateaus at intermediate temperatures from 200°C to 700°C. It was identified that Alloy 617 is dominated by three types of serrations, known as Types D, A+B, and C. The activation energy values for each serration type were obtained by the Arrhenius equation. By using the obtained activation energy values, the serrated yielding map and the DSA mechanism were drawn and manifested. In addition, the relationship between the tensile strength and strain rate at higher temperatures above 700°C was found to be closely related to the amounts of slip lines. In the scanning electron microscope (SEM) fractographs, there was a significant difference at the low, intermediate, and high temperatures, but almost the same to the three strain rates.

1. Introduction

A very high temperature reactor (VHTR) is currently being researched as one of the promising candidates for Generation IV (Gen IV) reactors to economically produce electricity and hydrogen [1]. A lot of aspects should be considered for developing this VHTR system because the goals are to achieve a highly economical, proliferation-resistant reactor with enhanced safety and minimal waste. The VHTR system consists of several major components such as a control rod system (CRS), a reactor pressure vessel (RPV), a hot gas duct (HGD), and an intermediate heat exchanger (IHX), as shown in Fig. 1. The IHX is designed with a life span of 60 years under operating conditions up to 950°C [1–5]. It is very crucial to choose an appropriate material which has superior

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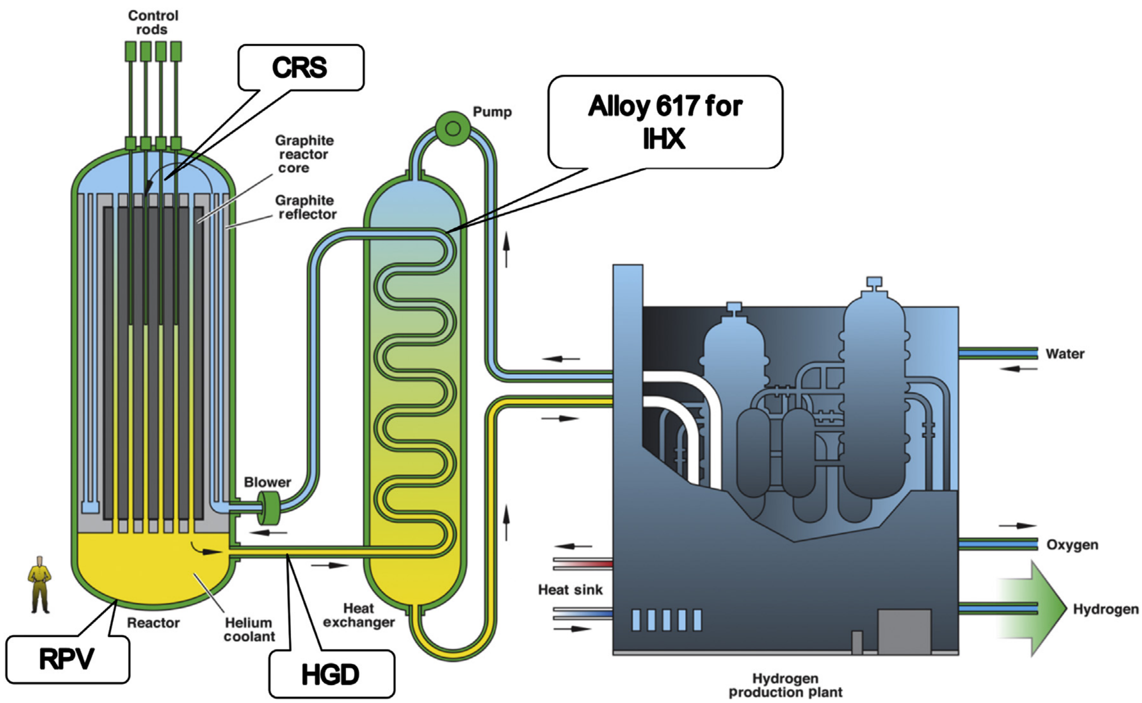

Fig. 1 – Schematic illustration of very high temperature reactor (VHTR). CRS, control rod system; HGD, hot gas duct; IHX, intermediate heat exchanger; RPV, reactor pressure vessel.

mechanical properties against severe temperature conditions for a long service time.

Nickel-based super-alloys have been proposed for use in VHTR components. Among these alloys, Alloy 617 is considered as one of the prime candidates for the IHX, due to its advanced mechanical properties [1–5]. Investigation into these mechanical properties should be carried out comprehensively for design and safety considerations, because a significant degradation of mechanical properties may occur due to a serrated yielding phenomenon in high-temperature environments [6,7]. This phenomenon results in strain localization that can affect crack initiation and propagation under upset conditions with sudden increases in applied mechanical stresses [8]. The serrated yielding is caused by a dynamic strain aging (DSA) or Portevin–Le Chatelier (PLC) effect, and is found in a uniaxial tensile load at particular temperatures and strain-rate conditions. The DSA effect is indicated by a nonuniform deformation which is controlled by diffusion. It results from the interaction between solute atoms and mobile dislocation, whereas the mobile dislocation is temporarily arrested by solute atoms in the slip path [9–11].

In this study, the DSA behavior of Alloy 617 under tensile stress–strain was investigated. A series of tensile data was obtained from the tensile tests at temperatures ranging from 24°C to 950°C with the three strain rates of 10^{-3}/s, 10^{-4}/s, and 10^{-5}/s. Five flow relationships, Hollomon, Ludwik, Swift, Ludwigson, and Voce, were applied to describe the tensile true stress–strain curves. The DSA region of Alloy 617 was defined, and its mechanism was discussed from the activation energy values, which were obtained by applying the Arrhenius equation. In addition, fracture microstructures were observed by optical microscope (OM) and scanning electron microscope (SEM).

2. Materials and methods

The raw material of commercial grade Alloy 617 (Haynes 617, hereafter Alloy 617) was a hot-rolled plate with a thickness of 15.875 mm (5/8 inch). Its chemical composition is listed in Table 1. The tensile-test specimens were fabricated in a cylindrical form with a 30-mm-gauge length and 6-mm diameter with stress axis in the rolling direction. All specimens were polished along a specimen axis by employing #1000-grit sand paper.

The tension tests were performed using a universal testing machine with a 100-kN capacity (model: RB Unitech-M, R&B Inc., Daejeon, Republic of Korea), and a screw-driven load frame at constant crosshead velocities corresponding to strain rates of 10^{-3}/s, 10^{-4}/s, and 10^{-5}/s. It must be noted that because the strain rates were determined from the original gauge length, the strain rates might have dropped as the specimen was extended during the testing. The tension loading of stresses was applied to a specimen using an AC servomotor type. The main components of apparatus were composed of a three-zone heating furnace, temperature controller, data acquisition system (PC and monitor), and program controller. The test temperatures were controlled within ±2°C and a thermocouple was attached to the gauge section of specimen. Microstructures of the fractured

Table 1 – Chemical compositions of Alloy 617 (wt. %).

C	Ni	Fe	Si	Mn	Co	Cr
0.08	53.11	0.949	0.084	0.029	12.3	22.2
Ti	P	S	Mo	Al	B	Cu
0.41	0.003	0.002	9.5	1.06	< 0.002	0.0268