Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

An Improved Methodology for Obtaining the Initial Loading Strain in Creep of Alloy 617

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1. Introduction

A very high temperature reactor (VHTR) is one of the most promising Gen-IV reactors for the economic production of electricity and hydrogen. Its major components are the reactor internals, reactor pressure vessel (RPV), hot gas ducts (HGD), and intermediate heat exchangers (IHX). Alloy 617 is a prime candidate material due to its superior creep resistance above 800°C to other potential superalloys [1,2]. Since the components are designed to be used over a 40 year lifetime at a high temperature, the isochronous stress-strain curves (ISSC) should be developed to avoid an excessive deformation of the materials during an intended service life because they are designed with a target life based on a specified amount of allowable strain and stress. However, the ISSCs for Alloy 617 were not developed although they were prepared in the ASME draft code case, which was insufficient for a design use.

In this study, the tensile elastic and plastic strains corresponding to the initial loading strain in creep were determined using an improved method in addition to the RCC-MR code and Blackburn's methods, and their results were compared and discussed.

2. Methods and Results

2.1 Overview and an improved method

For a design application of high-temperature materials, it is necessary to construct the ISSCs, which can be developed using Young's modulus, average tensile hardening rule and creep strain laws. The strain used in the ISSC is total strain, ε_{tot}, given as

$$\varepsilon_{tot} = \varepsilon_{el} + \varepsilon_p + \varepsilon_c \qquad (1)$$

where ε_{tot} is the total strain as a % corresponding to stress σ, ε_{el} is the elastic strain (%), ε_p is the plastic strain (%), and ε_c is the creep strain (%). The elastic and plastic components can be derived, as follows [3, 4]. Hence, this study does not deal with the strain of creep component.

The elastic strain in percentage is calculated using the following formula,

$$\varepsilon_{el} = \sigma / E \times 100 \qquad (2)$$

where E is Young's modulus in MPa. To determine the plastic strain, two methods are introduced and a new method is proposed as follows.

First, for the RCC-MR code method, the plastic strain can be derived from the tensile work hardening equation given by the formula as follows [3].

$$\varepsilon_p = D\,(\sigma / \sigma_y)^m \qquad (3)$$

where σ_y is the average yield strength at a 0.2% offset, ε_p is the plastic strain induced by stress σ, and D and m are material constants. The plastic strain is limited to 1.5% in the above equation for the purpose of calculation of the design curves.

Then, for the Blackburn's method, the elastic strain is identically obtained by Eq. (2). The Blackburn's equation can be derived from the tensile work hardening equation given by the following formula [5].

$$\varepsilon_p = D_1(\sigma - \sigma_p)^{m_1} \quad (\text{for } \sigma \geq \sigma_p) \qquad (4)$$

where ε_p is the plastic strain induced by stress σ, and D_1 and m_1 are the material constants. Also, σ_p is the true stress at the proportional elastic limit.

Finally, a new method is herein suggested to obtain the tensile plastic strain. The equation is a modification of Eq. (3) used in the RCC-MR code. Similarly, the plastic strain is derived from the tensile work hardening equation given as,

$$\varepsilon_p = D_2\,(\sigma / \sigma_p)^{m_2} \quad (\text{for } \sigma \geq \sigma_p) \qquad (5)$$

where ε_p is the plastic strain induced by stress σ, and D_2 and m_2 are material constants, which are determined from the tensile test dada. Also, σ_p is the true stress at the proportional elastic limit. The stress term in the equation uses the proportion elastic limit instead of the 0.2% offset yield stress used in the MCC-MR code. It can be regarded as a useful equation because the experimental σ_p values often have been used as a material parameter in the evaluation and analysis of high-temperature materials. Eqs. (3), (4), and (5) were applied to Alloy 617.

2.2 Application results of three methods

To obtain the initial loading strains in creep of Alloy 617, the tensile elastic and plastic strains corresponding to the initial loading strains in creep were used. The tensile curves were obtained from the tensile tests at the temperatures of 800°C, 850°C, 900°C, and 950°C of Alloy 617. The Young's modulus, 0.2% offset yield stress σ_y, proportional elastic limit σ_p, and ultimate tensile stress (UTS) were determined at each temperature, as listed in Table 1. Hence, it is noted that the values of Young's modulus referred to an Inconel 617 (brand name) brochure provided by Special Metals. The materials constants D, m, D_1, and m_1 were determined graphically from the slope and intercept on the plots of the log stress (σ/σ_y, σ-σ_p, and σ/σ_p) against the log strain (ε_p) in Eqs. (3), (4), and (5). The summary is listed in Table 2.

Table 1. Material properties obtained for Alloy 617

Temp. (^{o}C)	E (MPa)	Yield Stress, σ_y (MPa)	Proportional Elastic Limit, σ_p (MPa)	UTS (MPa)
800	157000	259.2	242.0	327.0
850	153000	212.8	181.0	235.5
900	149000	168.9	139.3	190.7
950	144000	132.3	107.3	148.7

Table 2. Material constants determined for Alloy 617

Temp. (^{o}C)	RCC-MR		Blackburn		New method	
	D	m	D_1	m_1	D_2	m_2
850	0.01347	10.055	1.33E-06	2.573	2.28E-03	9.44
850	0.01347	10.055	1.33E-06	2.573	3.23E-03	9.06
900	0.00748	11.700	9.01E-08	3.250	9.07E-04	11.37
950	0.00350	15.662	2.19E-09	4.343	2.78E-04	13.37

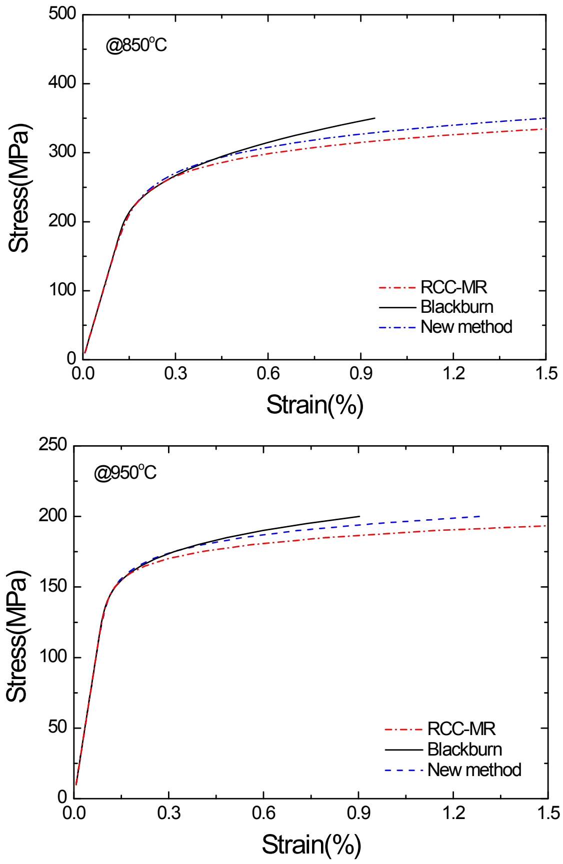

Fig. 1. Comparisons of three methods for typical stress-strain curves calculated at 800°C and 950°C

In the calculation of the equations, the stress ranges were properly considered for 10 to 450MPa. The final results of the stress-strain (elastic+plastic) curves, which were obtained using the three methods at 800 °C, 850°C, 900°C, and 950°C, and typical results at 850°C and 950°C are shown in Fig. 1.

In the elastic regime, the three methods were identical, and in the plastic regime, the Blackburn's equation was higher in the stress-strain curves than the RCC-MR code. The new method is better because it lies midway between the two methods. However, it is suggested that the three methods can be utilized to calculate the elastic and plastic strain of Alloy 617, because the general creep conditions at 800°C, 850°C, 900°C, and 950°C of Alloy 617 correspond to a lower elastic regime under the plastic regime.

3. Conclusions

The tensile elastic and plastic strains corresponding to the initial loading strain in creep were determined using the RCC-MR, Blackburn, and a new method. The tensile properties were obtained from the tensile tests performed at 800 °C, 850°C, 900°C, and 950°C of Alloy 617. In the elastic regime, the three methods were identical, and in the plastic regime, the Blackburn's equation was higher in the stress-strain curves than the RCC-MR code. The new method was better because it lies midway between the two methods. However, it is suggested that the three methods can be utilized to calculate the elastic and plastic strain of Alloy 617, because the general creep conditions at 800°C, 850°C, 900°C, and 950°C of Alloy 617 correspond to a lower elastic regime rather than the plastic regime.

Acknowledgements

This study was supported by the Korean Ministry of Education, Science & Technology through its National Nuclear Technology Program.

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