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Creep rupture behavior of semi-solid cast 7075-T6 Al alloy

N. Mahathaninwong [a], Y. Zhou [a], S.E. Babcock [b], T. Plookphol [a], J. Wannasin [a], S. Wisutmethangoon [c,*]

[a] Department of Mining and Materials Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand
[b] Department of Materials Science and Engineering, College of Engineering, University of Wisconsin-Madison, Wisconsin 53706, USA
[c] Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand

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ABSTRACT

The creep rupture behavior of semi-solid cast 7075-T6 Al alloy produced by the Gas Induced Semi-Solid (GISS) process was investigated and compared to that of commercial 7075-T651 Al alloy. The semi-solid cast 7075-T6 Al alloy displayed lower minimum creep rate and longer creep rupture time than the commercial 7075-T651 Al alloy. On the basis of their stress exponent, n, values of 6.3, dislocation creep was seemingly the predominant mechanism controlling the creep deformation of both alloys. The creep rupture time of the semi-solid cast 7075-T6 Al alloy was distinctly longer than that of the commercial 7075-T651 Al alloy at stress regimes of 120–140 MPa. This difference was attributed to the lower precipitate coarsening and higher precipitate density in the semi-solid cast alloy. Creep cavities predominately controlled the creep rupture of the semi-solid cast 7075-T6 Al alloy despite the appearance of precipitate coarsening. The commercial 7075-T651 Al alloy creep rupture behavior was controlled by the combination of rapid precipitate coarsening and creep cavities. However, de-cohesion between insoluble particles and the matrix is evidently accelerated with increasing stress to 180 MPa, leading to cavity propagation and resulting in the convergence of creep rupture time in the semi-solid cast 7075-T6 Al alloy to that of the commercial 7075-T651 Al alloy.

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1. Introduction

Creep resistance is one of the properties required for use of materials in high temperature applications [1]. Creep results from a combination of temperature and stress variable effects. The minimum or secondary creep rate, creep life, and creep strain are evaluated for accessing creep performance. Creep resistance of precipitate hardenable alloys can be enhanced by dispersions of fine precipitates as they provide effective obstacles to dislocation movement [2,3].

Wrought 7075-T6 Al alloy is a precipitation-hardened alloy that possesses excellent mechanical properties at temperatures between 25 and 100 °C. Its tensile strength sharply decreases with increasing temperature at temperatures above 100 °C [4], however. For example, the tensile strength of commercial 7075-T651 Al alloy decreases from 598 MPa at 25 °C to 297 MPa at 200 °C [5]. Microstructure stability enhanced creep resistance of 7075 Al alloy has been achieved by addition of Zr, which forms small precipitates of Al_3Zr as a stable dispersoid phase [6]. In contrast, precipitate coarsening that occurs during creep of 7010 Al alloy, which has a composition similar to 7075 Al alloy, leads to a loss in creep strength [7]. Rapid precipitate coarsening occurs together with loss of coherency when the alloy is used under high temperature applications [2,3]. Similarly, over-aged precipitates in Al–Zr alloys also result in creep resistance loss [8]. Therefore, finely-dispersed precipitates obtained through an optimum T6 heat treatment yield a possibility to increase creep resistance for precipitation hardening alloys. The creep properties of wrought 7075 Al alloy have been widely studied [9–12]. This study examined the creep properties of semi-solid cast 7075 alloy that was produced by a novel Gas Induced Semi-Solid (GISS) process and processed via the optimum T6 heat treatment to induce finely-dispersed precipitates. It showed its creep properties to be superior to commercial 7075-T651 Al alloy.

The development of the GISS process to produce semi-solid cast 7075 Al alloy is described in Ref. [13]. Optimum T6 heat treatment conditions for the alloy were determined and the tensile properties of the alloy were found to be lower than that of commercial 7075-T651 Al alloy [14]. The present work explored the creep properties of semi-solid cast 7075-T6 Al alloy produced by the GISS process. The investigation focused on the creep rupture behavior of the alloy and the microstructure prior to and after testing to gain a better understanding of the mechanisms governing this behavior. The Creep rupture characteristics of commercial 7075-T651 Al alloy were examined in parallel for comparison.

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* Corresponding author. Tel.: +66 81 6781243; fax: +66 87 4287195.
E-mail address: sirikul@me.psu.ac.th (S. Wisutmethangoon).

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2. Experimental methods

The semi-solid cast 7075 Al alloy was prepared through the GISS process by introducing gas bubbles to the molten alloy at a temperature of 643 °C for 7 s and holding it for 30 s before squeeze-casting at a pressure of approximately 80 MPa. These alloy samples were cast as square plates of dimensions 100 × 100 × 15 mm. The as-cast plates were cut into small samples with dimensions of 15 × 100 × 15 mm and processed through the optimized T6 heat treatment. Specifically, these samples were solution heat treated at 450 °C for 4 h, quenched in 25 °C water, and then artificially aged at 120 °C for 72 h. These samples are referred to as "semi-solid cast 7075-T6 Al alloy" through the rest of this report. The commercial 7075-T651 Al alloy used in the present work was obtained as 12.7 mm-thick rolled plates in the T651 condition, solution heat treatment at 480 °C, cold stretched by 3%, and aged at 120 °C for 24 h. The chemical compositions of the alloys shown in Table 1, were determined by Optical Emission Spectroscopy (OES) after casting the SSM alloy and prior to measuring the commercial alloy.

The alloy samples were machined into dumbbell shaped test samples with a gage length of 25 mm and a gage section diameter of 5 mm for creep testing. All creep tests were performed in a custom-built lever-beam type creep test device developed by Zhou [15] and shown in Fig. 1(a). The specimen was fitted align the middle of the furnace as shown in Fig. 1(b) and (d). The specimen temperature was determined to a precision of ±1 °C using a thermocouple attached to the center of the gage section and a digital temperature meter. The elongation of the specimen was detected and recorded using a linear variable differential transformer (LVDT) to measure the displacement of the reference rod. The reference rod was connected to the lever plate, which, inturn, was attached to the sample (Fig. 1(c) and (d)). The pull rod connected the sample to the load. Creep rupture tests were performed in air under a constant load condition at initial stresses ranging from 120 to 180 MPa and a temperature of 200 ± 1 °C. Prior to loading, the creep specimens were preheated to 200 °C at a ramp rate of 4 °C/min, the maximum allowed by the furnace design, and held at temperature for 15 min.

Table 1
Chemical composition of the semi-solid cast 7075-T6 Al alloy (SSM) and the commercial 7075-T651 Al alloy (Commercial) in %wt.

Elements	Zn	Mg	Cu	Fe	Si	Cr	Mn	Al
SSM	6.08	2.50	1.93	0.46	0.40	0.19	0.03	Bal.
Commercial	5.92	2.64	1.70	0.19	0.07	0.19	0.04	Bal.

The microstructure was characterized by using a combination of optical microscopy (OM), scanning electron microscopy (SEM), energy dispersive X-ray spectrometry (EDS) in the SEM, and transmission electron microscopy (TEM). For optical and scanning electron microscopy examinations, specimens were ground and polished using standard metallography methods. In order to prepare TEM specimens, each specimen was machined into a 3 mm diameter rod. This rod was then sliced into approximately 0.8 mm thick disks using a low speed diamond saw. Both sides of the disks were mechanically polished with 1200-grit SiC and 5 μm micro-polishing alumina powder, leaving a sample that was then 40–60 μm thick. These thin disk specimens were then electropolished in a Tenupol-3 electropolisher with a solution of 20–25 vol% nitric acid and 80–75 vol% methanol from −15 to −20 °C and an applied current of 1.2–1.5 A.

3. Results and discussion

3.1. Microstructure of the alloys prior to creep testing

Fig. 2 shows the microstructure the semi-solid cast 7075-T6 Al alloy and the as-obtained commercial 7075-T651 Al alloy revealed on the polish cross-section of the samples prior to creep testing. Longitudinal cross-sections aligned along the gage length are show in both cases. Insoluble second-phase particles that formed during the forming process and remained through the solution heat treatment, were observed in the microstructure of both alloys. The semi-solid cast 7075-T6 Al alloy contained insoluble second-phase particles with dimensions of 5–65 μm and area fractions of 0.93%. In contrast, the particle fragments are smaller with dimension in the range of 2–15 μm and area fraction of 0.55% in the commercial 7075-T651 Al alloy, where they aligned as stringers in the rolling direction. Al_7Cu_2Fe, $Al_{23}CuF_{e4}$, Al_6Fe, and Mg_2Si particles have been observed in 7075 Al alloy in other studies [12,16–18]. EDS analyses of the samples used for

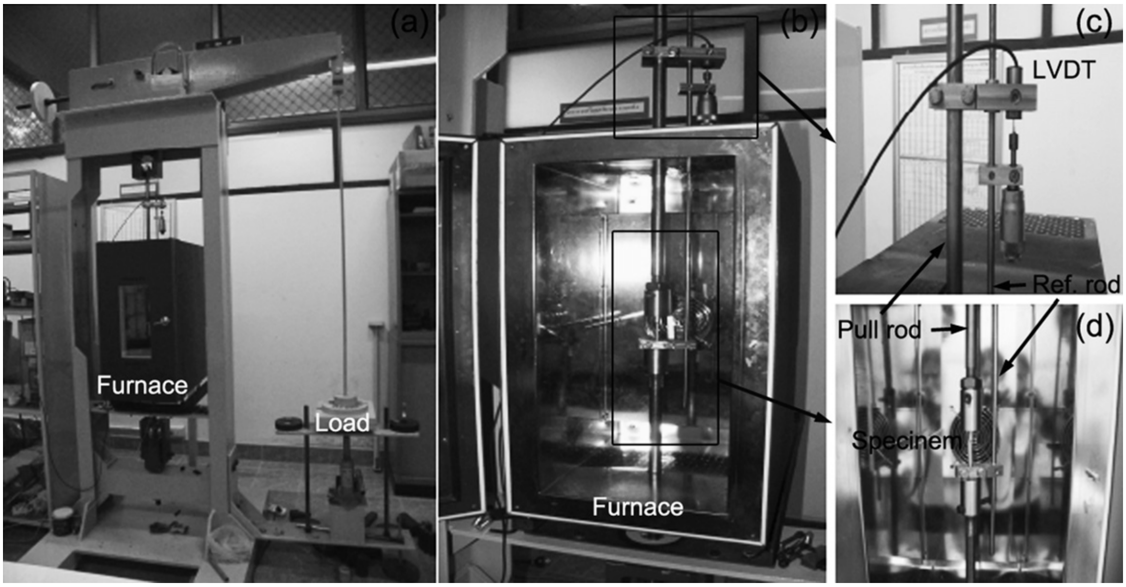

Fig. 1. Creep machine.

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