CREEP CRACK GROWTH IN RAPIDLY SOLIDIFIED ALUMINUM ALLOY 8009

A. Saxena and K. A. Jones
School of Materials Science and Engineering
Mechanical Properties Research Laboratory
Georgia Institute of Technology
Atlanta, GA 30332-0245, USA

Abstract

Creep deformation and creep crack growth tests were conducted on a rapidly solidified aluminum alloy 8009 to evaluate the suitability of crack tip parameters such as the stress intensity parameter, K and the C_t-parameter for characterizing creep crack growth behavior. It is shown that at 316°C, the initial creep crack growth is characterized by C_t and it is characterized by K in the later portions of the test. The switch in the crack tip parameter for characterizing creep crack growth is accompanied by the establishment of a steady-state damage zone ahead of the crack tip consisting of creep cavities which nucleate at the dispersoids introduced in this material for strengthening.

Introduction

Rapidly solidified dispersion strengthened aluminum alloys (RSAA) are thermally stable at temperatures in excess of 300°C and are therefore candidate materials for high temperature structural applications[1,2] in which the creep and the creep crack growth behavior is of considerable interest.

Fracture mechanics based test methods and life prediction methodology are well developed for creep-ductile materials (creep ductility in excess of 10%)[3]. In these materials, creep crack growth is accompanied by significant creep deformation and the crack tip parameters which characterize the rates of crack growth are well established[3]. In creep-brittle materials (creep ductility on the order of 1-2 percent or less), the crack tip stress is significantly influenced by the growing crack and parameters based on the assumption that the crack tip is stationary are no longer meaningful. This limitation opens the question whether C_t or C^* can be used to characterize creep crack growth in such materials. The purpose of the research reported in this paper was to explore the limits of C_t/C^* and the stress intensity parameter, K, for characterizing the creep crack growth in 8009 Al alloy and to study the mechanisms of creep deformation and crack growth in these materials.

Materials and Specimens

The 8009 Al alloy (also known as FVS0812) has a chemical composition consisting of 8.5% Fe, 2.3% V and 1.7% Si Alloys of this composition are first rapidly solidified (cooling rates in excess of 10^5K/sec) by a planar flow casting method[4] to produce thin strips, 25μ thick. These strips are then pulverized into a powder, degassed and vacuum hot pressed into billets with about 95% density. The billet is then extruded into the final shape. In this case, the extruded thickness was 43mm of which the top and bottom 6.25mm were machined to provide a strip that was 30.5mm thick. The resulting microstructure consists of ultrafine grain size (1μ diameter) from the rapid solidification and an even distribution of dispersoids ranging in size from 30 to 80nm[4]. The dispersoids are a cubic quaternary intermetallic, $Al_{12}(Fe,V)_3Si$ which resists coarsening at temperatures less than 400°C. Therefore, the microstructure is very stable up to those temperatures.

Standard compact type specimens which were 25.4mm wide were machined in the L-T orientation and several cylindrical tensile and creep specimens were machined in the longitudinal orientation. These specimens were 2mm in diameter and 10mm in gage length. The tensile tests were performed in accordance with the ASTM standard E8-90[5], the creep deformation tests in accordance with ASTM Standard E139-83[6] and the creep crack growth tests in accordance with ASTM standard E1457-92[7]. All mechanical testing was conducted at 316°C.

The fracture surfaces of the tested compact type and creep rupture specimens were analyzed to characterize the creep cavity growth and coalescence phenomena.

Results and Discussion

The 0.2% yield strength of the test material at 25 and 316°C was 295 and 180 MPa, respectively and the ultimate tensile strength was 27.3 and 195 MPa, respectively at those same temperatures. The percent elongation to fracture was approximately 12 to 13 percent at both temperatures.

Creep Deformation and Rupture

The creep deformation behavior at 316°C and stress levels of 85.5, 100.6 and 107.0 MPa is shown in Fig. 1. The 85.4 MPa test was terminated after a steady-state creep rate was established while the other two tests were continued till rupture. The creep ductility was less than 2% in the ruptured specimens which characterizes the material as being creep-brittle. There is also significant primary creep strain present in all creep tests. Figure 1 also shows creep test results from a specimen taken from a different lot (lot II) of Al 8009 which was produced with a different thermal-mechanical treatment. The creep behavior of this specimen was quite different in comparison to those from Lot I. The Lot II was significantly more creep resistant. This lot to lot variability is a concern in comparing our results from the earlier creep crack growth data reported by Leng, et. al.[8]. It appears that the material used in the latter study was from Lot II while all our creep crack growth tests were performed on the material from Lot I.

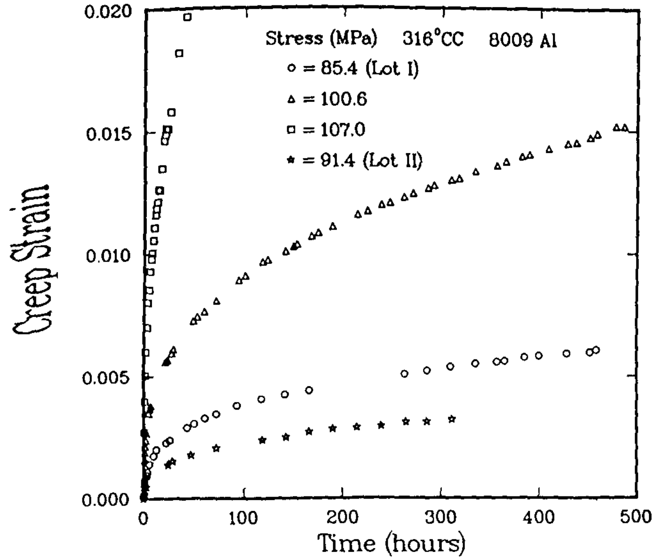

Fig. 1 - Creep Strain as a function of time at various stress levels

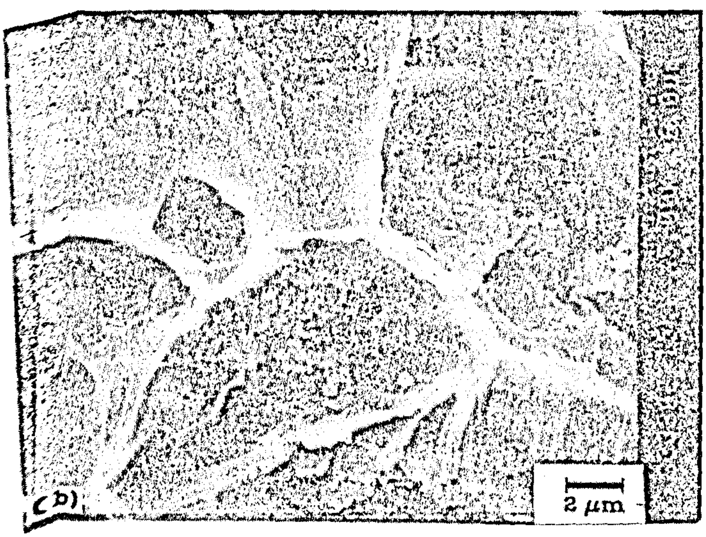

Fig. 2 - Creep cavities on the fracture surface of a creep rupture specimen tested at a stress of 101.6 MPa

Another observation from the creep data is the extreme sensitivity of creep rates to small variations in stress. The stress exponents for describing the secondary creep rates were on the order of 50 to 60. A possible explanation is as follows.

Alloy 8009 is a dispersion strengthened material with an aluminum matrix. When the specimen is loaded at elevated temperature, the creep rates in the Al matrix are expected to be much higher than in the dispersoids. Therefore, decohesion between the Al matrix and the dispersoids will occur resulting in the matrix carrying a higher fraction of the applied stress. Thus, a relatively small increase in nominal stress on the specimen translates into a larger increase in stress on the Al matrix because of the high volume fraction of the dispersoids. Thus, the dependence of strain rate on stress is expected to be high. Figure 2 shows a SEM fractograph from the creep specimen tested at 101.6 MPa showing the creep cavities supporting the above argument. The final cavity sizes decreased with increasing stress and also cavities did not nucleate and grow on each dispersoid. This is expected to be a stochastic process because formation of a cavity is expected to redistribute the stress and suppress the formation of other cavities in its vicinity. Also, a higher stress will tend to nucleate more cavities thus the final cavity sizes are expected to be small because rupture occurs when neighboring cavities grow and coalesce.

Creep Crack Growth

Creep cracks in alloy 8009 grow by nucleation, growth and coalescence of creep cavities as seen in Fig. 3. This figure shows the crack tip region of an interrupted creep crack growth specimen. Figure 4 shows a typical fractograph from a creep crack growth specimen showing cavitation features similar to those of the creep rupture specimen confirming that the crack growth mechanism is by creep. Figure 5 shows a plot of the cavity diameter as a function of creep crack extension for several specimens. The trend in each case was an initially increasing cavity size which reaches a maximum value and subsequently decreasing size with further crack extension.

Figures 6 and 7 show that the creep crack growth rates as a function of the stress intensity parameter, K, and the C_t parameter, respectively. Both figures also include data from two specimens tested at 150°C. This alloy exhibits a ductility minima at 150°C[8], therefore, these tests were conducted to briefly examine this phenomenon. It was observed that the rupture times of CT specimens were much shorter at 150°C compared to 316°C for tests initiated at the same K levels as expected if ductility decreases at 150°C. In this paper, we will focus primarily on the results from the 316°C tests with temperature effects being will be the subject of a future paper.

The da/dt versus K behavior shows little correlation. All tests show decreasing crack growth rates initially followed by increasing crack growth rates. The minima in crack growth rate coincides with the crack extension at which the creep cavities attain a maximum value. These results point to a relaxing stress field due to creep deformation being present during the initial portion of the tests. A decreasing crack growth rate and an increasing cavity sizes are both consistent with this conclusion. It then follows that during the initial period, the crack growth rate should correlate with C_t. This trend is in fact observed in Fig. 6 where the initial portions of the test are in the high crack growth rate region. During the later portion of the tests, no

Fig. 3 - Creep cavitation damage in front of a growing creep crack

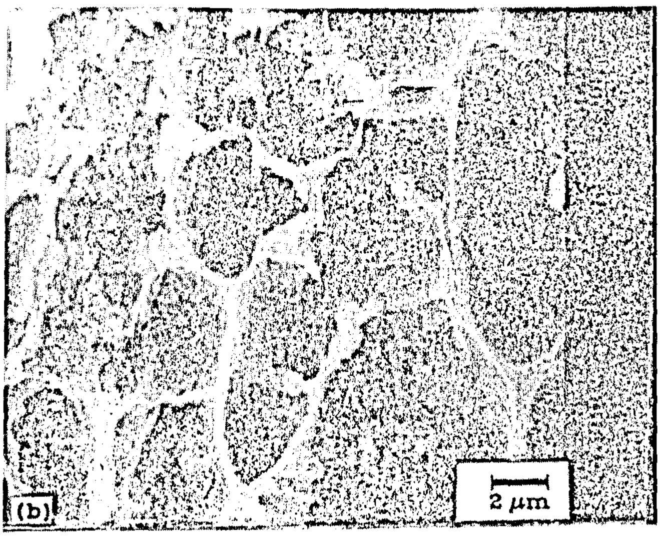

Fig. 4 - Creep cavitation on the fracture surface of a creep crack growth specimen

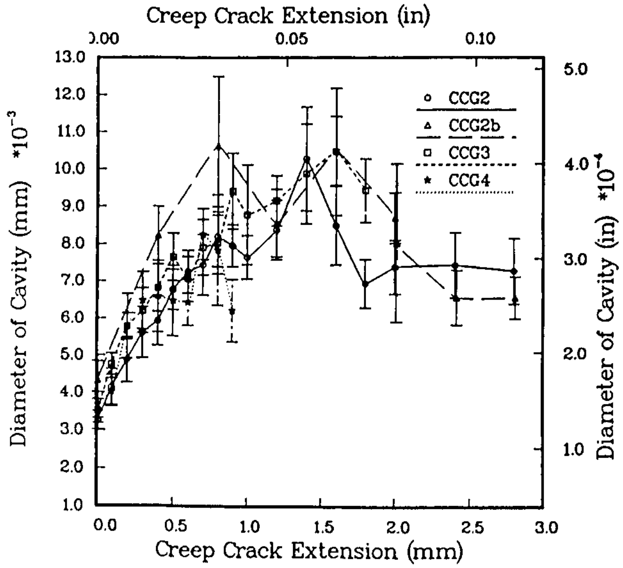

Fig. 5 - Creep cavity diameter as a function of crack extension for various creep crack growth specimens

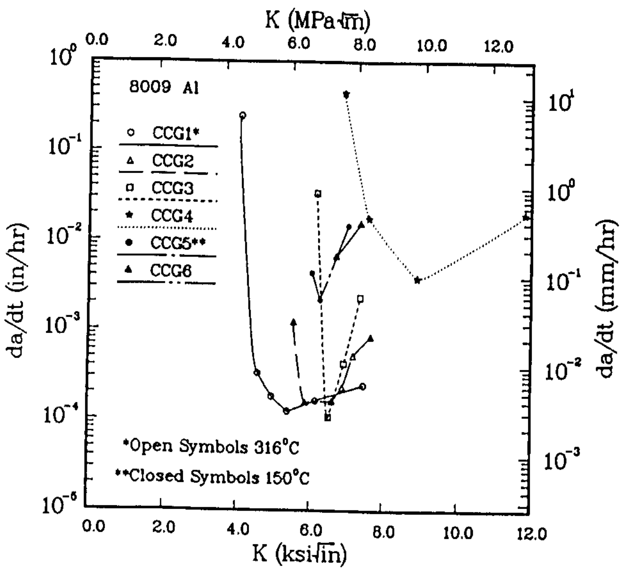

Fig. 6 - Creep crack growth rate (da/dt) versus the stress intensity parameter, K

correlation is observed between da/dt and C_t. However, plotting the data from the later portion of the test (after attainment of minima is da/dt values) shows good correlation between da/dt and K, Fig. 8. We can then conclude that after an initial period of transient crack tip stresses due to a growing creep zone size, a steady-state condition is reached during which the da/dt correlates with K. Thus, both K and C_t are relevant crack tip parameters for characterizing the creep crack growth behavior in Al alloy 8009 at 316°C. Further tests are recommended to study this trend in more depth.

Summary and Conclusions

1. Creep deformation rates in Al alloy 8009 at 316°C are highly sensitive to increases in stress.

2. Creep crack growth in alloy 8009 occurs by growth and coalescence of creep cavities which nucleate at the dispersoids.

3. The creep crack growth rates during the first 1.5mm of crack extension appear to correlate better with C_t and the subsequent crack extension with K at 316°C.

4. The transient period of crack extension characterized by C_t is also characterized by a rapidly changing creep cavity diameter. The cavity diameter changes much less significantly when steady-state conditions are reached and the creep crack growth rates are characterized by K.

Acknowledgements

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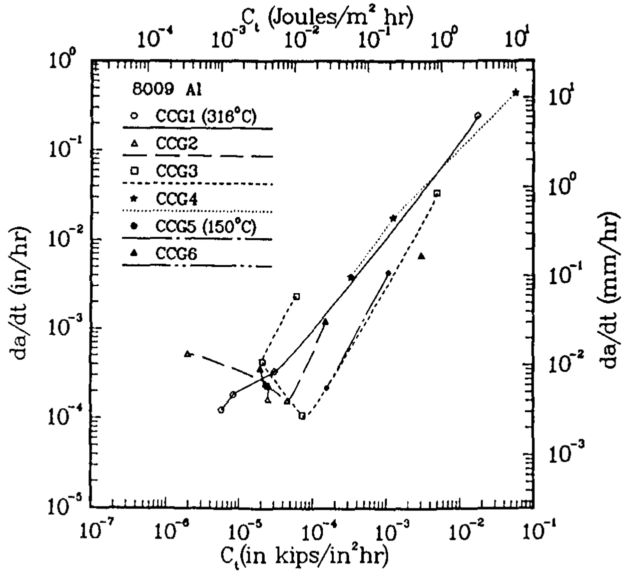

Fig. 7 - Creep crack growth rate as a function of the C_t parameter

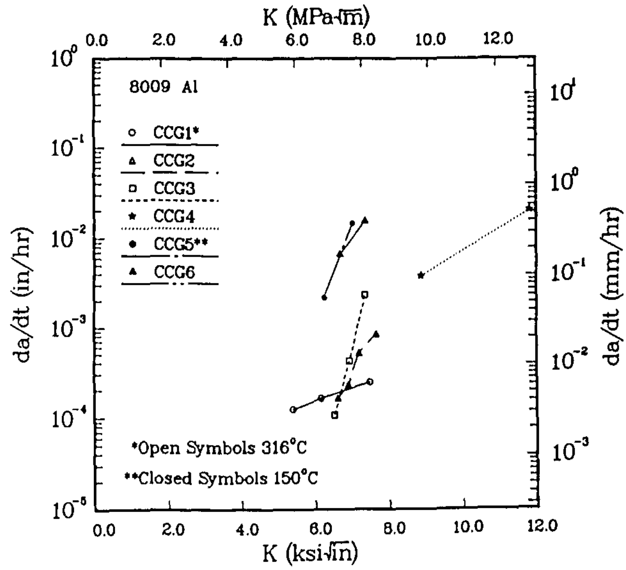

Fig. 8 - Creep crack growth rate from the portion of the test beyond minimum da/dt as a function of K