EFFECT OF EXTRUDING TEMPERATURE ON CREEP BEHAVIOR OF SPRAY-FORMING PROCESSED Al-8wt%Fe ALLOYS

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ABSTRACT Tensile creep tests were performed at 573K under constant stress conditions of 60 ~100MPa in an Al-8wt%Fe alloy, which was rapidly solidified and subsequently extruded at three different extruding temperatures, 573K, 673K, and 773K. The effect of extruding temperature on creep rate of the alloy was examined. Tensile tests were also conducted at 573K. No significant effect of extruding temperature was observed either on tensile properties nor on hardness values at room temperature, while the specimen extruded at 773K exhibited smaller creep rates in the entire range than those extruded at 573K and 673K. The SEM observation of as-extruded specimens showed no difference in the size and distribution of intermetallic compounds (Al_3Fe). The TEM observation revealed that matrix grain size was very fine (about 1 μm) and dislocation density was relatively low in the matrix.

Keywords: *Al-8wt%Fe alloy, spray-forming, extrusion temperature, creep, TEM*

1. INTRODUCTION

Aluminum alloys have been used for the aerospace and automotive applications which require both lightness and strength. Strengthening of the aluminum alloys are generally achieved by precipitation hardening. This procedure is not necessarily sufficient for the practical use of the aluminum alloys at elevated temperature. Improvement of high temperature strength is an important problem to be solved for the aluminum alloys.

Recent advances in rapid solidification processing have succeeded in developing new aluminum alloys having superior strength at elevated temperatures. An example is the powder metallargy-processed (P/M) Al-Fe alloys. The alloys containing about 8~12wt% Fe exhibit characteristic microstructure with thermally-stable intermetallic compounds dispersed in the Al matrix whose grain size is as fine as dispersoids.

There are some reports on the mechanical properties of the Al-Fe alloys and these alloys have good strength at 573K[1,2]. Although there are some works tried to explain the improved high temperature strength in terms of dispersion hardening[3], the responsible deformation mechanism has not been presented yet. It is known that the strength of Al-Fe binary alloys increase by addition of rare metals such as vanadium and cerium[4,5]. But this effect is evident at relatively low temperatures.

For fabrication of the rapidly solidified Al-Fe alloys, extrusion at elevated temperature is indispensable. When the hot extrusion is performed in the neighborhood of 673K corresponding to $0.7T_m$ of aluminum, the hot extrusion process should affect the microstructure and hence strength of the alloys. But few works have been done concerning the effect of hot extrusion conditions, in paticular, hot extrusion temperature.

In this study, tensile creep properaties were investigated at 573K on the Al-8.3wt%Fe alloys. The alloys rapidly solidified by spray-forming process were extruded at three different temperatures, 573K, 673K and 773K.

2. EXPERIMENTAL

The alloy used in the present study was fabricated at Sumitomo Light Metal Industries,Ltd. using the spray-forming process. This is the direct method to produce a large billet by rapid cooling melt from the alloy. Cooling rates achived by this process is, however, somewhat slower (about 10^2 K/sec) than other rapid-cooling processes. Nevertheless, the product (billet) is so large that we can obtain a number of specimens from the same billet. The chemical analysis showed the billet to contain 8.30% Fe, 0.10% Si, less than 0.01% Cu and Al the rest in weight. The billet was divided into several smaller cylindrical billets. The billets were heated upto three differernt temperatures, 573, 673 and 773K using an induction furnace, and were hot extruded into a cylindrical rod with a reduction ratio of 1:10. The extruding speed was 1m /min. The total time required for the initial heating and the successive extruding was about 10 minutes. The extruded bars were air-cooled to room temperature.

Cylindrical tensile specimens with 6 mm in diameter and 30 mm in gage length were machined from the extruded bars, to have the tensile axis parallel to the extrusion direction. Tensile creep tests were conducted at 573K in air under a constant stress condition in the range of 60～120 MPa. Test temperature was controlled carefully using two thermocouples in contact with the specimen. Displacement was measured by the extensometer equipped with a pair of linear voltage differential transducers. High temperature tensile tests were carried out at 573K using the Instron-type testing machine at various constant crosshead speeds. The resultant initial strain rate ranged from 3×10^{-6} to 1×10^{-3}/s. The tensile tests were also performed at room temperature at the initial strain rate of 1.41×10^{-4}/s.

Microstructural observation was performed using a scanning electron microscope (SEM) and transmission electron microscope (TEM) both for as-extruded and creep-raptured specimens. The samples were cut parallel to the extrusion, namely the tensile direction. For the SEM observation the samples were chemically polished using 0.5% HF. Thin foils for TEM observation were prepared by standard electropolishing techniques using a solution of 10% Perchloric Acid in methanol at 243K.

3. RESULTS AND DISCUSSION

3.1 Tensile deformation behavior at 573K

The effect of extrusion temperature on the room-temperature tensile strength was examined using as-extruded specimens at 773K and 573K. The average UTS value was about 260 MPa and no siginificant difference was observed between the two extrusion temperature conditions. Vickers hardness test results also suggested no significant difference between them. For the tensile tests at 573K, the stress-strain response was as follows: Following an elastic region, short strain-hardening region was observed in the beginning of plastic deformation. After that, steady-state deformation started and continued to failure. Figure 1 shows logarithm of initial strain rate ($\dot{\varepsilon}$) plotted against the steady state stress (σ). The specimens extruded at 773 K exhibited higher steady-state stress than those extruded at 573K. Both data for the specimens extruded at 773K and at 573K fall on the lines with a similar slope. This result implies that deformation mechanism is similar for the two specimens extruded at different temperatures.

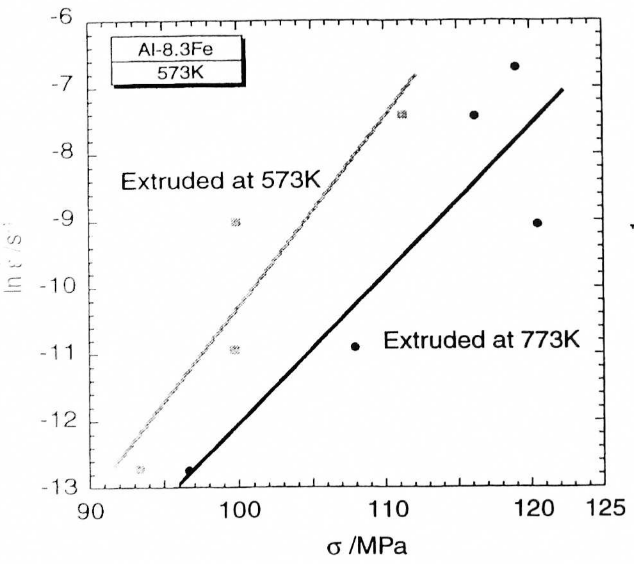

Fig. 1 Relation between initial strain rate and steady state stress at 573K for the specimens extruded at 573K and 773K.

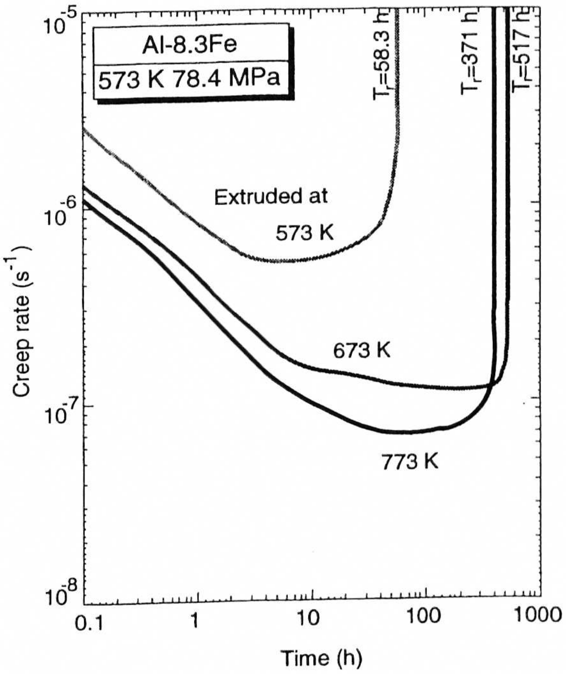

Fig. 2 Typical creep rate vs time curves obtained at 573K for specimens extruded at 573K, 673K and 773K.

3.2 Effect of extrusion temperature on creep behavior

Typical creep rate vs time curves at 573K, under 78.4 MPa are shown in logarithmic scale in Fig. 2. Following the long primary creep regions, creep rate reaches minimum value for all of the three specimens extruded at 573, 673 and 773K. So called steady state creep region is not apparent.The creep rate started to increase after the short period of minimum creep rate and continued to failure.

Obviously, the specimen extruded at higher temperature exhibited smaller creep rate in the entire region. The minimum creep rate of the specimen extruded at 773K is, thus, one tenth of that extruded at 573K.

Creep tests were performed under different stress conditions. The minimum creep rate is plotted against the applied stress in Fig. 3. Data from the tensile tests at 573K are also shown by broken lines in the figure. The creep data in Fig. 3 appear to fall on two lines. The apparent stress exponent is found to be about 13 and 17 for the specimens extruded at 573 and 773K, respectively. The large stress exponent values has generally been obtained in the P/M dispersion hardened alloys[6]. Neither threshold stress nor transient stress is noted in the stress region of 60～120 MPa used in the present study. These results show that higher extrusion temperature is advantageous for high temperature creep, and the superiority is more evident under the lower stress conditions. The tensile test results shown by broken lines also supportes the above mentioned superiority.

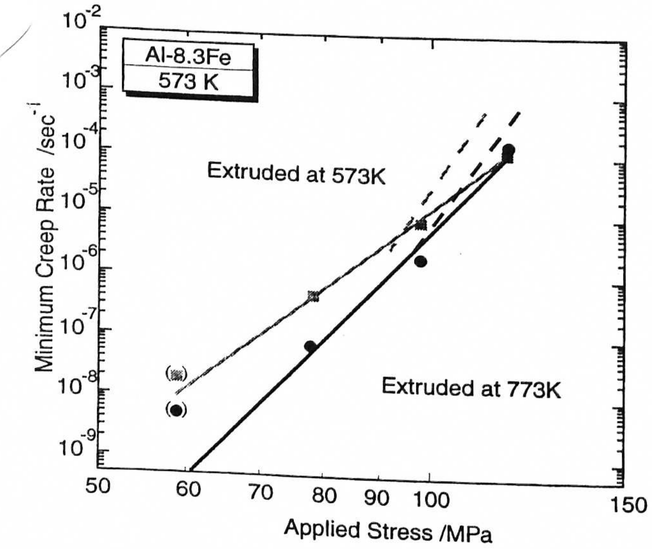

Fig. 3 Relation between the minimum creep rate and applied stress at 573K for the specimens extruded at 573K and 773K. The creep rates at 58.8MPa were obtained before the creep rate reached the minimum value in the interruption test. Broken lines show data of the tensile tests at 573K.

Fig. 4 SEM image of the Al-8.3wt% Fe alloy extruded at 773K.

3.3 Distribution of Al_3Fe intermetallics and grain structure of matrix

Distribution of fine intermetallic dispersoids in Al matrix was examined by SEM observation. Microstructure of the 773K specimen is shown in Fig. 4. In this picture, dark contrast region is the Al matrix and fine white particles are the dispersoids. The dispersoids are considered to be Al_3Fe[7].

The volume fraction of the dispersoids was found to be about 16% as estimated from the weight fraction. There was no significant difference in distribution and size of Al_3Fe in specimens extruded at 573K and 773K. Therefore, the extrusion temperature seems to have weak influence in controlling the volume fraction and distribution of the dispersoids. Also, observation of the creep raptured specimens has indicated that coarsening of the dispersoids does not occur during the creep tests at 573K.

Very fine grain structure was revealed in the Al matrix by TEM observation. According to the dark-field electron microscopy, the grain size was found to be about 1~3 μm as small as the dispersoids. This fact is an interesting feature of the rapidly solidified Al-Fe alloy. The dispersoids are located mainly on the grain boundary, and some of them within the grains. The dislocation structure of the as-extruded specimens were examined by TEM. From the extensive tilting experiments it was found that the average dislocation density within the grain was very low as, for example, shown in Fig. 5(a). But in some grains tangled dislocations were also observed as shown in Fig. 5(b). The contrast difference among the grains suggested existence of high-angle grain boundaries and the grains with tangled dislocations such as shown in (b) were very rare.

The microstructural difference in the as-extruded specimens was not enogh to explain the creep property difference between the two specimens extruded at 773K and 573K. Further investigation is needed for the deformed specimens.

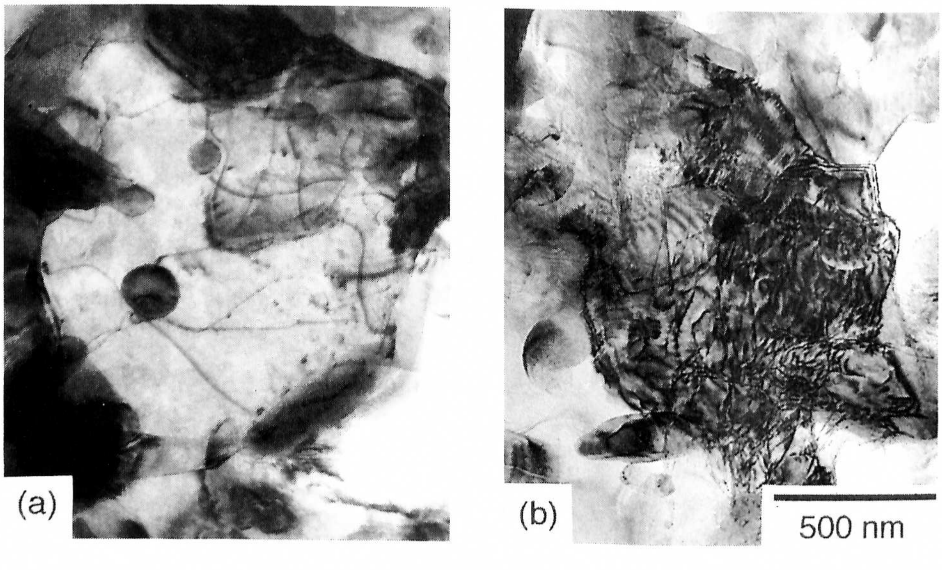

Fig. 5 TEM image of the Al-8.3wt% Fe alloy extruded at 773K. Low density of trapped dislocations and tangled dislocations are shown in (a) and (b).

4. CONCLUSIONS

The following conclusions were drawn from the present study by examining creep behaviors of the spray-formed and hot-extruded Al-8wt%Fe alloys.

1. No significant effect of extruding temperature was observed either on the tensile properties nor on the hardness values at room temperature. For the high temperature tensile tests at 573K the specimens extruded at 773K exhibited higher ultimate strength than specimens extruded at 573K over the wide range of strain rate.
2. The specimens extruded at higher temperature exhibited smaller creep rates in the entire creep region. The minimum creep rate of specimen extruded at 773K was one tenth of that extruded at 573K at the applied stress of 78.4 MPa, being more distinct at lower stresses.
3. Microstructure of the as-extruded specimen consists of Al matrix with very fine grain size of 1 ~ 3 μm and dipersion of the fine intermetallics Al_3Fe. The dispersoids are located mainly on grain boundaries. Dislocation density wihtin grains is relatively low. The microstructual difference in the as-extruded state was not so different as to explain the difference of mechanical properties.

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