SUPERPLASTICITY OVER WIDE RANGES OF TEMPERATURE AND STRAIN RATE IN A 5083 ALUMINUM ALLOY

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ABSTRACT Dependence of superplasticity on temperature and strain rate have been investigated over the wide ranges including the solidus temperature and four orders of strain rates for a 5083 aluminum-magnesium base alloy. The large elongations more than 300% were obtained on wide ranges over 200K and two orders. Such large elongations were attributed to both of the grain boundary sliding and the solute-drag controlled creep mechanisms. Filaments (or fibers) suggesting the presence of the liquid phase during deformation were observed on fracture surfaces for the specimens tested at the temperatures below the solidus. However, no large elongation was obtained in the test condition in which filaments were observed.

Keywords: *superplasticity, 5083 alloy, solute-drag controlled creep, liquid phase, filament*

1.INTRODUCTION

Recent studies have reported that fairly large elongations have been observed at high temperatures in coarse-grained Al-Mg alloys [1,2]. It was pointed out that such large elongations were not due to the grain boundary sliding behavior that is typical of most fine-grained superplastic alloys. On the other hand, the relation between a superplastic phenomenon and the presence of a liquid phase at an interface or grain boundary has been discussed for several years [3]. However, a sufficient understanding of the effect of the liquid phase on superplasticity has not been acquired yet.

In the present study, to discuss the deformation mechanism and the rule of a liquid phase at the grain boundary in a commercial aluminum-magnesium base alloy, dependence of superplasticity on temperature and strain rate have been investigated over the wide ranges including the solidus temperature and four orders of strain rates for a 5083 Al alloy.

2.EXPERIMENTAL PROCEDURE

A superplastic 5083 aluminum alloy used in this study were produced with the ordinary ingot metallurgy by Sky Aluminum Company, Japan. The material was received in the form of rolled sheets of 1.5mm thick and the chemical composition is listed in Table 1. The solidus temperature was determined as 854K by DSC analysis. The tensile specimen was machined with a 4mm gauge length, a 6mm parallel length and a 6mm radius of fillets.

Table 1 Chemical composition of 5083 aluminum alloy used (mass%).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.03	0.04	Tr.	0.65	4.70	0.10	Tr.	0.01	Bal.

Tensile tests were carried out in air in the ranges of 623 to853K for the 5083 alloy using an Instron type testing machine at an initial strain rate of $2.8\text{x}10^{-4}$ to 1.4s^{-1}. The specimens were tested after heating at a rate of 0.57Ks^{-1} and subsequent holding of 1.8ks at a given temperature. The fracture surfaces of the broken specimens were observed by scanning electron microscopy (SEM). The chemical composition of fracture surfaces was determined by energy-dispersive X-ray spectrometers (EDS).

3.RESULTS AND DISCUSSION

3.1 Flow stress

Figure 1 shows the nominal stress-strain curves at an initial strain rate of $2.8\text{x}10^{-2}\text{s}^{-1}$ for a 5083 alloy. The curve at 773K seems to represent the typical superplastic behavior with the initial stress peak and the subsequent gradual decrease. The peak stress and the elongation to failure decreases markedly as temperature raises and approaches the solidus temperature. The arrow of 853K in the figure indicates the peak stress, and besides the elongation at 853K is only about 0.01.

The maximum nominal stress as a function of temperature for the 5083 Al specimen is plotted in Fig. 2. At a strain rate of $8.3\text{x}10^{-4}\text{s}^{-1}$, the maximum stress lowers gradually with increasing temperature, and then it is sharply reduced from a temperature being about 20K lower than the solidus temperature of 854K. The slight unchanged state of the maximum stress is observed around 830K. The temperature dependence of the maximum stress at a low strain rate is stronger than that at a high strain

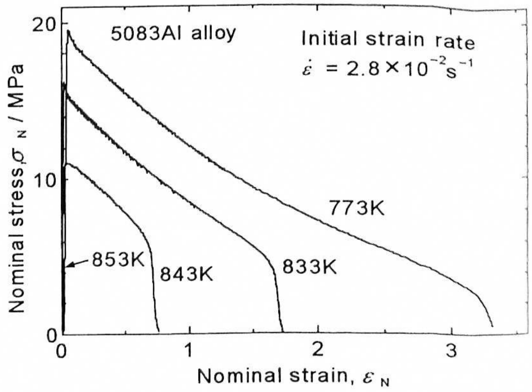

Fig. 1 Nominal stress vs nominal strain plots for a 5083 aluminum alloy at $2.8\times10^{-2}\text{s}^{-1}$.

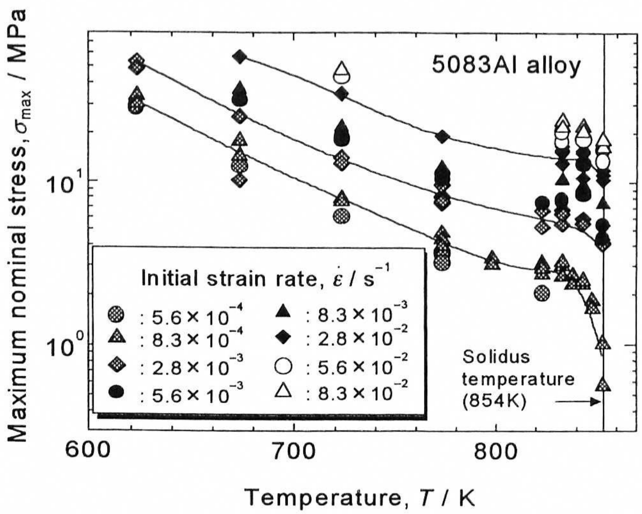

Fig. 2 Relationship between maximum stress and temperature in a 5083 Al alloy.

rate, although the change of the maximum stress at each strain rate is analogous to each other.

3.2 Ductility

The change in the elongation to failure against temperature is illustrated at various strain rates in Fig. 3. Fairly large elongations, of up to 300%, are obtained over the wide temperature range of about 200K. Such large elongations have been observed previously even in several coarse-grained aluminum alloys containing magnesium [1,2], as mentioned above. The large elongations observed in the coarse-grained alloys have been understood to be the results of a solute-drag controlled creep mechanism. Therefore, the large elongations for the present 5083 alloy should be attributed to both mechanisms of the superplasticity and the solute-drag controlled creep. It should be noted that the change in the elongation against temperature is not strongly dependent upon the strain rate. This fact also suggests the large elongation due to not only the conventional

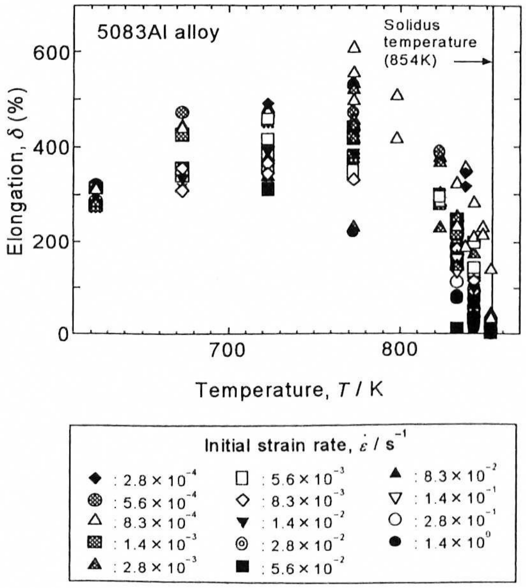

Fig. 3 The relationship between the elongation and temperature for a 5083 Al alloy.

superplastic mechanism. As shown in the figure, the elongation indicates the maximum value at 773K, and a remarkable decrease in the vicinity of the solidus temperature, in contrast to the 7475 alloy in our previous investigation [4].

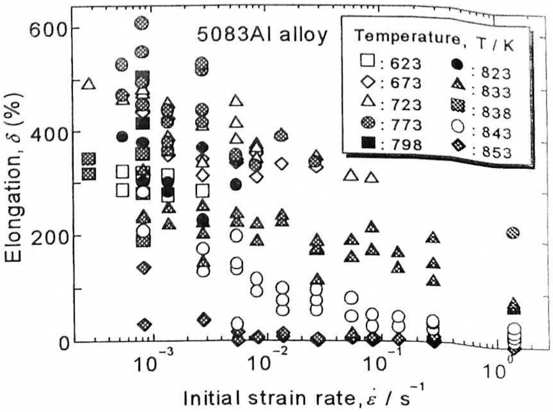

Fig. 4 Elongation as a function of initial strain rate at various temperatures.

The elongation as a function of the initial strain rate is re-plotted in Fig. 4. It is obvious that large elongations more than 200% are gained more than three orders of strain rates. The 300% elongation is over two order strain rates.

In order to discuss why the large elongations more than 300% were obtained on wide ranges both of temperature and strain rate, the reduction of area is investigated systematically. The modified reduction of area, ϕ^* was determined here based on the assumed cross-sectional area, A_f^* of gauge part deformed uniformly up to the elongation to failure. The value of ϕ^* is given by the next equation.

$$\phi^* = 1 - \frac{A_f}{A_f^*} \qquad (1)$$

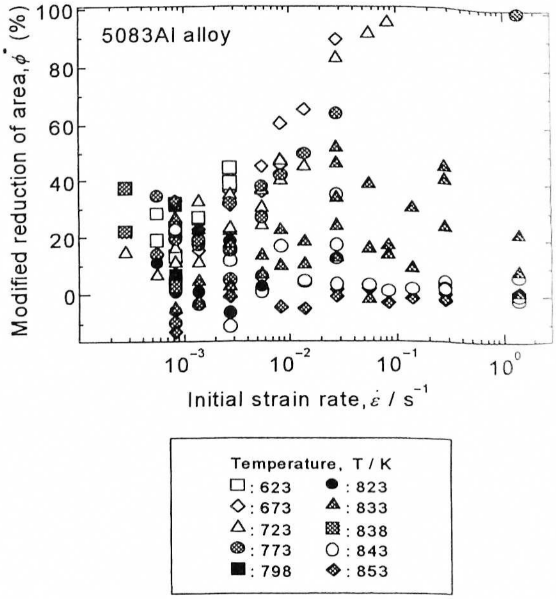

Fig. 5 Modified reduction of area as a function of initial strain rate for various temperatures.

A_f is the minimum cross-sectional area at local fracture. Figure 5 shows the modified reduction of area ϕ^* against the initial strain rate for various temperature. As in the figure, ϕ^* tends to increase with increment of strain rate, especially at lower temperatures. The large ϕ^* means that the dominant mechanism is graininterior deformation for gaining the large elongation. It is, therefore, found that the high ductility at less than 773K and more than $10^{-2}s^{-1}$ is mainly due to the graininterior deformation, that is, solute drag creep. On the other hand, the largest elongation about $10^{-3}s^{-1}$ in Fig 4 corresponds to a fairly small value of the modified reduction. This indicates that the largest elongation is attributable to the grain boundary sliding mechanism. Consequently, it is understood that the reason why the 5083 Al alloy exhibited the large elongations over wide ranges of temperature and strainrate is the superimposed operations of two mechansms, that are grain boundary sliding and solute drag creep.

3.3 Fracture surface

In order to discuss the relationship between the elongations and the test temperature in the vicinity of the solidus temperature, the fracture surfaces were observed by SEM. The fracture surface of the broken specimen tested at 833K and $8.3 \times 10^{-4} s^{-1}$ in Fig. 6. The elongation to failure of the specimen is 322%. The typical filaments (or whiskers) are observed for the 5083Al specimen as well as the 7475 specimen deformed in the vicinity of solidus temperature. The filaments are as fine as $1 \mu m$ and about $100 \mu m$ long. This observation suggests the viscous flow of liquid-like material [5]. It is obvious that the existence of the filaments is not directly related to the elongation for the present alloy, because one of the two deformation mechanisms, solute drag creep cannot be relared to the liquid-like material at the grain boundary.

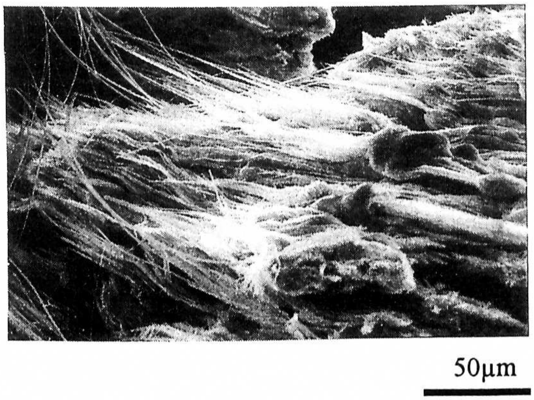

Fig. 6 SEM micrograph showing filaments in the 5083 Al specimen deformed at 833K and $8.3 \times 10^{-4} s^{-1}$.

The chemical composition of fracture surface including filament structure was determined by EDS analysis for the specimens tested at 833K and in the initial strain rate range from 2.8×10^{-3} to $1.4 s^{-1}$. The composition determined by the point analysis was strongly dependent on position and specimen. The concentration of Mg is in the range of 4.14 to 14.12 mass% and averages 7.09 mass%, which is fairly higher than 4.70% for the specimen composition (Table 1). This fact shows solute segregation at grain boundaries. The solidus temperature is estimated to be about 821K for an Al-7.09 mass% Mg alloy based on the phase diagram of Al-Mg binary system [6]. Then, the local melting at grain boundaries is presumed to occur at more than 821K. It is, therefore, suggested that filament formation results from the local melting at grain boundaries.

Finally, the effect of the local melting on ductility is discussed. As mentioned above, the elongation of the present alloy indicated a remarkable decrease in the vicinity of the solidus temperature, in contrast to the 7475 Al alloy [4]. The result in the 7475 Al appears to show a positive effect of the local melting. So, why did not the 5083 Al alloy indicate a large elongation near the solidus temperature? This is regarded as the reduction in elongation caused by grain growth, which is supported by the slight unchanged state of the maximum stress observed around 830K (Fig. 2).

4. CONCLUSIONS

The superplastic deformation have been investigated over the wide ranges including the solidus temperature and four orders of strain rates for the 5083 aluminum alloy. The results obtained are as follows:

1. The maximum stress lowers gradually with increasing temperature, and then it is sharply reduced from a temperature being about 20K lower than the solidus temperature at a comparatively-low strain rate.
2. The large elongations more than 300% were obtained on wide ranges over 200K of temperature and two orders of strain rate. Such large elongations were attributed to both of grain boundary sliding and a solute-drag controlled creep mechanisms.
3. The typical filaments (or whiskers) are observed for the present 5083Al specimen deformed in the vicinity of solidus temperature as well as the 7475 specimen. Chemical composition analysis by EDS suggested that filament formation results from the local melting caused by the solute segregation at grain boundaries.

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