SUPERPLASTIC BEHAVIOR AT HIGH STRAIN RATES IN SIC PARTICULATE REINFORCED 7075 ALUMINUM COMPOSITES

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Abstract

The superplastic behavior of three MA7075 aluminum alloys reinforced with SiC particulates , of which volume fractions are 5, 10, and 15 % respectively, has been investigated at initial strain rates between 10^{-5} s^{-1} and $3x10s^{-1}$ at a temperature of 793 K .

At extremely high strain rates from $5x10^{-1}$ to $3x10$ s^{-1} (Region 2), the strain rate sensitivity exponent,m, was larger than 0.36, and maximum superplastic elongations higher than 200% were obtained for the three composites . Grain boundary sliding and rotation was observed in the specimens deformed in this region. In contrast, the strain rate sensitivity was less than 0.13 at low strain rates (Region 1) ,with corresponding low elongations (< 100%).

Threshold stresses (σ_{th}) estimated by using an extrapolation method increased with increasing of the SiC particulate content. It was suggested that the transition from Region 1 to Region 2 arose from the effect of the threshold stress on the superplastic model with grain boundary sliding.

Introduction

In recent years, extensive investigations have been carried out on aluminum alloys reinforced with ceramic particulate or whisker such as SiC. The addition of silicon carbide has been well known to be very effective for improvement of the ambient temperature strength and stiffness of Al-based alloys. However, low ductility in composite materials than matrix alloys leads to difficulty in final forming for these composite materials.

The phenomenon of superplasticity has been shown to be a useful property in the difficult forming materials. Recently, superplastic behavior in 2124Al-20 vol.% SiCw composite at very high strain rate range has been found by Nieh et al [1], and development in superplasticity has also been reported on other some composite aluminum alloys[2-6]. However, the superplastic behavior and deformation mechanism in composite materials is still less well understood than in conventional superplastic alloys[7-9].

In this study, the high strain rate superplastic behavior of 7075 Al alloys reinforced with SiC particulate, and the effect of SiC particulate volume fraction on the stress-strain rate relationships of the composite materials have been studied. The superplastic alloys were fabricated by using the appropriate mechanical alloying and thermo-mechanical processing in order to refine the grain structure required for high strain rate superplasticity[4].

Experimental

Material Processing

A 7075Al-0.3 wt.% Zr billet used for fabrication of the composite materials was prepared by continuous casting and the chemical composition of the billet is shown in Table 1. From the billet after heat-treatment at 753 K for 7.2ks following 673K for 43.2ks, fibers (d≈60 μm, l≈3mm) were produced by using metal cutting chatter technique. These fibers were mixed with 0, 5, 10, or 15 vol.% SiC particulates by using vibrational ball mill for 10.8 ks in argon atmosphere in order to obtain composite powders. Each composite powder was compacted at 773 K in nitrogen atmosphere, resulting the compacted blocks in size of 50 mm in dia. and 20 mm in height. These composite blocks were hot compressed from 20 mm to 5mm at 773K, and then warm rolled down to 1.5 mm in thickness at 523K or 623 K. The composite sheets reinforced with 0, 5, 10, and 15 vol.% SiC particulates are called as MA7075, MA7075+5SiC, MA7075+10SiC, and MA7075+15SiC, respectively, here-in after.

The examination of microstructures by SEM and TEM revealed that SiC particulates were distributed uniformly within matrix in three MA7075+SiC composites. Very fine equiaxed grain (or sub-grain) structures, of which average grain sizes are less than 1μm , were obtained in these composites, although MA7075 alloy showed the very coarse grain structure. Fig.1(a) and (b) are typical transmission electron microstructures of the MA7075 and MA7075+10SiC specimens before tensile test, respectively.

Table 1. Chemical Composition of the Billet (wt.%)

Zn	Mg	Cu	Cr	Zr	Si	Fe	Mn	Ti	Al
5.80	2.51	1.68	0.24	0.34	0.04	0.08	0.10	0.01	bal

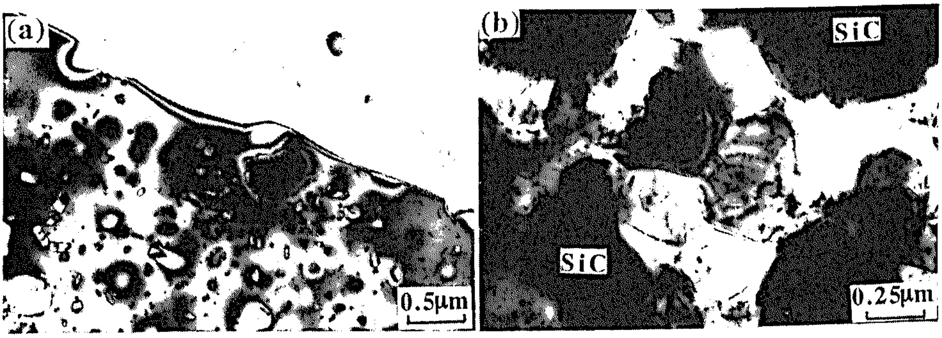

Fig.1 TEM micrographs of (a) MA7075 alloy, and (b) MA7075+10SiC composite before tensile test.

Tensile Test

Test specimens, of which size is 6mm in width and 12 mm in length at gage portion , were cut from the composite sheets parallel to the rolling direction. Tensile tests were carried out at the initial strain rate range of 10^{-5} s^{-1}~$3x10$ s^{-1} at a temperature of 793 K, by using an Instron type testing machine (10^{-5}~$5x10^{-1}$ s^{-1}) and a fatigue machine ($5x10^{-1}$~$3x10$ s^{-1}).

Metallography

Thin foils for transmission electron microscopy were prepared by Jet polishing in an electrolyte of 30% nitric acid in methanol.

Results and Discussion

Superplastic Properties

The comparison of log true stress,σ, at 20, 40 and 80% strain as a function of log strain rate,$\dot{\varepsilon}$, is shown in Fig.2 for three composites. It can be seen from Fig.2, that the true stress for each composite tends to increase slightly with strain, probably because of grain growth during deformation. In three composites, the values of strain rate sensitivity,m, estimated from the slopes of the logσ-log$\dot{\varepsilon}$ curves for 20% strain were larger than 0.36 at high strain rates (Region 2) and , in contrast, less than 0.13 at low strain rates (Region 1). In Region 1, m values decreased to the values less than 0.03. It implies the existence of threshold stress. With increasing of SiC particulates content , the true stress increased and the high m values were obtained at more higher strain rate range. The increase of true stress was more remarkably in Region 1.

The total elongations for three MA7075+SiC composites as well as MA 7075 alloy at a temperature of 793 K are shown in Fig.3, as a function of initial strain rate. The very low values of total elongation less than 10% were obtained in the

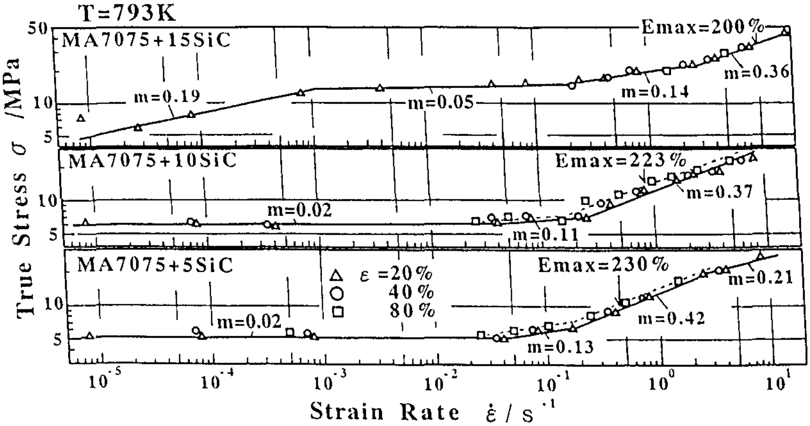

Fig.2 Comparison of log true stress, σ, at 20, 40 and 80% strain as a function of log strain rate, $\dot{\varepsilon}$, for MA7075+5SiC, MA7075+10SiC , and MA7075+ 15 SiC composites at 793K.

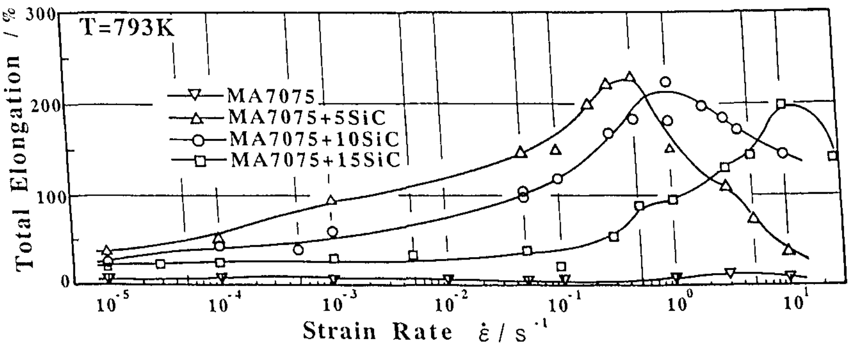

Fig.3 Comparison of total elongation as a function of log strain rate, $\dot{\varepsilon}$, for MA7075 alloy, and MA7075+5SiC, MA7075+10SiC , and MA7075+ 15 SiC composites at 793K.

whole strain rate range for MA7075 alloy because of very coarse grain structure, as shown in Fig.1(a). However, in three composites with fine grain microstructure, total elongation increased with strain rate , and reached the maximum superplastic elongations higher than 200% at the very high strain rates between from $5x10^{-1}$ and $3x10\ s^{-1}$.

It was found from the comparison between Fig.2 and 3 that the maximum elongation for each composite material was obtained correspond with the strain rate range showing high m values (Region 2). It is well known that the optimum superplastic strain rate increase with decreasing the grain size. Therefore, it is very interested to be pointed out that the strain rate showing the maximum elongation shifted with increasing volume fraction of SiC particulate, although the average grain size was similar between these composites.

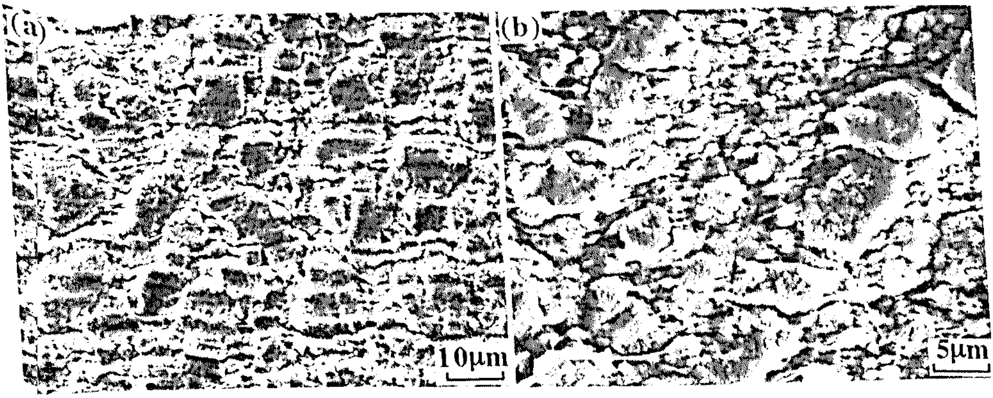

Fig. 4 SEM micrographs of MA7075+15SiC specimens deformed to (a) 52% and (b)198% ,at T=793K and at $\dot{\varepsilon}=10\ s^{-1}$. Tensile axis is horizontal.

Microstructures

Topological examination was performed using SEM. Fig.4 (a) and (b) are SEM micrographs of the MA7075+15SiC specimen surfaces deformed superplastically to about 52% and 198%, respectively, at $\dot{\varepsilon}=10\ s^{-1}$ and T=793 K. In the specimen surface after 52% elongation , two types of zone can be observed. First zones are seen as the stringers of equiaxed small grains oriented at an angle of approximately 45 deg with respect to the tensile axis. Second zones are the flat large surface areas surrounded by the stringers. After 198% elongation, the width of the stringers or the area of the first zones increased remarkably, as shown in Fig.4 (b). The size of equiaxed small grains is comparable with that of the grains or sub-grains observed at the specimen interior by TEM. Thus, the second zones seemed to be composed of groups of the grains or sub-grains.

The microstructure change in the specimen surfaces with superplastic deformation, as shown in Fig.4, suggested that ,on the beginning of the strain, localized deformation by means of shear of groups of grains occurred along the grain boundary surfaces oriented to 45 degree to the tensile axis, because such orientation is related to the direction of a maximum shear stress. Thus, new grains were exposed from the interior of specimen due to the grain boundary sliding.

Similar microstructure change with Fig.4 was also observed in the early stage of high strain rate superplastic deformation of PM7475-0.7Zr alloy[9]. In the case of the PM7475-0.7Zr alloy, the microstructure change was explained by the deformation process with dynamic recrystallization. On the other hand , Zelin et al [10]has proposed the cooperative grain boundary sliding (CGBS, ie. movement of a group of grains as a unit) model as a superplastic mechanism. However, further works are necessary to clear the reason of the grain boundary sliding of group of grains in MA7075+SiC alloys.

Threshold stress

The strain rate sensitivity of less than 0.05 in the low strain rate side of log σ-log $\dot{\varepsilon}$ curves in Fig.2 suggests the existence of threshold stress ,σ_{th} . In the case where a threshold stress is present, superplastic deformation is usually described by an following normalized equation for power-low creep[11].

$$(\dot{\varepsilon}kT)/(DGb)=A(b/d)^{p}[(\sigma-\sigma_{th})/G]^{n} \qquad (1)$$

, where kT are Boltzman's constant time the absolute temperature, D is the diffusivity, G is the temperature dependent shear modulus, b is the burgers vector. A is a mechanism dependent constant, n is the stress exponent for the effective stress σ_e ($=\sigma-\sigma_{th}$), and p is the grain size exponent for the grain size d.

An apparent temperature dependent threshold stress can be estimated from a linear extrapolation of the flow stress data to zero strain rate when log σ-log $\dot{\varepsilon}$ data, as shown in Fig.3 in this study, is replotted as $\dot{\varepsilon}^{1/n}$ against σ on a double linear scale [10-14]. In this experiment, stress exponent of n=2, 3, or 5 was assumed for the estimation of σ_{th} from log σ-log $\dot{\varepsilon}$ curves at 20% strain, because these n values have been predicted by the theoretical models of creep or superplastic deformation. However, reasonably linear relation could be obtained only for n=2, as shown in Fig.5 .

The similar behavior was observed also in the result of compression test for the MA7075+SiC alloys[9]. Thus, the values of σ_{th} at 793 K were estimated to be 3.6, 5.2 and 13.0 MPa for MA7075+5SiC, +10SiC, and +15SiC alloys, respectively.

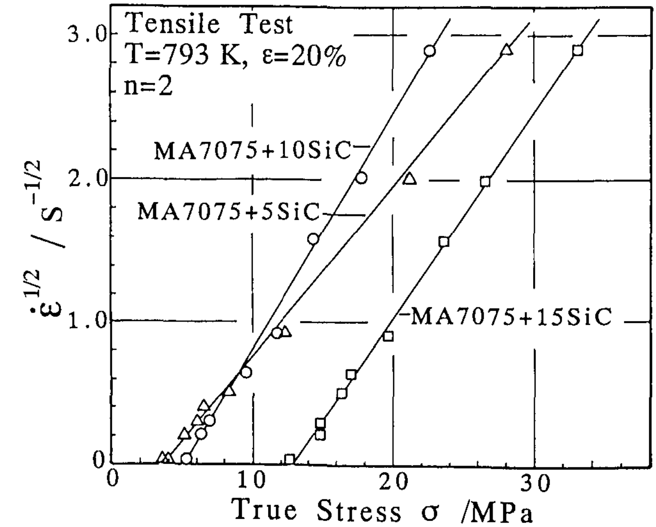

Fig.5 Plots of $\dot{\varepsilon}^{1/2}$ against σ for three MA7075+SiC composites .

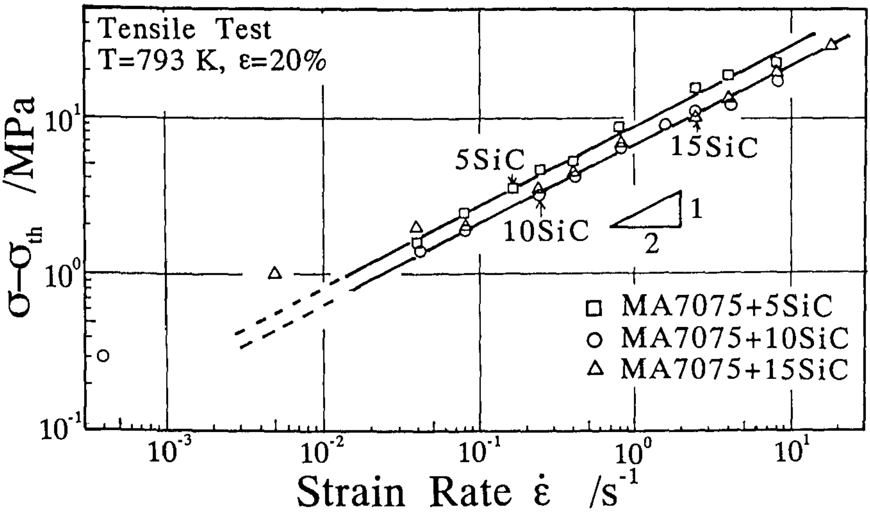

Fig.6 Double logarithmic plots of the strain rate and the effective stress σ_e ($=\sigma-\sigma_{th}$) for three MA7075 +SiC composites. Arrows show the transition strain rates from Region 1 to 2 for each composite.

Double logarithmic plots of $\dot{\varepsilon}$ and the stress subtracted from σ by σ_{th} , $\sigma-\sigma_{th}$, for the three composite materials are shown in Fig.6. It can be seen from Fig.6 that the datum points for each composite can be connected by a straight line yielding a slope of about 0.53. This value is close to the value of 0.5 predicted from the grain boundary sliding model accommodated by dislocation slip. This implies that the grain boundary sliding could be the primary deformation mechanism for high strain rate superplasticity in the MA7075+SiC composites .

Conclusions

(1) At the extremely high strain rate range from $5x10^{-1}$ to $3x10$ s^{-1}, the strain rate sensitivity exponent m was larger than 0.36 (Region 2), and maximum elongations higher than 200% were obtained for the fine grained MA7075 alloys reinforced with 5-15 vol.% SiC particulates. In contrast, the values of m were less than 0.13 at low strain rates (Region 1), with corresponding low elongations (<100%).

(2) Grain boundary sliding and rotation was observed in the specimens deformed in Region 2.

(3) With increasing of the SiC particulate content, the true stress increased in the whole strain rate range, and the transition in strain rate between Region 1 and Region 2 moved to be higher.

(4) Threshold stresses ,σ_{th} , estimated by using an extrapolation method increased also with increasing of the SiC particulate content.

(5) A double logarithmic plot of the strain rate and the effective

stress($\sigma_e=\sigma-\sigma_{th}$) can be approximated by a straight line with a slope of about 0.5 for MA7075+SiC composites. This value of the strain rate sensitivity exponent was explained by the value of 0.5 predicted from the grain boundary sliding model accommodated by dislocation slip.

(6) The transition from Region 1 to Region 2 was considered to be arose from the effect of the threshold stress on the superplastic model with grain boundary sliding.

Acknowledgements

The authors wish to express their gratitude for the financial supports from a Grant-in Aid for Scientific Research of the Ministry of education, Japan (04452279) , and a grant from the Yazaki Memorial Foundation for Science & Technology.

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