HIGH STRAIN RATE SUPERPLASTICITY OF A SiCp/6061 ALUMINUM ALLOY COMPOSITE MADE BY A VORTEX METHOD

Takeo HIKOSAKA*,Tsunemichi IMAI,and Toshiro KOBAYASHI*****

* Industrial Research Institute, Aichi Prefectural Government
** National Industrial Research Institute of Nagoya
***Toyohashi University of Technology

ABSTRACT The superplastic characteristics of a SiCp/6061 aluminum alloy composite fabricated by a vortex method before squeeze casting, extrusion and hot rolling was investigated in temperature range of 673~873K. The SiCp/6061 aluminum alloy composite was hot-rolled in rolling strain per pass 0.1 and at 573K to build fine-grained microstructure. The composite exhibits the m value of 0.3 and the total elongation of 200~350% in the strain rate range from 0.008 to $1.3s^{-1}$ and in the temperature more than 853K. Threshold stress can be obtained from relationship between flow stress and $\dot{\varepsilon}^{1/2}$ and the relationship between effective stress and strain rate indicates the m value of 0.5. The fracture surface of the composite of Cu and Zn in filaments was analyzed and the filaments were elongated by grain boundary sliding with a partially liquid phase.
***Keywords**:high strain rate superplasticity, SiCp/6061 aluminum alloy composite, a vortex method,threshold stress, filaments*

1.INTRODUCTION

Ceramic particulate reinforced aluminum composites(MMC) indicate higher specific modulus and strength, excellent heat resistance and wear resistance and have a potential to apply to automobile components, aerospace structures, semiconductor packagings and so.on.. But, a serious problems in practical application of the composites are that their machining and plastic deformation at room temperature are difficult. The near-net shap forming developted for the metal matrix composites was casting process such as a vortex method and squeeze casting, but recently, high strain rate superplasticity(HSRS) for the metal matrix composites was found and has been applied to produce engineering components with precise and complicate shapes[1]. The authors found that the HSRS could produce in fine SiC particle dispersed aluminum composites fabricated by a vortex method which is practical and low cost processing for MMC[2]. Superplastic characteristics are thought to depend on thremomechanical processing such as heat treatment, strain amount and temperature, and material factors such as grain size, crystal size, and kind of matrix, and volume fraction of reinforcement, and test conditions such as temperature and strain rate[3-14].
In this study, the superplastic characteristics of the SiCp/6061 aluminum alloy composite fabricated by a vortex method before squeeze casting, extrusion and hot rolling are investigated in order to make clear deformation mechanism of the HSRS.

2.EXPERIMENTAL PROCEDURE

The materials used in this study was a 6061 aluminum alloy reinforced with fine SiC particles SiC with 0.6μm average diameter and α-type of crystal structure and fabricated by a vortex method. Volume fraction of the composites is 20vol%. Molten aluminum alloy heated at 1023K was stirred with the preheated SiC particles and with 0.3wt% Ca, and 0.15wt% Sb at rotating speed of 500~800rpm in a crucible for 10.8ksec. And also, 0.3wt% Mg to 6061 aluminum alloy of 4kg was added to compensate the evaporation during a stirring so that the final Mg content in matrix become 0.9wt%. Ti was added using by Al-5wt%Ti-B alloy to prevent reaction of SiC particle for the molten metal. The as-cast composite with size of ϕ65x130mm was further forged at 1123K in atmosphere under pressure of 100MPa by a squeeze casting machine in order to remove the defects. The chemical compositions of a 6061 aluminum alloy used as matrix and SiCp/6061 aluminum alloy composite are shown in Table 1.
The hot extrusion and hot rolling were used to produce the HSRS in the composites. The hot extrusion was performed with the extrusion rare of 56 at 673K. Hot rolling samples with size of 6x45mm was made by machining that was hot-rolled by pack rolling method[7]. Temperature of hot

rolling was at 573K, and rolling strain per pass used is less than 0.1 and the reheating time between each rolling pass was about 300s. The final thickness of the hot-rolled composite was about 0.75mm(total rolling strain was 94%). Tensile specimens with a 4mm gage width and a 5.5mm gage length was pulled in the testing temperature ranging at 673`873K and in the strain rates ranging at $3x10^{-1}$ ~$1.3s^{-1}$. After conducting the tests, TEM and SEM observations were carried out.

Table 1 Chemical compositions of a 6061 Al alloy and the SiCp/6061 Al composite

	Chemical composition(mass%)										
	Si	Cu	Fe	Zn	Mg	Mn	Cr	Ti	Ca	Sb	Al
6061Al	0.68	0.29	0.20	0.14	0.75	0.03	0.07	0.02	-	-	Bal
PRM20vol%	8.67	0.25	0.40	0.16	0.90	0.02	0.06	0.14	0.10	0.16	Bal

3.EXPERIMENTAL RESULTS AND DISCUSSION

Fig.1 shows SEM microstructure of SiC particle after hot rolling in the composite. The SiC in the composite hot-rolled at strain of 94% is seen to be dispersed uniformly. And some of large SiC particles was observed to be crushed during hot rolling.

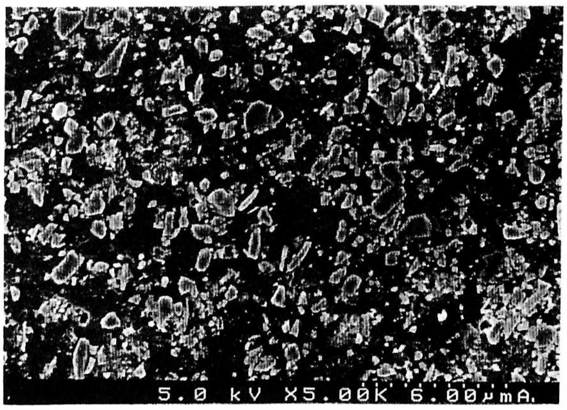

Fig.1 SEM micrographs of hot-rolled plate with the SiCp/6061 Al alloy composite

Fig.2 shows the relationship between the strain rate and the flow stress for the SiCp/6061 Al alloy composite as a function of testing temperature. The rolling temperature and rolling strain per pass used are 573K and 10%. The flow stress decreases with raising temperature and increases linearly with a raising strain rate in the strain rate range more than $2x10^{-1}$ s^{-1} in double logarithmic graph and the strain rate sensitivity of the flow stress (m value) indicates 0.3 in the strain rate from $2.5x10^{-2}$ s^{-1} up to $1.3s^{-1}$ and in the temperature range more than 843K, and which indicates constant flow stress for strain rate less than $2.5x10^{-2}$ s^{-1} appears, and the threshold stress decreased with raising testing temperature.

Relationship between the strain rate and the total elongation for the composites as a function of testing temperature, is shown in Fig.3. Total elongation were obtained of more than 100% in the wide strain rate region from more than $2.5x10^{-2}$ s^{-1} in the case of temperature more than 853K, and in the case of the temperature less than 853K the total elongation became less than 100%. The higher total elongation might be related to the part liquid phase at interface between matrix and SiC, because the testing temperature more than 853K is a little high than solidus temperature(836K).

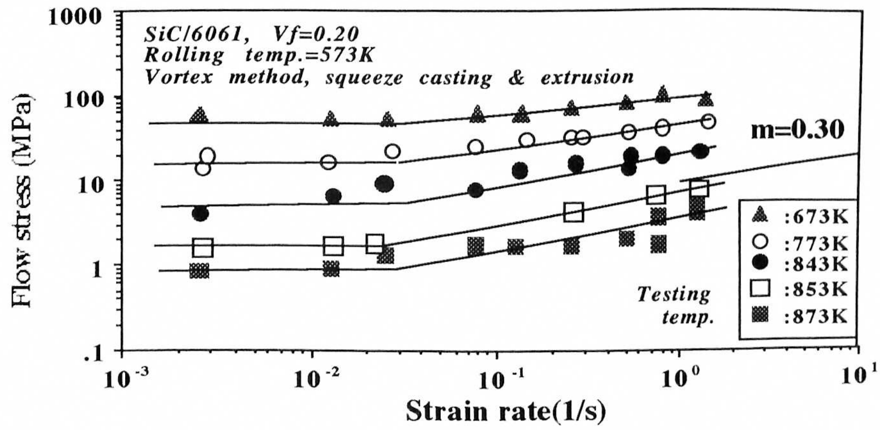

Fig.2 Relationship between flow stress and strain rate in the SiCp/6061 Al alloy composite as a function of temperature

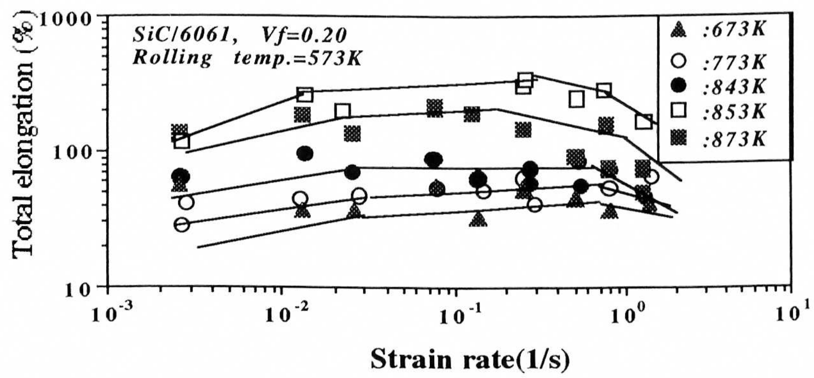

Fig.3 Relationship between total elongation and strain rate in the SiCp/6061 Al alloy composite as a function of temperature

Constitutional equation for superplasticity is expressed[10,11] by

$$\dot{\varepsilon} = (A/KT)(b/d)^p((\sigma - \sigma_{th})/E)^n D_0 \exp(-Q/KT) \qquad (1)$$

where k is Boltzmann's constant, T is the absolute temperature, σ_{th} is a threshold stress, E is the Young's modulus, b is the Burgers vector, d is a grain size, n is a stress exponent, p is the grain size exponent, A is dimensionless constant, D_0 is the relevant diffusion coefficient and Q is the activated energy of deformation. A threshold stress of the superplastic deformation is able to obtain with flow stress against strain rate $\dot{\varepsilon}^{1/2}$

$$\sigma = \dot{\varepsilon}^{1/2} + B \qquad (2)$$

The threshold stress calculated from the flow stress when $\dot{\varepsilon}^{1/2}$ becomes 0 by stress exponent of n=2 and equation(2). In this case, reasonably linear relation could be obtained only for n=2, as shown in Fig.4.

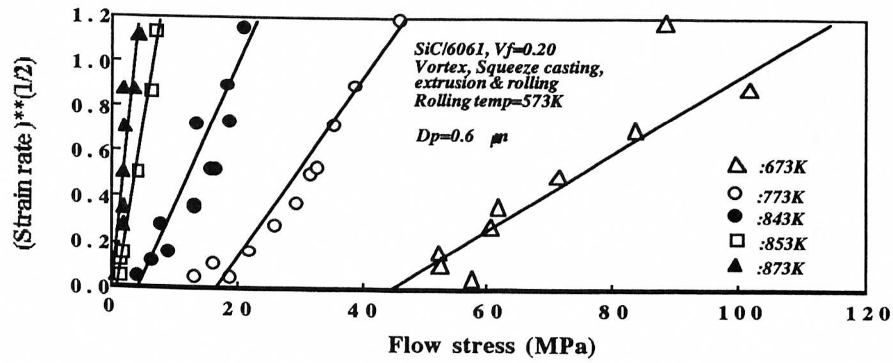

Fig.4 Plots of a strain rate $\dot{\varepsilon}^{1/2}$ against the flow stress for the SiCp/6061 Al alloy composite

Fig.5 shows relationship between effective flow stress (σ-σ_0) and strain rate of the SiCp/6061 aluminum alloy composite. In the logarithmic effective flow stress(σ-σ_0)-logarithmic strain rate relation-ship, the flow stress increases linearly with raising strain rate and the m value becomes about 0.5, although the m value indicates 0.3 in the relationship between the logarithmic flow stress σ and logarithmic strain rate shown in Fig.2.

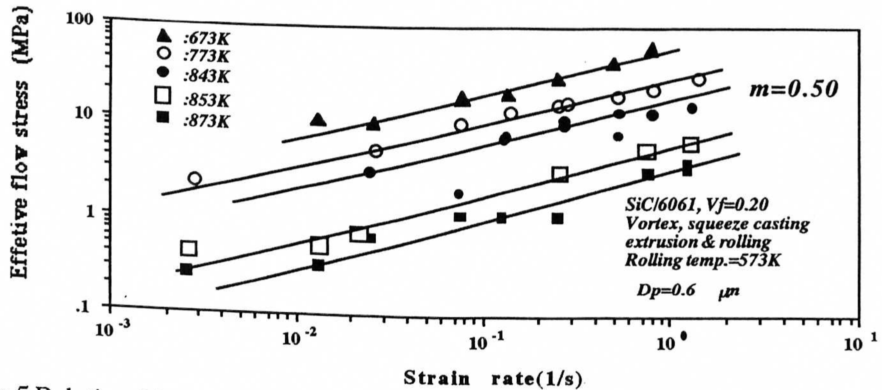

Fig.5 Relationship between effective stress and strain rate for the SiCp/6061 Al alloy composite

Fig.6 SEM microstructure of specimen surface near of the fracture surface and the strain rate of 0.25s-1 at 873k.

Fig.6 shows SEM microstructure of specimen surface near the fracture surface of the SiCp/6061 Al alloy composite pulled at strain rate of $0.25s^{-1}$ and at 873K. The surface have striation structure Fig.7 shows fracture surface of the composite pulled at the strain rate of $0.025s^{-1}$ and at 873K and Table2 shows EPMA analysis for a filament and matrix in the fracture surface of Fig.7. The EPMA results indicates that filaments have higher Si, Cu, Zn contents than those in the matrix. The solid temperature of the composite was 836K and the incipient melting point was 880K. The solid and melting temperature of the composite decreases due to the Mg, Si, Cu segregation[2,9-14] at a grain boundary and an interface in the SiC/6061 Al composite so that semi-solid phase[7] is thought to produce interface sliding between matrix and SiC particles during the superplastic deformation at 853k.

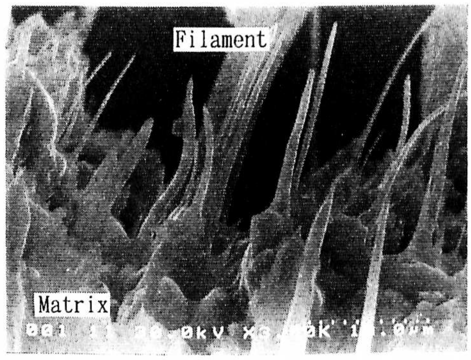

Fig.7 SEM fracture surface pulled at the strain rate of 0.025s-1 and at 873k.

Table 2 EPMA analysis for filament and matrix on the fracture surface after pulling at 873K.

Analysis point	Element(mass%)					
	Si	Mg	Cu	Zn	Fe	Al
Filament	7.07	1.34	4.06	1.12	0.06	86.35
Matrix	5.24	1.32	0.25	0.09	0.11	92.99

Fig.8 shows TEM microstructure of the SiCp/6061 Al composite after superplastic deformation. The grain size is about 1.6 to 2μm, and the presence of dislocation on the grain was observed. The TEM microstructure also has dispersoid in the matrix. The SiC/6061 Al composite fabricated by a vortex method has a lots of alloy components.

4. CONCLUSIONS

The superplastic characteristics of the SiCp/6061 aluminum alloy composite fabricated by a vortex method before squeeze casting, extrusion and hot rolling was investigated.

1) The SiCp/6061 composite exhibits the maximum total elongation of about 340% at the strain rate of $0.24s^{-1}$ and at 853K.
2) The SiCp/6061 Al composite has a threshold stress in the strain rate less than $0.25x10^{-2}$ s^{-1}.
3) The SiCp/6061 composite indicates the m value of 0.5 in the relationship between effective flow stress and strain rate.
4) The fracture surface of the composites contains many filaments and it is thought that concentration of Cu and Zn detected at the interface produces a partial melting and the filaments were elongated by grain boundary sliding with a partial liquid phase.

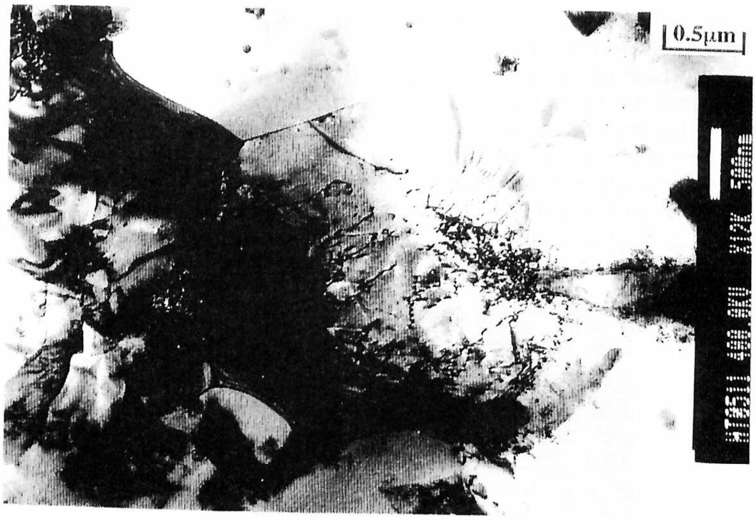

Fig.8 TEM microstructure of as-heated SiCp/6061 Al alloy composite.

REFERENCES

[1]S.Kennerkneche,Fabrication of Particulate Reinforced Metal Composite,Edited by J.Masounave & F.G.Hamd.(1990,Publishod by ASM International),87.
[2]T.Hikosaka,T.Imai,T.G.Nieh and J.Wadsworth:Scripta Metallugica, et Materialia,31-9 (1994) ,1181.
[3]T.G.Nieh,C.A.Henshall and J.Wadsworth:Scripta Metallurgica,18-12(1984),1405.
[4]M.G.Zelin, W.L.Moore and P.K.Chaudhury:Metal&Materials Society(1995),67.
[5]T.Hikosaka,T.Imai:Scripta Materialia,36-2(1997),145.
[6]T.Imai,M.Mabuchi,Y.Tozawa and M.Yamada:J.Materials Science letters,9(1990),255.
[7]G.L'.Esperance,T.Imai and B.D.Hong:ibid,379.
[8]T.Imai,M.Mabuchi and T.Tozawa:Superplasticity in advanced materials edited by S.Hori,M.Tokizane and N.Furushiro (A Publication of JSRS,1991),373.
[9]T.Hikosaka and T.Imai:Materials Science Forum,233-234(1997),243.
[10}J.E.Bird,A.K.Mukherjee andJ.E.Dorn:QuantitativeRelation between Properties and Microstructures Israel Univ.Press.(1969),255.
[11]F.Carreno,O.A,Ruano:Materials Science and Engineering, A 214 (1996), 177.
[12]T.Imai,G.L'.Esperance & B.D.Hong:Scripta Metall,et Materials,31-3(1994),321
[13]T.G.Nieh,T.Imai,J.Wadsworth and S.Kojima:Scripta Metall, et Materials,31-12(1994),1685.
[14]T.Imai,G.L'.Esperance,B.D.Hong & S.Kojima:ibid,33-8 (1995) ,1333.