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Plastic Deformation of SiCw/6061Al Composites

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SUMMARY: The characteristics of plastic deformation of SiCw/6061Al composites were investigated in the present paper. The results show that the critical compression reduction of SiCw/6061Al composite varies slightly with the strain rate. However, it changes greatly with the deformation temperature. A maximum critical reduction of 83% was achieved at 600℃. The flow stress of composites and matrix alloy are similar when the temperatures are above the solidus of the matrix, while the temperature below it they are much different. The flow stress of the composites conforms to the power $\sigma=K\dot{\varepsilon}^{m}$ law. The optimum compression temperature for the SiCw/6061Al composites is 580℃~620℃.

KEYWORDS: SiCw/6061Al composites, Plastic deformation, Compression, Flow stress,

INTRODUCTION

SiCw/6061Al composites were widely used for its excellent properties[1]. But the poor machinability limited their development[2-3]. To solve the problem, near-net-shape plastic forming of SiCw/6061Al should be investigated. High strain rate superplasticity is a valuable way to attain the purpose[4-5]. Compression is nearer to engineer than tensile deformation. So the present study focuses mainly on compression characteristics and the effects of deformation parameters on properties of post-compressed composites.

EXPERIMENT RESULTS AND DISCUSSION

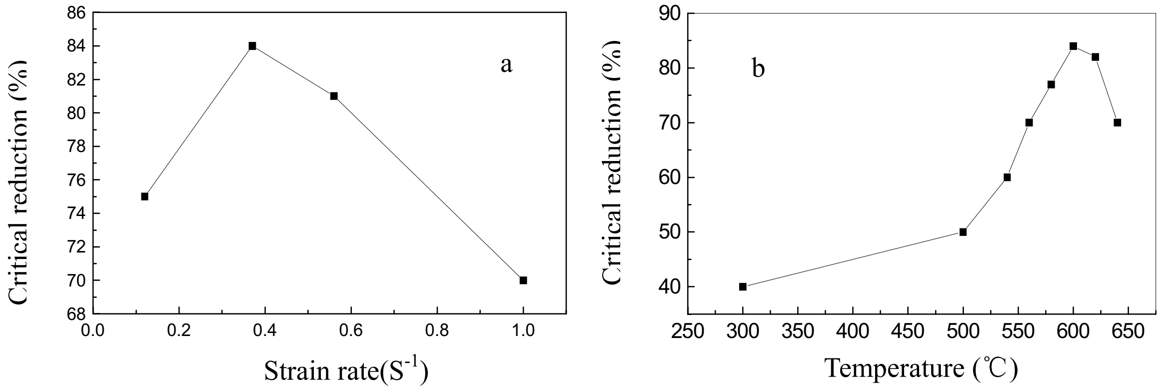

Fig 1 Critical reduction dependence of Strain rate (a), Temperature (b) of SiCw/6061Al

Fig 1 (a) shows that critical compressive reduction （the value of the compressive deformation that causes sample cracking）changes slightly with strain rates. In the strain rate

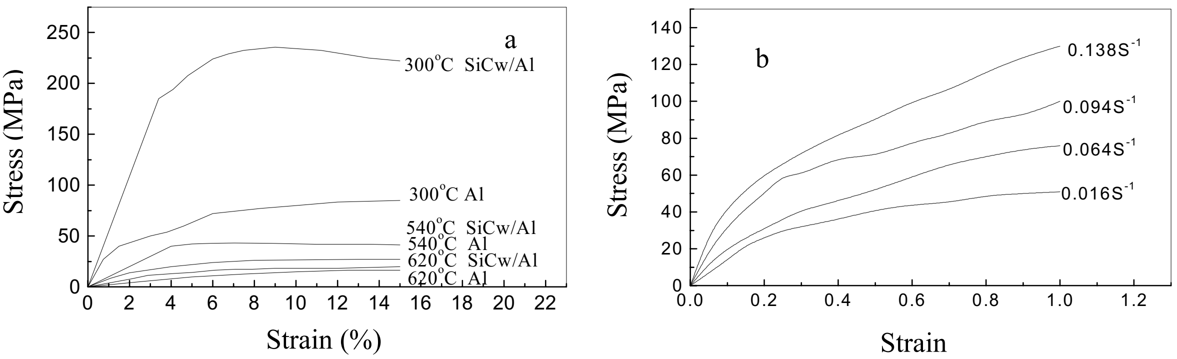

Fig 2 True stress-True strain curves of SiCw/Al and Al at different Temperature (a), Strain rate (b)

range $0.37\sim0.56S^{-1}$, compressive reduction of 80% is obtained. Critical reductions at different temperatures are shown in Fig1 (b). It can be seen that the compressive reduction at temperatures in solid –liquid region is much higher than that in solid region. From the results it is expected that composite components with complex shape can be achieved by plastic forming. The phonomenon can be explained by the effect of the liquid phase during the high stain rate compression.The results show at 540℃, which is 40℃ lower than the partial melting point measured by DSC, a small critical reduction 60% was obtained. This result is due to the development of microcracks at the interface between matrix and reinforcement, which would be generated by high stress concentration at the interface. At 580℃, which is very close to the partial melting point, a large critical reduction of 83%was obtained. The large reduction resulted from the disappearance of microcracks. It is supposed that the nucleation of cracks is suppressed by low stress concentration at the interface due to the presence of liquid phase. At 640℃, which is 60℃ higher than the partial melting point, a small critical reduction of 70% was obtained. The small reduction could be explained by the excessive development of cavitation due to too much liquid phase at the interface and grain boundaries. It is suggested that the presence of adequate amount of liquid phase gives rise to the effective accommodation required for grain boundary sliding for the composite.

The true stress-true strain curves for the SiCw/6061Al composite and the unreinforced 6061 aluminum alloy tested at different temperatures are shown in Fig 2 (a). The flow stress of both the composite and the matrix alloy decreases with increasing deformation temperature. It can be seen that when the deformation temperature is lower than the solidus of matrix, the flow stress of the composite is much higher than that of unreinforced alloy, leading to a lower plastic forming ability of the composite compared with the unreinforced alloy. However, at temperatures higher above the solidus of matrix, the flow stress of the composite is only slightly higher than that of the unreinforced alloy, indicating that the plastic forming ability of the composite is as high as that of the unreinforced alloy.

The compressive stress-strain curves of the composites were obtained at 580℃ with different strain rates, as shown in Fig.2(b). The compressive stress increases with increasing strain rate. It accords with power law $\sigma=K\dot{\varepsilon}^{m}$ (σ is the true flow stress, $\dot{\varepsilon}$ is the true strain rate, k is a constant incorporating structure and temperature dependency, the strain-rate sensitivity, m value, is the slope of the curve ($d\ln\sigma/d\ln\dot{\varepsilon}$)).

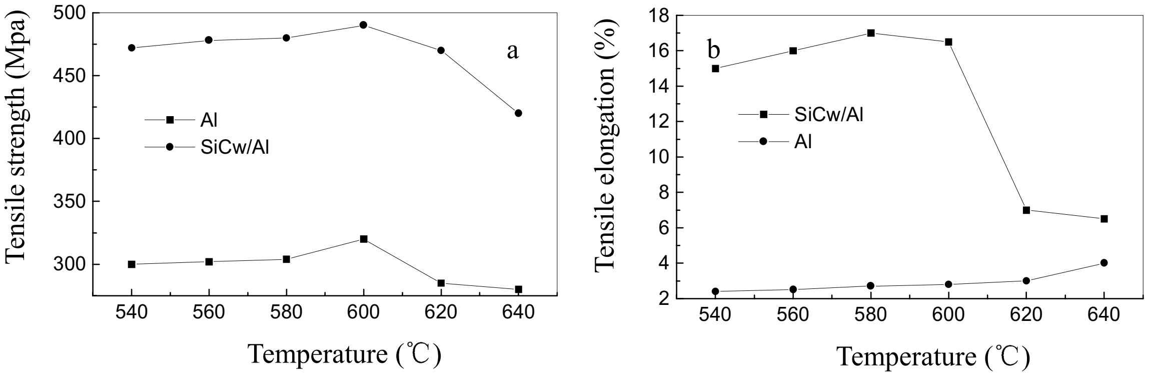

Fig 3 Tensile strength (a), Elongation (b) dependence of temperatures of SiCw/Al and Al

Fig. 3 shows the effects of compressive deformation temperature on the tensile properties of the 6061 aluminum alloy and SiCw/6061Al composites. The tensile strength of all the hot compressed composites is lower than that of the as cast composite (525 MPa), but higher than 410 MPa, while the strength of the 6061 aluminum alloy is about 300 MPa which is much lower than that of the composites. The tensile strength of the composites increases with increasing temperature over the range of 540℃ to 600℃, while it decreases in the range of 600℃ to 640℃. The tensile strength of the 6061 aluminum alloy also increases with increasing temperature and decreases when the compressive temperature is higher than 600℃. It can be seen from Fig.3 (b) that the elongation of the composites increases with increasing temperature. The elongation of the 6061 aluminum alloy is much higher than that of the composites, but it decreases markedly when the compressive temperature is higher than 600℃.

It has been demonstrated by tensile superplastic deformation tests of aluminum alloys that many voids were formed after a large amount of plastic deformation, which results in a significant decrease of the properties of the aluminum alloy. However, in this research, voids can be hardly found in the compressive deformed aluminum alloy, so that the tensile strength of the deformed 6061 aluminum alloy decreased only slightly compared in relation to that of as cast alloy (which is about 320 MPa), as shown in Fig.3. It is suggested from Fig.3 that when the aluminum alloy is compressive deformed at 600℃ (which is a little higher than the solidus of the 6061 alloy of 580℃), some voids could be welded by the small amount of liquid phase[6,7], so that the maximum tensile strength is obtained at 600℃ as shown in Fig.3. This result indicates that the existence of a little part of liquid phase is benefit for the densification of the aluminum alloy during the compressive plastic deformation. However, when the deformation temperature is higher than 600℃, the amount of the liquid phase increases and the liquid phase tends to aggregate or even is squeezed out of the samples. The liquid phase is solidified after compression and some casting defects may appear, resulting in a decreased tensile strength as shown in Fig.3.

The strength of the SiCw/6061Al composite is much higher than that of the aluminum alloy (as shown in Fig.3) mainly because of the addition of the SiC whiskers. The distribution and length of the whiskers greatly affect the properties of the composite. According to the

$$\sigma_c = \sigma_m \left(\frac{l}{d} \right) v_f \sum_{i=1}^{n} \frac{\cos^2 \alpha_i}{n} + \sigma_m \qquad (1)$$

previous result[8],the strength of SiCw/Al composite conform to the above equation:

Where α_i is the angle between the orientation direction of the whiskers and the tensile direction, n is the total number of whiskers, l/d is the mean aspest ratio, σ_m is the flow stress of the matrix and Vf is the volume fraction of whiskers.

It can be seen from the above equation, α_i and are l/d two important factors to affect the strength of the composite. With increasing l/d of and $\sum_{i=1}^{n}\frac{\cos^2\alpha_i}{n}$ the strength of the composite increase. In the as cast SiCw/6061Al composite, the SiC whiskers with an average length of 10 μm distribute randomly, as shown in Fig.1. After the compressive plastic deformation, lots of whiskers break and most of them rotate to the direction perpendicular to the compressive direction, as shown in Fig.4. Table 1 shows the length of whisker composites after compression at different temperatures. It can be seen that the whisker length of the composite after compression is much lower than that of the as cast composite. On the other hand, whisker rotation during composite make the for the deformed composite be higher than that for the as cast composite, which leads to higher strength of the deformed composite than the as cast composite. Therefore, it can be concluded that whisker length is the dominate reason for the change of the strength of the composites after compression.

During compressive deformation of the composites, the whiskers must move and rotate to accommodate the matrix deformation. At lower temperatures, the matrix had a higher resistance to whisker redistribution and results in lots of whisker breakage. With increasing deformation temperature, the matrix has a lower flow stress and provides a lower resistance to whisker redistribution. Therefore, the length of the whisker in the deformed composites increases with increasing deformation temperature, as shown in Table 1. Table 1 also shows that there is a higher increment of the whisker length when the temperature increases from 580℃ to 600℃. It was tested by DSC that the solidus temperature of the matrix alloy in the SiCw/6061Al composite used here was 580℃. Therefore, when the composites were deformed at the temperature above 580℃, liquid phase would appear, especially at the SiC-Al interface, which has been proved in references[9-11]. The liquid phases at the SiC-Al interface may serve as a lubricant for whisker redistribution and greatly decreased the breakage of the whiskers, leading to a increased whisker length in the composites deformed at temperatures above 580℃. The whisker redistribution and breakage can be clearly seen in Fig.4. The above discussion indicates that the strength of the deformed composite should increase with increasing deformation temperature. However, from Fig.3 it can be seen that the strength of the composite decreases obviously when the deformation temperature is higher than 600℃. One reason for the decreasing strength is the casting defects formed during solidification of the liquid phase. On the other hand, when the composites were deformed at temperatures higher than 600℃, a great amount of liquid phase was formed and tended to aggregate. The aggregated liquid phase led to some “whisker-poor-fields” and also

Table 1 Average length of the whiskers in the composites after compression at different temperatures

Temperature (℃)	540	560	580	600	620	640
Whisker length (μm)	2.2	2.9	3.8	6.1	6.3	7.0

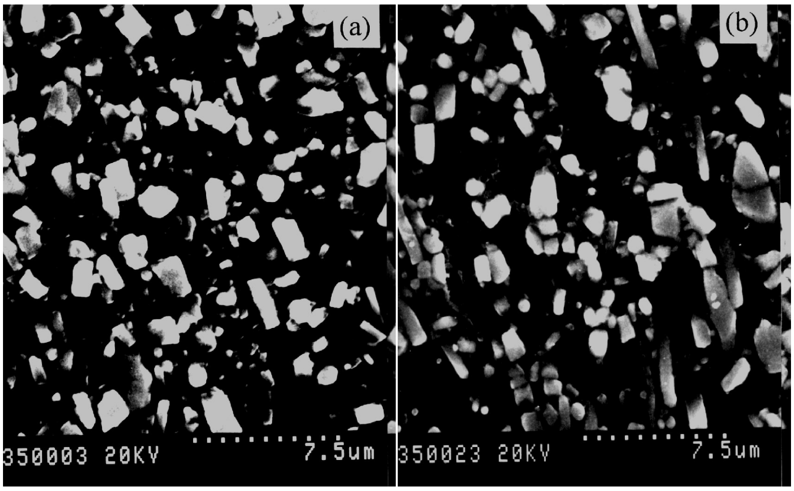

Fig. 4 SEM photographs showing the distribution and breakage of whiskers in the SiCw/6061Alcomposites after compression at (a) 560℃, (b) 600℃ and (c) 640℃.

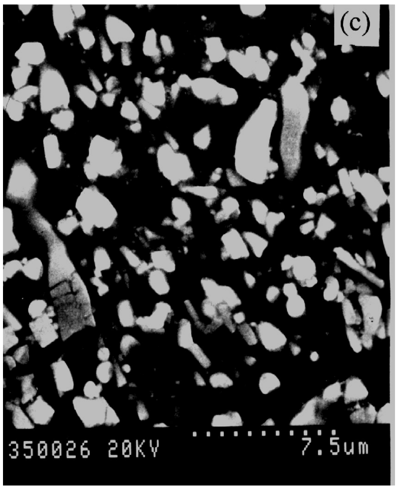

Fig. 5 SEM photograph showing the uneven distribution of the SiC whiskers in the SiCw/6061Alcomposite after compression at 640℃.

some "whisker-rich-fields", which is the other reason for the decreasing strength of the composite. The uneven distribution of the SiC whiskers can be seen in Fig.4 (c) by comparison with Fig.4 (a) and (b). Fig.5 shows a typical field for the uneven distribution of the whiskers.

CONCLUSION

From the above analysis, it can be concluded that the critical compressive reduction increases with increasing temperature when the temperature is below 600℃,while above 620℃ it decreases. A critical compression reduction of 80% can be achieved at 600℃.In the solid-liquid region, critical reduction changes slightly with strain rates in the region used here. The deformation behavior of the composites and matrix alloy are similar when the temperatures are in the solid-liquid region, although they are much different in solid phase region. The optimum deformation temperature and strain rate for the SiCw/6061Al composite is 580~620℃.

ACKNOWLEDGEMENTS

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REFERENCES

1. Suk-wan,L. and Yashimori, N., “Superplasticity of Whisker Reinforced 2024Aluminum Alloy Composites Fabricated Squeeze Casting” Scripta Metall., 1995.Vol.32, P1911.
2. Nieh,T.G.and Henshall, C.A., “Superplasticity of High Strain Rates in a SiC Whiskers Reinforced Al Alloy”, Scripta Metall., 1984.Vol.18, P1405.
3. Mabuchi, M. and Higashi, K., “Superplastic Behavior at High Strain Rates in a Particulate Si_3N_4 /6061 Aluminum Composite”, Scripta Metallurgica et Materialia, 1991.Vol. 25, P2003
4. Imai,T. and L’Esperance, G., “High Strain Rate Superplasticity of AlN Particulate Reinforced IN90 Pure Alluminum Composite”, Scripta Metallurgica et Materialia, 1995.Vol.33, P1333
5. Kim, W.J. and Yeon, J.H., “Deformation Behavior of Powder_metallurgy Processed High-Strain-Rate-Superplastic 20%SiCp/2124Al Composite in a Wide Range of Temperature”, Materials Science and Engineering, 1999 Vol.A269, P142
6. Soon, H. H. and Kyung, H.C., “Effect of Vacuum Hot Pressing Parameters on the tensile Properties and Microstructures of SiC-2124Al Composites”, Mater.Sci.Eng., 1995.Vol.A194, P165
7. Iwashi,H. and Mori, T., “Mechaisms of Cavity Shrinkage Static Annealing in a High Strain Rate Superplastic Si_3N_4p/Al-Mg-Si Composite”, Mater.Sci. and Eng., 1998. Vol. A242, P32
8. Xiong, Z. and Geng, L. “Investigation of High Temperature Deformation Behavior of a SiC Whisker Reinforced 6061 Aluminum Composite”, Composite Science and Technology, 1990.Vol.39, P117
9. Koike,J. and Mabuchi, M. “In Situ Observation of Partial Melting in Superplastic Aluminum Alloy-Composites at High Temperature”, Acta metall. Mater., 1995.Vol. 43, P199.
10. L’Esperance,G. and Imai, T. “Superplasticity in Advance Materials”, Japan.Soc.for Res. on Superplasticity, 1991. P379.
11. Nieh, T.G. and Wadsworth, J., “High-Strain-Rate Superplasticity of an Al6061-SiCw Composite”, J.Metals, 1992.Vol.11, P46