Effect of reinforcing-particle size on the formation of microbands in SiC_P/6151Al metal matrix composites

L. F. LIU
State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Science, Beijing, 100080, People's Republic of China; Department of Physics, Xiangtan University, Xiangtan, Hunan, 411105, People's Republic of China

L. H. DAI*
State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Science, Beijing, 100080, People's Republic of China
E-mail: LHDAI@LNM.imech.ac.cn

G. W. YANG
Department of Physics, Xiangtan University, Xiangtan, Hunan, 411105, People's Republic of China

Particle reinforced metal matrix composites (MMC_P) has been identified as attractive materials for applications in aerospace, defense and automotive industries [1]. This is because the incorporation of ceramic particles into metal matrix materials can significantly increase their specific stiffness, strength and wear resistance. It is well known that the mechanical behavior of this class of materials is strongly affected by their microstructures. During the past several decades, many attempts have been made to explore the relationship between microstructure and deformation behavior in MMC_P. These works lead to a dependence of flow stress on volume fraction of reinforcing particles but not on particle size. Current experiments results made by Ling *et al*. [2, 3] and Lloyd [4], however, have demonstrated that both particle size and volume fraction exert influence on the mechanical behavior of MMC_p. Very recently, Dai *et al*. [5, 6] have proposed a mechanism-based strain gradient-strengthening law to explain the effect of particle size in MMC_P. However, few efforts have been made to address the effect of particle size on microbands formation in MMC_p.

In view of the aforementioned observations, the effect of the reinforcing particle size on the formation of microbands in SiC_P/6151 Al matrix composites has been investigated experimentally in this paper. Additionally, the formation mechanisms of microbands in MMC_P were analyzed.

In the present work, MMC_P have been manufactured following a PM route: mixing, compacting, and hot extrusion. The aluminum alloy 6151 was chosen as the matrix, and SiC_P particle of different sizes (dp = 7 um, 28 um) with the fixed volume fraction ($f_p = 7\%$) was used as the reinforcement. A series of axial compressive tests were performed by MTS-810 materials testing system, and three kinds of materials were used (Al matric and the two composites). During the course of testing, the strain rate was fixed at $\dot{\varepsilon} = 5 \times 10^{-4}\ s^{-1}$. After tests, samples were cut along their axes for microscopic observations. The observations of the virgin composite have demonstrated that SiC_p combines tightly with aluminum matrix, and no obvious defeats can be found.

Figs 1–3 are typical micrographs of loaded samples of aluminum matrix and its composites respectively. These micrographs show that the incorporation of the reinforcing particles can effectively block the formation of microbands. Furthermore, one can find from the micrograph that the reinforcing particle size has a strong effect on the formation of microbands: the smaller the particle size, the fewer the microbands. This means that the small reinforcing particles are more effective than the larger particles to block the formation of microbands in MMC_P.

The formation of microbands in monolithic metal materials has been adressed by many researchers and several models have been developed in the past [7–12]. Among these models, the double dislocation walls (DDW) model presented by Huang and Gray [7–9] has been widely accepted. The key point of DDW model is that two closely-spaced dislocations sheets of opposite sign can be formed via polarization plus annihilation processes during dislocations' moving. This is the precondition to produce double-wall-like features in monolithic metal materials.

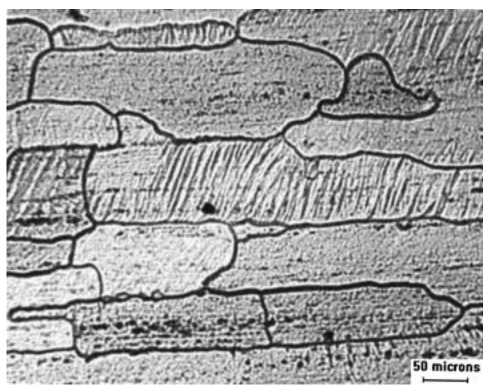

Figure 1 Micrograph of compressed 6151Al.

* Author to whom all correspondence should be addressed.

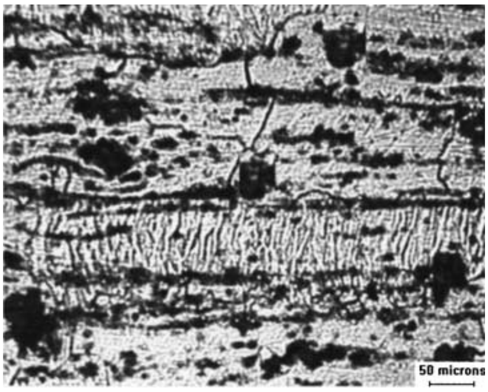

Figure 2 Micrograph of compressed SiCp/6151Al (dp = 28 μm).

For MMC_P, the conditions for microband formation are different from monolithic metal materials. First, SiC_P, particles block dislocations of the opposite sign gliding and gathering to their own sides respectively. Then dislocations were hard to be polarized and annihilated in the central portion of the band structure. Therefore, the double-wall-like features are difficult to form. Secondly, in the course of deformation, lots of geometrically necessary dislocations are demanded in the matrix to accommodate deformation mismatch due to the difference in the thermomechanic properties between the metal matrix and the reinforcing particles. Hence, many dislocations are absorbed by the reinforcing particles. This further decreases the annihilation process of dislocations in the in the central portion of the band structure. For these reasons, the formation of the microband is difficult in MMC_P due to the blocking effect of reinforcing particles.

As for the effect of reinforcing particle size on the formation of microbands in MMC_P, we can understand it by the geometrically necessary dislocation concept. For MMC_P, the geometrically necessary dislocation density ρ_G can be determined by [5]:

$$\rho_G = \frac{6f_p}{bd_p}\varepsilon \tag{1}$$

Where b is Burgers vector, f_p and d_p is the diameter of particles and the volume fraction of particles respectively. From (1), we can find that, at the fixed volume fraction, the smaller the particles, the higher geometrically necessary dislocation density. So, the small SiC_p particles can absorb more dislocations than the large

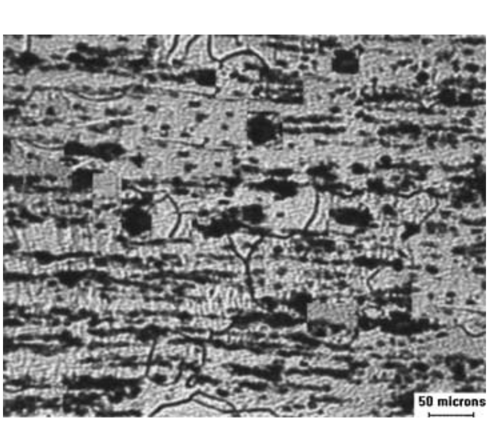

Figure 3 Micrograph of compressed SiCp/6151Al (dp = 7 μm).

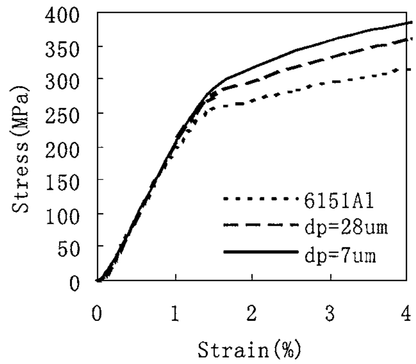

Figure 4 Stress-strain curve ($\dot{\varepsilon} \approx 5 \times 10^{-4}$ s^{-1}).

ones. This makes it difficult that the dislocation be polarized and the annihilated in the small-particle composite. Therefore fewer microbands can be found in the small-particle composite than in the large-particle composite.

On the other hand, as a kind of microdamage, microbands will weaken the macroscopic mechanical behavior of materials. That is to say, if a material contains a lot of microbands, its carrying-load capacity is poor. Since fewer microbands can be found in 7 um particle-composite, the strengthening behaviors should be better than that of 28 um particle-composite and the matrix. Our experimental results testified this points. Fig. 4 is the stress-strain curve acquired in the tests. From the figure, one can find that the flow stresses of 7 μm particle-composite are the highest among three materials.

In summary, the effect of particle size on the formation of microbands in SiC_P particles reinforced aluminum matrix composites is investigated in this paper. The results demonstrated that the small particle has a better blocking effect on formation of microbands in MMC_P than the large particle.

Acknowledgments
The authors gratefully acknowledge the financial support of this work by the National Natural Science Fund of China (No. 19902017).

References
1. T. W. CLYNE and P. J. WITHERS, "An Introduction to Metal Matrix Composites" (Cambridge University Press, Cambridge, UK, 1993).
2. Z. LING, L. LUO and B. DOOD, *J. de Physique* **4** (1994) 453.
3. Z. LING, *J. Comp. Mater.* **1.34**(2) (2000) 101.
4. D. J. LLOYD, *Int. Nater. Rev.* **39** (1994) 1.
5. L. H. DAI, Z. LING and Y. L. BAI, *Scripta Materialia* **1.41**(3) (1999) 245.
6. *Idem.*, in *ICCE*, Vol. 6 (1999) p. 147.
7. J. C. HUANG and G. T. GRAY, *Acta Metall* **37**(12) (1989) 3335.
8. *Idem.*, *Mater. Sci. Engng* **A103** (1988) 241.
9. *Idem.*, *Metal. Trans.* **20A** (1989) 1061.
10. F. J. TORREALDEA and J. GIL SEVILLANO, in "Strenth of Metals and Alloys," ICSMA 6, Vol. 1., edited by R. C. Gifkins (Pergamon Press, Oxford, 1983) p. 547.
11. U. F. KOCKS, T. HASEGAWA and R. O. SCATTERGOOD, *Scripta Metall.* **14** (1980) 449.
12. P. J. JACKSON, *ibid.* **17** (1983) 199.

Received 16 July
and accepted 1 October 2001