Experimental study on the formation of shear bands and effect of microstructure in Al-2124/SiCp composites under dynamic compression

Z. Ling, L. Luo, B. Dodd

► To cite this version:

Z. Ling, L. Luo, B. Dodd. Experimental study on the formation of shear bands and effect of microstructure in Al-2124/SiCp composites under dynamic compression. Journal de Physique IV Proceedings, 1994, 04 (C8), pp.C8-453-C8-458. 10.1051/jp4:1994870 . jpa-00253431

HAL Id: jpa-00253431

<https://hal.science/jpa-00253431>

Submitted on 1 Jan 1994

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Experimental study on the formation of shear bands and effect of microstructure in Al-2124/SiC_p composites under dynamic compression

Z. Ling⁽¹⁾, L. Luo and B. Dodd

Department of Engineering, University of Reading, Reading RG6 2AY, U.K.

Abstract : Al-2124 alloy reinforced with 17% vol. SiC particles with three sizes 3, 13, 37 μ m (MMCs) were tested under impact compression using a Split Hopkinson Pressure Bar (SHPB) system. Micro-examinations of tested samples revealed microscopic characteristics of the formation of shear bands occurring in the MMCs. As a comparison, the matrix material, Al-2124 alloy was also tested. Shear bands formed more readily in Al-2124/SiC_p reinforced with 3 μ m particles than in Al-2124 alloy and the alloy reinforced with 13 or 37 μ m SiC particles. The relations between microstructural distributions, spacing of SiC particles and formation of shear bands have been analysed.

1. INTRODUCTION

A shear band is a narrow region of highly localised plastic deformation, which has been observed particularly when materials are deformed at high strain rates, for example, in high speed metal forming or machining. It results from several competing processes among which strain hardening and thermal softening are the main factors [1,2,3]. The former results from the production, motion and interference of dislocations and other defects which tend to increase the resistance to flow. The latter is caused by the production of heat during the non-conservative plastic flow process which tends to reduce the resistance to flow by lowering the activation barriers associated with the atomic mechanism of deformation. Both factors are strongly influenced by the rate of the plastic flow. Generally, the localised deformation occurs more readily in materials with a low strain hardening rate, low strain rate sensitivity, low thermal conductivity and high thermal softening effect. Since the localisation of deformation induces a loss in load-carrying capacity and is often a precursor to failure, it is therefore of great interest to fully understand the formation of a shear band in industrial materials [4].

Recently, a great deal of research has been carried out on metal matrix composites containing hard particles (MMC). The reinforcement particles which are hard and brittle restrict the movement of dislocations and increase dislocation densities in the matrix [5,6], thus enhancing the stiffness and strength of the materials. It is similar to one of the formation factors of shear bands, strain hardening. Because of the hard particles, the heterogeneity in MMC_p is much higher than that in the pure matrix material. The microstructural effect, such as that of matrix grain size, particle size and their distributions, therefore may become a major factor in the formation of localised deformation in MMC_p. Some research on localised deformation occurring in MMCs has been reported [7,8]. To obtain an essential understanding of localised deformation in MMCs, in this report, we used a Split Hopkinson Pressure Bar (SHPB) system to test the MMCs and the aim was to investigate the formation process of the localised deformation and the microstructural effects related to this process.

2. EXPERIMENTAL PROCEDURE

2.1 Material and Specimen Preparation

The materials used in this study are Al-2124 and Al-2124 reinforced with 17% volume fraction of 3, 13, and 37 μ m SiC particles. They were in the form of 12mm thick hot rolled plates supplied by BP Metal Composites Ltd. The chemical composition is shown in Table 1. The microstructure of the virgin materials are shown in Fig.1 in which, SiC particles are

(1) Present address: LNM, Institute of Mechanics, The Chinese Academy of Sciences, Beijing 100080, China

aligned along the rolling direction, the smaller the particles, the clearer their alignment(Figs.1b,c,d). No broken SiC particles, voids or debonding between particles and the matrices could be seen. It should be noticed that the size of the matrix grains is about 3mm. Specimens for impact compression tests were machined to cylinders with diameters of 5mm and aspect ratio of unity. The machining direction of the specimens is along the rolling direction of the plates.

Before testing, specimens were solution heat treated, i.e. heated to 530°C and held for about 55 minutes then quenched in water. To prepare the samples for micro-examination, the fractured regions of the specimens were sectioned parallel to the compression axes. The sectioned regions were then fine polished for metallurgical examination.

Table 1 Chemical Composition of Base Al-2124 alloy

Element	Cu	Mg	Mn	Fe	Zn	Si	Cr	Ti&Zr	Others (each)	Others (total)	Al
Weight (%)	4.0- 4.4	1.3- 1.6	0.4- 0.7	<0.3	0.25	0.2	0.1	0.2	< 0.05	< 0.2	Balance

2.2 Mechanical Tests

A Split Hopkinson Pressure Bar(SHPB) was used to carry out the impact compression tests. During tests, different impact speeds were chosen to obtain different compression stress levels. The impact speeds are between 15 m/s and 20 m/s in these experiments. The test data are shown in Table 2. [9]

Table 2 Impact Compression Test Data

Specimen No.	Material	Impact Speed (m/s)	Strain Rate (1/s)
EBBAC51S	Al-2124 alloy	15.43	2100
EBBAC52S	Al-2124 alloy	20.5	3000
EBBBC52S	3μm MMC	15.4	2100
EBBIC51S	13μm MMC	15.43	2100
EBBJC51S	37μm MMC	15.15	2100
EBBIC52S	13μm MMC	20.6	3000
EBBJC52S	37μm MMC	20.24	3000

3. EXPERIMENTAL RESULTS

3.1 Mechanical Response

The compressive stress-strain curves of reinforced and unreinforced Al-2124 alloy are shown in Figures 2a and 2b. Fig.2a shows stress-strain curves of Al-2124 and Al-2124 reinforced with 17% volume fraction of SiC particles with three sizes, 3, 13, and 37μm, under impact speeds of 15.5 m/s, i.e. strain rates of 2100 1/s. One clear feature in the figures is that, under the same loading conditions, the yield stress and flow stress of these composites varies with the size of SiC particles. The smaller the SiC particles, the higher the yield stress and flow stress of MMCp, for example, the flow stress of the composite containing larger SiC particles, say 37μm, is lower than that for smaller SiC particles, 3 or 13μm, reinforced composites. Even under a impact speed of 15.5 m/s the MMCp containing 3mm SiC particles has higher yield and flow stresses than the other two MMCps(13 and 37μm) subjected to a higher impact speed, 20.5 m/s, and strain rate, 3000 1/s (see Fig.2b).

3.2 Microscopic Observation

Observations of these impact specimens were carried out on VICKERS-55 and NEOPHOT-21 microscopes. The observations focused on the formation of localised deformation, or shear bands which occurred in the MMCp.

Plastic deformation under compressive loading is initial homogeneous. As load increases the plastic deformation localises into flow along the direction of maximum shear stress, i.e. 45 degree to the loading direction. The localisation level depends on the loading level and the strain rate in the tests, see Fig.3. In Al-2124, grain deformations increases with the impact speed. When the impact speed is 20 m/s and the strain rate is about 3000 $1/s$, the localised deformation is very obvious, where grains have been elongated and distorted with their orientations along the 45 or -45 degrees planes(Fig.3a). While at the impact speed of 15.5 m/s and a strain rate of about 2100 $1/s$, the plastic deformation is large and its orientations are along the 45 or -45 degrees, but no obvious grain distortion could be seen(Fig.3b). Fig.4a shows the microscopic observations on Al-2124 reinforced with 3mm SiC particle. The orientation of aligned particles changed markedly in parallel to the zones of large plastic flow under an impact speed of 15.4 m/s, and the deformed band forms with its width about 10mm (Fig.4a(1)). Fig.4a(2) shows a localised shear band with a crack in it. Its width is less than 10mm. But under the same loading conditions, localised deformation was not obvious in the other two MMCs(13 and 37 μ m SiC). The plastic deformation occurring in the matrix of the MMC(13 μ m SiC)(Fig.4b) is much clearer than that in MMC(37 μ m)(Fig.4c) in which only relatively slight plastic flow is seen in the matrix, between the large particles. When the impact speed is increased to 20.5 m/s, i.e. a strain rate of 3000 $1/s$, a white etched shear band was observed along the tip of the macrocrack in sample MMC(13 μ m)(see Fig.5a). The same type of band was also observed in the sample MMC(37 μ m) and some microvoids and broken particles can be seen in the sample(see Fig.5b). In these MMCs with bigger particles, plastic flow appears in the matrix between hard particles and along the maximum shear direction, and the alignment of particles along localised flow is not obvious. This is due to the fact that the width of the shear bands is about or less than the size of the particles and the spacing between particles is larger than that in 3 μ m MMC.

4. DISCUSSION

Comparing the observed results, it is clear that, when the material is reinforced, the hard particles resist the movement of dislocations in the matrix and increase the strength of the composites. The size of the particles therefore is another factor in the formation of shear bands because when the volume fraction is the same the larger the particle size, the larger the spacing of the particles. The conclusion, in every case, is that, the shear bands seem to follow the planes of maximum shear strain. That means that microstructural features seem to have no effect on the direction of shear band initiation[3]. There is no evidence showing that individual particles provide sites for shear bands. It is rather, we believe, the collectively weaker slip plane where the localisation initiates. It should be mentioned that, in the pure matrix materials, dislocation pile-up often occurred at the grain boundaries. Normally, the level of dislocation pile-up at the hard particle boundaries is considered higher than that at the grain boundaries. It is shown by the present observations (see Figs.4b and 4c) that the level of distortion of the matrix grains depends on the particle size and spacing of particles. Since the SiC particles are almost rigid comparing to the matrix the plastic deformation will occur dominantly in the matrix.

The initiation and propagation of cracks is within the bands and causes the final fracture of the specimens. The particles don't seem to provide sites for shear bands but they do provide sites for microdamage to initiate in the bands, see Fig. 6a. The propagation of cracks is not necessarily assisted by the particles, see Fig. 6b where the crack propagates in the matrix though there are particles nearby.

From the present study the conclusions can be summarised as follows:

- (1) A prominent feature of the macro-mechanical properties of the MMCs subjected to impact compressive loading is that the flow stress of the composites depends on their reinforced particle size for a given volume fraction. Generally, the yield stress and flow stress of MMC reinforced with "large" SiC particles, say 37 μ m, is lower than that of those reinforced with "small" SiC particles;
- (2) In MMC reinforced with small SiC particles(3mm) shear bands and localised deformation are more readily obtained than in the pure matrix material and the MMCs reinforced with larger SiC particles with the same volume fraction;
- (3) Shear bands formed in the present MMCp depend on the impact speed, strain rate and the effect of microstructure of the composites, in which the reinforcement particle size and matrix grain size are important.
- (4) Cracks initiate and propagate within the bands. The particles provide sites for the initiation of microdamage but do not necessarily assist crack propagation.

ACKNOWLEDGEMENT

This work is part of a research programme funded by the EC under grant BE4500-90 to whom the authors are grateful. Also Zhong LING would like to thank the Royal Society and the Chinese Academy of Sciences for their financial support during the study. Also the helpful assistance of Mr D. Keeley, Mr J. Jiang and Ms H. Shen are most appreciated.

REFERENCES:

- [1] Rogers, H.C., *Ann. Rev. Mater. Sci.* 9(1979), pp.283-311
- [2] Bai, Y., Dodd, B., *Adiabatic Shear Localisation* (Pergamon Press, 1992)
- [3] Dornéval, R., *Materials at High Strain Rates*, (edited by T.Z. Blazynski, Elsevier Applied Science Publishers Ltd, 1987), pp.47-70
- [4] Anand, L., et al, Report of the NSF Workshop on Localised Plastic Instabilities and Failure Criteria, *Int. J. of Plasticity*, 6(1990), pp.I-IX
- [5] Clyne, T.W., Withers, P.J., *An Introduction to Metal Matrix Composites*, Cambridge University Press, Cambridge, (1992)
- [6] Lewandowski, J.J., et al, *Material Science & Engineering*, A107(1989), pp.241-255
- [7] Lee, K., et al, *Metallurgical Transactions A*, 24A (1993) p895
- [8] Hong, S.I. et al, *Acta. Metall. Mater.* No.8, 41(1993), pp2337-2351
- [9] Ling, Z., *Localised Deformation and Fracture in Al-2124 reinforced with SiC Particles*, (Research Report to the Royal Society/Chinese Academy of Sciences. Sept.1993)

Figure 1. Microstructure of the materials before test

Figure 2. The stress-strain curves (engineering) of the MMCs and unreinforced alloy
(a) impact speed about 15.5 m/s; (b) impact speed about 20.5 m/s .

Figure 3. Plastic flow of Al-2124 alloy under impact compression loading

Figure 4. (a) Localised deformation of Al-2124/SiC_p(3μm) under impact compression. (15.5 m/s)

Figure 4. Plastic flow of the matrix between big particles in Al-2124/SiC_p under impact compression. (15.5 m/s)

Figure 5. Localised plastic flow and crack of Al-2124/SiC_p under Impact compression (20.5 m/s)

Figure 6. Microdamage and crack in Al-2124/SiC (3 μ m) under impact compression(20.5 m/s)