

ELASTIC ANISOTROPY IN PARTICLE/FIBER REINFORCED

ALUMINUM METAL MATRIX COMPOSITES

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INTRODUCTION

Metal matrix composites hold high promises as engineering materials. In order to take full advantage of their promising properties, the complex nature of the composites must be understood. Some questions thus arising; how do different manufacturing processes influence the microstructure and how can the mechanical properties of the composites be explained and predicted from knowledge of their microstructure.

The elastic properties of a composite material depend on many parameters: volume fraction, geometrical shape, size distribution, orientation and distribution of the reinforcement and the properties of the matrix. Mathematical models have been developed for some specific shapes and distributions of the reinforcement. Christensen [1] derived the effective shear and bulk moduli for a dilute suspension of elastic spherical particles in a continuous phase of another elastic material. Ledbetter et al. [2] used a scattering theory to explain the elastic behavior of a particle reinforced composite in which randomly oriented ellipsoidal particles were nonhomogeneously distributed. Experimental work by Lee et al. [3] showed that in particle-reinforced composites the second-order elastic constants increase linearly with the particle content. Their results suggested that the dominant factor in influencing the anisotropy is the content of reinforcement. Spies & Salama [4] investigated the influence of the reinforcing phase on the texture and found that the fourth-order expansion coefficients change linearly with the particle content. Their results indicate that the presence of particles in the composites leads to considerable changes in the texture of the aluminum matrix.

The objective of this study is to obtain information about what features in the microstructure of the composites are causing their anisotropic behavior. This was accomplished by comparing the particle size distribution in three orthogonal directions, with the ultrasonic velocities measured along the same directions. Three series of SiC-particle reinforced composites were examined. Two series comprised of extruded samples while the third consisted of pressed specimens. Each series included samples of different particle content. Also, three squeeze-cast samples with different particle/fiber content were

examined. In the extruded composites, the properties along the extrusion direction were found to be different from those in the directions perpendicular to the extrusion direction. This behavior is explained in terms of the presence of texture in the matrix. The squeeze-cast specimens also showed an anisotropic behavior which is induced by preferred orientation of the fiber reinforcement.

MEASUREMENTS

Specimens

The metal matrix composites (MMC) used in this investigation comprised of aluminum alloys as the matrix material and either SiC-particles or alumina fibers and particles as the reinforcement. The specimens which have Al-6061 as matrix were received as pressed plates, whereas the composites containing Al-7064 and Al-8091 were obtained as extruded rods. The alumina reinforced specimens were all squeeze-cast. The volume fractions of reinforcement in the composites used are shown in table 1.

The coordinate systems were chosen such that in pressed samples the x_1 and x_2 -axes are in the plate at right angles to each other and the x_3 -axis is along the compression direction (normal to the plate). In the extruded specimens the x_1 and x_2 -axes are perpendicular to the extrusion direction and orthogonal to each other. The x_3 -axis is along the extrusion direction. In the squeeze-cast samples the x_1 and x_2 -directions are in the fiber rich layers at right angles to each other, and the x_3 -direction is perpendicular to the fiber rich layers.

Microstructure

The particle size distribution and the area fraction covered by the reinforcement in each plane were estimated in each specimen. This was accomplished by scanning the faces of the specimen under an optical microscope and taking photographs at several "representative" locations along the three chosen directions. The particle size distributions were obtained from these micrographs by counting the particles and estimating their size. The size of a particle was estimated using its projected area on the face which, in turn, is equal to the area of a circle having the diameter d . The particle was considered to belong to the size range

Table 1. Metal-Matrix Composites used in investigations

Manufacturing method	% Reinforcement in Composites	
Pressed plates	Al-6061 + 0% SiC	
	Al-6061 + 25% SiC	
	Al-6061 + 40% SiC	
Extruded rods	Al-7064 + 0% SiC	
	Al-7064 + 15% SiC	
	Al-7064 + 20% SiC	
	Al-8091 + 0% SiC	
	Al-8091 + 10% SiC	
	Al-8091 + 15% SiC	
Squeeze-cast	Al-Si-Cu-Ni-Mg + 20% Al ₂ O ₃	(Mat A)
	Al-Si + 20% Al ₂ O ₃	(Mat B)
	Hüttenaluminum + 20% Al ₂ O ₃	(Mat C)

where the inequalities $n < d < n+1$ are satisfied, where n and $n+1$ are the lower and upper limits of the size range. Also from the micrographs, features like orientation, shape and distribution of the reinforcement were examined.

Ultrasonic velocities

Measurements of the ultrasonic velocities were performed using the pulse-echo-overlap method, which is described in detail elsewhere [5]. A pulse of approximately 1- μ sec duration of variable pulse-repetition rate is generated and impressed on a transducer which is acoustically bound to the specimen. The reflected echoes are received by the same transducer, amplified, and displayed on an oscilloscope. Two of the displayed echoes are then chosen and exactly overlapped by critically adjusting the frequency of the cw oscillator. This frequency f is employed to compute the ultrasonic velocity using the relation $V=2lf$, where l is the thickness of the specimen. X- and Y-cut transducers of 10 and 2.25 MHz were used for the generation of the longitudinal and transverse waves respectively.

RESULTS AND DISCUSSION

The particle size distribution and the fiber/particle content, estimated from optical micrographs, are shown in figures 1-4. Table 2 and 3 contain the area fractions covered by the reinforcement. The data are accurate to within 10% of the nominal values. Table 4,5 and 6 give the ultrasonic longitudinal and shear velocities measured. The velocities are denoted V_{ij} , where i and j are the directions of propagation and polarization respectively. The velocities are found to be reproducible to within 0.5%.

From figures 1-3 one finds that in the pressed samples, the particle size distributions as well as the area fractions covered by the reinforcement are the same in the three directions within the accuracy of the measurement. On the micrographs the reinforcement showed no features explaining the differences in ultrasonic velocities measured. This suggests that the anisotropy is due to the texture in the aluminum matrix. The similar anisotropic behavior in the specimen without reinforcement also confirms this statement. However, the presence of SiC-particles is found to vastly enhance the anisotropy.

Table 2. Area fractions covered by the SiC-particle reinforcement.

Direction	6061+ 25% SiC	6061+ 40% SiC	7064+ 15% SiC	7064+ 20% SiC	8091+ 10% SiC	8091+ 15% SiC
1	26.3	37.7	20.6	23.9	12.7	17.5
2	22.6	36.3	18.7	23.7	12.1	16.5
3	24.0	31.7	16.5	21.0	11.8	15.3

Table 3. Area fractions covered by the alumina fiber and particle reinforcement (%).

Direction	Material A			Material B			Material C		
	Particle	Fiber	Total	Particle	Fiber	Total	Particle	Fiber	Total
1	12.0	11.9	23.9	8.5	12.6	21.1	1.0	13.2	14.2
2	20.4	2.5	22.9	15.2	2.7	17.9	12.5	3.2	15.7
3	18.7	2.9	21.6	15.7	2.0	17.7	13.7	2.7	16.4

Table 4. Ultrasonic velocities in SiC particle-Al pressed composites (m/s)

Velocity	6061+ 0% SiC	6061+ 25% SiC	6061+ 40% SiC
V ₁₁	6407	7224	8058
V ₂₂	6422	7287	8084
V ₃₃	6358	6979	7841
V ₁₂	3098	3785	4507
V ₁₃	----	----	----
V ₂₁	3103	3798	4505
V ₂₃	----	----	----
V ₃₁	3200	3676	4398
V ₃₂	3195	3692	4412

Table 5. Ultrasonic velocities in SiC-particle-Al extruded composites (m/s)

Velocity	7064+ 0% SiC	7064+ 15% SiC	7064+ 20% SiC	8091+ 0% SiC	8091+ 10% SiC	8091+ 15% SiC
V ₁₁	6251	6728	6935	6617	6890	7002
V ₂₂	6233	6733	6875	6611	6903	7000
V ₃₃	6250	6902	7071	6626	7025	7141
V ₁₂	3077	3457	3591	3511	3723	3827
V ₁₃	3069	3485	3667	3498	3738	3848
V ₂₁	3075	3448	3593	3507	3719	3818
V ₂₃	3095	3477	3625	3496	3731	3834
V ₃₁	3056	3490	3666	3492	3745	3856
V ₃₂	3090	3469	3595	3494	3741	3852

Table 6. Ultrasonic velocities in alumina particle and fiber-Al squeeze-cast composites (m/s)

Velocity	Composite A	Composite B	Composite C
V ₁₁	7032	6967	6670
V ₂₂	7033	6969	6712
V ₃₃	6904	6835	6524
V ₁₂	3694	3656	3419
V ₁₃	3669	3578	3336
V ₂₁	3681	3657	3439
V ₂₃	3683	3594	3345
V ₃₁	3644	3560	3325
V ₃₂	3675	3606	3329

In the two series containing extruded specimens (Al-7064 and Al-8091) the reinforcement showed the same features in the three directions (compare figures 2 and 3). Nevertheless, in the reinforced samples the longitudinal velocities are higher in the extrusion direction, whereas the velocities are the same in the samples without reinforcement. This behavior further indicates that the anisotropy is caused by texture in the aluminum matrix but also indicates that the presence of the SiC-particles enhance the formation of texture.

In the squeeze-cast specimens (composites A,B,C) the ultrasonic longitudinal velocities, given in table 6, are considerably higher in the plane of the fibers than in the directions perpendicular to that

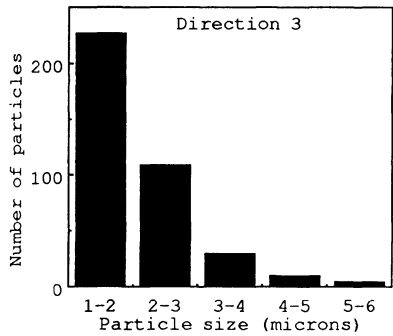
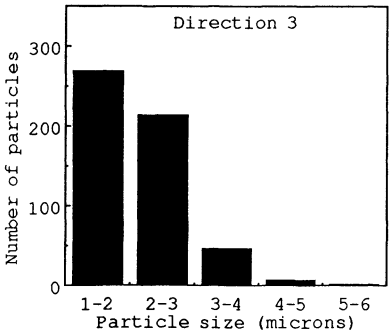
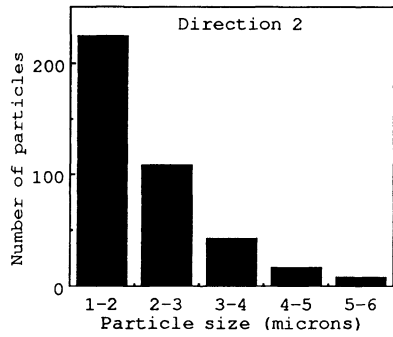
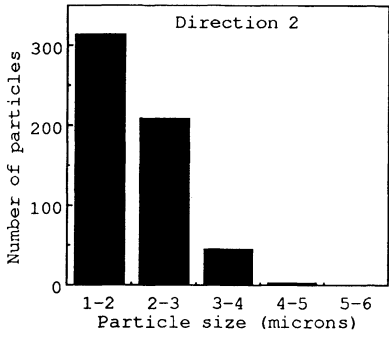
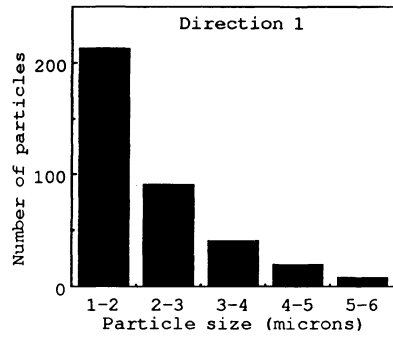
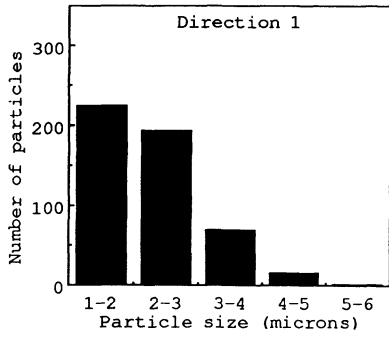


Fig.1 Particle size distribution in 25% SiC-6061 Al

Fig.2 Particle size distribution in 20% SiC-7064 Al

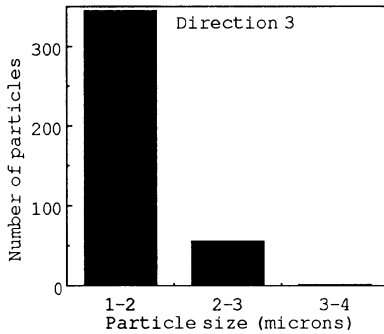
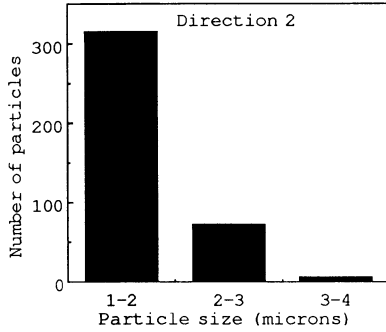
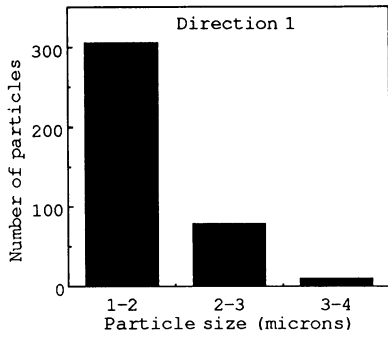


Fig.3 Particle size distribution in 15% SiC-8091 Al

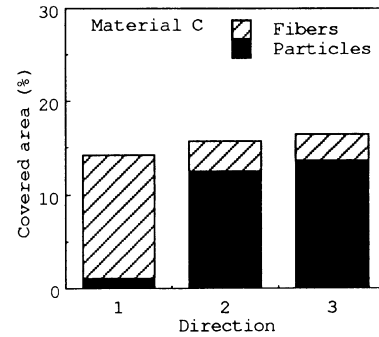
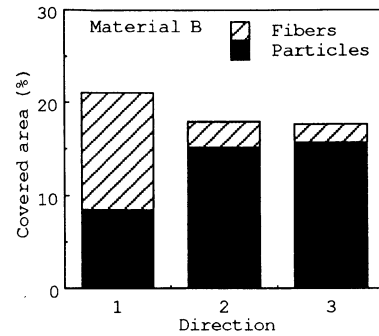
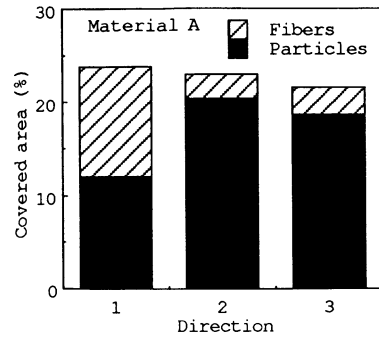


Fig.4 Area fractions covered by the reinforcement in composites A,B and C

plane and the higher the fiber content the higher the difference in velocity. No difference in longitudinal velocity was, however, found for waves propagating in the plane of the fibers having different polarization directions. Furthermore, the velocities of the shear waves propagating normal to the plane of the fibers but polarized in different directions are the same whereas the velocities of the shear waves propagating in the plane of the fibers are higher when the waves are polarized in the plane than when the waves are polarized normal to the plane. This means that the squeeze-cast specimens show a transversely isotropic behavior which is in agreement with their microstructure.

From above it can be concluded that in pressed as well as in extruded metal-matrix composites, there is anisotropy between the longitudinal elastic constants in the pressed or the extrusion direction and those in the plane perpendicular to this direction. The anisotropy in these composites is also found to be enhanced as the amount of reinforcement is increased, and can be interpreted as the result of the formation of texture in the aluminum matrix. In squeeze-cast composites, however, the anisotropy is likely to be due to the anisotropy in the fiber reinforcement.

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