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INVESTIGATION OF MECHANICAL PROPERTIES OF SIC-PARTICULATE REINFORCED COMPOSITES MATERIAL

Praveen Kumar Soni, S P Shrivas, Richa Pahwa

Mechanical engineering department, Chouksey engineering college, Bilaspur

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Email: info@jusres.com

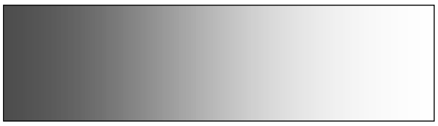
ABSTRACT

High strain rate tests in the range of 1000-3000s-1 were conducted using a compression type Split Hopkinson Pressure Bar (SHPB) set-up. The compression true stress-strain curves of the tested elastic-plastic FGM systems were satisfactorily approximated using the equal-stress model while the high strain rate testing in SHPB involved complex wave propagation events between the layers of FGM. The samples failed under compression at high strain rates particularly at the interface of the layer of the lowest impedance. This result was also confirmed with LSDYNA3 finite element modeling of a 10 and 20% SiC layered composite material system. The model has shown that higher compressive stress-time history occurred in the layer of the lowest impedance during SHPB testing. Microscopic observation of the failed samples was further shown that the mechanically weakest link of the layered samples was the interfaces between the layers. This was solely due to the formation of a thin oxide layer at the interfaces. The modeling results were further found to be promising in modeling of FGM systems for future investigations.

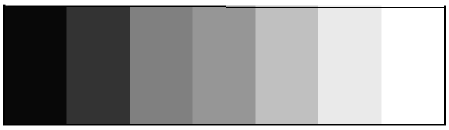
KEYWORDS: Sic Particulate, Composite Material, Mechanical Strength.

1. INTRODUCTION

Recent advances in materials processing and engineering have led to a new class of materials called Functionally Graded Materials (FGMs). FGMs display continuously or discontinuously (discretely) (Figures.1(a) and (b) varying compositions and/or microstructures and related properties including hardness, density, thermal conductivity, resistance, Young's modulus and etc., over definable geometrical distances according to the desired function. The gradients can be continuous on a microscopic level, or they can be laminates comprised of gradients of metals, ceramics, polymers, or variations of porosity/density.



(a)



(b)

Figure 1 Gradient architecture of FGMs; (a) continuously graded and (b) discretely layered FGMs.

The history of FGMs may be dated back to 80s. The initial idea of a graded material was to combine the incompatible properties of heat resistance and toughness with low internal thermal stress, by producing a compositionally graded structure of distinct ceramic and metal phases [1]. In 1987 a large national project entitled, *Research on the Basic Technology for the Development of Functionally Gradient Material for Relaxation of Thermal Stress*, commenced in Japan. The project was aimed at developing superheat-resistant materials for the propulsion system and air-frame of the space plane [1]. Because of high thermal gradients, metallic structures have traditionally been coated with heat-resistant materials.

2. OBJECTIVE OF WORK

The effects of using different types of finite element approximations on the predicted stress wave propagation through a graded material were investigated. Using conventional elements they simulated one dimensional stress waves using a distinct phase model, a discretely layered model and a smoothly varying model. Results of the simulations showed that different discretization caused a relative shift in the wave speed and the magnitude of this shift increased with time.

The property gradient in a continuously nonhomogeneous material will cause a continuous change in acoustic impedance as a function of position. Using conventional elements in modeling elastic stress wave propagation in a graded material produces a piece-wise constant approximation for the actual impedance and this causes distinct boundaries for the stress waves where in the actual nonhomogeneous system these distinct boundaries do not exist [9]. Thus using graded finite elements in modeling the stress wave propagation in continuously nonhomogeneous materials can be beneficial [10].

1. To find out the behavior and Poisson's ratios of deformation layered material
2. Predict the corresponding individual layer properties based on equal-stress method.
3. Modeling observations of two layers composite material system have to be measured.
4. Determine the bonding strength between layers in melting processes.

3. MATERIALS AND MMC PROCESSING

Both single layer and multi-layer composites were prepared using a powder metallurgy route schematically shown in Figure 2. The process starts with the mixing of appropriate amounts of basic ingredients (Al and SiC powders) inside a plastic container, which was rotated on a rotary mill in order to form a homogeneous powder mixture. Then powder mixture is compacted at 600 MPa in a cylindrical steel die with a diameter of 16 mm using a uniaxial hydraulic press. For the multi-layer samples thickness of the individual layers is adjusted to be equal. In the compaction of multi-layer samples, the layers are sequentially pre-compressed at a lower stress (100 MPa) and then they were compacted altogether at 600 MPa in order to provide a strong bonding between layers. Resulting samples are cylindrical in shape with 16 mm and 10 mm in diameter and height respectively. In a further step the cold compacts are heat-treated at 650˚C for 1 hour in a Protherm PLF160 laboratory furnace in order to homogenize the compacts and relief the stress concentrations. The heat treatment is performed in an enclosed steel box (welded steel box) in order to prevent the oxidation of the compacts. The heat treated MMCs samples are then quasi-statically deformed using a Shimadzu AG-I 250KN Tension-Compression Test Machine at a strain-rate of 1.7x 10^{-3} s^{-1} up to 60% strain. During compression testing the interface between two layers bends at the edges because of the difference between the Poisons ratios of the layers. Such a bend interface for a 2-layer sample after quasi-static deformation. Finally to obtain a straight interface between layers, the deformed samples are cut into a square cross-section of 10 mm long as shown in Figure 4.6 with dash lines. These samples are further compressed at various strain rates in order to see the effect of strain rate on the deformation behavior. Using above technique, relatively dense single and multi layered MMCs were prepared.

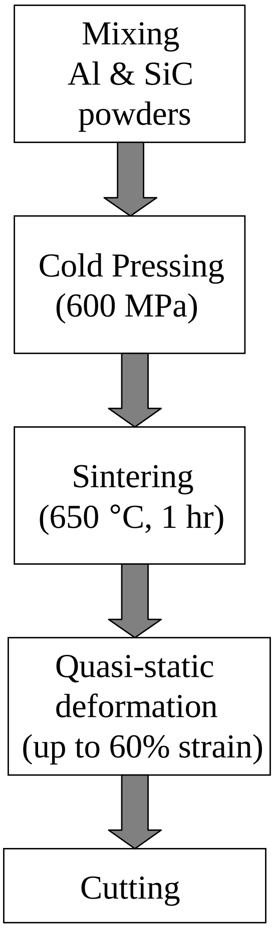


Figure 2: Schematics of sample preparation

High Strain Rate Testing

As the nineteenth century progressed, there was an increasing awareness that the properties of materials under impact differed from those under static loading. Historically, the first experimental study of high strain rate deformation was reported by Zhang [10], he used a long thin bar known as the Hopkinson Pressure Bar, to measure the pulse shape induced by an impact. In 1948, Davies developed a technique using condensers to measure the strains existing in the pressure bar. The following year Kolsky added a second pressure bar to Hopkinson's original apparatus, hence the name *Split* Hopkinson bar. The split Hopkinson bar technique, which has been initially used in compression, has been extended to tension [4] and torsion [5]. An arrangement, which permits, loading with one and just one pulse in compression, as well as in tension, has been reported in the work of Nemat-Nasser and co-workers [6].

4. DENSITY MEASUREMENTS

Densities of both single-layer and multi-layer samples were measured and relative densities were calculated as explained in section 3.3, before and after quasi-static deformation. The density measurement results are shown in Figure 5.1 for single and multiple layer samples. Also as shown in this figure, the quasi-static deformation is effective in increasing the relative densities of the single and multi-layer samples. A relatively higher density is also seen in Figure 5.1 for single layer Al samples before and after quasi-static deformation, while single layer 20% SiC samples show relative lower densities as compared with single layer samples of Al and 10% SiC. The relative densities of multi layer samples are also comparable with those of Al and 10%SiC single layer samples and the relative densities of single and multi layer samples, after quasi-static deformation, are higher than 98% except 20% SiC single layer sample as depicted in Figure 3.

The reduced relative densities of the single layer composite samples as compared with Al sample before and after quasi-static deformation is likely due to the lack of inelastic deformation capability of the SiC particles, leading to insufficient plastic deformation for the enclosing of the porosities which are presumably existed between matrix-particle interfaces. The plastic deformation may also induce damage accumulation in the form of matrix voiding and cracking and particle cracking which have reverse effect on the relative densities of the composite single samples. Before testing of samples the sample surfaces and sides were carefully checked for the visible macro-cracks and none was found. Few of the samples were also cut through cross-section and prepared metallographically for microscopic observations. Again no cracks were observed in polished surfaces.

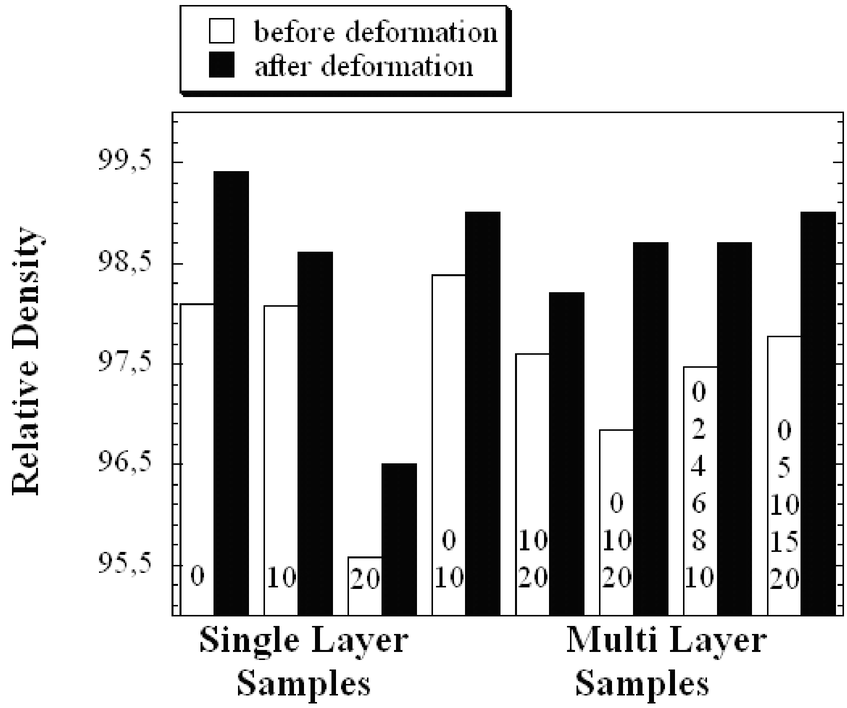


Figure 3. Relative densities of single and multiple layers

Microscopy

Table 1 summarizes failed specimens at high strain rates. Among the tested single layer samples, Al and 20% single layer samples did not show any failure while 2 samples of 10% SiC failed. In 3, 5 and 6 layer samples failure occurred through the separation of the first layer, Al, at the highest gas gun pressure corresponding to the strain rates of ~3000 s^{-1}. SEM studies have shown that the SiC particles fractured during the separation of the interface. It was also found that during processing of MMC layers a thin oxide layer formed between the layers. The formation of thin oxide layer is expected to be effective to reduce the bonding strength between the layers and therefore the failure occurred at the interfaces.

Table 5.1 Failed Specimens at High Strain Rates.

	Type	Number of Specimen	Test Pressures	Number of broken samples
Single-layer samples	Al	6	30,60,90	None
	10%SiC	6	30,60,90	2
	20%SiC	7	30,60,90	None
Multi-layer samples	0/10	5	30, 90	None
	10/20	5	30, 90	None
	0/10/20	6	30, 90	4 , 90psi (Al layer)
	0/2/4/6/8/10	4	30, 90	2 (90)
	0/5/10/15/20	6	30, 90	2 , 90psi (Al layer)

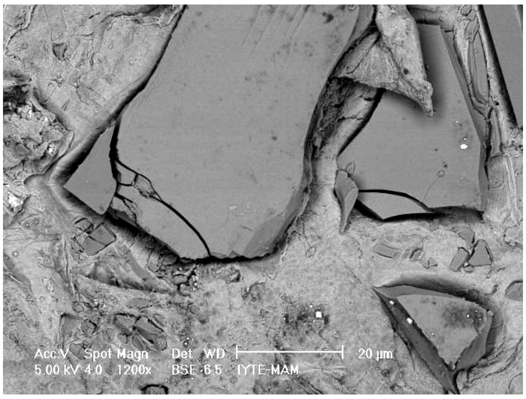


Figure 4.SEM images of the failed 0/10/20 sample 0/10 interface tested at 90 psi showing fractured SiC particles.

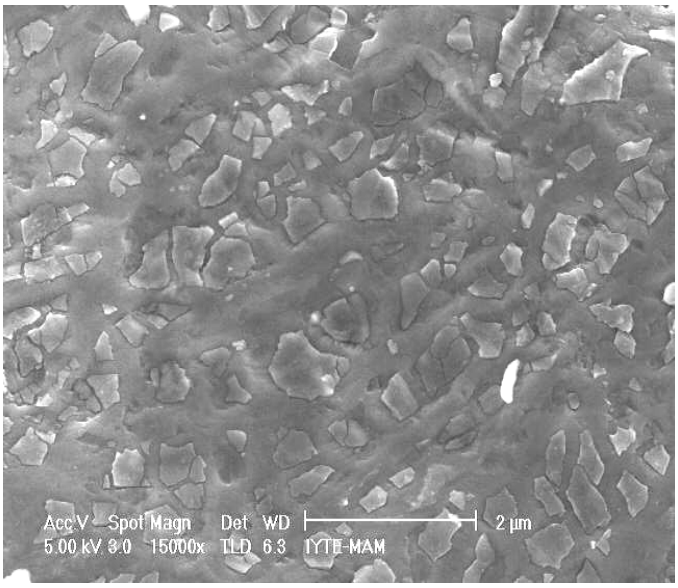


Figure 5SEM images of the failed 0/10/20 sample 0/10 interface tested at 90 psi showing oxide plates.

The wave propagation in SHPB is quite complex. The compressive wave passing through the Al layer is reflected as a compressive wave at the interface with a higher impedance layer of the composite while it is reflected as a tensional wave from the specimen-bar interface. The compressive waves returned from the interfaces increases the magnitude of the compressive wave in the layer while the returned tensional wave tends to reduce the compressive wave. As the wave is reflected back and forth between the layers and between the specimen-bar interfaces, the analysis of the wave propagation becomes very difficult. But the failure in the first layer signaled that large compressive stresses occurred in the first layer or at the interface between Al and composite layer, which will be shown in the next section.

5. CONCLUSION

In this study, FGM systems composing of SiC-particulate Al composites of varying reinforcement volume fractions and single layer composites were manufactured by following a powder metallurgical route.

1. The deformation behavior of layered material system was found to be quite complex due to the differences between the Poisson's ratios of the individual layers leading to non-homogeneous deformation of layers.
2. The true stress-strain curves of discretely layered samples at quasi-static strain rates can however be approximated by using the corresponding individual layer properties based on equal-stress method.

3. The deformation behavior of layered samples at high strain rates was complicated due to the complex wave propagation events between the layers and SHPB bars and sample as well.

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