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Neutron Diffraction Analysis on Particulate Reinforced Metal Matrix Composites and Its Verification Using FEM

Taegyu Lee [a], Hobyung Chae[b], Soo Yeol Lee[b], Ho Jin Ryu[a]*
[a]*Department of Nuclear and Quantum Engineering, KAIST, Daehak-ro 291, Yuseong-gu, Daejeon, 34141, Korea,*
[b]*Department of Materials Science and Engineering, Chungnam National University, Daehak-ro 99, Yuseong-gu, Daejeon, 34134, Korea*
*Corresponding author: hojinryu@kaist.ac.kr

1. Introduction

As a non-destructive test, neutron diffraction can measure the internal stress by measuring the lattice spacing of the specimen [1]. Neutron diffraction is particularly useful for investigating the mechanical behavior of two-phase materials such as TRIP and TWIP steels [2]. However, because the neutron diffraction method measures the average strain [3], it is difficult to analyze the brittle material in which stress is not released by slip and concentrated. In addition, it is not known which strain, among FCC{311} lattice strain or weighted average phase strain, explains the mechanical behavior correctly. Therefore, in this study, the internal stress of Al/SiC metal matrix composites (MMCs) with the different SiC particle sizes by characterizing the FCC{311} lattice strain and weighted average phase strain by neutron diffraction and FEM.

2. Methods and Results

2.1 Preparation of Material and its Characteristics

The sizes of SiC powder (Saint-Gobain) were 10 µm, 30 µm, and 50 µm, and 7075 aluminum alloy powder with 80 µm in diameter (Kojundokorea) were prepared. The powders were mixed using a 3D mixer with 50 rpm for 5 h and the volumetric ratio of the two powders was 55:45. The Al/SiC MMCs were consolidated using the liquid pressing technique [4]. The liquid pressing was performed at 900 °C under 100 MPa then MMCs were air-cooled. The fabricated composites were cut into ø6 × 8 cylinders to perform a compression test.

The density of fabricated samples was measured by the Archimedes method and the samples showed less than 3% of porosity. Fig. 1 is the scanning electron microscopy (SEM) image of the microstructure of fabricated samples with 30 µm-sized SiC particles.

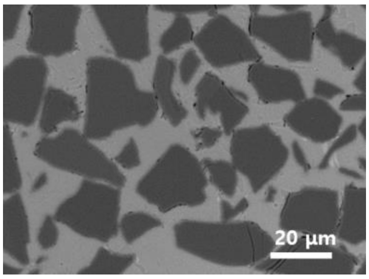

Fig. 1. The microstructure of fabricated composites.

2.2 In-situ Neutron Diffraction

The compression tests were performed at the VULCAN beamline (BL-7) of Oak Ridge National Laboratory (USA) and in situ neutron diffraction patterns were obtained during the compression test. The stress increasing rate was 0.75 N/s during the compression test and the chopping frequency was 30 Hz.

The compression test results are shown in Fig. 2, The sample with a smaller size reinforcement shows higher strength and lower total strain, while the sample with a larger size reinforcement shows the opposite. In addition, MMCs show very high strength compared to 7075 alloy.

The mechanical behavior of composites using 10 and 50 µm-sized SiC reinforcements was traced through neutron diffraction. At this time, the internal stress was measured based on the strain rate of aluminum. When measuring the mechanical behavior, two methods were used, one was to measure the strain of the Al (311) plane (Fig. 3), and the other was to measure the weighted average phase strain of Al using Rietveld refinement (Fig. 4). In the axial direction, the results show a monotonically increasing compressive strain of the Al matrix. In addition, a smaller amount of matrix strain is observed at the same stress when small SiC reinforcements are used. There is no significant difference between FCC{311} lattice strain and weighted average phase strain of Al in the axial direction but there is some difference in the transversal direction. In the transversal direction, commonly matrix elongated at an early stage and compressed at stress higher than 150 MPa due to the constraint by SiC reinforcement. There are some differences between FCC{311} lattice strain and weighted average phase strain of Al in transversal direction and averaged strain. Averaged strain shows amplified strain result compared to FCC{311} lattice strain.

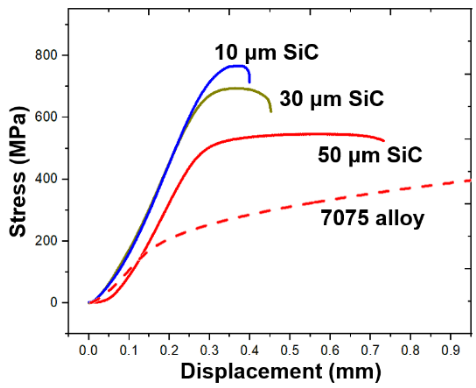

Fig. 2. The compression test results.

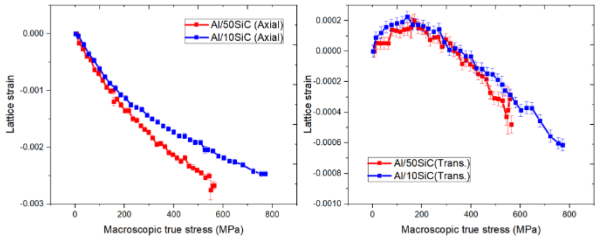

Fig. 3. Axial FCC{311} lattice strain (left) and transversal strain (right).

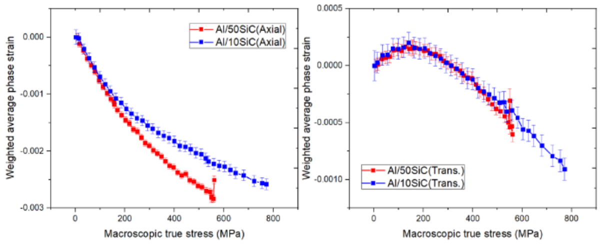

Fig. 4. weighted average phase strain of Al axial (left) and transversal strain (right) of Al.

2.3 Finite Element Method Analysis

The three-dimensional microstructural geometry of the actual MMCs was created through the Dream 3D program. The created geometry is transferred to a FEM code after creating the mesh to simulate the compression test. The properties used at this time are shown in Table 1.

Table I: Properties of simulated materials

	SiC	Al
Modulus	400 GPa	70 GPa
Yield strength	1400 MPa	280 MPa
Poisson ratio	0.19	0.33

As shown in the results of the FEM (Fig. 5), it can be seen that when the reinforcement is large, the deviation in the stress applied to the reinforcement increases. Therefore, it is also confirmed that the maximum value of the stress also increases in the same bulk stress. Even in the case of the Al matrix, it can be confirmed that the deviation in stress increases as the size of the reinforcement increases. However, it was confirmed that the average stress value was not significantly affected.

The stress applied to SiC and Al was calculated through the compression test simulation, and the stress was compared with the result measured through neutron diffraction. The accuracy of calculating mechanical behavior using the strain of the (311) plane and the weighted average phase strain was compared using simulation results as a reference.

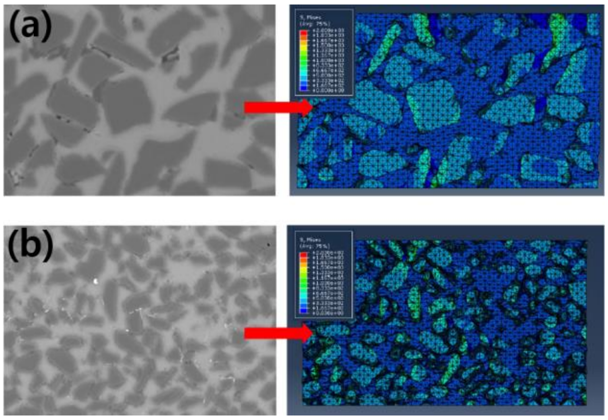

Fig. 5. FEM simulation results of Al/SiC composites with large size reinforcement (a) and small size reinforcement.

3. Conclusions

In this study, the stress distribution of MMCs with varying reinforcement size was investigated by using the neutron diffraction technique. The strain of Al (311) and the weighted average phase strain of Al were compared. The accuracy of both methods was measured through FEM analysis. After that, the stress dispersion according to the size of the SiC particles and the fracture behavior were analyzed.

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