Residual Stress Measurement of SiC tile/Al7075 Hybrid Composites by Neutron Diffraction

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1. Introduction

A requirement to make ceramic/metal composites for many parts of industry has been identified. Especially, military industries have been used specific ceramics, such as B_4C, SiC, and Al_2O_3 for military armor applications due to their mechanical properties [1, 2]. In this research, SiC which has low density, high compressive strength, and high elastic modulus was used to fabricate the armor plate. In addition, Al which has low density and high toughness was used for a metal matrix of the composites. If two materials are combined, the composite can be effective materials for light weight armor applications.

However, the existence of a large difference in coefficients of thermal expansion (CTE) between SiC and Al matrix, SiC/Al composites can have residual stresses [3] while cooled in the fabrication process. Previous research reported that residual stresses in the composites or microstructures have an effect on the fatigue life and their mechanical properties [4]. Some researchers reported about the residual stresses in the SiC_p/Al metal matrix composites by numerical simulation systems, X-ray diffraction, and destructive methods [4, 5].

Among useful methods for measuring residual stress, such as X-ray diffraction, neutron diffraction, hole-drilling and magnetic techniques, the neutron diffraction method can be used to measure the residual stress in the bulk type of composites without destruction of the samples.

Even though some research reported regarding the residual stress of the SiC_p/Al system or an Al7075 alloy using X-ray diffraction [6], there is no published work regarding the residual stress measurement of SiC tile/Al7075 hybrid composites using the neutron diffraction. The objective of this study was to analyze the residual stresses in the SiC/Al7075 hybrid composites by neutron diffraction.

2. Methods and Results

2.1 Preparation of the samples

The cubic SiC tile (SiC_t, 8 x 8 x 8 mm^3) was used to fabricate the SiC_t inserted SiC_p/Al7075 hybrid composites (18 x 18 x 18 mm^3). Fig. 1 shows the schematic of SiC_t inserted SiC_p/Al7075 hybrid composites. The Al7075 (Al, 5.6–6.1% Zn, 2.1–2.5% Mg, 1.2–1.6% Cu) reinforced by 50 vol.% of SiC_p were prepared for the Al metal matrix composites (MMC) by liquid-press process [8]. Using the liquid-press process, the composites were fabricated at 750 ℃ with 20 MPa of applied pressure. After fabricating the composites, they had been cooled down in the furnace with a cooling rate of 20 ℃/min until 470 ℃. The Al7075 matrix of the SiC_t/Al7075 hybrid composites always had 50 vol.% SiC_p reinforcement in this study. In addition, SiC_p with 30 ㎛ of particles size, as-received SiC_t, and as-received Al7075 were prepared for the reference (d_0) as a stress-free state.

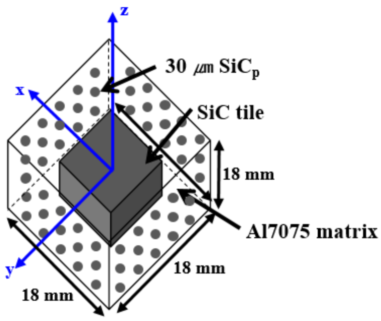

Fig. 1. The schematic diagram of SiC tile inserted 50 vol.% SiC_p/Al7075 hybrid composite fabricated by liquid-press process.

2.2 The measurement of residual stress

In this study, the neutron diffractometer DN1 (Fig. 2) of National Nuclear Energy Agency (BATAN, Indonesia) was used to analyze the residual stresses. The measurement was performed at a wavelength of λ=1.8365 Å and with a gauge volume of 3 x 3 x 3 mm^3. The Al (111) and SiC (111) peaks were investigated by neutron diffraction. Table I shows the specific conditions of the neutron diffraction measurement.

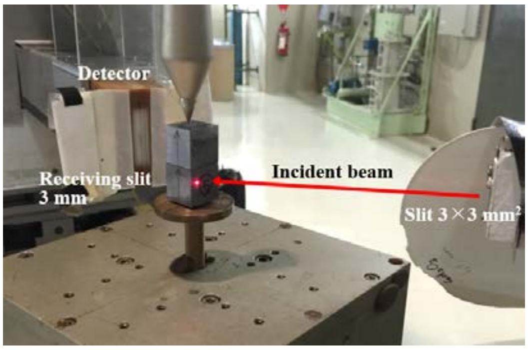

Fig. 2. The photograph of the experimental set-up for residual stress analysis by neutron diffractometer DN1.

Table I: Conditions of neutron diffraction measurement

Monochromator	Si (311) focused
Wave length	1.8365 (Å)
Detector	He3 2-D position sensitive detector (PSPD)
Slit system	Incident: 3 mm x 3 mm Receiving: radial collimator (3 mm)
h k l plane	SiC (111), Al (111)
Young's modulus E, Poisson's ratio *v*,	SiC: E = 410 GPa, *v* = 0.168 Al7075: E = 71.7 GPa, *v* = 0.33
Coefficient of thermal expansion α at R.T.	SiC: 4.0 x 10^{-6}/℃ Al7075: 23.6 x 10^{-6}/℃

2.3 Results

For calculation of residual stress, d_0 values of SiC_t, SiC_p and Al7075 which consist of SiC_t/Al7075 hybrid composites were measured. The peak positions of diffraction patterns and d_0 values are summarized in Table Ⅱ and used to calculate residual stress of SiC_p/Al7075 composites and SiC_t/Al7075 hybrid composites.

Table Ⅱ: Summary of reflection plane, measured diffraction angle, and d-spacing for d_0 data.

Reflection plane (*hkl*)	Measured diffraction angle (°)	d-spacing (Å)
Al (111)	45.7748	2.5627
SiC_p (111)	43.03208	2.6915
SiC_t (111)	43.06019	2.6897

Also, the residual stress of 50 vol.% SiC_p/Al7075 composite was measured to investigate the effects of encapsulation of SiC tile in the SiC_p/Al7075 composites.

The residual stress can be calculated by following equations [7].

$$\varepsilon = (d - d_0)/\, d_0 = -\cot(\theta)(\theta - \theta_0) \qquad (1)$$

where,
d = measured lattice plane distance
d_0 = lattice place distance at stress-free state
θ = measured central angle of diffraction peak
θ_0 = central angle of diffraction peak at stress-free state

$$\sigma_i = \frac{E_{hkl}}{1+\upsilon_{hkl}}\left[\varepsilon_{ii} + \frac{\upsilon_{hkl}}{1-2\upsilon_{hkl}}(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz})\right] \qquad (2)$$

where,
σ = residual stress
E_{hkl} = elastic modulus of lattice plane (*hkl*)
υ_{hkl} = poisson ratio of lattice plane (*hkl*)
ε = strain
i = direction of stress

The calculated strain and residual stress of Al and SiC_p are summarized in Table Ⅲ. The measured data clearly showed that Al phase had the tensile residual stress and SiC phase had the compressive residual stress at the center position of the sample due to their difference in CTE.

Table Ⅲ: Summary of reflection plane, d-spacing, strain, and residual stress of 50 vol.% SiC_p/Al7075 composite.

Reflection plane (*hkl*)	d-spacing (Å)	Strain	Residual stress (MPa)
Al (111)	2.5693	3397.64	383.85
SiC_p (111)	2.6892	-873.1	-384.02

The SiC_t inserted 50 vol.% SiC_p/Al7075 hybrid composite (see in Fig. 3(a)) was measured to analyze the effect of the SiC_t encapsulation on the residual stress of the SiC_p/Al7075 composites. The diffraction peaks of SiC tile (111) are shown in Fig. 3(b). The Al (111) and SiC_p (111) was measured with seven positions from 2.5 mm off from surface of the sample to analyze the effect of the different measured position. SiC tile was also analyzed at two positions. The residual stresses of Al phase at seven positions indicated tensile stresses. However, the residual stresses of both SiC_p and SiC_t showed compressive stress. Although these results were same as 50 vol. % SiC_p/Al7075-MMC, Al phase (111) of the SiC_t inserted SiC_p/Al7075 hybrid composites had higher residual stress than the residual stress of 50 vol.% SiC_p/Al7075 composite due to the effect of encapsulation of SiC tile. In addition, the central position of the sample had higher residual stress than the surface area.

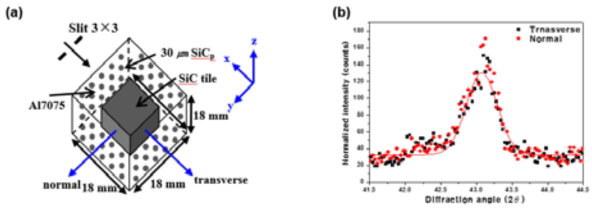

Fig. 3. (a) Schematic diagram of SiC_t inserted 50 vol.% SiC_p/Al7075 composites and (b) diffraction peak of SiC tile (111) at the center position with transverse and normal beam direction.

3. Conclusions

In order to analyze the residual stress of SiC/Al composites, the neutron diffraction as the non-destructive method was performed in this research.

The 50 vol.% SiC_p/Al7075 composites and SiC tile inserted 50 vol.% SiC_p/Al7075 hybrid composites were measured to analyze the residual stress of Al (111) and SiC (111). Both samples had the tensile residual stresses in the Al (111) and the compressive residual stresses in the SiC (111) due to the difference in CTE. In addition, as goes to the center of the sample, the residual stress data were increased due to the effect of encapsulation of SiC tile and a gap of cooling time between surface and center point.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF, No. 2014M3C1A9060721) grant funded by the Korea government (MSIP). The Korean Neutron Beam Users Association (KNBUA) also supported to go to BATAN with the program of supporting graduates to use the foreign neutron facility.

Furthermore, we appreciate Dr. Wanchuck Woo and Dr. Dong-Kyu Kim of KAERI for consultation.

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