ANALYSIS OF INTERFACIAL SHEAR STRENGTH OF SiC/Al COMPOSITE BY ACOUSTIC EMISSION METHOD

Yun Lu and Mitsuji Hirohashi

Department of Mechanical Engineering, Faculty of Engineering, Chiba University, 1-33,
Yayoi-cho, Inage-ku, Chiba 263, Japan

(Received July 2, 1997)

(Accepted September 18, 1997)

1. Introduction

It is widely known that the mechanical properties of fiber reinforced metal matrix composites depend on the mechanical bonding state of interface between fiber and matrix [1]. Interfacial shear strength, as an important parameter, is often used to estimate the bonding of the interface [2,3]. In order to evaluate the interfacial shear strength, pull-out [4,5], push-out [3,6] and multiple-fracture methods [2,7] have been used. Multiple-fracture method, which is also called single-fiber-composite technique [2], relies on multiple fragmentation under axial tension of a single fiber embedded in a matrix. However, it is not easy to examine the number of the multiple fragmentation. On the other hand, acoustic emission (AE) method, which is an effective one to monitor the failure process in structure material, has been applied to polymer or metal matrix composites [8,9]. We have examined the micro fractures, such as yielding of the matrix, failing of the interface and multiple breaking of the fibers in SiC/Al composite by using acoustic emission method [10]. In that work, it was cleared that the number of the broken fiber in the composite was in correspondence with AE events when amplitude is over 100dB.

In this study, three kinds of single fiber SiC/Al composites with different interfacial bonding strength were fabricated by the hot press processes. The number of the multiple broken fiber were evaluated by acoustic emission method during the tensile test, and then the interfacial shear strengths were calculated. Further, the number was also investigated by extracting the multiple fragmentation in the composite, and counting the number of the load drop on the load-time curve after the tensile test. Finally, both the number of the multiple broken fiber and the interfacial shear strength obtained from AE and the other two methods were compared and discussed.

2. Materials and Experimental Methods

2.1 Materials and specimens

The matrix material for the present study was 0.3mm thickness of A1050 pure aluminium plate. SiC_{CVD} fiber produced by Textron Specialty Materials (type SCS-2) with a diameter of 140 μ m was used as reinforcement material. Aluminium plate was cut into pieces (30×70mm) which were then annealed at 300°C for 30min. In order to arrange the fibers on the pieces orderly, U-shaped grooves with a 0.5mm interspace were made on one side of the aluminium pieces by pressing stainless steel wires (with a

TABLE I
Conditions of the Hot Press Processes

Process	I	II	III
Temperature (K)	773	873	893
Pressure (MPa)	28	47	56
Time (min)	10	20	40

diameter of 140 μm) into the pieces. SiC fibers were put into the grooves on the surface of one aluminium piece, which was then overlapped by an other aluminium piece. Hot press processes were carried out to make the SiC/Al composites.

Single fiber SiC/Al composites were fabricated by three kinds of hot press processes at the atmosphere. The conditions of the processes are given in Table I. A weaker interfacial bonding was formed by process I, while a stronger interfacial bonding was obtained by process III. To examine the strength of the SiC fibers in the SiC/Al composites, the fibers were extracted by dissolving the matrix with 10% NaOH water solution, and then tensile tests were carried out for the fibers.

2.2 Tensile test and acoustic emission method

Tensile tests were carried out by a tensile testing machine with screw driven and constant crosshead (Shimadzu, AG-5000ES). All tensile tests were performed at room temperature with a constant crosshead speed of 0.5mm/min and a gauge length of 30mm. The load was recorded as a function of time using a load-time recorder. Tensile specimens, in which the single fiber exists at the center, were cut into 12mm in width from the pieces of SiC/Al composites. The fiber volume fraction of the specimens is on the order of 0.26%. Tabs of aluminium were set to both the ends of all tensile specimens. For each process, the tensile tests of the SiC/Al composites and the extracted SiC fibers were performed over 30 and 50 times respectively.

AE signals during the tensile tests of the SiC/Al composites were measured with an AE analyzing system (9602 LOCAL PROCESSOR) produced by NF Electronic Instruments as shown in Fig. 1. In order to avoid the effect of plastic deformation of the composite specimen on the AE signals, an AE sensor (AE-900M-WB) was put on the center of a chuck which was specially designed in this test being connected to one side of the specimen as shown in Fig. 1. The AE signals were amplified by the local processor to a gain of 40dB after giving a gain of 40dB with a pre-amplifier. The data was analyzed by a computer, which was connected to the local processor with a GP-IP interface. To avoid the noise, a

Figure 1. Schematic drawing of acoustic emission system.

TABLE 2
Weibull Parameters of the Strength of Extracted SiC Fiber

Process	N	σ (GPa)	m	σ_0 (GPa)
Virgin fiber	50	4.68	11.20	4.89
I	52	4.12	5.96	4.46
II	50	4.42	7.73	4.71
III	51	4.44	6.13	4.80

highpass filter with a frequency of 100KHz and a discriminating level of 75dB were set, resulting from the pre tensile tests. Also according to the previous work [10], the events over 100dB were used as the number of the multiple broken fiber.

2.3 Calculation of critical length of the multiple broken fiber

The average number N of the multiple broken fiber was calculated with the AE events over 100dB for the three processes. Thereafter, the critical length L_c was calculated by Equation 1 [11], in which the distribution of the length of the multiple broken fiber was considered. The average length $\bar{L}$ was calculated from dividing the gauge length by $N+1$.

$$L_c = \frac{4}{3} \bar{L} \quad (1)$$

In order to verify the results obtained from AE method, the number of the multiple broken fiber in only gauge length was examined by dissolving the aluminium matrix by 20%NaOH water solution gradually (called extracted method) after the tensile test. On the other hand, the number was also counted by counting the load drops on the load-time curve (called chart method). Both the extracted and the chart methods have been used for fiber reinforced metal matrix composite in Reference 2.

The interfacial shear strength was calculated by Equation 2 as following:

$$\tau_s = \frac{d}{2} \frac{\sigma_f}{L_c} \quad (2)$$

where d is the diameter of fiber ($140\mu\text{m}$) and σ_f is referred to the fiber strength. The size effect of fiber strength can be evaluated by Equation 3, considering the fiber strength to obey Weibull distribution.

$$\sigma_f = \sigma_0 \left(\frac{L_c}{L_0} \right)^{-1/m} \Gamma \left(1 + \frac{1}{m} \right) \quad (3)$$

where σ_0 represents the scale parameter, m is the shape parameter and L_0 is a standard length (gauge length), which is 30mm. Γ is a gamma function. In this study, σ_0 , and m of the strength of the extracted fiber were used as ones in Equation 3.

3. Experimental Results and Discussion

The average strength and Weibull parameters of the extracted fibers are shown in Table 2. The parameters, which changed in data after the hot press processes, were used for the calculation of the interfacial shear strength. As an example, a load-time curve and AE events over 100dB of SiC/Al composite are shown in Fig. 2. The number of the multiple broken fiber obtained by the AE method was

Figure 2. Load and AE events over 100dB during the tensile test (process III).

corresponding to that by the chart method from the comparison between the load drops and AE events over 100dB. The number of the multiple broken fiber obtained from the same piece of specimen by both AE and the extracted method is shown in Fig. 3. The number obtained by AE method is almost the same as that using the extracted method. However, for a little part of the specimens, the number obtained from the AE method is one more than that obtained by the extracted method. The average numbers of the multiple broken fiber for all the specimens are calculated and listed in Table 3. The average numbers are almost the same between AE and the chart methods for the three processes, but they are a little larger than that obtained from the extracted method. It is considered that a little of multiple fragmentation in the tabs can be observed and removed during dissolving the aluminium matrix gradually, but the counts in the tabs can not be removed in both AE and the chart methods.

Figure 3. Number of the multiple broken fiber by AE and the extracted method.

TABLE 3
Average Number of the Multiple Broken Fiber of the Three Processes

Process	N	Average number of the multiple broken fiber		
		AE	chart	extraction
I	29	1.39	1.41	1.35
II	32	4.42	4.41	4.31
III	32	4.48	4.47	4.19

The critical lengths were calculated with Equations 1. Then the interfacial shear strengths were calculated by Equations 2 and 3 for the three processes. The results are shown in Table 4. Using each of the three methods, the critical length and the interfacial shear strength were found to be almost the same for each of the three processes, although the counts of the multiple broken fiber in the tabs can not be removed in both AE and the chart methods as stated above. The interfacial shear strengths, which are the strongest for process III and the weakest for process I, are considered to be in a correct range for the three processes. The above results indicate that AE method is an effective and convenient one for investigating the interfacial shear strength. It is expected that the number of the multiple broken fiber in the tabs are removed with a special filter using two sensors.

4. Conclusion

SiC/Al composites with different interfacial bonding strength were fabricated by the hot press processes. The interfacial shear strength was examined by counting the number of the multiple broken fiber in the composite using AE method. The chart and the extracted methods were also adopted for comparison. The experimental results indicate that AE method is an effective and convenient one to investigate the interfacial shear strength of fiber reinforced metal matrix composite.

Acknowledgment

The authors wish to thank Mr. Yukio ARAOKA for his help producing some specimens.

TABLE 4
The Critical Length and the Interfacial Shear Strength

Process	Le (mm)			τ_s (MPa)		
	AE	chart	extraction	AE	chart	extraction
I	16.74	16.60	17.02	19.07	19.26	18.71
II	7.38	7.39	7.53	50.36	50.28	49.23
III	7.30	7.31	7.71	53.84	53.75	50.52

References

1. Y. Kagawa and A. Okura, J. Iron and Steel Institute of Japan. 75, 1719 (1989).
2. J. L. Houpert, S. L. Phoenix, and R. Raj, Acta Metall. Mater. 42, 4177 (1994).
3. Y. Kagawa and A. Okura, J. Japan Institute of Metals. 56, 278 (1992).
4. C. H. Hsueh, J. Materials Science. 25, 818 (1990).
5. K. Honda and Y. Kagawa, J. Japan Institute of Metal. 58, 91 (1994).
6. C. R. Ananth and N. Chandra, J. Composite Materials. 29, 1488 (1995).
7. S. Ochiai, K. Osamura, P. W. M. Peters, and K. Schulte, Proc. Japan-U.S.CCM-V, p. 505 (1990).
8. J. G. Bakuckas, W. H. Prosser, and W. S. Johnson, J. Composite Materials. 28, 305 (1994).
9. K. Komai, K. Minoshima, M. Nakano, and Y. Uematsu, Advances in Fiber Composite Materials, p. 59, The Society of Materials Science Japan (1994).
10. Y. Lu, M. Hirohashi, and H. Asanuma, Tran. Japan Society of Mech. Eng. A62-593, 97 (1996).
11. Y. Kagawa, Fiber Reinforced Metals Composite, p. 232, CMC Company (1985).