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The Frequency Characteristics of Elastic Wave by Crack Propagation of SiC/SiC Composites

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Key Words: SiC/SiC Composite Ceramics, Fiber reinforced SiC matrix(SiC/SiC), Wave propagation, Acoustic emission(AE), Wavelet analysis, Dominant frequency.

ABSTRACT

We studied on the nondestructive evaluation of the elastic wave signal of SiC ceramics and SiC/SiC composite ceramics under monotonic tensile loading. The elastic wave signal of cross and unidirectional SiC/SiC composite ceramics were obtained by pencil lead method and bending test. It was applied for the time-frequency method which used by the discrete wavelet analysis algorithm. The time-frequency analysis provides time variation of each frequency component involved in a waveform, which makes it possible to evaluate the contribution of SiC fiber frequency. The results were compared with the characteristic of frequency group from SiC slurry and fiber. Based on the results, if it is possible to shift up and design as a higher frequency group, we will can make the superior material better than those of exiting SiC/SiC composites.

1. Introduction

Since silicon carbide has many advantages of thermal and mechanical properties, it is necessary especially in aerospace and advanced energy systems (1). Though the SiC/SiC composites have superior characteristics as a structural material, these are very brittle and have complex structure. Referencing the previous author's works(2,3,5~9), for example, when it sintering with the additive 3 wt.% Y_2O_3, it was most suitable, its properties were demonstrated as the mechanical superiority and relatively concentrated on the highest frequency group.

In brittle materials like the ceramics, if we would make the strength to be high, as the similar density of the composites, we should make the stiffness to be high. The high stiffness presents the high frequency at the micro-structure on the whole. In order to give the high stiffness to structural material under the similar density of the composites, if it would be possible to control the matrix formation with certain amount of sintering additives or SiC fiber, it would be obtained as the high frequency. So it is necessary to investigate the characteristic frequency of the SiC composites.

In this work, we at first analyzed the frequency of AE for the SiC fiber tows and the wave propagation by the pencil lead method. From the results, the frequency of the SiC slurry could be classified as the characteristic frequency into the different frequency group each other. At last, after analyzing the AE frequency when composites specimen fractured by bending load, we can understand that the every frequencies become to classify corresponding to some cases of frequency group. Using the information of analyzing the characteristic frequency group, it will be possible to feed back into improvement of process with the sintering additives and reinforcement of the SiC fiber.

2. Experimental Materials and Test Method

In this study the SiC/SiC composite materials were prepared as products based on the NITE(Nano-

Infiltration Transient Eutectic Phase Sintering) Process (4). The SiC fiber tows(Tyranno SA, fiber diameter 7.5 µm, PyC layers 500 nm, 1600 f/b) coated by Pyrolytic Carbon were used as reinforcement. Figure 1(a) shows the cross section of Tyranno SA fiber used in this experiment. Beta-SiC nano-phase power with an average particle size of 100 nm was used for matrix formation, and after mixing as the rate of 90:10, 6 wt.% Al_2O_3 and 4 wt.% Y_2O_3 were sintered as slurry of additives.

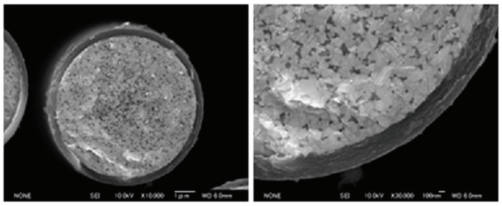

Figure 1(a) Cross section of Tyranno-SA SiC/SiC fiber.

That is, after infiltrating the Tyranno SA fiber bundle (40~45 vol.%) to the slurry, the SiC/SiC was made by NITE process at 1850 ℃ with 20 MPa pressure in Ar gas for 1 hr. Figure 1(b) shows the UCS of uni-directional(0°) fiber bundle reinforcement in Figure 1(b), and CCS of cross-directional(90 °) fiber bundle sintering in Figure 1(c).

The sintered plates were cut into specimens of 3 mm × 4 mm × 18 mm, fracture test was performed by three point bending test with cross head speed 0.5 mm/min in room temperature.

The wave detecting system was used, the trigger detecting the AE signal and duration time for a event were about 15 µsec and 102.4 µsec, respectively. And the frequency of the elastic wave signal was analyzed by using the discrete wavelet analysis method.

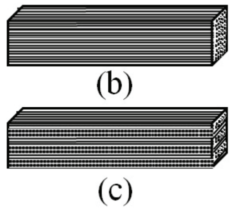

Figure 1(b) Uni-directional composite specimen (UCS), (c) Cross-directional composite specimen (CCS)

The tensile test of SiC fiber tows was applied according to the carbon fiber tensile test. When the fiber tows cut off due to the tensile load (5N) speed 0.5 mm/min, the elastic wave signal was obtained by the AE sensor attached to the fiber tows rear side in Figure 1(d).

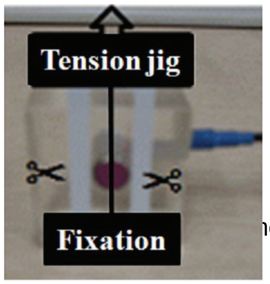

Figure 1(d) AE ıod for the signal sensing of

3. Results and discussion

3.1 Frequency characteristics of SiC fiber tows fracture

Figure 2 shows the results of the time-frequency analysis when the burst AE signal was obtained, one by one, by a SiC fiber tow fracturing and these compared with respect to two kinds of SiC fiber diameter. In the case of fracturing SiC fiber diameter of 7.5 µm, the frequency group was concentrative to the range about 468 kHz and additively found at components of 322 kHz and 585 kHz.

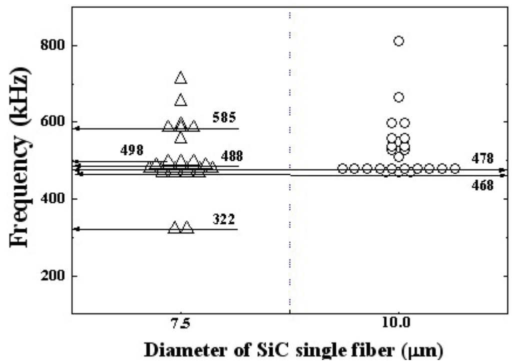

Figure 2 Frequency concentration and distribution according to each SiC fiber diameter (7.5 μm/10 μm).

In the case of fracturing SiC fiber diameter of 10 μm, the frequency group shows that it is concentrative between 468 kHz and 478 kHz. When the SiC fiber tow fractured, these characteristic frequency of fracture instant are found at similar and/or near the frequency band of SiC fiber tow, so we can understand that the central frequency of the SiC fiber tow, both sides, is of about 478 kHz.

3.2 Frequency analysis of wave propagation under the reinforced direction of SiC fiber

The elastic wave signals of UCS and CCS were detected by pencil lead method. Figure 3(a) shows a typical signal of CCS, it is very interesting that the wave signal has semi-beat phenomena in a duration time. It can be confirmed on the frequency and wavelet analysis, so we are understand that the semi-beat is repetitive in time response at about 50 μsec and 80 μsec in Figure 3(a) and Figure 3(c). In Figure 3(b) the frequency shows two components of 146 kHz and 166 kHz of which are relatively near and large amplitude in range of 100 kHz and 200 kHz. In the elastic wave with respect to the micro-structural feature of regular reinforcement of SiC fiber diameter of 7.5 μm, these semi-beat phenomena did occur in the CCS only, but it did not occur in the UCS. It is remarkable that the beat frequency exists in the burst AE signal, and it is considered as one of rare and unique feature occurring when the fiber-reinforcement has a regularity of cross directional type and also same diameter.

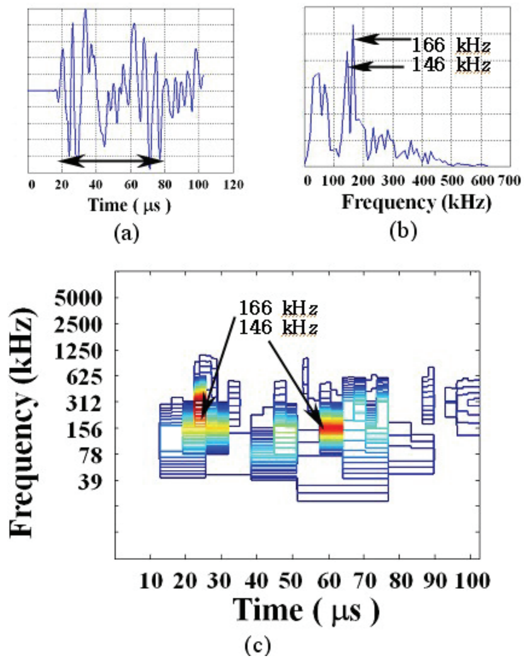

Figure 3 (a) Time response of AE signal, (b) Frequency spectrum, and (c) Contour map of WT analysis for CCS.

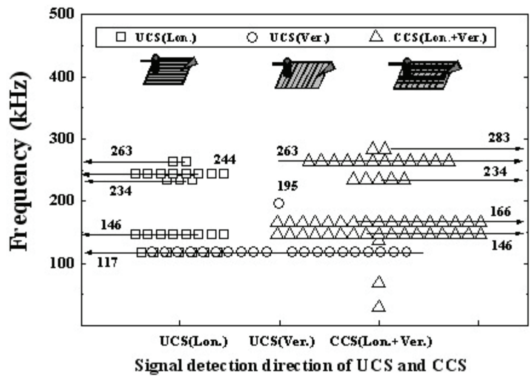

Figure 4 Time-frequency analysis of signal from UCS and CCS.

Figure 4 represents the results of the time-frequency after using the pencil lead method for creating the AE and analyzing the wave signal captured. In case of UCS(Lon.) these are shown that the relatively low frequency group is distributed over about 117 kHz to 263 kHz, but differently the frequency group in case of UCS(Ver.) is almost concentrated at 117 kHz. From experimental results of the author's work(2,3), it was suggested that the component of frequency, 117 kHz, could be seen as the characteristic frequency of SiC slurry, because it had a strong relation to the micro-structural space between the SiC fiber and slurry in itself. And also, it is impossible to detect the signal of SiC fiber by pencil lead method, which the lead has a limitation with the more large size beyond the diameter of SiC fiber, that is, the SiC fiber can not be easy excited by the lead force of which has the very low frequency comparatively. In case of CCS(Lon.+Ver.) there is no the component of low frequency, 117 kHz, it show that the characteristics have not only the high frequency group, 234 kHz up to 283 kHz, but also the semi-beat frequency, 146 kHz and 166 kHz.

3.3 AE characteristics of SiC/SiC composite ceramics fracture

Figure 5 shows the frequency distribution of which was determined as the highest power spectrum density of the deep red contour map by wavelet analysis(10) and FFT with respect to the AE signal. And also, through the three point bending test, the AE signals were continuously obtained for the UCS and CCS up to completely break down according to the load speed. From the results of UCS(Lon.) at left side in Figure 5, it shows that the frequency components occurred most frequently are of 322 kHz, 498 kHz, 527 kHz and 703 kHz. These are confirmed as the same and/or slightly high frequency when the SiC fiber diameter of 7.5 ㎛ cut off in Figure 2. In Figure 2 and Figure 5 it seems that the frequencies of the SiC fiber fracture are implied on the whole as the center frequency of the burst AE signal. The result shows that these frequency components come out most frequently are of 244 kHz, 283 kHz, 361 kHz, and 605kHz of CCS(Lon.+Ver.) at right side in Figure 5.

Then we can find that the frequencies are more concentrative at the low frequency group between 244 kHz and 283 kHz, relatively, and also the common frequencies justly exist with the frequency of the SiC fiber tow cutting off. It is assumed that the frequency group between 244 kHz and 283 kHz occurred due to the regular uniformity of micro-structural slurry with respect to the cross and uni-directional reinforcement of the SiC fiber.

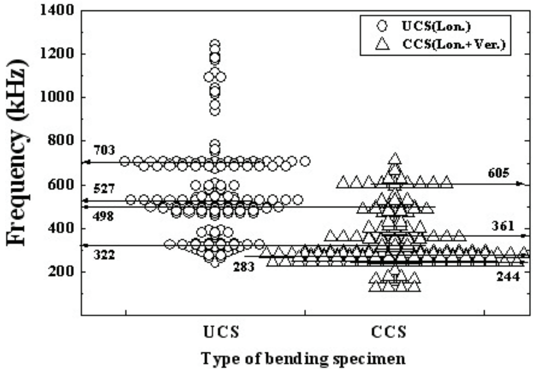

Figure 5 Relationship of dominant frequencies of UCS(Lon.) and CCS(Lon.+Ver.)

Because the SiC fiber bundle is perpendicularly reinforced, so its micro-structural space with infiltrating slurry must be geometrically composed bigger than that of UCS(Lon.). At the UCS(Lon.) with narrow space, that is, the physical characteristic of SiC fiber is dominative rather than that of SiC slurry, relatively at the CCS with big space that of SiC slurry is more dominative. Referencing the author's previous study(2,3), the frequency group beyond the 244 kHz is considered as the characteristic frequency of SiC slurry with respected to the space between the SiC fiber bundles reinforced. In Figure 5 the characteristic frequency of SiC fiber is found strongly at the UCS(Lon.), and in the CCS that of SiC slurry is considerably more dominative and also providing with the frequency of the SiC fiber.

4. Conclusions

Through comparing with the characteristic frequency of the elastic wave by pencil lead method and that of crack initiation by bending test of the SiC/SiC composites specimen, the following results are obtained as: from the result of tension test of SiC fiber tows with the different diameter, the frequencies of the fiber fracture were commonly concentrated at the frequency band of about 478 kHz. By pencil lead method we could confirm that the semi-beat frequency existed at the burst AE signal with respect to the micro-structural feature of regular reinforcement of SiC fiber, this semi-beat phenomena did occur in the CCS only. In the case of UCS the characteristic frequencies of the SiC fiber was found dominant strongly, and in the CCS that of SiC slurry is considerably more dominative and also providing with the characteristic frequency of the SiC fiber. Through improving of the sintering additives method and/or of the micro-structural property for the SiC slurry, if it would be possible to shift the characteristic frequency of the SiC slurry up to more high frequency group, we could have a structural material with the superior mechanical properties.

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