

SPECIMEN SIZE EFFECT ON THE IN-PLANE SHEAR PROPERTIES OF SILICON CARBIDE/SILICON CARBIDE COMPOSITES

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OBJECTIVE

The objective in this study is to investigate the size dependency of in-plane shear strength, which significantly influences the on off-axial tension. A further objective is to distinguish the volumetric effect and geometric effect on shear properties. Also, in further investigation, relationships between tensile and shear properties were evaluated.

SUMMARY

Miniaturization of test specimens is often necessary to evaluate the physical and mechanical properties of materials under severe environments. The validation of these techniques requires an understanding of the role of geometric and volumetric (size) effects on the mechanical behavior of the material. Although considerable work has been dedicated to understand size and geometric effects on the off-axis tensile strength of continuous fiber-reinforced ceramic matrix composites, little work has been focused on the effect these variables on their shear properties. This paper will present the results of a study aimed at assessing the effect of notch separation and specimen thickness on the shear strength of a 2-D SiC/SiC composite by the Iosipescu test method. Provisions for mounting miniature test specimens using a fixture for standard size specimens are discussed.

PROGRESS AND STATUS

1. INTRODUCTION

Small specimen test technique (SSTT) for tensile testing has been developed to meet several demands [1]. First of all, in the field of fusion research, SSTT has been considered one of the effective methods to evaluate irradiated materials because of possibility to reduce radiological waste. SSTT also has an advantage to make distribution of defects uniform in composites. This is very important to evaluate composites with complex fracture behavior. In addition, statistical analysis will be available as the number of specimens increases. And what is most important is to make it possible to evaluate mechanical properties of extremely small materials for practical use.

It is noted that fusion structural components have finite size, so miniaturization of specimen size, given intrinsic size effects associated with composites, is problematic[2, 3]. The weakest link theory is often mentioned to discuss this problem [4]. This says that quasi-brittle materials like monolithic ceramics lose strength as specimen volume increases. The size effect is also closely dependent on fracture mode, fabric architecture, loading directions, environments and other variables [5, 6]. So it is very important to identify key factors governing size effect.

Composite strength is significantly dependent on the properties of reinforcing fibers. It has been shown experimentally and theoretically that maximum strength was roughly proportional to volume fraction of fibers aligned with the tensile axis [7]. However it is also well known that composite strength decreased a lot because of the anisotropy due to its characteristic architecture, once the loading direction changed from the longitudinal direction of fibers [8]. This is because a change in fracture mode occurs from tension of fibers to shear or detachment at fiber/matrix interface. What is most important is that the change of fracture mode made size dependency on tensile properties quite different.

According to our previous research [9], $[0^\circ/90^\circ]$ SiC/SiC composites had a size effect, dependent on architecture. Tensile strength of 3-D SiC/SiC was determined by the fiber strength itself and hence it had a length effect following the weakest link theory. The fiber volume fraction for 3-D configuration was different in gauge width due to the structural limitation and hence tensile properties, which had a close relation to fiber properties, had also specific size dependency related to axial fiber volume fraction. On the contrary, 2-D SiC/SiC had nearly no size dependency. However tensile properties in off-axis tension had quite different size dependency from that of $[0^\circ/90^\circ]$ SiC/SiC. Tensile strength reduced as gauge width decreased for both architectures, once the loading direction came apart from longitudinal direction of fiber [8]. This is due to the change of fracture mode from tension of fiber to shear strength between bundles or debonding strength at F/M interface, as mentioned before. In this study, more detailed discussion about the former effect, i.e. size effect of in-plane shear, has been carried out.

2. EXPERIMENTAL

Material

A plane-weave (P/W) SiC/SiC composite was prepared by Ube Industries, Ltd., Japan. This composite has stitching fibers in the transthick direction. First of all, Si-Ti-C-O fiber bundles (Tyranno™-LoxM, Ube Industries, Ltd., Japan) used as reinforcements had undergone a surface modification before weaving in order to optimize the fiber-matrix interface. Due to this treatment, composition gradient interphase with excess carbon was formed close to the fiber surfaces [10]. Then, these composites were synthesized by polymer impregnation and pyrolysis (PIP) process. This composite had relatively high porosity above 10 % after the PIP sequences and especially inter-bundle porosities near stitching fibers were characteristic. Hence, this made the bulk density quite lower, about 2.2 Mg/m^3 .

Iosipescu Test

In order to evaluate size effect on the in-plane shear strength, Iosipescu shear test was conducted. Schematic illustrations of test specimens and test fixture were as shown in Fig. 1. Distance between notches and specimen thickness were varied in each specimen. Specimens for the evaluation of volumetric effect were designed as possessing the same aspect ratio, i.e. notch separation to thickness, but different volume, respectively. On the contrary, specimens for the evaluation of geometric effect had the same volume but different aspect ratio. All the tests were carried out on the guideline of ASTM C1292. Crosshead speed was chosen 0.6 mm/min . Shear stress was calculated as load divided by the effective area, which means fracture area measured after testing. After the tests,

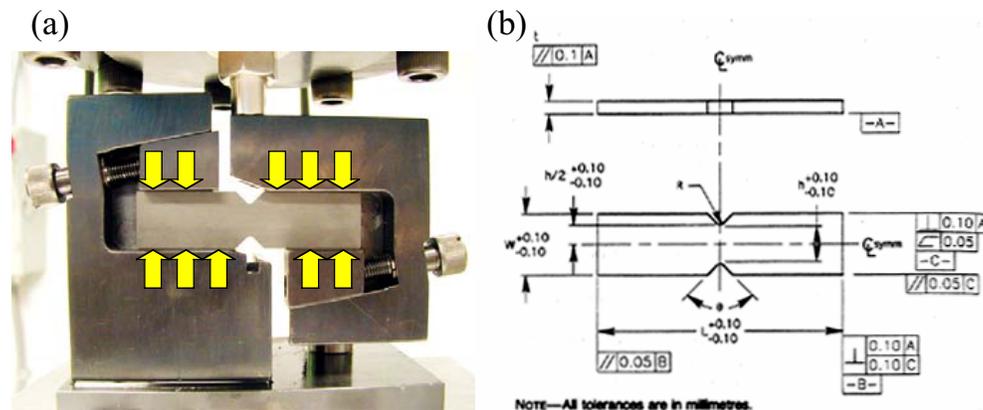


Fig. 1. Schematic illustration of (a) test fixture and (b) Iosipescu specimen.

fracture surfaces were observed by optical microscopy and scanning electron microscopy (SEM).

3. RESULTS AND DISCUSSION

In-Plane Shear Behaviors

Typical stress-displacement relations in Iosipescu tests were shown in Fig. 2. All the curves had proportional behaviors in the beginning. Just beyond proportional limit, it became non-linear due to the accumulation of matrix cracks. At the maximum, large stress drops occurred due to the failures of fibers by tension in the transverse-loading direction. At this time, visible large cracks were observed between notches. Beyond this point, the friction of pullout fibers and fiber bundles maintained all the applied loads. After the period of gradual decreases of loads, stress dropped again. This means complete failures of pullout fibers by shear.

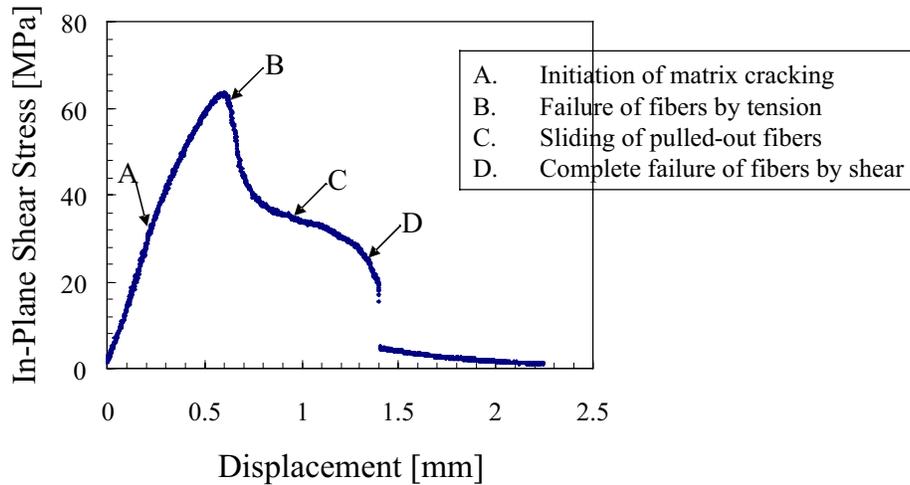


Fig. 2. Typical stress-displacement curve of Iosipescu test for SiC/SiC.

According to fracture surface (Fig. 3), main crack propagated between fiber bundles not in intra bundles. Pullouts of fibers were very numerous and long. These fracture appearances were very similar to those of tension.

Specimen Size Effect on In-Plane Shear Properties

Fig. 4 shows the size dependency of the maximum in-plane shear strength. This showed gradual increase of maximum shear strength for reduced gauge width. In particular, it was clearly significant that strength increases for the specimen with reduced aspect ratio, in case of the constant volume in the gauge section. With increasing aspect ratio, shear strength tended to converge into some constant value (Fig. 4 (a)). On the contrary, in case of the constant aspect ratio, there was no clear difference in specimen size (Fig. 4 (b)). This meant that size dependency of the in-plane shear strength was

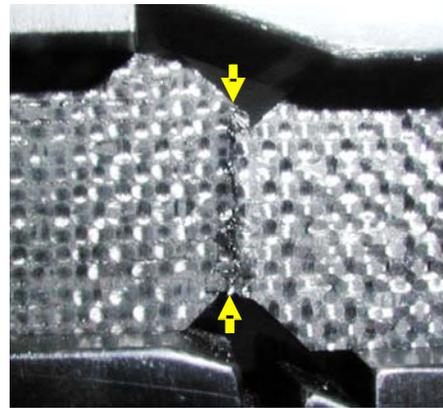


Fig. 3. Crack propagation between inter bundles.

considered due to the geometric effect. Therefore composites with small aspect ratio might have a strength increase regardless of specimen size. However it is necessary to investigate the mechanism of the strength increase and also to discuss the relationships with the stress drop observed in the off-

axis tension in case of the small aspect ratio.

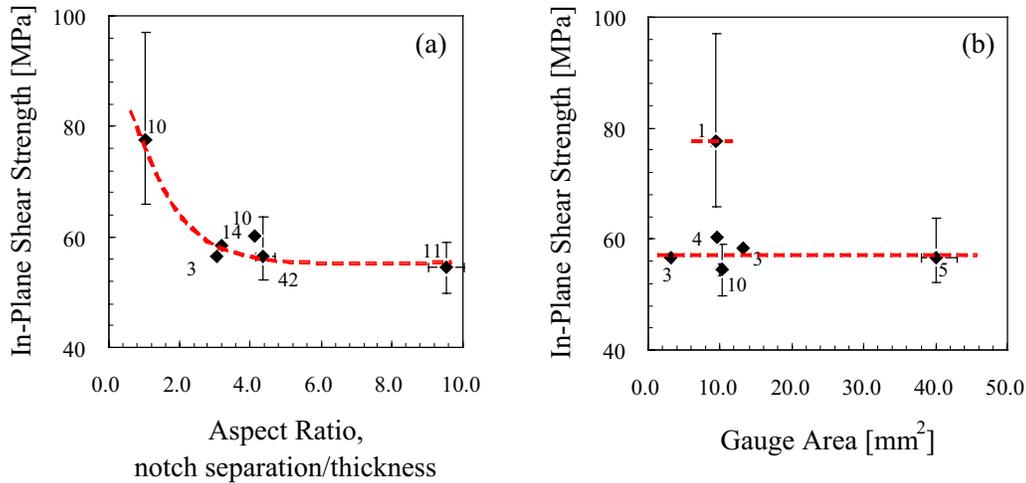


Fig. 4. Specimen size dependencies on in-plane shear strength; (a) geometric and (b) volumetric effects. (Note: numbers in figures (a) and (b) mean gauge area and aspect ratio, respectively.).

Relationships between Tensile and Shear Properties

Fig. 5 shows the width dependency of tensile strength compared to that of shear. Some reasons were considered for the reduction of off-axis tensile strength in the short gauge width and in this study in-plane shear was mentioned. However, this research on the size dependency of the in-plane shear strength showed opposite tendency to that of off-axis tension. In fact, tensile strength in off-axis tension might be determined by the weak debonding strength at the fiber/matrix interface not the in-plane shear, since there was no complex cross of weaving in shorter gauge width and each fiber was easy to detach with no special restriction by weaving architecture. Further investigation is necessary for complete understanding.

4. CONCLUSIONS

In order to investigate the size effect of the in-plane shear strength of SiC/SiC composites and to discuss the relationship between tensile and shear properties, Iosipescu test was performed. Key conclusions were summarized as follows.

1. In-plane shear strength by Iosipescu test showed a specimen geometric dependency. Maximum shear stress was nearly constant with no relation to the specimen gauge area. However, it tended to increase as the aspect ratio, width to thickness, decreased.
2. Size effect on the in-plane shear strength was quite opposite to that on the off-axis tensile strength. This indicated that in-plane shear was not the critical fracture factor in off-axis tension. Other mechanisms like the detachment strength at the F/M interface might make an effect on the stress reduction in small sized material. Further investigation about this is strongly required.

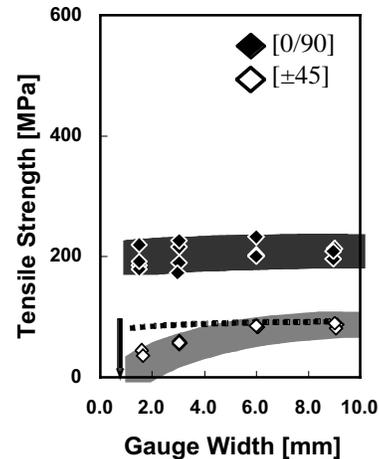


Fig. 5. Width effect on tensile strength for 2-D SiC/SiC.

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