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Initial Micro Fracture Behavior of Woven Fabric Composites

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SUMMARY : It is known that the knee point appears in consequence of microfracture as transverse cracking in case of woven fabric composites. It is considered that to study of these transverse cracks lead to the evaluation of interface inside of a fiber bundle.

In this study, initial fracture behavior of textile composite was examined. Initial fracture in woven fabric composites is transverse crack inside of fiber bundles. Initial fracture stress and strain were evaluated by knee point. The obtained initial fracture properties of one ply lamina and 10 plies laminate were well agreed. Moreover, evaluation method of interphase property inside of fiber bundle by using knee point on stress strain curve was discussed.

KEYWORDS: Initial micro fracture, Transverse crack, Interface property, Woven fabric composite

INTRODUCTION

A characteristic property of woven fabric composites is a knee point in the stress-strain curve as shown in Fig.1. It is supposed that initial fracture is agreed with knee point. Thus, knee point found on the stress-strain curve of tensile test is considered to use quantitative evaluation of initial fracture. Initial fracture of woven fabric composites is transverse crack, that is, fracture inside of fiber bundle. So, knee point is also considered to use quantitative evaluation of interphase inside of fiber bundle.

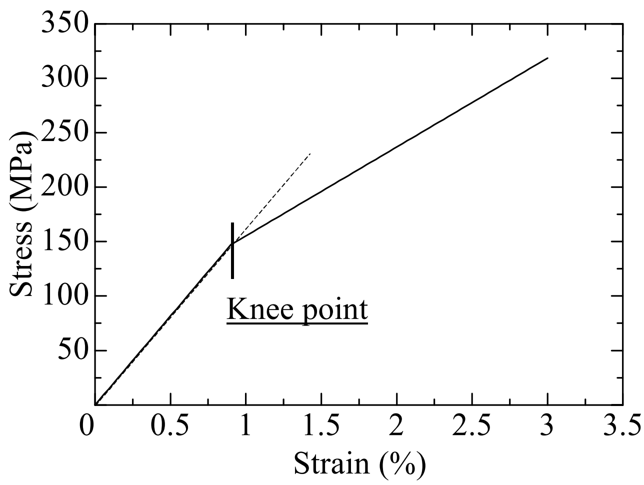

Figure 1 Knee point on stress-strain curve.

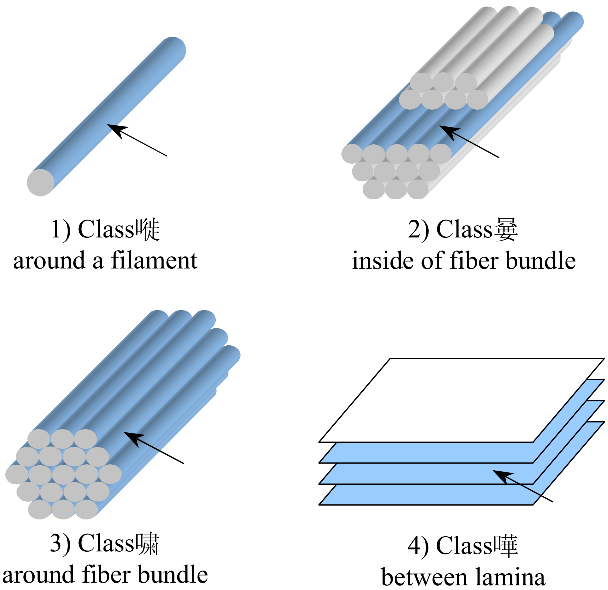

Figure 2 Classification of interface.

Woven fabric composites have mainly been investigated by evaluation of mechanical properties. In particular, the effect of the interface on mechanical properties has attracted attention in recent years. With regards to surface treatment, numerous studies have been conducted in order to improve the adhesive properties of the fiber/matrix interface. Figure 2 shows a classification of fiber/matrix interfaces[1]; Interface around a single fiber filament (class□), Interface inside of a fiber bundle (class□), Interface around a fiber bundle(class□), and Interface between laminas (class□). Generally, embedded single filament test has been used to evaluate the interfacial properties. For usual glass cloth composites, not for monofilament glass resin composite, fabric structure and fiber orientation should be taken into consideration to interpret the interfacial effect on the mechanical properties of composites. It is considered that to study transverse cracks leads to the evaluation of the class□ interface (interphase inside of fiber bundle).

In this study, the micro fracture behavior in textile composite was investigated by tensile test and in-situ observation. Replica observation at side edge of 10 plies woven composites was conducted to know the micro fracture behavior. In order to identify the initial fracture, tensile tests of woven fabric composites with 1 ply were also performed and evaluation method of initial fracture was conducted. Moreover, evaluation of interface inside of a fiber bundle was discussed.

MICRO FRACTURE BEHAVIOR

Materials used in this study were plain glass woven fabrics (WE18W: Nitto Boseki Co., Ltd., Japan) as reinforcement with 0.4 wt% silane coupling agent and vinyl ester resin (R-806; Showa Highpolymer Co., Ltd., Japan) as the matrix resin. The room temperature catalyst used was 0.7 phr methylethylketoneperoxide (MEKPO). Laminate consisting of 10 plies glass cloths was fabricated for tensile test.

In order to investigate micro fracture behavior, replica observation at the edge surface was performed. Replica observation was conducted as follows; prior to the testing, the surface at one side edge of the specimen was polished. During the tensile tests, the testing machine was periodically stopped and the polished edge surface of the specimen was replicated on a replica film (cellulose acetate film) with methyl acetate as resolvent. The replica film was then observed under optical microscopy. The initial fracture strain on stress-strain curves and the strain at which the transverse crack appears well agreed.

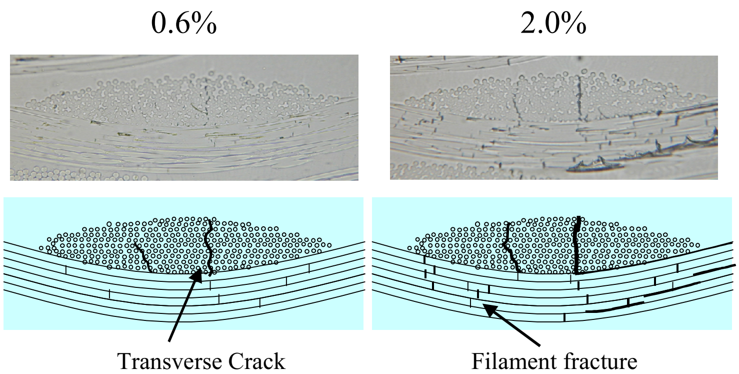

Figure 3 Fracture aspect.

Table 1 Replica observation results.

	Fracture strain (%)
Initiation of transverse crack	0.4
Transverse crack	0.6
Filament fracture	0.6
Delamination at interface	2.0

Figure 3 shows results of replica observation, and Table 1 shows strain at which each fracture occurred. Transverse cracks can be found at 0.4%. The number of cracks increased, and the cracks were enlarged with increasing the strain. The breakage of filaments was also observed. Abruptly increase of the transverse cracks from when the knee point was observed on the stress-strain curve was remarkable.

TRANSVERSE CRACK

One-ply composite was fabricated by hand lay-up technique, and tensile testing was performed to know the onset and growth of transverse cracks clearly. Observation of transverse cracks in fiber bundles using optical microscopy was performed. During the tensile tests, the testing machine was periodically stopped. Figure 4 shows the fracture aspect by optical microscopic observation. Transverse cracks appeared at 1.0% strain in weft fiber bundles, and the number of the cracks increased, and the crack was enlarged with increasing the strain. This fracture process was similar to 10plies laminate.

As previous study, transverse crack was determined, observing a scattering of light from the

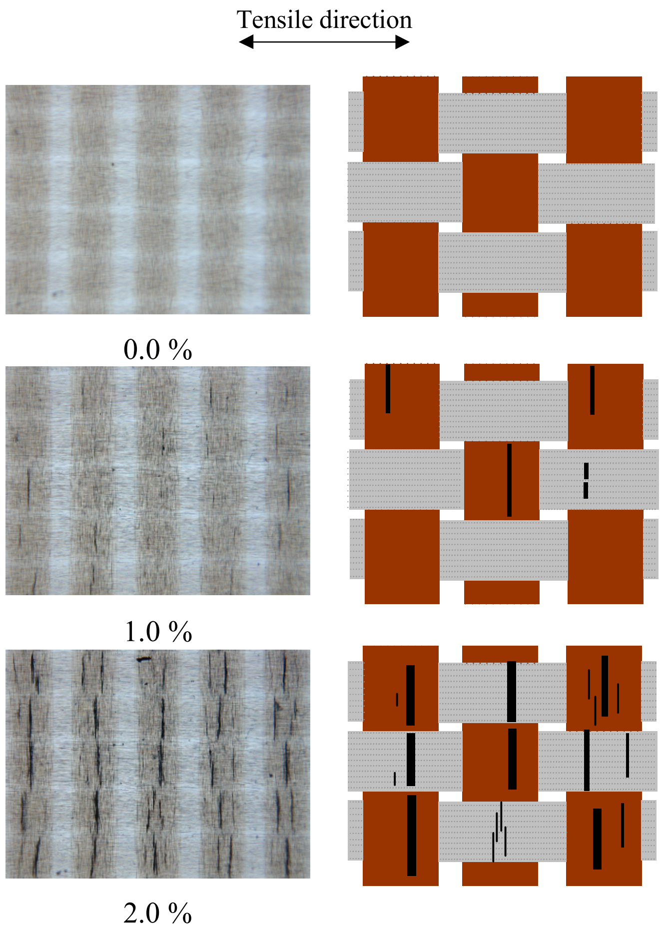

Figure 4 Fracture aspect.

cracking part of the specimen[2,3]. To determine its appearance, the image processing was carried out as follows; the picture of the specimen recorded on a video tape was taken into image analyzer. In order to detect the transverse crack clearly, edge detection was at first carried out along to the tensile direction to detect bright lines running to the transverse direction. Second, the brightness of the picture was transformed to the binary brightness. Finally, the number of white pixels was counted. A series of image analysis was carried out for the picture at every 2 seconds of the tensile test. The point of initial microfracture was decided as the beginning of the increase in point of the number of white pixels. The stress and strain in the specimen were measured when the initial microfracture occurred. Figure 5 shows typical stress-time curve and relationship between increase of white pixels and time. Initial micro fracture behavior can be determined easily. However, this image analysis method cannot apply to thick, lightproof composites.

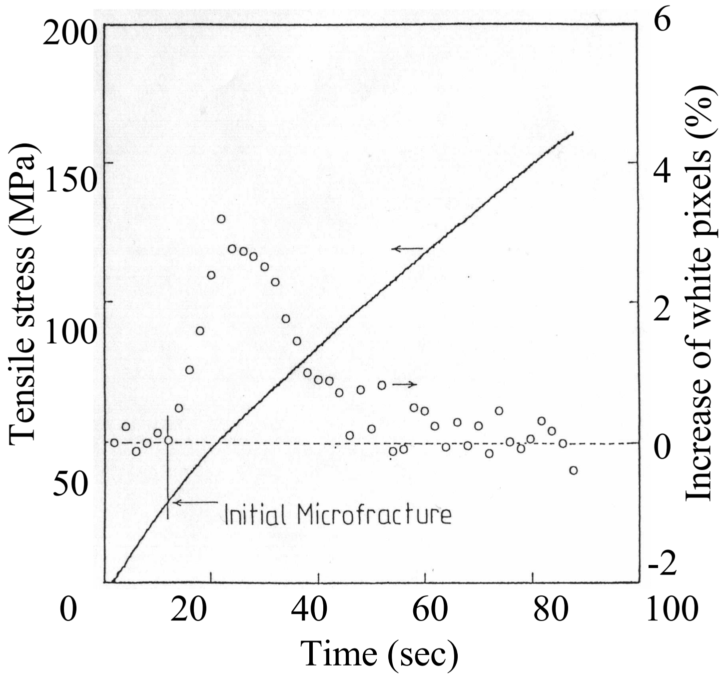

Figure 5 Stress-time curve and relationship between increase of white pixels and time

KNEE POINT ON STRESS-STRAIN CURVES

It is considered that initial fracture is agreed with knee point. Thus, knee point found on the stress-strain curve of tensile test is considered to use quantitative evaluation of initial fracture. The stress and strain at knee point were defined as initial fracture stress and initial fracture strain, respectively.

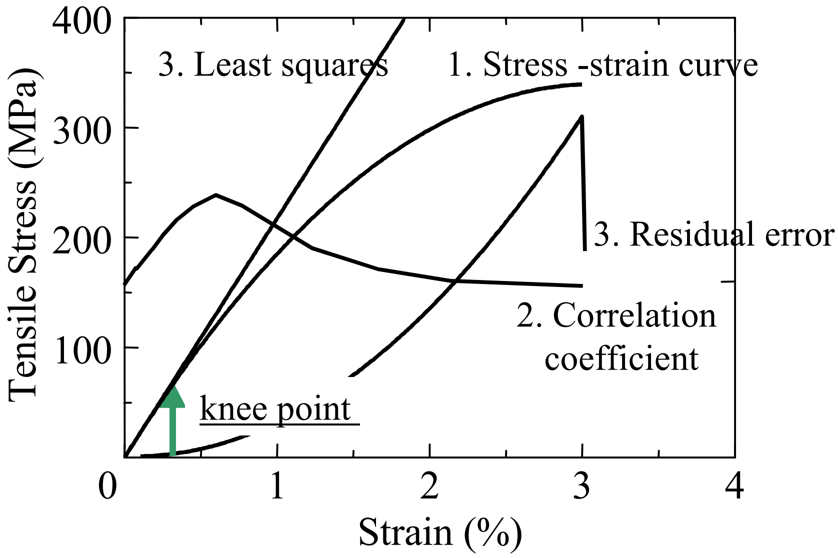

Figure 6 Explanation to identify knee point.

Knee point was identified by following procedure, which was explained by Fig.6;

1. Data of stress and strain obtained during tensile test was accumulated from the first to a certain point.
2. The correlation coefficient for the data from the first to every point was calculated until the highest value was obtained.
3. The point that the residual error between each next point became negative was defined as knee point.

Considering Fig.5 sample, the initial fracture strain at knee point and strain at which the transverse crack appears well agreed. Namely, this evaluation method is able to evaluate initial fracture quantitatively.

Table 2 shows initial fracture stress and strain of one ply and 10 plies composites. Strain at which transverse crack observed in one ply was different from initial fracture strain. On the other hand, transverse crack observed strain and initial fracture strain were well agreed in case of 10 plies composites. Moreover, initial fracture stress and strain of one ply and that of 10 plies were well agreed as shown in Table 2.

Table 2 initial fracture stress and strain.

	Initial fracture stress (MPa)	Initial fracture strain (%)
1ply	104	0.50
10plies	97.8	0.42

INTERFACIAL PROPERTY

Initial fracture of woven fabric composites is transverse crack, that is, fracture inside of fiber bundle. Thus, knee point found on the stress-strain curve of tensile test is considered to use quantitative evaluation of interphase. In this section, interfacial properties were considered to use different surface treatment quantity.

Material used in this section was plain glass woven fabric (WE18W: Nitto Boseki Co., Ltd., Japan) as reinforcement. The glass woven fabrics were treated with 0.01, 0.4 and 1.0wt% acryl silane coupling agent. The matrix resin used was vinyl ester resin (R-806 ; Showa Highpolymer Co., Ltd., Japan). The room temperature catalyst used was 0.7 phr methylethylketoneperoxide (MEKPO). One ply composite was prepared by a hand lay up method.

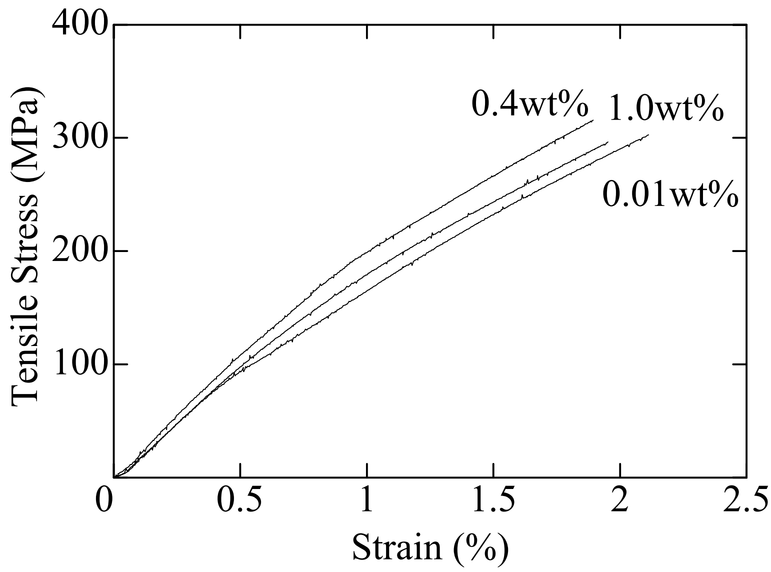

Figure 7 Stress-strain curves.

Tensile tests of composites were performed in order to clarify the effect of surface treatment concentration on the mechanical properties. Figure 7 shows stress-strain curves. Similar fracture process as Fig.4 was observed in 0.01 and 1.0wt% treated specimen. Transverse cracks appeared in weft fiber bundles, and the number of the cracks increased, and the crack was enlarged with increasing the strain.

Table 3 shows initial fracture stress and strain, and Fig.8 shows the change in initial fracture stress with silane concentration. Initial fracture stress of 0.4wt% silane treated specimen shows the highest value. Too much coupling agent decrease the initial fracture stress. Similar tendency could be observed in case of single fiber embedded test [4].

Table 3 Initial fracture stress and strain.

	Initial fracture stress (MPa)	Initial fracture strain (%)
0.01wt%	87.3	0.45
0.4wt%	97.5	0.43
1.0wt%	87.9	0.43

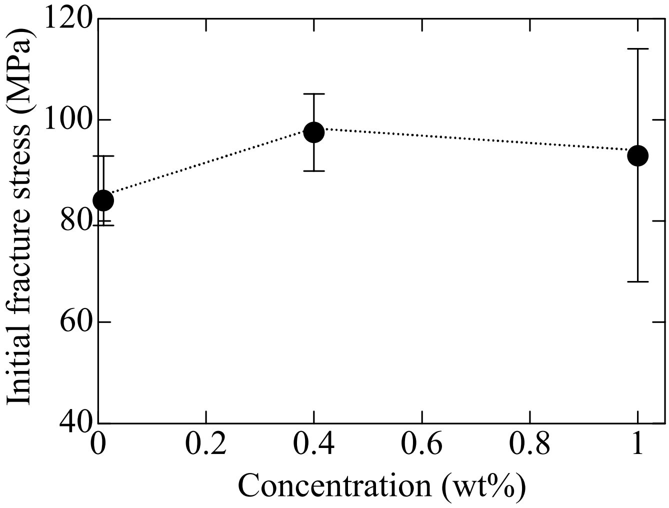

Figure 8 The change in initial fracture stress with silane concentration.

CONCLUSION

In this study, initial fracture behavior of textile composite was considered. Initial fracture in woven fabric composites is transverse crack inside of fiber bundles. Initial fracture stress and strain were evaluated by knee point. The obtained initial fracture properties of one ply lamina and 10 plies laminate were well agreed. Moreover, evaluation method of interphase property inside of fiber bundle by using knee point on stress strain curve was developed.

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