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Effect of processing on the durability of fiber reinforced plastics

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ABSTRACT: Many kinds of molding methods for composites have been developed for quite a while. The characteristics of composite should be similar using any molding method when the same material system is used. However the mechanical properties of the composite will be different by using the different forming method.

In this study, woven glass cloth was used to fabricate composites. Various kinds of molding methods such as hand lay-up, pre-wet and resin transfer molding were employed and the low-cycle fatigue test of the composite with different molding methods was performed. As a result, during low-cycle fatigue test of glass cloth composites, interfacial adhesion in VARTM specimens was worse than that in hand lay-up and pre-wet specimens, which affected the crack propagation and bending properties of the composites.

KEYWORDS: Low-cycle fatigue test, crack propagation

INTRODUCTION

There are various kinds of molding methods for composites, i.e. hand lay-up, autoclave processing and resin transfer molding. The mechanical properties and performance of these composites would largely depend on the materials, design, and processing.

Generally it is assumed that the characteristics of composite materials would be similar after molding since they look the same and contain the same materials. However mechanical properties such as modulus and strength of the composite will be vastly different when they are formed by using different impregnation process. For example, in hand lay-up, the resin was rubbed against the fiber. On the other hand, in VARTM, the resin would flow only fiber surface. Especially long-term behavior of composite such as fatigue properties might be highly different because the interfacial properties between fiber and matrix would be different due to different flow process. It means that the impregnation condition to fiber bundle affects the mechanical properties in long-term.

In this study, woven glass cloth was used to fabricate composites with different forming methods, i.e. hand lay-up, pre-wet, and VARTM. Apart from static mechanical properties, the glass cloth composites were exposed to low-cycle fatigue test to gauge the crack initiation and propagation characteristics.

MATERIALS

Glass cloth (Nitto Boseki Co., Ltd. ;WF230 100BS6) was used as reinforcements while epoxy resin (AXSON 5015) was used as the matrix. Composite panels were molded by using the hand lay-up, Pre-wet and VARTM techniques. The stacking sequence of the laminate consists of 8 layers: $[45/-45/0/90]_s$. After manufacturing, the laminate was post cured at 80°C for 16 hours. Volume fraction, V_f of glass cloth specimen was determined by pyrolysis. Each V_f for the glass cloth composites was 32% in hand lay-up, 31% in pre-wet and 35% in VARTM.

EXPERIMENTS

Static tensile and bending tests

The size of tensile test specimens was 200 mm in length and 25 mm in width. Rigid polyvinyl chloride tabs (1 mm thick, 25 mm wide and 50 mm long) were adhered to the gripping area prior to the test. The span length was 100 mm. Axial strain was measured by using strain gauges with a 10 mm gauge length. Tensile tests at a cross-head speed of 1 mm/min were performed by using an Autograph universal tester (SHIMADZU). AE (Acoustic Emission) was used to identify the initial fracture. Matrix cracking can be detected by the 140 kHz transducer while reinforcement fiber rupture can be detected by the 1 MHz transducer as proven in previous studies.

The bending specimens were cut to a size of 50 mm in length and 20 mm in width. The span length was set to 30 mm with a span length to thickness ratio (L/h) of 30. Bending test was conducted by using an Instron universal testing machine (Type 55R4206) with a cross-head speed of 1 mm/min.

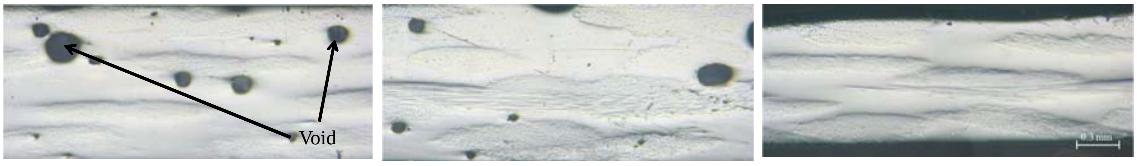
Low-cycle bending fatigue test

Static bending test was initially performed in order to determine the initial fracture stress. Then a low-cycle bending fatigue test was performed by applying cyclic loads onto the specimens. Low-cycle bending fatigue test on the composites was performed by using an Instron universal testing machine (Type 55R4206). The cross-head speed was 2 mm/min. The total number of cycles was set at 103. Cross-sectional observation was performed at every 10 cycles by using a reflection-type optical microscope (OLYMPUS-PME3). The edge surface of the specimen was polished prior to fatigue test in order to facilitate microscopic observation.

RESULTS

Cross-sectional observation

The microscope photographs of the specimens are shown in Fig. 1. In the hand lay-up and pre-wet specimens, voids can be detected throughout the cross section of the specimens. However, no voids could be found in the VARTM specimens. In addition, the VARTM specimens were thinner than that of hand lay-up and pre-wet.



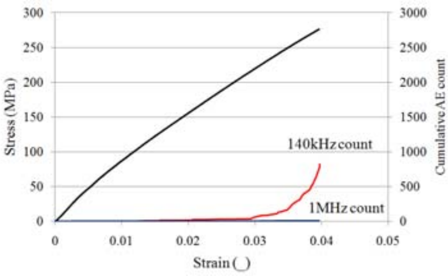
Hand lay-up **Pre-wet** **VARTM**

Fig. 1 Cross section of composite with different molding method

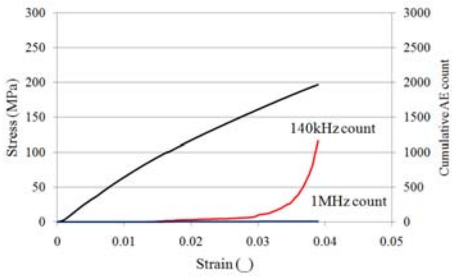
Tensile properties

Figs. 2(a), (b) and (c) show the tensile stress-strain curves of all specimens with AE count. AE count from the 140 kHz transducer drastically increased after a strain of 0.35 in all specimens, which indicates the generation of many micro-fractures. AE count detected by the 1MHz transducer was lower than that of 140 kHz in all specimens, which also indicates that fiber rupture is not a dominating factor for the failure of specimens.

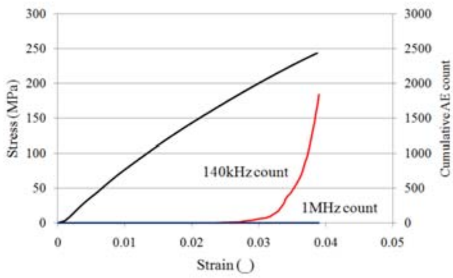
Table 1 compiles the results from tensile test. Tensile strength was the highest in VARTM specimens, followed by Hand lay-up and Pre-wet specimens. However, the difference in strength was not significant. Cumulative AE count was the highest in VARTM specimens, followed by Pre-wet and Hand lay-up. Totally, tensile modulus, tensile strength and initial fracture stress would be dependent on the V_f in the specimens.



(a) Hand lay-up specimen



(b) Pre-wet specimen



(c) VARTM specimen

Fig. 2 Stress-strain curves

Table 1 Results of the tensile test

	Modulus (GPa)	Strength (MPa)	V_f (%)	Cumulative AE count	Initial fracture stress (MPa)
Hand lay-up	13.2	232	32	1488	124
Pre-wet	11.7	197	31	1540	95
VARTM	14.8	240	35	1793	133

Bending properties

Fig. 3 shows a compilation of the stress-deflation curves for all specimens. Fracture deflection was smaller in Hand lay-up specimens while similar deflections were recorded in VARTM and Pre-wet specimens prior to fracture

Table 2 summarizes the result of bending tests. Hand lay-up specimens recorded the highest modulus and strength although its V_f was lower than VARTM specimens. In the case of woven fabric composite, transverse crack occur inside of fiber bundle and the transverse cracks was resulted from debonding between fiber and matrix. The transverse crack was regarded as interfacial fracture in this study. Thus the difference in the strength could be attributed to the difference in interfacial adhesion in each specimen.

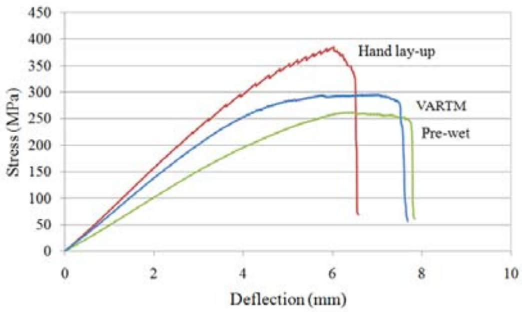


Fig. 3 Stress-deflection curves in each specimen

Table 2 Results of the bending test

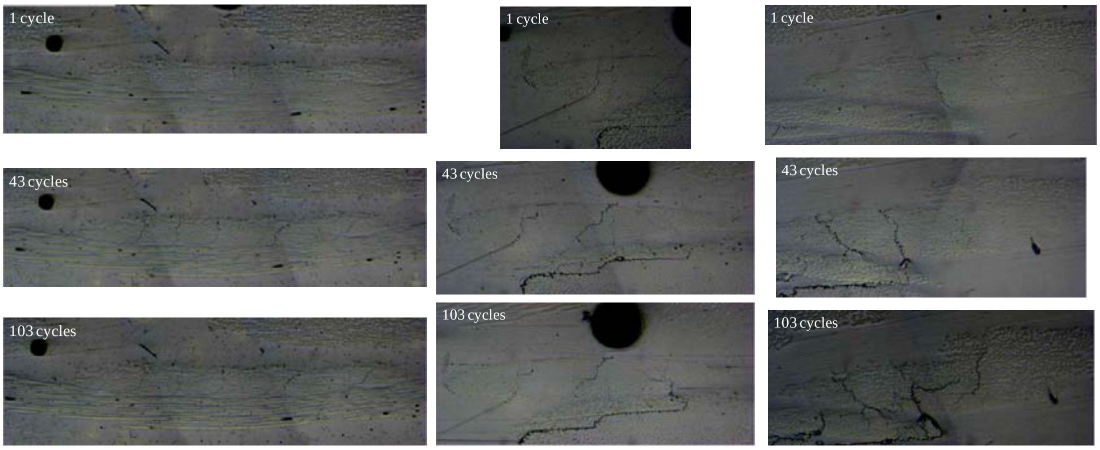
	Modulus (GPa)	Strength (MPa)	V_f(%)
Hand lay-up	13.6	385	32
Pre-wet	6.22	263	31
VARTM	10.9	296	35

Crack propagation

Figs. 4(a), (b) and (c) shows the cross-sectional photograph for all specimens at designated number of fatigue cycles. In the case of hand lay-up specimens, three transverse cracks in one fiber bundle could be initially observed. Although changes in crack length were not obvious, the number of cracks increased with increasing fatigue cycles. In the pre-wet specimens, short initial cracks could be observed and these would progress into longer cracks with increasing fatigue cycles. Meanwhile, more cracks would also be created with longer loading cycles. In the case of VARTM specimens, large cracks could be observed at the center of fiber bundle while length of the crack progress would also increase with increasing fatigue cycle.

The crack length in a fiber bundle at various number of fatigue cycles was measured for all specimens and compiled in Fig. 5. Total longest crack propagation was detected in VARTM, followed by Pre-wet and hand lay-up specimens. Moreover the crack length would drastically increase after 73 cycles in the VARTM specimens.

From these result, it can be concluded that the interfacial adhesion between the fiber and matrix in VARTM was worse than that in hand lay-up and pre-wet specimens, which affected the bending properties of the composite.



(a) Hand lay-up (b) Pre-wet (c) VARTM

Fig. 4 Cross-sectional observation

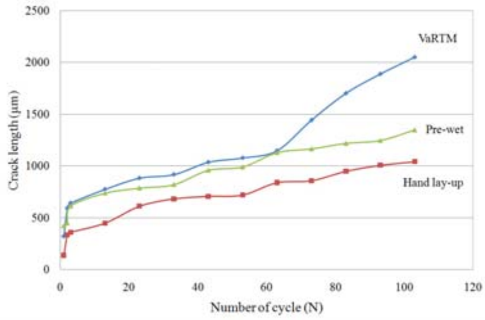


Fig. 5 Crack length of each cycle in each specimen

CONCLUSIONS

In this study, the effect of various molding processes on the mechanical properties of composites was clarified. During low-cycle fatigue test of glass cloth composites, interfacial adhesion in VARTM specimens was worse than that in hand lay-up and pre-wet specimens, which affected the crack propagation behavior and resulted bending properties of the composites. Therefore not only combinations of materials but also forming method are very important to generate sustainable composite materials.