Mechanical Characteristics of Composite Reinforced by Short and Plain Woven Carbon Fiber with Vinyl Ester Matrix Modified by Submicron Glass Fiber

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The submicron glass fiber (sGF) was used to modify the vinyl ester resin used as the matrix for short and plain woven fiber composite. Mechanical characterization tests of resin as well as composite were conducted to access effect of sGF modification. The Single Edge Notch Bending (SENB) test showed the improvement from 26 to 61% of Mode I fracture toughness when 0.3wt% and 0.6wt% of sGF added into resin. The strain concentration around fiber tip of the model specimen with modified matrix also diminished compared to that of unmodified resin. These results contributed to the increase of bending and tensile strength of the plain woven fiber composite. However, in the case of short fiber composite, the static strengths were unchanged with the addition of submicron glass fiber modifier.

Key words: submicron glass fiber, vinyl ester (VE) matrix, short carbon fiber (CF), plain woven fiber composite, composite modifier

1. Introduction

Reducing the weight of transportation vehicles is one of the effective ways to solve the problems of deducing energy consumption, pollution and barriers of emission reduction regulations. There has been an increasing attention for lighter materials in automotive, aircraft industry led to the development of innovative light weight constructions and the use of lightweight materials such as carbon fiber reinforced plastics [1-3]. Woven fiber fabric can be defined as interlaced warp and weft fiber in a repetitive pattern or weave style such as plain, twill, satin, etc. Therefore, woven composites possess numerous characteristics all of which arising from their interlaced fibrous structure such as the symmetric and balanced properties, the ease of manufacture and handling as well as superior impact properties [4-6]. In addition to the strong interest in exploiting the advantages of woven fiber composite (WFC), the demand for composite with the versatile processing ability, relatively low fabrication costs motivated the huge attention in short-fiber composite for sub-parts in automotive, marine and aeronautic applications [7-9]. Though the fiber fabrics are well known for their low cost, light weight and impact resistance but the presence of float and crimp during yarn interlacing causes deterioration of mechanical performance of composite [10]. The inter-laminar fracture toughness of the material with a layered structure is poor and cracks

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between the layers easily lead to a fatal result [11). Whereas, the studies on failure mechanism of short carbon fiber composites (SCFC) pointed out that under loading condition, the cracks start at the fiber ends and propagate along the fiber-matrix interface or through the matrix and cause the final failure [12,13). To improve the mechanical performance of short carbon fiber composite and woven fiber composite, many studies used micro and nano-fillers to modify the matrix [11,14,15). In this present study, the vinyl ester resin was modified with submicron glass fiber (sGF) to investigate the effect of this filler to fracture toughness of matrix as well as to static strengths of WFC and SCFC.

2. Material and Methods

2.1 Materials

The short and continuous fiber involved 25mm chopped carbon fiber (T700SC-12K50C – Toray Industries, Inc) and plain woven fabric (TR3110M – Mitsubishi Chemical Corporation) used as reinforcement in this study. The matrix was vinyl ester resin supplied by DIC Corporation. Submicron glass fiber (FMW – 1700, Nippon Muki Co., Ltd) with diameter in the range of 0.4 to 2.4μm and the length from 20 to 200μm. The minority of glass fiber has the excessively large length until around 1mm. Matrix was modified with submicron glass fiber (sGF) by homogenization of sGF and VE in a lab-scale mixer at the speed of 5000 rpm for 30 minutes.

2.2 Preparation of composite

To prepare composite from chopped carbon fiber (CF), resin and fiber were divided up into equal parts. After that, each layer of resin was covered by each layer of fiber which was sprinkled carefully on that to reach the maximal contact of fiber and resin. The process was conducted on the negative mold followed by consolidating mixture by a roller and then by a heat pressure machine after closing the mold with the positive mold. The mold was kept under the pressure of 15 MPa during the curing process for 3 hours at 80^0C. After taking out from the mold, the sample was post-cured at 100^0C for 3 hours for ensuring the complete cure of matrix.

The plain woven fabric composite were fabricated by hand lay-up method, each sample consist of 8 carbon fabric layers arranged in the order of $[0\text{-}90]_8$. The processing condition was the same with that of SCFC. The weight content of carbon fiber for short fiber composite as well as plain woven composite was 50%.

2.3 The mode I fracture toughness of single edge notch bending

Single edge notch bending (SENB) sample was prepared to estimate the fracture toughness behaviour of resin with the addition of sGF. Specimen coupons were cut from resin plate with dimensions of 45x10x5mm^3. Pre-crack and natural crack were created by the diamond cutter and fresh razor, respectively. The test was carried out under three point bending load and the crosshead rate of 10 mm/min as pointed out in the ASTM D5045.

2.4 Measuring strain distribution of model specimen

To observe the strain distribution around the fiber tip of short carbon fiber (sCF), a model specimen of composite was prepared with sCF in 25 mm long embedded into VE. Pre-cracks with crack length approximate 1.5mm was made by the diamond cutter at both sides then natural cracks introduced by slicing razor at the pre-crack root before testing. The sample surface was painted by white and black paints to create a speckle pattern for digital image correlation analyze (Fig.1). Sample size was 40x20x0.5mm^3. The tensile load was applied to the model specimen at a constant cross head speed of 1mm/min.

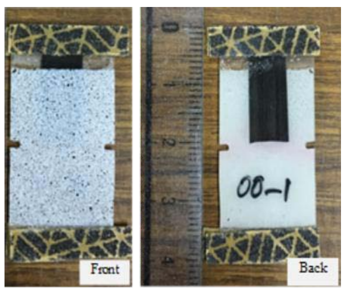


Fig. 1. Image of model specimen with speckle pattern from black and white paint for measuring strain distribution (front and back side).

2.5 Characterization of mechanical property of composite

For the sake of decreasing the scatter of data in static strength tests, the width of short fiber composite specimens was larger (40mm) compared to that of plain woven fabric composite (15mm). Bending load mode for SCFC was four point bending test while that of woven fiber composite was three point bending. The tests followed the standard of ASTM D790-17 (three points) and ASTM D6272 (four points) for flexural tests. Tensile test was conducted following the ASTM D3039/D3039M-17 with the sample in the dimension of 200x25x3mm^3.

3. Results and Discussion

3.1 Fracture toughness of SENB specimen

The critical stress intensity factor of sGF modified VE by 0.3 and 0.6wt% was improved 26 and 61%, respectively compared to that of unmodified VE, as can be seen in Fig.2. The SEM observation revealed that the fractured surface become rougher by adding the sGF, and existence of sGF (inside the black circles at Fig.3b) was clearly observed at fractured surface of modified VE. These results suggest that the fracture toughness of VE was effectively improved by mechanical bridging of added sGF at crack front.

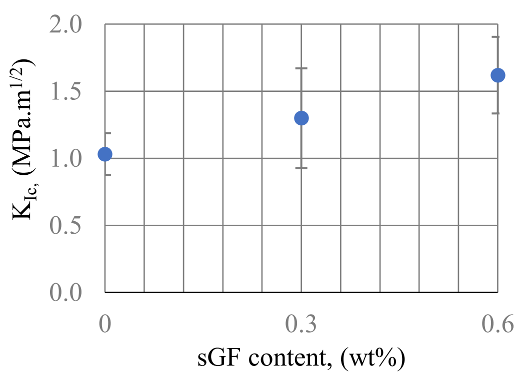
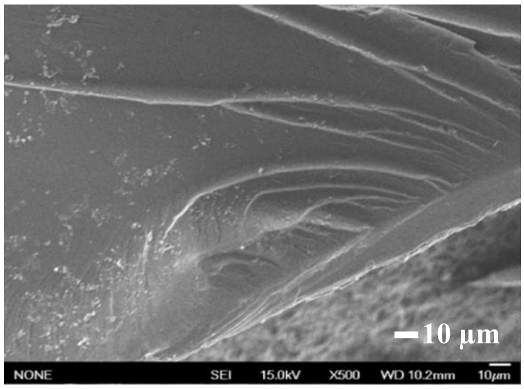
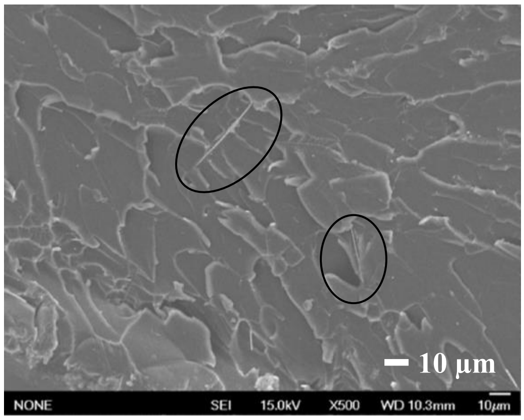


Fig. 2. The fracture toughness of resin with respect to sGF content.



(a)



(b)

Fig. 3. Fractured surface SEM images of (a) unmodified-resin and (b) 0.6wt% sGF-modified resin after fracture toughness test.

3.2 Strain distribution around carbon fiber tip

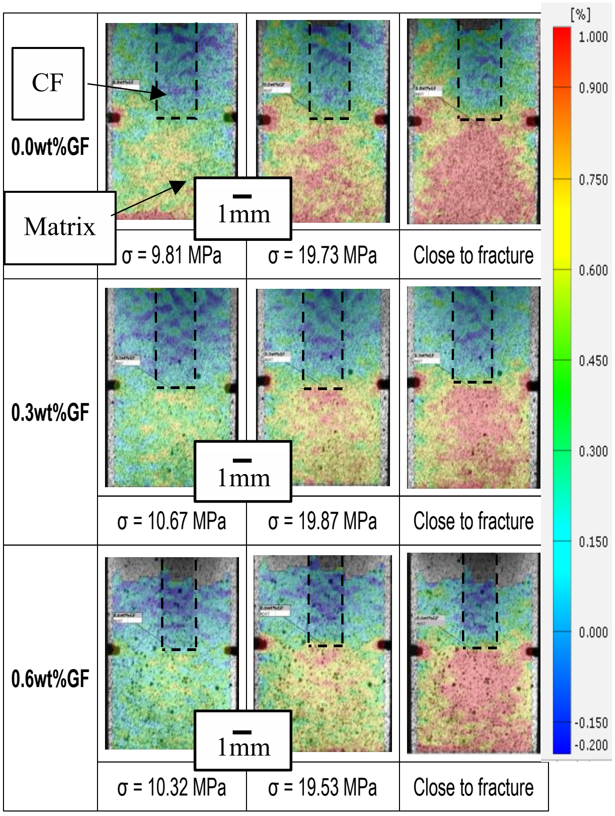


Fig. 4. Strain distribution of composite models consisted of single fiber bundle and unmodified/modified VE.

Fig.4 shows the strain distribution along longitudinal direction of model composites under same level of tensile load. In this figure, the position of embedded carbon fiber bundle was illustrated by black dash lines. Test results showed that the strain around carbon fiber bundle tip and pre crack was increased with increase of applied stress level. However, when matrix was modified with sGF, the strain concentration was suppressed. These results indicate that the existing of added sGF is helpful to avoid stress concentration at carbon fiber tip.

3.3 The static strength of SCFC and plain woven fabric composite

Fig.5 and Fig.6 show the four point bending strength and tensile strength of SCFCs, respectively. Generally, sGF modification did not enhance the static strengths of SCFC as expected.

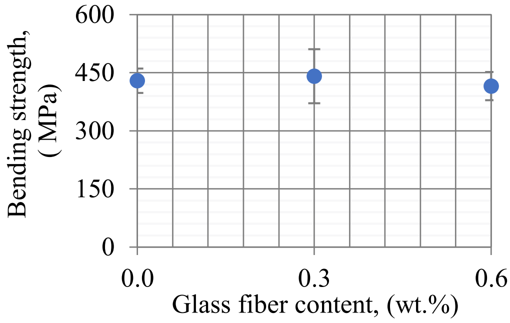


Fig. 5. Four point bending strength of SCFCs at different contents of sGF.

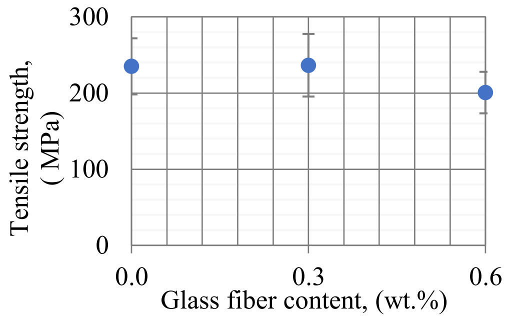


Fig. 6. Tensile strength of SCFCs at different contents of sGF.

However, a reverse tendency was observed in the case of plain woven fabric composite. Both of bending and tensile strength increased with the increase of sGF content in matrix as pointed out in Fig.7 and Fig.8. There was the increment from 12 to 38% for the flexural strength while the tensile strength also improved 11% by 0.6wt% sGF modification. These results are good agreement with those of plain woven textile carbon fiber reinforced epoxy matrix reported by Kazuya Okubo et al[11). That study explained the improvement in mechanical properties of composite thanks to the prevention of interfacial crack propagation with large resistance between carbon fiber bundles in Mode-II and modified matrix around the texture points where comparatively large strain energy would be released. Besides, the increment of fracture toughness in matrix and the degradation of strain concentration around fiber tip thanks to the presence of sGF also contributes to mechanical performance of modified WFC. Contrary to plain woven fiber composite has undulation of yarn induce many local stress concentrations, fiber ends of

SCFC have been shown to substantially concentrate the tress in the adjacent matrix. Obviously, as pointed out by S.Y. Fu et al[13], the failure is closely related to the number of fiber ends. Therefore, the unchanged of static strengths of SCFC with the addition of sGF might be the huge number of fiber ends of short fibers caused a high stress concentration that the sGF modification was not enough for compensating this negative effect.

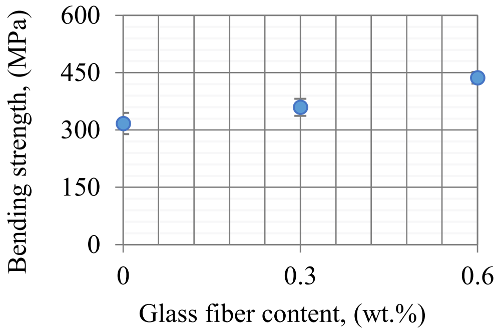


Fig. 7. The bending strength of plain woven fabric composite with respect to weight content of sGF.

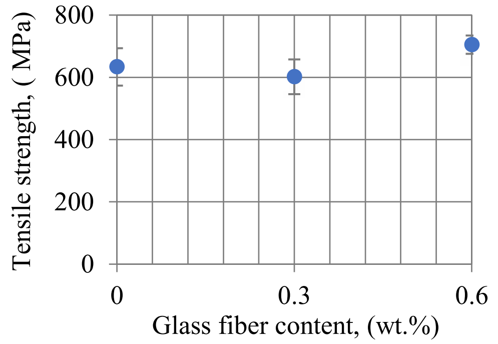


Fig. 8. The tensile strength of plain woven fabric composite with respect to weight content of sGF.

4. Conclusions

Mechanical characterization tests of resin and composite reinforced by short and plain woven fiber were conducted to evaluate effect of sGF modification. Results are summarized as follows:

1. The critical stress intensity factor of modified VE was improved up to 26 and 61% by 0.3 and 0.6wt% sGF addition, respectively compared to that of unmodified resin.

2. Modifying resin with sGF decreased the strain concentration around fiber tips in model specimens.

3. There was the increase of bending and tensile strength of plain woven fiber composite when the matrix was modified with submicron glass fiber. These improvements were contributed from the increment of fracture toughness and the decrease of strain concentration around fiber tips thank to the presence of sGF as fore-mentioned. However, the static strengths of short carbon fiber composite were unchanged with the addition of sGF modifier. This result might cause by huge number of fiber ends lead to effect of sGF modification are not enough to compensate for the high stress concentration at tips of fiber.

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