EFFECT OF FIBER ORIENTATION ON THE MECHANICAL PROPERTY OF INJECTION MOLDED JUTE AND JUTE HYBRID REINFORCED COMPOSITES

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The main setback of natural fiber reinforced plastics is their low mechanical properties as compared to glass fiber reinforced plastics. In order to overcome this problem, one of the solutions of hybridization of natural fibers with glass fibers was proposed. The tensile property was investigated. However, the mechanical properties did not improved linearly by the increase of the jute fiber volume fraction. A non-linear correlation between the fiber contents and tensile strength in the hybrid composites could be observed whereby the optimum hybridization of GF 10wt% and JF 20wt%. Microscopic observations revealed that the distribution and orientation of glass and jute fibers would be different with increasing jute fiber content. Therefore, based on the fiber orientation on the fracture surface, modulus calculation was attempted by introducing Rule of Mixture. Although predicted results did not show good agreement with the experimental results, it is considered to be a first step to analysis the effect of fiber orientation to the mechanical property.

1. Introduction

Recently, with the increasing high concerns on the sustainability issues represented by the environment and resource protection, natural fiber-reinforced composites as an environmentally friendly material has been attractive [1-4]. Because the development of natural fiber is helpful to reduce the usage of petro-based fibers such as glass fiber which is now widely applied in many fields including constructions as well as automobiles. Although the green composite i.e. a combination of natural fiber and biodegradable polymer is desired, the mechanical properties of green composites are much low than inorganic fiber reinforced plastics. Besides the green polymers most of which are absent of ductility, the natural fibers are also with relative lower and bigger scattering mechanism property. That is to say, at present, a whole green composite is not satisfied the needs of the society. Therefore, people proposed “green degree” as well as “recyclable degree”. In automobile factories of Japan, a green-degree of 30 is required for composites, i.e. natural components of 30wt% should be included.

Based on the above background, in this study, glass fiber (GF), jute fiber (JF), and [GF/JF] hybrid reinforced polypropylene (PP) composites were fabricated by injection moldings. The tensile mechanical property was investigated. It is found that in [GF/JF]/PP hybrid composite, the increase of JF wt% contributed an increased linearly tensile modulus. However, the tensile strength kept almost same and even showed a decrease trend when the wt % of JF exceed 20wt%. It is considered that the optimum hybrid ratio exists for both high tensile modulus and tensile strength. Based on the fiber orientation on the fracture surface, hybrid composite modulus prediction was attempted by introducing Rule of Mixture. Although predicted results did not show good agreement with the experimental results, it is considered to be a first step to analysis the effect of fiber orientation to the mechanical property.

2. Experimental

2.1. Long fiber pellet preparation

In this study, two types of long pellets were used, including both glass fiber / polypropylene (GF/PP) and jute fiber / polypropylene (JF/PP). Both of them were prepared by long fiber pultrusion technology. The continuous GF or JF fiber yarns are pultruded from the roving stand. Then they pass through the Hyper part where twin screw extruder provide PP resin. Later, the fiber yarns coated with resin go through impregnation head where the resin impregnated into fiber yarn and the rest resin is moved out of the yarns. During curing process, the yarns impregnated with resin are twisted and pulled out. Finally, those cured strands are cut into separated pellets with any desirable length. Here the lengths of the pellets were 11mm for GF/PP and 7mm for JF/PP pellet, respectively.

2.2. Dumbbell specimen preparation

Firstly, the above two types of pellets i.e. GF/PP and JF/PP which were prepared by long pellet machine and the additional PP pellet which was prepared by normal pellet machine were dried in an oven at 80°C for three hours to remove the moisture. (PP pellet was used to dilute the weight ratio of GF or JF in composites). Then they were dry blended according to the various weight fractions listed in the Table 1 and fed into the injection machine (Toyo PSS TI-30F6) to mould the dumbbell shape specimens. The processing condition was set at barrel temperatures of between 190-200 °C. The mold temperature was set at 50 °C while cooling time was 20s.

2.3. Experiments

Static tensile tests were conducted for all the specimens by an Instron type universal testing machine at a constant cross-head speed of 10mm/min. (the room temperature was about 25ºC and the humidity was about 55%). For each material system, three duplicate tests were done. The stress-time curve for each specimen was recorded using a computer data logger for further analysis. The tensile modulus of elasticity was measured by strain gauge extensometer (Dynamic, Instron LTD).

2.4. Optical microscopy and scanning electron microscopy (SEM)

Post failure cross sectional observations were carried out on the selected test specimens using an optical microscope and a field emission scanning electron microscope (Hitachi, S-4200). Gold was sputtered onto the specimens for electron conductivity before SEM observation.

Table 1 Specimens and the content of each component

Sample ID	GF wt%	JF wt%	PP wt%	Green degree %
G10	10	0	90	0
G30	30	0	70	0
G10J5	10	5	85	5
G10J10	10	10	80	10
G10J20	10	20	70	20
G10J30	10	30	60	30
J5	0	5	95	5
J10	0	10	90	10
J20	0	20	80	20
J30	0	30	70	30

3. Results and discussion

3.1. Mechanical properties

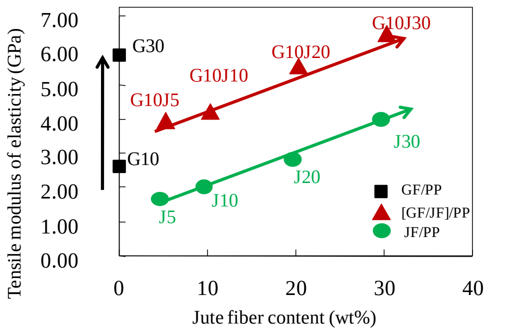
The experimental results are averaged and summarized in Table 2. Referring to the tensile modulus of elasticity for all of the specimens as illustrated in Fig.1(a), it is found that no matter which systems, with the increase of glass fiber and/or jute fiber content(s), the tensile modulus were increase linearly.

On the other hand, the tensile strengths show various trends as illustrated in Fig.1(b). Although the tensile strength of non-hybrid specimens were plotted as a function of the fiber weight fractions, the enhancement from JF was significantly lower than that from GF. In details, compared to neat PP polymer (average tensile strength is about 30 MPa), G30 which was reinforced by 30wt% glass fiber was more than 3 times stronger. While J30 composite which have 30wt% JF reinforcement was only 1.5 times stronger. It is considered that the higher strength of the GF contribute to the higher strength in GF/PP composites. However for [GF/JF]/PP hybrid composites, the effect of fiber loading on the strength were completely different from that of non-hybrid composites. The hybrid composites, which incorporate 10wt% of GF and JF from 5wt% to 20wt%, have similar tensile strengths although JF volume increases. While, with the JF weight fraction increased to 30wt%, the tensile strength of G10J30 deceased and even was lower than G10.

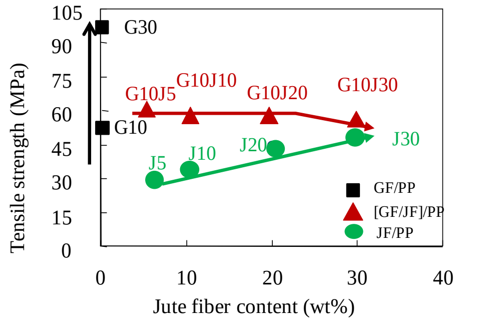
These results suggest that the jute fibers were not able to effectively reinforce the matrix. For natural fiber/glass fiber hybrid composites, an optimum fiber hybrid ratio might exist for both enhanced modulus and strength.

Table 2 Tensile properties of GF/PP; JF/PP and [GF/JF]/PP

Sample ID	Tensile modulus of elasticity (GPa)	Tensile strength (MPa)	Elongation at break (%)	Break time (sec)
G10	2.77	59.1	4.14	30.50
G30	5.96	97.8	3.49	27.30
G10J5	4.01	61.2	3.90	25.50
G10J10	4.25	56.4	3.57	23.93
G10J20	5.59	56.7	3.00	17.68
G10J30	6.30	50.6	2.34	12.95
J5	1.75	30.5	9.89	78.10
J10	2.08	33.4	5.03	34.53
J20	2.76	39.2	3.75	22.50
J30	3.74	45.6	2.43	18.00



(a)Tensile modulus of elasticity



(b)Tensile strength

Fig. 1 Relationship between tensile properties and fiber weight fraction

3.2 Effect of fiber orientation on the mechanical properties

The modulus of short fiber reinforced plastics is significantly affected by the fiber orientation against the loading direction, and the fiber orientation was generated by the resin flow during molding process. From this reason it is important for strength prediction to analyze the fiber orientation in the reinforced plastics. In the glass fiber reinforced plastics Kelly-Tyson's method [5] has often been applied for the strength prediction by measuring both the fiber length distribution and the fiber orientation. In glass fiber reinforced system the glass fiber can be remained by burning the resin out, however, this method is not applicable for the natural fiber reinforced system.

According this restriction how to determine the fiber orientation should be developed for the strength prediction of natural fiber reinforced plastics. Therefore the observation of fracture surface and marking of fibers on the fracture surface was proposed as the first prediction method. Although there are so many degrees of the fiber orientation, they would be simplified to only two orientation i.e. 0 or 90 degree. If the angle is small than 45 degree, it is considered as 0 degree. If it is big than 45 degree, it is regarded as 90 degree.

Therefore, as the first step of this analysis method, marking of fibers was conducted for glass fiber and jute fiber respectively, and all the fibers were divided into 0° or 90° orientation against the fracture surface firstly. As an example shown in Fig.2, 0 degree glass fibers, 90 degree glass fibers, 0 degree jute fibers and 90 degree jute fibers on the fracture surface of the G10J30 specimen could be obtained from the observation based on the SEM photograph and image analysis software (COSMOS32 Library Corporation).

Secondly, the numbers of all of the glass and jute fibers in 0 degree and 90 degree orientations based on the observation of the pictures were counted. Here, is the account of jute fiber in 0 degree. Similarly, and is the account of jute fiber in 90 degree, glass fiber in 0 degree and glass fiber in 90 degree. Late those values were put to those equations (1-4) to calculate their fiber volume fractions.

$$V_{f(Jute0)} = V_{f(Jute)} \frac{n_{Jute(0)}}{n_{Jute(0)} + n_{Jute(90)}} \quad (1)$$

$$V_{f(Jute90)} = V_{f(Jute)} \frac{n_{Jute(90)}}{n_{Jute(0)} + n_{Jute(90)}} \quad (2)$$

$$V_{f(Glass0)} = V_{f(Glass)} \frac{n_{Glass(0)}}{n_{Glass(0)} + n_{Glass(90)}} \quad (3)$$

$$V_{f(Glass90)} = V_{f(Glass)} \frac{n_{Glass(90)}}{n_{Glass(0)} + n_{Glass(90)}} \quad (4)$$

Here, $V_{f(Jute0)}$, $V_{f(Jute90)}$, $V_{f(Glass0)}$, $V_{f(Glass90)}$ are the fiber volume fractions of 0 degree jute fiber, 90 degree jute fiber, 0 degree glass fiber and 90 degree glass fiber respectively. Similarly, the resin also divided according to the fiber orientation. The results of the calculated each fiber and resin volume in 0 or 90 degree were summarised in Table 3. Then, the fracture area was separated into two parts i.e. 0 and 90 areas as shown in Fig.3. 0 area includes 0 degree fibers (jute or/and glass) and the 0 degree resin. Similarly, 90 area contains 90 degree fiber (jute and/or glass) and the corresponding 90 degree resin. Then the calculation results in Table 3 could be changed individually to satisfy the total volume of each 0 and 90 area to be 100%. Here $V'_{f(Jute0)}$, $V'_{f(Glass0)}$ and $V'_{m(0)}$ are the relative volumes of 0 degree jute, 0 degree glass and 0 degree resin in 0 area part while $V'_{f(Jute90)}$, $V'_{f(Glass90)}$ and $V'_{m(90)}$ are the relative volumes of 90 degree jute, 90 degree glass and 90 degree resin in 90 area part respectively. Both of them are follow the formula 5&6, i.e.

$$V'_{f(glass0)} + V'_{f(jute0)} + V'_{m(0)} = 1 \quad (5)$$

$$V'_{f(glass90)} + V'_{f(jute90)} + V'_{m(90)} = 1 \quad (6)$$

Then tensile modulus of 0 and 90 parts were calculated according to the formula 7~8. Then the tensile modulus of the composite was considered to be calculated by the formula 9 based on the tensile moduli of 0 and 90 and their effective ratio.

$$E_0 = E_{f(glass)}V'_{f(glass0)} + E_{f(jute)}V'_{f(jute0)} + E_m V'_{m(0)} \quad (7)$$

$$\frac{1}{E_{90}} = \frac{V'_{f(Glass90)}}{E_{Glass}} + \frac{V'_{f(Jute90)}}{E_{Jute}} + \frac{V'_m}{E_m} \quad (8)$$

$$E_c = E_0 \frac{V_0}{V} + E_{90} \frac{V_{90}}{V} \quad (9)$$

In the calculation, E_{Jute}, E_{Glass} and E_m is the modulus of jute fiber, glass fiber and matrix in the values of 55GPa, 76GPa and 1.1GPa respectively [6-10]. As compared the results between calculation and experiment in Table 4, it is found that big difference exists in the Jute reinforced

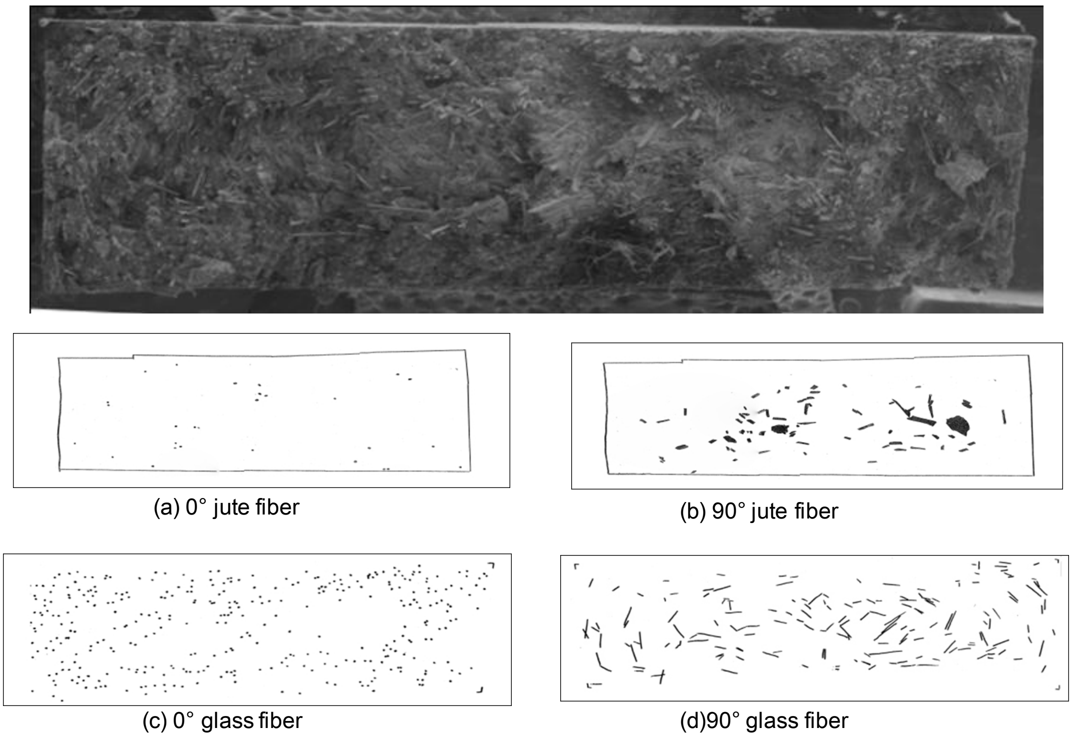


Fig. 2 Fiber orientations on the fracture surface of G10J30

composites. It is considered that there are two reasons: one is that the distribution of jute fiber is inhomogeneous and the other is that the number of jute fiber is difficult to count because some of them are combined together.

It is found that jute fibers trend to orient towards transversal direction and concentrated in the core lay as compared to the glass fibers which are relative homogeneously. This highly anisotropic fiber orientation in the hybrid composites could be the main reason for the lower mechanical property especially when high jute content is present. Similarly, G10J30 (or J30) have more jute fibers than G10J20 (or J20), but most of them are orienting to the transversal direction. It is considered that although jute fiber volume is increased in G10J30 (or J30), the increased jute fibers volume did not bring a homogeneous distribution and could not contribute to the tensile property in longitudinal direction. That is why G10J30 (or J30) have low tensile property than G10J20 (J20).

Table 3 The calculated each orientated fiber and resin volume based on observation.

Specimen		Number	Vf (%)	Vm (%)
G10	0-glass	837	2.45	61.19
Vg:3.85%	90-glass	480	1.40	34.96
G10J20	0-glass	667	2.76	40.21
Vg:4.12%	90-glass	330	1.36	19.89
Vj:15.83%	0-jute	214	10.23	12.90
	90-jute	117	5.60	7.05
G10J30	0-glass	415	2.73	31.53
Vg:4.27%	90-glass	236	1.55	17.93
Vj:24.62%	0-jute	136	11.75	10.33
	90-jute	149	12.87	11.32
J20	0-jute	108	9.21	53.22
Vj:14.75%	90-jute	65	5.54	32.03
J30	0-jute	62	10.06	33.91
Vj:22.88%	90-jute	79	12.82	43.21

4. Conclusion

The main setback of natural fiber reinforced plastics is their low mechanical properties as compared to glass fiber reinforced plastics. In order to overcome this problem, one of the solutions of hybridization of natural fibers with glass fibers was proposed.

The tensile property was investigated. However, the mechanical properties did not improved linearly by the increase of the jute fiber volume fraction. A non-linear correlation between the fiber contents and tensile strength in the hybrid composites could be observed whereby the optimum hybridization of GF 10wt% and JF 20wt%.

Microscopic observations revealed that the distribution and orientation of glass and jute fibers would be different with increasing jute fiber content. Therefore, based on the fiber orientation on the fracture surface, hybrid composite modulus prediction was attempted by introducing Rule of Mixture. Although predicted results did not show good agreement with the experimental results, it is considered to be a first step to analysis the effect of fiber orientation to the mechanical property.

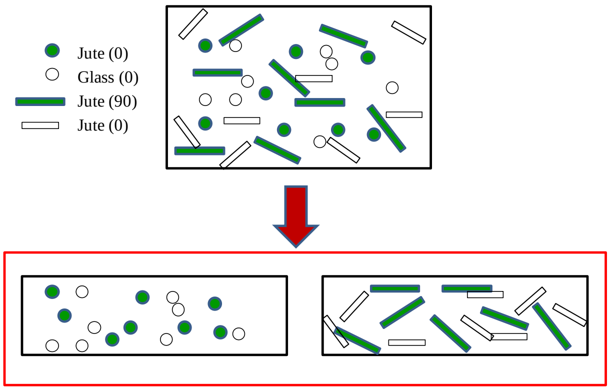


Fig.3 The fracture area separated into two parts i.e. 0 and 90 areas

Table 4 Table of the calculated tensile moduli of 0 and 90 parts, their effective ratios and the composite modulus compared with experimental results.

Specimens	E0	V_0/V	E90	V_{90}/V	Ec Calculation	Ec Experimental
G10	3.98	0.64	1.14	0.36	2.95	2.77
G10J20	12.57	0.66	1.38	0.34	8.78	5.59
G10J30	15.97	0.56	1.63	0.44	9.71	6.30
J20	9.05	0.62	1.29	0.38	6.13	2.76
J30	13.43	0.44	1.42	0.56	6.70	3.74

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