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Effect of molding condition on tensile properties of hemp fiber reinforced composite

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Abstract—In this study, the effect of molding condition on the tensile properties for plain woven hemp fiber reinforced green composite was examined. The tensile properties of the composite were compared with those of the plain woven jute fiber composite fabricated by the same process. Emulsion type biodegradable resin or polypropylene sheet was used as matrix. The composites were processed by the compression molding where the molding temperature and its heating time were changed from 160 to 190°C and from 15 to 25 min, respectively. The following results were obtained from the experiment. The tensile property of hemp fiber reinforced polypropylene is improved in comparison with polypropylene bulk. The strength of composite is about 2.6 times that of the resin bulk specimen. Hemp fiber is more effective than jute fiber as reinforcement for green composite from the viewpoint of strength. The molding temperature and time are suitable below 180°C and 20 min for hemp fiber reinforced green composite. Hemp fiber green composite has a tendency to decrease its tensile strength when fiber content is over 50 wt%.

Keywords: Green composite; molding condition; tensile properties; hemp fiber; biodegradable resin; polypropylene.

1. INTRODUCTION

Glass fiber reinforced plastics (GFRPs) have been used for many mechanical components. The GFRPs have been replaced with metals in many applications because of their superior advantages such as durability, high specific strength, stiffness and so on. To process the GFRPs, polymer resins, such as polyimides or unsaturated polyesters, have been used as their matrix. However, with current environmental concerns, there is a waste problem after use. As GFRPs are derived from petroleum feedstock, they are not degradable within normal environments. Glass fiber has high chemical stability, and it is also difficult to dispose of by

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incineration. So, composite materials, particularly those using thermoset resins, are quite difficult to recycle or reuse. As the solution to such problems, there is a great deal of interest in developing green composites. These green composites are defined by fully sustainable, biodegradable, environment friendly and renewable fibers and resins, particularly those derived from plants.

Recently, there have been some studies on manila hemp or bamboo fibers as reinforcement of green composite. Manila hemp fiber reinforced composite has a high strength of 350 MPa [1, 2]; but it presents problems with cost and there is only a small market. For bamboo fiber reinforced composite, there are several studies of the mechanical properties [3–5]. The hemp fiber among natural fibers has been used for fishing net and rope for hundreds of years. Hemp fiber is also expected to have potential as a material for reinforcement of the green composites because of its ready availability in the commercial market with reasonable cost as well as its high rate of growth in the farm field. The published papers with hemp fibers almost always used thermoset and theromoplastic resins [6, 7]. So hemp fiber reinforced green composite was chosen in this study.

The molding condition of the natural fiber is more effective to mechanical properties than that of artificial glass fiber. For ramie fiber reinforced composite, there is an effect of molding condition using alkali treatment [8]. For kenaf fiber reinforced composite, there is an effect of molding condition on tensile strength [9]. But there are few papers about molding conditions for hemp fiber reinforced composite.

In this study, the effect of molding condition on tensile properties is examined for this green composite. The experimental data were also compared with those obtained with reinforcement of jute fiber and matrix of polypropylene.

2. EXPERIMENTAL

2.1. Materials

Figure 1 shows plain woven jute and hemp fibers used as reinforcement. Emulsion-type biodegradable resin (Miyoshi Oil and Fat Co. Ltd., PL-1000) was used as matrix. The pure resin has 68 MPa, 6.0% and 1.26 g/cm^3 in tensile strength, tensile elongation and density in solid state, respectively. Polypropylene sheet (Shin-Kobe Electric Machinery Co. Ltd., Kobe Polysheet PP-N-AN) was also used as the matrix of hemp fiber composite.

2.2. Preparation of preform

At first, two fiber cloth sheets were cut to the size whose width was 400 mm and length was 250 mm in case of fabricating green composite. Then, the emulsion of biodegradable resin was carefully varnished on the top of the fiber cloths using a clean brush. These sheets were dried at 75°C for 24 h in an oven. After drying, the

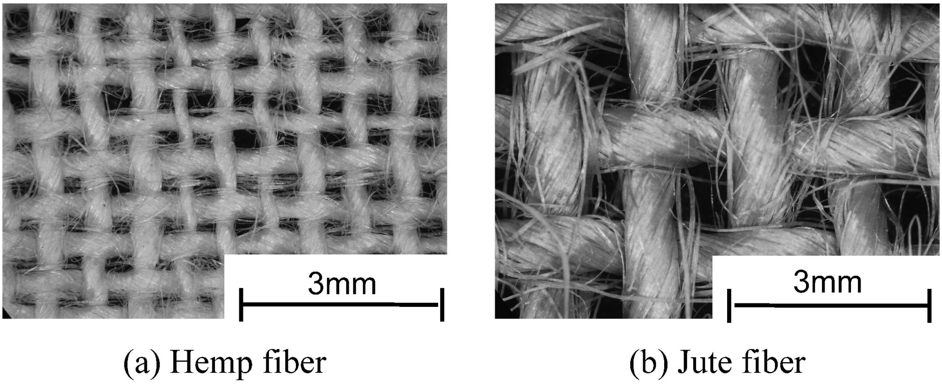

Figure 1. Appearance of hemp and jute fiber.

sheet was referred to as the 'preform sheet' in this study. The six preform sheets were laminated in a mold to fabricate the composite shown in the next section. The same technique was applied in fabricating the jute fiber composite. In this study, the composites using six hemp and jute sheets were called H6GC and J6GC, respectively.

2.3. Molding method

Figure 2 shows the schematic drawing of vacuum molding method. The plate of the composite was molded with a conventional hot pressing technique (Toyo Seiki Seisaku-syo, LTD., Mini Test Press MP-WCL). To process the composite, laminated preform sheets described in the last section were put into the machined metallic mold. The mold with material was vacuumed with the heat resisting film bag in the process. The molding temperatures of upper and lower parts are called Up and Lo, respectively. The molding temperature was changed as a parameter shown in Table 1. The molding pressure was kept at 4.3 MPa in fabricating the green (hemp and jute) composite. When polypropylene was used as matrix, hot pressing was conducted under 0.8 MPa at 190°C and 210°C as Up and Lo temperatures, respectively. After pressing, the composite was cooled to 40°C with a cooling system within 5 min. For hemp fiber reinforced polypropylene, fiber weight contents were changed at 27%, 42% and 56%.

2.4. Experiments

Figure 3 shows the geometry of a tensile specimen cut from the molded plate described in the last section. The dimensions of the specimen were referred to the type B-I in JIS K7054 (Japanese Industrial Standard, testing method for tensile properties of glass fiber reinforced plastics). The fiber volume fractions (weight contents) are 46% (48 wt%) and 51% (56 wt%) for hemp fiber green composite and jute fiber green composite, respectively. A static tensile test was conducted by using a universal testing machine (Shimadzu Co., Autograph AG-IS). The tensile strain

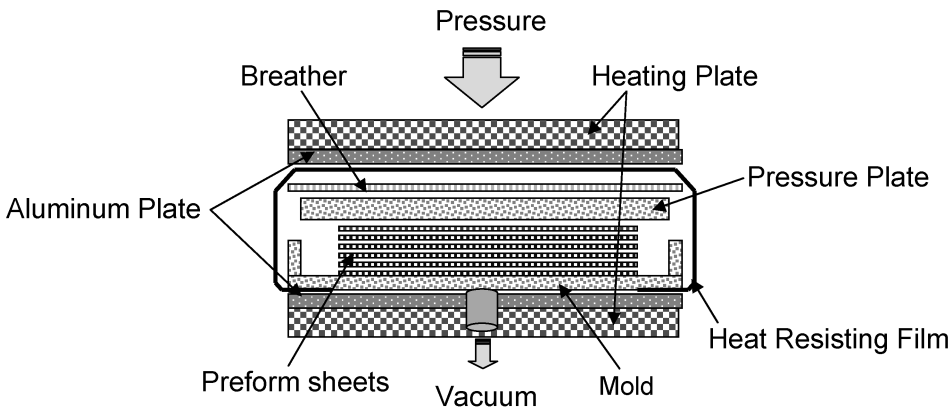

Figure 2. Hot pressing system of green composite.

Table 1.
The molding temperature of hemp fiber green composite

Molding temperature	Case I	Case II	Case III
Upper part temp.	160	170	180
Lower part temp.	170	180	190

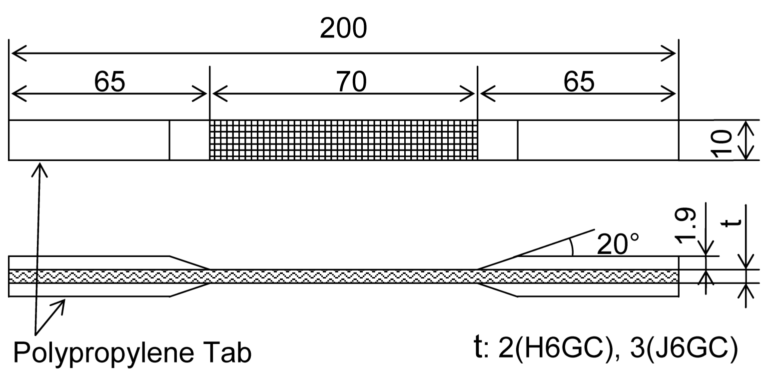

Figure 3. Geometry of tensile specimen.

in 25 mm of gage length was measured by an extensometer (MTS System Co., 634. 11F-24), and signal conditioner (Kyowa Electronic Instrument Co. Ltd., CDV-230C) under 1.0 mm/min of crosshead speed. The Young's modulus was defined as the approximate linear slope in the range of 0.05 to 0.25% of strain. The fracture surfaces of hemp fiber composites were observed by scanning electron microscope (Hitachi High-Technologies Co., S-4000).

3. RESULTS AND DISCUSSION

3.1. Tensile properties of hemp fiber reinforced polypropylene

Figure 4 gives stress–strain curves for hemp fiber reinforced polypropylene (HFRP). Table 2 shows the tensile properties of the composites. This table indicates that tensile strength increased with increasing fiber content. The maximum strength corresponding with 2.6 times of that of resin bulk was obtained at 56 wt% of hemp fiber content. Moreover, Young's modulus and knee point stress of HFRP increase with increasing fiber content. The maximum Young's modulus and knee point stress with 2.8 and 1.8 times of that of resin bulk were obtained at 56 wt% of hemp fiber content. For practical use, knee point stress was used for structural design. So the improvement of knee point stress is meaningful. Therefore, the data shown in this section confirmed that the hemp fiber worked as effective reinforcement in the composite processed with the current technique shown in this study.

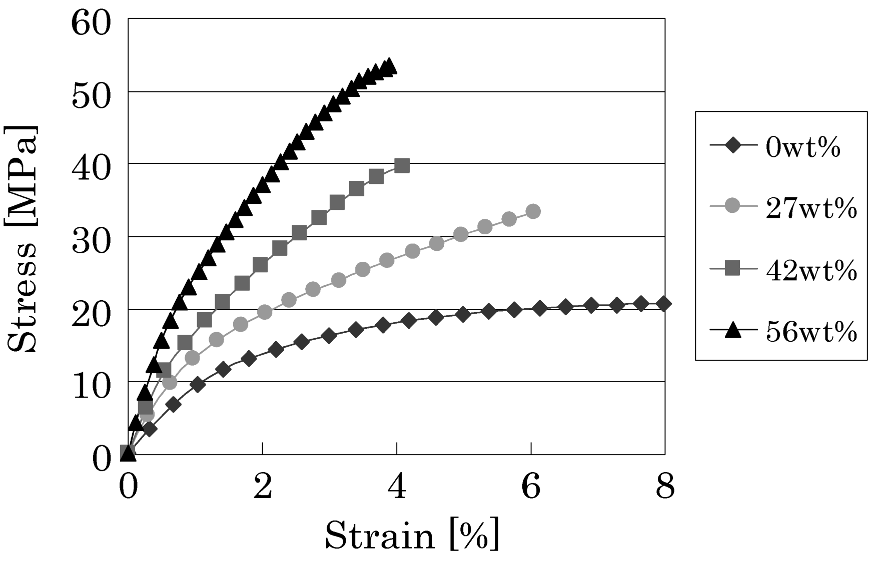

Figure 4. Typical tensile stress–strain curves of polypropylene bulk (0 wt%) and hemp fiber reinforced polypropylene.

Table 2.
Tensile properties of hemp fiber reinforced polypropylene

Fiber content [wt%]	0	27	42	56
Tensile strength [MPa]	20.8	34.4	39.9	53.6
Young's modulus [GPa]	1.1	1.7	2.9	3.1
Knee point stress [MPa]	11.7	15.7	17.3	20.8

3.2. Tensile properties of hemp and jute fiber green composite

Figure 5 shows the relationship between tensile strength and strain of hemp fiber (H6GC) and jute fiber (J6GC) composites. Table 3 shows the mechanical properties of the composite. These specimens were fabricated at Case II condition. The data shows tensile strength of the hemp fiber composite was higher than that of jute fiber composite, while their initial stiffness was independent of the kind of fiber. As the stress increased, the effect of properties of reinforcements becomes great. For J6GC, knee point stress was about 25 MPa. On the other hand, there was no knee point for H6GC. This phenomenon affects their strength. The fracture strain for J6GC is smaller than that of H6GC. The result suggests that hemp fiber was effective to the current material system with the processing method shown in this study.

3.3. Effect of molding condition on hemp fiber green composite

Table 4 shows the tensile properties under each molding condition for hemp fiber composite. Here, Cases I, II and III were defined in Table 1. Table 4 shows that the highest strength was obtained at the Case II molding condition which was 94.4 MPa. The molding condition for lowest tensile strength was the Case I. This indicates the

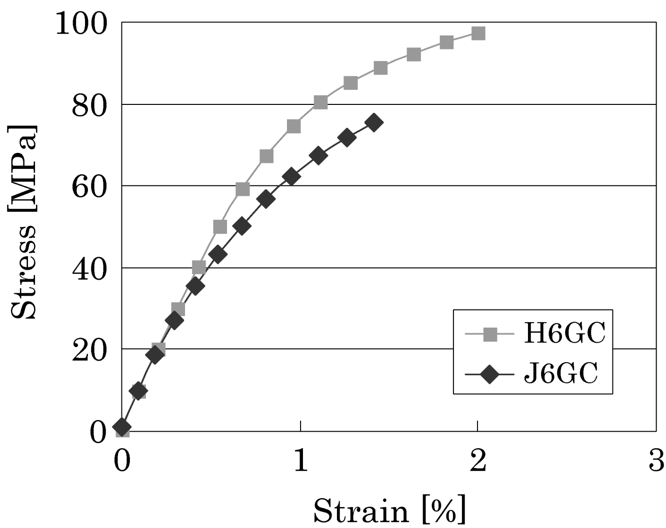

Figure 5. Typical tensile stress–strain curves of J6GC and H6GC.

Table 3.
Tensile properties of green composite

Reinforcement	Hemp	Jute
Tensile strength [MPa]	96.7	76.5
Young's modulus [GPa]	9.2	8.4
Fracture strain [%]	2.1	1.4

Table 4.
Tensile properties of H6GC under molding condition

Molding temp.	Case I			Case II			Case III		
Molding time	15 min	20 min	25 min	15 min	20 min	25 min	15 min	20 min	25 min
Tensile strength [MPa]	76.9	75.7	81.3	94.4	93.3	87.7	88.2	85.3	83.0
Young's modulus [GPa]	8.0	7.5	7.8	8.4	8.6	9.0	8.1	8.3	8.8

Table 5.
Ultimate tensile force of hemp fiber after heat

Heating temp.	160°C			170°C			180°C		
Heating time	15 min	20 min	25 min	15 min	20 min	25 min	15 min	20 min	25 min
Tensile force [N]	76.7	71.8	68.7	80.3	71.2	72.8	79.9	71.5	62.1

temperature of Case I was not enough for molding of this composite. In this case, as molding time increases, tensile strength increased. This is because that heat transfer rate in the mold was low. Young's modulus does not show any tendency in the Case I. On the other hand, in Cases II and III, the highest strength was obtained when the time was 15 min. The strength in 20 min is almost equal to that in 15 min at Case II. In the case of 25 min, the strength was lowest at Cases II and III. In these cases, Young's modulus increased as the molding time increased. As a reason, it is thought that the stiffness of fiber itself increased.

Table 5 shows the ultimate tensile force of the fiber bundle after the fibers were heated under the condition shown in this table. The test result showed the ultimate tensile force of the hemp fiber decreased with the heating time. Especially, the decreasing rate was significant when the fiber was exposed with high temperature (180°C). Therefore, strength reduction of Case III is thought to be due to this fiber degradation at elevated temperature condition for the hemp fiber composite.

Figure 6 shows the fracture surface of the H6GC and biodegradable resin bulk specimen under different conditions. In these cases, molding time was 15 min. This figure shows that the fracture surface looks brittle in the case of low molding temperature (Case I). It has also the same brittle pattern in resin bulk. So, the reason that the strength of Case I is low is its brittle property. On the other hand, pull-out of hemp fiber can be seen in Case III. Pull-out of fiber means that the interface strength is not enough. So this weak interface is the reason that the strength is not high at the Case III. In the Case II, few pulled out fibers can be seen, and the fracture surface is not brittle. So this is the reason that this case has the highest strength.

This study found that appropriate molding condition for the hemp fiber composite is the 180°C of molding temperature and 20 min of pressing time.

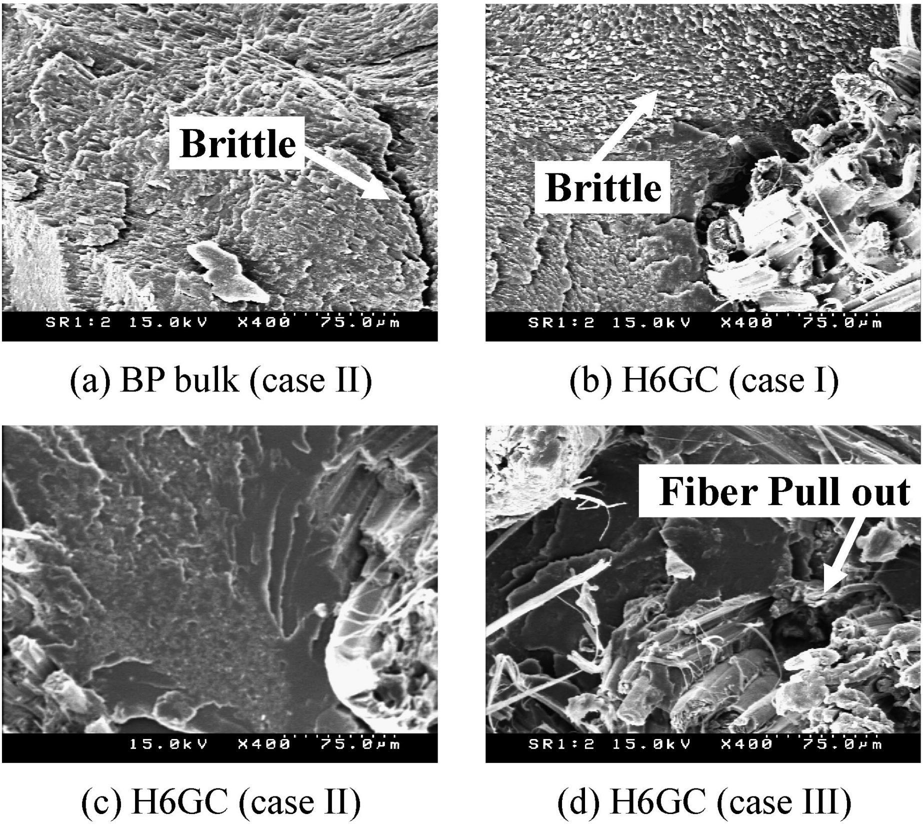

Figure 6. SEM photomicrographs of fracture surface of H6GC and BP bulk.

3.4. Effect of fiber content to hemp fiber green composite

Figure 7 shows the relationship between tensile strength and fiber content of hemp fiber composite processed under the molding condition of Case II. This figure shows that the tensile strength increased with fiber content under 50 wt%. The tensile strength of the composite exceeded 90 MPa that was expected for a semi-structural member, when fiber weight content was about 50 wt%. However, tensile strength has a tendency to decrease when the fiber content is over 50 wt%. This is because the resin does not distribute uniformly when the fiber content is over 50 wt%. Figure 8 shows the surface of green composites in the case when fiber contents are 48 wt% and 63 wt%. In this figure, fiber cloth pattern can be seen on the surface in the case when fiber content is 63 wt%. This phenomenon shows that the resin in not enough when the fiber content is over 50 wt%. The limit might be contributed by poor distribution of the matrix around the fibers which form a small clearance between them.

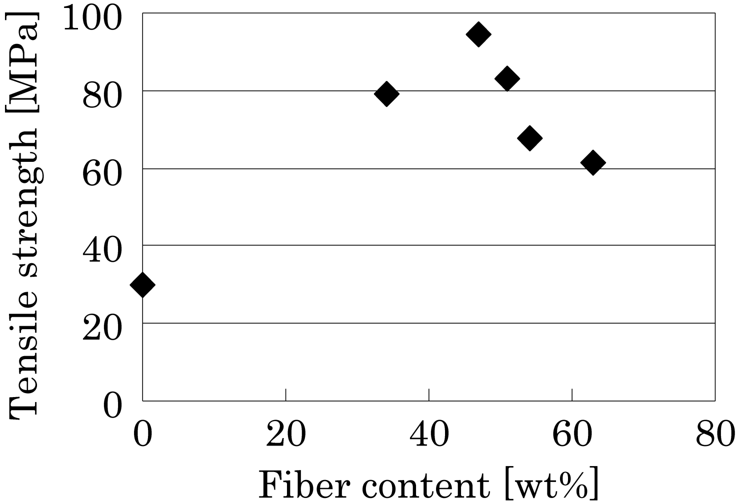

Figure 7. Relation between tensile strength and fiber content of hemp fiber green composites.

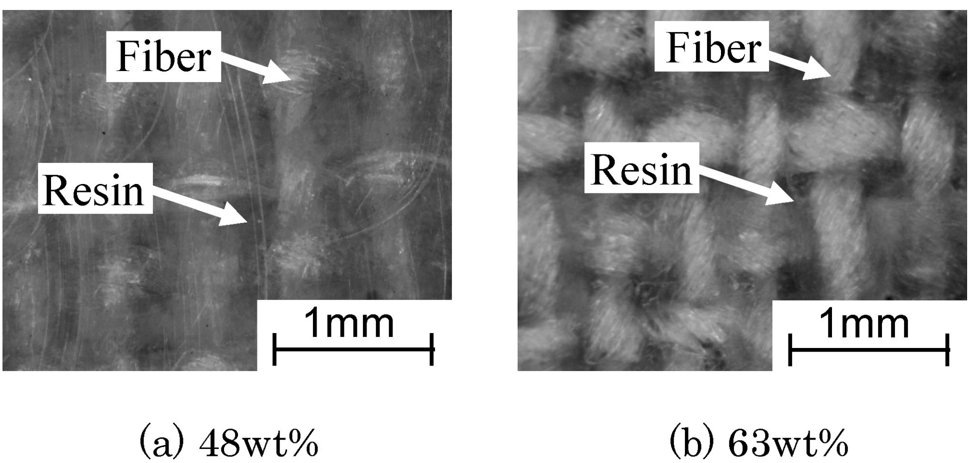

Figure 8. Appearance of hemp fiber green composite.

4. CONCLUSIONS

1. The tensile property of hemp fiber reinforced polypropylene is improved in comparison with polypropylene bulk. The strength of composite is about 2.6 times of that of resin bulk specimen.
2. The tensile property of hemp fiber green composite is higher than that of jute fiber green composite. Therefore hemp fiber is a more effective reinforcement for green composite.
3. For desirable molding conditions, molding temperature is below 180°C and molding time is below 20 min of hemp fiber reinforced green composite.

4. Hemp fiber green composite has a tendency to decrease the tensile strength when fiber content is over 50 wt%.

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