

EFFECT OF MOLDING CONDITION ON THE MECHANICAL PROPERTIES OF HEMP FIBER/POLY(LACTIC ACID) COMPOSITES.

K. Takada¹, S. Kobayashi¹

¹ Dept. of Mechanical Engineering, Tokyo Metropolitan Univ., Tokyo, Japan,

* Corresponding author (koba@tmu.ac.jp)

Keywords: *hemp fiber, PLA, micro-braiding*

1 Introduction

Advances in science and technology pose new challenges on the materials in relation to certain environmental issues, such as biodegradability, recyclability, eco-friendliness etc., that need to be addressed to help preserve and protect our environment. Composite materials from the renewable natural fibers and biodegradable matrices have been developed in the past decade in an attempt to find alternatives to the fossil fuel-based polymeric materials in the automotive and packaging industries. For an example, Khondker et al [1] investigate jute fiber reinforced poly(lactic acid) (PLA) composites. In their study, jute fiber and PLA are natural and biodegradable materials, respectively.

Composites developed based on thermoplastic matrix materials have several advantages over those based on thermoset matrix materials, such as storage stability of intermediate materials without freezing device, higher stability in mechanical performance, cycling usage ability, in situ adaptability (e.g., through a hot treatment), and so on, and hence have received more attention in recent years. Unlike thermoset polymers, thermoplastic polymers have relatively high viscosity. Therefore, it is more difficult to impregnate thermoplastic resin into continuous fiber yarns. A lot of studies for the short fibers reinforced thermoplastic composites are performed, for example, jute fiber composites by A. K Bledzki, et al [2], flax fiber composites by Benjamin Bax et al [3] and hemp fiber composites by Nina Graupner et al [4]. However, there are few studies about continuous natural fiber reinforced composites.

In order to improve the impregnation of thermoplastic resin into fiber yarns, Sakaguchi et al. developed a micro-braiding method to supply flexible material design on continuous fiber reinforced thermoplastic composites [5]. The developed method allows many design choices of thermoplastic matrices. Furthermore, high matrix impregnation and good fiber dispersion can be

expected since the reinforcing fibers and the matrix fibers can be combined as one braided yarn.

It is well known that the mechanical properties of a continuous fiber reinforced thermoplastic composite are affected by its processing conditions such as pressure, temperature, holding time, and so on. In this study, Hemp fiber/PLA composites fabricated at different conditions, those composites were performed tensile tests. This study investigates the effect of molding condition on the mechanical properties of hemp fiber/PLA composites.

2 Experimental

2.1 Molding Methods

The reinforce fiber used in this study was hemp fiber (590 tex). The matrix material used in this study was biodegradable PLA fiber (55 tex) from TORAY., Japan. An intermediate material fabricated using a micro-braiding technique. Continuous hemp fibers were used as the straightly inserted axial fibers, and matrix fibers were braided around the reinforcing hemp fibers (Fig. 1).

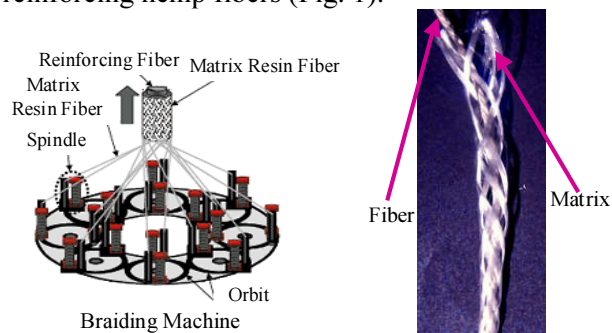


Fig. 1 Fabrication of Micro-Braiding.

Fabrication of continuous hemp fiber reinforced PLA thermoplastic composites consisted of two-fold process. The first step included 20 times winding the intermediate material in parallel onto a metallic

frame. The second step involved placement of the metallic frame with intermediate materials in a pre-heated molding die for consolidation by compression molding to produce composite specimens (Fig. 2). The effects of molding temperature (170 °C, 190 °C, 210 °C and 230 °C) and pressure (1 and 3 MPa), time (4 and 8 min) were investigated. Twelve types of hemp/PLA composite specimens were fabricated.

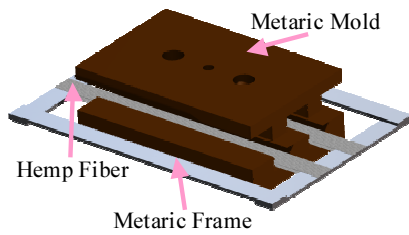


Fig. 2 Alignment of Micro-Braiding for compression molding.

2.2 Tensile testing

Tensile specimens of 180 mm × 20 mm in nominal dimensions, with the fiber axis along the loading direction were used in this study. Specimens were clamped over an area of 30 mm × 20 mm at each end, which results in a gauge length of 120 mm. Aluminum tabs were glued on the clamped area. Strain was measured using a strain gauge, which were bonded onto the central surface of the specimen. Tensile test were conducted using an AGS-1000A with a cross-head speed of 1.0 mm/min.

2.3 Thermal Gravimetric Analysis

Thermal gravimetric analysis (TGA) was used to determine the thermal degradation temperature of hemp fiber. The measurements were conducted from room temperature to 170, 190, 210 and 230 °C, at a rate of 5 °C/min, at hold time of 30 min under air atmosphere.

2.4 FTIR measurement

FTIR measurement was used to investigate thermal degradation of hemp fiber during molding. Hemp fibers were extracted from the composites using chloroform. FTIR spectra were obtained by ATR method. The test conditions were measurement

range from 400 to 4000 cm⁻¹ and cumulated number of 20.

2.5 Calculation of fiber volume fraction and porosity

The calculation fiber volume fraction V_f and porosity are based on the two weight and volume relationships that are general for all composite materials:

$$w_c = w_f + w_m \Rightarrow 1 = \frac{w_f}{w_c} + \frac{w_m}{w_c} = W_f + W_m \quad (1)$$

$$v_c = v_f + v_m + v_p \Rightarrow 1 = \frac{v_f}{v_c} + \frac{v_m}{v_c} + \frac{v_p}{v_c} \quad (2)$$

$$= V_f + V_m + V_p$$

where w and v are weight and volume, respectively, W and V are weight fraction and volume fraction, respectively, and the subscripts c , f , m and p are composite, fibers, matrix and porosity, respectively.

Based on the density of fibers and matrix, expressions for V_f and V_m , V_p can be formed:

$$V_f = \frac{\rho_c}{\rho_f} W_f \quad (3)$$

$$V_m = \frac{\rho_c}{\rho_m} W_m \quad (4)$$

$$V_p = 1 - (V_f + V_m) \quad (5)$$

where ρ is density. Density is determined based on the principle of Archimedes.

3 Results and discussion

The stress-strain curve of the composites molded at 170 °C, 190 °C and over 210 °C are shown in Fig. 3 and 4, 5, respectively. Tensile tests could not be conducted on the specimen molded at 230 °C - 3 MPa - 8 min, because the composites was severely degraded during molding. In case of molding temperature of 170 °C, elastic moduli were clearly changed with molding pressure and time.. In contrast, in case of molding temperature of over 190 °C, elastic moduli were kept almost constant. In order to evaluate quantitatively, the elastic modulus of the composites molded at different conditions are shown in Fig. 6. When the process temperature increased

from 170 °C to 190 °C, elastic modulus increased. When the process temperature increased over 190 °C, elastic moduli were kept constant.

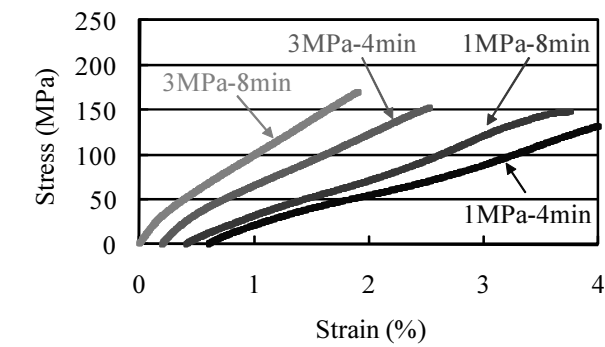


Fig. 3 Stress-Strain curve of hemp/PLA composites molded at 170 °C.

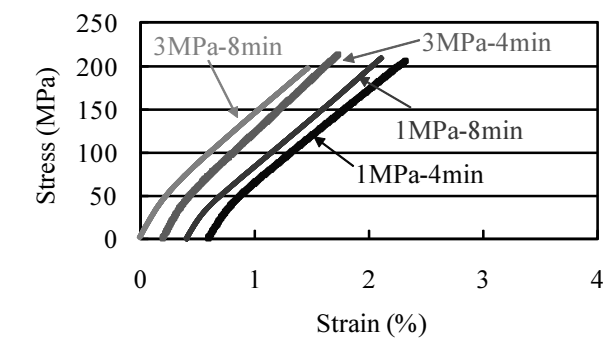


Fig. 4 Stress-Strain curve of hemp/PLA composites molded at 190 °C.

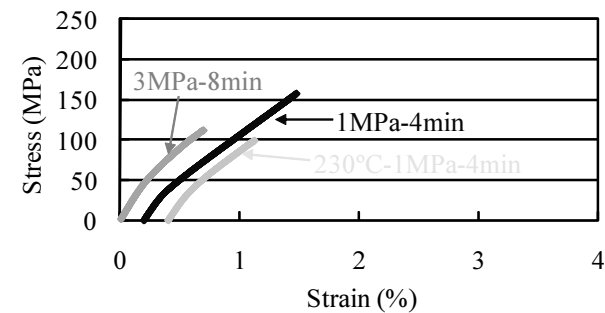


Fig. 5 Stress-Strain curve of hemp/PLA composites molded at over 210 °C.

The tensile strength of the composites molded at different conditions are shown in Fig. 7. When the process temperature increased from 170 °C to 190 °C, tensile strength also increased clearly, whereas the process temperature increased over 210 °C, tensile strength decreased. In addition, molding pressure and time hardly affected tensile strength.

The fracture strain of the composites molded at different conditions are shown in Fig. 8. Fracture strain also decreased with increasing molding temperature.

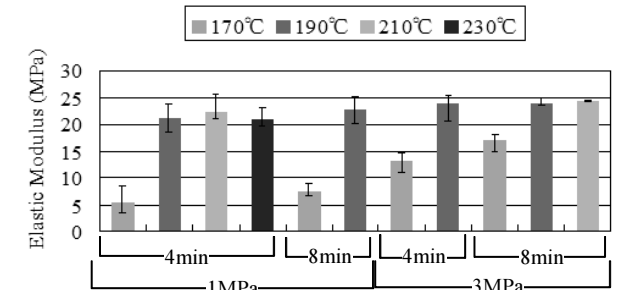


Fig. 6 Elastic modulus of hemp/PLA composites molded at different conditions.

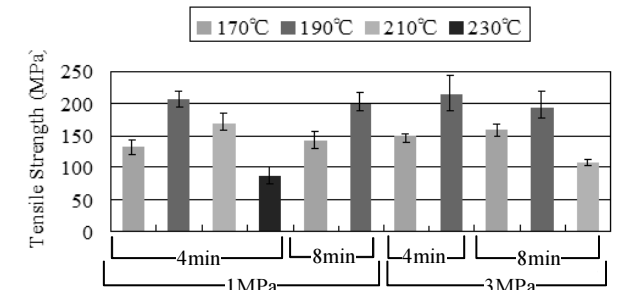


Fig. 7 Tensile strength of hemp/PLA composites molded at different conditions.

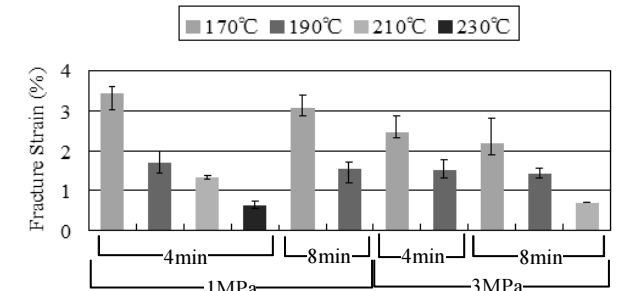


Fig. 8 Fracture strain of hemp/PLA composites molded at different conditions.

As mentioned above, when the process temperature increased from 170 °C to 190 °C, elastic modulus and tensile strength increased and fracture strain decreased. In general, increasing molding temperature reduces viscosity of resin, which result in the good impregnation. At the same time, the melt overflowing from a molding die makes fiber volume fraction of a composite higher. Increasing moduli and strength with temperature may be attributed to increasing volume fraction. Higher fracture strain at molding temperature 170 °C indicated poorer impregnation and interfacial bonding between fiber and matrix. That is, bonding

between fiber and matrix was imperfect and stress was not transferred from matrix to fiber. In this case, only matrix was loaded and fibers were left as unstressed state.

In case of molding temperature over 210 °C, tensile strength and fracture strain decreased. It is thought that hemp fiber was thermally degraded. This result was similar tendency with the investigations about hemp fiber by Madsen et al [2, 3].

In order to evaluate impregnation, the results of cross-sectional observation is shown in Fig. 9. Fig. 10 shows the enlargement of unimpregnated and impregnated area. Impregnation was improved with increasing temperature, qualitatively.

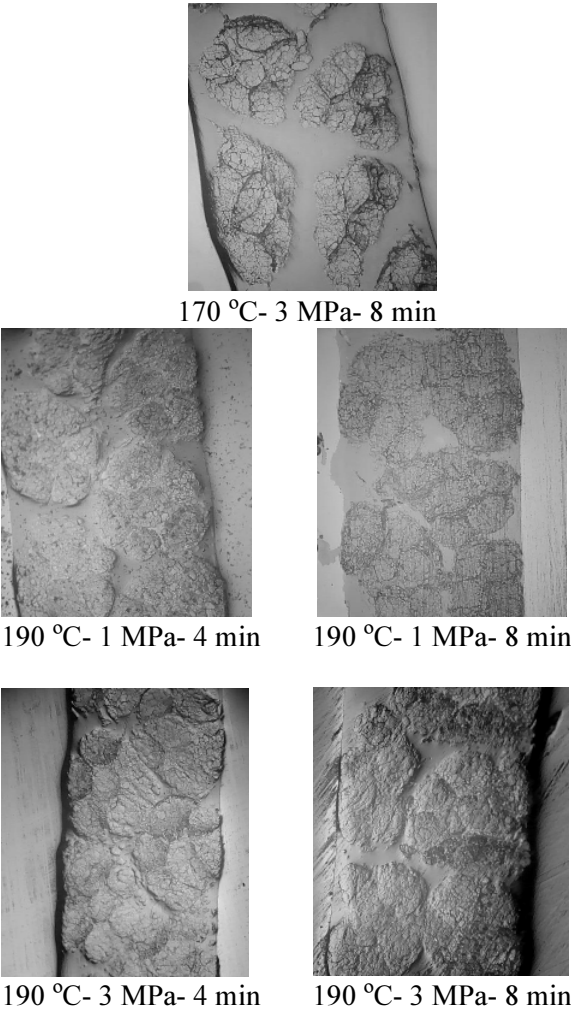


Fig. 9 Cross section area of hemp/PLA composites molded at different conditions.

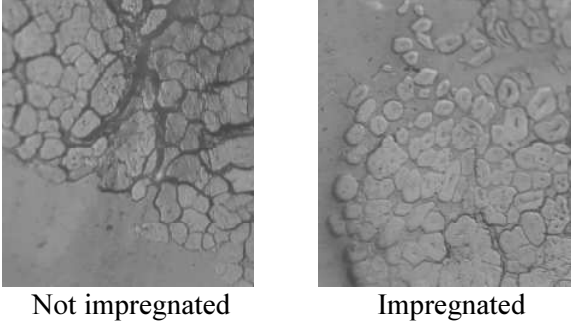


Fig. 10 Typical not impregnated area and impregnated area of hemp/PLA composites.

The fiber volume fraction of the composites molded at different conditions are shown in Fig. 11. As expected, fiber volume fraction increased with increasing molding temperature. The porosity of the composites molded at different conditions are shown in Fig. 12. When the molding temperature increased from 170 °C to 210 °C, porosity decreased. This was due to the improvement in impregnation and collapse of lumen in the fiber. In case of molding temperature of 230 °C, porosity increased remarkably. This may be caused by gas generation due to thermal decomposition of fiber.

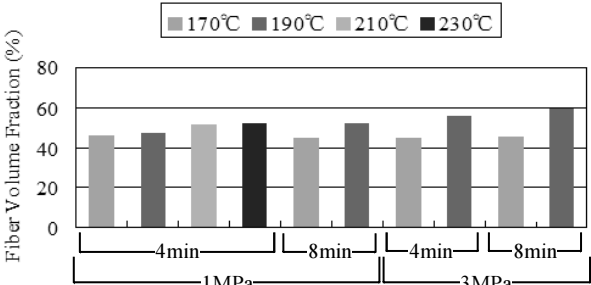


Fig. 11 Fiber volume fraction of hemp/PLA composites molded at different conditions.

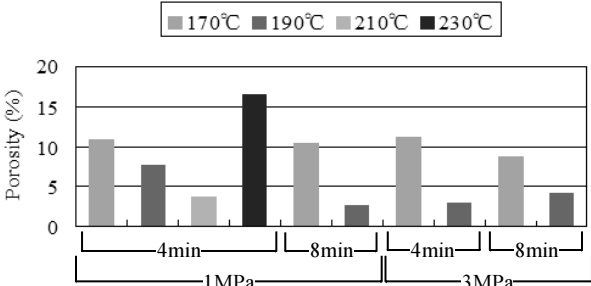
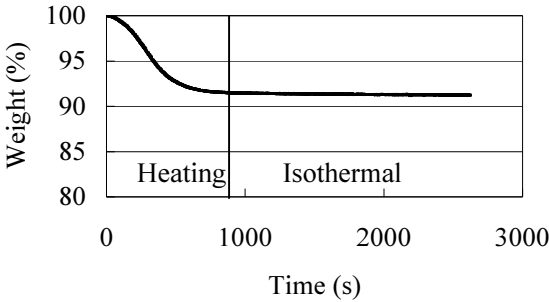


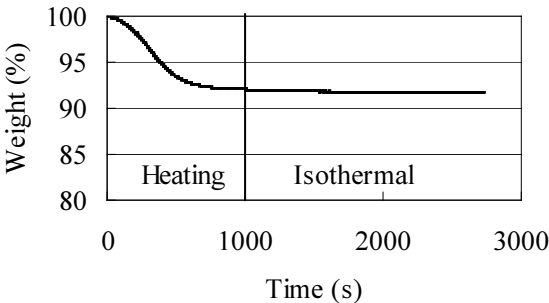
Fig. 12 Porosity of hemp/PLA composites molded at different conditions.

To investigate decomposition temperature of hemp fiber, TGA curves are obtained as shown in Fig. 13. Data at 210 °C and 230 °C show significant weight

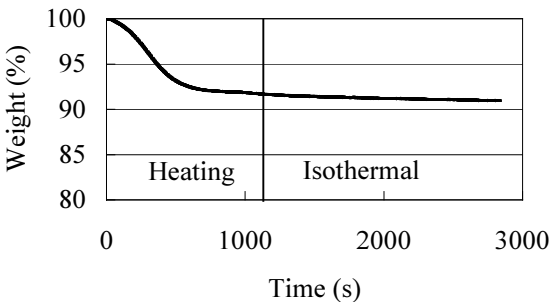
loss at isothermal stages during tests, especially in 230 °C. The IR spectra of hemp fiber molded at different conditions are shown in Fig. 14. Fig. 14 shows that molding conditions 210 °C- 3 MPa- 8 min and 230 °C- 1 MPa- 4 min reduced intensity of the band at 1730 cm⁻¹. Band at 1730 cm⁻¹ shows C=O of hemicelluloses [8]. It is thought that hemp fiber is thermally degraded at molding temperature at 230 °C and longer molding time at 210 °C.



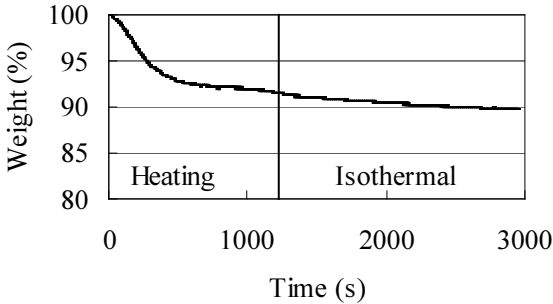
(a) 170 °C



(b) 190 °C

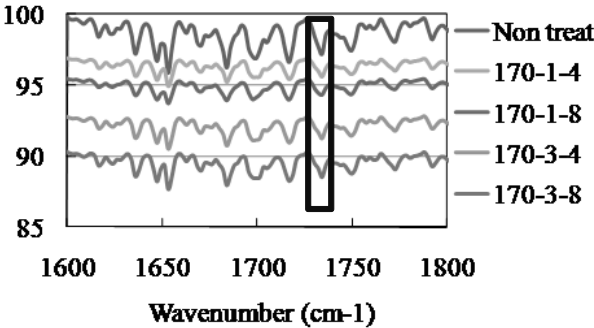


(c) 210 °C

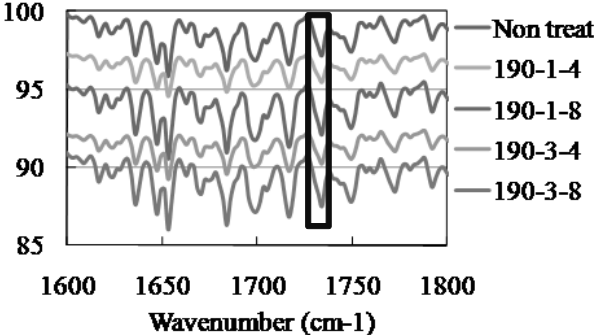


(d) 230 °C

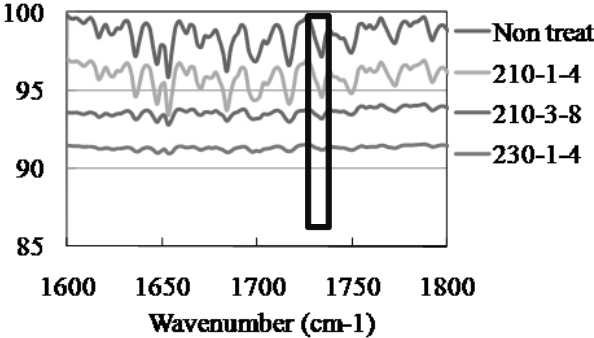
Fig. 13 TGA curve of hemp fiber at different conditions.



(a) 170 °C



(b) 190 °C



(c) over 210 °C

Fig. 14 IR spectra for hemp fibers molded at different conditions.

4. Conclusion

In the presented study, hemp fiber/PLA composites were fabricated and investigated to clarify effects of molding condition on the mechanical properties. When the process temperature increased from 170 °C to 190 °C, elastic modulus and tensile strength increased and fracture strain decreased. This is due to the impregnation and fiber volume fraction. In case of molding temperature over 210 °C, tensile strength and fracture strain decreased. This is due to thermal degradation of hemp fiber.

References

- [1] O. A. Khondker, U. S. Ishiaku, A. Nakai, H. Hamada "A novel processing technique for thermoplastic manufacturing of unidirectional composites reinforced with jute yarns". *Composites: Part A* 37 (2006) 2274-2284
- [2] A. K. Bledzki, A. Jaszkievicz "Mechanical performance of biocomposites based on PLA and PHBV reinforced with natural fibers – A comparative study to PP". *Composites Science and Technology* 70 (2010) 1687-1696
- [3] Benjamin Bax, Jorg Mussing "Impact and tensile properties of PLA/Cordenka and PLA/flax composites". *Composites Science and Technology* 68 (2008) 1601-1607
- [4] A. K. Bledzki, A. Jaszkievicz "Mechanical performance of biocomposites based on PLA and PHBV reinforced with natural fibers – A comparative study to PP". *Composites Science and Technology*, 70 (2010) 1687-1696
- [5] M. Sakaguchi, A. Nakai, H. Hamada, N. Takeda "The mechanical properties of unidirectional thermoplastic Composites Science and Technology 60 (2000) 717-722
- [6] B. Madsen, P. Hoffmeyer, A. B. Thomsen, H. Lilholt "Hemp yarn reinforced composites-I. Yarn characteristics". *Composites: Part A* 38 (2007) 2194-2203
- [7] B. Madsen, P. Hoffmeyer, H. Lilholt "Hemp yarn reinforced composites-II. Tensile properties". *Composites: Part A* 38 (2007) 2204-2215
- [8] X. Colom, F. Carrillo, F. Nogues, P. Garriga "Structural analysis of photodegraded wood by means of FTIR spectroscopy". *Polymer Degradation and Stability* 80 (2003) 543-549