Transactions of the Materials Research Society of Japan 29[5] 1885-1888 (2004)

Compression Molding and Mechanical Properties of Green-Composite using Ramie/PLA Non-Twisted Commingled Yarn

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In recent year, increased emphasis has been placed on developing the biodegradable composites with the goal of protecting the environment. In this paper, the Ramie/PLA biodegradable composites were molded and their mechanical behaviors were discussed. The non-twisted commingled yarn constructed with ramie and PLA fibers as reinforcement and matrix respectively was pre-molded to achieve the good penetration and dispersion of matrix and reinforcement. The compression molding with heating was performed to melt PLA fibers, and the green-composites reinforced by ramie fibers were obtained. The volume fraction of ramie fiber was varied for wide range, and the bending, tensile and impact tests were performed for the molded composite. The results were compared with those of matrix material and usual twisted commingled yarn. The microscopic observation was also carried out to examine the fracture mode of composite. It is concluded here that the fairly higher bending and strength and tensile modulus were obtained for our molded composites. This may be caused by the good penetration of matrix between fibers, and good dispersion of fibers. Especially, the impact value was fairly larger than that of PLA matrix at the higher volume fraction of ramie fiber.

Key words: Green composite, Ramie fiber, PLA, Non-twisted yarn, Compression molding, Mechanical properties

1. INTRODUCTION

To meet a wide variety of recent engineering request, many research efforts related to the development of new materials have been carried out actively in many fields. Especially, in field of composite materials, attention has been shifting from glass and carbon fibers to natural fibers because of their renewable nature, low cost, low density and low energy consumption(1),(2). Moreover the biodegradable matrix material is required to protect the environment. It is important to achieve a good dispersion of reinforcement and good impregnation of matrix material between fibers for the composites. So, many researchers have challenged to obtain a superior composite by using powder coated yarn(3), co-woven fabric(4) and commingled yarn(5). Especially, commingled yarn is expected to the good properties. However, the twisted process of commingled yarn contributes the cause of cracks in the composite(6). Under these circumstances, the present paper discusses the compression molding and mechanical properties of biodegradable composite (green-composite) molded by using ramie/PLA non-twisted commingled yarn.

2. MOLDING METHOD

2.1. Spinning of non-twisted commingled yarn

The ramie/PLA non-twisted commingled yarn was pre-molded by using staple fibers of ramie (length:80mm, fineness:8.63dtex) and PLA (length:76mm, fineness:1.55dtex). Here, the length of PLA staple is nearly equal to that of ramie fiber in order to achieve the good spinning. Spinning process of non-twisted commingled yarn is as follows. Namely, the gathered ramie and PLA fibers were loosed by roller card machine (TCM-SC: Intec Co Ltd) and then mixed together to make the ramie/PLA web. The sliver type mixture was made from the web. After that the mixed ramie and PLA fibers were oriented uni-directionally by using the drawing flame (TCM-DF-4S: Intec Co Ltd). Finally, the sliver was covered by PLA filament around the sliver under the condition of 240w/m. Figure1 shows the aspect of pre-molded ramie/PLA non-twisted commingled yarn.

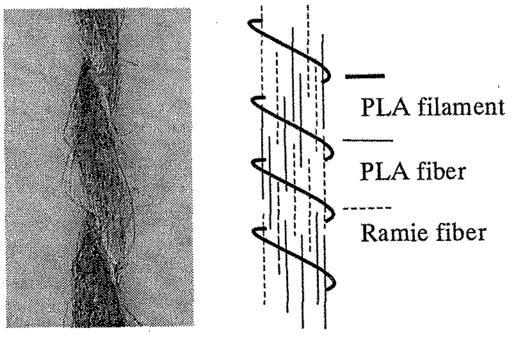


Fig.1 Aspect of non-twisted commingled yarn

2.2. Molding green-composite

Figure2 shows the aspect of molding process. Firstly the non-twisted commingled yarn was rolled up around the metal flame. The 0.18N of tension was loaded the yarn to protect the yarn from slacking. After the drying process of yarn at 50℃ for 3hours, the metal frame with yarn was inserted in the die and compressed at 180℃ for 5min. Finally, the uni-directionally reinforced green-composite with 3mm thickness was obtained after naturally cooling process. The green-composites molded under the condition of 180℃/3min were also prepared in order to discuss the effect of molding condition on the mechanical properties of composite.

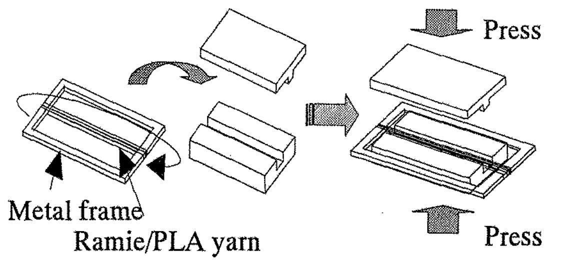


Fig.2 Aspect of molding process

3. EXPERIMENTAL METHOD

3.1. Tensile strength and heat deterioration of ramie fiber

The tensile test was performed for the single ramie fibers to investigate the properties of ramie as reinforcement. The single ramie fibers were heated 140, 160, 180, 200 and 220℃ for 6, 30 and 60min respectively, before tensile tests in order to discuss the thermal damage of ramie fiber during the compression molding process of the green-composites. The cross head speed and gauge length were 50mm/min and 50mm, respectively throughout the tensile tests.

3.3. Measurement of mechanical properties

The bending, tensile and impact test were carried out for the molded green-composites to discuss the mechanical properties. The size of specimen was rectangular shape of 10mm width, 3mm thickness, and the length are 68mm, 200mm and 68mm for bending, tensile and impact tests, respectively. The cross head speeds were 5mm/min for the case of strength, 0.5mm/min for the case of modulus. The span length and gauge length were 48mm and 100mm for bending and tensile tests, respectively.

4. RESULTS AND DISCUSSION

4.1. Thermal property of ramie fiber

Figure3 shows the relation between temperature and tensile strength for the ramie fiber. It is noted from the figure that the value of strength is almost 800MPa over at the room temperature, and keeps an almost constant value until 140℃. However, the rapid decrease of strength can be seen in the range of 150~180℃. It should be noted here that the decrease of strength appears at lower temperature for the longer heating time. As a result, heating time of 6min is good for heating temperature of 180℃ adopted in this paper.

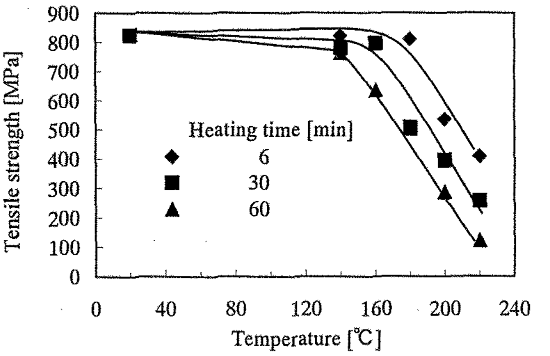
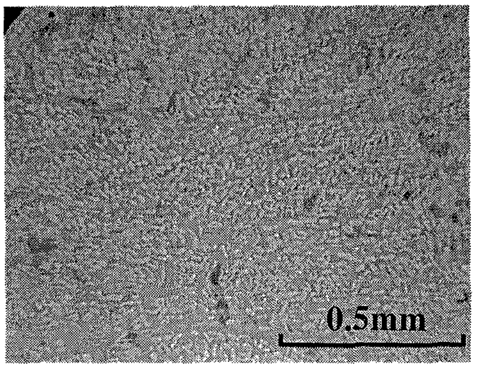
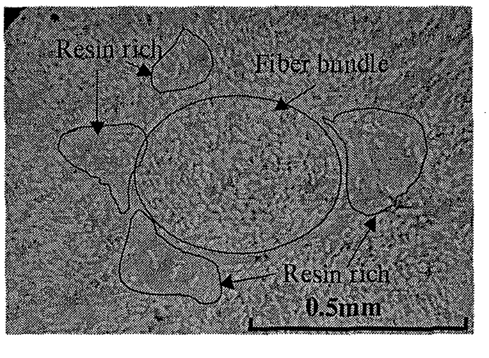


Fig.3 Heat deterioration of ramie fiber



(a) Specimen based on non-twisted yarn

(V_f =45%)



(b) Specimen based on twisted yarn

(V_f=45%)

Fig.4 Polished cross sections of composites based on non-twisted and twisted yarns

4.2. Observation on cross sections of composites

Figures4 (a) and (b) show the results of microscopic observation on cross sections of composites molded by using non-twisted (0t/m) and twisted (70t/m, 150t/m)commingled yarns, respectively, where the volume fraction of ramie fiber V_f=45%. It is cleared from the figures that the good dispersion of ramie fibers can be obtained for the composites molded by using non-twisted commingled yarns. The resin rich part, however, can be seen for the composites molded by using twisted commingled yarns. This phenomenon was similar to the composite molded by using carbon/nylon6 commingled twisted commingled yarn by Matsuo et al.[6]. The resin rich part may be caused by the twisting process of yarns. Namely, the resin rich part was forced out from the ramie/PLA bundle by twisting during compression molding. Matsuo et al. pointed out in their paper[6] that the crack occurred easily at the resin part.

4.3. Bending property

Figures5 and 6 show the bending strength and modulus for molded composites. In these figures, the data based on the heating tomes 3min and 5min are plotted together. It is noted here that the values for the case of 5min are larger than or almost equal to those for the case of 3min. This may be caused by the incomplete melting and penetration of PLA resin for the case of 3min.The values of strength and modulus take maximum in the range of V_f=45%~65%, and the values are almost 3 times and 5times as large as those of PLA resin for strength and modulus, respectively. These results indicate that ramie fiber is good for the reinforcement of PLA resin.

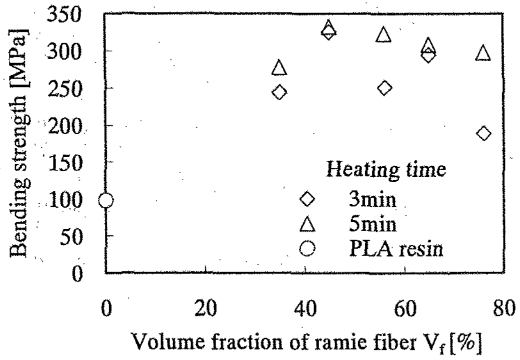


Fig.5 Bending strength of molded composite

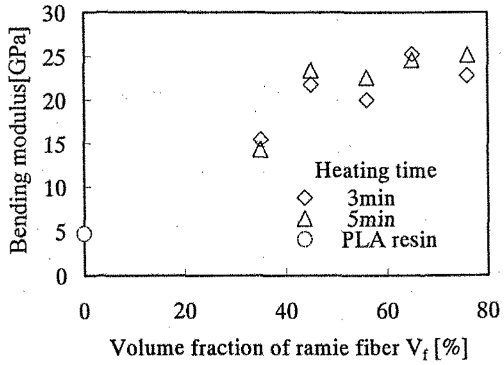
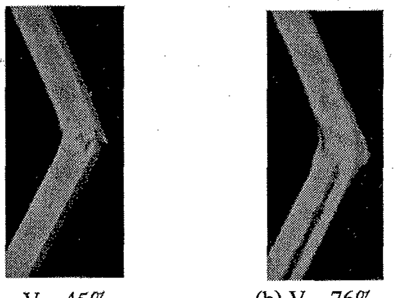


Fig.6 Bending modulus of molded composite

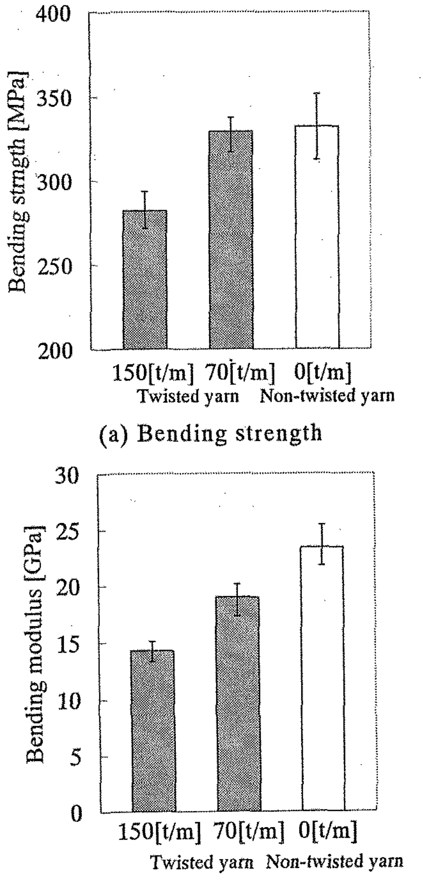
Figure7 shows the typical aspect of bending fracture for the composites of V_f=45% and 76%. In the case of V_f=45%, the crack firstly occur at the surface loaded the tensile stress. Meanwhile, the de-lamination may be caused by the lack of PLA resin for the higher volume fraction of ramie fiber.

Now, it is important to clear the effect on "non-twist" on the mechanical behavior of composite. Then the data are compared with data for twisted yarn as follows. Figures8 (a) and (b) show the bending strength and modulus for the composites molded by using twisted yarn together with the data for the non-twisted yarn. It is noted that the strength and modulus decrease with increasing the twisted number. The decrease of strength may be caused by the said resin rich for the twisted yarn, and the decrease of modulus may be caused by the off-axis of ramie fiber to the tensile axis for the twisted yarn. It is concluded from these results that the non-twisted commingled yarn behaves as a superior raw material for the molding of green-composites.



V_f =45% (b) V_f =76%

Fig.7 Typical aspect of bending fracture



(a) Bending strength

(b) Bending modulus

Fig.8 Bending modulus and strength for twisted and non-twisted yarns

4.4 Tensile property

The tensile strength and modulus are plotted against the volume fraction of ramie fiber in Fig.9 and 10, respectively. The maximum values of strength and modulus appear in the range of V_f=45%~65% as same as said result of bending property. Figure 11 shows the aspect of tensile fracture and the de-lamination can be seen in the case of higher volume fraction V_f=76%. The decrease of the tensile strength at V_f =76% may be caused by lack of PLA resin. It is considered that the de-lamination is typical fracture mode of uni-directionally reinforced composites.

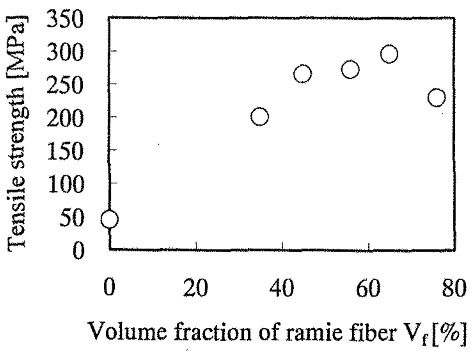


Fig.9 Tensile strength of molded composite

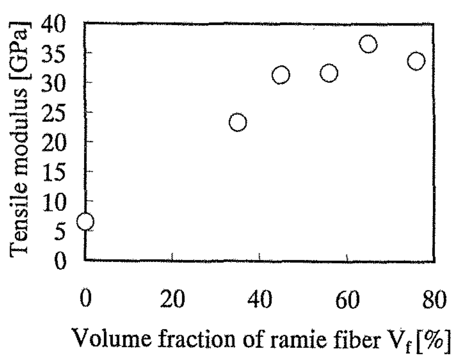
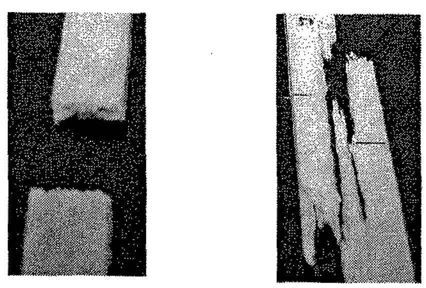


Fig.10 Tensile modulus of molded composite



(a) V_f=45% (b) V_f=76%

Fig.11 Typical aspect of tensile fracture

4.5. Impact property

Figure12 shows the Izod impact value of the notched composites (2mm in depth). It should be noted from the figure that the impact value increased largely with increasing the volume fraction of ramie fiber. The impact value at V_f=76% is about 30 times as large as PLA resin. The fracture mode is fiber braking as shown in Fig.13. The pull-out of ramie fiber can not be seen here. This fact is a typical fracture mode for the long fiber reinforcement. Therefore the higher impact energy may be consumed for the deformation of ramie fiber.

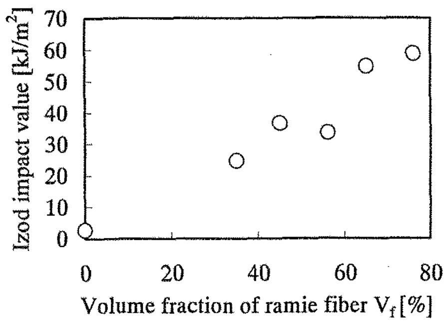
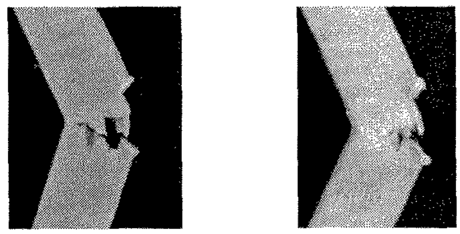


Fig.12 Izod impact value of molded composite



(a) V_f=45% (b) V_f=76%

Fig.13 Typical aspect of impact fracture

5. CONCLUSION

In this paper, the compression molding and the mechanical properties of green-composites based on ramie/PLA non-twisted commingled yarn were discussed to develop the biodegradable composites with superior mechanical properties.

The followings are concluded.

(1) Good dispersion of reinforcements and good penetration of PLA matrix can be obtained by using non-twisted yarn as molding raw materials of composites.
(2) The optimum volume fraction of bending and tensile properties exists in the range of V_f =45%~65%.
(3) Fairly large values of bending and tensile strength such as 300MPa over can be obtained by using the non-twisted commingled yarn as raw material of compression molding.
(4) Fairly large Izod impact value can be obtained by using the long ramie fiber in comparison with that of PLA matrix.

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(Received October 10, 2003; Accepted October 31, 2003)