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A Fabrication Process of High Volume Fraction of Jute Fiber/Polylactide Composites for Truck Liner

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Aiming at the green manufacturing technology of automotive industry, in the past, some researchers have developed green materials—fully degradable natural fiber reinforced polylactide composites. In the researches, the natural fiber volume fraction (or weight fraction) ranges from 20% to 55%. In order to lower the cost of the composites, an effective way is to increase natural fiber volume fraction and decrease polylactide fraction. In this research, a more uniform fiber blending method is employed, and the natural fiber volume fraction is increased to 70%. The fabrication process includes two steps: felt making and hot pressed molding. Short jute fiber and short PLA fiber are blended on a fiber opening machine in terms of fiber volume fractions, 60% and 70% respectively. The mixtures are carded and needle punched to make felt. Then the felt is hot pressed at 180 ℃, and the jute/PLA composites are fabricated. Mechanical properties of the composites with different fiber volume fractions are investigated. Real size truck liners are successfully manufactured. The composites have very good formability and processability.

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1. Introduction

Environmental pressure and the shortage of the natural resource has increased the urgency for development of green design and manufacturing technology. Green design and manufacturing technology is to aim at minimizing major environmental impact at all stages in the life cycle of a product, especially with regard to the sourcing of raw materials, the purchasing of components for use, and the end-of-life disposal.[1] Materials that have less impact on environment are known as green materials, which are less energy consuming, less harmful to health when processed, recyclable, and sustainable.

Polylactide (PLA) is a degradable polymer called "green plastic for the 21st century",[2] not only because it is degradable but that it is synthesized from renewable resources as well, such as corn or potatoes. It attracted much attention in recent years for the reasons that it offers an alternative to maintaining sustainable development of economically and ecologically technology leading to the reduction of fossil-based raw materials, complete biological degradability, the reduction in the volume of garbage and compostability in the natural cycle, protection of the climate through the reduction of carbon dioxide released, as well as the application possibilities of agriculture resources for the production of green materials.

PLA can be totally degraded in aerobic or anaerobic environments in two months to five years, and chain fragmentation can be obtained at higher humidity and temperature as soon as 7 days.[3] Due to its degradability when exposed to heat and humidity, nowadays, polylactide is mainly used for packaging applications such as food packaging for short shelf life products, containers, drinking cups, salad cups, overwrap and lamination films, and blister packages.

Another favorable property is its higher strength (35-60MPa) and elastic modulus (3.5GPa) than those of commonly used plastics such as polypropylene (30MPa and 1.6GPa respectively). This makes it possible to manufacture structural components.

Automotive industry largely uses glass fiber reinforced polymeric composites to make structural components for purpose of weight reduction. Lightweight material application to automobile is an effective approach to lower energy consumption.[4,5]

However, glass-reinforced plastics still exhibit shortcomings such as their relatively high fiber density, difficulty to machine, and

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poor recycling properties, particularly the potential health hazards posed by glass-fiber particles.

The awareness of environment protection all over the world and the release of strict guideline and regulation in European and some Asian countries concerning automotive end-of-life requirement forced the automakers to seek eco-friendly materials to make car "greener". Therefore, over the past ten years, natural fibers have been used as reinforcement in composite components for automobiles. The advantages of natural fiber are its low cost, low density, renewability, high strength and modulus of elasticity and low heat conductivity. These make it very suitable for automotive components, especially for interior components.

Natural fiber as reinforcement in PLA is a perfect combination to make eco-friendly composites. Such composites are fully degradable materials. In recent years, aiming at automotive applications, a lot of work has been performed to fabricate natural fiber reinforced polylactide composites.[6-10] Most work has focused on the fabrication and mechanical properties improvement.

Currently, one of the restrictions for polylactide to be largely used in automotive industry is its higher price. To lower the total cost of natural fiber reinforced polylactide composites, an effective way is to increase the fiber volume fraction in the composite. However, in the case of very high fiber volume fraction, the adhesive bonding between fibers and resin is weakened due to the poor wetability and thus resulting in the mechanical properties decrease. Therefore, the fiber volume fraction has a limitation. Some researchers fabricated and investigated the mechanical properties of natural fiber reinforced PLA. In their researches, the fiber volume fraction (or weight fraction) ranges from 20% to 55%.[7]

The authors of this article fabricated and investigated jute/polylactide composite with 50% fiber volume fraction in their previous work by using a simple film stacking method. The inherent characteristic of this method is the difficulty to blend the resin and the fiber uniformly. Therefore the composite obtained by this method showed layered microstructure. Nevertheless, the composites still have acceptable mechanical properties.

It is possible to increase fiber volume fraction further if a better blending method is applied. In this research, in order to improve the adhesive bonding between jute fiber and PLA resin, and thus to increase fiber volume fraction as high as possible, a new blending method is applied to fabricate jute fiber/PLA composite.

Short jute fiber and short PLA fiber are blended on a fiber opening machine in terms of fiber volume fractions, 60% and 70% respectively. The mixtures are needle punched to make felt. Then the needled felt are hot pressed at 180℃, and the jute/PLA composites are thus fabricated. Mechanical properties of the composites with different fiber volume fractions are investigated. Real truck liners of the composite were successfully fabricated.

2. Materials and Fabrication Process

Polylactide fiber (3D/38F) was purchased from Shenzhen BrightChina Industrial Co., Ltd.. The density of the PLA fiber is 1.24g/cm^3. The melting index at 190℃ is 10-15g/10 min. The yielding strength is 54MPa. The fiber length is around 80mm. The morphology of PLA fiber is shown in Fig. 1(a).

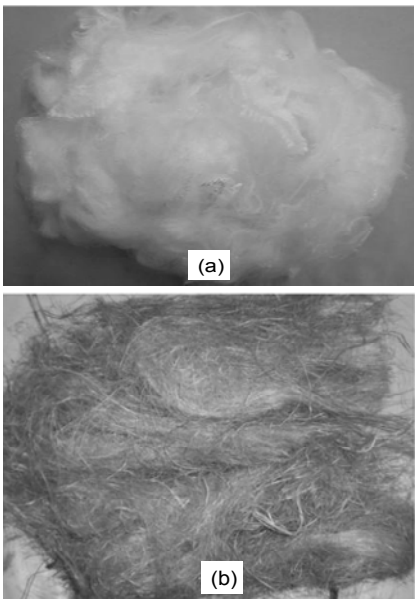

Fig. 1 Morphology of polylactide fiber and, (b) China jute fiber

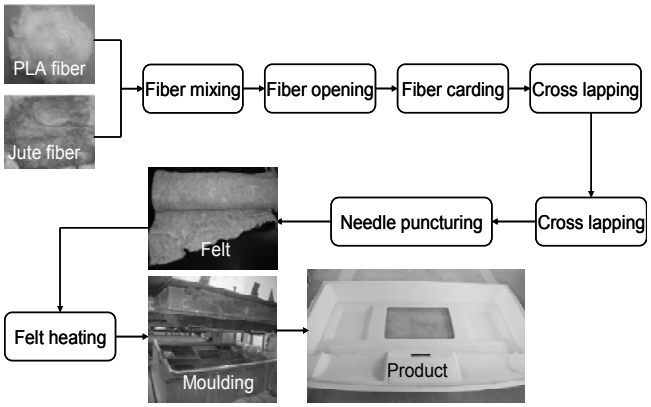

Fig. 2 Fabrication process of a truck liner

China jute fiber was used as reinforcement in composite. China jute (Abutilon theophrasti Medic) is a regional grown fiber plant. It is a preponderant renewable resource in China. The fiber, removed from jute stem by retting, with original length of 2.5-4m, was cut into short fibers of 100mm. The density of the fiber was tested to be 0.94g/cm^3. The morphology of jute fiber is shown in Fig. 1(b).

The main process includes two steps: making felt and pressed molding. They are described as follows.

Fibers of polylactide and jute were weighed according to the fractions in the expected composites. In this research, the volume ratio of PLA fiber and jute fiber is 3:7 and 4:6, respectively. Then two fibers were mixed and fed into a fiber opening machine to be further mixed. And then a combing process was followed by putting the mixture into a carding machine. The next step was cross lapping of the combed fiber mixture and needle puncturing to make felt.

Felt of fiber mixture was cut according to the product shape and size. The felt was covered by two polypropylene films on the top and bottom and put them together onto a heating machine for 5min at 180℃. The surface decoration fabrics were placed to the upper

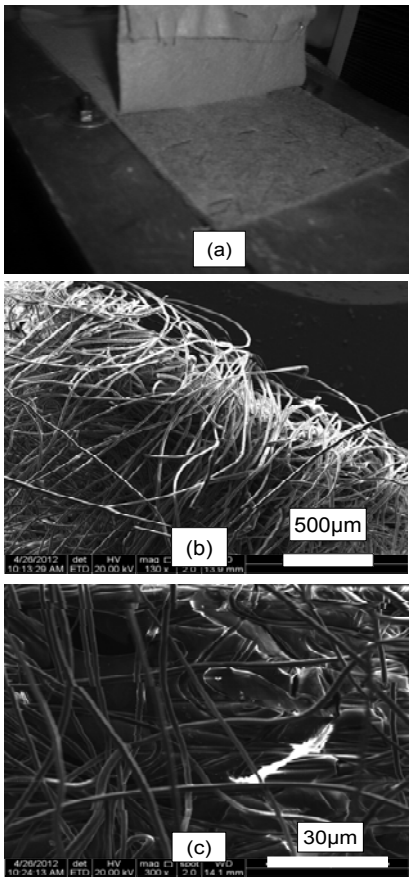

Fig. 3 (a) Peeling test diagram (b) and (c) microstructure of fiber bonding on the composite after peeling

mold and the lower mold in advance. Then the hot felt was quickly moved between the upper and lower mold on a cold press machine. After 5min pressing at 0.45MPa, the product was removed from the machine and following trimming processes were carried out. The detail process is shown in Fig. 2.

3. Quality Inspection Result and Mechanical Property Test

There has not been authoritative quality inspection standard issued for vehicle interior decoration products until now. The product quality inspection items are determined by the agreement between supplier and buyer, generally, size and shape tolerance, flexibility for easey installation, tensile strength, adhesion between the decoration fabrics and the fiber reinforced layer. Most of the above items are inspected qualitatively and quantitatively in this research.

Our concern mainly focuses on the mechanical property of the composite, the surface decoration fabric adhesion to the base composite. The appearance of the product does not show any apparent defects. The adhesion of the surface decoration fabric to the jute fiber composite was measured by using peeling test. The test diagram is shown in Fig. 4(a). The maximum peeling force is tested to be 43N. Then peeling strength is calculated to be 3.3N/cm. After peeling test, fibers from the surface decorating fabric adhered

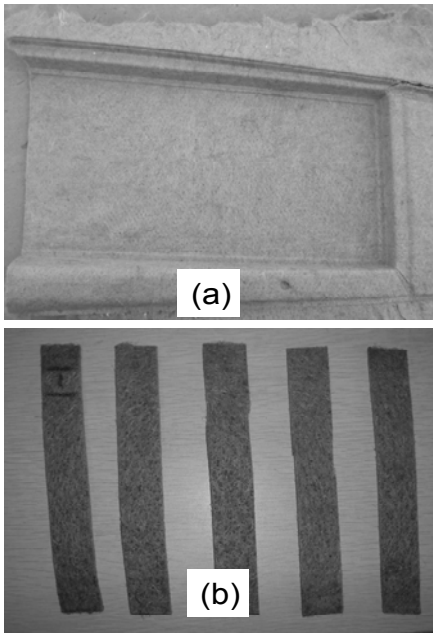

Fig. 4 Jute/PLA composite plate and tensile samples

to the composite surface can be observed, as shown in Fig. 3(b) and (c) taken by scanning electronic microscope. The good adhesion benefits from the melting of polypropylene (PP) film. The use of PP film between surface decoration fabric and base composite has two purposes: the first is that PP is an adhesive when it is melted, and the second is that the PP film serves as a moisture-proof layer.

Tensile strength of the composites was tested. Samples were cut from a composite plate, as shown in Fig. 4. Tests were conducted on a universal testing machine with a cross head speed 2mm/min. At least 5 samples were tested and the testing results were averaged as the tensile strength. The strength of the composite with 60% jute fiber volume fraction is 1.9 ± 0.33MPa. The strength of the composite with 70% jute fiber volume fraction is 3.69 ± 0.57MPa.

4. Conclusions

In this study, fully degradable polylactide composites with 60% and 70% volume fraction of jute fiber are fabricated and real truck liners of the above two composites are manufactured. The manufacturing process and the mechanical property are investigated. The results are summarized below:

1. Composites with high jute fiber volume fraction can be fabricated by using fiber mixing, felt making, and hot pressed method. The fibers can be uniformly mixed by this method.
2. Mechanical property of the composite materials has been tested. The strength of the composite with 60% fiber volume fraction is 1.9 ± 0.33MPa, whereas the strength of composite with 70% fiber volume fraction is 3.69 ± 0.57MPa.
3. The peeling strength of the surface decorating fabric adhesion to the composite is 3.3N/cm. Good adhesion is also evidenced by scanning electronic microscope observation.
4. Real size truck liners have been manufactured. The products have excellent formability, and processability.

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REFERENCES

1. Kang, Y. C., Chun, D. M., Jun, Y., and Ahn, S. H., "Computer-aided Environmental Design System for the Energy-using Product (EuP) Directive," Int. J. Precis. Eng. Manuf., Vol. 11, No. 3, pp. 397-406, 2010.
2. Ray, S. S. and Bousmina, M., "Biodegradable Polymers and Their Layered Silicate Nanocomposites: In Greening the 21st Century Materials World," Prog. Mater. Sci., Vol. 50, No. 8, pp. 962-1079, 2005.
3. Hu, R. H., Sun, M. Y., and Lim, J. K., "Moisture Absorption, Tensile Strength and Microstructure Evolution of Short Jute Fiber/Polylactide Composite in Hygrothermal Environment," Mater. Design, Vol. 31, No. 7, pp. 3167-3173, 2010.
4. Park, C. W., Kwon, K. S., Kim, W. B., Min, B. K., Park, S. J., Sung, I. H., Yoon, Y. S., Lee, K. S., Lee, J. H., and Seok, J., "Energy Consumption Reduction Technology in Manufacturing - A Selective Review of Policies, Standards, and Research," Int. J. Precis. Eng. Manuf., Vol. 10, No. 5, pp. 151-173, 2009.
5. Jeon, K. W., Shin, K. B., and Kim, J. S., "Evaluation of Tension-Compression and Tension-Tension Fatigue Life of Woven Fabric Glass/Epoxy Laminate Composites used in Railway Vehicle," Int. J. Precis. Eng. Manuf., Vol. 12, No. 5, pp. 813-820, 2011.
6. Hu, R. H. and Lim, J. K., "Fabrication and Mechanical Properties of Completely Biodegradable Hemp Fiber Reinforced Polylactic Acid Composites," J. Comp. Mater., Vol. 41, No. 13, pp. 1655-1669, 2007.
7. Graupner, N., Herrmann, A. S., and Mussig, J., "Natural and Man-made Cellulose Fibre-reinforced Poly (lactic acid) (PLA) Composites: An Overview about Mechanical Characteristics and Application Areas," Comp. Part A: Applied Science and Manufacturing, Vol. 40, No. 6-7, pp. 810-821, 2009.
8. Graupner, N., "Improvement of the Mechanical Properties of Biodegradable Hemp Fiber Reinforced Poly (lactic acid) (PLA) Composites by the Admixture of Man-made Cellulose Fibers," J. Comp. Mater., Vol. 43, No. 6, pp. 689-702, 2009.
9. Reddy, K. O., Maheswari, C. U., Rajulu, A. V., and Guduri, B. R., "Thermal Degradation Parameters and Tensile Properties of Borassus flabellifer Fruit Fiber Reinforcement," J. Reinf. Plast. Comp., Vol. 28, No. 18, pp. 2297-2301, 2009.
10. Chen, F., Liu, L. S., Cooke, P. H., Hicks, K. B., and Zhang, J., "Performance Enhancement of Poly (lactic acid) and Sugar Beet Pulp Composites by Improving Interfacial Adhesion and Penetration," Ind. Eng. Chem. Res., Vol. 47, No. 22, pp. 8667-8675, 2008.