<Short Communication>

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The Properties of Bamboo Flour-Plastic Composites with High Filler Content Formulations

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Abstract

Bamboo flour was used as a filler in the manufacture of bamboo flour-plastic composites. The properties of bamboo flour-plastic composites with 80% filler contents were examined using waste bamboo flour, polypropylene (PP), and maleic anhydride-modified polypropylene (MAPP) and/or polytetrafluoroethylene (PTFE). The compounds could be successfully manufactured using a Henschel type mixer, and then the composite boards were made by compression molding and extrusion molding. The composite boards made from both moldings showed good fracture strengths and water resistance by the addition of compatibilizer. The mechanical properties of boards made with extrusion molding and a ratio of bamboo flour:PP:MAPP=80:20:2 were bending fracture strength; 74MPa, and water absorption (WA) after 24hr immersion in water; 1.5%. The color of composites darkened with the addition of an additive. The addition of PTFE significantly increased luster and smoothness of the appearances of the composite boards.

Key words : bamboo flour, 80% filler contents, compatibilizer, JIS A 5741

1. Introduction

Bamboo is one of the most traditional materials of biomass origins in Japan and Southeast Asia. The bamboo has been used in construction materials and industrial arts materials, daily life products, tea service sets, medicine, food additives etc¹⁾. But in Japan bamboo has caused an environmental problem for other plants because of its high propagative power¹⁾. In this study we tried to make a bamboo flour-plastic composite as a new, effective use of bamboo material. Many wood flour-plastic composites with low and medium percentages of wood, generally 40~70%, have been made in the USA and Europe for use in housing, cars, decks, and railings^{3~6)}. We previously reported more

wood-like wood flour-plastic composites with more than 80% filler contents, as a more environmentally, friendly composite product^{7,8)}.

In this paper, the properties of eco-friendly bamboo flour-plastic composites with 80% filler contents were examined using waste bamboo flour, polypropylene (PP), and maleic anhydride-modified polypropylene (MAPP) and/or polytetrafluoroethylene (PTFE) as a lignocellulosic material, a thermoplastic polymer, and a compatibilizer.

2. Experimental process

2.1 Materials

The materials used in this study were Japanese bamboo flour of moso-take (*phyllostachys pubescens*), a thermoplastic polymer, polypropylene (PP), MAPP which is polypropylene grafted with maleic anhydride as a compatibilizer, and a lubricant. The bamboo flour was supplied by Nippon Amimono Kogyo Co. The size

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Table 1 Size distribution of bamboo flour (%)

10~20mesh	20~60mesh	60~100mesh	100mesh~
2.6	20.2	44.0	33.6

Photo. 1 SEM microphotograph of bamboo flour. A bar length indicates 1mm

Table 2 Chemical components of defatted bamboo flour (%)

α -cellulose	Hemi-cellulose	Lignin
20.5	40.1	36.2

and shape of bamboo flour are shown in Table 1 and Photo. 1. The components of defatted bamboo flour obtained from chemical analysis are shown in Table 2. The thermoplastic polymer was a random PP (PM930V, density 0.9g/cm^3 , melting point $150\text{--}153^\circ\text{C}$, San Allomer Co.) The compatibilizer was MAPP(H1100P) obtained from Toyo Kasei Kogo Co., which was used as a coupling agent to improve the compatibility and adhesion of the bamboo flour and PP^{9,10}. The lubricant was polytetrafluoro ethylene, PTFE (Metablen A-300, Mitsubishi Rayon Co.). This bamboo flour contains much hemicellulose, which may affect the heat and moisture content.

2.2 Blending procedure

Compounds of the above materials could be successfully made using a Henschel type mixer (SMV-20A type, Kawata Co.) as shown in Photo. 2. All of bamboo flour, PP, MAPP, and PTFE were fed into the mixer. The mixer was operated while the temperature increased from room temperature to 180°C at a blade speed of 1380rpm. Composite materials were created using four ratios of bamboo flour/PP/MAPP/PTFE, ① 80/20/0/0, ② 80/20/2/0, ③ 80/20/2/2, ④ 80/20/2/5, by weight.

Photo. 2 A Henschel type mixer, the inside of container

2.3 Molding process

Two molding process, compression molding and extrusion molding, were used to make composite boards.

Compression molding

The compounds were used after drying at 60°C . The composite boards were made using a hot platen (Model F type, Sinto Co.) 24g of compounds were put into a steel press-frame measuring $80\times 100\text{mm}$ and Teflon film sheets were used to avoid adhesion of compounds to the stainless steel surface. The compounds were then pressed at 200°C for 15min under 11MPa to prepare a composite board with an average thickness of 2.5mm and density of 1.17g/cm^3 . The board was cut into three pieces of $25\times 100\text{mm}$, which were used as test pieces.

Extrusion molding

The compounds were fed into a conical counter-rotating twin screw extruder (Taitan 68, Cincinnati Extrusion Co.) with an out let of $60\times 7\text{mm}$. Good press conditions were determined by trial and error as shown in Table 3. The long composite board obtained was cut into test species of $140\times 35\times 7\text{mm}$ size. The board density of a sample was in the range of $1.10\text{--}1.26\text{g/cm}^3$.

2.4 Mechanical test and water absorption test

The performance of composite boards was evaluated by bending test and water absorption test. The bending strength and water resistance of test pieces were determined according to Japanese Industrial Standard method, JIS A 5741 for wood plastic recycled composite¹¹ and JIS A 5908 for particleboards¹². The bending

Table 3 Process conditions for extrusion in the twin-screw extruder

Screw	Cylinder 1	Cylinder 2	Cylinder 3	Temperature (°C)			
				Adapter	Die 1	Die 2	Die 3
120	178-205	178-195	175-178	170-175	175-177	140-162	65-89
Screw speed (rpm)		Feeder speed (rpm)		Resin temp. (°C)		Output (kg/hr)	
1.0-2.0		0.5-1.0		176-179		7.6-18.2	

strength was measured by the three point bending strength test machine (Model TCM-500, Shinko Tushin Co.). The water resistance was determined by measuring the swelling and water absorption of test pieces after immersing the sample into water at room temperature ($22 \pm 2^\circ\text{C}$). An average of 3~6 specimens were tested for each experiment.

3. Results and discussion

3.1 Appearance of composites

The good compounds were obtained by blending with bamboo flour, granular PP, MAPP flour, and PTFE flour in the Henschel type mixer. In comparison to the same ratio, composites with PTFE were observed to be more lustrous and smooth than those without PTFE, particularly in extrusion molding as shown in **Photo. 3**. The difference became more obvious as the PTFE contents increased.

Photo. 3 Appearance of extrusion molding composite board (ratio of bamboo:PP:MAPP:PTFE=80:20:2:5)

3.2 Properties of composite boards by compression molding

Results of bending tests and water absorption tests on composite boards made with four different kinds of proportions by compression molding are shown in **Fig. 1** and **Fig. 2**. The error bars and dotted lines represent

Fig. 1 Effects of the difference of compositions on the mechanical properties of compression molding composite boards.

Symbol: ① a ratio of bamboo flour/PP/MAPP/PTFE80/20/0/0, ② 80/20/2/0, ③ 80/20/2/2, ④ 80/20/2/5

one standard deviation and the allowable level for standards, respectively.

The modulus of rupture (MOR), modulus of elasticity (MOE) and dimensional stability of all specimens of composite boards were improved by addition of MAPP. The composite boards made with the ratio of bamboo:PP:MAPP=80:20:2 showed the maximal MOR of 43.5MPa, maximal MOE of 3.23GPa, and best water resistance. But none of the specimens passes the level (less than 10%) of water absorption for JIS A5741 (**Fig. 2 (a)**).

3.3 Properties of composite boards by extrusion molding

Results of bonding test and water absorption test of composite boards prepared with four differential levels by extrusion molding are shown in **Fig. 3** and **Fig. 4**. The performance of composite boards made with extrusion molding was improved by addition of MAPP even more than that of composite boards made with compression molding, and significantly passed the standard levels of bending strength (more than 20MPa) and water resistance (less than 10% water absorption, 12% thickness swelling, and 3% linear expansion for JIS standard). The composite boards made with the

Fig. 2 Effects of the difference of compositions on the water resistance of compression molding composite boards. Symbol is same as in Fig. 1.

Fig. 3 Effects of the difference of compositions on the mechanical properties of extrusion molding composite boards. Symbol is same as in Fig. 1.

ratio of bamboo:PP:MAPP=80:20:2 showed the best performance; MOR of 73.7MPa, MOE of 4.68GPa, water absorption of 1.48%, thickness swelling of 1.10%, linear expansion in lengthwise direction of 0.12%, and linear expansion in widthwise direction of 0.20%. These values were similar to those of wood flour plastic composites⁷⁾. These superior properties of bamboo flour plastic composites might be the result of the copious hemicellulose in bamboo flour and its optimal size. The water resistance of composite boards was improved by addition of 5parts PTFE.

4. Conclusion

The properties of bamboo flour-plastic composites

with 80% filler contents were examined using waste bamboo flour, polypropylene (PP), and maleic anhydride-modified polypropylene (MAPP) and/or polytetrafluoroethylene (PTFE) as a lignocellulosic material, a thermoplastic polymer, and a compatibilizer respectively.

The compounds could be successfully manufactured using a Henschel type mixer (Kawata Co.), and then composite boards were molded by using a hot platen and a conical twin screw extruder. The bending fracture strength and water resistance of composites were evaluated. The composite boards made by compression molding and extrusion molding showed good fracture strengths and water resistance by the addition of compatibilizer. The extruded composites showed better fracture strengths and water resistance than the composites made by compression molding. The mechanical properties of boards made by extrusion molding showed best performance with the following ratio; bamboo flour:PP:MAPP=80:20:2, namely bending fracture strength; 74MPa, and thickness swelling (TS) after 24hr immersion in water; 1 %. The color of composites darkened with the use of an additive. The appearances of the composites presented luster and smoothness by the addition of PTFE.

Fig. 4 Effects of the difference of compositions on the water resistance of extrusion molding composite boards. Symbol is same as in Fig. 1.

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References

- 1) Wood technological association of Japan, "The Encyclopedia of Wood Industry" in Japanese, p. 290 (1999).
- 2) M. Norimoto, *Wood Industry (Mokuzai Kyogyo)* in Japanese, **61**, 430 (2006).
- 3) A. A. Klyosov, "Wood-Plastic Composites", p. 12 (2007) Wiley-Interscience.
- 4) M. J. A. Chowdhury, M. P. Wolcott, *Forest Product Journal*, **57**, 46 (2007).
- 5) D. J. Gardner, S. R. O'Neill, S. M. Shaler, Biographies & Abstracts in 9th International Conference on Wood & Biofiber Plastic Composites, P. 23 (2007).
- 6) C. Weinrich, "Sixth International Conference on Wood fiber- plastic Composites", p. 155 (2002) Forest Products Society.
- 7) M. takatani, A. Ikemiya, Y. Nagata, T. Kitayama, T. Okamoto, *J. of The Adhesion Society of Japan*, **41**, 301 (2005).
- 8) M. takatani, O. Kato, T. Kitayama, T. Okamoto, M. Tanahashi, *J. of Wood Science*, **46**, 21 (2000).
- 9) J. M. Felix, P. Gatenholm, *J. Appl. Polym. Sci.*, **42**, 609 (1991).
- 10) M. Ueda, *J. of The Adhesion Society of Japan* (in Japanese), **37**, 504 (2001).
- 11) Japanese Industrial Standard (JIS). Wood-plastic recycled composite. JIS A 5741 (2006).
- 12) Japanese Industrial Standard (JIS). Particleboards. JIS A 5908 (1996).

<研究速報>

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高フィラー含有量の竹粉/プラスチック複合体の特性

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要 旨

竹粉/プラスチック複合体の製造にフィラーとして竹粉が用いられた。フィラー含有量 80% のリグノセルロース/プラスチック複合体の特性は、廃棄竹粉、ポリプロピレン (PP)、無水マレイル化ポリプロピレン (MAPP)、およびポリテトラフルオロエチレン (PTFE) を用いて調べられた。コンパウンドは、ヘンシェル型ミキサーで良好に作製でき、そして複合体は、熱圧縮成形法と押出し成形法で製造された。両方の成形方法ともに、相溶化剤を添加することによって良好な強度と耐水性を示した。特に押出し成形法で竹粉：PP：MAPP=80：20：2 の比率では、曲げ強度(MOR)74MPa、水中浸漬 24 時間後の吸水率 (WS) 1.5% であった。複合体の色彩は、添加剤の添加により濃くなった。PTFE の添加は、複合体の外観を著しく光沢にそしてスムーズにした。

- 1) T. A. Gardner, S. H. O'Neill, & M. Shahan, *Biodegradable Plastics: A Practical Guide to the Use of Wood and Bamboo*, Elsevier, Amsterdam, 1997.
- 2) C. W. Smith, "Sixth International Conference on Wood-Plastic Composites," p. 155 (2002) Forest Products Society.
- 3) M. Takatori, A. Kikuchi, Y. Nakayama, T. Kikuchi, *Journal of the Japanese Society of Wood Science and Technology*, 41, 381 (2002).
- 4) M. Takatori, O. Kato, T. Kikuchi, T. Okamoto, *Journal of Wood Science*, 48, 21 (2002).
- 5) J. M. Felix, P. Gantenbein, *J. Appl. Polym. Sci.*, 42, 605 (1991).
- 6) M. Taka, *Journal of the Japanese Society of Wood Science and Technology*, 37, 504 (2001).
- 7) Japanese Industrial Standard (JIS) Wood-plastic composite, JIS A 5741 (2003).
- 8) Japanese Industrial Standard (JIS) Particulate JIS A 5308 (1995).

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- 1) *Wood technological association of Japan, "The Encyclopedia of Wood Industry," in Japanese*, p. 310 (1997).
- 2) M. Nishimura, *Wood Industry (Nihon Kogyo)* in Japan, p. 41, 430 (2003).
- 3) A. Kikuchi, *Wood Plastic Composites*, p. 12 (2002) Wiley-Interscience.
- 4) M. T. A. Gardner, M. F. W. Smith, *Forest Product Journal*, 47, 42 (2007).

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