Analysis of Mechanical Properties of Wood Flours Composites to Improve the Strength of Truck Deck Floor Boards

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트럭 Deck Floor Board의 강도향상을 위한 목분복합재의 기계적특성 분석

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ABSTRACT

The deck floor of a cargo truck becomes damaged and aged due to the continuous loading of the loading cargo and external environmental factors. Floor boards made of wood and metal are often used. In the case of wood, the cost is high due to the use of imported wood, and the strength is easily deteriorated due to environmental factors. In the case of metal materials, the durability is higher than that of wood, but problems are raised due to the effect of major factors that hinder the weight reduction, and the effects of corrosion. In order to replace this structure design, this study proposed a wood fiber composite using natural raw materials. Woody composites are being used as environmentally friendly exterior materials with the combined advantages of plastic, and wood; low cost and low density. However, due to the nature of the woody composites, the properties are different depending on the contents of the matrix, reinforcing agent, additives, compatibilizer, etc. In this study, we investigate these problems through analysis of the microstructure and mechanical properties according to proper content and injection molding conditions. As a result, it is considered that the wood deck composite can replace the current Deck Floor Board and current deck floor boards through continuous continued research and results of this study.

Key Words : Wood Plastic Composites(목재 플라스틱 복합재), Wood Flours(목분), Injection Molding(사출성형), 3-point Bending Test(3점굽곡시험), Deck floor Board(척재바닥판)

1. Introduction

The existing deck floorboard materials in trucks are made of steel or wood. However, steel is not an ideal material for lightweight vehicles and has many problems, as its life is short due to environmental factors. Materials such as acacia, bamboo, and synthetic wood are some of the typical wooden materials. However, they have chronic...
quality problems due to environmental problems with short lifespan and difficulties in wood supply. As a result, extensive research and development has been conducted to search for alternative materials. As an alternative material, wood-plastic composites (WPCs) using natural raw materials such as wood can be applied. WPCs are inexpensive, low density, and can be subjected to easy chemical modification as well as having a low-wear property against processing devices and efficient production. Thus, WPCs have many advantages as an eco-friendly exterior materials that overcome the drawbacks of plastic and wood materials\[1\].

WPCs are fabricated by extrusion and injection molding by mixing wood fiber, wood flours, thermoplastic polymer resin, compatibilizer, antioxidant, etc. Previous studies found that since the mechanical properties and moisture content of WPCs differ according to the input amount of maleic anhydride grafted polypropylene (MAPP), which is a compatibilizer, the optimum mixture proportion should be adjusted according to the use purpose. Since the content of MAPP and wood flour density are correlated, an appropriate amount of MAPP should be mixed\[2\]. In addition, the content of additives in the production of WPCs affects the performance and processability significantly. WPCs are vulnerable to distortion, splitting, and color change and should be manufactured using appropriate content proportions to improve the physical properties\[3\]. The deck floors in trucks, which is the target of this study, are exposed to high loads and external environments steadily as they are mounted externally in trucks. Thus, the effect of moisture and large loads on the deck floor must be investigated. In this regard, this study aims to replace existing deck floors with WPC, which is an eco-friendly exterior material, and presents the results of three-point flexure test, which is a mechanical property test, to investigate the effect of large loads on the proposed material.

2. Fabrication and analysis of WPC

The injection molding method was used to fabricate a specimen that were used to evaluate WPCs. The equipment used to produce pellets and mix resins was a twin-screw extruder in which screw diameter was \( \Phi 32 \text{mm} \) and length ratio \((L/D)\) was 24. The extruder consisted of six heaters including compressive nozzles. The schematic diagram is shown in Fig. 1. Although there were a number of factors that determined the moldability and precision of injection-molded products such as molding temperature and pressure, the WPCs were extruded and injected with the optimized conditions as determined in a previous study\[4\]. Temperature at the time of extrusion was set to 195 °C in the extrusion die side and 175–205 °C in the feeder side. A rotation speed of the screw in the extruder was 80 rpm, and a rotation speed of the feeder was 7 rpm during the extrusion. In addition, a compatibilizer MAPP was inputted to improve the mechanical properties and uniform distribution during extrusion, and the content was fixed to 2% (wt.%) in the mixture. The pellets fabricated through this process were dried for 12 hours after extrusion. Then, they were injection-molded to tensile, compressive, and flexure test specimens using an injection molding machine, shown in Fig. 2. Since problems such as residual stress and deformation may occur if the injection molding conditions are inappropriate, injection pressure during the filling and packing processes and cooling procedure after ejection must be considered\[5\]. The injection molding machine used to fabricate the specimens was a 120-ton inverter injector for precision molding. In the injection molding machine, mold temperature was set to 210 °C and that in the feeder side was set to 180 °C. The injection pressure was fixed to 30 bar to inject the specimens. The resin and wood flour types, and content ratios (wt.%) to fabricate WPCs, are presented in Table 1.

The physical properties of each of the WPCs are
dependent on the bond characteristics of the reinforcing agent and resin. Thus, a scanning electron microscope (SEM) analysis was conducted to investigate whether the WPCs were fabricated with appropriate processes. Figs. 3 and 4 show the analysis images using a SEM to check the microstructure of the fabricated WPCs.

Table 1 Composition of wood plastic composites

| Matrix | Reinforced | Weight for reinforced | Weight for matrix |
|--------|------------|-----------------------|-------------------|
| HDPE   | None       | 0 %   | 100 % |
|        | WPC-PP     | 10 %  | 88 %  |
|        |            | 20 %  | 78 %  |
|        |            | 30 %  | 68 %  |
|        | Bamboo     | 10 %  | 88 %  |
|        |            | 20 %  | 78 %  |
|        |            | 30 %  | 68 %  |
| HDPE   | None       | 0 %   | 100 % |
|        | WPC-PP     | 10 %  | 88 %  |
|        |            | 20 %  | 78 %  |
|        |            | 30 %  | 68 %  |
|        | Bamboo     | 10 %  | 88 %  |
|        |            | 20 %  | 78 %  |
|        |            | 30 %  | 68 %  |

(a) Bamboo composite (Matrix: HDPE)
(b) WPC-PP composite (Matrix: HDPE)
Fig. 3 shows the SEM analysis image to check the internal microstructure of the fabricated WPC by adding the wood flour content by 30% to the high-density polyethylene (HDPE) resin. Fig. 4 shows the SEM image of the WPC by adding WPC-polypropylene (PP), in which reinforcing agent bamboo and waste woods are pre-mixed with PP resin, at 30% of the PP volume. In the SEM images, voids were distributed uniformly in general and PP resin had a better mixing property with wood flours than that of HDPE resin.

3. Analysis on the mechanical characteristics of WPCs

Three-point flexure tests were conducted to verify the bond characteristics of resin and reinforcing agent in the WPC. They were conducted to verify whether the randomly distributed wood flour reinforcing agent was bonded with the resin, thereby playing a role of distributing the flexural load applied from the outside\cite{6}. The three-point flexure tests were performed in accordance with the ASTM D 790 standards to analyze the mechanical characteristics of the injection-molded WPCs. Fig. 5 shows the specimen shape. The test employed a universal material testing machine from Shimadzu. The loads and displacement produced in the test were put into Eqs. 1 to 3 to convert the load and displacement into flexure strength ($\sigma_f$), Strain ($\epsilon_f$) and flexure modulus ($E_f$) for the analysis\cite{7}.

The meanings of the abbreviations in the equations are as follows: $P$ refers to load (N), $L$ is span (mm), $b$ is a width of beam (mm), $d$ is a depth of beam (mm), $\epsilon_f$ is a strain (mm/mm), $D$ is a maximum displacement (mm), $\sigma_{fN}$ is flexure strength at the N-th point (MPa), and $\epsilon_{fN}$ is a flexure strain at the N-th point (mm/mm).

$$\sigma_f = \frac{3PL}{2bd^2}$$  \hspace{1cm} (1)

$$\epsilon_f = \frac{6Dd}{L^2}$$  \hspace{1cm} (2)

$$E_f = \frac{(\sigma_{f2} - \sigma_{f1})}{(\epsilon_{f2} - \epsilon_{f1})}$$  \hspace{1cm} (3)
Tables 2 presents the results of flexure strength and flexural modulus according to the types and content ratios of wood flour and resin. The flexure strength and modulus of the WPCs using the HDPE resin showed a low increase rate overall. The maximum flexure strength of the WPC mixed with 30% of bamboo reinforcing agent was 38.5 MPa, which was increased by more 30% than that of the pure HDPE. The flexural modulus was 1,724 MPa, which was increased by 85%.

Table 3 presents the flexure test results of the fabricated WPCs according to the types and content ratios of PP resin and the wood flour. When PP resins were used, the flexure strength of the WPC in which WPC-PP was added by 10% was 57.3 MPa, which was increased by 90% more than that of the pure PP resin, and the flexural modulus was significantly increased to 2,374 MPa (by approximately 140% more than that of the pure PP resin). In the case of the other reinforcing agent, bamboo, the flexure strength was also similarly increased by approximately 90%, and the flexure modulus was increased by 120%, approximately. In the case of the WPCs, in which each reinforcing agent was added by 30%, the flexure strength and modulus were increased by approximately 280% and 255%, respectively. In contrast, the WPCs, in which WPC-PP was mixed by 30%, showed a lower flexure strength than that of the pure HDPE. Thus, it was found unsuitable to be applied to the deck floor.

Figs. 5 to 9 show diagrams to verify the flexure characteristics according to the content ratio of reinforcing agent mixed in each of the resins. Despite the content of the wood flours having increased, the flexure strength and modulus of the HDPE did not increase significantly. However, in the case of PP-resin WPCs, the flexure strength increased at lower weight for reinforcement and then decreased as the wood flour was increased whereas the modulus were increased. This result verified that the PP resin was a more appropriate matrix to fabricate the WPCs than the HDPE resin, as the physical properties were more improved when the WPCs were combined with PP resin than with HDPE resin.

Table 2 Flexure test results of wood flours-HDPE composites

| Reinforced | Weight for Reinforced | Weight for Matrix | Flexure Strength MPa | Chord Modulus MPa |
|------------|-----------------------|-------------------|---------------------|------------------|
| None       | 0 %                   | 100 %             | 29.2                | 924              |
| WPC-PP     | 10 %                  | 88 %              | 36.5                | 1,123            |
|            | 20 %                  | 78 %              | 34.1                | 1,276            |
|            | 30 %                  | 68 %              | 25.1                | 1,760            |
| Bamboo     | 10 %                  | 88 %              | 31.5                | 1,166            |
|            | 20 %                  | 78 %              | 35.3                | 1,468            |
|            | 30 %                  | 68 %              | 38.5                | 1,724            |

Table 3 Flexure test results of wood flours-PP composites

| Reinforced | Weight for Reinforced | Weight for Matrix | Flexure Strength MPa | Chord Modulus MPa |
|------------|-----------------------|-------------------|---------------------|------------------|
| None       | 0 %                   | 100 %             | 39.6                | 974              |
| WPC-PP     | 10 %                  | 88 %              | 57.3                | 2,347            |
|            | 20 %                  | 78 %              | 57.2                | 2,768            |
|            | 30 %                  | 68 %              | 51.7                | 3,764            |
| Bamboo     | 10 %                  | 88 %              | 57.4                | 2,019            |
|            | 20 %                  | 78 %              | 58.2                | 2,162            |
|            | 30 %                  | 68 %              | 53.2                | 33,463           |

Fig. 6 Flexure stress of wood flours-HDPE composites
4. Conclusions

The existing deck floorboards in trucks are made of wood or steel, which cannot be used for long time. Thus, this study aimed to replace them with WPCs. To do this, this study fabricated specimens using injection molding to perform the analysis of the mechanical characteristics. The WPCs were injection-molded by mixing bamboo pellets or WPC-PP pellets with HDPE resin and PP resin. The conclusions of the present study are summarized as follows:

1. The problems of natural distortion and discoloration by light, and moisture content when existing deck floorboards made of wood and used for a long period of time can be solved by the study result.

2. The SEM analysis result showed that the bond state of each resin and wood flour seemed good, but the mixing properties of the bamboo reinforcing agent was better with HDPE resin than with PP resin, and the mixing properties of the WPC-PP reinforcing agent was better with PP resin. In addition, the injection conditions of the fabricated WPCs were performed appropriately, which was verified through SEM analysis.

3. The flexure test results for the mechanical characteristics analysis exhibited that the mechanical characteristics were not improved even if the HDPE resin was increased, whereas the mechanical characteristics were improved as the content of PP resin was increased, which indicated that the PP resin had better bonding characteristics with the WPCs.

Acknowledgments

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REFERENCES

1. Chun, S. J. and Lee, S. Y., “Thermal Stability of Polypropylene-Based Wood Plastic Composites by The Addition of Ammonium Polyphosphate,” Journal of Korean Wood Science Technology, Vol. 42, No. 6, pp. 682-690, 2014.
2. Qiu, W., Zhang, F., Endo, T. and Hirotsu, T., “Effect of Maleated Polypropylene on the Performance of Polypropylene/Cellulose Composite,” Polymer Composite, pp.448-453, 2005.
3. Kang, I. A., Lee, S. Y., Doh, H. H., Chun, S. J., and Yoon, S. L., “Water Absorption of Wood Flour-Polypropylene Composites: Effects of Wood Species, Filler Particle Size and Coupling Agent,” Journal of the Korean Wood Science and Technology, Vol. 38, No. 4, pp.298-305, 2015.
4. Han, S. R. and Jeong, Y. D., “Mechanical Properties of Elastomer TPVs due to Injection Molding Conditions,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 5, No. 1, pp.27-32, 2006.
5. Joe, Y. S., Park, C. H., Pyo, B. G., Rhee, B. O. and Choi, D. H., “Optimization of Valve Gates locations Using Automated Runner System Modeling and Metamodels” Transactions of Korea Society Automotive Engineering, Vol. 22, No. 2, pp.115-122, 2014.
6. Lee, K. Y. and Cho, D. W., “Mechanical and Impact Properties and Heat Deflection Temperature of Wood Flour-Reinforced Recycled Polyethylene Green Composites,” Elastomer and Composites, Vol. 46, No. 3, pp. 223-230, 2011.
7. ASTM D 790, “Standard Test Methods for Flexural Properties of Unreinforced and...