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Development and Evaluation of Turbulent Air Mixing Process for Manufacturing Wood Fiber and Thermoplastic Fiber Composites[*1]

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ABSTRACT

A new device that uses turbulent air for mixing wood fibers with thermoplastic fibers was designed and its mixing effectiveness was evaluated in wood fiber and polypropylene fiber composites. Composites made by the turbulent air mixing (TAM) process performed better than composites made by the conventional Rando-Webber forming or nonwoven web process with an additional needling step. Thus, the TAM process proved to be a simple and efficient method in mixing wood fibers with short thermoplastic fibers for the production of wood fiber and thermoplastic fiber composites.

Keywords : Turbulent air mixing (TAM) process, wood fiber, thermoplastic fiber, composite

1. INTRODUCTION

Technology is needed for recovering lignocellulosic and plastic wastes from municipal solid waste (MSW), which contains large quantities of wood, paper, and plastic materials. A vast amount of MSW is now being buried or incinerated, in spite of its potential as a valuable and useful resource that can used to make composite panels.

In 1995, MSW amounted to 17,437,000 tons in Korea. Of the total waste stream, 30.5% consisted of paper (4,097,000 tons, 21.5%), wood (697,000 tons, 4%), and plastic (871,000 tons, 5%). Methods used for disposal of MSW were landfill (72.3%), recycling (23.7%), and incineration (4.0%). The most important area for improvement is recycling for two reasons: (1) the increased pressure to reduce the amount of MSW entering landfills and (2) the increasing cost of landfilling.

Combining wood and plastic materials can offer enormous opportunities for recycled ingredients in wood-based composites for producing new materials tailored to end-use requirements (Wegner *et al.*, 1992). In late 1980, researchers at the Forest Products Laboratory (FPL) of the U.S. Department of Agriculture, Forest Service, began studies on two technologies for producing composites: the nonwoven web and melt blending. The nonwoven web is made with a Rando-Webber forming machine and melt blending uses extrusion technology. These processes were not developed as new technologies for using wood and plastic wastes

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but originated from conventional technologies in the textile and plastic extrusion industries. The processes differ in the geometry of the materials (Youngquist & Rowell, 1989; Youngquist *et al.*, 1992).

Nonwoven web technology has been used to produce such items as diapers, hygienic products, and table napkins, as well as wood-plastic composite products. Composites are made through mechanical mixing of wood and plastic fibers. The blended fibers pass through a needling step that produces a low-density mat where the fibers are mechanically entangled. With this technology, lignocellulosic fibers can be incorporated in amounts greater than 90 weight percent. In addition, lignocellulosic fibers can be precoated with a thermosetting resin. Nonwoven web technology is suitable for manufacturing simple flat composites as well as complicated three-dimensional composites, with very low to high densities. Because longer fibers are required, nonwoven composites can achieve better mechanical properties than composites made through the melt-blending process, although interfacial bond is weaker than that obtained by the melt-blending process (Youngquist & Rowell, 1989). Applications for nonwoven web composites include oil adsorbent, filters, furniture, walls, door frames, doors, flooring, and packaging (Youngquist, 1995).

The FPL conducted practical research on nonwoven web composites using a laboratory-scaled Rando-Webber forming machine. Lignocellulosic and thermoplastic fibers were mixed by passing through a spiked drum, transferred via an air stream to a moving support bed, and subsequently formed into a continuous, low-density web of intertwined fibers contained between two thin layers of spunbonded polyester fabric. The web was then passed through a needling process where fishhook-type needles passed through the web thickness, increasing interlocking of the fibers. This additional needling step cannot be omitted in conventional nonwoven web technology, which uses long thermoplastic fibers.

Recently, Yoon and Lee (1996, 1997), Shin (1997), and Lee (1997) reported the properties of composites made with turbulent air mixing (TAM), a process that does not require a needling step. In 1997, a pilot-scale machine manufacture from TAM, forming, prepressing, and trimming parts was installed in the Forestry Research Institute in Korea.

In mixing wood fibers with thermoplastic fibers by a turbulent air stream, the most important factor may be the geometry of the thermoplastic fibers, such as length, denier, and crimp. In the present paper, we report the effect of thermoplastic fiber length on properties of TAM composites. We also evaluate the TAM process through comparing the properties of composites made by this process with those made by the conventional Rando-Webber forming process at FPL.

2. MATERIALS & METHODS

Wood fibers of radiate pine (*Pinus radiata*), obtained from Taesung Wood Industry Co., Inchon, Korea, were produced from medium-density fiberboard-grade chips, steamed for 2 to 3minutes at 7 to 10kgf/cm^2, refined by a double-revolving disk, and flash-dried at 160℃ in a tube dryer. The fibers were not precoated with a thermosetting resin. Polypropylene fibers, obtained from Kolon Merak Ltd., Kimchon, Korea, were tow, 3-denier, with a melt flow index of 25g/10min, and not crimped. For investigating the effect of polypropylene fiber length on composite properties, 0.5, 1.0, 1.5, 2.0, 2.5, 3.8, and 5.2cm long fibers were prepared by a paper clipper.

Manufacture of wood and thermoplastic fiber composites by the TAM process and the newly developed TAM device are shown in Figs. 1 and 2, respectively. The turbulent air for mixing both fibers is developed in a mixing box by impinging the fibers and the incoming compressed air (7 to 8 kgf/cm^2 in pressure) from the compressor through five 3-mm nozzles. The bottom of the mixing box

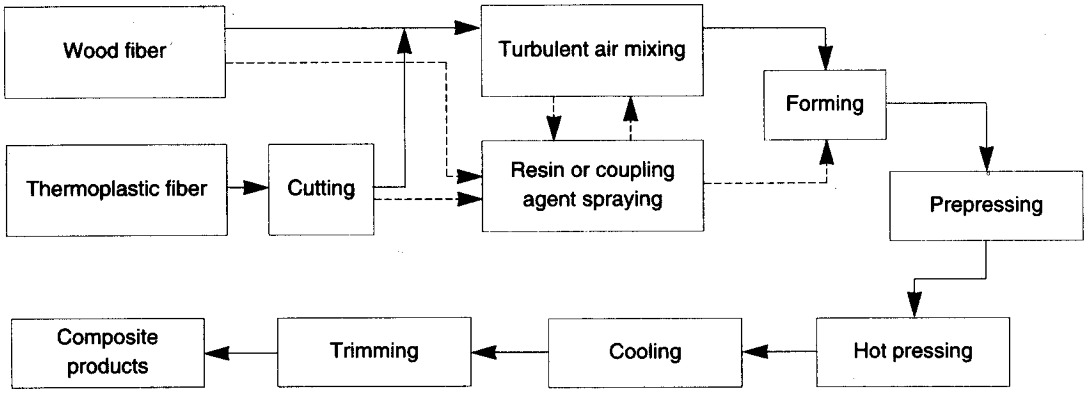

Fig. 1. Manufacturing process of wood fiber and thermoplastic fiber composites by turbulent air mixing (TAM) method.

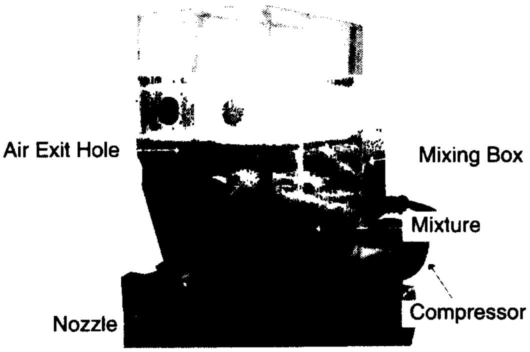

Fig. 2. Photograph showing the structure of turbulent air mixing device.

is beveled to prevent stagnation and to aid in discharging the fiber mixture. This turbulent air mixer is able to mix fibers up to 60% of its volume.

The composite panels were made with 90% wood fiber and 10% polypropylene fiber on the basis of oven-dried weight and a target density of 1.0g/cm^3. The mats were hot-pressed at 195℃ for 6 minutes at a maximum pressure of 60kgf/cm^2 and then cooled in a cold press for 3 minutes at a maximum pressure of 60kgf/cm^2. The composite panels were 25, 25, and 0.3 cm in length, width, and thickness, respectively. Five replicates of each type of composite panel were made. Mechanical and physical properties of the composites were tested following ASTM D1037-87 (1987).

3. RESULTS & DISCUSSION

Results from the effect of polypropylene fiber length on properties of composites made with wood and polypropylene fibers are presented in Figs. 3 to 6. These figures show that mechanical and physical properties of composites with polypropylene fibers 0.5 to 2.5cm long are better than those with polypropylene fibers 3.8 to 5.2cm long. This may be attributed to the increased uniformity of the mats with short polypropylene fibers; long fibers tend to be distributed unevenly in the mat because of entanglement. Thus, the TAM process appears to be more or less unsuitable for manufacturing composites with long polypropylene fibers.

The composites made with wood fibers and polypropylene fibers 0.5 to 2.5cm long satisfies the requirement of ANSI/AHA A135.4 (1982). At polypropylene fiber length levels of 3.8cm or longer, the composites show increased water absorption and thickness swelling but decreased bending properties, and the increasing rate in water absorption and thickness swelling is greater than the decreasing rate in bending properties (Figs. 3 to 6). This may reflect that short thermoplastic fibers require no additional needle punching process after the TAM process for manufacturing wood fiber and thermoplastic fiber composites. In contrast, the conventional Rando-Webber forming process

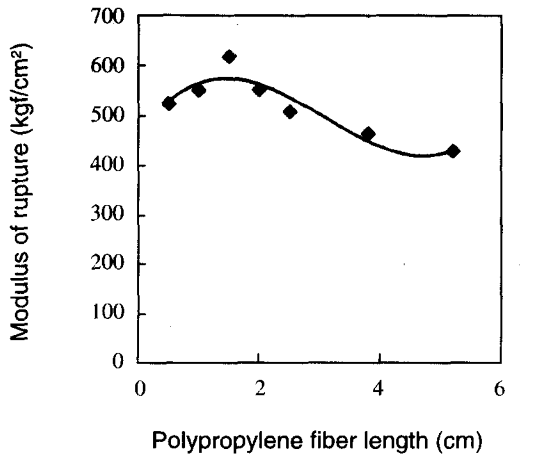

Fig. 3. Modulus of rupture of composites by length of polypropylene fiber.

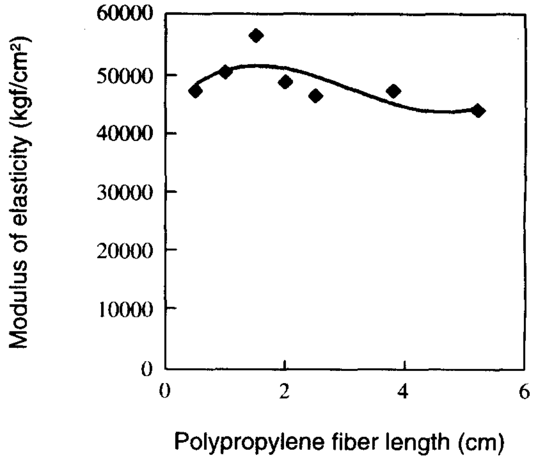

Fig. 4. Modulus of elasticity of composites by length of polypropylene fiber.

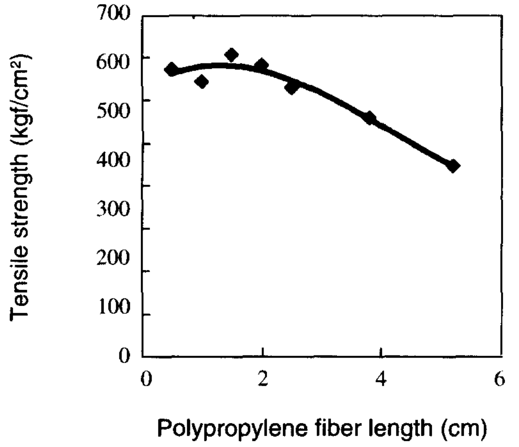

Fig. 5. Tensile strength of composites by length of polypropylene fiber.

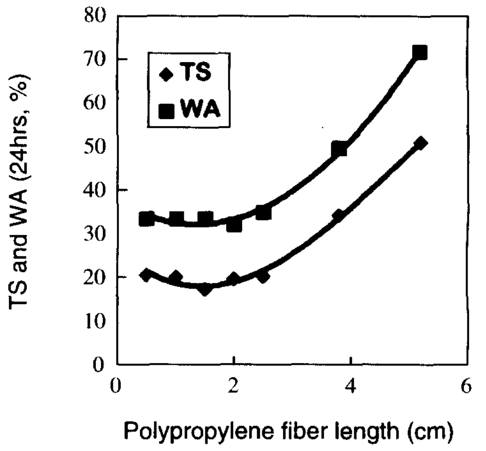

Fig. 6. Thickness swelling (TS) and water absorption (WA) of composites by length of polypropylene fiber.

developed by the Forest Products Laboratory (FPL) requires a needle punching process for obtaining mat uniformity because this process uses long thermoplastic fibers for manufacturing wood fiber and thermoplastic fiber composites. In the TAM process, long thermoplastic fibers show a tendency to be more unevenly distributed than are short fibers, and thus the turbulent air mixer is considered to be rather unsuitable for mixing long thermoplastic fibers with wood fibers in manufacturing composites.

As the length of polypropylene fiber increases, mechanical and physical properties generally decrease, and composites made with 1.5cm-long polypropylene fiber exhibited the highest mechanical and physical properties. The optimal geometric condition of thermoplastic fiber for making composite panels may be roughly derived from the designed experiments. However, determining the optimal condition seems has been very difficult because of the complicated interrelation of many variables, such as turbulent air stream, fiber length and denier, pressure of compressed air, structure of mixer, mixing time, and proportion of wood fibers to thermoplastic fibers.

Figs. 7 and 8 compare the mechanical and physical properties of composites made by the TAM process and those of composites made by the conventional Rando-Webber forming process at FPL (Youngquist *et al.*, 1992). According to this comparison, mechanical and physical properties of composites made by the TAM process exceeded the values reported by Youngquist *et al.* (1992). This may be primarily caused by the difference in manufacturing method and thermoplastic fiber geometry between the processes because composites made with short thermoplastic and wood fibers by only the TAM method appear to perform better than those made with long thermoplastic and wood fibers by the Rando-Webber forming method with an additional needling step for increasing fiber interlocking in the composite mats. Thus, the TAM process is thought to be an efficient and simple way of improving the performance of wood fiber and thermoplastic fiber composites.

The difference in the performance of composites made by these two processes may be attributed to mat uniformity if the other conditions (i.e., hot pressing schedule, density and composition ratios, etc.) are not different to a great extent. Better mat uniformity helps to improve bond efficiency in the composite panels. It plays an important role in enhancing the composite performance. The longer the polypropylene fiber, the poorer the mechanical and physical properties because of the uneven distribution of polypropylene fibers (Figs. 3 to 6). The phenomenon of uneven distribution of polypropylene fiber can be identified visually as the presence of many bundles of polypropylene fibers in the mat.

Wood fiber and thermoplastic fiber composites made by the TAM process may have a variety of applications because they can be easily made in the required density levels with 5% to 80% polypropylene fiber and 95% to 20% wood fiber in accordance with product types. Potential products include low-density automobile components; floor, wall, packaging, and furniture components; housing structure; filters; and geotextile mats.

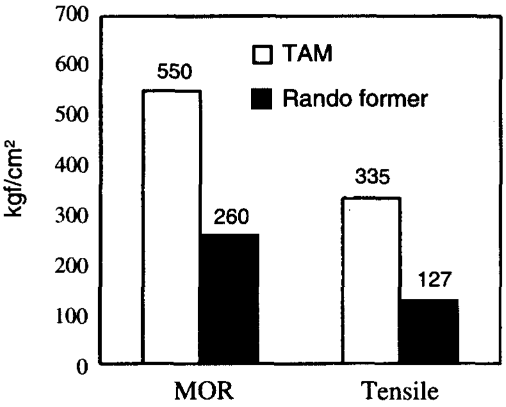

Fig. 7. Comparison of modulus of rupture (MOR) and tensile strength between composites by turbulent air mixing (TAM) process and those by conventional Rando-webber forming process.

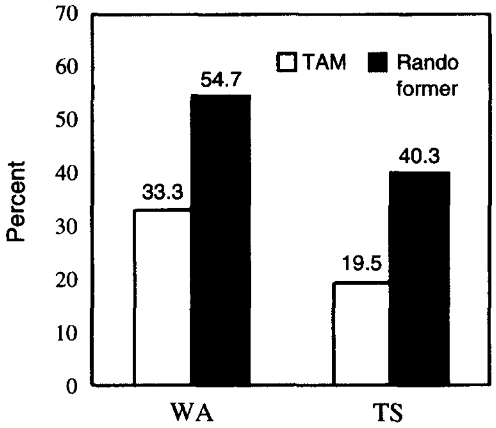

Fig. 8. Comparison of water absorption (WA) and thickness swelling (TS) between composites by turbulent air mixing (TAM) process and those by conventional Rando-webber forming process.

4. CONCLUSION

A new mixing device was designed using turbulent air for mixing wood fibers with thermoplastic fibers. Its effectiveness as a mixing process was evaluated by making composites with wood and polypropylene fibers and testing them for mechanical and physical properties. The TAM process appeared to be able to mix wood fibers and thermoplastic fibers efficiently and to have several advantages: (1) the process does not require a needle punching process, (2) composite performance and density can be easily controlled because more than 70% thermoplastic fibers can be incorporated, (3) TAM is more effective in mixing short (0.5 to 2.5 cm) thermoplastic fibers than long ones (3.8 to 5.2 cm) fibers, and (4) composites have higher mechanical and physical properties compared to composites made by the conventional nonwoven web or Rando-Webber process. Long fibers tend to form an uneven mat due to their irregular distribution and entanglement, and thus generally produce composites of low quality. In this respect, higher mechanical and physical properties in turbulent-air-mixed composites made with short thermoplastic fibers might be attributed to increased uniformity of the mat.

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