Development of Low-Density Wooden Molding Mat Using Bicomponent Fibers

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Abstract

We attempted to use wood shavings in their raw curled flake form as a base material in a mat to be used primarily as a heat-insulating/acoustic material in houses. The molding succeeded in producing a low-density (0.03 to 0.08 g/cm^3) wooden molding mat with bicomponent fibers as the binding component. After evaluating self-support and form retention, the inclusion of kenaf bast fiber was found to improve formability. Self-support and form retention were found with a combination including 5 percent bicomponent fiber. For examining the molding process, a relatively simple method of using a dust collector with an air blower that is used in carpentry allowed spreading of various fibrous materials and homogeneous mixing of the ingredients. Thermoforming could be achieved over a short time by using a heat-through dryer.

Acoustic/heat-insulating materials, such as glass wool, are inexpensive construction materials with excellent properties, and they are widely used in a range of manufacturing areas—from construction and domestic appliances to the automotive industry. Unfortunately, during the demolition of homes and scrapping of household equipment, their classification and processing for disposal become problematic. Furthermore, in recent years, emphasis has been placed on reducing the environmental burden through life cycle assessment, leading to a demand for novel, bio-based materials to replace those such as glass wool. This study sought to use wood shavings, arising from the manufacture of supports and other structural materials for homes, in their original curled flake form as a base material for making heat-insulating/acoustic materials for houses. Traditionally, wood shavings have been used as heat-insulating material, e.g., sealed in bags and laid under floors or in ceilings. Their stabilizing effect on the temperature within an indoor environment has been confirmed in recent years (Yamasaki et al. 2008). Various performance evaluations on walls using wood shavings as heat-insulating material have also been conducted (Sekino and Kawamura 2003; Kawamura et al. 2004a, 2004b; Sekino et al. 2005; Sekino and Yamauchi 2007; Taniuchi et al. 2008). However, problems remain in their formability, which is a factor in their practicality for buildings (particularly in walls), and in manufacturing methods and their associated productivity/cost, etc.

This study tested a method for forming the basic material (i.e., wood shavings) into a mat form that is different from the addition of adhesive and hot pressing used in typical board molding; it uses bicomponent fibers as a binding component in a thermoforming method. Examination of the potential of bicomponent fibers confirms that they can be formed relatively simply and quickly into a mat form and that the mats have excellent heat insulation and acoustic performance. This report discusses a method for creating mats using bicomponent fibers and their associated formability.

Materials and Methods

Wood shavings and kenaf bast fiber

The basic materials of wood shavings, kenaf bast fibers (hereafter ‘‘kenaf’’), and bicomponent fibers are shown in

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Figure 1. The primary material (i.e., wood shavings) was taken from Japanese cedar (*Cryptomeria japonica*) with an air-dry density of 0.35 to 0.40 g/cm^3 and was manufactured with a planing machine similar to those used for the production of common home structural elements such as structural lumber. The wood shavings were curled flakes, and they were about 0.2 mm thick at their thickest part, with length and breadth varying from 5 to 20 mm.

The kenaf were as shown in Figure 1; roughly spread fibers from kenaf bast of 80-mm length were used. It was expected that adding a long fiber such as kenaf would give rigidity to the moldings.

Bicomponent fibers

Bicomponent fibers are composite fibers, as shown in Figure 1, with a cross section composed of two resins of different properties and are relatively common construction materials. Figure 2 shows a schematic diagram of bicomponent fibers and their heat-bonding mechanism. The sheath is composed of a resin with a melting point lower than that of the core; by heating to a temperature at which only the sheath melts, fibers may be welded together. The elements are composed of a combination of polyolefin-type resins such as polyethylene, polypropylene, and polyethylene terephthalate. The fibers are used for car interior materials, sanitary napkins, and house interior materials, such as nonwoven materials, suggesting that they would be suitable for this process in terms of human health and safety.

As shown in Figure 2, bicomponent fibers are either a concentric type with the core at the center of the sheath or a parallel type with an inclined core in which the cross section allows for the fibers to take a somewhat wavy form. In this study, we used two types of fibers, ES and ESC (ES Fibervisions), both composed of a polypropylene core with a polyethylene sheath, with a fineness of 2.2 dtex and a length of 5 mm. The decitex unit (dtex) is an international standard that shows the thickness of fiber, where 1 dtex is 1 g per 10 km of fiber.

Spreading fibers and mixing

For spreading fibrous materials and mixing their various types, we tried applying an air blower with a chamber in which the basic materials can float together. Its outline is shown in Figure 3. A dust collector was modified so that the air blower evacuates the collector bag while simultaneously drawing the raw material in through a separately installed collector vent and circulated. First, the system was circulated until the bicomponent and kenaf fibers were sufficiently separated; then wood shavings were drawn in, and the raw materials were mixed together.

The manufacturing conditions for the mat are summarized in Table 1. Weight proportions of bicomponent fibers (BF) were evaluated at 0, 2, 5, 8, and 10 percent. To examine the effect of kenaf, the remainder of each combination was composed of wood shavings and kenaf with respective ratios of 100:0 (composition A) and 70:25 (composition B), giving a total of 10 different mixtures.

Thermoforming

This process used a bicomponent fiber weld mechanism to join the elements. The mixed basic materials were placed in a mold with internal dimensions of 310 by 310 mm in a

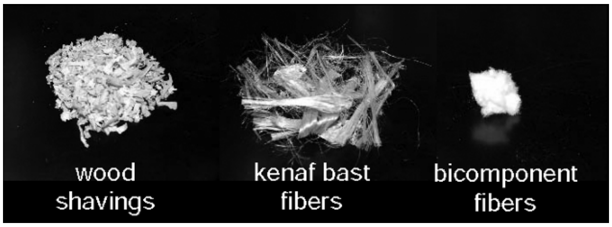

Figure 1.—Raw materials of wooden insulation mat: (a) wood shavings, (b) kenaf bast fiber, and (c) bicomponent fiber.

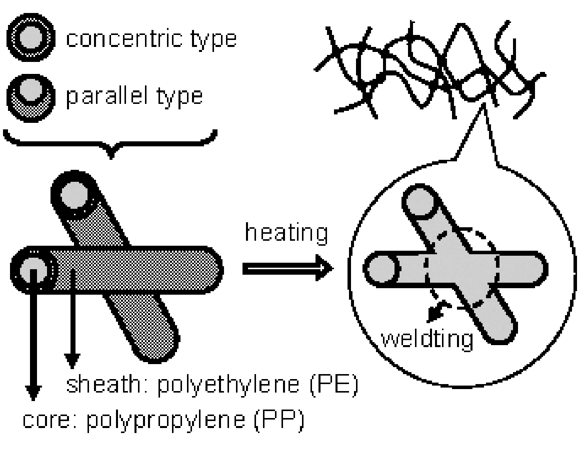

Figure 2.—Schematics of bicomponent fiber and its welding mechanism.

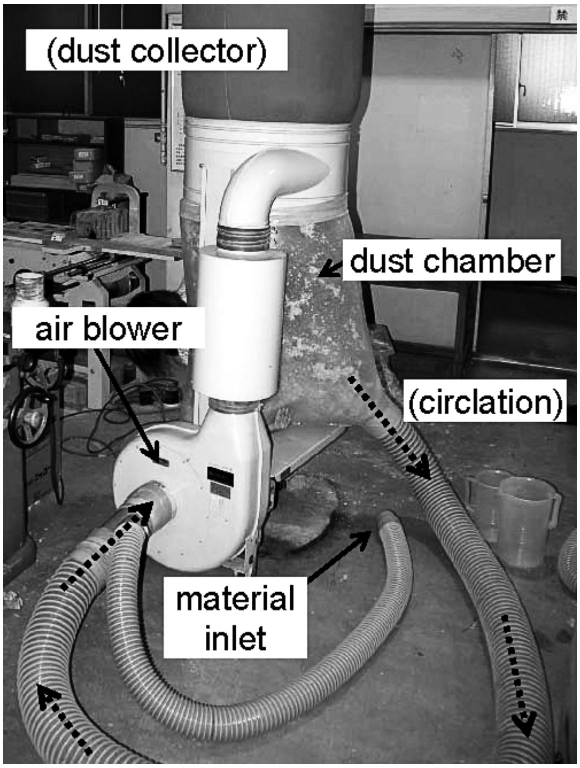

Figure 3.—Spreading of fibers and mixing of raw materials using simple dust collector.

Table 1.—Molding conditions.[a]

Composition condition	Combination rate (wood shavings:kenaf:BF)	Thermoforming method
Composition A	100:0:0	Oven dryer
	98:0:2	Temperature: 160°C
	95:0:5	Time: 120 min
	92:0:8	
	90:0:10	
Composition B	74:26:0	Heat-through dryer
	72:26:2	Temperature: 160°C
	70:25:5	Time: 5 min
	68:24:8	Airflow rate: 10 m/min
	66:24:10	

[a] The target density for both compositions was 0.03 to 0.08 g/cm^3; the target thicknesses were 25, 28, and 100 mm.

quantity according to the target density and thickness, and the thickness was controlled. They were then thermoformed by the two methods given in Table 1. Figure 4 is a schematic showing a method using a heat-through dryer. The mold maintained breathability in the thickness direction by using wire netting, and the raw materials were heated by passing hot air through. The air temperature was set to 160°C at an airflow rate of 10 m/min for a process time of 5 min. For the method using an oven dryer, the mixture was heated by putting the mold itself in a conventional oven dryer. The heating temperature was set to 160°C for a heating time of 2 hours. Following the designated heating time in either case, the mixture was cooled at room temperature and removed from the mold. Samples for measuring various properties were prepared using the oven dryer. The moldability of the manufactured forms was evaluated for self-support and form retention as given below.

Evaluation of self-support

In addition to being able to support itself within the wall, the form needs to maintain its shape during placement and transport. In order to evaluate this, the free deflection of the sample when supported as a cantilever beam was measured. The test piece dimensions were set to 310 by 100 by 28 mm; pieces were fixed at a distance of 110 mm in the length direction from the tip, with the remaining 200 mm deflecting freely. This deflection was then measured with a laser range finder at regular intervals from the anchor. There were three test pieces. Statistical analysis was done to the end deflection amount in each density according to the Bonferroni multiple comparison test (Ott and Longnecker 2001).

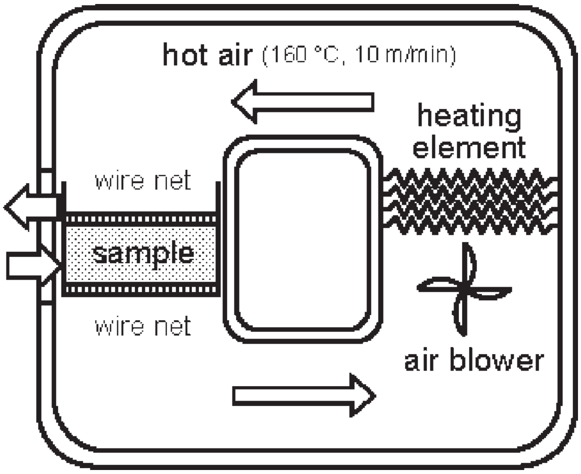

Figure 4.—Schematic of heat-through dryer.

Evaluation of form retention

The molded forms do not require structural load capacity for their purpose; however, impacts arising during manufacture or handling during construction may lead to the destruction of the molded pieces. Because no standard evaluation methods have been established for this class of material, similar developmental studies have made evaluations using independent falling impact tests (Sekino and Kawamura 2003; Kawamura et al. 2004a, 2004b). The present work used similar evaluation methodologies using a repeat free-fall test. The test piece dimensions were set to 310 by 310 by 25 mm; when dropped in free fall from a height of 7.5 m, the mass, W_n, of the largest piece remaining undestroyed was measured, and the mass retention was obtained over 12 repeats. There were three test pieces. Statistical analysis was done on the mass retention after the 12 repeats, as mentioned above.

Thermal conductivity

Specimens of 0.05-g/cm^3 density and 25-mm thickness were made by composition B. The measurement was executed on the basis of International Organization for Standardization (ISO) 8302 (ISO 1991).

Absorption coefficient

Specimens of various densities were made by composition B and 25-mm thickness, and the normal incidence absorption coefficient was measured. The measurement system of WinZac MTX Version 3.1.0 (Nittobo Acoustic Engineering Co., Ltd.) that conformed to ISO 10534-2 (ISO 1998) was used. The air layer in the back of the specimen was set to 0 mm.

Results and Discussion

Spreading fibers and mixing

Bicomponent and kenaf fibers were spread according to the current method; however, bicomponent fibers had different postspread characteristics according to their type. Postspread bicomponent fibers are shown in Figure 5. Concentric types were uniformly spread in a flocculating manner and were then scattered with approximate homogeneity (Fig. 5a). In contrast, while parallel types spread initially, they then formed clumps approximately 5 mm in diameter that circulated inside the system; therefore, they

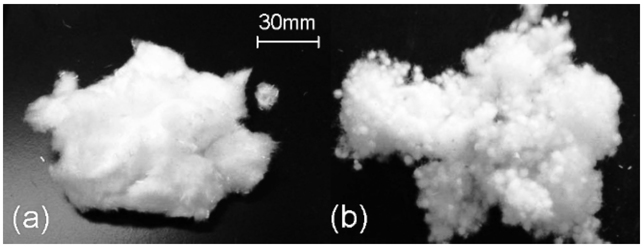

Figure 5.—States of bicomponent fiber after the spreading process: (a) concentric and (b) parallel.

could not be homogeneously mixed with the kenaf and wood shavings introduced thereafter (Fig. 5b). Considering their cross-sectional shape, the fibers are greatly curled and easily become entangled with each other, hence this phenomenon. Consequently, the subsequent sample preparation and property measurements used only the concentric bicomponent fibers. Spreading of kenaf and bicomponent fibers is considered to occur mainly through collision of bundles of fibers with the fins of the air blower. Simultaneously, air currents around the fiber bundles are expected from Bernoulli's principle to act perpendicular to the direction of flow in order to unravel the fibers and spread them. This principle has been explored by the analysis and verification of spreading in fiber bundles by Kawabe et al. (1997) and Kawabe and Matsuo (1998), where the spreading of carbon fiber bundles was performed. In addition, kenaf were cut at various lengths when spread.

The time required for spreading and mixing is affected by the mixing ratio and mass of raw material; for this test system, it was around 2 min for 700 g of raw material. Three types of raw material are considered to have mixed together while being suspended in the chamber. This mixture method allowed three sample types to be mixed homogeneously.

Thermoforming

Thermoforming was possible only when the bicomponent fibers were added. Because the sample was breathable in the thickness direction, draft heating using a heat-through dryer was possible, allowing thermoforming with a 5-min processing time, even for the condition with the most airflow restriction (100-mm thickness) and high density (0.08 g/cm^3). In contrast, when using the oven dryer, because air was not forcibly passed in the thickness direction, a considerable amount of time was required for the temperature at the center to rise; for the sample size used in this study, 2 hours of heating was required. Because draft heating with the heat-through dryer uses relatively simple equipment, has an extremely short processing time, and depending on ventilation capacity, does not rely on the sample size, it is considered to be a heat processing method that is appropriate for industrial use.

One of the mats produced—100 mm thick, a density of 0.06 g/cm^3, and composition B with 5 percent BF—is shown in Figure 6. The mats produced had flexibility and resilience. Figure 7 is a photomicrograph of the sample shown in Figure 6. It shows the melting of the bicomponent fiber sheaths and the fusing of the fibers together. Simultaneously, bicomponent fibers are predicted to have also fused with kenaf and wood shavings. The material cannot be formed at a temperature so low that it does not melt the polyethylene sheath (120°C) or at a temperature so high that it also melts the polypropylene core (180°C). The material is thus characterized as being produced through dry processes at moderate temperatures, and it is considered to have advantages over common adhesive-based board-making processes in terms of simplicity.

Samples with a density greater than about 0.08 g/cm^3 could not be manufactured under the conditions of this study. This is because even when compressed and thermoformed, spring-back in the thickness direction was caused. The spring-back is considered to be caused by the shape of the wood shavings. Therefore, the internal bonding of the mats was lower than that of adhesive-based wood-based boards.

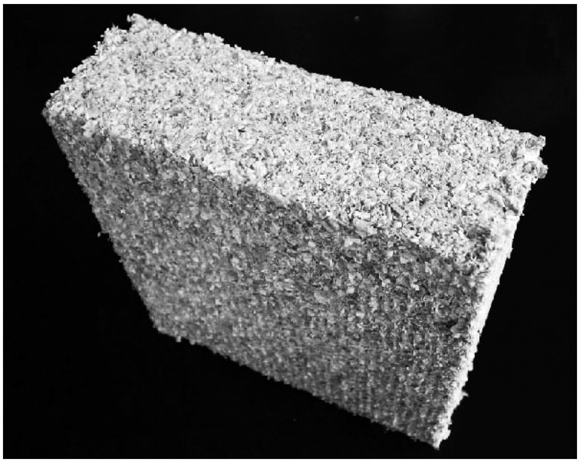

Figure 6.—A sample wooden molding mat.

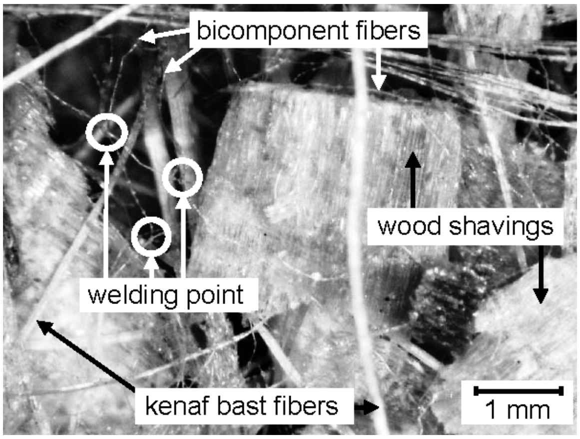

Figure 7.—Photomicrograph of the sample molding mat.

Because the density and proportion of bicomponent and kenaf fibers are considered to affect the form retention and self-support and are the factors involved in moving and laying the material for construction, these are examined below.

Evaluation of self-support

Figure 8 shows the deflection amount of a test piece when supported as a cantilever beam. Since mixtures not containing bicomponent fibers could not be formed, they could not be tested. Despite the fact that in both composition A and composition B the empty weight of the cantilever section increased as the density became higher, the deflection amount decreased because the bonds between elements also become denser. Deflection decreased with increasing proportion of the bicomponent fiber; even under low-density conditions (e.g., composition B, 0.03-g/cm^3 density), a 10 percent combination was found to give excellent self-support. The addition of kenaf in composition B sought to improve rigidity (self-support) through the combination of long fibers. As a result, for all combinations, the deflection amount was lower than for composition A. Wood shavings were supported as they entangled themselves with kenaf spread in flocculation, and as these connected with each other, it led to increased self-support as

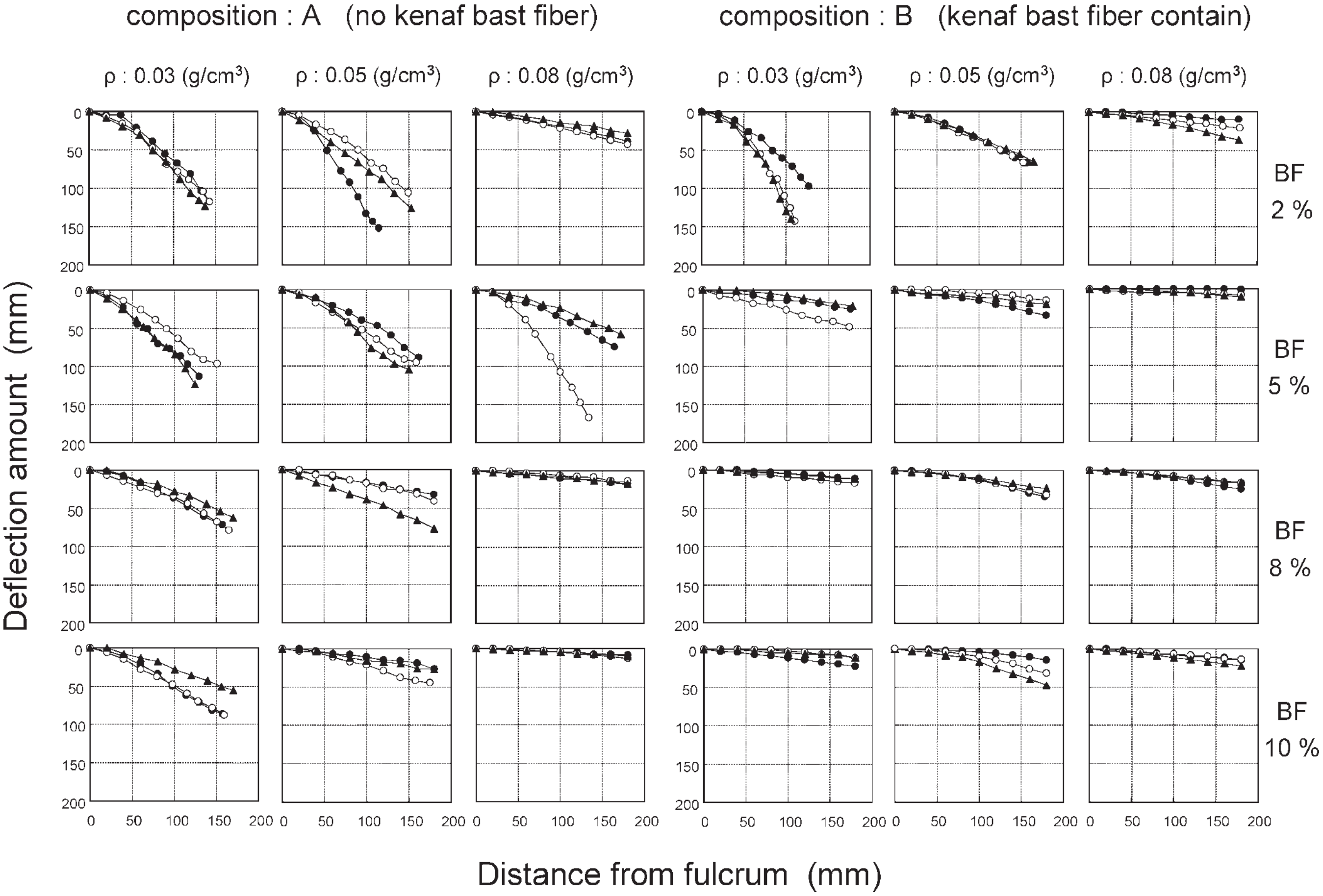

Figure 8.—Deflection of wooden mat as cantilever beam.

intended. When a statistical analysis was done, there was hardly a significant difference in the density of 0.08 g/cm^3 regardless of the mixing ratio. At a density of 0.05 g/cm^3, the deflection amount of 2 and 5 percent BF of composition A was larger than the other conditions at 0.05-g/cm^3 density (95% significant), and at a density of 0.03 g/cm^3, the deflection amount of 5, 8, and 10 percent BF of composition B was smaller than the other conditions at 0.03-g/cm^3 density (95% significant).

Although the amount of the ingredient acting as a binder was small compared with the adhesive-based wooden boards, it had good formability. When subject to a survey of their performance in terms of handling and practicality for construction, samples with deflection less than 50 mm were given a positive evaluation referring to the glass wool with 0.032-g/cm^3 density that did not use binder. From this evaluation, target self-support was observed in the 5 percent BF combination under composition B. Even using only wood shavings (composition A), a combination with 10 percent BF or less was found to give the target self-support.

Assuming that a cantilever beam is subject to uniform loads by empty weight, Young's modulus (E) is obtained from the following formula. For conditions with virtually no deflection, calculation was made from a fixed load P at the tip:

$$E = \frac{q}{24I\delta}x^2(6l^2 - 4lx + x^2) + \frac{P}{6I\delta}(3lx^2 - x^3)(\mathrm{Pa}) \qquad (1)$$

where

q = load per unit length (N/mm),
I = second moment of section (mm^4),
δ = deflection amount (mm),
x = distance from the fulcrum (mm),
l = beam length (mm), and
P = load applied to the tip (N).

Calculating Young's modulus from each measuring position on the cantilever gives generally similar values, showing deformation approximating a free deflection curve. As an example, where 0.026 GPa of E was estimated from the property used as an index (end deflection amount 50 mm), E was 0.006 ± 0.002 GPa under composition A, 0.05-g/cm^3 density, and 2 percent BF, which had extremely large deflection. On the other hand, 10 percent BF satisfying the target condition showed 0.037 ± 0.013 GPa of E. Composition B, 0.05-g/cm^3 density, and 5 percent BF, showed 0.070 ± 0.032 GPa, making quantitative comparison possible. A generalization of the results that considers changes in thickness and sample size is possible. The proportion of kenaf that is effective at improving self-support is investigated further based on this view.

Evaluation of form retention

Figure 9 shows the mass retention in a repeat falling test. Factors for small reductions in mass are scatterings of fine wood shavings and powder from test pieces not held by the bicomponent fibers. Large mass reductions are from the partial destruction of the test piece. There was generally no significant destruction of test pieces for almost any of the conditions in composition B that contained kenaf. No significant differences were shown among all conditions (density and bicomponent fiber content) at a significance level of 5 percent. For composition A, which did not contain kenaf, good form retention was found with over 8 percent BF. However, for 5 percent BF of low density, 2 percent BF of low density, and 2 percent BF of medium density, a significant difference was shown for other conditions at a significance level of 5 percent. These trends can be explained by the connection and its extent between elements, as seen in the observations for evaluating self-support. However, particularly for compositions such as 2 and 5 percent BF in composition A with large mass reduction, a trend conflicting with the above observations was found where mass retention rate decreased with increased density. This is considered to be due to the impact of acceleration increasing in proportion to mass increase. However, because dust scraped off the test pieces is considered a problem from a practical perspective, some remedy is required.

Thermal conductivity

Thermal conductivity of the mat showed 0.039 W/m/K, which is smaller than the standard value of 0.042 W/m/K required in ISO 8142 (ISO 1990) for glass wool of 0.064-g/cm^3 density. We now examine various factors in thermal conductivity.

Absorption coefficient

Frequency response of the mats showed a similar tendency to the glass wool. The peak frequency shifted to the low-frequency side, and the value of absorption coefficient rose as the density increased. When comparing the mats with glass wool under equal density, the mats were inferior to glass wool at a low density. However, performance exceeding that of glass wool was obtained at a high density; the mat of 0.08-g/cm^3 density showed a performance almost equal to glass wool of 0.096-g/cm^3 density.

Considerations concerning fire-retardant addition and production cost

As a method of giving a certain level of fire-retardant property, treating with the flame retardant of borate or phosphate series is effective. It could be suitable to spray the reagent solution into the chamber of the dust collector during mixing. It is homogeneously treatable by this technique, and it is expected that the solvent will evaporate at the same time in the thermoforming process.

It is provisionally calculated that the cost of basic materials is about equal to that of glass wool and cheaper than that of urethane foam. It is thought that the price would depend on the manufacturing scale. For spreading fibers and mixing materials, it is necessary to design new equipment of a certain scale based on this research. However, the thermoforming process can apply the basic manufacturing process used for nonwoven cloth. Therefore, it is expected that bicomponent fiber–bonded wood shavings mats could be manufactured efficiently and at a price competitive with potential substitute products.

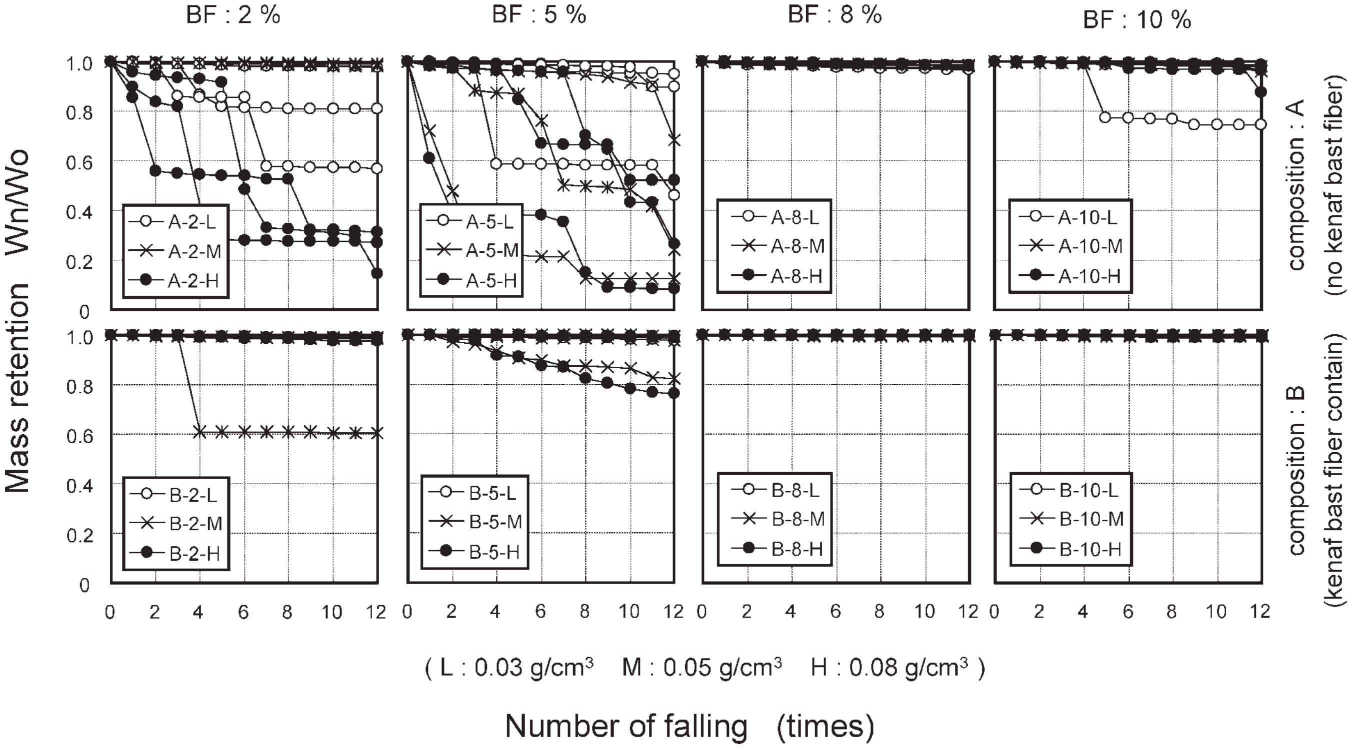

Figure 9.—Weight retention on falling impact test.

Conclusions

We attempted to use wood shavings in their raw curled flake form as a base material in a wooden molding mat to be used primarily as a heat-insulating/acoustic material in homes. In an investigation of the molding process and formability applying the bicomponent fiber as a binding component, a low-density (0.03 to 0.08 g/cm^3) wooden molding mat was achieved.

A relatively simple method using a simple air blower (carpentry dust collector) allowed for simultaneous spreading of various fibrous materials and homogeneous mixing of ingredients, establishing the basic process. The cross-sectional form of bicomponent fibers was conductive to homogeneous mixing. The application of a heat-through dryer allowed thermoforming in a short time. In an evaluation of the self-support and form retention regarding the formability of the mats, the addition of kenaf was found to improve formability; a requisite performance of self-support and form retention was found with mixtures of 5 percent BF at all density conditions. In our next article, we plan to report on the effect of the proportion of kenaf on heat-insulating and acoustic performance.

Acknowledgments

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