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Effect of adding steam-exploded wood flour to thermoplastic polymer/wood composite

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Abstract The effect of steam-exploded wood flour (SE) added to wood flour/plastic composite was examined using SE from beech, Japanese cedar, and red meranti and three kinds of thermoplastic polymer: polymethylmethacrylate, polyvinyl chloride, and polystyrene. Addition of SE increased the fracture strength and water resistance of the composite board to an extent dependent on the polymer species and the composition of wood/SE/polymer. However, water resistance decreased with the increasing proportion of SE when SE meranti was added. Effects of the wood species of SE on the properties of resulting board were small. An increased moisture content of wood flour or SE (or both) increased the variation of board performance.

Key words Wood flour · Thermoplastic polymer · Wood/polymer composite (WPC) · Steam explosion

Introduction

In an earlier paper we reported an excellent effect of steam-exploded beech flour as an additive to a wood adhesive based on phenol-formaldehyde resin.[1] Here, the effect of steam-exploded wood flour (SE), from wood species beech, Japanese cedar, and red meranti, as an additive to wood/plastic composite was investigated.

Wood plastic composite has attracted attention as a method of recycling wood and plastic waste and of preparing water-resistant wood-based material without using formaldehyde-based adhesives.[2–4] Plastic polymers have molecular backbones consisting of hydrophobic carbon–carbon chains. On the other hand, the principal constituent of wood species is carbohydrates (e.g., cellulose and hemicellulose), which are abundant in hydrophilic hydroxyl groups or at least polar oxygen atoms. Therefore, it is not expected, in principle, for a mixture of wood species and plastic polymers to have strong mutual intermolecular bonding interaction. In an attempt to increase the compatibility of the two components, several compounds have been examined as to their effect as dispersants, modifiers, or coupling agents.[2,5] Sometimes the components themselves (wood and additives) were modified through derivatization, co-polymerization, or both.[6,7] The guiding principle of these treatments is to increase the compatibility of the two by increasing the hydrophilicity of polymers and decreasing the hydrophilicity (or increasing hydrophobicity) of wood. In the general preparation of plastic/wood composite, wood as fiber or flour is blended with thermoplastic polymers, and the resulting mixture is molded directly from the mixture or after being pelleted.

Steam-exploded wood flour has long known as a raw material for preparing plastic-like molded wood products, although the technology is not widely used nowadays.[8] It may be expected that SE is a good additive to plastic/wood composite because wood components are decomposed into fragments of low molecular weight, and hydrophilicity may be decreased by dehydration through high temperature treatment. In this context, it is of interest to see what happens when SE is added to wood/plastic composites. The results of our recent study on the effect of adding SE to thermoplastic/wood composite are reported here. Excellent fracture strength and water-resistant properties of the resulting composite board were obtained.

Experimental

Materials

Steam-exploded wood flour was prepared as described[1] by steam-exploding beech (*Fagus crenata*), Japanese cedar

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(*Cryptomeria japonica*), and red meranti (*Shorea negrosensis*) wood chips (a mixture of heartwood and sapwood) after cooking at 215°C (about 2.1MPa) for 8min. The exploded mixture was used in experiments after drying at 60°C. Some of the chemical composition of SE was reported in the preceding paper.[1] Thermoplastic polymers used in this work were commercially available polystyrene (PST; average degree of polymerization, *Pn* = 2500; Hitachi Chemical Co.), polymethylmethacrylate (PMMA; *Pn* = 6000;Yoneyama Reagents Industry), and polyvinyl chloride (PVC; *Pn* = 1020, Kishida Reagents Chemicals). No plasticizers or additives were added to the polymers. Mixed soft wood material, a flour of 20 mesh pass, was used after drying at 60°C.

Preparation of composites

Wood/plastic composite was prepared with a fixed ratio of (wood + SE)/plastic polymer, 7/3 by weight, and varying the ratio of wood/SE by 10%, from 70/0 (wood only) to 40/30. In a typical preparative procedure, a mixture of wood and SE was placed in a vat, and plastic polymer dissolved in a suitable solvent (benzene for PST, acetone for PMMA, tetrahydrofurane for PVC) was poured over the wood/SE mixture; the mixture was stirred with a spatula. The solvent was allowed to vaporize in a hood, and the residue was air-dried overnight. The material thus obtained was powdered with a ball mill, and 19.2g of the powder was put into a press frame of 80 × 100mm size and hot pressed at 130°C for 10min under 90MPa pressure to prepare a composite board of average 2.0mm thickness. The board was cut into three pieces of 25 × 100mm, which were used as test pieces for analyses of three-point bending and water resistance according to Japanese Industrial Standard methods.[9] The board density of a sample was calculated by measuring the average thickness at three points: center, one-quarter, and edge. Actually, the observed density varied from the estimated value of 1.2 by + 0.08. Water resistance was determined by measuring time-dependent change of the thickness swelling and water absorption of the test pieces after immersing the board into water at room temperature. An average of five samples were tested for each experiments.

Results

Bending test

Results of bending tests of the pressed boards are shown in Figs. 1–3 with variation of plastic materials (PST, PVC, PMMA). Each figure shows the dependence of the modulus of rupture on the wood flour/SE ratio and the wood species of the SE. Similar results for the modulus of elasticity of the composite boards are summarized in Figs. 4–6. In each figure the experimental value for molded plastic itself is also shown for comparison.

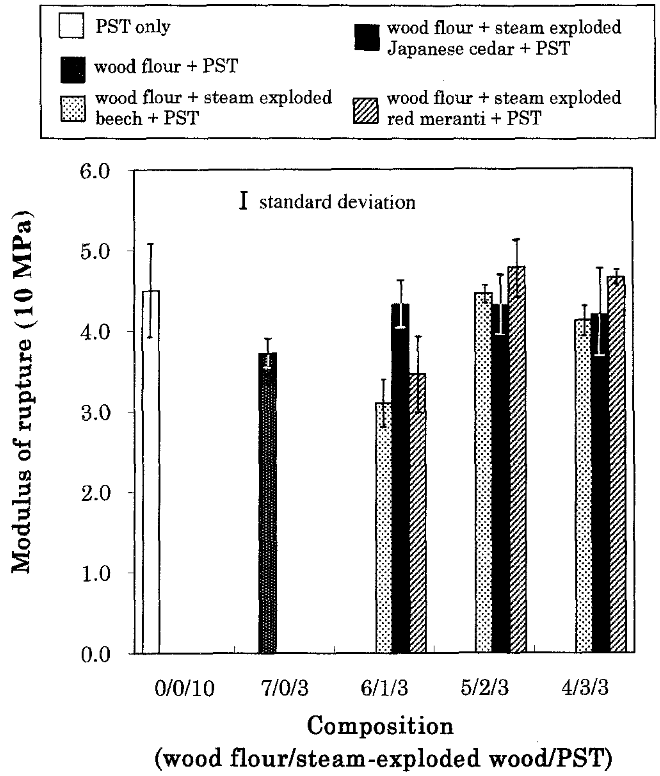

Fig. 1. Moduli of rupture of wood flour/steam-exploded wood/polystyrene (*PST*) composites

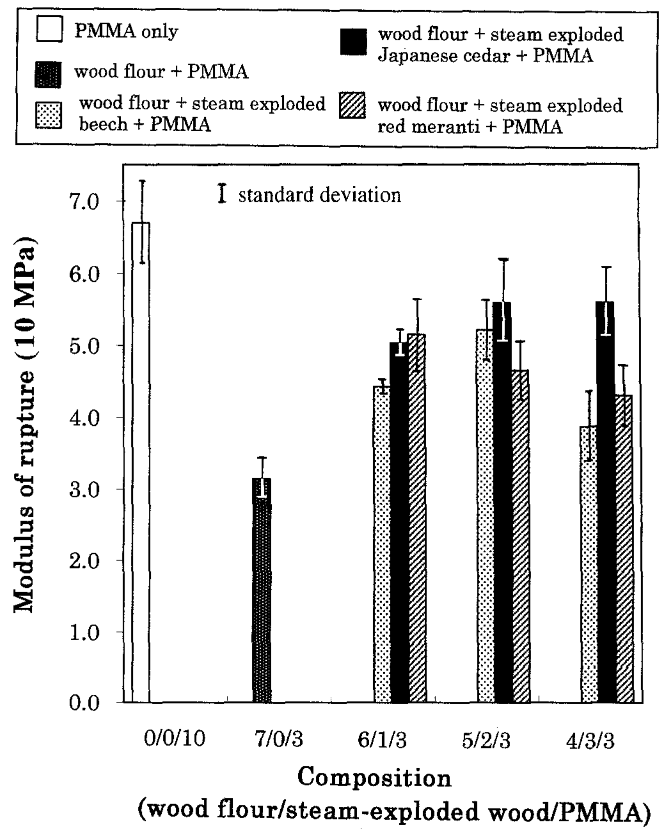

Fig. 2. Moduli of rupture of wood flour/steam-exploded wood/poly(methylmethacrylate) (*PMMA*) composites

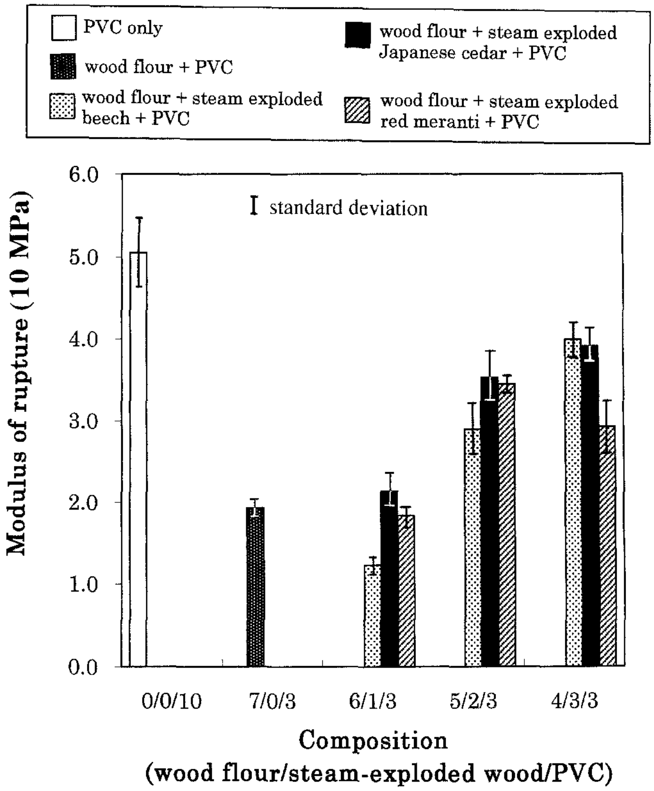

Fig. 3. Moduli of rupture of wood flour/steam-exploded wood/poly(vinyl chloride) (*PVC*) composites

Water resistance

The results of thickness swelling and water absorption tests are summarized in Table 1.

Discussion

The modulus of rupture, modulus of elasticity, and water resistance of the wood plastic board were generally increased by replacing wood flour with SE, although the composition at which the best performance of the board was obtained differed depending on the plastic polymer and, to a lesser extent, the wood species of SE. The modulus of rupture of PST composite exhibited good performance at a wood flour/SE ratio of 5/2 for all the SE wood speceis (Fig. 1), which is almost as high as the value for the board made from PST only. The modulus of rupture of the PMMA composite exhibited good performance at a wood flour/SE ratio of 5/2 or 6/1 for all kinds of wood species of SE (Fig. 2). Then the modulus of rupture of PVC composite exhibited good performance at a wood flour/SE ratio of 4/3 for SE of beech and Japanese cedar (Fig. 3). The modulus of elasticity of the PST or PMMA composite using SE showed good performance regardless of the amount and kinds of SE (Figs. 4, 5), which was superior to that of PST or PMMA polymer board, respectively. In contrast, the modulus of elasticity of PVC composite showed a maximum at the ratio of 4/3 regardless of the kinds of SE (Fig. 6), which exceeded that of PVC board. The water resistance of all composites using SE was better than that of composites without SE regardless of the plastic polymer (Table 1). Especially good

Table 1. Specific gravity and water resistance of wood flour/steam-exploded wood/polymer composites

Parameter	7/0/3[a]	6/1/3[a]			5/2/3[a]			4/3/3[a]		
		B	JC	RM	B	JC	RM	B	JC	RM
PST										
d	1.184	1.187	1.240	1.186	1.211	1.242	1.211	1.250	1.193	1.233
TS (%)	5.52	6.43	2.45	5.92	3.12	2.13	4.36	3.47	3.04	6.98
	(0.79)	(0.08)	(0.12)	(0.17)	(0.06)	(0.37)	(0.38)	(0.42)	(0.06)	(0.52)
WA (%)	5.17	7.29	3.09	10.33	5.01	3.20	6.65	6.48	5.25	4.69
	(0.57)	(0.79)	(0.34)	(0.76)	(0.12)	(0.36)	(0.54)	(0.86)	(0.43)	(0.35)
PMMA										
d	1.208	1.252	1.190	1.192	1.260	1.256	1.248	1.293	1.257	1.262
TS (%)	4.87	2.62	5.00	4.77	2.21	3.38	2.69	1.45	2.94	2.65
	(0.25)	(0.18)	(0.36)	(0.37)	(0.18)	(0.26)	(0.30)	(0.25)	(0.35)	(0.37)
WA (%)	6.26	5.86	7.62	7.83	3.33	4.55	5.83	4.06	4.69	4.51
	(0.16)	(0.40)	(0.35)	(0.56)	(0.38)	(0.52)	(0.45)	(0.02)	(0.33)	(0.43)
PVC										
d	1.176	1.185	1.238	1.145	1.201	1.294	1.296	1.274	1.283	1.275
TS (%)	9.28	8.64	7.96	9.98	8.73	3.99	6.50	5.77	3.12	5.07
	(0.98)	(0.18)	(0.78)	(0.59)	(0.53)	(0.19)	(0.45)	(0.56)	(0.29)	(0.41)
WA (%)	15.92	13.89	10.09	22.26	15.10	7.20	11.88	10.62	6.44	11.33
	(0.54)	(0.84)	(0.40)	(1.00)	(0.77)	(0.57)	(0.78)	(0.74)	(0.67)	(0.11)

d, specific gravity; WF, woof flour; SE, steam-exploded wood; B, beech; JC, Japanese cedar; RM, red meranti; TS, thickness swelling; WA, water absorption
Numbers in parentheses are standard deviations
[a] WF/SE/polymer ratio

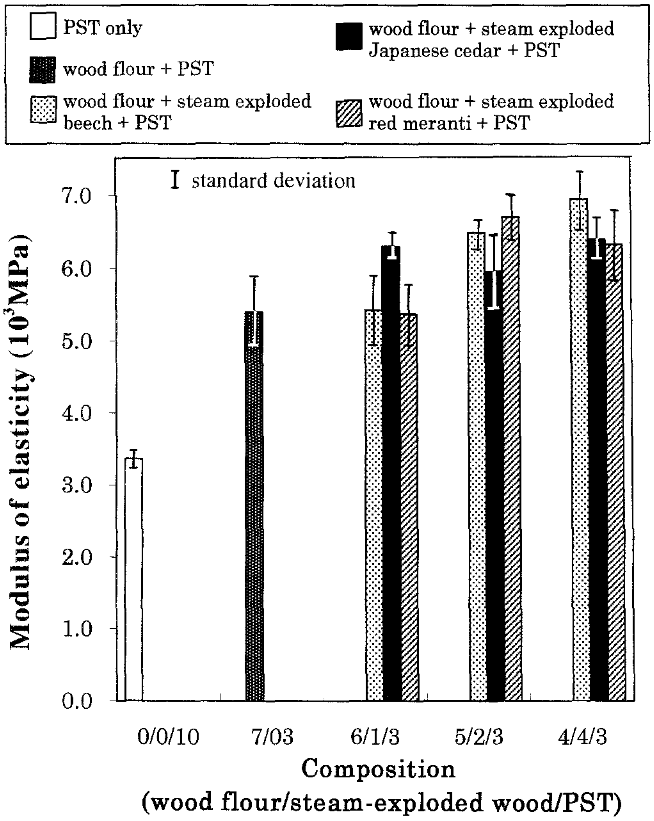

Fig. 4. Moduli of elasticity of wood flour/steam-exploded wood/polystyrene composites

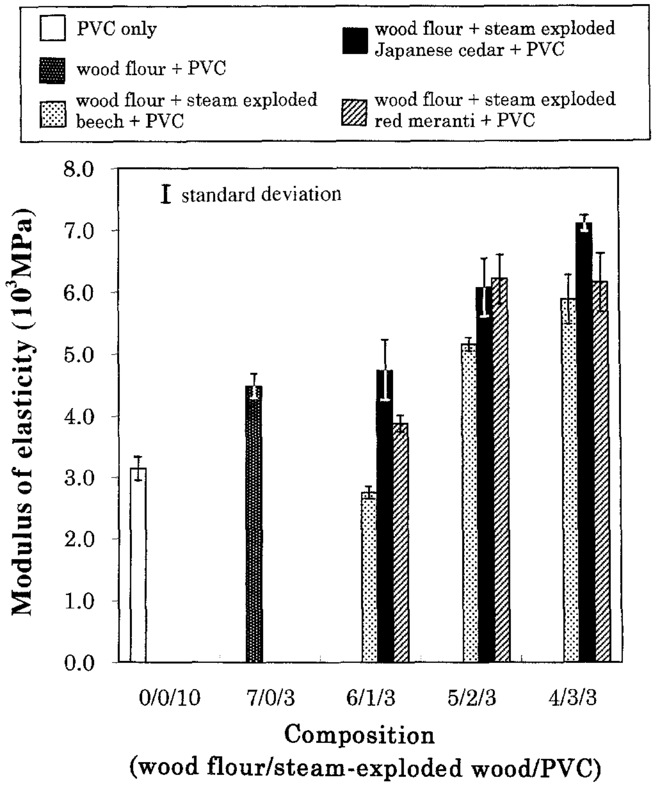

Fig. 6. Moduli of elasticity of wood flour/steam-exploded wood/poly(vinyl chloride) composites

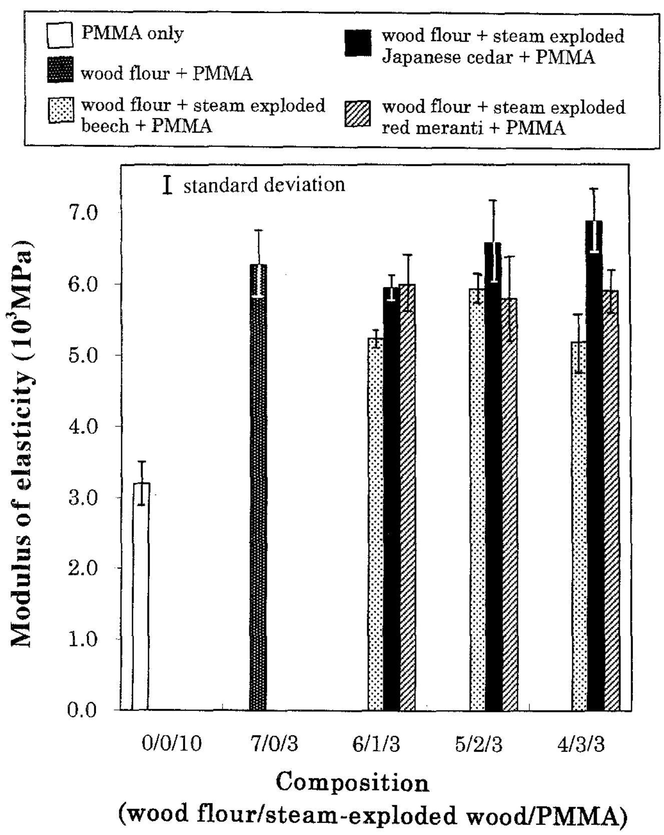

Fig. 5. Moduli of elasticity of wood flour/steam-exploded wood/poly(methyl methacrylate) composites

water resistance (thickness swelling and water absorption) was obtained at wood flour/SE ratios of 5/2, 4/3, and 4/3 for PST, PMMA, or PVC composite, respectively.

The characteristics of wood plastic composites using SE can be summarized as follows. The boards with the best performance were obtained with a wood flour/SE ratio of 5/2 for the PST composite, 4/3 for the PVC composite, and 6/1 or 5/2 for the PMMA composite. There was some effect of the SE wood species, but the influence was smaller than the effect of the polymer. In most cases, values for the maximum fracture strength and modulus were almost the same as those of the polymers themselves and scarcely exceeded them. It may be concluded at this point that the resulting composite has properties intermediate between wood and plastic polymers, and that the addition of SE makes the composite more plastic-like.

It is important to discuss here the effect of SE in the composite. As described above, wood and plastic are not expected to generate a strong mutual interactive force unless some special device improving the compatibility is applied. SE might behave as a compatibilizer with properties intermediate between the two components. However, according to our results[10] the performance of the composite board is poor when the density of the board is as low as 0.8–0.6. This result indicates that the effect of SE as a compatibilizer is not significant. Another effect of SE is based on its higher flowability at the press temperature. In the well known Masonite method of wood-based board production, a board of good performance is prepared when the final density of the board is 1.1–1.4.[8] It is well known that the performance of wood species is, in general, dependent on the density of the material: the higher the density, the better the performance in terms of fracture strength and so on. An increase in the density of the material would lead to greater interaction of components in the composite material. Judging from the results, the authors conclude that the effect of SE is based on the increased contact of the components of the composite at higher density.

Conclusions

Addition of steam-exploded wood flour to wood/plastic composites increased the fracture strength and water resistance of the resulting composite board to an extent mainly dependent on the polymer species used. The effect of the wood species was less significant.

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References

1. Takatani M, Fukumoto S, Fujita S, Yamazaki T, Hamada R, Kitayama T, Okamoto T (1998) Performance of phenol-formaldehyde based wood adhesives containing steam exploded beech four. Holzforschung 52:651–653
2. Wolcott MP (ed) (1993) Wood fiber/polymer composites. Madison, Forest Products Society, pp 1–134
3. Caufield DF, Rowell RM, Youngquist JA (eds) (1996) Wood fiber/polymer composites. Forest Products Society, Madison, pp 1–256
4. Rowell RM, Schultz TP, Narayan R (eds) (1992) Emerging technologies for materials and chemicals from biomass. American Chemical Society, Washington, DC, pp 1–451
5. Conner AH, Christiansen AW, Myers GE, River BH, Vick CB, Spelter HN (eds) (1991) Wood adhesives 1990. Forest Products Research Society, Madison, pp 163–190
6. Rowell RM, Cleary BA, Rowell JS, Clemons C, Young RA (1993) Results of chemical modification of lignocellulosic fibers for use in composites. In: Wolcott MP (ed) Wood fiber/polymer composites. Forest Products Society, Madison, pp 121–127
7. Narayan R (1992) Compatibilization of lignocellulosics with plastics. In: Rowell RM, Schultz TP, Narayan R (eds) Emerging technologies for materials and chemicals from biomass. American Chemical Society, Washington, DC, pp 57–75
8. Stamm AJ, Harris EE (1953) Chemical processing of wood. New York, Chemical Publishing Co, pp 360–362
9. Japanese Industrial Standard (1994) Particleboards, JIS A 5908 (in Japanese). Tokyo, Japan
10. Ito H (1996) BS thesis (in Japanese), Faculty of Agriculture, Kinki Daigaku University