Microscopic Interpretation on Thickness Swelling Mechanism of Nonwoven Web Composites from Wood Particles and Polypropylene Fibers

Shoo Geun Chae · Young Geun Eom

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ABSTRACT

Control particleboards were significantly higher in thickness swelling than wood particle-polypropylene fiber composites and their thickness swelling increased with the increase of target density. In the composites, thickness swelling did not vary significantly with the increase of target density but increased with the increase of wood particle content. And the composites with fine wood particles were significantly lower in thickness swelling than those with coarse wood particles irrespective of target density and formulation. In the scanning electron microscopy, significantly higher thickness swelling in the composites with coarse wood particles was thought to be the result of more interfacial separations by higher swelling stresses.

keywords: wood particle, polypropylene fiber, nonwoven web composite, thickness swelling

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1. INTRODUCTION

Internally and externally, wood and plastic wastes have been the subject of studies in the composite industry with the intention of solving wastes problem as well as furnishing raw materials. Till now, wood particles have rarely been discussed as the raw material in manufacturing composites with plastic wastes through the melt-blending technology, differently from wood fibers or flours. This may be attributed the facts that wood wastes can be more easily converted to fibers or flours and can be more uniformly distributed in the plastic matrix than particles.

Particles from wood wastes can be mixed without difficulty up to 90 weight percent in the nonwoven web composites, and performance of thermoplastic composites made using wood particle was reported to be superior to that of commercial particleboards (Wegner et al. 1992). In nonwoven web composites, thus, extensive studies are needed for more efficient use of wood particles.

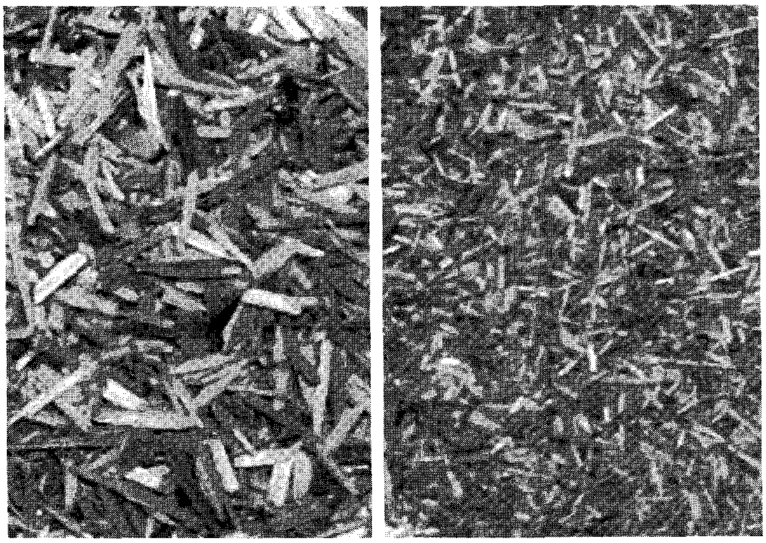
From this point of view, the effect of wood particle size on the thickness swelling, probably one of the most important properties, in the nonwoven web composites from wood particles of different sizes and polypropylene fibers was discussed in the present study.

2. MATERIALS AND METHODS

2–1 Materials

2-1-1 Wood particles for composites and control particleboards

Wood particles of acicular type for core layer of commercial three-layered particle-boards (Table 1) were used in manufacturing both wood particle-polypropylene fiber composites and control



〈Fig. 1〉 Coarse (left) and fine (right) wood particles.

particleboards. These wood particles consisting of slabs of sosna (*Pinus sylvestris*), municipal and construction wastes, and secondary mill residues were sized into coarse and fine particles by screens of 5, 8.2, and 20 mesh. Coarse wood particles referred to the elements caught between 5 and 8.2 mesh screen, and fine wood particles referred to those passing through 20 mesh screen (Figure 1). And these wood particles were dried to moisture content of about 3.8 to 4.2% and were kept in plastic bag for preventing moisture uptake.

2-1-2 Polypropylene fibers for composites

Deep green coloured polypropylene fibers (Table 1) were 1±0.1 ㎝ long and 3 denier with the melt flow index (MFI) of 25 g/10min. and 1% in moisture content. These fibers were kept in plastic bags for preventing moisture uptake.

According to hot pressing cycles

〈Table 1〉 Characteristics of wood particles and thermoplastic fibers.

Type	Characteristics
Wood Particle	· Origin : mixed particles -slabs of sosna (*Pinus sylvestris*) -secondary mill residues -construction wastes -municipal wastes · Type : for core layer · Moisture content -fine particles : 3.8% -coarse particles : 4% · Size & aspect ratio (length/diameter)[a] -fine particles : 5~8.2 mesh, 16.13 (9.61/0.65) -coarse particles : -20 mesh, 8.89 (13.97/1.70)
Polypropylene Fiber	· Melting temperature (T_m) : 170~175℃[b] · Denier : 3 · Melt flow index (MFI) : 25 g/10min · Moisture content : 1% · Length : 1±0.1 ㎝ · Density : 0.91 g/㎤ · Elongation : 30~50%[b] · Hygroscopicity : 0.01%[b] · Use : carpet, wear, sports wear, rope, packing material[b]

[a] Each mean from 100 measurements.

[b] Source from Kim (1995) and The Korean Fiber Society (1994).

established by preliminary experiments, composites were manufactured to reach the target densities as closely as possible. The higher pressure was applied in hot pressing composite mats with higher target density and wood particle content. Especially, 2-phase press cycle was applied in hot pressing composite mats with polypropylene fiber content of 50% because the excessive pressure made molten polypropylene fiber flow severely during the hot pressing and yield thinner composites than intended. In the first phase, thus, maximum pressure was applied to compress the mats to thickness of stops. Subsequently, pressure was reduced just for holding the mat at the intended thickness. Unloaded composites after hot pressing were cooled in a cold press at a room temperature to prevent the springback in thickness direction.

〈Table 2〉 Experimental design in manufacturing wood particle- polypropylene fiber composites.

Processing Variable			Manufacturing Condition				
			Hot pressing			Cooling	
Particle Size	Formulation (WP:PPF)[a]	Target Density (g/cm³)	Temp. (℃)	Time (min.)	Pressure (kgf/cm²)	Time (min.)	Pressure (kgf/cm²)
Coarse Particle	50:50	0.5	195	6	3.0	3	0.12
	60:40		195	6	4.5	3	0.30
	70:30		195	6	7.5	3	0.30
	50:50	0.6	195	6	6.0	3	0.12
	60:40		195	6	7.5	3	0.30
	70:30		195	6	12.0	3	0.30
	50:50	0.7	195	6	12.0	3	0.12
	60:40		195	6	15.0	3	0.30
	70:30		195	6	22.5	3	0.30
	50:50	0.8	195	6	22.5	3	0.12
	60:40		195	6	22.5	3	0.30
	70:30		195	6	30.0	3	0.30
Fine Particle	50:50	0.5	195	6	3.0	3	0.12
	60:40		195	6	4.5	3	0.30
	70:30		195	6	7.5	3	0.30
	50:50	0.6	195	6	6.0	3	0.12
	60:40		195	6	7.5	3	0.30
	70:30		195	6	12.0	3	0.30
	50:50	0.7	195	6	12.0	3	0.12
	60:40		195	6	15.0	3	0.30
	70:30		195	6	22.5	3	0.30
	50:50	0.8	195	6	22.5	3	0.12
	60:40		195	6	22.5	3	0.30
	70:30		195	6	30.0	3	0.30

[a] Based on oven-dry weight of wood particle (WP) and polypropylene fiber (PPF).

〈Table 3〉 Experimental design in manufacturing control particleboards.

Particle Size	Target Density (g/cm³)	Solids Content of Resin (%)	Resin Content[a] (%)	Mat Moisture Content (%)	Hot Pressing Condition Temperature (℃)	Time (min.)	Pressure (kgf/cm²)
Coarse Particle	0.5	60	10	10.7	150	5	7.5
	0.6	60	10	10.7	150	5	12.0
	0.7	60	10	10.7	150	5	22.5
	0.8	60	10	10.7	150	5	30.0
Fine Particle	0.5	60	10	10.7	150	5	7.5
	0.6	60	10	10.7	150	5	12.0
	0.7	60	10	10.7	150	5	22.5
	0.8	60	10	10.7	150	5	30.0

[a] Based on oven-dry weight of resin and wood particle.

2-2 Methods

2-2-1 Manufacturing composites

Wood particle-polypropylene fiber composites measuring 300 ㎜ long, 230 ㎜ wide, and 5 ㎜ thick were manufactured according to a completely randomized experimental design (Table 2).

Four composites by wood particle size, wood particle and polypropylene fiber formulation, and target density were manufactured for comparison with control particleboards. Wood particles and polypropylene fibers were first roughly mixed by hand and then evenly mixed for 50 to 60 seconds in a specially designed air mixer using turbulent air of 7 to 8 ㎏/㎠ in pressure. These mixtures were transferred and formed manually into mats in the forming frame, followed by hot pressing (Table 2).

2-2-2 Manufacturing control particleboards

Four single-layered control particleboards measuring 300 ㎜ long, 230 ㎜ wide, and 5 ㎜ thick were manufactured by particle size and target density for comparison with composites.

Manufacturing variables of control particleboards are shown in Table 3.

The urea-formaldehyde resin, which is used almost exclusively for particleboard manufacture, with solids content of 60% was used as a thermosetting adhesive. And ammonium chloride(NH_4Cl) in powder form was added as a hardener in the proportion of 1% based on solids weight of resin. As a water repellent, wax emulsion with solids content of 55% was incorporated in the resin at the level of 0.4%, based on the oven-dry weight of wood particles.

The prepared adhesive was applied to

wood particles in a glue mixer at the resin content of 10% on the basis of oven-dry weight. The manually formed mats in the forming frame were hot pressed at a temperature of 150℃ for 5 minutes. The hot pressing conditions are shown in Table 3. According to hot pressing cycles established by preliminary experiments, composites were manufactured to reach the target densities as closely as possible

2-2-3 Testing thickness swelling and scanning electron microscopy

For testing thickness swelling, four test specimens measuring 50 × 50 ㎜ were cut from each type of wood particle-polypropylene fiber composite and control particleboard, followed by immersion in water for 24 hours at a room temperature according to ASTM D 1037-93 (1995).

Through the scanning electron microscopy, the common edges between dry and wet specimens of composites were examined in thickness direction for detecting the change of internal structure such as the shape, distribution, and binding pattern of wood particles and molten polypropylene fibers. Here, the wet specimens mean those dried after thickness swelling test and the dry specimens mean those conditioned at a relative humidity (RH) of 65±1% and a temperature of 20±3℃ in conformance with ASTM D 1037-93 (1995).

The common edges for observation of internal structure were sputter-coated with a 50㎚ layer of gold using a JEOL JFC-1100E ion sputtering device and then viewed with a JEOL JSM 5410LV scanning electron microscopy (SEM) at an accelerating voltage of 20㎸.

2-2-4 Statical analysis

The measurements of thickness swelling were statistically analyzed using a Statistical Analysis System (SAS) program. In this study, the analysis of variance (ANOVA) was conducted through the use of a completely randomized design (CDR) for the test differences to investigate the effects of formulation, target density, and wood particle size. The significances of treated means were tested at a 95% significance level, and then compared by Tukey's and T-test methods.

3. RESULTS AND DISCUSSION

3–1 Thickness Swelling

The average thickness swelling of wood particle- polypropylene fiber composites and control paticleboards by formulation, target density, and particle size are given Figures 2 to 5.

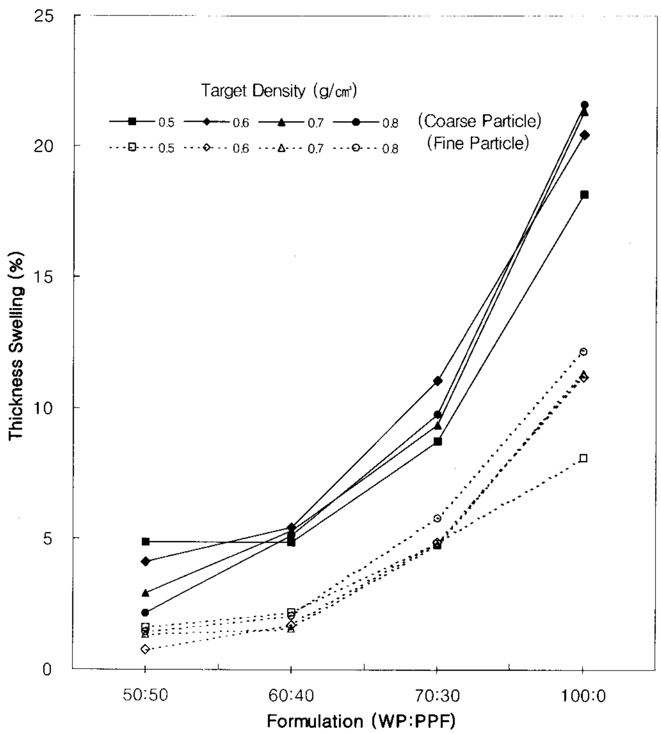
In thickness swelling of composites after 2-hours immersion in water, the effect of formulation appeared to be significantly higher than that of target density. And thickness swelling decreased with the increase of polypropylene fiber content but did not change with the variation of target density (Figures 2 to 5).

Lee (2000) explained that thickness

swelling in composites did not vary with the increase of target density due to the limited water uptake by the encapsulated wood particles with molten polypropylene fibers during hot pressing. Krzysik *et al.* (1991) reported that the composites underwent not only reversible swelling but also irreversible swelling in thickness direction by the release of residual compressive stresses imparted to the compressed products during hot pressing and could be a great problem in composites made from high percentages of wood fibers. Geimer *et al.* (1993) described that thickness swelling decreased significantly at polypropylene content levels above 40%, like the result in this experiment.

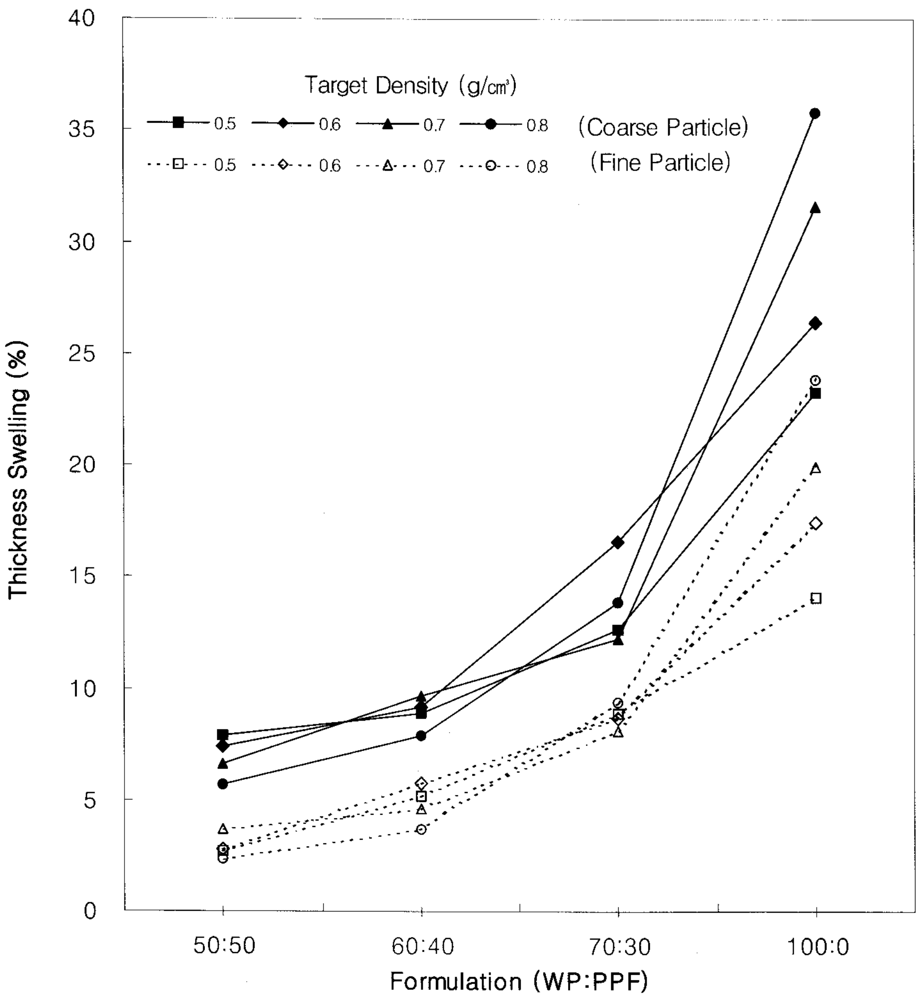
After 2 and 24 hours immersion in water, the composites with fine wood particles appeared to exhibit significantly lower thickness swelling than those with coarse wood particles irrespective of target density and formulation (Figures 2 to 5). This result was considered to be caused by the decreased water uptake and springback by smaller voids and lower swelling stresses in the composites with fine wood particles than in those with coarse wood particles.

Thickness swelling of control particleboards was higher than that of composites and increased with the increase of target density after 2 and 24 hours immersion (Figures 4 and 5) and this might be related to the larger amount of



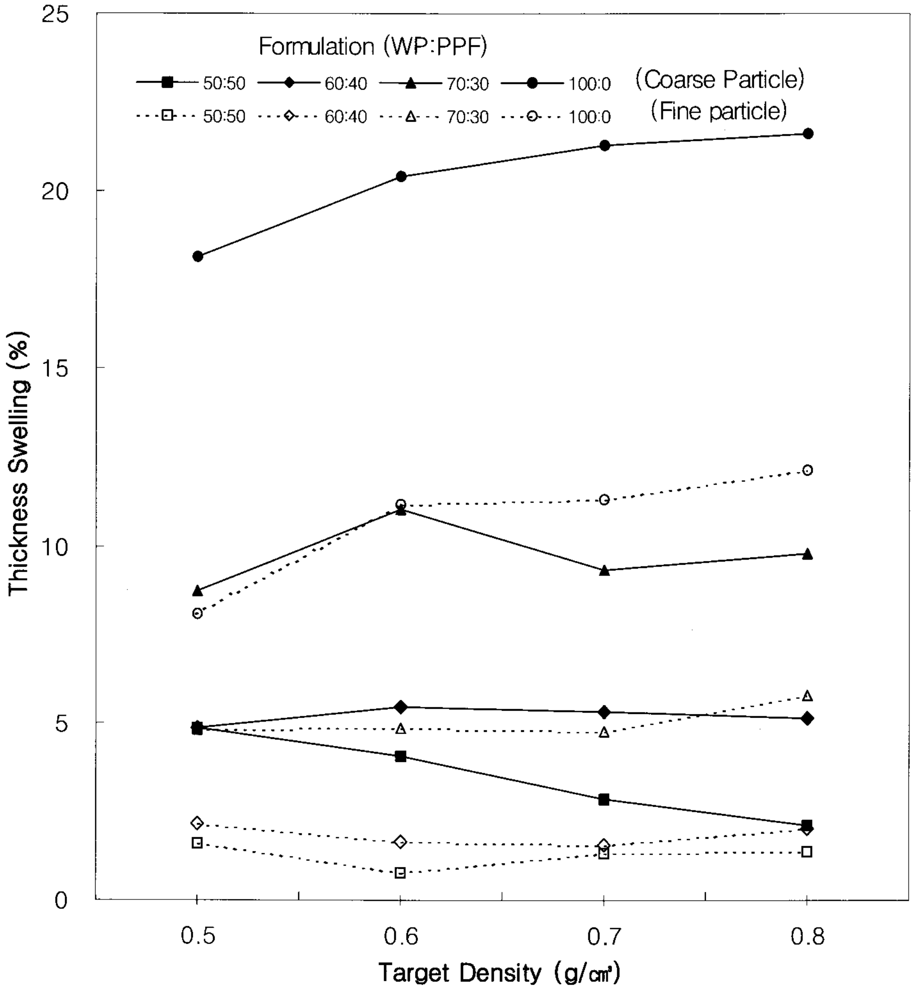
〈Fig. 2〉 Effect of formulation on thickness swelling of coarse and fine wood particle-polypropylene fiber composites after 2-hour immersion in water at room temperature. WP = wood particle; PPF = polypropylene fiber hydrophilic wood particles in the control particleboards. The contradictory result of less water absorption but greater thickness swelling observed in the control particleboards with higher density in present study might be due to greater springback resulting from the excessive built-up internal stresses by more wood particle content and compaction when exposed to liquid water.

In the effect of wood particle size, thickness swelling appeared to be significantly lower in particleboards with fine wood particles than in those with coarse wood particle (Figures 2 and 3), like the report by Duncan (1974). Similarly to the composites, this might be caused by the decreased water uptake and springback by smaller voids and lower swelling stresses in the control particleboards with fine wood particles than those with coarse wood particles. Geimer *et al.* (1975) described that dimensional stability was closely related to

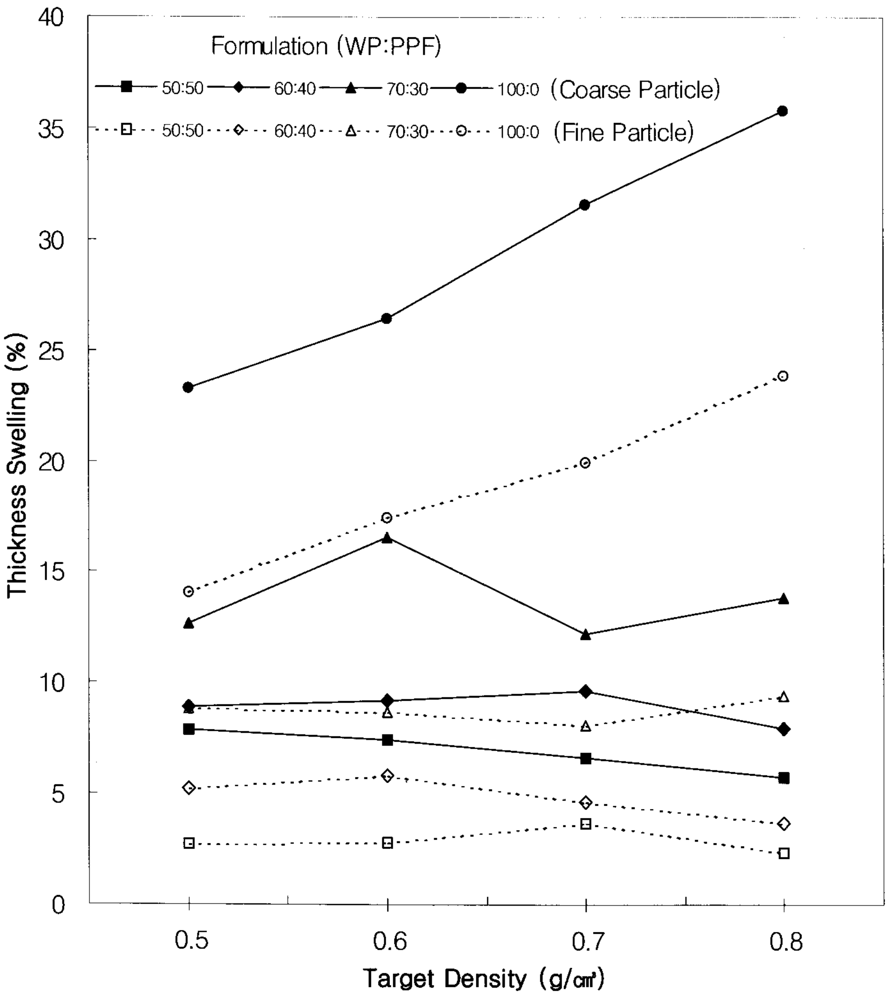


〈Fig. 3〉 Effect of formulation on thickness swelling of coarse and fine wood particle-polypropylene fiber composites after 24-hour immersion in water at room temperature. WP = wood particle; PPF = polypropylene fiber.

particle geometry with best thickness stability associated with smaller particles and best linear stability with larger particles. Kelly (1977) reported through literature review that better thickness stability was obtained in the boards produced from thin particles than those from thick particles. And he explained that the lower wood mass in each particle and increased number of particle-particle interfaces possibly allowed better dispersion of the hygroscopic swelling into the interparticle voids, resulting in less thickness swelling due to the swelling into the macroscopic board voids, not internal swelling within the wood particles.



〈Fig. 4〉 Effect of target density on thickness swelling of coarse and fine wood particle-polypropylene fiber composites after 2-hour immersion in water at room temperature. WP = wood particle; PPF = polypropylene fiber.



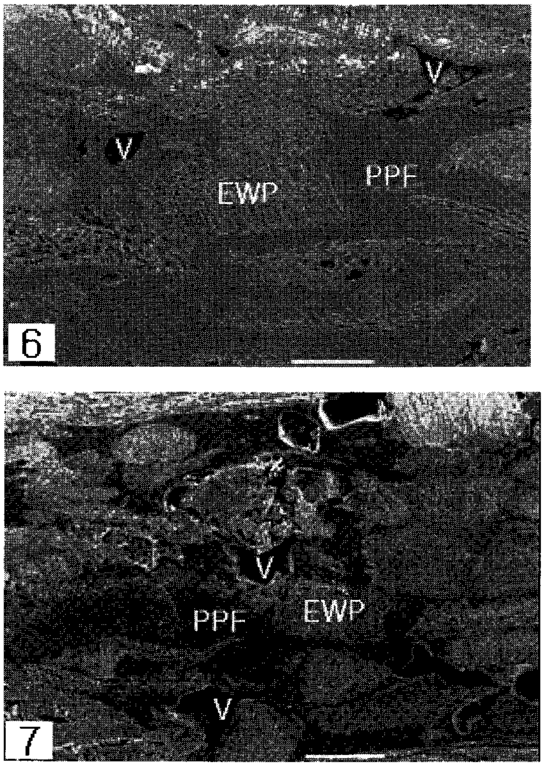
〈Fig. 5〉 Effect of target density on thickness swelling of coarse and fine wood particle-polypropylene fiber composites after 24-hour immersion in water at room temperature. WP = wood particle; PPF = polypropylene fiber.

3-2 Microscopic interpretation on thickness swelling mechanism

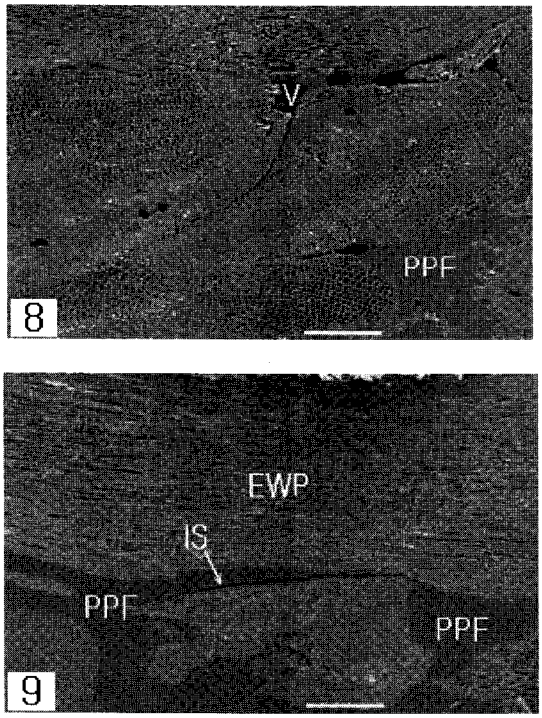
To elucidate the mechanism of thickness swelling in the composites through the observation of morphological changes of internal structures, the common edges of specimens before and after thickness swelling test by 24-hour immersion in water were used in the scanning electron microscopy.

Thickness swelling was not significantly varied with the increase of target density in the composites (Figure 5). This result was thought to be caused by the less water uptake by smaller void volume and more numerous wood particles encapsulated with molten polypropylene fibers in the composites with higher density, like the explanation by Eom and Yoon (1997) and Lee *et al.*(2002).

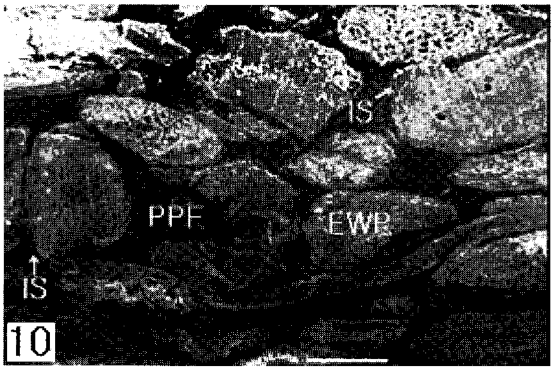
Thickness swelling, however, was significantly increased with the increase of wood particle content in the composites (Figure 4), like the results from wood fiber-polypropylene fiber composites (Kim and Eom 2002). This might be related to the increased water uptake and thickness swelling by more numerous voids unfilled with molten polypropylene fibers between wood particles in the composites with higher wood particle content. In the earlier research, Lee (2000) reported that higher thickness swelling in the composite with higher wood particle content and target density was caused by numerous voids and interfacial dislocation and explained that this dislocation happened by the greater stresses from swelling of compressed wood particles than the bond strength between polar wood and nonpolar plastic elements.

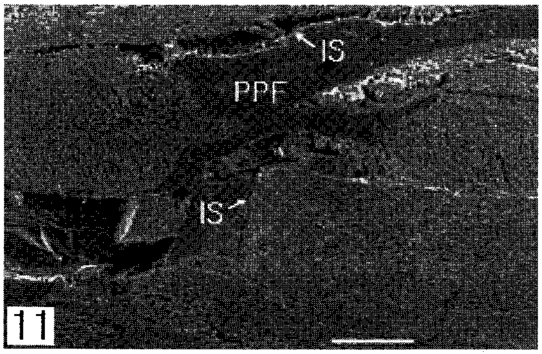


〈Figs. 6 and 7〉 Scanning electron micrographs showing internal structure of fine wood particle-polypropylene fiber composites with density of 0.7 g/㎤ under dry condition. -6: formulation 60:40. -7: formulation 70:30. PPF = molten polypropylene fiber; V = void; EWP = wood particle encapsulated by molten polypropylene fiber; Scale bars = 500 ㎛.



〈Figs. 8 and 9〉 Scanning electron micrographs showing internal structure of coarse wood particle-polypropylene fiber composites with density of 0.7 g/㎤ and polypropylene fiber content of 40%. -8: dry condition. -9: wet condition. PPF = molten polypropylene fiber; V = void; EWP = wood particle encapsulated by molten polypropylene fiber; IS = interfacial separation; Scale bars = 500 ㎛.





〈Figs. 10 and 11〉 Scanning electron micrographs showing internal structure of coarse and fine wood particle-polypropylene fiber composites under wet condition. -10: fine particles, density 0.8, and polypropylene fiber content 40%. -11: coarse particles, density 0.7, and polypropylene fiber content 30%. PPF = molten polypropylene fiber; EWP = wood particle encapsulated by molten polypropylene fiber; IS = interfacial separation; Scale bars = 500 ㎛.

Composites with coarse wood particles exhibited less layers of moisture barrier by molten polypropylene fibers than those with fine wood particles (Figures 6 to 9). This might cause significantly higher thickness swelling in the composites with coarse wood particles than those with fine wood particles (Figures 2 and 4). Also, occurrence of more stresses than the bond can withstand by the larger dimension of coarse wood particles was thought to be another reason of higher thickness swelling by more interfacial separation and higher springback (Figures 10 and 11).

4. LITERATURE CITED

1. American Society for Testing Materials. 1995. Standard test methods for evaluation properties of wood base fiber and particle panel materials. ASTM Designation: D 1037-93. Philadelphia, PA.
2. Duncan, T. F. 1974. Normal resin distribution in particleboard manufacture. For. Prod. J. 24(6): 36-44.
3. Eom, Y. G. and H. U. Yoon. 1997. Microscopic study on thickness swelling of nonwoven web composite. Forest and Humanity, Kookmin University

10(1): 117-129.

4. Geimer, R. L., W. F. Lehmann, and J. D. McNatt 1975. Engineering properties of structural particleboards from forest residues. In: Proceedings of the eight Washington State Univ.Symposium of Particleboard, March: 119-143.
5. Geimer, R. L., C. M. Clemons, and J. E. Wood, Jr. 1993. Density range of compression-molded polypropylene-wood composite. Wood and Fiber Sci. 25(2): 163-169.
6. Kelly, M. W. 1977. Critical literature review of relationship between processing parameters and physical properties of particleboard. General Technical Report FPL-10, Forest Products Laboratory, Madison, WI, USA: 20-22.
7. Kim, J. W. and Y. G. Eom. 2002. Microscopic interpretation of thickness swelling mechanism in wood fiber-polypropylene composite. Jour. Korean For. Sco. 91(2): 231-240.
8. Krzysik, A. M., J. A. Youngquist, G. E. Myers, I. S. Chahyadi, and P.C.Kolosick. 1991. Wood-polymer bonding in extruded and nonwoven composite panels. In: Proc. Symp. Wood Adhesives 1990-Wood/nonwood Composites. Conner, A.H., A.W.Christiansen, G. E. Myers, B. H. River, C. B. Vick, and H. N. Spelter, eds., USDA Forest Serv., Forest Products Laboratory, Madison, Wis.: 183-189.
9. Lee, C. H. 2000. Studies on manufacturing wood particle- polypropylene fiber composite panel. MS Thesis, Kookmin University, Seoul, Korea.
10. Lee, C. H., J. K. Cha, and Y. G. Eom. 2002. Studies on the thickness swelling mechanism of wood particle-polypropylene fiber composites by scanning electron microscopy. Mokchae Konghak 30(3): 48-58.
11. Wegner, T. H., J. A. Youngquist, and R. M. Rowell. 1992.Opportunities for composite from recycled wood based resources. In: Proceedings of Materials Research Society Symposium: Materials interactions relevant to recycling of wood-based materials. Rowell, R. M., T. L. Laufenberg, J. K. Rowell, eds., Material Research Society, Pittsburgh: 3-15.