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# Effects of Density, Resin and Particle Types on Properties of Composites from Wood Particle Mixed with Coating Paper[*1]

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## ABSTRACT

This research was carried out to investigate the effects of density, resin and particle types on the physical and mechanical properties of the composites made from various wood particles mixed with coating paper. The experiment was designed to apply with three particles (flake, chip, and fiber) and three resin types (urea, phenol and PMDI resin). The mixed ratio of coating paper to wood particle was fixed on 50 to 50% in each board making. And also it was designed to apply for four density levels (0.6, 0.7, 0.8 and 0.9 $g/cm^3$) and four mixed formulations of coating paper to wood particle (10:90, 20:80, 30:70, and 40:60 %) to analyze clearly the effects of PMDI resin.

Coating paper-wood particle composites have acceptable bending strength (MOR, MOE) though the mixed ratio of coating paper was increased, but have low internal bond strength and poor dimensional stability (WA, TS, LE). Composites with high density had higher mechanical properties but showed lower physical properties than composites with low density. In conclusion, at least up to 20% mixed ratios, coating paper-wood particle composites have acceptable physical and mechanical properties, and PMDI resin has possibility for coating paper-wood particle composite manufacture.

***Key words*** : Composites, Coating paper, Physical properties, Mechanical properties, Mixed ratios, Board densities, Resin types.

## INTRODUCTION

Traditionally, paper has been one of the most widely used printing and packing materials which means that significant amount of waste-paper are produced. And paper was a single-largest stream of materials in municipal solid waste (MSW).

In Korea in 1992 from the official data, nearly 2,325,500 ton are recovered and the rate was 44%. Recovery of paper for recycling has increased in recent years, but coating paper was difficult

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to recycling.

Primary limitations to greater use of the mixed grade of paper are those associated with deinking capability and contaminant removal

The use of waste papers as a raw materials for fiber-based products such as hardboard was explored by Auchter (1973). In addition, other materials such as bark-free aspen chips, pallets, dismantled railroad cars, and elm bolewood and branches from urban forests were evaluated as furnish for hardboard by Auchter (1973) and Laundrie and Mcnatt (1975) in the past.

Many boards exhibited problems with dimensional stability. Half of the boards did not have acceptable performance in linear expansion upon exposure to increased relative humidity as reported by Laundrie and Mcnatt (1975).

Steinmetz (1974) found that up to 50% of waste waxed corrugated boards could be used to make wet-formed hardboard, and that such furnish could increase internal bond, bending strength and stiffness, and reduce linear expansion.

Stokke and Liang (1991) studied to properties of panels made of 50 to 50% mixtures of shredded paper and wood flakes, hammermilled paper and wood particles, and shredded paper and thermomechanically pulped wood fibers. In general, such panels have acceptable bending properties (MOE and MOR) as compared to commercial products, but have low internal bond strength.

Thickness swelling performance varies, but is generally greater than 25 %. It was found that addition of secondary foamed polystyrene to hardboard may reduce thickness swelling.

Until now, Many studies investigated and evaluated properties of composite made from wood fiber mixed with waste paper. However, Studies on composite made from the mixture of wood particle and coating paper, were not investigated yet.

The aim of this experiment was to investigate the effects of resin types, wood particle types, mixed ratios of coating paper to wood particle, and board densities on the properties of composites from the wood particle mixed with coating paper.

## MATERIALS AND METHODS

### Materials

Wood flakes from lauan veneer, cut to 1mm thickness, wood particles from pallman chipper, screened 4 to 25 mesh, and wood fibers for medium-density fiberboard-grade were prepared.

Coating papers to the size of 1.5cm length and 0.3cm width were cut from the coating papers regardless of thicknesses.

They controlled to definite moisture content in the conditioning room for mat formation.

To manufacture test boards, PMDI resin, 90% solids content, which diluted with xylene solution, from O-kong Bond Inc., Korea, urea resin, 54% solids content and phenol resin, 40% solids content were used.

### Processing

Various process parameters of particle composites from wood particle mixed with coating paper listed in Table 1. The composites were manufactured by experiment schedules in the laboratory as Table 1.

Board sizes were 25 by 20 by 1cm in a small laboratory scale.

Blending of urea, phenol, PMDI resin used spraying in rotary drum blender. Aluminum foil between caul and mat used to prevent sticking problem between paltens in bonding PMDI resin.

### Test Methods

Mechanical (MOR, MOE, IB) and Physical (WA, LE, TS) testing were followed by Korean standards F 3104 (1984) and also all test specimens were conditioned to equilibrium moisture content at 60±3% relative humidities and 20±1℃ temperatures before test.

The physical and mechanical properties tested

**Table 1.** Conditions of manufacturing variables in composites from wood particle mixed with coating paper

| Variables | Types or Levels | Manufacturing schedules |
|---|---|---|
| Wood Particles | Flake, Chip, Fiber | Mixed ratio 50:50, Resin additive content 10%(Urea), 5%(Phenol), 3%(PMDI), Board densities 0.7g/cm$^3$, Press temp. 150℃, Press pressure 35kgf/cm$^2$, Press time 20sec./mm(Urea), 30sec./mm(Urea), 15sec./mm(PMDI) |
| Resin | Urea, Phenol, PMDI | Mixed ratio 50:50, Resin additive content 10%(Urea), 5%(Phenol), 3%(PMDI), Board densities 0.7g/cm$^3$, Press temp. 150℃, Press pressure 35kgf/cm$^2$, Press time 20sec./mm(Urea), 30sec./mm(Phenol), 15sec./mm(PMDI) |
| Mixed ratio (coating paper: wood particle) | 10:90, 20:80, 30:70, 40:60 | Resin additive content 3%(PMDI), Press temp. 150℃, Press pressure 35kgf/cm$^2$, Press time 20sec./mm |
| Board densities (g/cm$^3$) | 0.6, 0.7, 0.8, 0.9 | Resin additive content 3%(PMDI), Press temp. 150℃, Press pressure 35kgf/cm$^2$, (0.6, 0.7 board density), 40kgf/cm$^2$(0.8, 0.9 board density), Press time 20sec./mm |

and measured for 8 replications from each trial of levels.

## RESULTS AND DISCUSSION

### Effects of Wood particle and Resin types

#### Physical Properties

Table 2 contains the results of tested physical properties of coating paper-wood particle composites according to wood particle and resin types.

The ranges of board densities of coating paper-wood particle composites and control boards were 0.71~0.83g/cm$^3$ and 0.67~0.74g/cm$^3$, respectively. And also the ranges of moisture contents of these composites and control boards were shown 6.83~10.9%.

Water absorption and thickness swelling of coating paper-wood particle composites were 36.8~109.4%, and 18.7~51.9%, respectively, and those of control boards were 23~114%, and 8.7~40.4%.

In all types of resins, water absorption and thickness swelling of coating paper-wood particle composites were generally higher than those of control boards.

This result indicates in the before studies by Laundrie and Mcnatt (1975) and Stokke and Liang (1991), that dimensional stabilities of waste paper-wood fiber board were less than control board. We obtained same results and tendencies with these studies.

But, coating paper-wood flake composite applied to PMDI resin in this study had similar values to control board. According to previous studies about PMDI by Chelak and Newman (1991), and Hawke *et al.* (1993), PMDI resin had excellent dimensional properties. These properties of PMDI demonstrated the possibility in bonding between coating paper and wood particle compared with phenol or urea resin.

#### Mechanical Properties

Table 3 contains the results tested mechanical properties of coating paper-wood particle composites according to wood particle and resin types.

From the results, MOR and MOE of coating paper-wood particle composites were 83~237 kgf/cm$^2$, and 18.4~44.9tonf/cm$^2$, respectively, and those of control boards were 159~376kgf/cm$^2$, and 21.1~43.2tonf/cm$^2$.

Though these results are more lower than control boards, bending strengths of the coating paper-wood flake composites and the coating paper-wood chip composites applied to PMDI resin or phenol resin were similar to those of

**Table 2.** Physical properties of coating paper-wood particle composites according to wood particle and resin type

| Particle type | Waste paper | Resin | Density[a] (g/cm³) | MC[b] (%) | WA (%) | | TS (%) | |
|---|---|---|---|---|---|---|---|---|
| Flake | Coating paper | PMDI | 0.76 | 9.81 | 36.73 | BCD[c] | 18.68 | DE |
| | | Urea | 0.72 | 9.56 | 54.04 | ABC | 43.75 | B |
| | | Phenol | 0.83 | 9.93 | 75.26 | A | 42.83 | B |
| | Control | PMDI | 0.68 | 8.82 | 30.80 | BCD | 38.69 | EF |
| | | Urea | 0.68 | 9.02 | 50.72 | DBC | 22.96 | F |
| | | Phenol | 0.72 | 9.06 | 84.17 | AB | 56.42 | C |
| Chip | Coating paper | PMDI | 0.77 | 7.74 | 79.19 | CD | 79.19 | CD |
| | | Urea | 0.71 | 7.53 | 67.99 | DEF | 67.99 | D |
| | | Phenol | 0.76 | 8.21 | 94.73 | B | 94.73 | B |
| | Control | PMDI | 0.71 | 9.74 | 72.84 | CDE | 72.84 | D |
| | | Urea | 0.67 | 9.46 | 57.21 | F | 57.21 | E |
| | | Phenol | 0.70 | 10.20 | 84.52 | BC | 84.52 | CD |
| Fiber | Coating paper | PMDI | 0.74 | 6.83 | 80.82 | C | 80.82 | CDE |
| | | Urea | 0.72 | 7.32 | 83.90 | C | 83.90 | DE |
| | | Phenol | 0.71 | 8.22 | 109.40 | AB | 109.40 | BC |
| | Control | PMDI | 0.74 | 10.90 | 65.09 | C | 65.09 | E |
| | | Urea | 0.67 | 9.36 | 86.85 | BC | 86.85 | DE |
| | | Phenol | 0.73 | 9.88 | 114.33 | A | 114.33 | AB |

Notes ; [a] based on oven-dry volume
[b] based on oven-dry weight
[c] mean with the same letter is not significantly different at the 5 percent level from Tukey's test.

**Table 3.** Mechanical properties of composites from wood particle mixed with coating paper by wood particle and resin type

| Particle type | Waste paper | Resin | MOR (kgf/cm²) | | MOE (tonf/cm²) | | IB (kgf/cm²) | |
|---|---|---|---|---|---|---|---|---|
| Flake | Coating paper | PMDI | 237 | BC* | 44.9 | A | 5.5 | A |
| | | Urea | 83 | E | 18.4 | C | 0.4 | D |
| | | Phenol | 181 | D | 35.5 | B | 4.9 | AB |
| | Control | PMDI | 263 | AB | 43.3 | A | 4.6 | ABC |
| | | Urea | 295 | A | 43.2 | A | 4.9 | AB |
| | | Phenol | 249 | ABC | 39.7 | AB | 5.1 | AB |
| Chip | Coating paper | PMDI | 192 | BC | 28.8 | B | 5.4 | CD |
| | | Urea | 146 | C | 26.3 | BC | 3.6 | D |
| | | Phenol | 154 | C | 25.5 | BC | 3.7 | D |
| | Control | PMDI | 225 | B | 28.2 | B | 12.8 | B |
| | | Urea | 221 | B | 28.2 | B | 17.1 | A |
| | | Phenol | 166 | C | 21.5 | C | 7.6 | C |
| Fiber | Coating paper | PMDI | 189 | C | 28.7 | ABC | 1.4 | BC |
| | | Urea | 187 | C | 28.3 | BC | 1.4 | BC |
| | | Phenol | 111 | D | 18.8 | D | 0.8 | C |
| | Control | PMDI | 376 | A | 32.7 | A | 4.1 | A |
| | | Urea | 181 | C | 25.7 | C | 0.8 | C |
| | | Phenol | 159 | C | 21.1 | D | 0.4 | C |

Notes ; * mean with the same letter is not significantly different at the 5 percent level from Tukey's test.

control board.

Compare with results reported by Stokke and Liang (1991), except coating paper-wood flake boards, the values of bending properties applied to particle type coating paper in our study were similar to those of shredded or hammermilled paper-wood particle composite.

Internal bond strengths of coating paper-wood particle composites were 0.4~5.5kgf/cm$^2$, and these of control boards were 0.4~17.1kgf/cm$^2$. Internal bond strength of coating paper-wood particle composite was generally lower than that of control board in all types of resins.

This result reported already by Deppe (1985), Stokke and Liang (1991) and Kryzysik et al. (1993) that internal bond strengths of waste paper-wood fiber mixed board were less than those of control board.

But in our study coating paper-wood flake composite applied to PMDI resin had higher internal bond strength than that of control board. This is due to the effect of PMDI resin bonding. And then we think that in bonding wood particle and coating materials, PMDI resin effectively affected.

These results indicates possibility of PMDI resin using in coating paper-wood particle composite manufacture.

## Effects of Mixed ratio and Board density in PMDI resin application

### Physical Properties

Table 4 contains the results tested physical

**Table 4.** Physical properties of composites from wood particle mixed with coating paper by mixed ratios and board densities in PMDI resin application

| Board Density (g/cm$^3$) | Coating Paper/ Wood particle | Density[a] (g/cm$^3$) | MC[b] (%) | LE (%) | | TS (%) | | WA (%) | |
|---|---|---|---|---|---|---|---|---|---|
| 0.6 | 0:100 | 0.57 | 10.70 | 0.50 | B[c] | 17.45 | C | 53.41 | B |
| | 10:90 | 0.58 | 10.34 | 0.69 | AB | 25.05 | B | 75.10 | A |
| | 20:80 | 0.60 | 10.01 | 0.69 | AB | 30.45 | A | 76.81 | A |
| | 30:70 | 0.62 | 9.52 | 0.71 | A | 29.24 | AB | 71.73 | A |
| | 40:60 | 0.61 | 9.31 | 0.73 | A | 29.36 | AB | 74.16 | A |
| 0.7 | 0:100 | 0.68 | 10.94 | 0.81 | B | 34.20 | B | 61.53 | C |
| | 10:90 | 0.67 | 10.00 | 0.95 | A | 37.69 | A | 75.79 | AB |
| | 20:80 | 0.70 | 9.34 | 0.87 | AB | 41.71 | A | 80.93 | A |
| | 30:70 | 0.70 | 8.83 | 1.01 | A | 35.90 | A | 74.12 | AB |
| | 40:60 | 0.69 | 8.59 | 0.93 | A | 36.82 | A | 71.52 | B |
| 0.8 | 0:100 | 0.77 | 9.92 | 0.92 | A | 34.77 | C | 67.29 | B |
| | 10:90 | 0.77 | 9.65 | 1.04 | A | 38.83 | BC | 75.08 | AB |
| | 20:80 | 0.79 | 9.15 | 1.08 | A | 44.83 | A | 79.44 | A |
| | 30:70 | 0.81 | 8.94 | 1.00 | A | 43.10 | AB | 76.28 | AB |
| | 40:60 | 0.80 | 8.38 | 0.95 | A | 38.66 | BC | 74.61 | AB |
| 0.9 | 0:100 | 0.85 | 10.00 | 1.05 | A | 43.95 | B | 68.52 | A |
| | 10:90 | 0.86 | 8.84 | 1.07 | A | 44.06 | B | 76.88 | A |
| | 20:80 | 0.90 | 9.09 | 1.10 | A | 47.21 | AB | 80.45 | A |
| | 30:70 | 0.92 | 8.78 | 1.21 | A | 51.07 | A | 77.70 | A |
| | 40:60 | 0.89 | 8.37 | 1.25 | A | 49.59 | AB | 75.37 | A |

Notes ; [a] based on oven-dry volume

[b] based on oven-dry weight

[c] mean with the same letter is not significantly different at the 5 percent level from Tukey's test.

properties of coating paper-wood particle composites according to the board densities and the mixed ratios of coating paper to wood particle applied to PMDI resin.

The ranges of board densities of coating paper-wood particle composites by target density levels 0.6, 0.7, 0.8, and 0.9g/cm$^3$ were obtained 0.58~0.62 g/cm$^3$, 0.67~0.7g/cm$^3$, 0.77~0.81g/cm$^3$, and 0.86~0.92g/cm$^3$, respectively. Board densities of control boards by density levels were 0.57, 0.68, 0.77, and 0.85g/cm$^3$, respectively as shown in Table 4.

The ranges of moisture contents in both of the coating paper-wood particle composites and the control boards were 8.37~10.94%.

As the increase of the mixed ratio of coating paper to wood particle in the range from 0 to 20%, water absorption was shown increasing tendency but decreased in the range from 30 to 40%. Thickness swelling and linear expansion of composites were increased as accordance with the increase of the mixed ratio of coating paper.

These results coincides with Marcin *et al.* (1992) and Rowell and Harrison (1992), which dimensional stabilities of waste paper-wood fiber board were less than control board.

But, the difference of values of dimensional stabilities among the coating paper-wood particle composites have not significance at 95% confidence level.

As the increase of board densities of composites, water absorption, thickness swelling, and linear expansion were increased.

This is similar to the result for commercial particle board, which as increasing of board densities of particleboards, thickness swelling were increased as reported by Gatchell et (1966), Halligen and Schniewind (1972), and Hse (1975).

**Table 5.** Mechanical properties of composites from wood particle mixed with coating paper by mixed ratio and board density in PMDI resin application

| Board Density (g/cm$^3$) | Coating Paper/ Wood particle | MOR (kgf/cm$^2$) | | MOE (kgf/cm$^2$) | | IB (kgf/cm$^2$) | |
|---|---|---|---|---|---|---|---|
| 0.6 | 0:100 | 169 | A* | 22.8 | A | 6.86 | A |
| | 10:90 | 144 | AB | 20.6 | AB | 6.47 | AB |
| | 20:80 | 120 | BC | 18.9 | BC | 5.84 | ABC |
| | 30:70 | 118 | BC | 17.2 | C | 4.03 | BC |
| | 40:60 | 109 | C | 16.7 | C | 3.68 | C |
| 0.7 | 0:100 | 191 | A | 26.1 | A | 8.71 | A |
| | 10:90 | 174 | AB | 25.5 | A | 7.73 | AB |
| | 20:80 | 174 | AB | 25.1 | A | 6.45 | BC |
| | 30:70 | 168 | AB | 25.0 | A | 5.94 | BC |
| | 40:60 | 157 | B | 23.7 | A | 4.91 | C |
| 0.8 | 0:100 | 272 | A | 34.4 | A | 10.23 | A |
| | 10:90 | 253 | AB | 33.8 | A | 7.86 | AB |
| | 20:80 | 240 | AB | 33.7 | A | 7.58 | AB |
| | 30:70 | 233 | B | 33.3 | A | 6.78 | B |
| | 40:60 | 226 | B | 33.1 | A | 6.35 | B |
| 0.9 | 0:100 | 293 | A | 35.6 | A | 13.45 | A |
| | 10:90 | 287 | AB | 35.1 | A | 10.09 | B |
| | 20:80 | 286 | AB | 35.0 | A | 7.83 | BC |
| | 30:70 | 272 | AB | 34.8 | A | 6.98 | C |
| | 40:60 | 252 | B | 34.3 | A | 6.71 | C |

Notes ; * mean with the same letter is not significantly different at the 5 percent level from Tukey's test.

### Mechanical Properties

Table 5 contains the results tested mechanical properties of coating paper-wood particle composites according to the board densities and mixed ratios of coating paper to wood particle applied to PMDI resin.

From the results as the mixed ratios of coating paper were increased, bending (MOR, MOE) and internal bond strength were shown decreasing tendency, but not significantly different between decreasing values of MOR or between MOE values in mechanical properties. These tendencies were similar to the studies by Rowell *et al.* (1991), and Krzysik *et al.* (1992).

Compared with the properties requirements of 150 type particle board in KS F 3104 (minimum MOR = 130kgf/cm$^2$, minimum MOE = 20tonf/cm$^2$), the coating paper-wood particle composites, except the composites of 0.6g/cm$^3$ density with 30 to 40% mixed ratios, had higher MOR and MOE. Though IB of coating paper-wood particle composites were lower than control boards, except the density of 0.6g/cm$^3$ composites with 30 to 40% mixed ratios, the values of IB were higher than property requirements of 200 type particle board in KS F 3104 (minimum 5kgf/cm$^2$).

As the increase of board densities of composites, bending and internal bond strength were increased. This is similar to the tendency for commercial particle board, which as increasing of board densities of particleboards, bending strengths were increased as reported by Stewart and Lehmann (1973), and Vital *et al.* (1974).

## CONCLUSION

From the above results and discussion it may be concluded as follows;

In general, coating paper-wood particle composites applied to PMDI resin had acceptable bending strength (MOR, MOE) as compared with control board. In internal bond strength and dimensional stability, coating paper-wood flake composite applied to PMDI resin was generally superior than those of composites applied to urea or phenol resin.

Coating paper-wood particle composite have acceptable bending strength (MOR, MOE) though the mixed ratio of coating paper was increased, but have low internal bond strength and poor dimensional stability (WA, TS, LE). Composites with high density had higher mechanical properties but showed lower physical properties than composites with low density.

In conclusion, at least up to 20% mixed ratios, coating paper-wood particle composites has acceptable physical and mechanical properties, and PMDI resin has possibility for coating paper-wood particle composite manufacture.

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