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Some Physical and Chemical Properties of Carbonized Wood Wastes(II)*1

Byung-Ro Kim*2 · Akiyoshi Mishiro*3

ABSTRACT

A total of forty five-ply, 30- by 30-cm lauan and larch plywood sheets were manufactured in the laboratory using commercial urea and phenol resin adhesives; half of these sheets were treated with fresh concrete. Each sheet was carbonized for 2, 4, and 6hours at 400℃, 600℃, and 750℃, respectively, and their physical properties were measured. The yield of charcoal decreased as carbonization temperature and time increased. Charcoal yield was greater in plywood than in veneer, and slightly greater in plywood treated with concrete compared to untreated plywood. Plywood manufactured with phenol resin adhesive had higher pH, higher equilibrium moisture content (EMC), and greater adsorption of methylene-blue dye compared to plywood manufactured with urea resin. For concrete-treated plywood, pH was greater than 10 even when the sheets were carbonized for 2hours at 400℃. Although the EMC of the phenol resin plywood was higher than that of the urea resin plywood, EMC of the phenol resin was lower than that of the urea resin. The larch phenol resin plywood that was carbonized for 6 hours at 750℃ adsorbed more methylene-blue than did the commercial wood-based activated charcoal as a result of total pore volume and surface area.

Keywords : Waste wood, carbonization, carbon materials, Shorea sp., Larix dahurica, pore size, adsorption, methylene-blue

1. INTRODUCTION

Wastewood from demolished buildings, construction works, and goods distribution bases is regarded as rubbish. Most wastewood is incinerated or dumped in landfill sites, which causes various forms of environmental pollution such as generation of carbon dioxide, and various detrimental substances, and creates a shortage of ground for landfills. Wastewood could be a precious resources if it were reduced in weight and volume by carbonization, turning it into more safe and stable materials. Recently, charcoal has been widely used as a soil conditioner in agriculture, a to purify lake water, and as a humidity-controlling agent in housing. Utilization of wastewood as carbon materials may contribute to preserving and purifying the global environment.

Many studies have been conducted on anatomical, physical, and adsorptive properties of charcoal produced from wood (Abe, 1996; Abe *et al.*, 1996; Blankenhorn *et al.*, 1978; Cutter *et al.*, 1980; Hitom *et al.*, 1993a,b; McGinners *et al.*, 1971; Moore *et al.*, 1974; Parameswaran & Stamm, 1983). How-

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*2 College of Agriculture, Chungbuk National University, Cheongju 361-763, Korea
*3 Faculty of Agriculture, Niigata University, Niigata 950-21, Japan

ever, very few studies have been conducted on the physical and chemical properties of charcoal from wastewood (Ishihara, 1966).

In the present study, some physical and chemical properties of carbonized materials from plywood and used concrete form plywood were examined.

2. MATERIALS & METHODS

2.1 Manufacture of veneer

The rotary veneers of lauan (*Shorea* sp. 2.6mm thick) and larch (*Larix dahurica* 1.8mm thick) were prepared, using commercial urea formaldehyde resin and phenol formaldehyde resin adhesives (Oshika Ltd.).

2.1.1 Adhesives and spreading of glue

The components of urea resin and phenol resin adhesives were as follows (part by weight): urea resin (100), wheat flour (20), water (10), and NH_4CI (2); phenol resin (100), wheat flour (10), and water (5). The glue spread was 17.5g per glue line for 900cm^2.

2.1.2 Pressing conditions

Cold pressing was conducted under 10kg/cm^2 pressure for 20 minutes. For urea resin adhesive, hot pressing was also conducted under 10kg/cm^2 pressure at 120℃; lauan plywood (13mm) was pressed for 8 minutes and larch plywood (9mm) for 6minutes. For phenol resin adhesive, pressing was conducted under 10kg/cm^2 pressure at 145℃; lauan plywood was pressed for 8minutes and larch plywood for 6 minutes.

A total of 40 sheets of five-ply plywood, 30 by 30cm, were made from each veneer and each adhesive. Half of the plywood was treated with fresh concrete and stored for a week. The hardened concrete was then removed from the plywood; this plywood was designated as used concrete form plywood. The plywood and the used concrete form plywood were cut into 3- by 5-cm sections and carbonized.

2.1.3 Carbonization

The carbonization apparatus consisted of an electric furnace controlled by a heating and cooling temperature program. The carbonizing chamber was 29cm (inside diameter) by 30cm (height). The specimens were set in a stainless steel holder and placed in the center of the carbonizing chamber. Temperature was measured using a recorder with an AL/CT thermocouple positioned while the specimens were inside the furnace.

The carbonization conditions were as follows:

Carbonization temperature (°C)	Carbonization times (hrs)
400	2, 4 and 6
600	2, 4 and 6
750	2, 4 and 6

After carbonization, the furnace was turned off; the specimens were allowed to cool naturally in the furnace for about a day and were then weighed.

Table 1 shows the materials used, their abbreviated forms and their air-dried densities. The veneers and plywood from Larch have higher densities than Lauan veneers and plywood.

Table 1. Materials used and their air-dried densities.

Materials	Air-dried density
Plywood : *Shorea* sp. : Phenol resin (P-S-P)	0.53
Plywood : *Shorea* sp. : Ureal resin (P-S-U)	0.53
Plywood : *L. Dahurica* : Phenol resin (P-D-P)	0.70
Plywood : *L. Dahurica* : Urea resin (P-D-U)	0.68
Concreate-panel-plywood : *Shorea* sp. : Phenol resin (CP-S-P)	0.55
Concreate-panel-plywood : *Shorea* sp. : Urea resin (CP-S-U)	0.55
Concreate-panel-Plywood : *L. Dahurica* : Phenol resin (CP-D-P)	0.69
Concreate-panel-Plywood : *L. Dahurica* : Urea resin (CP-D-U)	0.70
Wood : *Shorea* sp. (W-S)	0.44
Wood : *L. Dahurica* (W-L)	0.55

2.1.4 Preparation of charcoal powder sample

The carbonized product (charcoal) was powdered with a mortar and pestle. Powder passed

through a 60-mesh screen was used for measurements. The commercial wood-based activated charcoal (Fujisawa Medical Supplies) was used for comparison.

2.1.5 Physical characterization of carbonized materials

The pH, equilibrium moisture content (EMC) at 20℃, and relative humidity (RH 65%), and amount of adsorption of methylene-blue dye of carbonized materials were measured. The measurement of pH and adsorption test of methylene-blue were made according to Japan Industrial Standard JIS K 1770 (Testing method for activated charcoal, 1967). The specific surface area, pore volume, and pore size distribution were determined. Micropore measurements were made with nitrogen gas by the gas adsorption method using an Autosorb-l-MP (Yuasa Ionics Co. Ltd). Pore size distribution was measured by mercury using a Poresizer-9310 (Micrometrics Co. Ltd).

3. RESULTS & DISCUSSION

3.1 Charcoal yield

The relationship between charcoal yield and carbonization temperature and time for phenol resin plywood from lauan is shown in Fig. 1. Charcoal yield decreased as carbonization temperature and time increased. Charcoal yield was slightly greater from plywood than from veneer. Charcoal yield from the used concrete form plywood was slightly greater than that from plywood. At the carbonization temperature of 400℃, yield from both lauan and larch phenol resin plywood was greater than that from urea resin plywood; however, no apparent difference was found between these woods at 600 ℃ and 750℃.

The relationship between charcoal yield and carbonization temperature (carbonization time was 4 hours) for urea resin, phenol resin, and concrete is shown in Fig. 2. Charcoal yield from phenol resin (30% to 48%) was about twice that from urea resin (14% to 26%). Yield from concrete was 92% to 98%. Charcoal yield from urea and phenol resins was greater than that from veneer, which explains why charcoal yield was greater from plywood than from veneer. Ito *et al.* (1997) also reported that wood impregnated with phenol resin had greater charcoal yield than unimpregnated wood at carbonization temperature of 400℃ to 500℃.

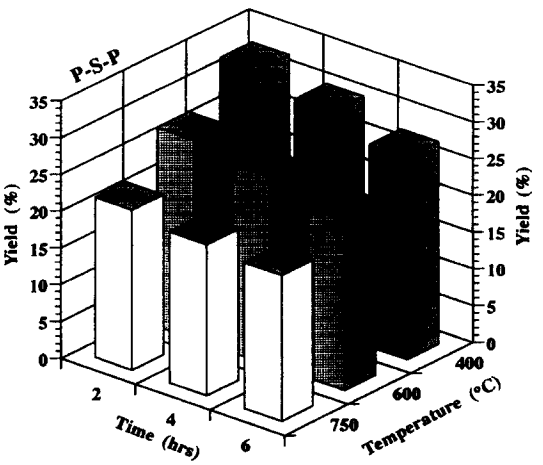

Fig. 1. Relationship between yield and carbonization temperature and time for phenol resin plywood from *Shorea* sp.(P-S-P).

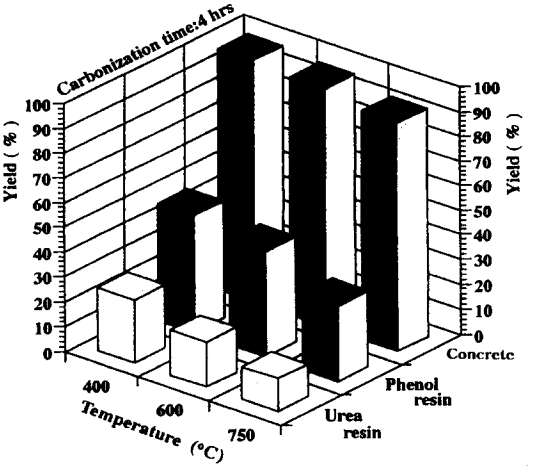

Fig. 2. Relationship between yield and carbonization temperature for phenol resin, urea resin and concrete(Time : 4 hours).

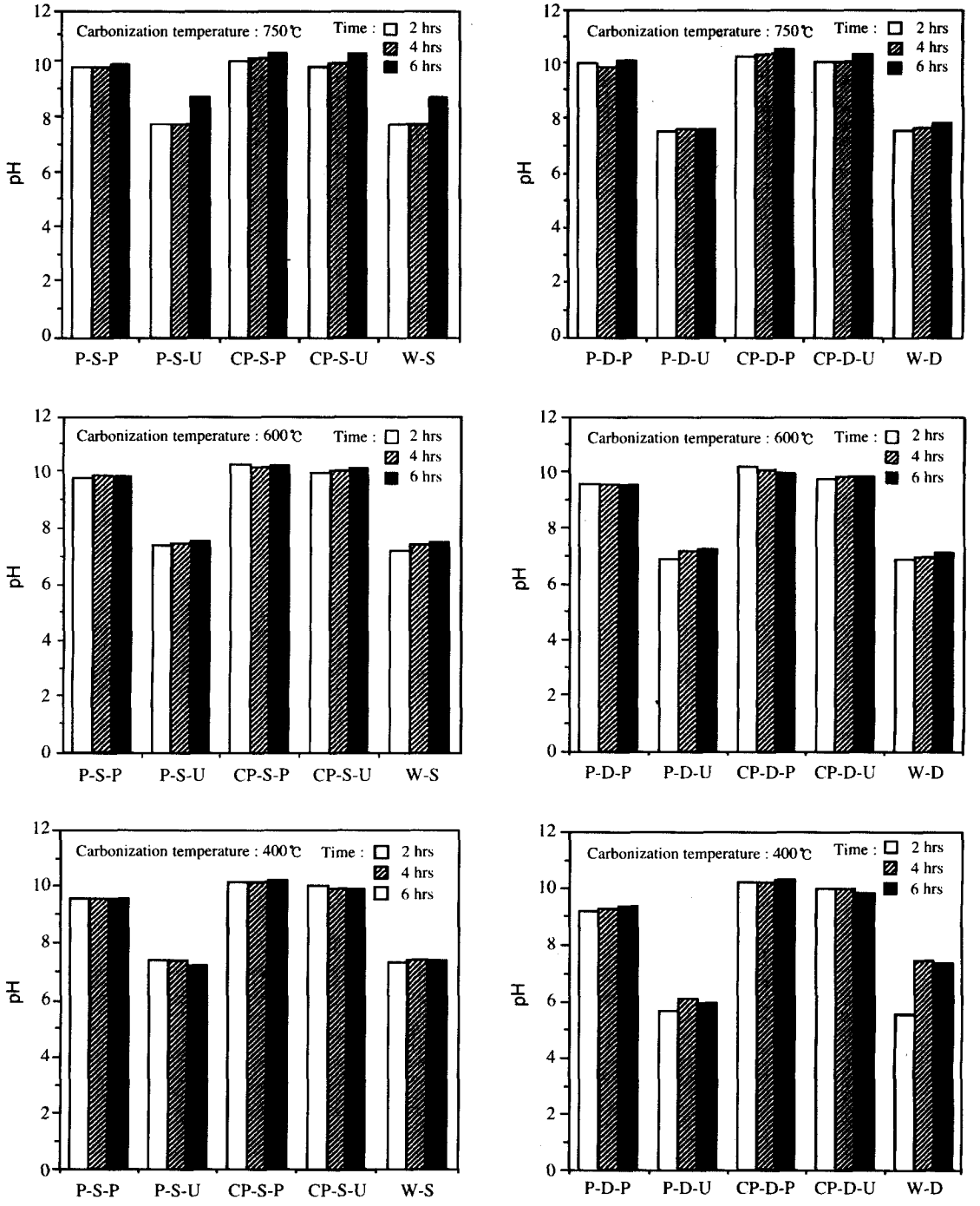

Fig. 3. The pH values of carbonized materials.
See Table 1 for P-S-P, P-S-U, CP-S-P, CP-S-U, W-S, P-D-P, P-D-U, CP-D-P, CP-D-U and W-D.

3.2 pH of carbonized materials

The pH of carbonized materials from lauan and larch (Fig. 3) and that of carbonized urea resin, phenol resin, and concrete are shown in Fig. 4. The pH of the used concrete form plywood (9.9~10.5) and phenol resin plywood (9.3~10.1) was higher than that of urea resin plywood and veneer. This is thought to result from the fact that the pH of the carbonized concrete and phenol resin was greater than that of carbonized urea resin. At 400℃ and 600℃, carbonization time did not exert an effect on pH of carbonized materials. However, pH of materials from lauan carbonized for 6 hours at 750℃ was slightly higher than that of materials carbonized for 2 and 4 hours at 750℃. This effect was marked for the carbonized urea resin plywood and veneer from lauan. Carbonized materials from larch showed no effect of carbonization time on pH at any given temperature. The pH of carbonized materials obtained in this experiment was similar to that of charcoal from wood (Ito *et al.*, 1997).

The carbonized phenol resin plywood produced from lauan and larch had greater pH than urea resin plywood; however, the type of resin did not affect the pH of used concrete form plywood. The pH of used concrete form plywood was more than 10,

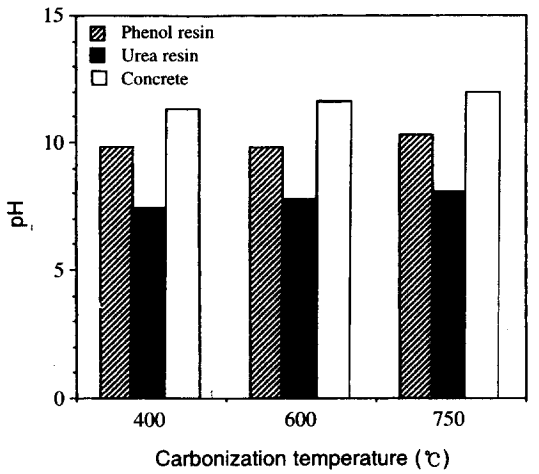

Fig. 4. The pH values of the carbonized phenol resin, urea resin and concrete (Carbonization time : 4 hours).

even when the sheets were carbonized for 2 hours at 400℃. The pH of lauan veneer, both before and after carbonization, was slightly greater than that of larch veneer. The pH of carbonized concrete showed a tendency to increase as carbonization temperature and time increased; however, the pH of carbonized urea resin and phenol resin was scarcely affected by carbonization temperature when carbonization time was 4 hours.

3.3 Equilibrium moisture content

The EMC of carbonized materials from lauan and larch are shown in Fig. 5 and the EMC of carbonized urea resin, phenol resin, and concrete are shown in Fig. 6. The EMC of materials carbonized at 400℃ and 600℃ ranged from 5.6% to 11.3%, and that of materials carbonized at 750℃ ranged from 13.8% to 24.1%(Fig. 5). Interestingly, the EMC was much higher in the carbonized materials from phenol resin plywood, suggesting considerably higher hygroscopicity. The carbonized materials from used concrete form plywood of phenol resin had an EMC of about 16.5%. In carbonized materials, the EMC showed a tendency to increase as carbonization temperature and time increased, even though this effect cannot be generalized(Fig. 6). Further studies are needed on the hygroscopic behaviour of carbonized materials produced from phenol resin plywood to determine why these materials had high EMC at a given temperature and relative humidity.

3.4 Adsorption of methylene-blue dye

At 400℃, carbonized veneers adsorbed slightly more methylene-blue dye than did the carbonized urea resin and phenol resin plywoods(Fig. 7). However, when carbonized for 6 hours at 600℃, the phenol resin plywood adsorbed more dye than did the carbonized veneer.

At 750℃, carbonized phenol resin lauan plywood had twice to three times the adsorption of carbonized veneer, and larch plywood had four to eight times the adsorption of carbonized veneer. The carbonized urea resin plywoods from both

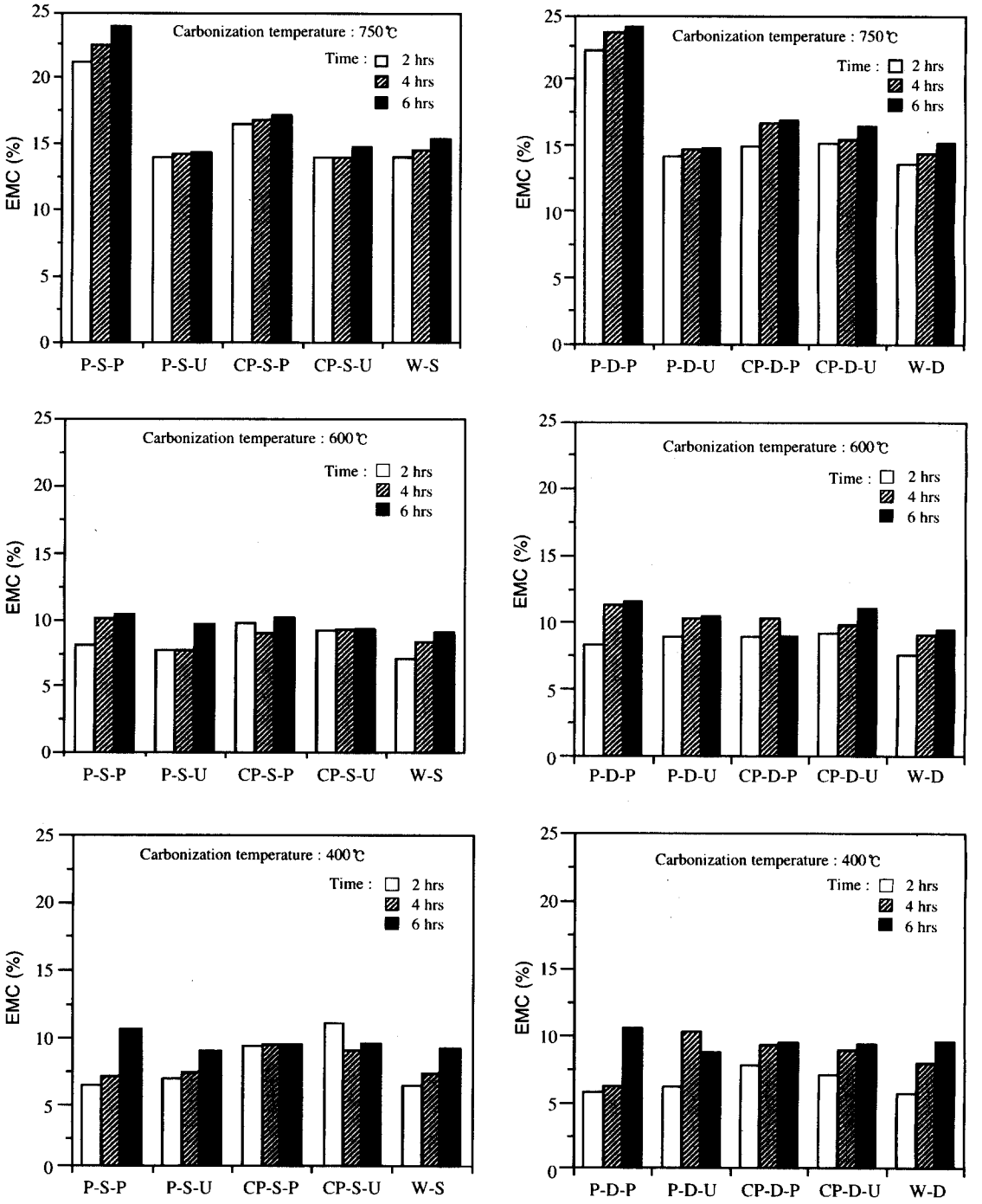

Fig. 5. Equilibrium moisture content (EMC) of carbonized materials at 20°C and 65 percent RH.
See Table 1 for P-S-P, P-S-U, CP-S-P, CP-S-U, W-S, P-D-P, P-D-U, CP-D-P, CP-D-U and W-D.

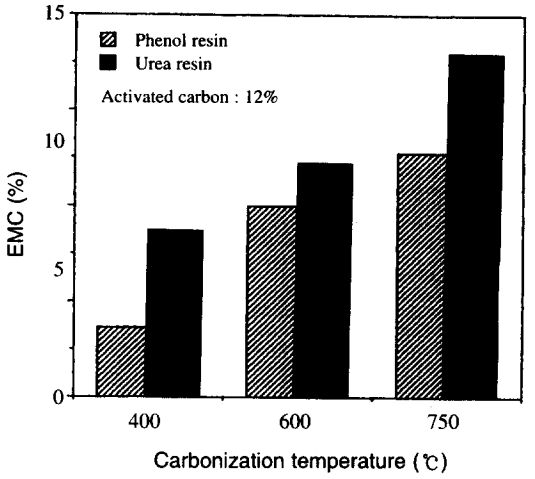

Fig. 6. Equilibrium moisture content(EMC) of carbonized phenol resin and urea resin (Carbonization time : 4 hours).

lauan and larch showed lesser amounts of adsorption than that of carbonized veneer at any given carbonization conditions. The adsorption of methylene-blue by carbonized phenol resin plywoods increased as carbonization temperature and time increased; this pattern was apparent for only carbonized phenol resin plywood.

Larch phenol resin plywoods carbonized for 6hours at 750℃ showed considerably greater adsorption of methylene-blue and this adsorption was greater than that of commercial activated charcoal(162mg/g), suggesting that phenol resin plywood could be used as carbon materials.

Fig. 8 shows amounts of adsorption of methylene-blue by carbonized urea and phenol resins. The EMC of carbonized urea resin was greater than that of carbonized phenol resin. However, the carbonized urea resin absorbed less methylene-blue than did the carbonized phenol resin, which adsorbed twice as much dye.

Fig. 9 shows the relationship between adsorption of methylene-blue and EMC. Adsorption tended to increase as EMC increased. However, phenol resin plywood carbonized for 6 hours at 750℃ showed significantly greater adsorption of methylene-blue.

3.5 Pore size distribution

Fig. 10 shows the pore size distribution of phenol resin plywood and urea resin plywood from lauan carbonized for 4hours at 600℃. Carbonized phenol resin plywood had more small-diameter pores than did carbonized urea resin plywood, which is apparently why the carbonized phenol resin plywood adsorbed more methylene-blue than did the carbonized urea resin plywood.

Fig. 11 shows the relationships between adsorption of methylene-blue and EMC and specific surface area for carbonized materials. It was apparent that adsorption tended to increase as specific surface areas increased. The higher amounts of adsorption of methylene-blue in phenol resin plywood from larch resulted in higher specific surface areas. A linear function was found between EMC and specific surface areas(Fig. 12).

4. CONCLUSION

A total of 40 sheets of lauan and larch five-ply, 30- by 30-cm plywoods were manufactured in the laboratory using commercial urea and phenol resin adhesives; half of these sheets were treated with fresh concrete. Plywood sheets were carbonized for 2, 4, and 6 hours at 400℃, 600℃, and 750℃ and their physical properties were analyzed. The results were summarized as follows:

1. Charcoal yield decreased as carbonization temperature and time increased. Charcoal yield was greater in plywood than in veneer, and slightly greater in used concrete form plywood than in plywood.
2. Carbonized phenol resin plywood had a higher pH than the urea resin plywood. In contrast, the resin type had no apparent effect on pH of the used concrete form plywood, which had pH greater than 10 even when carbonized for 2 hours at 400℃.
3. Materials carbonized at 750℃ had considerably greater EMC at 20℃ and 65% RH than those carbonized at 400℃ and 600℃, espe-

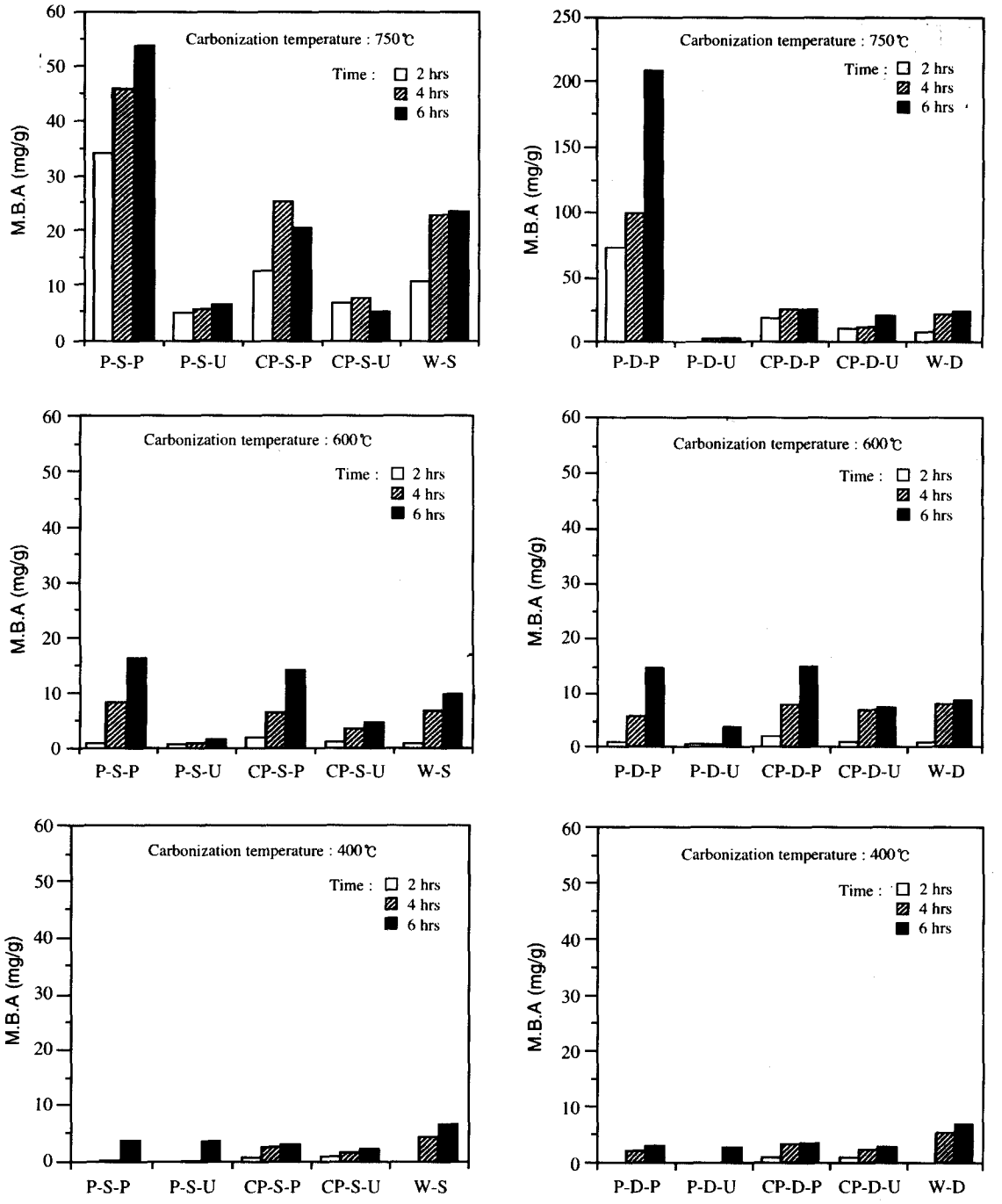

Fig. 7. Amounts of adsorption of methylene-blue(MBA) of carbonized materials.

cially the phenol resin plywood. Although the effects of carbonization time on EMC was not found in materials carbonized at 400℃ and 600℃, in materials carbonized at 750℃ EMC

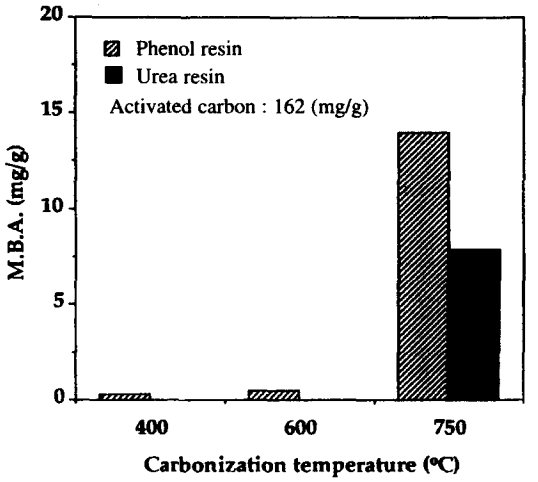

Fig. 8. Amounts of adsorption of methylene-blue(M.B.A) of the carbonized phenol resin and urea resin(carbonization time : 4 hours).

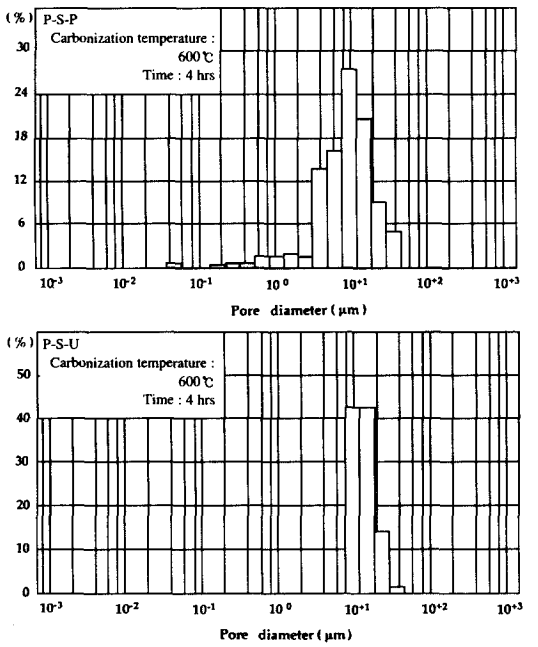

Fig. 10. Pore distributions for phenol resin plywood from *Shorea* sp.(P-S-P) and urea resin plywood from *Larix dahurica* (P-S-U).

increased as carbonization time increased. The carbon from phenol resin plywood had greater

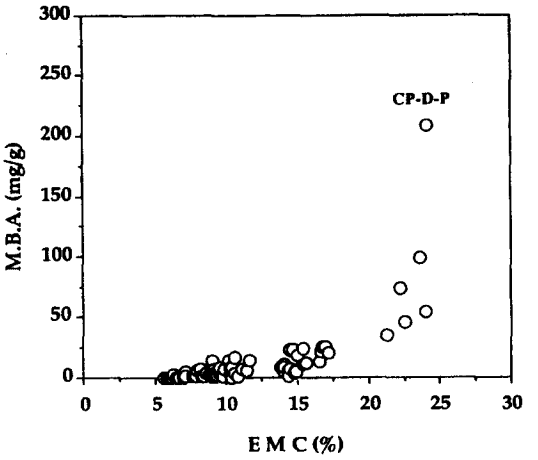

Fig. 9. Relationship between amounts of adsorption of methylene-blue(M.B.A) and EMC at 20°C and 65 percent RH.

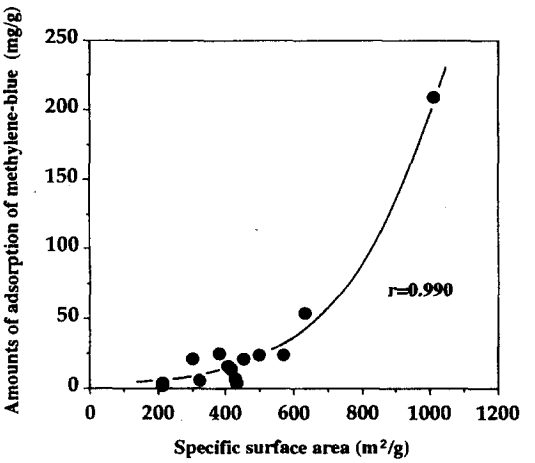

Fig. 11. Relationship between amounts of adsorption of methylene-blue and specific surface areas of carbonized materials.

EMC than that from urea resin plywood, although phenol resin carbon had less EMC than urea resin.

4. Carbonized phenol resin plywood had greater adsorption of methylene-blue dye than did carbonized urea resin plywood. In particular, phenol resin larch plywoods carbonized for 6hours at 750℃ adsorbed more methylene-blue than did commercial wood-based acti-

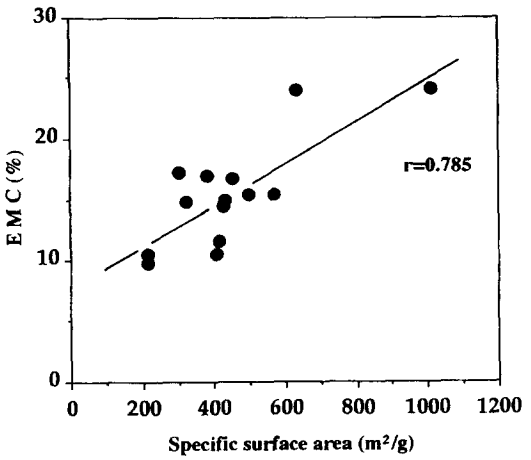

Fig. 12. Relationship between equilibrium moisture content(EMC) at 20°C, 65 percent RH and specific surface areas of carbonized materials.

vated charcoal. This increased adsorption of methylene-blue was influenced by total pore volume as well as specific surface areas of carbonized materials. Interestingly, carbonized materials from phenol resin showed greater hygroscopic properties and greater adsorption of methylene-blue. Additional research is needed in this area.

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