

Utilization of Kraft Black Liquor as Resin Binders *1

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요 약

소나무 크라프트 펄프제조과정중 회수된 폐액으로 Black liquor-phenol formaldehyde, Methylolated kraft lignin-phenol formaldehyde 및 Lignin cake-phenol resin의 세 종류의 접착제가 제조되었다.

Black liquor-phenol formaldehyde resin 제조시 Phenol의 약 60%를 크라프트 폐액으로 대체할 수 있다. 본 접착제의 최적압착조건은 160°C에서 7분간이었다. (상대접착력: 15.77kg/cm², 내수접착력: 8.54kg/cm²).

Methylolated kraft lignin-phenol formaldehyde resin 제조시 Phenol의 약 80~90%를 Methylolated kraft lignin으로 대용할 수 있었다. 본 접착제 제조시 pH를 2.6 용매로서 Methanol, 접착제 1g 당 0.2ml Formaldehyde를 첨가하는 것이 접착력이 가장 높았다. (상대접착력: 18.54kg/cm², 내수접착력: 10.08kg/cm²).

Lignin cake-phenol resin에서 Phenol양과 Kraft lignin양이 1:1일 경우에 접착력이 높았다. 본 접착제의 최적 압착조건은 150°C에서 4분간이었다. (상대접착력: 18.46kg/cm², 내수접착력: 12.3kg/cm²).

Abstracts

A kraft black liquor obtained from pulping of pine (*Pinus densiflora Sieb et Zucc*) was used for producing three kinds of adhesive such as black liquor-phenol formaldehyde resin, methyloated kraft lignin-phenol formaldehyde resin, and lignin cake-phenol resin.

In case of producing black liquor-phenol formaldehyde resin, about 60 percent of the phenolic resin could be replaced by black liquor. Also the optimal press condition appeared to be 160°C for 7 min. (15.77Kg/cm² in dry test, 8.54Kg/cm² in 4 hr. boil test).

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Phenol could be substituted up to 80-90 percent by methylolated kraft lignin. The suitable conditions of factors affecting bond quality were pH to 2.6, methanol as solvent and 0.2ml formaldehyde per 1g of the adhesives, respectively. The optimal press condition was 150°C for 4 min. (18.54Kg/cm² in dry test, 10.08Kg/cm² in 4 hr. boil test).

In preparing lignin cake-phenol resin, a suitable mixing ratio of phenol to powered kraft lignin was one to one by weight. The optimal press condition was 150°C for 4 min. (18.46Kg/cm² in dry test, 12.31Kg/cm² in 4 hr. hoil test).

1. INTRODUCTION

Next to cellulose lignin is an abundant natural renewable product. The lignin could be derived from wood as by-products of pulping and wood saccharification. However, lignin in pulping spent liquor has found commercially limited application by reason of its physical and chemical characteristics (Pearl, 1969¹⁹; Schweers, 1979²³).

Kraft lignin is almost burned for energy production and pulping chemicals recovery. A small portion of the sulfite lignins are only used for various applications such as dispersants, animal feed binders, surface active agents, and prepolymer for adhesives (Herrick and Hergert, 1977;¹⁴ Goheen, 1984)¹³). Of these possible uses the most promising application is the manufacture of adhesives for wood-based panels (Shen, 1977;²⁵, 1979;²⁶ Donald, 1984)⁵).

Lignin is polymers of phenylpropane units having structural properties similar to phenolic resins. Lignin can be cross-linked either by condensation reaction or by radical coupling reactions (Russell, 1978;²² Fengel and Wegener, 1984)¹⁰). The condensation can be caused from reaction between kraft lignin and chemicals such as phenol-formaldehyde, epoxies, isocyanates (Enkvist, 1975;⁷ Moorer et al., 1970;¹⁶ Gamø, 1984)¹²).

However there are several difficulties in promoting crosslinking reactions. The methoxyl

groups substituted in the aromatic rings, low molecular lignin and sugars in black liquor hinder kraft lignin molecules from making cross-linking reactions. To settle these problems, Enkvist et al. (1962)⁶) have worked out a way to demethylate the methoxyl groups by pressure heating with sodiumsulfide solution at about 250°C. Felicetta and Wenzel (1975)⁹) diminished the carbohydrate content in black liquor by fermentation processes. Forss and Fuhrmann (1979)¹¹) and Bar-Sinai and Wayman (1976)³) have published that the sugars and low molecular-weight lignin can be removed by ultrafiltration.

Many research on the utilization of lignosulfonate as adhesives has been reported, however there is a few information with respect to the production of adhesives from kraft lignin and phenol-formaldehyde. Dolenko and Clark (1978)⁴) prepared a dispersion of methylolated black liquor by acidification with sulfuric acid. The dispersion was mixed with phenolic resin, and used for manufacture of plywood. The results show that up to 70% of the petroleum-based PF resin can be replaced with kraft lignin on a weight-by-weight basis, and that wet strength and wood failure increase with decreasing pH of adhesives.

Johanson (1978)¹⁵) mixed air-drying kraft lignin and phenol-formaldehyde solution as a mixing weight ratio of 2:1 under acid solution. This mixture was used to glue a 2mm veneer to a

10mm chipboard. A practically 100% wood failure was obtained by splitting tests. Also Ramos et al. (1980)²¹⁾ made about 80% lignin-based adhesives from kraft lignin and phenol-formaldehyde resin, and suggested suitable reaction conditions on production of adhesives.

The objectives of this report was to investigate curing and adhesives properties of three kinds of kraft lignin PF resin according to production variables, such as amount of a mixed phenolic resin, pH of adhesives pressing time, and pressing temperature.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Concentrated black liquor

Chips of Pine (*pinus densiflora* SIEB. et ZUCC) were pulped in 15ℓ digester. The age and diameter of 3 trees were 28-31 years and 20-24cm at breast height, respectively. The kraft cooks were performed in following: active alkali, 20%; sulfidity, 25%; liquor-to-wood, 5:1; maximum temp., 170°C; time to maximum temp., 80 min.

The black liquor was separated from pulp contained about 14-18% solids. This black liquor was evaporated to a solid content of at least 50% at 75°C in water bath.

2.1.2 Preparation of veneer

Amberoi (*Pferocymbium beccarii* K. Schum.) rotary-cut veneers, 0.36mm thick for core and 1.15mm for face and back, were used in manufacture of three-plywood. Veneers (15 x 15 cm²) were conditioned to a final MC of 8-10% in incubator at 30°C for several weeks.

2.2 Experimental methods

2.2.1 Preparation of phenol-formaldehyde (PF) resin

A mixture of phenol 1 mole and formaldehyde 1.5 mole was heated slowly to 60°C at pH 9.0 under reduced pressure. After this condition was maintained for 1 hour, this mixture was again reacted for 1.5 hr. at 90°C using a reflux condenser. Final pH of the resin was adjusted to 7.0.

2.2.2 Preparation of black liquor-PF resin

According to Enkvist's method (1975)⁸⁾, concentrated black liquor was mixed with PF resin by stirrer. 10 parts of the mixture and 4 parts of 37% formaldehyde were mixed and heated for 3 hr. at 75°C using a reflux condenser.

2.2.3 Preparation of methylolated kraft ligni-PF resin

A mixture of concentrated black liquor 1.0 part and 37% formaldehyde 0.2 parts was covered with vinylwrap and kept for 4 days at room temperature. Thereafter, concentrated sulfuric acid was slowly added in the mixture to pH 4.0 under high speed mixing. During this addition methylolated kraft lignin(MKL) was precipitated from above solution as a dispersion of fine particles. The dispersion of MKL was mixed with PF resin at 65°C under high speed mixing. After conditioning of 1 day at room temperature, the mixture was separated as a semi-solid part and as a liquid part. The liquid part was decanted. The semi-solid part was dissolved with alcohol, and then used as adhesives (Dolenko and Clarke, 1978)⁴⁾.

2.2.4 Lignin cake-phenol resin

Concentrated black liquor was acidified to pH

9.0 by concentrated sulfuric acid under high speed mixing. Kraft lignin was precipitated from black liquor during this acidification. The resulting kraft lignin was filtered to yield lignin cake. 10 parts of lignin cake, 100 parts of phenol, 5 parts of sodium hydroxide and 160 parts of 37% formaldehyde were mixed, and heated for 3 hr. at 90°C using a reflux condenser (Adam and Schoenheer, 1981)¹⁾.

2.2.5 Measurement of physical properties and lignin contents of each solution.

The physical properties of each solution was measured by following methods.

- Nonvolatile content : KS M 3709(Dry oven)
 Viscosity : KS M 3708(Rotary viscometry)
 Specific gravity : KS M 3707(Pycnometer)
 pH : KS M 3712(pH meter)

Lignin contents in black liquor and lignin cake-phenol resin were calculated as UV-spectral absorbance of standard alkali lignin at 280nm (Paik, 1984)¹⁸⁾.

Physical properties and lignin contents of each solution are shown in Table 1.

Table 1. Properties of each solutions

	Sp. Gr. (25°)	pH (25°)	Viscosity (cp, 25°)	Nonvolatile con. (%)	Lignin in solid(%)
Concentrated black liquor	1.23	12.5	75	51.2	45.6
Methylolated black liquor	1.27	5.2	640	44.6	—
Lignin cake phenol resin	1.14	6.8	2,500	35.2	35.4
Phenol resin	1.13	7.0	65	51.0	—

2.3 Testing

Bonding strengths such as dry bond strength, wet bond strength after soaking 3 hr. in water at 30°C and 60°C, and wet bond strength after boiling repeatedly in water for 4 hr., were investigated by plywood shear testing. Also the wood failure on the sheared test piece was evaluated by eye-measurement. All results represent an average of 5 tests.

3. RESULTS AND DISCUSSION

3.1 Black liquor-phenol formaldehyde resin

3.1.1 Effect of weight ratio of black liquor to phenol-formaldehyde resin

The influence of weight ratio of black liquor to mixed phenol-formaldehyde on bond quality is illustrated in Table 2.

As seen in Table 2., bond quality was fairly affected by the amount of phenol-formaldehyde resin. As the weight of black liquor in this adhesives was decreased, shear strength as well as wood failures were significantly increased. Shear strength considerably increased at the ratio 6 to 4. The reason is caused by promoting of copolymeri-

Table 2. Influence of the amount of mixed phenol-formaldehyde on bond quality

Black liquor (parts)	Phenol resin (parts)	Shear strengths (Kg/cm ²)			
		Dry	After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
8	2	10.92(45)	7.85(30)	7.23(30)	5.31(20)
7	3	12.46(55)	8.54(35)	7.85(33)	6.58(25)
6	4	16.31(73)	10.77(60)	11.23(45)	8.70(40)

*Pressing temperature: 150°C, pressing time: 6 minutes.

zation reactions between phenol-formaldehyde and lignin with increasing the amount of phenol-formaldehyde (Fig. 1).

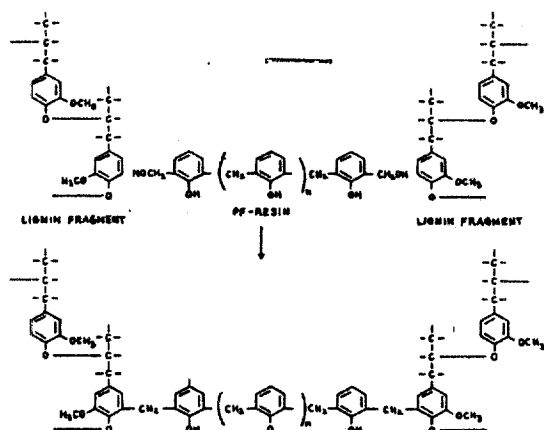


Fig. 1. Copolymerization of lignin with phenol-formaldehyde resin (Forss and Fuhrmann, 1979).

By using mixed phenol-formaldehyde and lignin at the ratio of 7 to 3, shear strength in dry test showed 12.5Kg/cm² which is similar to the result of Enkvist (1975)⁷⁾, however shear strength of boil test was lower than those of standard strength which can be permitted in mill test (7.5Kg/cm²). Therefore, the received result was only the weight ratio of 6 to 4.

3.1.2 Effect of pressing conditions

Effect of pressing conditions are shown in Table 3.

In dry test, good shear strength appeared at the lower press temperature (140°C) and longer press time (7 min.). However boil test for 4 hr. gave the stronger shear strength at 160°C than at

Table 3. Influence of pressing conditions of black liquor-phenol formaldehyde resin on bond quality

Press temp. (°C)	Press time (min.)	Shear strengths (Kg/cm ²)			
		Dry	After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
140	5	16.02(95)	11.77(35)	10.85(15)	7.08(10)
		16.69(70)	12.39(40)	11.00(10)	8.15(20)
160	5	14.46(30)	10.08(35)	8.62(55)	7.08(15)
		15.77(40)	11.39(40)	11.39(30)	8.54(20)

*Resin is a solution of black liquor and phenol-formaldehyde at a ratio of 6.0 to 4.0 on solids.

140°C. Namely dry strength was not influenced by press time, but wet strength noticeably increased with increasing with a longer press time. The received result was the condition with press temperature 160°C and press time of 7 minutes.

While Ramos et al. (1980)²¹⁾ reported that bond quality of plywood pressed at 140°C decreased with increasing press time. It is not coincided with the result of Shen (1974)²⁴⁾ and our experiment. Effect of press time and temperature on bond quality are yet controversial, because bond quality is affected by several factors such as species, thickness of veneer, the ratio of lignin and phenol-formaldehyde, gluing conditions, glue spread, moisture content of veneer, and etc. But it is approved that the adhesives produced from lignin need a longer press time and higher press temperature than another adhesives. This problem must be minutely studied here after.

In this experiments, shear strengths in wet test were usually lower. It is caused by high pH (12-12.5) of the adhesives, because kraft lignin and phenol resin was conglomerated by acid. If the pH of adhesives can be easily controlled to neutral considerably. Enkvist (1975)⁸⁾ controlled the pH of the adhesives to the weakly alkaline area (pH 7-11) with sulfuric acid, acetic acid or lactic acid. However the adjustment of pH needs a high skill.

3.2 Methylolated kraft lignin-phenol formaldehyde resin

3.2.1 Effect of weight ratio

The results obtained are shown in Table 4.

As seen Table 4., the weight ratio of methylolated kraft lignin to phenol resin did not definitely affect on bond quality of plywood. In dry test, shear strengths slightly increased with increasing phenol resin, but wood failures were almost constant. Also shear strengths in wet test did not show a uniform trend. As compared with above results, weight ratio of 8 to 2 gave good shear strengths. This trend agrees with Dolenko and Clarlee's results (1978)⁴⁾.

All results obtained from this experiment surpassed standard limit in shear strength, but it is peculiar that shear strengths were not simultaneously increased with increasing the amount of phenol. The reason is probably induced by two reaction mechanisms. As seen at Fig. 2., methylolated lignin is cross-linked by the condensation reaction of formaldehyde. While non-methylolated lignin is copolymerized by phenol as Fig. 1. According to Nimz (1983)¹⁷⁾, kraft lignin from softwood has about all 40 methylol groups constituting 30 methylol groups in aromatic ring and 10 methylol groups in side chain per 100

Table 4. Influence of weight ratio of methylolated kraft lignin to phenol resin on bond quality

MBL(parts)	Phenol resin (parts)	Shear strengths (Kg/cm ²)			
		Dry	After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
9	1	15.39(75)	11.54(80)	11.54(60)	9.08(53)
8	2	15.93(88)	12.15(80)	12.23(50)	9.77(58)
7	3	15.96(70)	10.58(80)	10.81(47)	8.75(62)
6	4	16.65(77)	10.15(60)	10.62(50)	9.15(71)

*Pressing temperature: 170°C, pressing time: 7 minutes.

phenylpropane units. Namely 40% of lignin in black liquor can be methylolated. Non-methylolated lignin, 60% of lignin, needs only phenol to copolymerization reactions. Therefore, this adhesives can give good strength as less phenol than black liquor phenol formaldehyde resin.

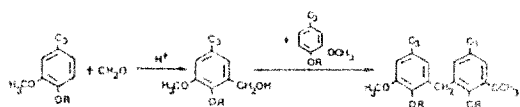


Fig. 2. Cross-linking of lignin by formaldehyde.

3.2.2 Effect of pH

The effect of the pH on bond quality is illustrated in Fig. 3 and 4.

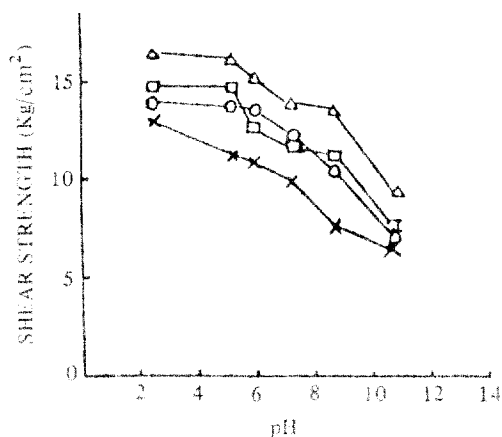


Fig. 3. Effect of pH on bond quality.

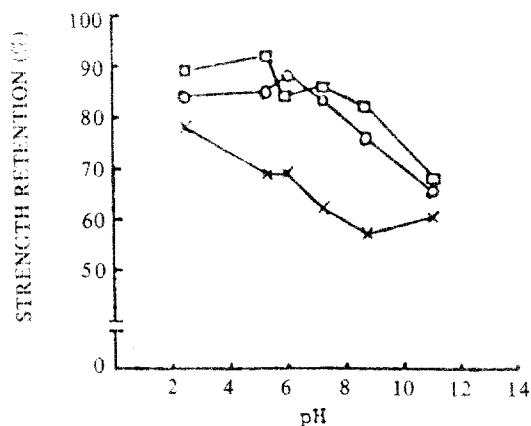


Fig. 4. Effect of resin pH on strength retention.

Fig. 3. showed that the pH induced the increase of shear strength and wood failure. The best shear strength was obtainable at pH 2.6. However, the adhesives of pH 6-7 is suited to use on plywood, because the adhesives without the adjustment of pH is originally neutral, and the acidic adhesives causes often corrosion on wood materials (Table 5). Fig. 4. showed the strength retention, ratio of the original dry strength to wet strength. The retention ratio of the below pH 7.3 maintained above 70-80%.

As compared with adhesives cured under alkaline condition, the adhesives cured under acidic condition gave a excellent strength. Increase of shear strength at acidic area may be related to solubility characteristics of kraft lignin. Under acidic conditions, the hydroxyl and carboxyl functional groups of even the low molecular kraft lignin will be present in the insoluble acidic forms. Therefore there are much lignin to be combined with phenol resin or formaldehyde (Dolenko and Clarke, 1978)⁴⁾. Another suggestion is that the such condition retain methylol groups reactive and are favorable reaction to form the ether linkages. Furthermore, at acidic pH, the separation of a substantial amount of the soluble inorganic salts, sugars, organic acids, etc., which have a detrimental effect on bond quality is promoted by the addition of acids. (Ball and Doughty, 1965)²⁾.

3.2.3 Effect on press conditions

The results obtained is given in Table 6.

Trend of the results was similar to the those of black liquor-phenol formaldehyde resin. In the same press temperature, shear strength decreased with increasing press time. At a given press time, shear strengths decreased with increasing press

Table 5. Influence of pH of methyloated black liquor-phenol formaldehyde resin on bond quality

pH of resin	Dry	Shear strengths (Kg/cm ²)		
		After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
2.6	11.62(95)	14.05(95)	14.85(93)	13.00(55)
5.3	16.16(88)	13.77(83)	14.85(68)	11.15(45)
6.0	15.23(70)	13.46(88)	12.77(43)	10.50(35)
7.3	14.00(43)	11.69(60)	12.16(63)	9.70(30)
8.8	13.69(40)	10.47(35)	11.24(50)	7.53(15)
11.0	9.69(25)	6.39(35)	6.62(35)	6.05(10)

*Resin is a solution of methyloated kraft lignin and phenol-formaldehyde at a ratio of 8.0 to 2.0 on solids.

*Pressing temperature: 170°C, pressing time: 7 minutes.

Table 6. Influence of press conditions of methyloated kraft lignin-phenol formaldehyde resin on bond quality

Press temp. (°C)	Press time (min.)	Shear strengths (Kg/cm ²)			
		Dry	After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
150	4	18.54(75)	15.85(60)	15.16(50)	10.08(25)
	6	18.62(70)	14.93(55)	13.85(45)	9.50(25)
	8	16.08(45)	14.08(40)	12.77(45)	9.69(25)
	10	15.23(45)	14.46(35)	12.38(40)	8.08(25)
170	4	20.31(95)	14.69(60)	12.77(50)	10.77(35)
	6	18.54(65)	14.85(60)	12.31(45)	9.47(25)
	8	14.63(45)	12.12(50)	9.85(40)	8.15(20)
190	8	12.31(50)	9.39(75)	9.68(70)	7.54(50)
	10	12.85(30)	8.15(40)	8.39(50)	6.16(35)

*Resin is a solution of methyloated kraft lignin and phenol-formaldehyde at a ratio of 9.0 to 1.0 on solids.

temperature. The results obtained in this experiment surpassed standard limit in shear strength, however, considering economical aspects, the optimum condition was regarded as press temperature of 150°C with press time of 4 minutes.

3.2.4 Effect of solvent

Effect of solvent on methyloated black liquor-phenol formaldehyde resin is shown in Table 7.

Ethanol and methanol gave almost similar results. However, iso-propanol revealed the significantly lower strength than ethanol and methanol. This reason may be due to difference in solubility

Table 7. Influence of solvent of methylolated black liquor-phenol formaldehyde resin on bond quality

Solvent	Shear strengths (Kg/cm ²)			
	Dry	After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
ethanol	13.69(50)	11.85(70)	12.46(45)	7.46(35)
methanol	13.20(50)	10.85(60)	11.62(35)	7.92(25)
iso-propanol	12.62(58)	9.85(50)	9.38(35)	6.16(25)

*Resin is a solution of methylolated kraft lignin and phenol-formaldehyde at a ratio of 9.0 to 1.0 on solids.

*Pressing temperature: 170°C, pressing time: 7 minutes.

of each solvent. The adhesives which are dissolved by these solvent will not have the same viscosity and solid content. Therefore, it is considered that this differences of viscosity and solid content exert effect on the shear strength of each adhesive.

Iso-propanol is not suitable to as solvent for methylolated kraft lignin-phenol formaldehyde resin, but alcohol-water mixtures containing about 10-30% by weight of water can dissolve such adhesives (Wabster, 1965).²⁷⁾

3.2.5 Effect of additional formaldehyde

Effect of additional formaldehyde is given in Table 8.

By addition of formaldehyde, shear strengths were more or less increasing trend within any limitation, as seen in Table 7. The highest shear strengths was obtainable at addition of 0.2 ml formaldehyde per 1g of adhesives weight. Therefore, addition of formaldehyde can induce a decrease of viscosity as well as solid content. Such decrease of viscosity and solid content bring about poor results.

3.3 Lignin cake-phenol resin

Table 8. Influence of additional formaldehyde of methylolated black liquor-phenol formaldehyde resin on bond quality

Additional formaldehyde	Dry	Shear strengths (Kg/cm ²)		
		After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
0 ml	11.00(25)	10.16(40)	9.93(40)	7.25(25)
0.1 ml	10.63(35)	8.93(63)	7.96(35)	7.75(25)
0.2 ml	13.08(20)	12.00(75)	11.23(35)	8.85(25)
0.4 ml	10.62(20)	8.15(10)	9.08(30)	8.75(20)

*Resin is a solution of methylolated kraft lignin and phenol-formaldehyde at a ratio of 9.0 to 1.0 on solids.

*Pressing temperature: 170°C, pressing time: 7 minutes.

Table 9. Influence of pressing condition of lignin cake-phenol resin on bond quality.

Press temp. (°C)	Press time (min.)	Dry	Shear strength (Kg/cm ²)		
			After 3hr. at 30°C	After 3hr. at 60°C	After 4hr. boil
130	6	12.85(35)	10.46(40)	9.16(20)	7.08(10)
150	4	18.46(80)	14.31(55)	14.00(50)	12.31(65)
	6	18.39(88)	15.23(80)	14.39(40)	11.77(35)
170	4	17.54(95)	15.86(85)	13.38(80)	12.77(63)
		17.69(75)	13.08(65)	14.31(70)	10.47(43)

*Pressing temperature: 170°C, pressing time: 7 minutes.

The resin is a solution of kraft lignin precipitated by acid and phenol-formaldehyde at a ratio of 9:1 on solid. Effect of press conditions of lignin cake-phenol resin is shown in Table 8.

As seen in Table 9, press temperature is regarded as the important factor in this adhesives. Difference of shear strengths was very great at temperature of between 130 and 150°C. Therefore, the higher press temperature than 150°C is required to obtain good shear strength. Wood failure in this adhesives were higher than previously other adhesives. The problem of this adhesives was also high pH by sodium hydroxide which was added to control the viscosity. Without the addition of sodium hydroxide, this adhesives is not solved.

In condensation of phenol with lignin, the phenol reacts in the ortho position. Most of phenol linkes with high molecular weight lignin, a small quantity of phenol uses in condensation of lignin. Nevertheless, the result in wet test was superior to another lignin-adhesives in shear strength. Wood failure in dry test was above 75-95% which is similar to the result of Adam and Schoenherr (1981)¹⁾. Further the effect of other conditions on lignin cakephenol resin have

to be studied in detail.

4. CONCLUSIONS

In case of black liquor-phenol formaldehyde resin, shear strength as well as wood failure increased with decreasing the mixed amount of black liquor. Also suitable press conditions appeared at 160°C with 7 min. But the strength retention of 4hr. boil test to dry shear strength was 50% at weight of 6:4. Therefore, the water-proof of this adhesives have to be studied further. Generally dry strength was not influenced by press time, but wet strength increased with increasing noticeably with a longer press time. Also it was difficult to control pH of this adhesives, because kraft lignin and phenol resin were conglomerated by acid.

A bond quality of methlolated kraft lignin-phenol formaldehyde resin was influenced by various factors. Decrease of resin pH was considerably increased the shear strength. The best shear strength was obtainable at low pH. Also the optimum condition was regarded as press temperature of 150°C with press time of 4 minutes. Effect of solvent showed that ethanol

and methanol was almost similar results except iso-propanol. Treatment of additional formaldehyde showed the most shear strength at 0.2 ml addition per 1g of the adhesives.

Kraft lignin cake-phenol resin was only investigated on the effect of press conditions. The adhesive press time was regard as the important factor. It is required higher temperature than the press temperature at 150°C to obtain good shear strength. Disadvantage of this adhesives was high pH by sodium hydroxide using for viscosity control.

Further, the effect of other conditions such as glue spread, moisture content of veneer and assembly time have to be studied in detail.

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