# PROPERTIES OF ORIENTED STRANDBOARD BONDED WITH PHENOL–UREA–FORMALDEHYDE RESIN

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*Received October 2013*

**OH YS & KIM JM. 2015. Properties of oriented strandboard bonded with phenol–urea–formaldehyde resin.** Phenol–urea–formaldehyde (PUF) resins, based on 14 and 24% urea addition of the resin solid weight, were synthesised in the laboratory and used as binders in oriented strandboards (OSBs). The resins were compared with laboratory-synthesised control phenol–formaldehyde (PF) resin. Laboratory OSBs were made with PF resin and PUF resins at two resin solid levels (3.5 and 4.5%). The properties of OSBs made using PF and PUF resins were evaluated. Performance tests showed that mechanical strength properties decreased with increasing urea addition, while dimensional stability increased. All OSBs showed good physical and mechanical properties.

Keywords: Adhesive, paulownia, free formaldehyde, resin synthesis

## INTRODUCTION

Oriented strandboard (OSB), which is glued engineered structural panel, is commercially produced in North America in the 1980s. Like plywood, OSB, which consists of three layers with each layer alternating 90º in orientation, shows good strength and dimensional stability. OSB is primarily used in residential wall, floor, and roof sheathing applications. OSB is likely to gain popularity due to its low price and use of small diameter logs from fast-growing trees and thinning logs as raw materials. In 2005, there were over 60 OSB plants in operation in North America (Botting 2008). In 2008, European OSB production was forecasted to grow at an annual rate of 10% between 2008 and 2012, reaching 5.8 billion $m^3$ in 2012 (Botting 2008).

Phenol–formaldehyde (PF) resin, which is a thermosetting resin, is widely used as a binder of OSB and plywood due to its excellent durability such as water resistance and thermal stability. Replacement of plywood with OSB is increasing the demand for phenolic resins. OSB requires as much as 50% more resin per unit volume than plywood (Sellers 2001). However, the price of PF resin is closely related to the price of phenol, which is derived from petroleum and the price of petrol has been increasing. The increasing price of PF resin has initiated research on finding alternative sources of adhesives or chemical feedstock in an effort to reduce the manufacturing cost (Sellers 2001).

The global demand for fibrous materials in wood-based panel industry has been growing. Fast-growing low-density hardwood such as aspen is ideal as raw material for structural panels (Sellers 2001). Paulownia is an appropriate wood species for short rotation hardwood plantations due to its very rapid growth (Ashori & Nourbakhsh 2009).

This study compared the properties of OSBs bonded with laboratory-synthesised phenol–urea–formaldehyde (PUF) resins and a laboratory-synthesised control PF resin.

## MATERIALS AND METHODS

### PF and PUF resin synthesis

Table 1 summarises the formulation of PF and PUF resins synthesised in this study. A PF resin was synthesised in the laboratory with phenol/formaldehyde mole ratio of 2.1 and sodium hydroxide/phenol mole ratio of 0.3. The general

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**Table 1** Formulation of phenol–formaldehyde (PF) and phenol–urea–formaldehyde (PUF) resins used in this study

| Formulation | PF resin (g) | PUF-14 resin (g) | PUF-24 resin (g) |
|---|---|---|---|
| $H_2O$ | 55 | 49 | 45 |
| Phenol (99%) | 439 | 356 | 296 |
| NaOH (50%) | 135 | 135 | 135 |
| HCHO (37%) | 786 | 786 | 786 |
| Urea | 0 | 89 | 153 |
| Total | 1415 | 1415 | 1415 |

cooking procedure was similar to that outlined by Oh et al. (1994) and Oh (2010).

PUF resins were similarly synthesised in the laboratory. The urea addition levels were 14 and 24% based on the resin solid weight. In calculating the targeted resin solid levels, charged phenol, sodium hydroxide and urea solid values were taken as such and formaldehyde-derived solids were taken as methylene group values, obtained by multiplying the charge weights with a factor of 14/30. Water, phenol and sodium hydroxide (50% solution) were charged into a stirred reactor and the reaction mixture was heated to 65–70 °C. A formaldehyde solution (37% concentration) was added drop-wise to the reaction mixture over 30 min, while keeping the reaction temperature in the same range by intermittent cooling using ice bath. After formaldehyde addition, the reaction temperature was maintained at the same range for 10 min and increased gradually to 85 °C over 30 min. The reaction temperature was maintained until the resin reached the H viscosity in the Gardener-Holdt viscosity scale. Urea of 14 and 24% respectively was added to the resins at the end of synthesis, cooled to room temperature and stored until property analysis and use.

## Resin analysis

The viscosities of resins were measured using a viscometer. The free formaldehyde content was measured using hydroxylamine hydrochloride method (Walker 1964). Gel time was measured using a gel timer at 100 °C. Resin solid levels were determined by heating 1 g of resin on an aluminium pan at 105 °C for 3 hours and calculated as below.

$$\text{Resin solid level (\%)} = \frac{\text{Sample weight after 3 hours}}{\text{Initial sample weight}} \times 100$$

## OSB manufacture

A mixture of wood strands comprising 60% *Calophyllum inophyllum* from Papua New Guinea and 40% *Paulownia coreana* from South Korea was obtained by a commercial wood product industry in Korea. The wood strands were 0.6 mm thick, 19 mm wide and 58 mm long. The moisture content of the strands was 4 to 5% based on the oven-dry weight.

Single-layer homogenous OSBs were manufactured in the laboratory using the processing parameters presented in Table 2. The time from resin application to panel pressing was 20 to 30 min.

## OSB performance test

Test specimens were cut from boards. Internal bond (IB), modulus of elasticity (MOE) and modulus of rupture (MOR) were determined in accordance with ASTM D 1037-99 (ASTM 2002). Panel water absorption and thickness swelling properties were observed after 24-hour soaking tests.

## Statistical analysis

Panel property results were analysed using SAS 1994. Analysis of variance (ANOVA) was used to determine differences within panels bonded with each resin type and resin solid application level. Significant differences ($p < 0.05$) were further

**Table 2** Panel manufacturing parameters

| Parameter | Condition |
|---|---|
| Panel dimension | 500 mm × 500 mm × 9.5 mm |
| Mat moisture content | 8 to 9% |
| Wax content | 1% based on oven-dry wood weight |
| Resin content | 3.5%, 4.5% based on oven-dry wood weight |
| Catalyst | None |
| Resin flow rate | 120 mL $min^{-1}$ |
| Air spray | 172 kPa |
| Target density | 673 kg $m^{-3}$ |
| Press temperature | 177 °C |
| Press time | 4 min |
| Replication | 3 boards per condition (total of 18 boards) |
| Board conditioning | 21 °C in 56% room relative humidity |

compared using t-test for least significance differences (LSD) from the SAS program (Steel & Torrie 1980).

## RESULTS AND DISCUSSION

### Resin properties

The PF and PUF resins made in this study showed very low free formaldehyde contents (less than 0.2%), as expected (Table 3). In general, a small amount of urea is added during the final stage of PF resin synthesis in order to capture the residual free formaldehyde without impairing resin performance, and to decrease resin viscosity and cost. Urea addition level at 14% appeared to be sufficient for keeping free formaldehyde content low. The resin solid level ranged from 44.8 to 46.1%. The resin viscosity ranged from 170 to 210 mPa s, which was suitable for resin applications with compressed air sprayer. The gelation times of PUF resins were shorter than that of PF resin. Shorter gelation time is attributed to increased resin reactivity because of the reaction between the PF resin and urea (Pizzi 1994). All test properties of the resins were in the acceptable range for bonding OSB.

### OSB performance test

OSB densities ranged from 675 to 702 kg $m^{-3}$ (Table 4). The LSD test showed that panel density was affected by resin type. Panel densities were significantly higher at 4.5% resin solid level than 3.5%. However, the panel density variation was quite low, suggesting that the mat forming operation was suitable in this study.

**Table 3** Properties of laboratory-synthesised PF and PUF resins

| Property | PF resin | PUF-14 resin | PUF-24 resin |
|---|---|---|---|
| Solid content (%) | 45.3 | 46.1 | 44.8 |
| Specific gravity | 1.18 | 1.19 | 1.18 |
| pH | 10.5 | 10.8 | 11.0 |
| Gel time (min) | 25.6 | 21.5 | 19.8 |
| Free formaldehyde (%) | 0.19 | 0.01 | 0.01 |
| Alkalinity (%) | 4.08 | 4.11 | 4.16 |
| Viscosity (mPa s) | 170 | 185 | 210 |

PF = phenol–formaldehyde, PUF = phenol–urea–formaldehyde

**Table 4** Test results of oriented standboards made from synthesised phenol–formaldehyde (PF) and phenol–urea–formaldehyde (PUF) resins

| Resin type | Resin solid (%) | Density (kg m$^{-3}$) | IB (kPa) | MOE (GPa) | MOR (MPa) | 24-hour TS (%) | 24-hour WA (%) |
|---|---|---|---|---|---|---|---|
| PF | 3.5 | 694 a | 572 a | 3.7 ab | 25.6 ab | 26.1 c | 49.5 cd |
| | 4.5 | 702 ab | 580 a | 3.9 a | 26.5 a | 24.5 c | 47.2 e |
| PUF-14 | 3.5 | 685 bcd | 560 ab | 3.3 ab | 23.0 c | 28.4 b | 50.6 c |
| | 4.5 | 693 abc | 575 a | 3.8 ab | 25.3 b | 25.6 c | 48.3 de |
| PUF-24 | 3.5 | 675 d | 490 c | 3.0 b | 19.7 d | 31.1 a | 54.8 a |
| | 4.5 | 681 cd | 540 b | 3.1 ab | 20.6 d | 29.4 b | 52.6 b |

IB = internal bond, MOE = modulus of elasticity, MOR = modulus of rupture, TS = thickness swelling, WA = water absorption; means with the same letter in the same column are not significantly different ($p < 0.05$)

The IB ranged from 490 to 580 kPa (Table 4). With increasing urea addition level in PUF resin, the IB of the panel decreased only gradually. The IB of panels bonded with control PF resin turned out to be higher than those of panels bonded with PUF resins. The LSD test showed that the IB differed significantly according to the resin type. However, panels bonded with PF and PUF-14 resins had an equivalent IB. There were significant differences in IB due to resin solid levels. In other words, the panel made in this study exceeded the minimum strength requirements for IB (345 kPa) according to Canadian Standards Association Standard 0437.0 for OSB type R-1 (CSA 1993).

MOE ranged from 3.0 to 3.9 GPa (Table 4). MOE values of panels bonded with PF and PUF resin types were very similar. There were no significant differences for MOE due to resin solid levels.

MOR ranged from 19.7 to 26.5 MPa (Table 4). The LSD test for MOR showed that the panel bonded with PF resin was significantly different from those made with PUF resin types. These differences suggest that PF resin exhibited the best bending properties (MOE and MOR) among the resin types examined. MOR was significantly higher at 4.5% resin solid level than at 3.5%. MOE and MOR decreased with increasing amount of urea added. However, the panel made in the present study exceeded the minimum strength requirements for MOR (17.3 MPa) according to Canadian Standards Association Standard 0437.0 for OSB type R-1 (CSA 1993).

Thickness swelling for all panels ranged from 24.5 to 31.1% for the 24-hour test (Table 4). The LSD test for thickness swelling after 24-hour water soaking showed that the panel bonded with PF resin had significantly lower value than panels made with PUF resin types. There were significant differences in 24-hour thickness swelling due to resin solid levels.

Water absorption ranged from 47.2 to 54.8% for the 24-hour test (Table 4). The LSD test for water absorption after 24-hour water soaking showed that panels made with PF resin absorbed significantly less water than those made with PUF resin types. There were significant differences in 24-hour water absorption due to resin solid levels. The differences in thickness swelling and water absorption were attributed to the relatively high content of alkalinity (Table 3). Differences were also due to the addition of urea in PUF resins, which could adversely affect dimensional stability properties (thickness swelling and water absorption) of the panel.

## CONCLUSIONS

Mechanical strength properties gradually decreased with increasing urea addition of the resin, while dimensional stability properties increased. Physical and mechanical properties differed significantly according to resin types and resin solid levels. OSBs bonded with laboratory-synthesised PUF resins exhibited good physical and mechanical properties. Overall, PUF resins could be used successfully as OSB binders. The

mixture of wood strands of *C. inophyllum* and *P. coreana* was suitable as raw material for the manufacture of OSB. The results provided a guide for cost saving of PF resin as OSB binder. PUF resin formulation could be used as binder in plywood manufacture.

## ACKNOWLEDGEMENT

This research was supported by the Yeungnam University research grant in 2013.

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