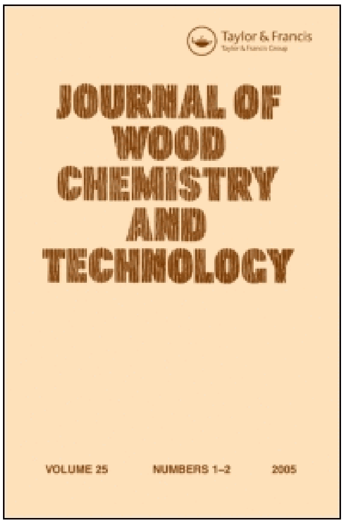

Journal of Wood Chemistry and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597282

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Zehui Jiang[a]; Daochun Qin[a]; Chung-Yun Hse[b]; Monlin Kuo[c]; Zhaohui Luo[d]; Ge Wang[a]; Yan Yu[a]
[a] International Center for Bamboo and Rattan, Beijing, China [b] United States Department of Agriculture (USDA), Forest Service, Southern Research Station, Pineville, Louisiana, USA [c] Department of Natural Resource Ecology & Management, Iowa State University, Ames, Iowa, USA [d] Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, China

To cite this Article Jiang, Zehui , Qin, Daochun , Hse, Chung-Yun , Kuo, Monlin , Luo, Zhaohui , Wang, Ge and Yu, Yan(2008) 'Preliminary Study on Chicken Feather Protein-Based Wood Adhesives', Journal of Wood Chemistry and Technology, 28: 3, 240 — 246
To link to this Article: DOI: 10.1080/02773810802347073
URL: http://dx.doi.org/10.1080/02773810802347073

Journal of Wood Chemistry and Technology, 28: 240–246, 2008

ISSN: 0277-3813 print / 1532-2319 online
DOI: 10.1080/02773810802347073

Preliminary Study on Chicken Feather Protein–Based Wood Adhesives

Zehui Jiang,[1] Daochun Qin,[1] Chung-Yun Hse,[2] Monlin Kuo,[3] Zhaohui Luo,[4] Ge Wang,[1] and Yan Yu[1]

[1]International Center for Bamboo and Rattan, Beijing, China
[2]United States Department of Agriculture (USDA), Forest Service, Southern Research Station, Pineville, Louisiana, USA
[3]Department of Natural Resource Ecology & Management, Iowa State University, Ames, Iowa, USA
[4]Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, China

Abstract: The objective of this preliminary study was to partially replace phenol in the synthesis of phenol-formaldehyde resin with feather protein. Feather protein–based resins, which contained one part feather protein and two parts phenol, were formulated under the conditions of two feather protein hydrolysis methods (with and without presence of phenol during hydrolysis), two formaldehyde/phenol molar ratios (1.8 and 2.0), and three pH levels (9.5, 10.5, and 11.5). Southern pine fiberboard bonded with feather protein–based resins was fabricated and bending strength, bending stiffness, internal bonding strength, and percent thickness swell were evaluated. Results indicated that the test parameters all significantly affected resin quality. The resin formulated with feather protein hydrolyzed in the presence of phenol, using a F/P ratio of 2.0, and at a pH of 10.5 performed as well as the neat PF resin. Based on our findings, feather protein is a potential cost-effective material for the production of PF-type adhesive resins.

Keywords: Feather, fiberboard, PF resin, protein hydrolysis

INTRODUCTION

Natural adhesives such as soy, blood, and hide glues served the wood industry for a long time for panel production.[1] These natural adhesives faded

This work was supported by the 11th Five Years Program for Science and Technology Development of China (No. 2006BAD19B04) and the "948" Program (2003-4-27) of the State Forestry Administration of China.

Address correspondence to Daochun Qin, International Center for Bamboo and Rattan, No. 8 Futong East Street, Wangjing Area, Chaoyang District, Beijing 100102, P.R. China. E-mail: qindaochun@gmail.com

after the 1960s because of slow production rates and the durability and bonding strengths provided with these natural glues were inferior to petroleum-based adhesives.[2] Phenol-formaldehyde (PF) resin was invented in the early 1900s, but only substituted natural glues after World War II, when the price of petroleum-based chemicals decreased.[3] Today, as petroleum-based chemicals are becoming more costly, there is a resurgent interest in environmentally friendly and renewable materials for wood adhesives (e.g., ongoing research into soybean flour-based adhesive resin formulations).[4–7]

It has been estimated that the U.S. poultry industry annually generates 3 to 5 billion pounds of waste feathers.[8,9] Except for a very small amount of waste feathers that are being used as a supplement to animal feed, most of this proteinacious material is land-filled. In recent years, however, some innovative uses of waste feather have been proposed.[8–10] In the case of wood adhesives, feather proteins possess several advantages over soy proteins: (1) feather protein is a keratin, and its hydrophobic nature endows a better water resistance to the final product; (2) feather protein is a fibrin, which is less likely to flocculate and is much easier to hydrolyze than globulins such as soy; (3) some components in feather protein are naturally anti-mildew.

This article reports a preliminary study on the synthesis of feather protein–based adhesives for medium density fiberboard (MDF) production, and the physical properties of MDF bonded with feather protein–based adhesives are compared to those using conventional PF resins.

MATERIALS AND METHODS

Feather Meal Hydrolysis

Acid and biological degradation methods have been widely used for the analysis (amino acid composition) and conversion of feathers into useful products.[11–15] In this research feathers were obtained as ground feather meal and hydrolyzed by two methods. The first method involved the dispersion of the feather meal in an aqueous solution containing 6% sodium hydroxide and 2% sodium bisulfite and hydrolyzed in a Parr pressure reactor for 2 h at 120°C to obtain hydrolyzate A. In the second method, hydrolyzate B was obtained by hydrolyzing the feather meal as per hydrozylate A in the presence of two equivalents of phenol (on a dry weight basis). In this procedure, the sodium hydroxide hydrolyzes the peptide bonds while sodium bisulfite cleaves the intra- and inter-molecular disulfide bonds.

Resin Synthesis

The conditions used to synthesize the feather hydrolyzate (A and B) containing adhesive resins involved (1) mixing two parts phenol to one part feather protein based on dry weight; (2) using the formaldehyde to phenol (F/P) molar ratios

Table 1. Physical properties of feather protein-based adhesive resins

Adhesive	Feather Hydrolyzate	F/P Ratio	pH	Viscosity (cps)	Solid Content (%)
A1	A	1.8	9.5	195	45.19
A2	A	2	9.5	205	43.46
A3	A	1.8	10.5	335	46.06
A4	A	2	10.5	402	42.97
A5	A	1.8	11.5	480	45.52
A6	A	2	11.5	578	44.60
B1	B	1.8	9.5	225	47.08
B2	B	2	9.5	200	44.08
B3	B	1.8	10.5	450	46.30
B4	B	2	10.5	385	44.01
B5	B	1.8	11.5	815	47.10
B6	B	2	11.5	527	45.10

of 2.0 and 1.8; and (3) using different reaction pH conditions, pH 9.5, 10.5, and 11.5. For the resin formulations resins containing hydrolyzate A, predetermined amounts of phenol and formaldehyde were added to hydrolyzate A, followed by pH adjustment and heating the mixture to 90°C for 2.5 h followed by cooling to room temperature. For the resins containing hydrolyzate B, no additional phenol was added based on the assumption that there was no loss of phenol during the hydrolysis of the feather meal. Thus, only a predetermined amount of formaldehyde was added, followed by pH adjustment and heating to 90°C for 2.5 h. Twelve different resin formulations were prepared as summarized in Table 1. These 12 feather protein–based resins and a commercial PF resin were used to manufacture southern pine fiberboard.

MDF Fabrication and Evaluation

Southern pine fiberboards, 12 cm × 12 cm × 3 mm in size, with a target density of 0.8 g/cm^3 were made with 8% resin solids based on dry weight of fiber. Each resin formulation was replicated 3 times and boards were pressed at 180°C for 5 min.

Modulus of rupture (MOR) and modulus of elasticity (MOE), internal bonding strength (IB), and percent thickness swell (TS, 24-h cold water soaking) were measured based on ASTM D1037-96 standard methods.[14] Bending properties and IB were determined with an Instron 4465 test machine. Bending properties were measured using 12 cm × 2.54 cm × 3 mm specimens, and the IB (2.54 cm × 2.54cm) and TS (2.54 cm × 5.0 cm) test specimens were obtained from the fractured bending specimens. Results were analyzed using Tukey's test with SAS software.

RESULTS AND DISCUSSION

Physical properties of synthesized feather protein–based adhesive reins are summarized in Table 1. Viscosity of the final resins increased with increasing pH during resin synthesis. Viscosity of resins synthesized at pH 9.5 and 10.5 ranged between 200 cps and 450 cps, which were easily sprayed during fiberboard fabrication. The resins synthesized at pH 11.5, however, were usually higher in viscosity (over 500 cps), making spraying much more difficult, and likely reduced the board properties because of the poor resin distribution. It was also found that the resins synthesized with the feather hydrolyzate B (hydrolyzed with presence of phenol) generally had higher viscosities than those synthesized with hydrolyzate A (hydrolyzed without phenol). This may indicate that hydrolyzate B facilitates crosslinking between the protein and phenol-formaldehyde during hydrolysis and resin synthesis. A possible reaction pathway is outline as follows:

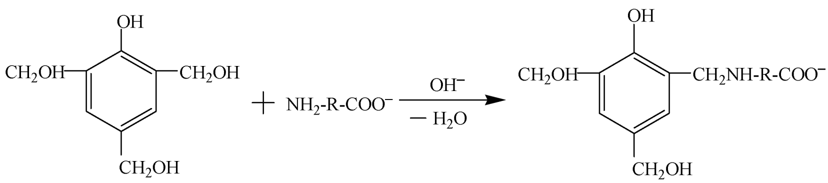

Table 2 summarizes the physical properties of the southern pine fiberboard bonded with feather protein–based resins. Statistical analyses of the resin performance are presented in Table 3. Internal bonding strength (IB) and percent thickness swell (TS) of composite panels are the most important properties in evaluating performance of adhesive resins. As shown in Table 3, pH and F/P ratio alone had a significant influence on the performance of resins formulated with hydrolyzed feathers, especially IB and TS. Resins formulated at pH 10.5 were superior to those formulated at pH 9.5 and 11.5, and resins formulated with 2.0 F/P ratio were better than those with the 1.8 F/P ratio. The method of feather hydrolysis only affected the percent thickness swell of the fiberboard, where resins containing feather hydrolyzate B (hydrolyzed in the presence of phenol) performed better than those containing hydrolyzate A (hydrolyzed without presence of phenol). Interactions between hydrolysis method and pH and between hydrolysis method and F/P, however, had a strong influence on the performance of the resulting resins. Figure 1 shows that the resin synthesized with feather hydrolyzate B at pH 10.5 performed better in IB and thickness swell than resins synthesized at the other conditions.

Table 2. Physical properties of southern pine fiberboard bonded with feather protein-based adhesive resins

Resin	Feather[1] Hydroly.	P/F Ratio	pH	Density (g/cm^3)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS[2] (%)
A1	A	1.8	9.5	0.84	40.10 a[3]	3179 a	0.44 cd	32.8 a
A3	A	1.8	10.5	0.83	41.77 a	2634 bcd	0.53 cd	19.2 ef
A5	A	1.8	11.5	0.81	42.08 a	2879 ab	0.43 cd	25.1 b
A2	A	2	9.5	0.85	31.89 c	2339 d	0.53 cd	23.4 bc
A4	A	2	10.5	0.85	42.75 a	2812 bc	0.62 bc	18.4 f
A6	A	2	11.5	0.84	42.22 a	2809 bc	0.70 ab	22.5 bc
B1	B	1.8	9.5	0.84	42.31 a	3063 ab	0.48 cd	20.8 d
B3	B	1.8	10.5	0.84	34.46 bc	2597 bcd	0.41 cd	20.1 de
B5	B	1.8	11.5	0.83	35.53 bc	2591 bcd	0.29 e	23.8 b
B2	B	2.0	9.5	0.86	38.48 ab	2861 ab	0.72 ab	20.9 d
B4	B	2.0	10.5	0.84	41.63 a	2770 bc	0.76 a	18.3 f
B6	B	2.0	11.5	0.84	31.63 c	2350 d	0.40 cd	20.2 de
PF	—	—	—	0.81	40.35	297.3	0.60	20.7

[1]Feather hydroly. A = alkaline hydrolysis without presence of phenol; hydrolyzate B = alkaline hydrolysis with presence of phenol. The feather-based resins contained 30% solids of feather hydrolyzate A or B.

[2] Percent thickness swell after 24-hour soaking in cold water.

[3]Means with the same letter are not significantly different at the 5% level.

Likewise, the resin synthesized with hydrolyzate B at the F/P ratio of 2.0 had better IB and less thickness swell than resins formulated at the other conditions (Figure 2). The interaction between pH and F/P ratio also had a strong influence on resin quality. Resins synthesized at pH 10.5 with an F/P ratio of 2.0 had better IB and lower TS than the other resin formulations.

Table 3. Statistical analysis of effects of feather protein-based adhesive resin synthesis on fiberboard physical properties

Factors	MOR	MOE	IB	TS
		$p =$		
Hydro(lysis)	0.0848	0.5407	0.8091	<0.0001
pH	0.0306	0.2270	0.0007	<0.0001
F/P	0.2789	0.0334	<0.0001	<0.0001
Hydro × pH	0.0001	0.0006	<0.0001	<0.0001
Hydro × F/P	0.3626	0.3264	0.1275	0.0194
pH × F/P	0.0106	0.0017	0.7280	0.0208
Hydro × pH × F/P	0.3447	0.0848	0.0735	<0.0001

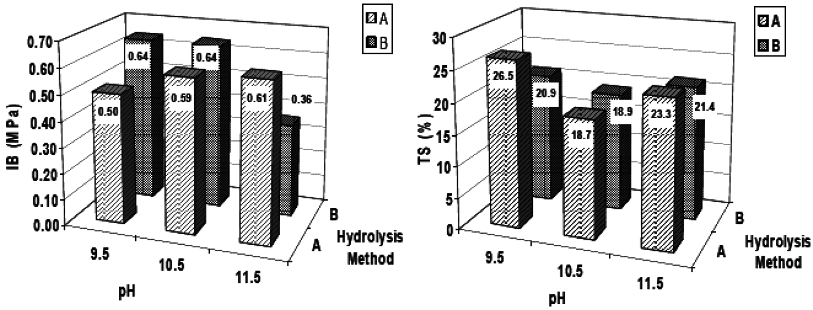

Figure 1 Effects of interaction between hydrolysis method and pH on internal bonding strength (IB) and percent thickness swell (TS) of southern pine fiberboard.

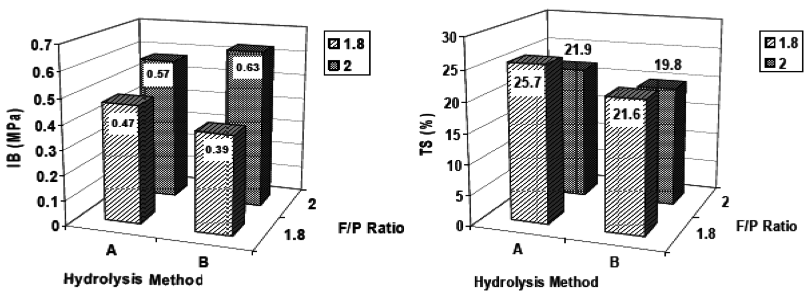

Figure 2 Effects of interaction between hydrolysis method and F/P ratio on internal bonding strength (IB) and percent thickness swell (TS) of southern pine fiberboard.

Three-way interaction among hydrolysis method, pH, and F/P ratio only influenced TS. The resin synthesized with hydrolyzate B at pH 10.5 and F/P ratio of 2.0 clearly had the best performance among the 12 feather protein–based resins (Table 2). This feather-based resin performed as well as the commercial PF resin in bending properties and IB, but had a significantly lower percent thickness swell at the 1% level. For larger boards, made from the same materials, TS may be the best indicator of board properties, and therefore feather proteins crosslinked with PF may not only be an effective PF-extender or filler, but enhancer of board properties.

CONCLUSIONS

Feather protein–based resins were formulated using two hydrolysis methods, two F/P ratios, and three pH conditions. The feather hydrolyzate obtained using one part feather meal hydrolyzed under alkaline conditions in the presence of two parts phenol and formulated with an F/P ratio of 2.0 at pH 10.5, produced a feather protein–based resin, which, at a level of 30% phenol replacement with feather protein, performed as well as a commercial PF resin. Based on these findings, it appears that feather protein is an effective co-polymer in such formulated resins, and may be a cost-effective supplemental raw material in the manufacture of PF-type wood adhesive resins.

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