H₂O₂ as a Modifier of Phenol–Formaldehyde Resin used in the Production of Particleboards

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ABSTRACT: The purpose of the research was to study the influence of H_2O_2 on the properties of fluid phenolic (PF) resin, the curing process, the cured resin structure, and the properties of the particleboards produced with its use. The influence of added H_2O_2 on resin usability at 20°C, on the gel time of the modified PF resin in the temperature range 110–140°C, and on the activation energy of the curing process were studied. Also, the structure of the cured resin was examined by Fourier transform infrared spectroscopy. Fi

INTRODUCTION

The properties of particleboards greatly depend on the kind and amount of the bonding agent applied during their production. In the process of manufacturing boards for use in the building industry, phenol-formaldehyde (PF) resins are commonly used because they emit only slight amounts of phenol and formaldehyde and because the boards glued with them are characterized by good physical and mechanical properties. In the process of gluing, PF resins show little sensitivity to humidity of the glued wood, and the resultant adhesive-bonded joints are relatively flexible, vibration resistant, and thermally stable. However, during the curing process, high temperatures or long pressing times are required and the cost of manufacturing the resins is relatively high. For these reasons, researchers strive to improve the technological and economical aspects of the production process, mostly by increasing resin reactivity.^{1,2} Most research on the activation of PF resins focuses on the production of water-resistant plywood. The scope of this research has only to a certain extent been concerned with polycondensation of resins in the technological process of producing particleboards. The process of resin activation should be conducted in such a way that, on the one hand, it does not decrease the usability of the mixed glue and, on the other hand, it shortens the polycondensation time at higher temperatures (i.e., during particleboard pressing).

nally, the properties of the obtained particleboards were determined. The results indicate that the H_2O_2 modification leads to greater reactivity of the phenolic resin and increases the mechanical properties of particleboards. In contrast, there is no significant influence of H_2O_2 on the water resistance of the particleboards. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 88: 3084–3092, 2003

Key words: adhesives; resins; modification; FT-IR

Previous studies in which numerous groups of chemical compounds were tested for the production of plywood and laminated wood, showing that encouraging results can be obtained by introducing inorganic oxidizing agents into PF resins because they are capable of speeding the curing process.^{3–5} Yet, it must be noted that many oxidizing agents are relatively expensive: assuming the oxidizing agents are mixed with glue in amounts up to 5% by weight in relation to the dry mass of the resin, a noticeable increase in the cost of manufacturing wood-based materials would result from their use. Also, oxidizing agents often contain heavy metals, which is a drawback from an ecological point of view. Therefore, for the purposes of this study, H₂O₂ was selected as the accelarator of the reaction of PF resin polycondensation. Its availability, low price, and the fact that it does not contain any elements or functional groups that unfavorably affect the health issues associated with the particleboards are undeniable advantages of this compound. Moreover, resins produced with H₂O₂ are characterized by long life. There are also sufficient grounds to assume that H₂O₂ can act in a twofold manner; that is, as an accelerator of the curing process and as an activator of the wood surface, which assists the adhesion process.^{6–8}

The purpose of the present work is to study the influence of H_2O_2 on the properties of fluid and polycondensated phenolic resin as well as particleboards produced with its use.

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EXPERIMENTAL

Materials

For research purposes, pure resol phenol–formaldehyde (PF) resin designed for use in the production of

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Cl	haracteristics of PF Resin	
Characteristic	Properties stated by the manufacturer	Actual properties
Appearance	Dark red liquid	Clear dark red liquid
Density, g/cm ³		1.21
Dynamic viscosity, mPa·s	90–500	465
Solids content, %	43–47	44.8
pH	_	11.63
Gel time at 120°C, s		206
Life, days	60	54
Free phenol content, %	max. 0.10	0.03
Free formaldehyde content, %	max. 0.100	0.034
NaOH content, %	max. 8.00	7.47

TABLE I Characteristics of PF Resi

particleboards was used (Fenokol 43, manufactured by CHEMKO, a. s., Strážske, Slovak Republic). The properties of the PF resin are shown in Table I.

The PF resin was modified with a liquid solution of $30\% H_2O_2$, with a density of 1.11 kg/dm^3 . The reagent was analytically pure. The H_2O_2 was produced by CHEMPUR, Piekary Śląskie, Poland.

Scotch pine (*Pinus silvestris L.*) flakes obtained under industry conditions were used to produce particleboards. The flakes were subjected to screen classification before being used for the production of particleboards. Dust and the fraction that was unable to pass through square mesh (2 mm on a side) were removed. Some of the flakes were ground in a vibratory ball mill. The resultant dust was used in preparing samples for analysis by Fourier transform infrared (FTIR) spectroscopy and determination of activation energy of the PF resin crosslinking. The cellulose used in the FTIR tests was manufactured by SERVA Feinbiochemika, Heidelberg, Germany. The reagent was analytically pure.

Influence of H₂O₂ on PF resin at 20°C

The use of oxidizing agents that activate the curing process leads to significant changes in the viscosity of the prepared mixed glue. Thus, it was possible to determine the influence of H_2O_2 added to the PF resin on the resin viscosity as a function of time. First,

immediately before the determination, solutions of mixed glue were prepared; the solutions contained 0, 1, 2, 5, 10, and 15 parts by weight of H_2O_2 per 100 parts by weight of dry resin solids. Every hour, the dynamic viscosity of the solutions was determined with a Höppler rheoviscometer manufactured by VEB MLW Prüfgeräte-Werk Medingen, Dresden. The name Höppler rheoviscometer is a brand name used by the manufacturer. However, the referred viscometer is in fact a falling-weight viscometer. The measurements were repeated over a period of 12 h, and an addition measurement was made after 24 h.

Gel time of PF resin modified with H₂O₂ and determination of the activation energy of crosslinking

The ability to activate the thermosetting resins with various additives is commonly estimated by measurements of the gel time of the mixed glue at temperatures of $\geq 100^{\circ}$ C. Therefore, the gel times were examined at the temperatures of 110, 120, 130, and 140°C. The solutions of mixed glue were prepared by adding H_2O_2 to the resin immediately before the determination. The mixtures consisted of 0, 1, 2, 5, 10, and 15 parts by weight of the H_2O_2 modifier per 100 parts by weight of the H_2O_2 modifier per 100 parts by weight of dry resin solids. The volume of the added H_2O_2 solution was constant. The amount of the modifier was adjusted by changing its concentration in the

TABLE II Changes with Time in Viscosity of PF Resin Modified with H_2O_2

						1	Dynamic	viscosity	∕, mPa•s					
H_2O_2 fraction						Meas	suremen	t time aft	er mixing	; <i>,</i> h				
%	0	1	2	3	4	5	6	7	8	9	10	11	12	24
0	423	423	423	423	423	423	424	425	426	426	427	427	427	432
1	419	423	428	429	436	441	448	458	468	512	546	567	587	756
2	415	423	447	487	498	512	532	558	576	643	687	745	812	1456
5	404	438	496	536	617	658	679	721	767	821	956	1056	1167	2954
10	387	442	513	607	733	829	920	998	1081	1201	1254	1432	1589	5123
15	371	456	523	638	791	876	945	1023	1199	1387	1676	1932	2130	7967

120

130

140

Influence	of H ₂ O ₂ Var	on the	Gel Tir mperatu	ne of Pl ires	F Resin	at
		-	H ₂ O ₂ Fr	action, %	Ď	
Curing	0	1	2	5	10	15
°C			Gel ti	ime, s		
110	432	410	390	353	304	284

180

102

72

164

100

71

159

99

71

143

98

70

208

103

73

220

106

73

TABLE III

solution. Moreover, to determine the possible influence of H_2O_2 on the reaction of PF resin towards wood, the following mixtures were prepared and tested: resin and distilled water; resin and H₂O₂; resin and pine dust; resin, pine dust, and distilled water; and resin, pine dust, and H₂O₂. The amount of H₂O₂ was 10 parts by weight. The amount of pine dust was 30 parts by weight of dry mass per 100 parts by weight of dry resin solids.

The gel times of mixed glue were used to assess the relative activation energy of the crosslinking process of the tested variants.⁹ A preliminary assumption was made that the curve illustrating the curing process with time, for the temperatures of 110, 120, 130, and 140°C, was a linear function (until the curing point was reached). Because the reaction rate increases along with the rise of the temperature, it is possible to correlate it with the reaction temperature. The logarithmic curve of the curing rate is dependent on the inverse of the absolute temperature as shown by the very good linear correlation. In these conditions, the activation energy (E_a) can be calculated on the basis of Arrhenius equation:

$$k = A \exp(-E_a/RT) \tag{1}$$

where k is the curing reaction rate constant, A is the pre-exponential factor, R is the gas constant, and T is the absolute temperature.

FTIR spectroscopic study of cured resin structure

FTIR spectroscopy was used to explain the influence of H_2O_2 on the structure of the cured resin, the wood substance, and the character of interactions between the resin and wood. The analyses were made for pine wood, cellulose, and phenolic resin before and after the activation with H₂O₂; for nonactivated and activated pine dust; and for cellulose with resin. All the samples were cured at various temperatures. The curing processes took place in test tubes placed in a glycerol bath. Moreover, the samples intended for FTIR analysis were dried under vacuum in the presence of P₂O₅ and later ground in a vibratory ball mill. Mixtures of these samples with KBr were prepared in the weight ratio 1:200 and homogenized in a ball mill. Then, 200 mg of the homogenized mixture were subjected to tableting in a hydraulic press under vacuum and a pressure per unit area of 100 MPa. The FTIR spectra were recorded with the Mattson Infinity FTIR spectrophotometer (Mattson Instruments, Madison, WI) at resolution of 2 cm^{-1} . Estimates of the baseline were made between 4000 and 2940, 2940 and 1737, and 625 cm^{-1} .

Production of the laboratory particleboards and examination of their properties

To examine the influence of H_2O_2 on the properties of particleboards glued with PF resin, single-layer boards with density of 700 kg/m³ and dimensions of $450 \times 450 \times 12$ mm were produced under laboratory conditions. The following pressing parameters were employed: pressure, 2.5 MPa; temperatures, 180, 200, and 220°C; time, 8-12 min. H₂O₂ was added to the glue, and the resultant mixture was spread over the particles in a slow-speed laboratory blender. The amounts of H₂O₂ were 0.0, 0.1, 0.2, 0.5, 1.0, and 1.5% in relation to the dry mass of the chip. The resin levels were 6, 8, 10, and 12%.

The properties of the particleboards were examined according to the relevant European Standards (EN):

	Gel Tin	ne of PF Resin v	vith Various Ad	ditives at Various Te	emperatures	
				Formulation		
Curing	PF resin	PF resin + H ₂ O ^a	PF resin + H ₂ O ₂ ^b	PF resin + pine dust ^c	PF resin + pine dust ^c + H ₂ O ^a	$\begin{array}{c} \text{PF resin} \\ + \text{ pine dust}^c \\ + \text{H}_2\text{O}_3^{\ b} \end{array}$
°C				Gel time, s		
110	403	430	301	171	190	150
120	206	215	149	103	142	94
130	100	104	99	75	89	71
140	68	73	71	60	69	63

TABLE IV

^a Water was added in the amount corresponding to the amount of water added as diluent of H_2O_{2} .

^b The amount of H_2O_2 added was 10% in relation to dry mass.

 $^{
m c}$ The amount of pine dust added was 30% of dry mass in relation to the dry mass of the resin.

		TA	BLE V			
	Curing I	Process	Kinetic	Par	ameters	
-	1					

Formulation	Activation energy, kJ/mol
PF resin	79.66
PF resin + H_2O	79.74
PF resin + H_2O_2	62.80
PF resin + pine dust	45.70
PF resin + pine dust + H_2O	46.25
PF resin + pine dust + H_2O_2	38.07

modulus of rupture (MOR) and modulus of elasticity (MOE) according to EN 310;¹⁰ internal bond (IB) according to EN 319;¹¹ swelling in thickness after 24 h according to EN 317;¹² and moisture resistance (test V 100) according to EN 1087-1.¹³

RESULTS AND DISCUSSION

Influence of H₂O₂ on resin stability at 20°C and curing kinetics

The influence of H_2O_2 on the stability of PF resin at 20°C is shown in Table II. The data show that as the amount of H_2O_2 in the resin increased to 5% the dynamic viscosity after 8 h (i.e., in the period of time used in the production conditions) increased slightly. Yet, the resins containing 10 and 15% modifier were characterized by much higher viscosity. The latter result, however, does not exclude the possibility of using the resin in industrial conditions.

The influence of the amount of H_2O_2 added to the resin on the gel time is illustrated in Table III. The data

show that at 110 and 120°C, the gel time shortened as the amount of the added modifier increased. This process is less distinct at 130 and 140°C.

The influence of H_2O_2 and other components present in the PF resin polycondensation process on its gel time is shown in Table IV. Water added to the resin in an amount that corresponds to that of H_2O_2 did not significantly affect the gel time of PF resin. However, the addition of pine dust shortened this time considerably, especially at lower temperatures. The greatest reduction of the gel times was observed when both H_2O_2 and pine dust were introduced to the resin.

The influence of H_2O_2 and other components present in the PF resin polycondensation process on the activation energy of this process, based on gel time measurements, is shown in Table V. The data confirm that H_2O_2 introduced into the resin along with pine dust leads to a significant decrease in the activation energy of this process.

FTIR spectroscopy

The FTIR spectra of the studied samples are shown in Figures 1–5. Qualitative analysis of spectra illustrated in Figure show that PF resins cured at 130 and 150°C are not significantly different. Other spectra, illustrated in Figures 2 and 3, show the influence of H_2O_2 on the structure of the cured resin. The qualitative and quantitative changes featuring at 130°C were slight. The action of H_2O_2 led to slight changes in the 1100



Figure 1 FTIR spectra of PF resins cured at (1) 130°C and (2) 150°C.



Figure 2 FTIR spectra of PF resins cured at 130° C, with (1H) and without (1) the addition of H₂O₂.

cm⁻¹ band. The influence of H₂O₂ on the structure of the cured resin was much more significant for the curing temperature of 150°C. In this case, under the influence of H₂O₂, peaks appeared at 1635, 1376, and 1063 cm⁻¹. The latter is a counterpart of the weak peak at ~1100 cm⁻¹ in case of the resin cured with the addition of H₂O₂ at

 130° C. Taking into account the expected oxidizing effect of hydrogen peroxide on PF resin, the observed changes should be ascribed to the formation of carboxylic ion. The quantitative changes are characterized by the increasing number of OH groups in the 3460 and 1205 cm⁻¹ bands in case of the oxidized resin.



Figure 3 FTIR spectra of PF resin cured at 150°C, with (2H) and without (2) the addition of H_2O_2 .



Figure 4 FTIR spectra of pine dust held at 100°C, with (PH) and without (P) the addition of H_2O_2 .

The FTIR spectra of pine wood before and after the activation indicate that there were considerable changes in the structure of wood treated with H_2O_2 (Figs. 4 and 5, respectively). The spectra vary in both a qualitative and a quantitative sense. The qualitative changes refer mainly to the "fingerprint" range (i.e.,

 $1740-600 \text{ cm}^{-1}$). In the spectra of wood that was not treated with H₂O₂, it is possible to distinguish bands characteristic of vibrations of the lignin aromatic ring at 1603 and 1510 cm⁻¹. However, in the spectra of wood activated with H₂O₂, there is no band at 1603 cm⁻¹ and the intensity of the band at 1510 cm⁻¹



Figure 5 FTIR spectra of cellulose held at 100°C, with (CH) and without (C) the addition of H₂O₂.

decreases by 35%. Because there were no qualitative or quantitative changes in the activated cellulose (Fig. 5), we assume that under the discussed conditions, H_2O_2 affected mostly the lignin system in wood, leading to the decomposition of its aromatic structure. Cellulose seems to have been much more resistant to the action of H₂O₂. Other than the changes in the aromatic system, a very intensive increment of systems containing carbonyl groups C=O (1738 cm⁻¹) occurs in the wood treated with H_2O_2 . Yet, the band at 1660 cm⁻¹ shifted to 1644 cm⁻¹, and its intensity increased 1.5 times, which may indicate that coupled ketone groups and C=C bonds (e.g., quinone methide groups) formed in the system. The decay of the lignin band at 1603 $\rm cm^{-1}$ and the reduction of the peak at 1510 cm^{-1} , coupled with the simultaneous intensification of the bands of cellulose and hemicelluloses at 3430, 1372, 1329, 1157, 1110, and 1054 cm⁻¹, lead to the conclusion that H₂O₂ caused some delignification of wood.

Particleboard properties

The results of studies on particleboards produced under laboratory conditions are presented in Tables VI to VIII. Introduction of increasing amounts of H₂O₂ into the PF resin led to a parallel increase in MOR. Other factors that affected the MOR of particleboards produced with H₂O₂-modified PF resin were the resin level and pressing time and temperature. At a pressing time of 8 min and temperatures of $\geq 180^{\circ}$ C, dimensionally stable particleboards of the assumed density and without delamination were obtained. The highest MOR values were achieved by boards with resin levels of 10 and 12%. With such resin levels, increasing the pressing temperature up to 220°C did not result in significant changes in MOR of the boards.

The addition of H₂O₂ considerably affected the MOE and IB of the particleboards. As the amount of the added modifier increased, the numerical values of MOE and IB almost doubled, indicating that the modifier strongly influenced the crosslinking process in the pressed board. Lengthening the pressing time up to 10 min made it possible to produce boards with satisfactory properties at temperatures >160°C. In this case, the highest values of MOR were obtained by boards with the resin levels of $\geq 8\%$. Further increases in the pressing time up to 12 min made it possible to produce particleboards with satisfactory MOR values at the lower temperature of 160°C and with 6% resin content. In this case, the MOR increased along with the increase in the amount of H₂O₂ added. Similarly, the influence of the pressing time on the MOE increased almost proportionally as the MOR of the boards pressed under the same conditions increased. However, the addition of H₂O₂ apparently did not affect the resistance of experimental particleboards to the action of water. Only boards produced at rela-

vels	h, %		1.5	12.8	12.6	11.9	12.2	11.8	11.6	12.1	11.6	11.1	12.1	11.5	11.1
in Le	fter 24		1.0	13.4	12.7	12.0	12.8	12.1	11.8	12.3	11.7	11.1	12.3	11.5	11.1
Resi	ness af		0.5	14.3	12.9	12.0	13.5	12.4	12.0	12.4	11.8	11.2	12.4	11.7	11.2
s and	thick		0.2	15.2	13.2	12.1	14.4	13.0	12.2	12.6	11.9	11.4	12.5	11.8	11.2
tures	ling in		0.1	16.1	13.6	12.3	15.0	13.6	12.4	12.9	12.1	11.6	12.7	12.0	11.4
npera	Swel		0.0	16.7	14.4	12.9	15.7	14.3	12.8	13.2	12.6	11.8	13.0	12.3	11.6
; Ten	a		1.5	0.09	0.11	0.11	0.11	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15
ssing	e, MP		1.0	0.08	0.11	0.11	0.11	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15
s Pre	istanc		0.5	0.08	0.10	0.11	0.11	0.12	0.13	0.13	0.13	0.14	0.14	0.15	0.15
ariou	ure res		0.2	0.08	0.09	0.10	0.11	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.15
at Va	Moistu		0.1	0.08	0.08	0.09	0.11	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.14
utes	I	ass, %	0.0	0.08	0.08	0.09	0.11	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.14
Min		dry m	1.5	0.53	0.54	0.63	0.60	0.65	0.74	0.70	0.79	0.82	0.81	0.83	0.84
Eight	«Га	chip	1.0	0.49	0.52	0.60	0.58	0.64	0.69	0.66	0.71	0.76	0.76	0.79	0.81
for]	ond, 1	ion to	0.5	0.42	0.45	0.54	0.55	0.61	0.64	0.60	0.63	0.68	0.68	0.72	0.78
essed	rnal b	n relat	0.2	0.35	0.44	0.52	0.50	0.57	0.60	0.51	0.60	0.62	0.56	0.63	0.66
s Pre	Inte	xide iı	0.1	0.31	0.32	0.36	0.32	0.37	0.46	0.42	0.53	0.58	0.42	0.51	0.56
oard		n pero:	0.0	0.27	0.29	0.33	0.31	0.33	0.35	0.32	0.48	0.53	0.38	0.44	0.50
ticleł		droger	1.5	1623	1929	2087	1812	2198	2248	2189	2268	2389	2264	2398	2543
f Par	', MPa	Hye	1.0	1554	1885	1916	1698	2145	2196	2111	2174	2269	2167	2272	2485
ties o	asticity		0.5	1476	1674	1726	1611	1863	2143	2032	2098	2187	2067	2214	2321
oper	s of ela		0.2	1354	589	0691	589	1782	845	006	995	2935	1987	2102	2178
he Pr	sulubc		0.1	056 1	287	356 1	186	427	586 1	712	819]	912	821	897 2	992
on t	M		0.0	901 1	034 1	243 1	045 1	311 1	378 1	490 1	742 1	857 1	721 1	818 1	897 1
Resin			1.5	3.9	4.8 1	6.2 1	5.8 1	7.1 1	8.2 1	8.8 1	9.3 1	9.7 1	9.2 1	9.8 1	0.2 1
olic]	MPa		1.0	2.2 1	4.3 1	5.8 1	5.1 1	6.8 1	7.9 1	8.3 1	8.6 1	9.2 1	8.9 1	9.2 1	9.7 2
Phen	pture,		0.5	1.3 1	2.8 1	4.7 1	3.6 1	5.6 1	7.2 1	7.5 1	7.9 1	8.1 1	8.1 1	8.9 1	9.2
the	of ruj		0.2 (9.7 1	1.8 1	2.6 1	2.2 1	5.1 1	5.8 1	5.4 1	6.8 1	6.9 1	6.6 1	7.3 1	7.9 1
ed to	dulus		0.1 (7.9	8.6 1	9.9 1	8.7 1	0.2 1	2.1	3.1 1	4.8 1	5.6 1	3.8 1	5.1 1	5.9 1
Add	Mc		0.0	5.8	7.4	8.3	7.3	8.7 1	9.9 1	0.8 1	3.6 1	4.2 1	2.6 1	3.9 1	4.4 1
e of H ₂ O ₂		ressing	°C °C	180	200	220	180	200	220	180 1	200 1	220 1	180 1	200 1	220 1
nfluence		tesin P	% %	6			8			10			12		
	Influence of H ₂ O ₂ Added to the Phenolic Resin on the Properties of Particleboards Pressed for Eight Minutes at Various Pressing Temperatures and Resin Levels	Influence of H ₂ O ₂ Added to the Phenolic Resin on the Properties of Particleboards Pressed for Eight Minutes at Various Pressing Temperatures and Resin Levels Modulus of rupture, MPa Modulus of elasticity, MPa Internal bond, MPa Moisture resistance, MPa Swelling in thickness after 24 h, %	Influence of H ₂ O ₂ Added to the Phenolic Resin on the Properties of Particleboards Pressed for Eight Minutes at Various Pressing Temperatures and Resin Levels Modulus of rupture, MPa Modulus of	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$ \begin{array}{ c c c c c c c c c c c c c c c c c c $									

Ilfull	uence of $H_2^{(1)}$	02 A	dded	to th	e Ph	enoli	c Re	sin o	n the	e Proj	pertic	ss of	Parti	TAE clebo	LE V ards	/II Press	ied fu	or Te	n Mi	nute	s at V	/arioı	15 Pr	essin	g Ter	mper	ature	s and	l Res	in Le	vels	
			Iodulu	s of n	upture	e, MPé	-		Modu	lus of	elastic	zity, M	Рa		Ir	Iternal	l bond	, MPa			Moi	sture r	esistaı	nce, M	Гa	Sw	elling	in thic	kness a	after 2	4 h, %	
Resin level.	Pressing temperature												Hydro	gen pt	roxid€	in re	lation	to chi	p dry	mass,	%											
%	°C	0.0	0.1	0.2	0.5	1.0	1.5	0.0	0.1	0.2	0.5	1.0	.1.	5 0.	0 0	1 0.	2 0	5 1.(0 1.	0.	0 0.	1 0.2	0.5	1.6) 1.5	0.0	0.1	0.2	0.5	1.0	1.5	
6	160 180 200	7.5 8.0 8.4	10.6 11.0	14.0 14.2	15.3 16.0	16.3 17.1 17.3	17.1 17.6 17.8	980 1213 1321	1391 1535 1645	184(1854	3 201 4 203 10	6 215 0 220 3 776	6 22(6 22(7 25(0000	30 0.4 34 0.4	4 0.5 8 0.5	56 0.6 2 0.5 1 0.6	1 0.6 7 0.5	55 0.6 8 0.6	8 0.0 0 0.1	9 0.0 0 0.1 1 0 0.1	0 0.1	0 0.1	0 0.15	1 0.12 1 0.12 1 0.12	2 16. 2 13. 11. r	3 15.8 2 13.2 13.2	8 15.1 2 13.2 13.2	14.9 12.5	13.5 10.9	16.6 10.9	
	220	11.5	14.4	16.9	18.9	20.2	21.1	1467	1945	214	3 253.	2 264	5 26	~0 %	16 0.5	8 0.6	4 0.7	5 0.8	2 0.8	4 0.1	2 0.1	2 0.1	2 0.1	3 0.1	3 0.13	3 10.0	5 10.6	5 10.6	10.5	10.5	10.5	
œ	160 180	8.9 10.1	13.2 13.4	16.1 16.2	16.3 18.2	17.3 19.4	18.2 19.8	1175 1409	1766 1721	212	9 214	7 226 0 244	9 23 ⁶ 0 24 ⁶	96 0.5 33 0.5	30 0.4 38 0.4	5 0.5 7 0.5	54 0.5 5 0.5	9 0.6	58 0.6 2 0.6	5 0.1	90 0.(9 0.1 1 0.1	1 0.1 2 0.1	1 0.1 2 0.1	1 0.12 2 0.14	4 11.6	8 13. ¹	3 11.5	12.6	12.5	12.4 11.2	
	200 220	11.4 14.0	14.0 15.9	17.8 17.8	18.8 19.8	20.3 21.0	20.3 22.1	1412 1835	1876 1902	235	4 223 7 243.	1 261 4 264	.1 26(3 271	28 0.4 2 0.5	H6 0.5 56 0.6	4 0.7	71 0.7 2 0.7	3.0 7 9.0.8	31 0.8 15 0.8	8 0.1 8 0.1	[2 0.1 [3 0.1	2 0.1 0.1	2 0.1 2 0.1	4 0.1 5 0.1	5 0.15 5 0.16	5 11. 5 10.	0 11.(4 10.4	0 11.(4 10.4	10.9	10.9	10.9 10.4	
10	160 180	11.2	15.4 15.4	17.0 18.2	18.0 20.2	18.2 21.1	18.3 71.4	1629 1646	1925	223() 241 249	1 245	8 25. 8 26	l8 0.	35 0.4 10 0.5	2 0.4	10 8 10 8 10 6	20.5	84 0.5 2.0 2	36 0.C)0 0.(10 c	9 0.1 110 c	1 0.1	1 0.1	4 0.15	13.1	9 13.4 1111	4 12.5	12.1	12.1	12.0 10.8	
	200	15.9	18.0	19.6	20.6	21.4	21.6	1970	2191	239(258	7 268	6 50 F		50 0.7 96 0.7	0.7	3.0 °C	0.8 0.8	6 0.8	- 0 - 1 - 0 - 1	4 0.1	4 0.1	6 0.1	4 0.1(0.1(4 0.16 6 0.16	2 10.5	9 10.5	9 10.5	10.8	10.8	10.8	
5	220 160	17.0 14 1	16.7 16.7	20.6 18.0	21.8 18.8	22.3 19.3	22.5 19.5	2210 1858	2387 2197	252	1 267 5 2463	8 275 8 250	36 272 3 254	39 0.5	58 0.7 15 0.4	5 0.8 7 0.8	30 0.5 7 0 4	5 0.5 7 0.4	80 0.5 6 0.4	0.1	2 0.1 2 0.1	0.1 0 1 0	6 0.1 2 0.1	7 0.1 0 15	7 0.17 0.13	7 10. 10.	2 10.	2 10.2 3 11 1	10.2	13.5	10.2 14.2	
71	180	14.2	17.3	20.3	22.0	22.2	22.2	1989	2274	259() 275(0 278	275	5 0.4 15 0.4	11 0.5 0.5	2 0.6	0.0	0.7	1. 0.7	4 0.1	4 0.1	4 0.1 0.1	5 0.1 0.1	5 0.15	5 0.15		3 10.5	3 10.5	10.4	10.6	10.7	
	200	19.9	20.7	22.0	22.1	22.2	22.6	2423	2587	269	8 271	3 278	9 28	12 0.6	56 0.7	2 0.7	3.0 6.	3 0.8	6 0.8	7 0.1	5 0.1	6 0.1 ¹	6 0.1	6 0.1(6 0.17	7 10.	3 10.5	3 10.5	10.4	10.4	10.4	
	220	20.0	21.3	22.0	22.3	22.9	23.4	2478	2654	275	4 276	5 284	3 28	⁷⁶ 0.8	30 0.5	5 0.8	3.0 28	50 6s	2 0.5	4 0.1	[6 0. <u>]</u>	7 0.1	8 0.1	8 0.1	8 0.18	8 10.	2 10.2	2 10.2	10.2	10.2	10.2	
Ilnflı	nence of $H_{2^{1}}$	02 A	dded	to th	e Ph	enoli	ic Re	sin o	n Pro	opert	ies o	f Parl	icleb	TAB oard:	LE V 5 Pres	'III ssed	for T	welv	e Mi	nute	s at V	rariot	ıs pr	essing	g Ten	nper	ature	s and	Resi	in Le	vels	
			Modulı	15 of 1	uptur	e, MP	a		Modu	ulus of	elasti	city, N	1Pa		П	nterna	l bonc	l, MPâ			Moi	sture r	esistaı	nce, M	IPa	Sw	elling	in thic	kness a	after 2	ł h, %	
Resin	Pressing											1	Hydro	gen p	eroxid	e in re	lation	to ch:	ip dry	mass	, %											
%	°C	0.0	0.1	0.2	0.5	1.0	1.5	0.0	0.1	0.2	0.5	5 1.4	9 1.	5 0.	0 0.	1 0.	2 0.	5 1.	0 1.	5 0.	0 0.	1 0.2	2 0.1	5 1.0) 1.5	0.0	0.1	0.2	0.5	1.0	1.5	
9	160 180	9.2 10.4	12.4 12.8	14.8 14.6	16.6 18.4	17.1 18.6	17.4 18.9	1413 1467	1545 1589	5 188	7 214 3 249	16 238 3 255	39 24 31 26	63 0 13 0.	37 0.4 38 0.4	t3 0.5 15 0.6	58 0.6 50 0.6	54 0.6 77 0.7	56 0.7 71 0.7	70 0.	10 0.1 12 0.1	0 0.1	0 0.1	1 0.1 0.1	2 0.15 0.15	2 14.	2 13.5 5 12 1	8 13.2	12.9	12.8	12.7 11.5	
	200	11.3	14.6	16.9	18.6	18.9	19.3	1578	1683	3 244	5 254	18 76 18 76	31 26	0.0 88 88	10 0.5	54 0.6	55 0.7	71 0.7	73 0.7	4 0.	12 0.1	0.1	2 0.1	0.1	0.15	111	5 11.	2 11.0	11.0	10.9	10.9	
8	220 160	12.6 11.3	14.2 14.2	17.3 16.4	19.8 16.8	20.3 17.8	21.2 18.4	1623 1426	1783 1783	218 218	1 201 9 215	237 237 237	24 24 24	37 U. 37 U.	#1 U.(39 0.4	50 0.6 18 0.5	0.6 26 0.6	8 0.6 8 0.6	50 0.7 1.0 2.0	50 U. 74 U.	13 U. 11 U.1	3 0.1 1 0.1	3 0.1 1 0.1	3 0.1 0.1	3 U.L 2 0.12	2 10. 14.	6 10.4 1 13.2	2 12.1	11.8	11.7	c.01 11.7	
	180	13.8	15.8	16.9	18.4	19.8	20.1	1638	1793	3 223	6 234	13 267	73 26	93 0	41 0.5	59 0.£	57 0.6	3.0 85	31 0.5	33 0.1	12 0.1	2 0.1	2 0.1	3 0.1.	3 0.14	4 11.	6 11.6	6 11.5	11.3	11.2	11.2	
	200	14.2 17.3	16.9 17.3	18.1 18.4	19.1 19.9	20.8 21.3	21.6 223	1663 1938	2231 2318	1 239	6 258 8 263	33 27(272	07 27. 19 27	26 0. 37 0. ¹	46 0.6 51 0.6	51 0.7 77 0.7	73 0.7 7 0.5	3.0 67	35 0.8 8 0.8	38 0.1 1	12 0. 13 01	3 0.1 9 0 1	3 0.1 0 1	5 0.1	5 0.15 5 0.15	5 10. 10.	$\begin{array}{c} 9 & 10.5 \\ 10.4 \\ 10.4 \end{array}$	$\begin{array}{c} 9 & 10.5 \\ 1 & 10.4 \end{array}$	10.8	10.8	10.8	
10	160	13.2	15.3	18.1	18.9	19.6	20.7	1698	1798	242	7 256	9 261	121	38 0.	11 0.4	18 0.6	51 0.6	4 0.7	72 O.7	78 0.1	12 0.1	2 0.1	2 0.1	3 0.1.	3 0.14	4 12.5	9 12.4	4 11.5	11.7	11.3	11.0	
	180	14.2	18.0	20.3	21.5	21.9	22.1	1764	2247	7 258	0 273	4 277	78 27	92 0.	18 0. E	59 0.£	.0 6č	3.0 77	32 0.5	34 0.7	13 0.1	3 0.1	3 0.1	4 0.1	4 0.15	5 10.	5 10.4	4 10.4	10.3	10.3	10.3	
	200 220	16.6 18.3	18.7 19.8	20.9 21.4	21.9	22.7 22.8	22.8 27.8	2166 2439	2325 2583	3 272 3 275	3 275 8 284	38 28 1 28	41 28 7 28	67 U. 33 U.f	57 0.7 88 0.7	74 0.8 76 0.8	33 0.5 8 0.5	36 0.5 19	39 0.5 39 0.5	39 0. 0	15 0.1 16 0.1	5 0.1 6 0.1	6 0.1 6 0.1	6 0.1 7 0.1	6 0.14 7 0.17	6 10. 7 10.	3 10. 10.5	3 10.5	10.3	10.3	10.3	

 $\begin{array}{c} 0.15\\ 0.15\\ 0.16\\ 0.16\\ 0.18\end{array}$

 $\begin{array}{c} 0.15 \\ 0.15 \\ 0.16 \\ 0.16 \\ 0.18 \end{array}$

0.14 0.15 0.15 0.15 0.16 0.16 0.17 0.18

0.760.140.860.150.890.160.950.17

 $\begin{array}{c} 0.72 \\ 0.83 \\ 0.88 \\ 0.92 \end{array}$

0.63 0.69 0.72 0.78 0.84 0.87 0.88 0.89

 $\begin{array}{c} 0.58 \\ 0.64 \\ 0.78 \\ 0.84 \end{array}$

 $\begin{array}{c} 0.43 \\ 0.51 \\ 0.64 \\ 0.70 \end{array}$

2763 2832 2896 2972

2663 2782 2883 2946

2626 2748 2863 2879

2542 2691 2743 2818

2116 2391 2589 2631

1891 1946 2261 2492

21.6 22.8 22.9 23.5

 19.8
 20.1

 21.6
 22.3

 22.4
 22.4

 22.8
 23.3

18.8 20.6 22.3 22.6

14.916.813.818.617.421.420.621.8

160 2200 2200

12

tively low pressing parameters were characterized by the decrease in swelling in thickness as the amount of H_2O_2 added increased. The accelerator did not distinctly influence the moisture resistance of the particleboards in the boiling test.

The favorable changes connected with the increase in strength properties of the particleboards are unquestionably associated with the activation process of PF resin caused by the action of H_2O_2 , which is illustrated by Tables II–V. Moreover, H_2O_2 affects the wood structure, especially lignin (Fig. 4), which leads to the growth of reactive groups in the wood surface as confirmed by FTIR analyses.

CONCLUSIONS

- 1. Introducing H_2O_2 into the fluid phenolic resin shortens the gel time and pot life of the resin as measured by the increase in viscosity with time and the decrease in activation energy of the polycondensation process. The degree to which these effects occur increases with the increase of the amount of H_2O_2 added. The observed changes of viscosity at 20°C do not limit the usability of obtained mixed glue in the industrial production of particleboards.
- Under the influence of H₂O₂, the structure of the cured phenolic resin, determined by FTIR analysis, undergoes minor changes that are apparently due to the increased number of carboxyl groups,

which are probably the result of oxidation of some hydroxymethylene groups.

- 3. The optimal fraction of H_2O_2 with regard to both the reactivity of the resin and the production of particleboards is 2–5%. This amount makes it possible to produce particleboards of the required properties in a shorter time, at lower temperature, and at decreased resin levels.
- 4. Introducing H₂O₂ into the mixed glue does not significantly influence the resistance of the particleboard to the action of water.

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