Bonding of wood fiber composites using a synthetic chelator-lignin activation system

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Abstract

Wood fibers, after thermo-mechanical pulping, have a high concentration of lignin on the outer surface of the fiber; the residual middle lamella of the woody cell wall. When wood fibers are oxidatively treated with a chelator produced by *Gloeophyllum trabeum* (a brown-rot fungus), in the presence of hydrogen peroxide (H_2O_2) and ferric iron (FeIII), free radicals are produced. Using a synthetic chelator to mimic the action of the free radical generating system, we applied the system to wood Fibers to activate the lignin-rich fiber. surface. Activating the lignin and/or extractives on the surface of the wood fibers, which has been shown previously by chemical and enzymatic means, can give lignin the functionality of a self'-bonding adhesive. In preliminary work, a wet-process hardwood fiberboard was produced using a pre-treatment with a synthetic model chelator, 2,3-dihydroxybenzoic acid (DHBA), which showed an increase in the internal bond strength over that of fiberboard without DHBA pre-treatment. In this research, wet and modified dry-process softwood fiberboard exhibited increased internal bond, modulus of rupture, and modulus of elasticity with DHBA pre-treatment compared to that of fiberboard without DHRA pre-treatment. The strongest boards produced used a 1:10 ratio of DHBA:FeIII with mM concentrations of peroxide. An FeIII-only treatment displayed similar bond and bending strengths to the chelator-mediated treatments (1:10) ratio, suggesting that natural phenolics and extractives in the wood were reacting similarly to low concentrations of DHRA through a chelator-mediated Fenton mechanism.

Lignin comprises as much as 40 percent of wood's mass, therefore the development of novel technologies for the use of lignin in composites is an attractive, environmentally intelligent goal. Lignin's random and noncrystalline network structure makes it a very thermodynamically stable biopolymcr (Glasser 1981).

In the fungal degradation or wood, white-rot fungi have been studied extensively because of their ability to degrade lignin in wood cell walls through the use of enzymes. Brown-rot fungi, although destructive to wood products, do not have the ability to fully metabolize lignin. Brown-rot attack results in the chemical modification of lignin in wood with only a limited decrease in lignin content (Highley 1987).

Chandhoke et al. (1992), Goodell et al. (1997), and others (Koenigs 1974, Backa et al. 1992, Hirano et al. 1905, Hyde and Wood 1997) found that certain brown-rot fungi, such as *Gloeophyllum trabeum*, secrete low molecular weight compounds, initially described

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as catecholate phenolics (Jellison et al. 1991, Chandhoke et al. 1992) that have been hypothesized to be involved in the degradation of wood by these fungi (Goodell et al. 1997, Kerem et al. 1999, Paszczynski et al. 1999, Xu and Goodell 2001). The orthodihydroxy forms of these catecholate compounds have the capability to bind and reduce the oxidized (ferric) form of iron (Pracht et al. 2001). Since it is known that wood-rotting fungi produce hydrogen peroxide (Koenigs 1974, Hyde and Wood 1997), the reduced iron is then available to participate in Fenton reactions (Haber and Weiss 1934, Schmidt et al. 1981) to initiate degradation of the wood cell wall in brown-rot fungi. The chelators produced by the fungi likely play a role in non-enzymatic wood decay processes since enzymes have been shown to be too large for initial wood cell wall penetration (Srebotnik et al. 1988, Flournoy et al. 1991, Blanchette et al. 1996, Jensen et al. 2001).

Bonding of lignocellulosic material is essential for the manufacture of particleboard, fiberboard, oriented strandboard, laminated wood products, and plywood. In current commercial bonding processes, an adhesive is spread or sprayed on the surface of the material. Procedures have been proposed to create adhesion through formation of wood-to-wood chemical bonds, but have not met commercial acceptance. Non-enzymatic methods to promote autoadhesion between lignocellulosic materials have received much attention over the last century. Linzell (1945) patented the fabrication of compressed fiber composites through the use of a ferric compound, such as ferric sulfate, to facilitate a self-bonding mechanism of wood. Stofko and Zavarin (1977) patented a process bonding lignocellulosic materials through the use of a liquid carrier and an oxidant with heat and pressure. In their system, white fir wood shavings were sprayed with hydrogen peroxide while another equal part of the shavings was sprayed with a catalyst solution of ferrous sulfate and hydrochloric acid. The strength of the bond was found comparable to the strength achieved by traditional adhesives. Philippou (1982) described a graft polymerization system of activated lignocellulosic surfaces with polymerizable chemicals. He used hydrogen peroxide, nitric acid, and peroxyacetic acid to modify the wood surface so that it was more reactive in polymerizing with chemicals like lignosulfonates and furfuryl alcohol. This chemical bridge between the wood surfaces demonstrated bonding properties comparable to that of phenolic adhesives.

Enzymatic systems to promote lignin activation and fiber bonding have also been proposed. For example, Kharazipour et al. (1993) and others (Haars and Hütterniann 1984, Felby et al. 1997, Kharazipour et al. 1997) described a procedure for bonding wood fragments together in the manufacturing of a composite product. A commonality in their procedures for bonding wood fragments is the activation of the middle lamella lignin of the wood cell wall through incubation with phenol-oxidizing enzymes. Using this technique, molded products were created without additional bonding agents or chemicals.

The chemical reactions involved in these self-bonding system are not fully understood, but oxidative coupling of phenolic units contained in wood is either the main or at least one of the main reactions leading to autoadhesion of lignocellulosic materials (Stofko and Zavarin 1977, Haars and Hüttermann 1984, Zavarin 1984, Felby et al. 1997, Kharazipour et al. 1997). With the described system, it is possible that free radical formation with subsequent coupling occurs precisely at the time when surfaces to be bonded arc in close contact (Stofko and Zavarin 1977).

The goal of this research was to determine the potential of a synthetic chelator-mediated free radical (CMFR) system (Goodell et. al. 1997, Xu and Goodell 2001) for use in lignin activation of wood fiber composites. Our objectives were to explore systems that may promote a more environmentally friendly, less expensive alternative for bonding of wood in the wood composite industry.

Materials and methods

Materials

Thermomechanically pulped *Pinus ponderosa* wood fibers with a small percentage of *Abies concolor*, provided by Louisiana Pacific Corporation in Missoula, Montana, were used in this study. The defibration process involved 0.55 MPa and 140°C in a steam digester applied to wood chips, shavings, and sawdust followed by Bower double disk refining at pressures > 0.55 MPa. The wood fibers were at a moisture content (MC) of 9 to 11 percent during fiberboard processing. A synthetic model chelator, functionally similar to the natural chelators produced by *G. trabeum*, 2,3-dihydroxybenzoic acid (DHBA) (Goodell et al. 1997), was used in this study for the bonding reactions with ferric (anhydrous ferric chloride) or ferrous (ferrous sulfate hexahydrate) iron (Aldrich Chemical Company). No enzymes were used in our process. Hydrogen peroxide at 30 percent w/w (Alfa Aesar Chemical Company) was used as the reactive oxidant for the Fenton reactions that we carried out in acetate buffer to maintain a furnish pH around 4.5. Urea-formaldehyde (UF) resin used in control samples was provided by Southeastern Adhesives Company. To blend the fibers and chemicals together, a liquids-solids blender (Patterson-Kelly Co.) was used.

For the dry-process fiberboard, a Wagner airless sprayer was used to atomize the chemicals. A vacuum system was used to form the mat within a plexiglass forming box with a perforated aluminum sheet base. A 152- by 352-mm laboratory hot-press (Fred S. Carver, Inc.) modified with four Chromalox heating cylinders (Omega Scientific) and two Robotemp heat controllers (VWR Scientific) was used for pressing the fiber panels. Two K-type thermocouples (Digi-Sense Cole-Parmer) allowed monitoring of the top and bottom platen temperature, while other thermocouples were used to monitor selected boards during the press cycle. Measurement of the vertical density profile of the fiberboard, was achieved using a QMS x-ray-based density profiler. The samples were tested for internal bond (IB) strength and static bending according to ASTM D 1037 using a model 4202 Instron test machine with a 10kN load cell.

Wet-process softwood fiberboard methods

Softwood fiber (500 g) was blended with acetate-buffered water and the iron species, followed by the 2.3-DIIBA and hydrogen peroxide when required for treatment. The chemicals and fiber were blended for 1 minute after each chemical addition. Table 1 shows the chemical concentrations of the treatments used in the experiment, which were calculated for a total solution volume of 8 L. Three fiberboard repetitions were produced

Table 1. – Experimental design for wet-process fiberboards.

Treatment	2,3-DHBA	$FeCl_3$	Fe_2SO_4	H_2O_2	NaAc, pH 4.5	Reaction time	Board reps.
	- - - - - - - - - - - - - - (mM) - - - - - - - - - - - - - -				(M)	(min.)	
A	--	--	--	20	0.05	5,30,60,180	3
B	--	--	5	20	0.05	5,30,60,180	3
C	--	--	10	20	0.05	5,30,60,180	3
D	0.5	2	--	20	0.05	5,30.60,180	3
E	--	--	--	--	0.05	5	3

Table 2. – Experimental design for dry-process fiberboards.

Chelator system	2,3-DHBA	$FeCl_3$	H_2O_2[a]	NaAc pH 4.5	Board reps.
	- - - - - - -(mM)- - - - - - -		(%w/w)	(M)	
A[b]	1	2	9.3	0.05	3
B[c]	1	10	9.3	0.05	3
C	5	10	9.3	0.05	3
D	1	0	9.3	0.05	3
E	5	0	9.3	0.05	3
F	0	2	9.3	0.05	3
G	0	10	9.3	0.05	3
H	0	0	9.3	0.05	3
I	0	0	0	0.05	3
J	0	2	0	0.05	3
K	0	10	0	0.05	3
L	100	200	9.3	0.05	3
M[d]	100	200	9.3	0.05	3
N	200	2000	9.3	0.05	3
UF resin (~10% w/w)	0	0	0	No buffer	3

[a]Hydrogen peroxide concentration mimics a similar concentration used in a patent by Skofko and Zavarin (1977).

[b]The DHBA:FeIII ratio mimics a similar ratio of Fenton-chelator systems used by Xu and Jordan (1988).

[c]The DHBA:FeIII ratio mimics similar ratios found to be reactive within the Fenton-chelator system in prvious work(Goodell et al. 1997, Xu and Goodell 2001).

[d]Instead of using 2,3-dihydroxybenzoic acid, catechol was used as the model chelator.

for each reaction time. The pH of the pulp was maintained around pH 4.5. Reaction times of 5, 30, 60, and I80 minutes were used.

Because the characteristic reaction time for the Fenton/ chelator system was not known, kinetic studies were performed to possibly reveal some information on the reaction mechanism with wood components. After each of the four reaction times, a 2-L, aliquot of the total 8-L suspension with approximately 125 grams of ovendry wood weight was removed from the blender. Each aliquot was added to 5 L of distilled water arid thoroughly mixed while screening through the forming box to remove most of the water from the fiber mat. The mat was prepressed at a pressure of approximately 34.5 kPa. The mat MC before pressing, ranged from 300 to 400 percent. A press cycle of 200°C and 2.76 MPa for 4 minutes, similar to a "toasting cycle" (Suchsland and Woodson 1990), was used to produce a 4-mm S2S board with a target density of 1.00 g/cm^3. After pressing, the fiberboard was removed from the press and placed in a 20°C incubator for cooling and to help facilitate the removal of the caul plates from the Fiberboard. Finally, two 51- by 51-mm samples for 1B strength tests were cut from the boards and conditioned at 55 percent relative humidity and 25°C for 1 week prior to testing. Tensile testing perpendicular to the surface (ASTM D 1037) was performed on the samples with a head speed of 0.305 mm/min. All statistical analysis was performed using SYSTAT 9.0 software.

Dry-process softwood fiberboard methods

Softwood fiber (100 g) was placed in the liquids-solids blender and and the chemicals were atomized onto the fibers following the experimental design shown in **Table 2.** After the treatment of wood fibers with 2,3-dihydroxybenzoic acid (DHBA), ferric chloride (FeIII), and acetate buffer (CMFR treatment) hydrogen peroxide was added. The pH of the furnish was maintained around pH 4.5, and in most cases pH adjustment was not necessary. Fibers were thoroughly mixed for 1 minute in the blender, and then for an additional minute after hydrogen peroxide addition. With CMFR treatments, the addition of DHBM to the iron would change the fibers purple to dark brown in color. After H_2O_2 addition, the color would change to a reddish brown. The MC of the fiber after mixing with 100 mL of the treatment solutions ranged from 100 to 120 percent MC and upon transfer to the forming box was 70 to 80 percent MC. This latter percent MC was the target MC before entering the hot-press and is defined for the purpose of this research as the "dry" treatment proccss. As a reference comparison for the dry treatment process, fiberboard was also produced using UF resin applied at 10 to 12 percent of the ovendry weight of wood.

After treatment, the fibers were vacuum-blown, and felted into the former/pre-press. A fluffed mat thickness of approximately 150 mm was produced and then pre-pressed to a constant thickness of 65 mm. The mat was then hot-pressed between aluminum caul plates with a steel screen to 5-mm stops. Press temperature was 170° to 180°C for a total time of ~ 380 seconds under 170 MPa of pressure to give a 5-mm S1S board with a target density of 0.90 g/cm^3.

Following pressing, the boards were cooled in a 20°C incubator and samples were prepared for 1B and static bending tests by conditioning at 18°C and 67 percent relative humidity for 2 weeks. Three boards were produced for each treatment. For each fiberboard, two 51- by 51-mm 1B samples and one 51- by 152-mm static bending sample were prepared. Modulus of rupture (MOR) and modulus of elasticity (MOE) were determined from the static bending sample. All statistical analysis was performed using SYSTAT 9.0 software.

Table 3 – Multiple comparison of IB values for wet-process treatments and reaction times.[a]

Treatment	Reaction time	Average density	IB
	(min.)	(g/cm²)	(MPa)
A	5	1.02	0.106 A
A	30	0.95	0.123 A
A	00	0.96	0.180 A
A	180	0.99	0.157 A
B	5	1.00	0 217 A
B	30	0.99	0.296 A,B
B	60	1.00	0.348 A,B
B	180	1.00	0.168 A
C	5	1.01	0.502 B
C	30	1.01	0.491 A,B
C	60	1.02	0.434 A,B
C	180	1.01	0.351 A,B
D	5	1.01	0.550 B
D	30	1.00	0.632 B
D	60	1.04	0.689 B
D	180	1.00	0.621 B
E	5	0.95	0.260 A

[a]The treatments shown here are the identical treatments, described in Table 1. Values followed by the same capital letter are not significantly different (a – 0.05)

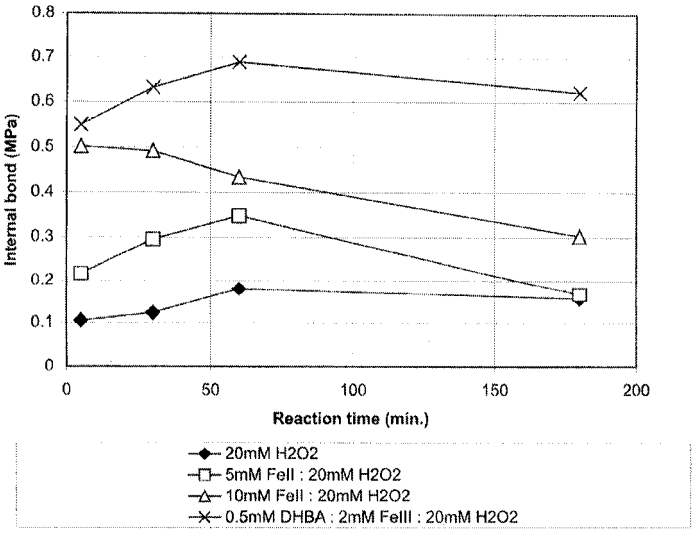

Figure 1. – Reaction time vs. internal bond strength relationships between various wet-process fiberboard treatments, The acetate-buffered water treatment was not compared between reaction times.

Results and discussion

Wet-process fiberboard

Table 3 compares the IB strength of all the fiberboard treatments across reaction times. Tukey's multiple mean comparison test was used to compare the means of each treatment with an overall significance level of a = 0.05. The mean comparison showed two significantly different board types. Treatments A (20 mM H_2O_2, 142 MPa) and B (5 mM FeII: 20 mM H_2O_2, 0.257 MPa) showed no significant difference from each other. Treatment E (water control, 0.260 MPa) showed no significant difference when compared to treatment A and B. Both treatment A and B were significantly different from the 5-minute reaction time in treatment C (10 mM FeII: 20 mM H_2O_2. 0.502 MPa). Treatment D (CMFR treatment, 0.623 MPa) was significantly different from treatments A, B, and E, but not significantly different from C.

The CMFR treatment (D) displayed one of the highest IB strengths when compared to other treatments, but since it was not significantly different from treatment C, it indicates that both treatments C and D promote activation of wood fiber components for bond formation. The 0.5:2 ratio of DHBA-FeIII produced an environment where the strongest bond was produced during hot-pressing. The weakest fiberboard treatment was the 20 mM H_2O_2-only treatment. Peroxide alone can oxidatively react with wood components to weaken and cleave covalent bonds, especially phenolic linkages, as seen with the bleaching of wood pulp for paper manufacturing (Gierer 1990); however, much of this oxidative reaction is likely due to the action of contaminating metals in the pulp. Significant bonding in our work with the wet-process system occured only in the presence of the complete Fenton system.

The effect of reaction time on the IB stength within each treatment is shown in **Figure 1.** Each treatment, except the 10:20 FeII:peroxide ratio, shows a peak of IB stength at the 60-minute reaction time with values as much as 0.14 MPa greater than the 5-minute reaction time. All samples decreased slightly in IB strength after the 60 minute reaction time. The treatments, however, showed much variation in bond strength at each reaction time.

Dry-process fiberboard

Table 4 shows a comparison of mechanical properties for the dry-process fiberboard. Tukey's multiple mean comparison test was again used to compare the means of each treatment with an overall significance level of a = 0.05. The average density values follow the strength values of IB, MOR, and MOE. The first three CMFR treatments, and the iron plus hydrogen peroxide reference sample arc denser compared to controls and most reference boards, except the board with a 1:10 ratio of DHBA to FeIII. The fact that the CMFR fiberboards exceeded the target density shows that densification continued throughout pressing and there was little springback after curing. More springback was apparent with the controls. The 1:10 chelator treated fiberboard displayed a density of 1.5 g/cm³. As this is

Table 4. – Multiple comparison of average mechanical property values for dry-process treatments. [a]

Treatment	Average density	IB	MOR	MOE
	(g/cm^3)	- - - - - - - - - (MPa) - - - - - - - - -		(GPa)
A	0.97	0.190 B	19.1 B	2.39 B
B	1.02	0.328 C	19.9 B	2.73 B
C	1.01	0.242 B,C	20.6 B	2.69 B
D	0.88	0.149 A,B	8.21 A	0.986 A
E	0.88	0.131 A,B	7.76 A	1.08 A
F	0.94	0.145 A,B	16.4 A,B	2.16 B
G	1.00	0.256 C	20.1B	2.68 B
H	0.87	0.139 A,B	8.00 A	1.06 A
I	0.86	0.0938 A,B	14.6 A,B	2.04 B
J	0.88	0.0522 A	5.74 A	0.614 A
K	0.78	0.0384 A	5.83 A	0.648 A
L	0.84	0.235 B,C	6.91 A	1.16A
M	0.87	0.212 B	8.13 A	0.986A
N	1.52	0.576 D	5.53 A	1.06 A
UF	0.87	0.447 C	43.4C	2.83 B

[a]The treatments shown here are the identical treatments descdrived in Table 2. Values followed by the same capital letter are not significantly different (a = 0.05).

the equivalent density of solid wood substance, this fiberboard was pressed to the maximum density ofwood, climinating voids.

For IB strength, the CMFR boards (samples B,G, and N) and the UF fiberboard **(Table 4)** showed the most significant difference between treatments. Treatments B (0.328 MPa) and N (0.576 MPa), the 1:10 ratio CMFR boards, displayed a significant increase in average IB compared lo all other controls. UF boards also displayed a significantly greater IB when compared to all other treatments, except B and G (0.256 MPa). Of the three CMFR treatments, the 1:10 ratio (B) of DHBA:FeIII shows the highest IB value and is statistically different from most treatments. Another high bond strength treatment was the 0:10 ratio reference sample (G), showing statistical similarities to the 1:10 treatment (B), the 5:10 treatment (C, 0.242 MPa), the high concentration DHBA:FeIII treatment (L, 0.235 MPa), and the UF fiberboard (0.447 MPa).

Because the iron/peroxide -only reference sample (G) displayed high IB strength, this suggests that the wood itself, if high enough in naturally occurring extractives and phenolics, may promote free radical bonding of lignin. Free phenolics or catechols with orthodihydroxy compounds function effecively as iron-reducing chelators (Goodell et al. 1997, Pracht et al. 2001, Xu and Goodell 2001). All controls without: iron or without hydrogen peroxide had low bond strength. The fact that treatments with DHBA but without iron exhibit low bond strength highlights the importance ofthe CMFR reaction for promotion of bonding. To further confirm the importance of the chelator:iron ratio dependence to enhance fiber bonding, a high concentration reference treatment (N) of 0.2 M DHBA: 2 M FeIII: 9.3 percent H_2O_2 was a pplied. This reference board, with a 1:10 ratio of DHBA:FeIII, displayed high IB strength exceeding all treatments including the UF reference board. The 1:10 DHBA:iron ratio used in these treatments supports previous results suggesting an optimal treatment ratio for free radical production (Xu and Goodell 2001) and wood fiber bonding.

Comparison of MOR and MOE of the boards shows that the CMFR fiberboards (A,B,C) are significantly different from the controls and most reference samples: however, treatment ratios 0:2 (F), 0:10 (G), and acetate-buffered water (I) were not significantly different from the CMFR fiberboard. The UF fiberboard (43.4 MPa) was stronger than the CMFR fiberboard (~20 MPa) in MOR, and only 4 percent stronger in MOE. The UF fiberboard (2.83 GPa) was comparable to the DHBA:FeIII (~2.6 GPa) and the 10 mM FeIII treatments F (2.16 GPa) and G (2.68 GPa) in MOE. As with the IB test, the CMFR treatments (A,B,C) displayed high MOR and MOE values. the iron control board (G) with only FeIII and hydrogen peroxide had significantly higher MOR, MOE, and IB values than all other controls. This supports the hypothesis that some natural chelators in the wood may actively bind and reduce iron to promote Fenton reactions.

Wood contains many types of natural iron-chelators such as hemicelluloses (i.e., mannose), extractives (i.e., terpenoids), or phenolic compounds bearing two or more adjacent hydroxyls, such as catechol and gallic acid. However, only metal binding compounds that can reduce iron will promote Fenton reactions. These chelators include various catechols and gallic acid. During brown-rot attack, iron is known to bind to cellulose and hemicelluloses more strongly than lignin, favoring a "Fenton" attack system by brown-rot fungi leading to extensive hemicellulose and cellulose degradation (Xu and Goodell 2001).

Interestingly, the 1:10 ratio of DHBA: FeIII (N) at high concentrations displayed low MOR (5.53 MPa) and MOE (1.06 GPa) even though bonding between the fibers was high, as shown by IB tests. At this concentration of Fenton reagents, in addition to promotion of lignin activation, there would be extensive oxidative cleavage within the cellulose microfibrils in the secondary cell wall layer, weakening the longitudinal strength ofthe fibers. Since IB measures bonding between fibers in the subaxial direction, bond strength depends more on interfiber bonds between lignin and other wood components.

The UF fiberboard had the highest MOR value in the sample set. Since UF does not degrade the wood, the fiber is able to retain its longitudinal strength.

Conclusion

Activation of softwood fiber using CMFR in a wet-process fiberboard method was performed to investigate this treatment's potential for bonding wood fiber. The 1:4 ratio of DHBA: FeIII with peroxide provided the highest bond strength compared to controls. There was no significant difference between reaction time and IB strength; however, iron reduction by the CMFR system has been shown to initiate rapidly with repeated iron reduction occurring over a >60-minute time period (Goodell et al. 1997) to sustain Fenton reactions.

In the activation of softwood fiber using a modified dry-process, the CMFR treatments produced a consistently

higher bond and had higher bending strength compared to controls not treatcd with the complete CMFR treatments. The strongest boards were produced using a 1:10 ratio of DHBA:FeIII with peroxide. When the 1:10 ratio was increased from the mM range to the molar concentration range of DHBA:FeIII, the highest IB strength and density resulted over all treatments. Increasing the concentration of the CMFR treatment by this magnitude, however, decreased bending strength significantly. The FeIII-only reference board displayed a similar bond and bending strength to the 1:10 DHRA:FeIII ratio boards, suggesting that natural chelators in the wood are reacting in a way similar to low concentrations of 2,3-DHBA in a Fenton-chelator mechanism. UF resin fiberboards with 10 to 12 percent solid content displayed the highest MOR strength properties over all the Fenton-chelator treatments, but showed similar MOE and IB properties to the Fenton-chelator boards. The amount of DHBA added to the wood fiber was not optimized; however, the data support use of a very short treatment time with DHBA in the 10- to 100-mM range to improve bonding and limit strength reduction.

Because all treatments in this study increased the MC of the fiber to greater than saturation, it is likely that the reactants in the CMFR system were able to penetrate into the interior of the fiber walls relatively quickly. Therefore, diffusion kinetics could hypothetically be responsible for a continuously mobile reaction front in the wood fibers (Zhang et al. 2000). In future work, it would be desirable to use a true dry-process system to limit diffusion of the reactants to the outer portion of the fiber and thus promote radical production at the site of the "lignin shell" surrounding the fibers, while limiting adverse free radical production in the cellulosic core of the fiber.

The CMFR system is designed to simulate the chemistry employed by brown-rot fungi in producing a "sustained" Fenton reaction to degrade and/or modify wood. It has been shown here that catecholate type chelators, such as 2,3-dihydroxybenzoic acid, are capable of mediating a Fenton type reaction with ferric iron and hydrogen peroxide for bonding wood fibers together in an autoadhesive manner. We have hypothesized that the free radicals produced in this Fenton reaction activate the lignin on the surface of the wood fibers. The improvement of bond formation may theoretically be caused by phenoxy radicals formed on the surface of, or within, the fiber to couple with each other, increasing the bond area and the number of reactive groups. Fenton-chelator catalyzed reactions may generate stable, or unstable, radicals in the lignin matrix and when hot-pressed the radicals on adjacent wood fibers couple to contribute to an autoadhesive effect.

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