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Full Length Research Paper

Accelerated weathering performance of cement bonded fiberboard

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Some mechanical and physical properties including total color changes of the cement bonded fiberboard exposed to accelerated weathering process have been investigated. The effects of density, wood fiber/ cement ratio and percent accelerator used on physical and mechanical properties of the weathered boards were determined. Comprehensive sets of replicated test data were generated in laboratory conditions and were analyzed statistically. The results obtained in this study were indicative of significant effects of accelerated weathering on physical and mechanical performance of wood fiber based cement bonded fiberboard. Weathering tends to decrease all physical and mechanical properties of the boards measured. Increase of density and percent of accelerators used generally causes an increase in mechanical properties of the boards. It was realized that increase of wood fiber / cement ratio resulted in an increase in modulus of rupture, thickness swelling, and water absorption while a decrease in modulus of elasticity. Percent accelerator used also cause an increase in thickness swelling and water absorption. Total color changes in weathered board were found to be only effected by density of the boards and percent accelerator used.

Key words: Cement bonded fiberboard, performance, weathering, color change.

INTRODUCTION

Cement-bonded wood composites (CBWC) have been on the market for over a century (Papadopoulos, 2006). CBWC take advantage of wood in its high specific stiffness, fracture toughness, strength to weight ratio, renewable natural resource, low cost as well as flexibility during processing, thermal and acoustic resistance, while the cement component acts purely as binder with a barrier layer to retard moisture intrusion, and resistant against biological attack (Ramirez-Coretti et al., 1998). More importantly, they are much better suited to fire, bio-deterioration and weathering applications to which solid wood and resin bonded composites are vulnerable (Dinwoodie and Paxton, 1991).

Despite their higher weight-to-strength ratio, wood-cement composites have become popular, particularly in Europe and Asia, for use as exterior siding, roofing and flooring applications to meet increasingly stringent building design regulations in case of fire, and failure in service.

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Most of the research in the field of cement bonded wood composites deals with cement bonded particleboard (Fan et al., 2006; Okino et al., 2005; Papadopoulos, 2008), compatibility of wood and non-wood species with cement (Papadopoulos, 2007), investigation on acceleration techniques (Soroushian et al., 2004), decay resistance (Papadopoulos, 2006), dimensional instability (Fan et al., 2006), and durability (Mohr et al., 2005). More recently, oriented strand board (Papadopoulos et al., 2006) and wood beams (Bejo et al., 2008) have been manufactured using cement as a binder. Recent studies also investigated suitability of non-wood resources in cement based composites (Aamr-Daya et al., 2008; Aggarwal et al., 2008; Ayaji et al., 2006).

A wide variety of production variables determine the physical and mechanical properties of cement bonded wood composites. Among those, wood/cement ratio, density, type and percent accelerators used, particle geometry, wood species, amount of water, pre-treatment of wood, chemical composition of wood, composition of cement was reported to be primary importance (Frybort et al., 2008).

Currently, there is no information about the effects of

Table 1. Accelerated weathering conditions subjected to the experimental boards.

Irradiation ($W\ m^{-2}\ nm^{-1}$)	Wave (nm)	Time (Hour)	Temperature (ºC)
0.77	340	UV 8	60 ± 3
		Condensation 4	50 ± 3
0.88	340	UV 8	70 ± 3
		Condensation 4	50 ± 3
0.88	340	UV 8	60 ± 3
		Condensation 4	50 ± 3
0.88	340	UV 8	60 ± 3
		Condensation 4	50 ± 3
0.63	340	UV 4	60 ± 3
		Condensation 4	50 ± 3
0.55	340	UV 8	70 ± 3
		Condensation 4	50 ± 3
0.44	340	UV 20	80 ± 3
		Condensation 4	50 ± 3

accelerated weathering process on cement bonded fiber-boards that were produced from cement/red pine wood fibers.Therefore, the objective of this study was to to examine performance of cement bonded fiberboards exposed to accelerated weathering process. For this purpose; some physical (thickness swelling, water gain) and mechanical (modulus of rupture, modulus of elasticity, and internal bond strength) properties as well as surface total color changes of the weathered boards were investigated.

MATERIAL AND METHODS

The first step of this study was to determine the inhibitory index in order to classify wood-cement compatibility. The inhibitory index was determined by as described in the literature (Jorge et al., 2004).

The second step of the study was to manufacture cement bonded fiberboard. The red pine woods were obtained from Isparta region in Turkey. All the chemicals used in this study was purchased from Yıldız Chemical Company, Ankara, with a purity of at least 99%. They were used as received. The bonding agent employed was commercial grade Portland cement, type II (42.5) supplied by Goltas cement factory, Isparta,Turkey.

Red pine (*Pinus brutia* Ten) particles were first converted to fibers using a stone mechanical refiner. Before refining, wood particles was placed in a water bed which 1% sodium hydroxide solution for overnight, than washed with fresh water and left in room conditions to dry until 7% moisture content achieved. Only coarse fibers were used in manufacturing of cement bonded boards.

A four factorial experiment has been design to investigate effects of weathering, density, wood / cement ratio, and accelerator. The wood: cement ratios applied in this study were 1:1, 1:2 and 1:3 based on the oven dry weight. Calcium chloride ($CaCl_2$ - 2, 4, 6% based on weight of cement) was introduced into cement slurry to accelerate cement set during hydration. Distilled water - $CaCl_2$ solution was first sprayed on predetermined amount of air-dried wood fibers, and thoroughly blended. Cement was subsequently added and the constituents were mixed until the cement paste was completely hydrated. The quantity of distilled water added, was calculated using the following formula (Fuwape, 1995).

water (liters) = 0.35 C + (0.30 – MC) W
where:
C = cement weight (Kg)
MC (%) = wood fibers moisture content (oven-dry basis)
W = oven-dry wood fiber weight (Kg).

After 10 min of mixing, the paste mixture was screened onto a metal plate which had been covered with wax paper. The mat was evenly distributed to provide as uniform a density as possible. Cold pressing took place under a pressure of 5 MPa to a 9 mm thickness, after which the board was retained in compression for 24 h. The target densities of the manufactured boards were; 1.0, 1.1 and 1.2 gr/cm^{-3} respectively. A total of 54 boards were made with the dimensions of 35 x 31 x 9 cm. After manufacturing, the boards were conditioned at 20°C and 65 % relative humidity and samples were cut to determine the IB (internal bond), MOE – MOR (modulus of elasticity and rupture), TS (thickness swelling after 24 h immersion in water), WA (Water absorption after 24 h immersion in water) in accordance with ASTM D 1037 (ASTM, 1998). The half of the boards were exposed to accelerated weathering process before testing. Accelerated weathering tests; exposure to heat, condensation and ultraviolet radiation, were carried out respectively on the boards using ATLAS UV 2000 test chamber. Table 1 presents exposure cycles applied to the boards. Absolute color differences (ΔE) of the weathered boards were measured by DataColor Spectrophotometer 110P using CIE L*,a*,b* standards. A four-way ANOVA general linear model procedure was employed for data to interpret principal and interaction effects on the properties of the panels manufactured. Duncan test was used to make comparison among board types for each property tested if the ANOVA found significant.

RESULTS AND DISCUSSIONS

The hydration test has shown that red pine has an inhibittory index of 25.65% (moderate inhibition). This means that red pine fibers can be utilized in wood cement composite manufacturing.

Average values of MOE, MOR, IB, TS and WA values

Table 2. Some mechanical and physical properties of experimental boards before weathering process.

Density	Wood / Cement Ratio	Accelerator %	MOR (MPa)	MOE (MPa)	IBS (MPa)	WA (%)	TS (%)
1	1	2	10.29 (1.38)	3045 (231)	1.17 (0.13)	27.80 (1.99)	2.92 (1.05)
	1	4	11.16 (1.52)	3125 (538)	1.27 (0.30)	25.71 (2.27)	1.57 (0.71)
	1	6	15.59 (1.57)	3945 (345)	1.40 (0.25)	24.11 (1.13)	3.65 (0.75)
	0.5	2	10.29 (1.63)	4214 (710)	1.08 (0.21)	17.80 (0.59)	0.71 (0.25)
	0.5	4	10.43 (1.30)	3969 (562)	1.22 (0.07)	20.90 (0.80)	3.07 (0.68)
	0.5	6	12.40 (0.76)	5049 (340)	1.60 (0.26)	23.55 (6.04)	3.74 (1.06)
	0.33	2	8.60 (1.15)	4588 (319)	1.31 (0.06)	17.86 (1.20)	0.70 (0.24)
	0.33	4	9.25 (1.43)	4590 (560)	1.52 (0.08)	20.21 (1.46)	0.57 (0.50)
	0.33	6	10.48 (1.79)	4438 (641)	1.34 (0.10)	18.87 (0.75)	0.60 (0.34)
1.1	1	2	10.21 (1.55)	2924 (302)	1.57 (0.13)	16.91 (1.49)	2.76 (0.81)
	1	4	11.83 (2.97)	3315 (565)	1.57 (0.19)	19.74 (1.96)	4.02 (0.57)
	1	6	13.75 (1.53)	3221 (234)	1.84 (0.15)	20.64 (1.92)	4.56 (0.97)
	0.5	2	11.09 (1.32)	4121 (363)	1.22 (0.09)	18.68 (0.96)	0.67 (0.21)
	0.5	4	10.18 (1.15)	4498 (747)	1.32 (0.19)	19.20 (0.96)	0.39 (0.23)
	0.5	6	14.08 (2.11)	5140 (889)	1.57 (0.20)	16.32 (0.64)	3.32 (0.81)
	0.33	2	10.54 (0.86)	4899 (600)	1.42 (0.18)	15.09 (2.03)	0.32 (0.15)
	0.33	4	10.08 (1.09)	5976 (779)	1.40 (0.17)	25.08 (2.59)	0.48 (0.22)
	0.33	6	12.66 (3.04)	6154 (1224)	1.40 (0.14)	16.51 (1.91)	0.62 (0.38)
1.2	1	2	12.62 (1.08)	3958 (207)	1.52 (0.18)	21.39 (1.89)	3.44 (0.38)
	1	4	12.62 (1.70)	3632 (450)	1.82 (0.23)	27.06 (7.34)	3.54 (0.62)
	1	6	19.80 (2.21)	4463 (383)	1.36 (0.18)	21.51 (1.38)	5.62 (1.37)
	0.5	2	11.46 (2.32)	4362 (670)	1.40 (0.39)	18.43 (0.70)	2.49 (0.83)
	0.5	4	8.39 (1.77)	5622 (972)	1.19 (0.14)	19.44 (2.35)	0.69 (0.22)
	0.5	6	19.89 (2.87)	6178 (728)	1.36 (0.11)	14.59 (0.59)	2.38 (0.46)
	0.33	2	11.21 (1.09)	5738 (528)	1.50 (0.23)	17.53 (0.65)	0.57 (0.19)
	0.33	4	9.27 (1.12)	4673 (705)	1.49 (0.14)	16.90 (1.11)	0.95 (0.20)
	0.33	6	19.22 (1.56)	7193 (780)	1.35 (0.27)	14.69 (3.17)	0.38 (0.21)

* Each value represents at least 6 replicates. Numbers in parenthesis are standard deviations.

as well as total color change obtained from the un-weathered and weathered samples are summarized in Table 2 and 3 respectively. The statistical analyses (ANOVA) clearly indicates that accelerated weathering tests, density, wood/cement ratio, accelerator used and some interactions of these main variables significantly affects the mechanical and physical properties of the experimental boards. However, among the main effects; wood / cement ratio has far more important than others. It appears that accelerated weathering process diminishes all the measured physical and mechanical properties of cement bonded fiberboards (Figure 1).

Figure 2 shows the decreases of wood / cement ratio resulted in a significant improvement in MOE, TS and WA properties at 5% level of significance. However, the MOR value was significantly increased, as the wood/cement ratio increased. Similar results have been reported by Moslemi and Pfister (1987) and Kandem and Yaguang (2002). However, Fryboard (2008) reported that the IB strength generally increases with greater cement/wood ratio, However, no significant effect of wood/cement ratio on IB was found within this study.

Increase in density generally resulted in higher MOE and MOR as shown in Figure 3. The relationship between increasing MORs with higher cement ratios and increasing MOEs with higher wood ratios may be explained by cement's rigidy and wood's elasticity (Kandem and Yaguang, 2002).

Increase in percent accelerators used also significantly produce higher mechanical properties as shown in Figure 4. The highest mean value of MOE (7193 MPa) was obtained with boards made at a wood/cement ratio of 0.33, and MOR (19.80 MPa) was determined with boards made at a wood / cement ratio of 1.0. Both higher values were also results of density of 1.2 and accelerator of 6 %. It can be seen in Table 2 and 3 that the mean IBs of the CBFs vary from 1.08 to 1.82 MPa for un-weathered samples, and from 0.97 to 1.60 Mpa for weathered samples. IB strength of the samples was significantly affected by accelerated weathering process and accelerator used. Generally, IB tends to increase with increasing cement ratio because cement acts as an adhesive to bind fibers

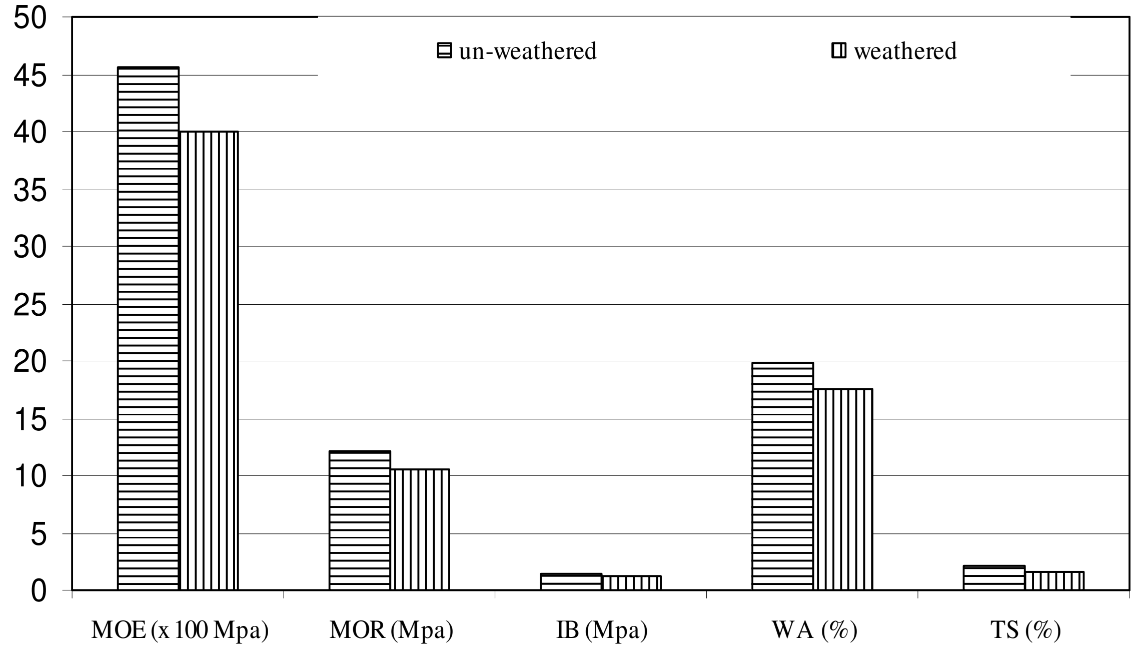

Figure 1. Effects of accelerated weathering on some physical and mechanical properties of boards.

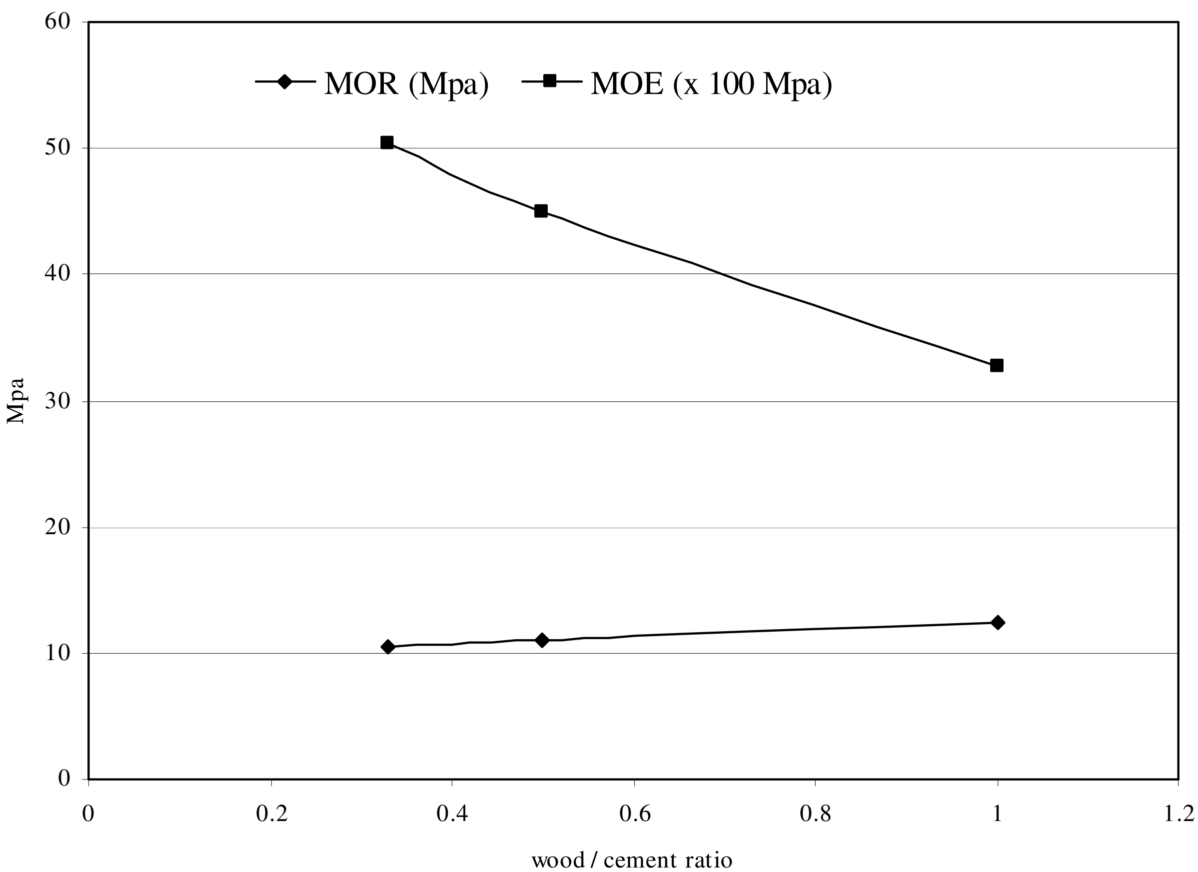

Figure 2. Effects of wood / cement ratio on modulus of elasticity (MOE) and modulus of rupture (MOR) of the boards.

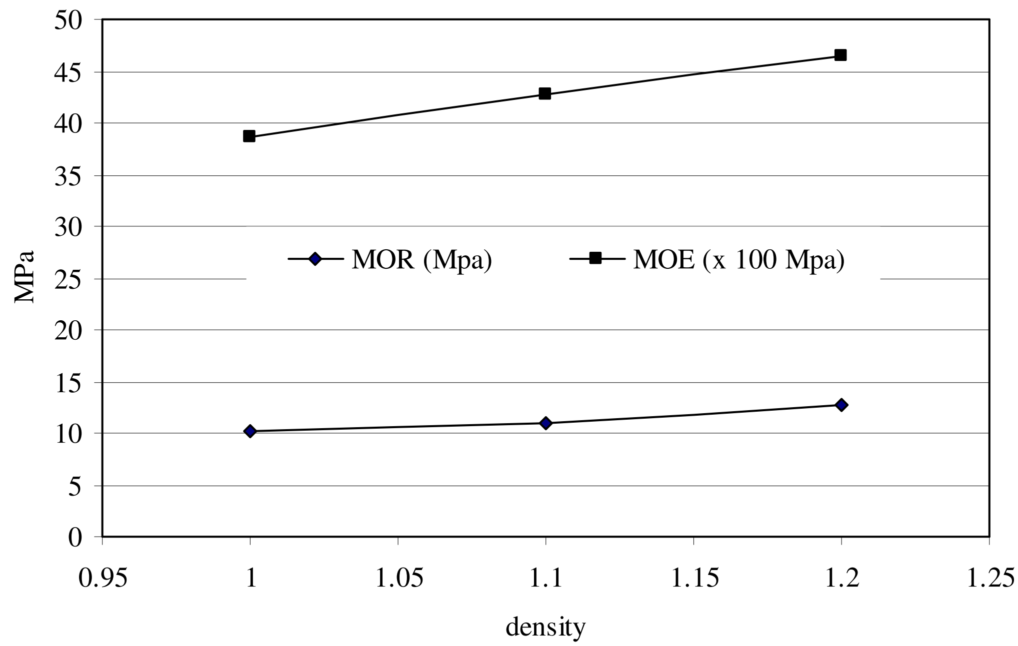

Figure 3. Effects of density on modulus of elasticity (MOE) and modulus of rupture (MOR) of the boards.

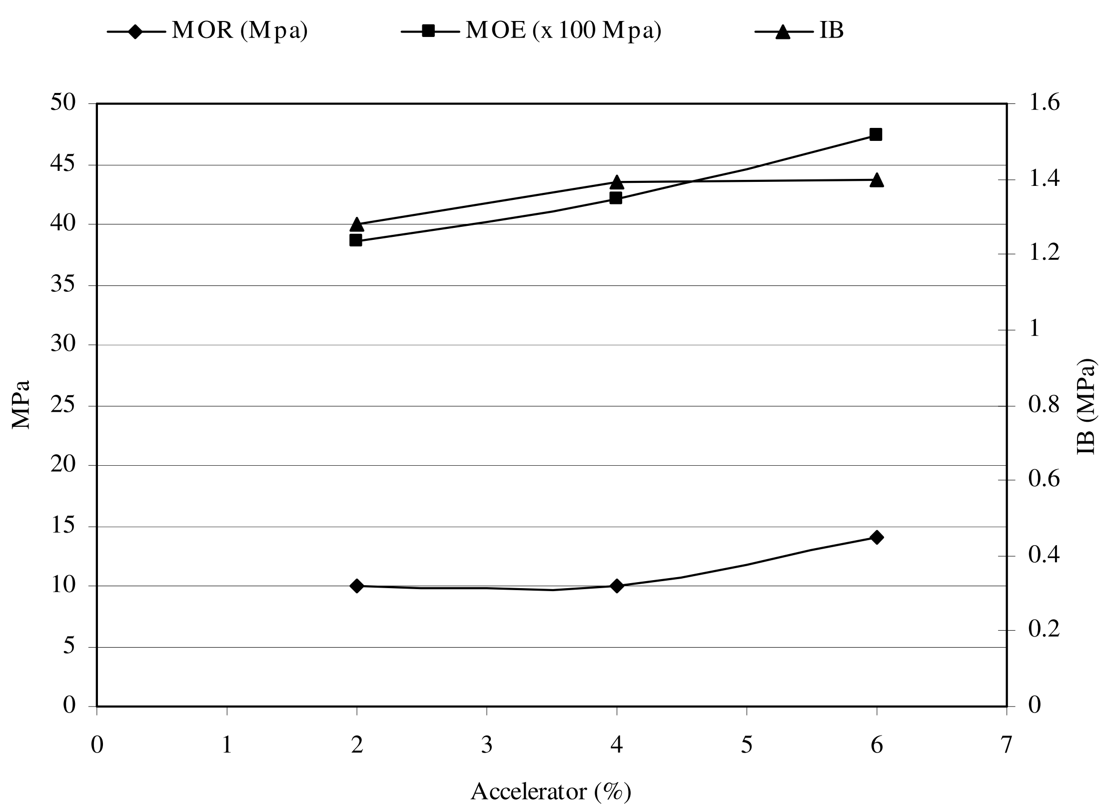

Figure 4. Effects of accelerator (%) on mechanical properties of the boards.

Table 3. Some mechanical and physical properties of weathered boards.

Density	Wood/Cement Ratio	Accelerator %	MOR (MPa)	MOE (MPa)	IBS (MPa)	WA (%)	TS (%)	Color Difference ΔE
1	1	2	9.23 (1.49)	2456 (466)	1.17 (0.25)	25.12 (6.25)	2.16 (0.19)	2.55 (0.33)
	1	4	9.90 (0.91)	2644 (325)	1.18 (0.14)	26.36 (5.91)	2.80 (0.23)	3.44 (0.28)
	1	6	12.41 (2.17)	2994 (524)	1.32 (0.14)	21.16 (4.35)	4.41 (0.53)	3.00 (0.74)
	0.5	2	8.82 (0.97)	3553 (185)	0.97 (0.14)	12.43 (1.53)	0.70 (0.14)	4.25 (1.53)
	0.5	4	8.97 (0.44)	3802 (328)	1.23 (0.31)	17.42 (1.76)	0.74 (0.30)	3.81 (1.65)
	0.5	6	9.73 (1.22)	3881 (562)	1.42 (0.09)	23.85 (2.52)	0.79 (0.54)	4.29 (1.38)
	0.33	2	7.25 (1.09)	3647 (547)	1.23 (0.08)	18.21 (4.07)	0.56 (0.12)	1.44 (4.33)
	0.33	4	8.47 (1.28)	4578 (460)	1.56 (0.13)	20.59 (5.54)	0.43 (0.08)	3.40 (1.58)
	0.33	6	11.00 (1.45)	5069 (697)	1.31 (0.19)	18.33 (1.56)	0.41 (0.05)	3.73 (0.87)
1.1	1	2	9.47 (0.64)	2379 (200)	1.24 (0.14)	24.59 (1.64)	1.99 (0.09)	3.76 (0.34)
	1	4	14.28 (1.50)	3740 (383)	1.35 (0.20)	15.71 (1.01)	3.70 (0.49)	3.23 (0.27)
	1	6	11.98 (3.14)	2865 (755)	1.13 (0.21)	24.29 (6.61)	2.62 (0.47)	2.52 (0.93)
	0.5	2	9.34 (1.18)	3540 (500)	1.19 (0.11)	12.88 (0.94)	0.62 (0.46)	2.50 (0.88)
	0.5	4	9.31 (0.72)	4950 (1007)	1.60 (0.16)	14.68 (0.99)	0.86 (0.18)	5.97 (2.06)
	0.5	6	10.87 (1.74)	4639 (678)	1.20 (0.10)	16.96 (2.47)	1.85 (0.38)	3.00 (0.73)
	0.33	2	9.31 (1.50)	4434 (650)	1.17 (0.22)	13.37 (1.59)	0.72 (0.39)	2.81 (1.20)
	0.33	4	7.66 (1.32)	4804 (551)	1.40 (0.27)	14.68 (1.69)	0.22 (0.09)	2.71 (1.45)
	0.33	6	10.60 (1.41)	5478 (394)	1.50 (0.21)	14.77 (1.72)	0.87 (0.10)	3.77 (1.17)
1.2	1	2	10.15 (0.84)	3192 (408)	1.19 (0.14)	18.36 (1.49)	2.12 (0.13)	3.61 (0.88)
	1	4	13.14 (1.39)	3439 (326)	1.45 (0.16)	14.69 (1.42)	3.04 (0.87)	6.36 (2.22)
	1	6	16.64 (0.74)	3476 (232)	1.44 (0.31)	15.98 (2.34)	3.73 (0.53)	3.14 (1.10)
	0.5	2	10.17 (0.49)	4133 (248)	1.24 (0.27)	15.61 (3.52)	1.14 (0.23)	3.09 (1.07)
	0.5	4	6.38 (0.41)	4034 (293)	1.26 (0.33)	15.56 (1.23)	0.26 (0.10)	3.79 (1.81)
	0.5	6	15.13 (0.82)	5101 (516)	1.47 (0.26)	12.36 (1.09)	2.43 (1.16)	2.91 (1.02)
	0.33	2	9.24 (1.28)	4301 (544)	1.45 (0.13)	15.15 (2.33)	0.64 (0.36)	2.88 (0.57)
	0.33	4	8.44 (1.12)	4361 (801)	1.22 (0.20)	16.86 (2.10)	1.26 (0.21)	7.40 (1.87)
	0.33	6	14.90 (1.94)	5892 (1027)	1.31 (0.13)	12.82 (1.26)	1.27 (0.07)	4.19 (0.62)

* Each value represents at least 6 replicates. Numbers in parenthesis are standard deviations.

together (Kandem and Yaguang, 2002). The average values of TS and WA vary from 0.32 to 5.62% and 14.69 to 27.80% respectively.

The total color change (ΔE) which varies from 1.44 to 7.40 in the experimental boards after accelerated weathering process was significantly affected by the density and percent accelerator (Table 3). Increase of density and percent accelerator resulted in an increase in total color change. However, these modifications are not surprising; because a number of researchers have already reported a definite correlation between weathering and color changes of lignocellulosic substrates (Sahin, 2002). However, most studies have shown that the natural color properties of species are modified upon heating conditions. This is attributed to the depolymerization reactions of cell wall wood polymers (Fengel and Wegener,

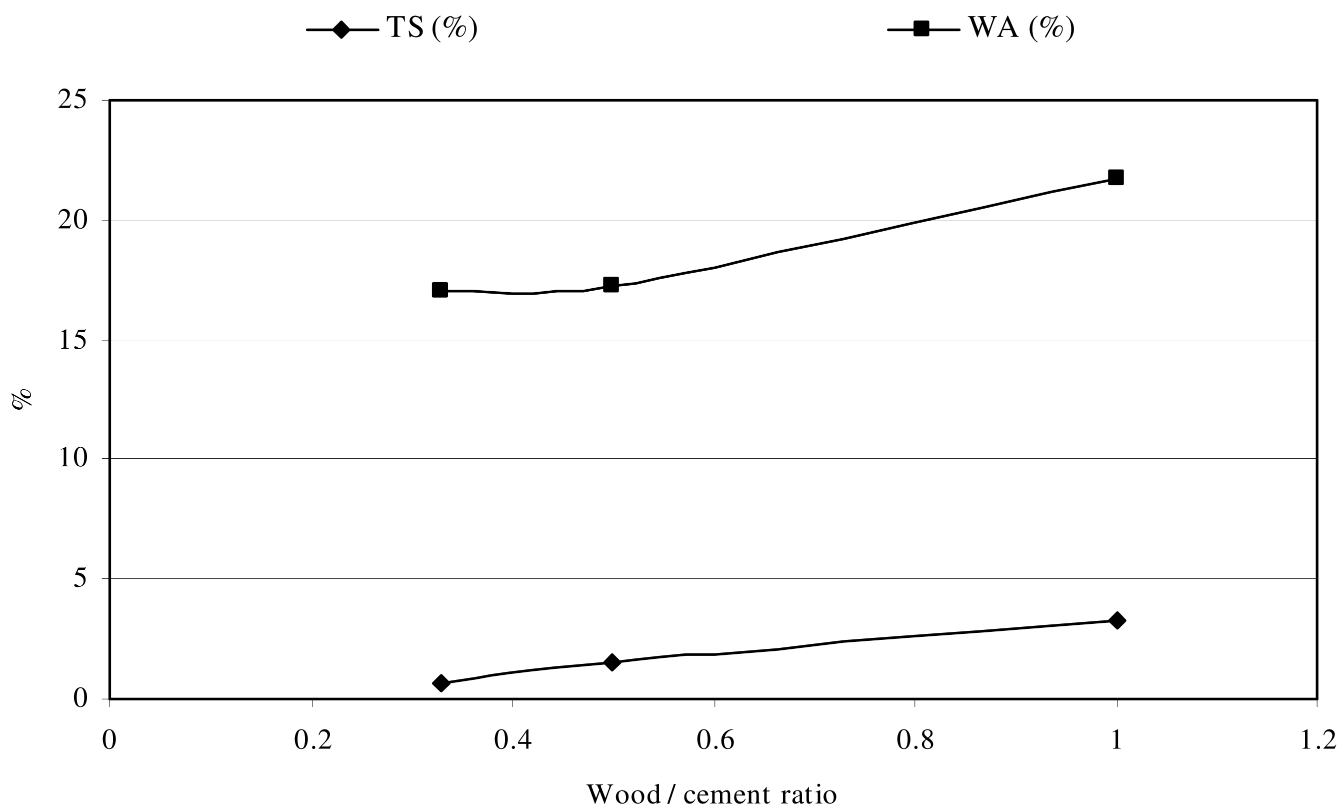

Figure 5. Effects of wood / cement ratio on thickness swelling (TS) and water absorbtion (WA) of the boards.

1984). Because lignin has various chromophore groups such as aldehyde, keton, carbonyl, acethyl, acid, etc, that are readily react with atmospheric conditions (Hon, 1991).

Moreover, increasing chemical accelerator level significantly affects on total color properties. It is well known that chlorine containing chemicals selectively effects on lignin which are oxidized to various forms including chromophore groups.

The effects of cement/wood ratio on the TS and WA of the CBFs are illustrated in Figure 5. The TS and WA of the boards after 24 h water soaking decrease as wood/ cement ratio decrease as expected. This is probably related to increase of bound water absorbed by wood cell walls. TS of the boards generally extend with higher density while WA lessens with higher density. Since higher density means more wood fiber and less internal voids within the boards, these results are somewhat can be anticipated (Figure 6).

Figure 7 shows that the ratio of accelerator used (%) significantly effects TS (%) of the boards but not WA (%) of the boards. Increase in accelerator (%) use surprisingly increases TS (%) of the boards.

Overall, experimental cement bonded fiberboards manufactured using lower wood/cement ratios, higher densities and accelerators were hardly affected by accelerated weathering process while effect was harsher for the boards manufactured using low density, high wood/cement ratio and low chemical accelerator.

Conclusions

The measured results clearly indicates that the accelerated wheathering process decrease all physical and mechanical properties of the boards made form red pine fiber/cement while causing a discoloration which is a sign of a chemical change on the surface of the boards.

However, increase of wood fiber / cement ratio resulted in an increase in MOR, TS, WA but a decrease in MOE. In general, the results of this study on the effect of accelerated wheathering treatment on cement bonded fiberboards are compatible with the findings in the literature.

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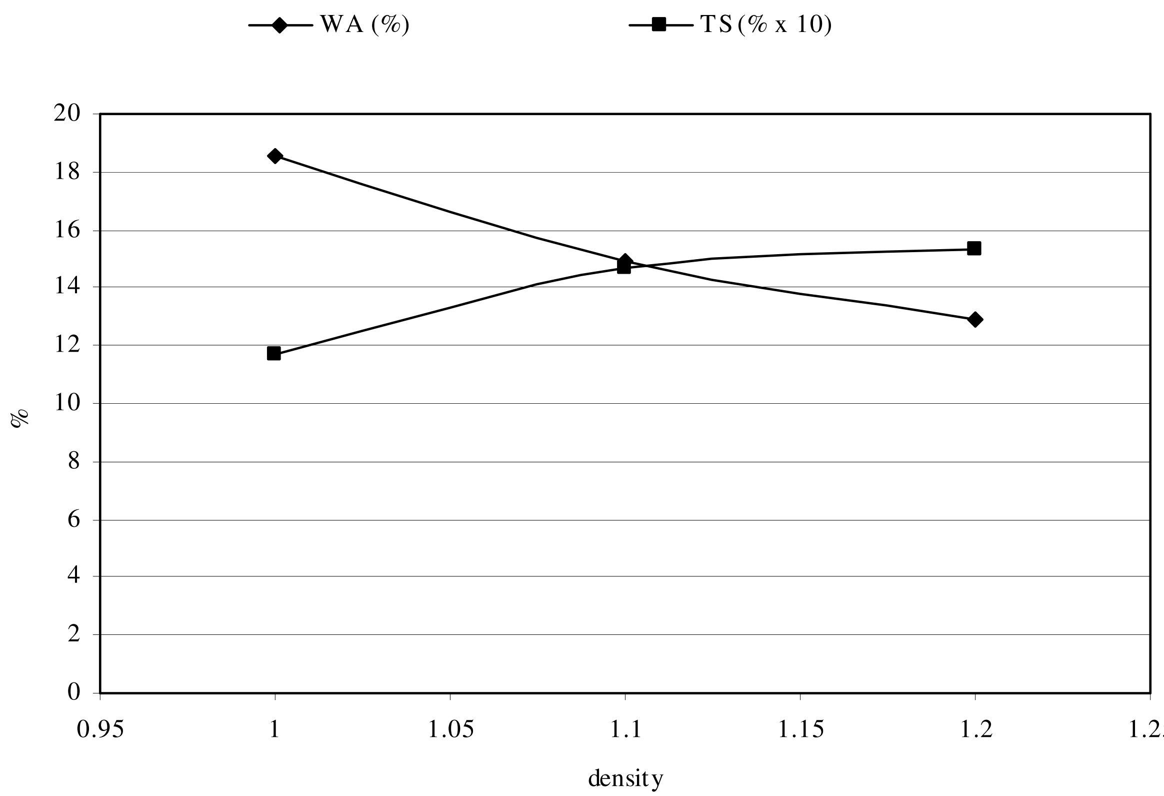

Figure 6. Effects of density on thickness swelling (TS) and water absorbtion (WA) of the boards.

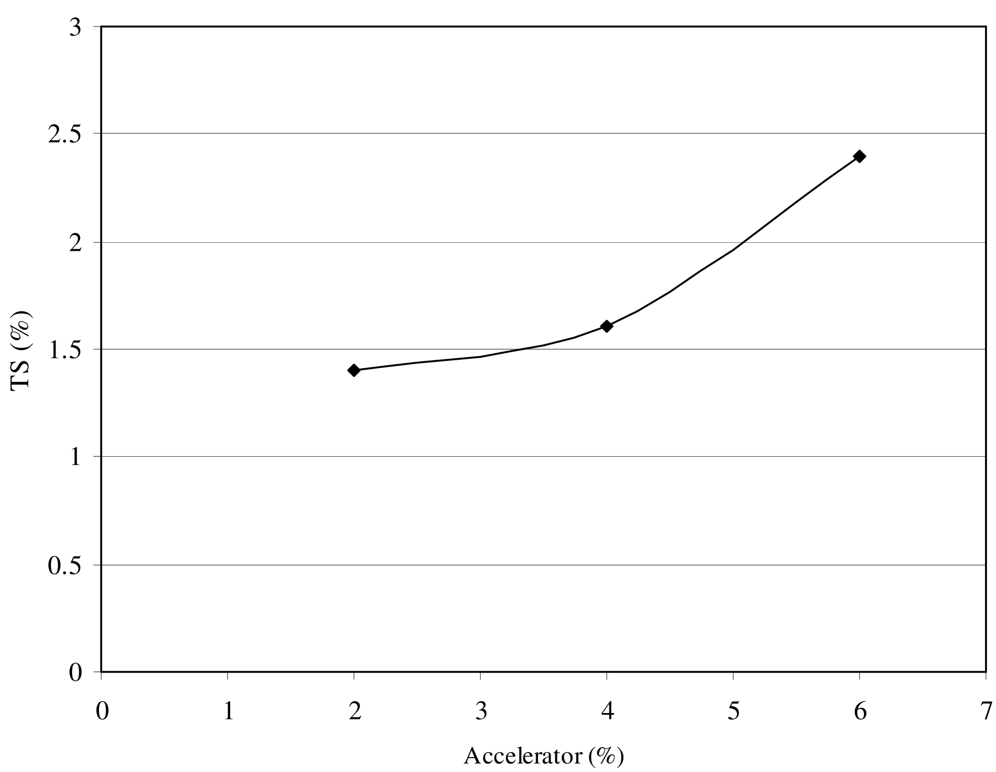

Figure 7. Effects of accelerator used on thickness swelling (TS) of the boards.

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