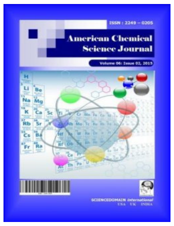

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The Effects of Boric Acid on Fiberboard Made from Wood/Secondary Fiber Mixtures: Part 2. Utilization of Recycled Old Corrugated Container Fibers

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Authors' contributions

This work was carried out in collaboration between both authors. Authors AIK and HTS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author AIK managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

It was realized that both boric acid (BA) and secondary fibers (S) from Old Corrugated Container (OCC) negative impact on thickness swelling (TS) properties of boards in water. However, the highest Modulus of Elasticity (MOE) values of both type boards were found at 90/10 Wood/Secondary fiber (W/S) ratio with values of 2966 MPa and 1009 MPa, respectively. It is clear that increasing secondary fiber content effects on lowering MOE values in some level. However, except of the boards of B10 and B10a which produced only from secondary fibers, all other experimental boards show higher MOE than standard value of 600 MPa.
The secondary fibers from recycled OCC can be useful for improving sound (acoustic) properties some level. Interestingly, the highest sound absorption (SA) coefficient of 0.91 and 0.81 were also found at 90/10 (W/S) mixture, respectively.

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Keywords: Secondary fiber; fiberboard; boric acid; sound absorption; waste paperboards.

1. INTRODUCTION

The demand on wood based products increases continuously due to population growth, new products introduced to market, technological developments and industrialization in developing countries. However, although wood is the major source of fiber supply, the deforestation in many areas of the world imposes the use alternative fiber sources as important for forest products industry [1-2]. Moreover, the need of reducing costs and environmentally friendly material, considerable research efforts have been carried out during last decades to explore the potential of cheap fiber alternatives (agro-based wastes, non-wood sources, etc.) for forest products industry [2]. On the other hand, an investigation concerning the use of the cellulose fibers from post-consumer waste paper as composite materials is essential in order to gain an insight into their properties [1,3-5].

Intensive research in engineered wood composite materials has been done since 1950s.Today; wood based composites have given many efficient end use areas including construction of buildings to aerospace structures. However, the reinforcement matrix system in a composite material determines the strengthening mechanism. It is thus convenient to classify composites according to the characteristics of the reinforcement element, such as; length, orientation, thickness, width, and/or ratios of stiffness/weight, strength/weight, etc [2,6,7].

Natural fibers (i.e. cellulose) have already well established to use in various type composite materials (fiberboards, wood-plastic composites, particleboards, etc.) to get high strength and stiffness with lower density properties. Hence, the cellulose fibers are added to a ductile matrix (i.e. urea-formaldehyde resin) to make it stiffer, while fibers are added to a brittle matrix to increase toughness. It is well known that these fibers are also flexible to allow a variety of methods for processing and have high aspect ratio of length/diameter that allows a large fraction of the applied to be transferred via the matrix to the fiber [1,2,6]. However, there has been an increasing trend to recycle waste papers to produce value-added products. In generally, majority of the recovered cellulose fibers have used for manufacturing various type of paper products. Moreover, increasing shortage of wood resources has effect to search alternative utilization of secondary cellulose fibers to forest products industry. One of the alternative utilization of cellulose fibers to use as raw materials for composite manufacturing [1,3-5]. There have already a number of study conducted for utilization of post-consumer waste papers for using in various levels of fiberboard manufacturing such as; high density [3], low density [4] and medium density [1,5,8] composite manufacturing. From all these studies, it was proposed that the use of waste fibers as reinforcement in synthetic resin (i.e; formaldehyde or isocyanate) has enormous potential in the field of composite manufacturing (bio-composites). The composites based on recycled fibers in optimized form present an acceptable behavior in comparison with virgin wood cellulose fibers [3-5,8-10].

The forest products industry has recently been interested in taking advantage of an environmentally friendly process of utilizing boron compounds in processes. Studies related to pulp yield increasing focused on modifications to the kraft process [11-13], and fire retardant of timber and composite materials [14-16]. A number of research groups reported that boric acid is a heat resistant compound and during burning, it can absorb heat and release water. Hence the burning area has become colder during evaporation of water with increasing charring and improves insulation of materials [14-19].

A wide variety of production variables determine the physical and mechanical properties of fiberboards manufactured from various sources and conditions. Among those, wood/non-wood fiber ratio, density, type and percent of adhesive used, fiber specification, etc., have already reported in various levels of data. However, currently, there is no information about the effects of various level of boric acid to wood/secondary fiber ratio (W/S) in matrix system. Therefore, the objective of this study was to examine performance of boric acid addition on UF bonded fiberboard made from various proportions of wood/secondary fiber mixtures. For this purpose; some technological and physical properties were investigated.

2. MATERIALS AND METHODS

The Old Corrugated Containers (OCC) was obtained from local waste paper trader, Isparta, Turkey. All the chemicals used in this study were purchased from Chemical companies that with a purity of at least 99% and they were used as received. The boric acid (BA) was supplied directly from Etibor A.Ş, as laboratory purity, Bandırma-Turkey.

The sorted Old Corrugated Containers were first converted to pulp using a 5 L. capacity, laboratory type standard disintegrator in water. After 30-40 minutes to disintegration, all the paper sheets convert to the pulp. Then the pulps washed with fresh water and screened on a 100 mesh screen to remove excess water. Then the pulps laid on laboratory conditions to air dried at 24 hours. After that the pulps was refined a stone based mechanical refiner to final fibrillation. The pulps were then dried at 105℃ (±3); until at least a 3.0% moisture content was obtained. The target densities of the manufactured boards were 0.65 gr/cm^{-3} (±0.05 g/cm^{-3}); a total of 66 boards (three from each 22 different conditions) were made with the dimensions of 420x330x10 mm. The detailed preparation conditions and physical and mechanical experiments of boards are given first part of this study. The Boric acid (BA) content of 5.0% (for type 1); 10.0% (for type 2) were used.

The sound absorption properties (Acoustic) of boards were determined according to TS EN 10534-2 standard that at least 12 samples tested with Brüel&Kjaer Tube Type 7758 instrument. With microphones in a pod, 100, 125, 130, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300 Hz in the frequency range, sound absorption coefficient of the samples with sound pressure level measured (T) [20].

$$T = (P_1 - P_2)/P_1 \quad (1)$$

Where, P1=incoming sound wave pressure, P2=outgoing sound wave pressure.

The standard test method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique) was used to determine thermal insulation behavior of composites according to ASTM C-1113-09 [21]. For determining mass burning rate, the test samples were cut as standard dimensions of 100x100x10 mm pieces and placed on the test apparatus at vertical position [22]. The boards were flamed at approx. 800℃ with the distance of 30-50 mm from the heater surface in duration of 5.0 min. At the end of test, the boards were weighted and mass loss calculated based on weight differences.

Thermogravimetric Analysis (TGA) is carried out using a Perkin Elmer SII instrument in order to measure changes in properties of boards as a function of increasing temperature (with constant heating rate). Thermogravimetric Analyzer, supported by a PC and software for control and data handling. Approximately 20 mg sample is introduced into a quartz sample's pan and heated to a preset temperature profile using nitrogen as purge gas at a scanning rate of 10℃/min

A one-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. Table 1 presents the board's types (codes) that proportion of wood/secondary fiber ratio and boric acid content in mixture.

Table 1. The board's code numbers and wood/secondary fiber ratio with BA content

Board code	W/S (%)	BA (%)	Board code	W/S (%)	BA (%)
B0	100:0	5.0	**B0a**	100:0	10.0
B1	90:10	5.0	**B1a**	90:10	10.0
B2	80:20	5.0	**B2a**	80:20	10.0
B3	70:30	5.0	**B3a**	70:30	10.0
B4	60:40	5.0	**B4a**	60:40	10.0
B5	50:50	5.0	**B5a**	50:50	10.0
B6	40:60	5.0	**B6a**	40:60	10.0
B7	30:70	5.0	**B7a**	30:70	10.0
B8	20:80	5.0	**B8a**	20:80	10.0
B9	10:90	5.0	**B9a**	10:90	10.0
B10	0:100	5.0	**B10a**	0:100	10.0

3. RESULTS AND DISCUSSION

The physical and mechanical properties obtained from experimental boards made from wood/secondary fiber (W/S) mixtures and two level of boric acid addition (5.0 and 10.0%) are summarized in Table 2. As shown in Table 2, all the average TS values were found range of 17-49% for type1, and 33-44% for type2 boards that is higher than standard value of 14% [23]. However, for both type boards, the lowest TS values of 17 and 33% were observed with B0 and B0a that produced only from wood fibers, respectively. In contrast, the highest TS values of 49 and 44% were also observed with B10 and B10a that produced only from secondary fibers, respectively. The similar results have already reported that increasing secondary fiber content from post-consumer papers or non-adhesive compound (i.e. boron compound) in board structure might cause increasing TS values of boards [9,10]. The results found in our study clearly consisted literature findings. Furthermore, the one way ANOVA analyses clearly indicate that boric acid addition (%) and W/S proportions affect the TS properties of the boards.

However, the statistical analyses (ANOVA) clearly indicate that the variables, such as boric acid content and W/S proportions significantly affect the mechanical properties of the boards. It was found that the highest MOR values of 19.23 MPa for type1 board (B1) that produced from 90/10 (W/S) ratio. However, It can be realized that further increasing secondary fiber proportion into furnish effects on lowering MOR values in some level. But the boards of A3, A5, A6, have found to be higher MOR values than standard value of 7.7 MPa. Moreover, it can also be realized for type2 boards that up to 60/40 W/S ratio (A1a, A2a, A3a, A4a), it is possible to produce boards with having higher MOR than standard value. Hence, it is reasonable to suggest that secondary fibers from recycled OCC and boric acid addition effects on MOR some level but it is possible to produce boards with higher MOR values than standard value.

The similar results was also observed for MOE properties that increase in percent secondary fibers negative impact on MOE some level (Table 2). However both type boards, the highest MOE values of 2966 MPa and 1009 MPa were found from 90/10 (W/S) ratio, respectively. In contrast, the lowest MOE values were observed for boards of B10 and B10a that produced only from secondary fibers for both type boards, respectively. It is clearly realized that secondary fiber and boric acid addition impact on MOE some level but it is possible to produce boards with higher MOE values than standard value of 600 Mpa (i.e. B1, B2, B3, B4, B5, B6, B8; B1a, B2a, B3a, B4a, B5a, B6a, B7a, B8a).

The result found for IB properties consisted with MOE and MOR results (Table 2) that increase in percent secondary fibers negative impact on IB values. However for both type boards, the highest IB values of 0.29 MPa and 0.27 MPa were found from 90/10 (W/S) ratio proportion, higher than standard value of 0.15 MP. It was also realized that further secondary fiber proportion and increasing boric acid content (from 5.0% to 10.0%) in furnish negative impact on IB properties. It can be concluded that secondary fibers from post-consumer OCC and boric acid addition effects on IB some level but it is possible to produce boards with higher IB values than standard value in some conditions (i.e. B1, B2, B3, B4; B1a, B2a, B3a, B4a).

A number of experiments were conducted at the 100-6300 Hz frequency range to determine sound absorption (SA) properties of experimental boards (Figs. 1 and 2). In general, it was realized that the increasing secondary fiber proportion effects improving sound absorption properties some level. It is important to note that although the mechanical and physical properties were found to be at moderate level (a little higher or less than standard values), this is another potential way that secondary fiber can be useful for improving sound (acuostic) properties of boards. The highest coefficient value of SA of 0.91 at 2000Hz for A1 boards (Fig. 1) while 0.81 at 200Hz were obtained for A1a boards (Fig. 2) that both produced from 90/10 (W/S) ratio with 5.0% (type1) and 10% (type2), boric acid content, respectively.

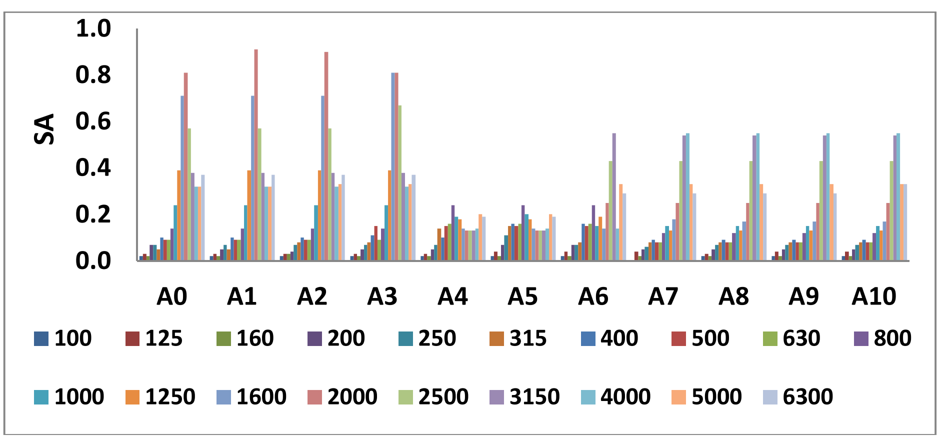

Fig. 1. Sound Absorption (SA) properties of type1 (5.0% BA) boards

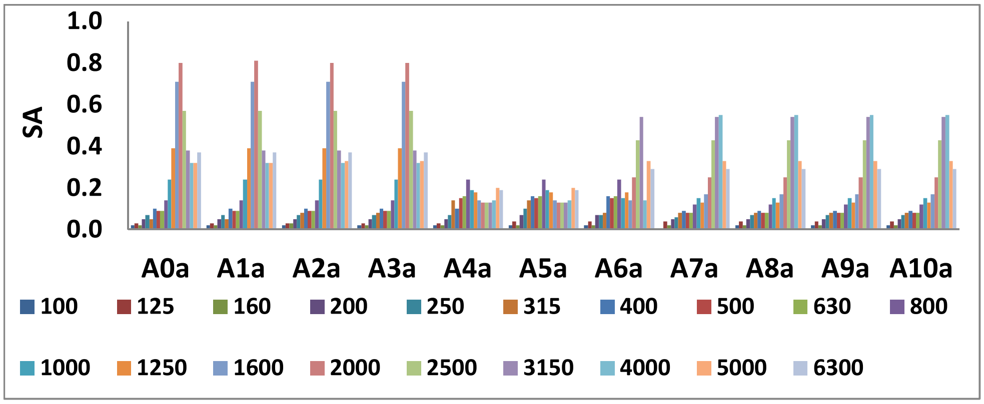

Fig. 2. Sound Absorption (SA) properties of type2 (10.0% BA) boards

Table 2. Physical and mechanical properties of boards made various proportions and BA

Board code	TS (%)	MOR (MPa)	MOE (MPa)	IB (MPa)	Board code	TS (%)	MOR (MPa)	MOE (MPa)	IB (MPa)
B0	17 (A)	15.59 (A)	2594 (A)	0.52 (A)	**B0a**	33 (A)	21.50 (A)	1471 (A)	0.50 (A)
B1	25 (BC)	19.23 (A)	2966 (A)	0.29 (B)	**B1a**	34 (B)	11.70 (B)	1009 (B)	0.27 (B)
B2	26 (BC)	7.81 (BCD)	1438 (BC)	0.23 (C)	**B2a**	35 (BC)	9.41 (BC)	892 (BC)	0.21 (CD)
B3	23 (B)	11.64 (B)	1866 (B)	0.21 (CD)	**B3a**	33 (BC)	11.15 (B)	892 (BC)	0.19 (C)
B4	42 (E)	5.34 (CDE)	973 (CD)	0.20 (DE)	**B4a**	36 (CD)	8.93 (BC)	829 (C)	0.18 (DE)
B5	44 (C)	8.75 (BC)	1768 (B)	0.13 (F)	**B5a**	35 (BC)	6.27 (CD)	768 (BC)	0.11 (F)
B6	35 (D)	8.82 (BC)	1571 (BC)	0.18 (E)	**B6a**	38 (D)	6.78 (CD)	775 (CD)	0.16 (E)
B7	38 (G)	3.60 (DE)	548 (DE)	0.10 (F)	**B7a**	37 (E)	3.70 (DE)	660 (DE)	0.08 (G)
B8	37 (FG)	2.17 (E)	619 (DE)	0.10 (F)	**B8a**	38 (DE)	4.00 (DE)	748 (BC)	0.08 (FG)
B9	38 (G)	3.30 (DE)	524 (DE)	0.12 (F)	**B9a**	37 (D)	2.78 (E)	561 (EF)	0.10 (F)
B10	49 (H)	3.20 (E)	327 (E)	0.14 (F)	**B10a**	44 (F)	3.43 (E)	468 (F)	0.12 (F)
TS EN 622-5 [23]	**14**	**7.7**	**600**	**0.15**	**TS EN 622-5 [23]**	**14**	**7.7**	**600**	**0.15**

Figs. 3 and 4 show thermal conductive (insulation) properties of both type experimental boards. The lowest thermal conductivity (better insulation) was found to be 0.1454 W/mK at type1 boards that made with 10/90 (W/S) fiber mixture (B9). Whereas the highest thermal conductivity value of 0.2029 W/mK was observed at type2 boards that made with 90/10 (W/S) fiber mixture (B1a) (Fig. 4). However, the results clearly indicate that the secondary fibers from OCC have positive impact on thermal insulation properties that increasing secondary fiber ratio lowering effects on thermal conductivity properties some level. In contrast, boric acid have negative effects on heat insulation properties that it is probably related to its heat conductivity properties that are typically higher than cellulose and 27.4 W/mK [1,19].

The weight loss of boards after mass burning test is shown in Table 3. It was observed that increasing secondary fiber effects increasing weight loss and charring formation. The results indicate that increasing boric acid content from 5.0% to 10.0% improve approx. 1-5% weight loss at similar conditions. This is a clear evidence for boric acid that it supports heat resistance properties of experimental boards manufactured from various proportions of wood-recycled OCC fiber mixtures. This is expected considering boron base compounds have usually considered as heat resistant compounds in many studies. It have already proposed that, boric acid could be absorb heat and release water. Hence the burning area might become colder during evaporation of water with increasing charring and improve insulation of materials [14-18].

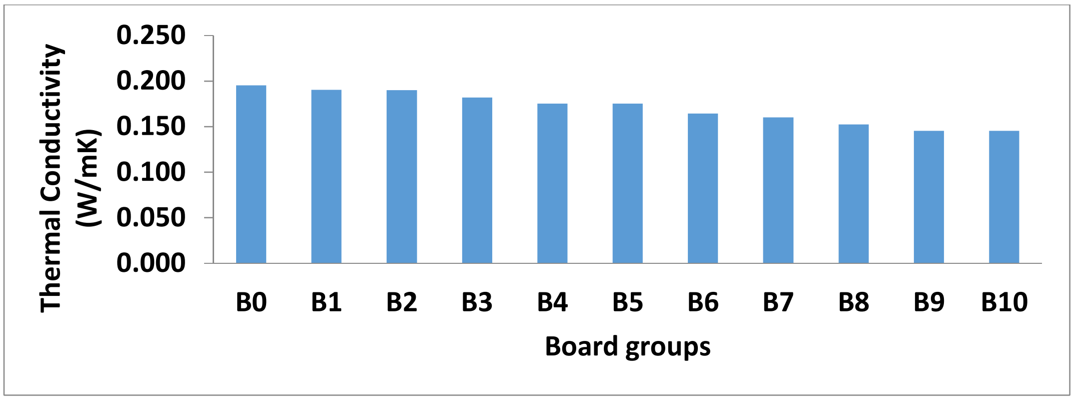

Fig. 3. Thermal conductivity properties of type1 boards

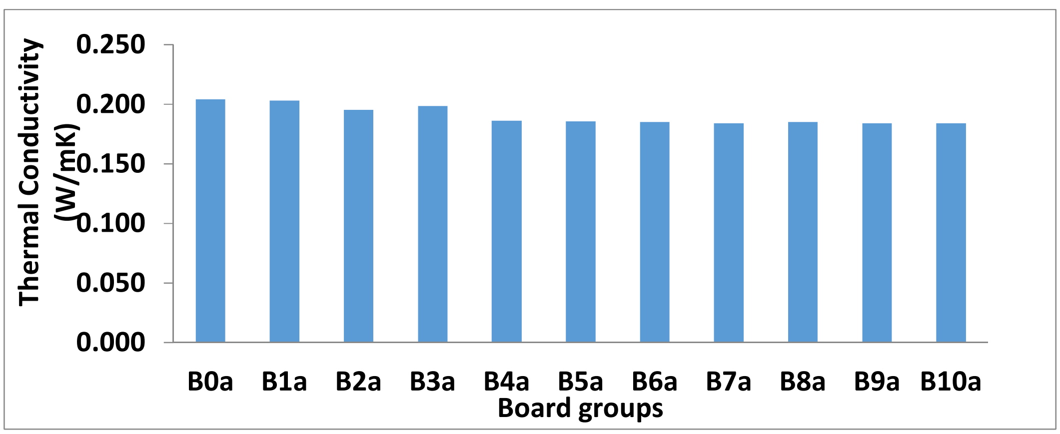

Fig. 4. Thermal conductivity properties of type2 boards

Table 3. The weight loss of boards after mass burning test

				Type1						
Board code	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
Initial weight (g)	88.3	90.7	87.1	92.0	92.3	104	87.1	94.3	91.6	88.9
Final weight (g)	71.6	72.3	73.2	75.8	75.7	87.1	74.4	75.9	73.7	69.6
Weight lost (%)	18.9	20.2	16.0	17.6	18.0	16.8	14.6	19.5	19.5	21.7
				Type2						
Board code	**B1a**	**B2a**	**B3a**	**B4a**	**B5a**	**B6a**	**B7a**	**B8a**	**B9a**	**B10a**
Initial weight (g)	81.8	84.0	80.6	85.2	85.5	96.9	80.7	87.3	84.8	82.3
Final weight (g)	67.2	6.9	68.7	71.2	71.1	81.8	69.9	71.3	69.2	65.3
Weight lost (%)	17.8	19.1	14.8	16.5	16.8	15.6	13.4	18.4	18.3	20.6

Table 4. TGA analyses of boards

Board code	Initial temp. (Tb)	Max. temp. (Tm)	Final temp. (Ts)	Board code	Initial temp. (Tb)	Max. temp. (Tm)	Final temp. (Ts)
B1	260.8	310.1	409.0	**B1a**	280.1	330.1	410.0
B2	260.9	311.1	409.2	**B2a**	283.5	332.2	410.0
B3	260.9	313.2	400.2	**B3a**	283.5	332.2	410.5
B4	262.4	313.2	402.3	**B4a**	283.5	333.1	413.2
B5	263.1	314.4	402.4	**B5a**	283.4	333.4	413.9
B6	263.5	314,2	402.4	**B6a**	284.2	334.3	415.0
B7	264.1	314.2	403.3	**B7a**	284.6	344.6	414.6
B8	264.3	314.6	403.4	**B8a**	285.1	345.6	415.8
B9	264.7	314.0	405.2	**B9a**	285.2	346.4	416.0
B10	264.6	315.2	405.3	**B10a**	285.3	349.3	416.0

TGA analyses results are shown in above Table 4. It can be realized that increasing boric acid content negative impact on thermal degradation that decomposition temperature was increased for type2 boards in all W/S proportions, compare to type1 boards. However, it can be seen that the type2 boards required approximately 20-32℃ higher temperature for decomposition compare to type1 boards at similar experimental manufacturing conditions. This is very important findings considering boric acid and board's thermal decomposition have a positive relationship.

4. CONCLUSION

There is number of reason for manufacturing a bio-composite material includes materials which are stronger, lighter, or less expensive when compared to traditional wood based materials. However, since increasing demand on bio-composites, this is leading to the need to investigate environmentally friendly, sustainable materials to replace existing ones for lowering cost.

In our study, it can be realized that recycled Old Corrugated Container fibers would have economic and environmental advantages for using fiberboard production alone or with combination of wood fibers. However for obtaining high physical and technological properties, optimum proportions of wood/secondary fiber mixture and boric acid content are necessary. Although increasing secondary fiber proportion and boric acid usually cause lowering strength and physical properties some level, both material have been found to offer advantages for improving sound (acoustic) and thermal properties of boards. It is clear that the alternative use of secondary fibers from post-consumer waste OCC can be useful for production of different purposes of fiberboards.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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