

Properties of Composite Panels Made from Secondary Fibers with Boric Acid

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ABSTRACT

The change in the dimension (Thickness Swelling; TS) was found to be high, at high boric acid content for boards made from Office paper/Newspaper (O/N) and Office paper/Old Corrugated Container (O/C) types. However, the boards made with 10% boric acid exhibits higher Modulus of Rupture (MOR) values than boards made with 5.0% boric acid. The highest value of MOR was found as 7.93 MPa with the addition of 10% boric acid with Newspaper/Old Corrugated Containers (3:1 by weight) mixtures. The Modulus of Elasticity (MOE) of the boards generally decreased with increasing boric acid content from 5% to 10% in furnishes. The Office paper/Newspaper had the highest MOE among the all formulations and considerable higher than standard value of 600 MPa. However, the highest value of MOE was found as 735.63 MPa with the mixture of 3:1 (by weight) proportions of Office paper/Newspaper proportions. The similar results were observed for Internal Bond (IB) properties of boards, as like MOE. While in general, increasing boric acid content from 5.0 to 10%, negative effects on IB properties of boards. It was also realized that the boric acid content and fiber proportions effects various level on thermal properties (thermal conductivity; TC). The boric acid had usually provided higher thermal resistance, but the difference between fiber proportions and fiber types consisting of boric acid was important. However, the lowest TC value of 0.1455 W/mK was found the boards made from only old corrugated containers fibers with 10% BA content. The sound absorption values of boards made from secondary fibers show a sound damping that it was steady increase up to 1600 Hz and then decreasing. It could be realized that the sound absorption properties of boards were generally better than that of in lower frequencies.

Keywords: Recycled paper, Composite, Boric acid, Mechanical properties, Acoustic properties

Borik Asit Katkılı Sekonder Liflerden Yapılan Kompozit Malzemelerin Özellikleri

öz

Ofis-gazete kağıdı(O/N) ve ofis-karton kağıdından (O/C) yapılan levhalarda borik asit içeriği arttıkça levhalardaki boyut değişiminin (Suda şişme; TS) yükseldiği tespit edilmiştir. Ancak %10 borik asit içeren levhaların Eğilme Elastikiyet Modülü (MOR), %5.0 borik asit içeren levhalara göre daha fazla olarak kendini göstermiştir. %10 borik asit ilavesiyle en yüksek MOR değeri, gazete/karton kağıdı (ağırlıkça 3: 1) karışımı için 7.93 MPa olarak bulunmuştur. Mobilyalarda, levhaların Elastikiyet Modülü (MOE) genellikle borik asit içeriği%5'ten %10'a yükselirken azalmıştır. Tüm formülasyonlar arasında en yüksek MOE ofis/gazete kağıdında, 600 MPa standart değerinden oldukça yüksek çıkmıştır. Bununla birlikte, en yüksek MOE değeri, ofis kağıdı/gazete oranlarının 3:1 (ağırlıkça) karışımı ile 735.63

MPa olarak bulunmuştur. Benzer sonuçlar, MOE'de olduğu gibi, levhaların yüzeye dik çekme direnci (IB) içinde gözlenmiştir. Genel olarak, borik asit içeriğinin %5.0'den 10'a çıkarılması, levhaların IB özelliklerine olumsuz etki eder. Borik asit içeriği ve lif oranı seviyesinin termal özelliklere (termal iletkenlik;TC) etkileride fark edildi. Borik asit genellikle yüksek termal direnç sağlar ancak lif oranı ve borik asit katkılı lif tipinin içeriği önemli olmaktadır. Bununla birlikte, en düşük TC değeri 0.1455 W / mK olan, %10 BA içeriği olan sadece karton kağıdı liflerinden yapılmış levhalar olduğu bulunmuştur. Sekonder liflerden yapılan levhaların ses yutma değerleri, sürekli olarak 1600 Hz'e yükselen ve ardından azalan bir ses sönümlenmesi göstermektedir. Levhaların ses yutma özelliklerinin genellikle düşük frekanslarda daha iyi olduğu anlaşılmaktadır.

Anahtar Kelimeler: Geri dönüşümlü kağıt, kompozit, borik asit, mekanik özellikler, akustik özellikler

INTRODUCTION

Composites are usually made by combining two or more materials that often ones that have different properties. These materials (i.e. binder and reinforcement) work together to give the composite unique properties (Vasiliev and Morozov, 2001). However, the binder surround and adhere together fibers or fragments of the other material, which is called the reinforcement (Vasiliev and Morozov, 2001; Hänninen and Hughes, 2010). People have been making composites since prehistorical times. One early example has by mixing mud and straw together to make bricks that are resistant to both squeezing and tearing (Vasiliev and Morozov, 2001; Hänninen and Hughes, 2010).

Some advanced composites are now made using natural fibers instead of synthetic materials. These are lighter and stronger but sometimes more expensive to produce. Thereby, a number of natural fiber sources have already been evaluated worldwide. Extensive literature available for determining chemical, physical and material (i.e. composite) properties of natural fibers (Atchison et al., 1989; English et al., 1997). However, cellulosic fiber based composite products could often be used as replacements for mineral or petrochemical based materials. It has already reported that when used appropriately, cellulosic fibers could deliver strength, thermal and acoustic insulation properties comparable to others. Moreover, the natural fibers are commonly derived from co-products of other processes (i.e. agricultural or forest waste), and hence generally has a low environmental impact (Rowell, 1995, White and Cook, 1997).

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. However, increasing shortage of wood resources, these effects to search alternative utilization of secondary cellulose fibers to forest products industry. In this regard, one of the new utilization of cellulose fibers that use as raw materials for composite manufacturing. Moreover, the use of waste fibers as reinforcement in synthetic

resin (i.e. formaldehyde) has enormous potential in the field of bio-composite manufacturing. These composites based on recycled fibres in optimized form present an acceptable behavior in comparison with virgin wood cellulose fibers (Nourbakhsh et al., 2010; Eshraghi and Khademislam, 2012).

It has been considered that the use of waste papers in composite or paper production is beneficial in terms of environmental and socio-economic aspects. The collected waste papers have increased more rapidly and a number of paper recycling mills are become commercially manufacture seconder pulp for various purposes in worldwide. However, environmental benefits have been one of the main drivers for recovered secondary cellulose fibers that use as alternatives for wood materials.

A variety of natural fibers for building applications have been commercialized already, but the recycled fibers investigated in this study are still rarely used in building practices. The cellulosic fibers are competitive materials thanks to their low density, well mechanical properties, easy processing, high stability, occupational health benefits, high quantity availability, low price, and reduced environmental impacts for their production (Nourbakhsh et al., 2010; Okino et al., 2000).

The study was aimed to prepare boards from recycled secondary fibers and also to determine the effects of secondary fiber proportions with boric acid addition (BA %) on the performance of the experimental boards.

MATERIALS AND METHODS

The post-consumer waste papers (office, newspaper and Old Corrugated Containers; OCC) were obtained from local waste paper trader, Isparta, Turkey. The boric acid was supplied directly from Etibor A.Ş, as laboratory purity, Bandırma-Turkey.

The waste papers were carefully sorted according to their inherent properties. That are; office papers coded as O; newspapers coded as N; and OCC coded as C. These waste materials separately converted to pulp

using a 5 L. capacity, laboratory type standard disintegrator in water.

A single flame combustion tests were carried out for determining the ignitability of experimental boards. Special types of flame combustion test system were built and conducted according to TS EN ISO 10534-2. (2003). The test samples were cut according to standard of 90x250 mm pieces and placed on the test apparatus at vertical position. A visual observation of the sample was made and results recorded as positive or negative whether the specimen ignition occurs or not the flame spreads in the vertical direction more than 150 mm above.

Both sound absorption (Acoustic) and thermal insulation properties (Thermal conductive) have been determined according to TS EN 10534-2 and ASTM-C 1113-

09 standards, respectively (TS EN ISO 10534-2., 2003; ASTM C1113/C1113M-09, 2013). For sound absorption tests, at least 12 samples tested with Brüel & Kjaer Tube Type 7758 instrument with microphones in a pod, 19 different frequency ranges (TS EN ISO 10534-2., 2003). Figure 1 shows typical schematic representative of the sound absorption (Acoustic) test equipment. For thermal conductive tests, at least 6 samples cut with dimensions of 120x60 mm. The KEM QTM 500 instrument was utilized and thermal conductivity unit determined (W/mK) (ASTM C1113/C1113M-09, 2013). The detailed information on panel production conditions, recycling process and experimental procedures may be found in former publications (Kaya, 2015; Kaya and Sahin, 2016). Table 1 presents the boards codes that proportion of secondary fiber ratios and boric acid content in furnish.

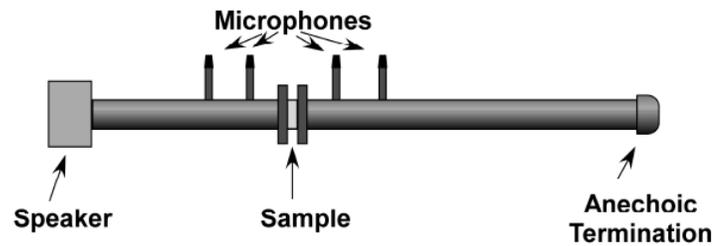


Figure 1. Schematic representative of a microphone method for determining acoustic properties

Table 1. The experimental board's code numbers recycled fiber ratio with boric acid (BA) content (x: 5.0%, y: 10 % boric acid content; O: Recycled office fiber, N: Recycled newspaper fiber, C: Recycled OCC fiber).

Board code	Fiber mixture (by weight)	BA (%)	Board code	Fiber mixture (by weight)	BA (%)
Recycled Office Paper/ Recycled Newspaper (O/N)					
D0x	1:0	5.0	D0y	1:0	10.0
D1x	3:1	5.0	D1y	3:1	10.0
D2x	1:1	5.0	D2y	1:1	10.0
D3x	1:3	5.0	D3y	1:3	10.0
D4x	0:1	5.0	D4y	0:1	10.0
Recycled Office Paper/ Recycled Old Corrugated Containers (O/C)					
E0x	1:0	5.0	E0y	1:0	10.0
E1x	3:1	5.0	E1y	3:1	10.0
E2x	1:1	5.0	E2y	1:1	10.0
E3x	1:3	5.0	E3y	1:3	10.0
E4x	0:1	5.0	E4y	0:1	10.0
Recycled Newspaper/ Recycled Office Paper (N/C)					
F0x	1:0	5.0	F0y	1:0	10.0
F1x	3:1	5.0	F1y	3:1	10.0
F2x	1:1	5.0	F2y	1:1	10.0
F3x	1:3	5.0	F3y	1:3	10.0
F4x	0:1	5.0	F4y	0:1	10.0

RESULTS AND DISCUSSIONS

Table 2 shows the Thickness Swelling (TS) of the experimental boards in water prepared from recycled paper products with 5.0 and 10% boric acid addition. The change in the dimension was found to be more for the higher boric acid content that made from Office paper/Newspaper (O/N) and Office paper/OCC (O/C) types. In 2 hour swelling conditions, the experimental boards had usually reached approximately 80-95% of Maximum Equilibrium Swelling values. These are expected and consisted with literature findings. In all manufacturing conditions and boric acid added levels,

the TS values of experimental boards were higher than standard value of 14%. It might be said that the increasing in the swelling, including secondary paper fiber mixtures is probably due to no any hydrophobic agents added during manufacturing that typically used 1.0% in commercial boards manufacturing (i.e. wax). However, TS values show that the effect of boric acid is more pronounced on act as lowering TS in lower boric acid (%5) for O/N and N/C type experimental boards. Moreover, the lowest TS was measured 28% for F3x and E1y boards, respectively that this value approximately two times higher than the standard value of 14%.

Table 2. The board's code numbers recycled fiber ratio with boric acid (BA) content (x: 5.0%, y: 10 % boric acid content; O: Recycled office fiber, N: Recycled newspaper fiber, C: Recycled OCC fiber).

Board code	TS (2h) (%)	TS (24h) (%)	Board code	TS (2h) (%)	TS (24h) (%)
Recycled Office Paper/ Recycled Newspaper (O/N)					
D0x	40	44	D0y	25	32
D1x	39	35	D1y	32	41
D2x	42	40	D2y	25	35
D3x	42	43	D3y	32	42
D4x	42	36	D4y	25	32
Recycled Office Paper/ Recycled Old Corrugated Containers (O/C)					
E0x	40	44	E0y	25	32
E1x	33	38	E1y	27	28
E2x	40	44	E2y	33	34
E3x	40	45	E3y	32	37
E4x	33	38	E4y	27	34
Recycled Newspaper/ Recycled Office Paper (N/C)					
F0x	40	44	F0y	25	32
F1x	26	29	F1y	22	32
F2x	28	31	F2y	35	33
F3x	24	28	F3y	31	37
F4x	33	38	F4y	27	34
TS EN 622-5	14				

Table 3 shows the Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Internal Bond (IB) strength properties of experimental boards made from the recycled waste papers and their proportions to each other. It was observed that boards made with 10% boric acid exhibits higher MOR than boards made with 5.0% boric acid content. The highest value of MOR was found as 7.93 MPa with the addition of 10% boric acid with Newspaper/OCC (3:1 by weight) mixtures (F1y). However, the boards of D1y; D2y; F1y and F2y show higher MOR values than standard value of 7.7 MPa. Moreover, the boards made with 5.0% boric acid exhibits lower MOR than standard value of 7.7 MPa among the

all conditions. The highest MOR value of 6.83 MPa was found with 5.0% boric acid addition of the proportions of 1:1 (by weight) Newspaper/OCC fiber proportions (F2x).

In contrast to MOR, the MOE of the boards generally decreased with increasing boric acid content from 5.0% to 10% in furnish (Table 3). 5.0% boric acid mixture with 3:1 (by weight) proportions of Office paper/Newspaper had the highest MOE among the all formulations and considerable higher than standard value of 600 MPa (Table 2). The boards of E1x; F1x; F2y and F3x displayed higher MOE properties in

comparison with the standard. The 10% boric acid added boards displayed diminished MOE properties in comparison with the 5.0% boric acid added boards at the similar manufacturing conditions. The highest value of MOE was found as 735.63 MPa with the mixture of 3:1 (by weight) proportions of Office paper/Newspaper proportions. However, the boards only prepared from the proportions of Office paper/Newspaper (D1y; D2y and D3y) with 10% boric acid show higher MOE values than standard value of 600 MPa.

In Internal Bond (IB) properties of experimental boards, similar results were also observed as like MOE properties (Table 3). In general, increasing boric acid content from 5.0 to 10%, negative effects on IB properties. The highest IB value of 0.19 MPa was found with 5.0% boric acid addition of at the proportions of 1:3 (by weight) Office paper/Newspaper fiber mixtures (E3x). However, for 5.0% boric acid addition conditions, the boards of E1x (0.16 MPa) and E3x (0.19 MPa) while for 10% boric acid addition, only E3y boards (0.17 MPa) show higher IB properties in comparison with the standard value of 0.15 MPa.

Table 3. The mechanical strength properties of boards with boric acid (BA) content (*x*: 5.0%, *y*: 10 % boric acid content; *O*: Recycled office fiber, *N*: Recycled newspaper fiber, *C*: Recycled OCC fiber).

Board code	MOR (MPa)	MOE (MPa)	IB (MPa)	Board code	MOR (MPa)	MOE (MPa)	IB (MPa)
D0x	2.96	484.0	0.11	D0y	3.03	473.0	0,09
D1x	6.49	1097.37	0.11	D1y	8.06	735.83	0.09
D2x	3.83	460.87	0.12	D2y	7.98	676.66	0.1
D3x	4.91	571.28	0.07	D3y	6.65	663.66	0.05
D4x	3.90	570.0	0.05	D4y	4.60	566.0	0.03
E0x	3.90	570.0	0.05	E0y	4.60	566.0	0.03
E1x	4.95	802.54	0.16	E1y	5.21	571.83	0.14
E2x	3.34	451.43	0.13	E2y	6.43	544.25	0.11
E3x	3.89	484.57	0.19	E3y	7.63	492.16	0.17
E4x	3.20	327.0	0.14	E4y	3.43	468.0	0.12
F0x	2.96	484.0	0.11	F0y	3.03	473.0	0.09
F1x	6.06	714.18	0.06	F1y	7.93	487.16	0.04
F2x	6.83	855.05	0.12	F2y	7.68	373.75	0.1
F3x	5.81	606.1	0.08	F3y	7.05	401.16	0.04
F4x	3.20	327.0	0.14	F4y	3.43	468.0	0.12
TS EN 622-5	7.7	600	0.15	TS EN 622-5	7.7	600	0.15

The thermal conductivity (TC) properties of boards show in Figures 2-4. It can be seen that the boric acid content and fiber proportions effects various level on thermal properties (thermal conductivity). In Figure 2, it is clearly realized that the increased boric acid content for Office paper/newspaper type boards, had usually improved to TC values for the boards of D1y; D2y; D3y while the lowest TC value of 0.1540 W/mK was found the boards made from only newspaper fibers with 5.0% BA content (D4x).

In Figure 3, it could be seen that increasing boric acid content at similar fiber proportions of Office paper/OCC (O/C), lowers thermal conductivity values and this could be proved with the improvements in the boric acid's thermal resistance for that type of fiber proportions. The lowest TC value of 0.1454 W/mK was found the boards made from only newspaper fibers with 10% BA level (E4y).

The less similar results were found for boards that made from Newspaper/OCC fiber mixtures (Figure 4). However, the boric acid had usually provided higher thermal resistance, but the difference between fiber proportions and fiber types consisting of boric acid was important. Moreover, the lowest TC value of 0.1455 W/mK was found the boards made from only OCC fibers with 10% BA content (F4y).

There should be many factors affecting the thermal resistance of the materials such as; fillers, fiber specifications, chemical modification of fibers and thermal resisting agents. However, decreasing in TC values may be attributed to the increasing boric acid content in fiber mixtures because it's specific thermal resistance properties (Kaya, 2015).

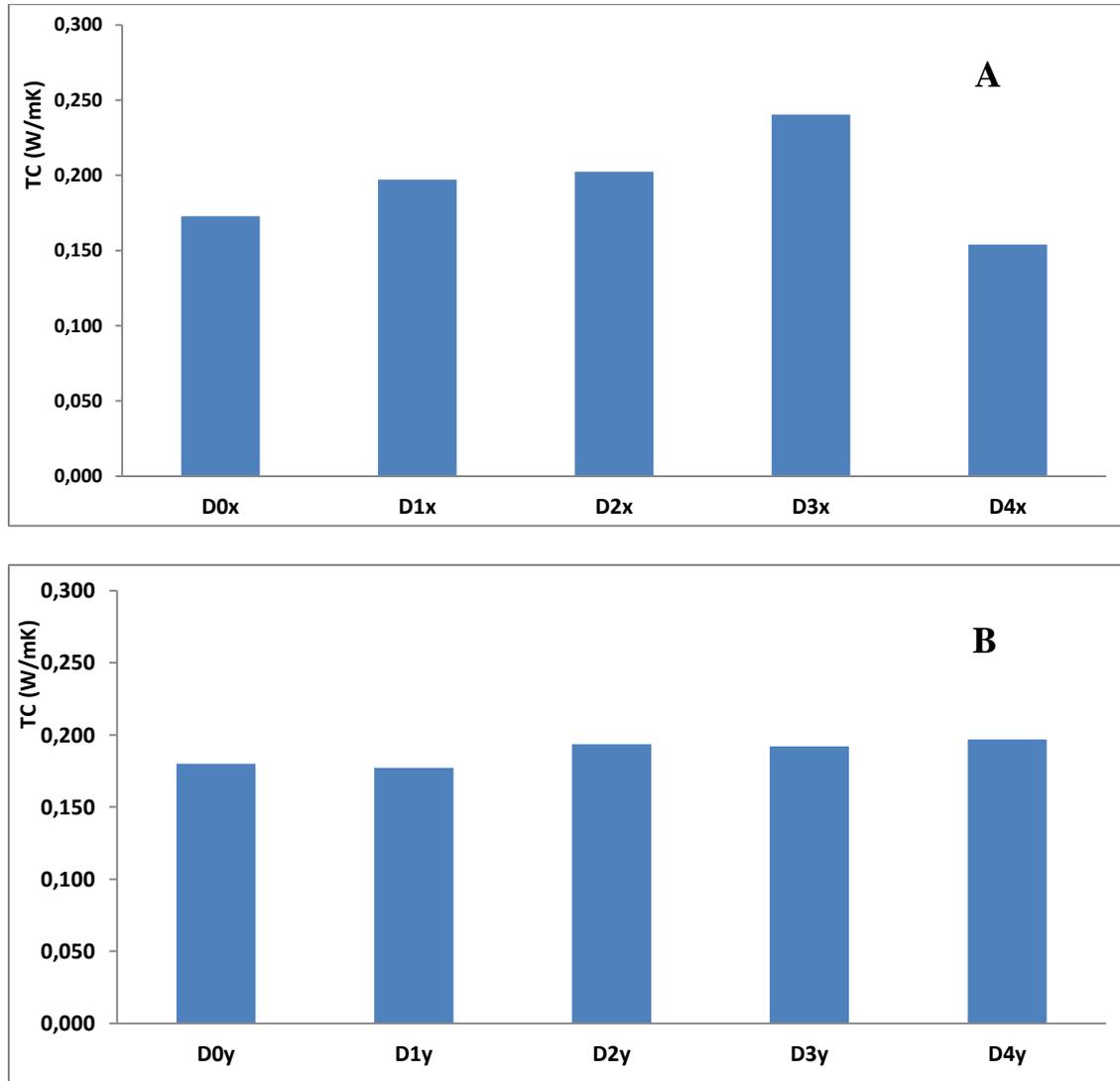


Figure 2. Thermal conductive (TC) (Insulation) properties of boards made with O/N mixtures with boric acid (BA) (A: 5.0%, B: 10 % boric acid content).

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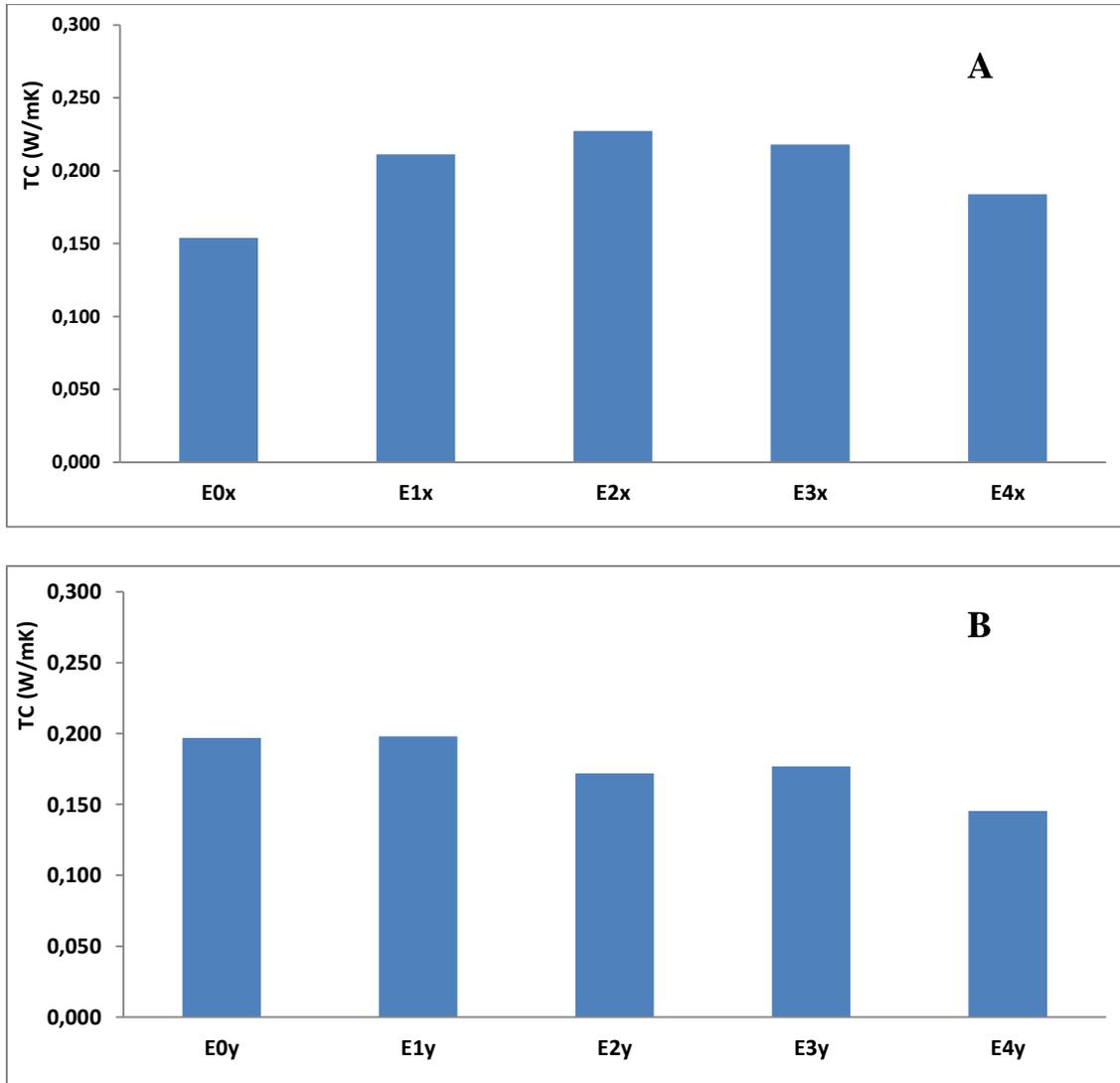


Figure 3. Thermal conductive (TC) (Insulation) properties of boards made with O/C mixtures with boric acid (BA) (A: 5.0%, B: 10 % boric acid content).

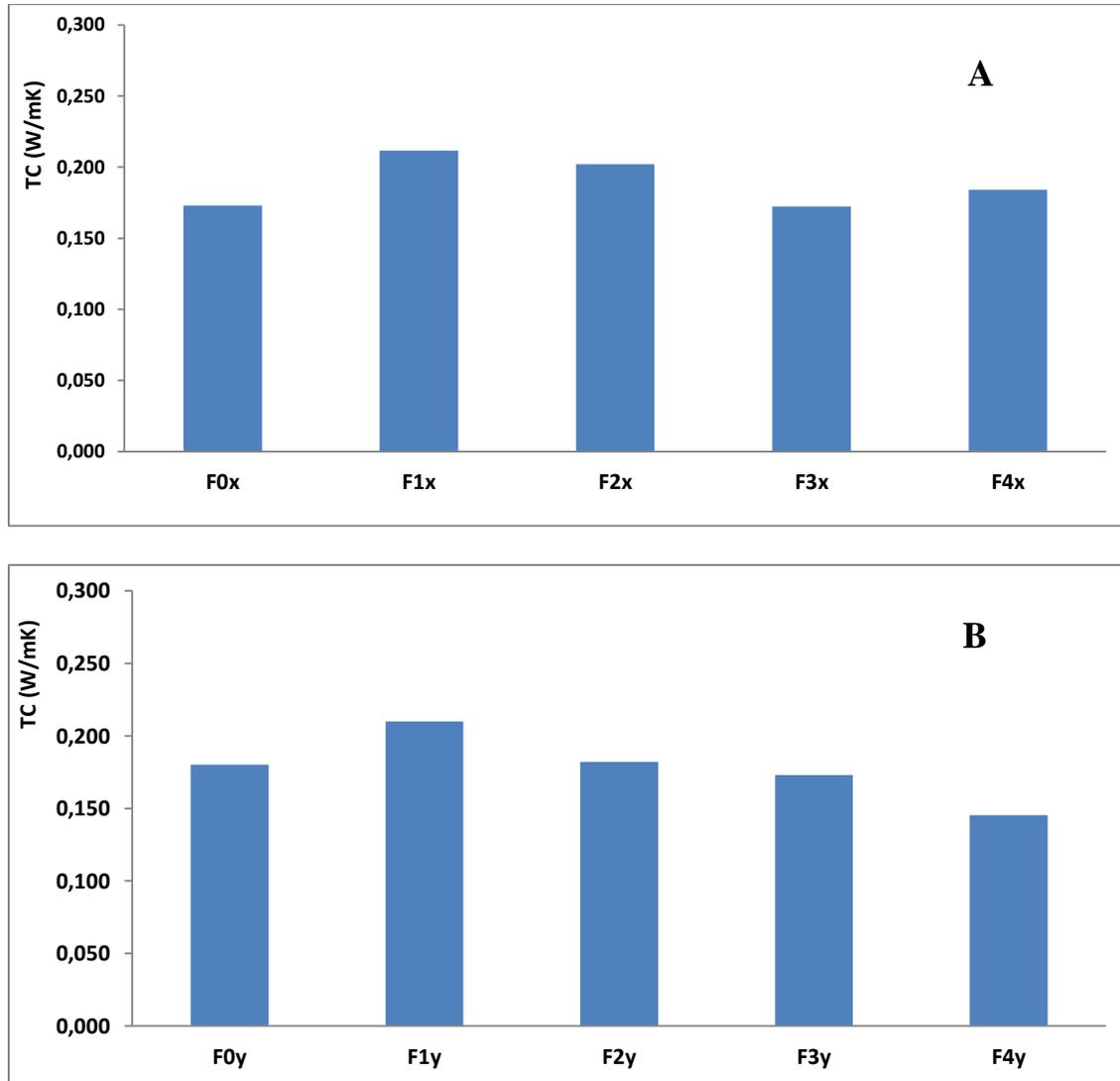


Figure 4. Thermal conductive (TC) (Insulation) properties of boards made with N/C mixtures with boric acid (BA) (A: 5.0%, B: 10 % boric acid content).

The control of noise, which is any undesired sound, is becoming important because the noise levels and their adverse effects on people. Sound absorption can be defined, as *'the incident sound that strikes a material that is not reflected back'*. It is the change of sound energy into some other form in passing through a medium. There are a number of techniques for determining the acoustic properties of materials. However, the measurement of air flow through a material is a physical property useful in evaluating its performance as an acoustic absorber. In order to examine the effect of fiber type and boric acid content at various frequencies, the sound properties of boards are shown in Figures 5a and b. Moreover, the sound absorption values of boards made from secondary fibers show a sound damping that it was steady increase up to 1600 Hz and then decreasing. It could be realized that the sound absorption properties of boards were generally better than that of in lower level frequencies and lower boric acid addition (5.0%). It was also realized that the sound absorption shows a various level of increase and decrease with some variables but in middle level frequencies (1250-1600 Hz) it shows sudden decrease in all conditions. It may be suggested that at middle level noise frequencies, the boards made from secondary fibers shows improved sound properties some level. This is very important considering experimental boards made from various levels of secondary fiber and boric acid mixtures that may be useful in building industry as alternative new composite materials for improving acoustic properties.

The burning behaviors of boards were conducted according to TS EN 11925-2 standard. The experimental

results were shown that all the boards manufacture with recycled paper fibers and boric acid combination are shown to not reaching the critical level of 150 mm distance. Thereby, these boards pass the minimum level of B2 class that shows only slight tendency to char on surface. These results implied a good boric acid-secondary fiber interface for all formulations.

CONCLUSIONS

A wide variety of production variables determine the physical and mechanical properties of boards manufactured from various sources and conditions. Among those like fiber ratio, density, type and percent of adhesive used, fiber specification, etc., which have been already reported by various researchers.

Although, high mechanical strength properties of composites from recovered secondary fibers are very difficult to prepare because of their inherent characteristics, the environmental awareness and focus of sustainability has supported the overall recycling issue and making alternative products rather than paper. However, currently, there is no proper data available about the effects of various level of boric acid addition to composite panel manufacturing from secondary fibers. It has been possible to produce, sustainable building materials from secondary raw materials (i.e., recovered cellulose fibers from waste papers) and it helps to conserve non-renewable sources of raw materials.

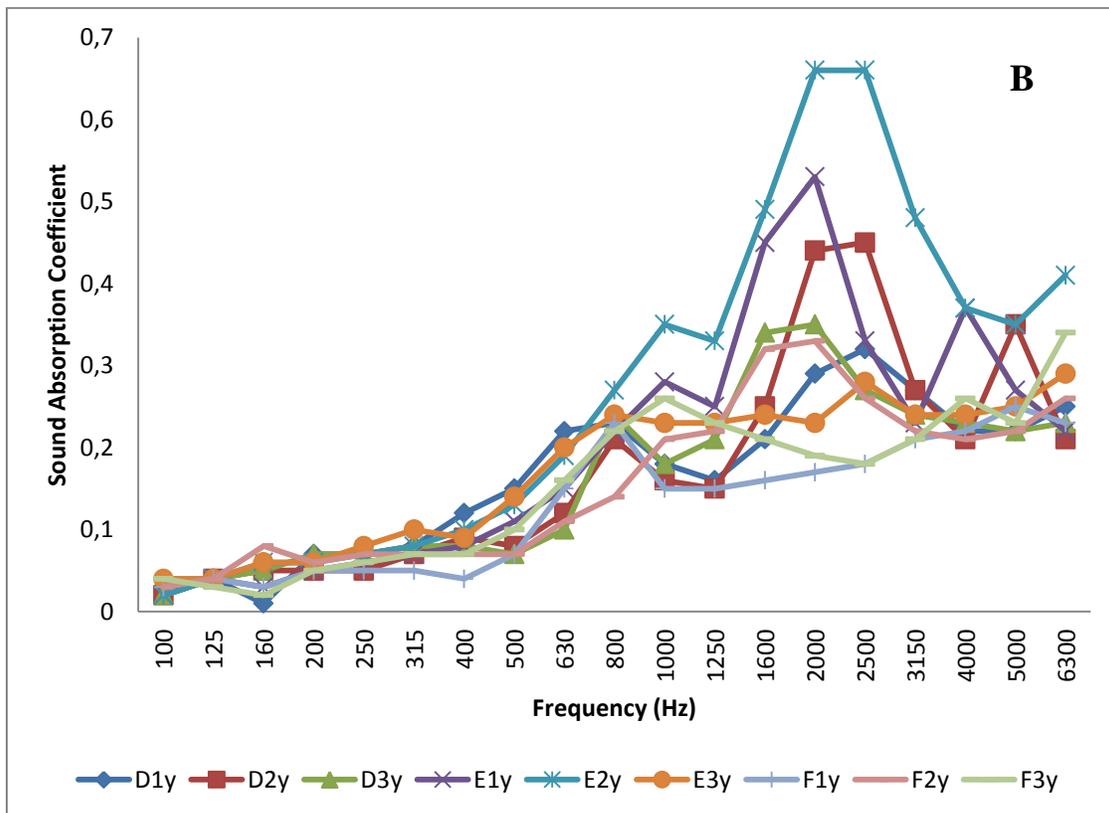
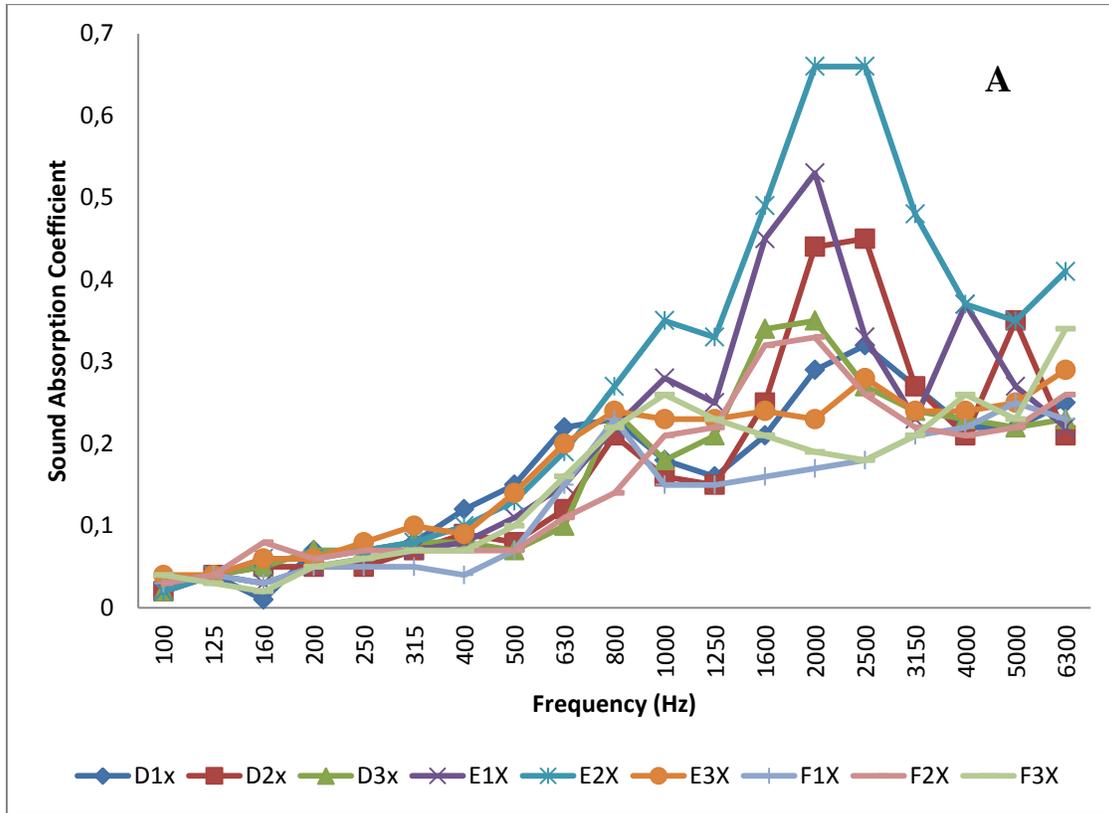


Figure 5. Sound absorption (acoustic) properties of boards made with: (a) N/C mixtures; and (b) with boric acid (BA) (**A:** 5%, **B:** 10 % boric acid content).

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