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Research Article

Gypsum-Based Boards Made from Mixtures of Waste Cellulosic Sources: Part 1. Physical and Mechanical Properties

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Abstract

It was realized that post-consumer waste paper, old corrugated container (OCC) and secondary fiber addition (cellulosic additives) to gypsum in panel structure negative impact on Thickness Swelling (TS) values in water. However, highest TS values of 23.32% (A6) in A-type, 12.76 (B6) in B-type and 7.79% (C6) in C-type experimental boards found at similar proportions (50:50 w/w) of gypsum and cellulosic additives while the lowest with control sample that was only 1.88%. Moreover, the boards produced by secondary fiber/gypsum mixture (C-type boards) under similar ratios (w/w) were found to higher IB strength than others. The highest IB strength value of 0.60 N/mm^2 found for C3 board while the ratio of the secondary fiber in the mixture to be more than 20%, negative effects on IB values to a certain extent. The addition of all three cellulosic sources to the gypsum structure increases the bending strength properties some level. At 10% (A2: 6.59 N/mm^2) and 50% (A6: 6.44 N/mm^2) proportion levels, A-type boards show higher bending strengths than the B- and C-type boards. In all manufacturing conditions and board types, the natural weathered boards have always shown lower hardness properties than counterpart control samples.

Keywords: Waste paper, Seconder fiber, Old Corrugated Container, Gypsum panel, Strength properties

Atık Selülozik Karışımı Kaynaklardan Üretilen Alçı Esaslı Levhalar: 1. Bölüm. Fiziksel ve Mekanik Özellikler

Öz

Bu çalışmada, atık durumdaki kağıtlar (A tipi), eski kullanılmış oluklu mukavvalar (B tipi) ve ikincil selüloz lifleri (C tipi) alçı yapısına katılarak kompozit deneme panel levhalar üretilmiştir. Araştırma bulgularına göre, bu hammaddelerin alçı yapısna katılması su içinde kalınlık artım değerlerini olumsuz etkilemiştir. A, B ve C tipi levhalarda en yüksek kalınlık artım değeri sırasıyla %26,32, 12,76% ve %7,79 olarak benzer üretim şartlarındaki A6, B6 ve C6 deneme levhalarında gözlemlenmiştir. Bu levhaların üretim şartları %50-50 (ağırlık/ağırlık) alçı-selülozik atık şeklindedir. Fakat en düşük kalınlık artım değeri ise sadece alçıdan üretilmiş levhada (kontrol levhası) %1,88 olarak ölçülmüştür. Sekonder lif/alçı karışımından üetilmiş C tipi levhalarda, aynı üretim şartlarında A ve B tipi levhalardan daha yüksek iç yapışma direnç (IB) özelliğine sahip deneme levhaları üretilmiştir. En yüksek iç yapışma direnci 0.60 N/mm^2 olarak C3 tipi levhada gözlemlenmiştir. Fakat %20 den daha yüksek sekonder lif eklenmesi alçıdan üretilmiş levhaların direnç özelliklerini olumusuz etkilemiştir. Alçı yapısına eklenen her üç tip hammadde de eğilme direnç özelliklerini (MOR) olumlu etki etttiği anlaşılmıştır. %10 ve %50 selülozik katkı durumunda, A2 (6.59 N/mm^2) ve A6 (6.44 N/mm^2) levhaları diğer B ve C

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tipi levhalara göre aynı üretim şartlarında daha yüksek eğilme direnç özelliği göstermiştir. Açık havada bekletilmiş tüm deneme levhalarının sertlik özellikleri, kontrol örneklerinden daha düşük olduğu anlaşılmıştır

Anahtar Kelimeler: Atık kağıt, Sekonder lif, Eski oluklu mukavva, Alçı levha, Direnç özellikleri

1. Introduction

The continuous increase in the demand on the wood materials, leads to a shortage of forest lands with increasing in the prices, which in turn efforts towards to the search alternative new raw material sources for the forest products industry. However, other approaches for this topic are the preservation of environment and decreasing the destruction of natural forests. Thereby, many studies have already been conducted on new biomass sources such as; annual plants, lignocellulosic wastes, recovered cellulose fibers (e.g. secondary fibers), agricultural residues, throughout the world (Konukcu, 2001; Rowell, 1996; Şahin, 2006).

Since paper was first invented in China at 105 A.D by T'sai Lun, it has still remained important materials for writing, drawing and communication purposes in our daily lives. At present, hundreds type of paper-based products (e.g. corrugated cardboards, bags, cleaning/sanitary, writing, cigarette, wrapping, etc.,) utilized worldwide by consumers (Baipai, 2013; Thompson, 1992). However, after the use of those products, they are often disposed as household or municipal solid wastes. Because of the presence of cellulose in sheet structure, the recovery of this valuable material is particularly important in terms of protecting environment and energy savings. Moreover, the recycling of paper-based products has a simpler production process that significant reduction of operational costs and energy with less environmental pollution (e.g. air, soil or water). More information on paper recycling benefits and advantages could be found elsewhere (Baipai, 2013 and 2018; Cathie and Guest 1991; Spangenberg, 1993; Thompson, 1992).

Although a number of studies have already conducted utilization of recovered cellulose fibers (secondary fibers) for papermaking, there is very limited research on the use of those for composite panel production. Grigoriou (2003) was used three different paper types (newspaper, office and magazine) with isocyanate as resin by mixing wood at various proportions for making composite materials. He reported that the addition of wax to that mixture (between 0.7-2.0%) significantly reduced the thickness swelling (TS) values of that panels (Grigoriou, 2003). Yang and his group (2002), utilized waste paper particles with 10% urea-formaldehyde (UF) as resin with some fire-retardant substances (0.8-1.0%). It was found that the mechanical strength properties of the boards were lower than those of MDF and particle boards but they show well insulation properties (Yang et al., 2002). It was reported that addition of secondary fibers that recovered from old corrugated container to fiberboard structure more than 40% significantly reduced the properties of the panels (Hwang et al., 2005). In recent study, it was investigated the possibilities of fiberboard production from secondary fibers recovered from three different paper types (newspaper, office paper and old corrugated container) with a synthetic binder (UF). It was stated that the secondary fibers could be used individually or mixture in various proportions together to produce panel products with acceptable some strength and technological properties (Kaya, 2015).

Gypsum is one of the oldest building materials used throughout history. In the archaeological studies, some of the gypsum remnants which were used in 6800-5700 BC were found in Çatalhöyük, Konya (Demir, 2019). Today, it is estimated that around 3 billion tons of gypsum reserves could be operated in worldwide, and nearly half of them are estimated to be located in the USA. However, one of the main drawback of gypsum as a building material is its heaviness and brittleness. Hence, gypsum boards does not have strong impact resistance for some building applications. This drawback could be overcome by combining gypsum with various materials in order to impinging better mechanical performance with sound and fire resistance (Herhández et. al. 1999).

Although some research has already conducted utilization of waste paper and secondary cellulose fibers for various purposes rather than papermaking, there is no comprehensive study on the use of post-consumer waste papers, OCC and secondary fibers for gypsum-based panel production. In this sense, composite production possibilities were conducted by using these three different cellulose-based materials with gypsum. Moreover, the determination of the variables and the suitability of those with the gypsum-based composite panel production approaches have been investigated. Thereby, this study divided to two part, in first part, it was studied the physical and mechanical strength properties of cellulosic added gypsum-based composite panels. In the second part, some chemical and technological properties of those panels have been investigated.

2. Materials and Methods

2.1. Materials

Old Corrugated Container (OCC) obtained from a local company, Isparta-Turkiye. THe OCC typically contains various types of papers at inside (corrugated) or outer surfaces (liner papers) such as; kraft liner, test liner, NSSC and fluting etc. The waste papers supplied from edge clipping of pressing process (fully bleached Kraft type) that there is no any further (i.e. writing or printing) procedure applied. The general properties of waste papers as follows;

- **Grammage:** 48-90 g/cm^2,
- **Bulkiness:** 1.6-2.0 cm^3/g,
- **Brightness (%):** >85 (ISO 2470-2),
- **Opacity (%):** 86-90 (ISO 2471).

Both type of paper based products were turned into particles through hand scissors and screned to suitable particle dimensions. The 30-50 mm particles were utilized for adding to gypsum/water mixture. They were then dried at athmospheric conditions until at least a 10-12% moisture content was obtained.

The secondary fibers were produced from post-consumer waste paper (print paper grade, fully bleached kraft). These were converted to secondary pulp using, laboratory type standard disintegrator in water. After 30-35 minutes to disintegration, all the sheets convert to the pulp. Then the pulps washed with fresh water and screened on a 200 mesh screen. After, the pulps laid on laboratory conditions to air dried at 24 hours, the pulps was refined a stone mechanical refiner to final fibrillation level.

2.1. Methods

The bonding agent employed was commercial grade perlite plaster type Gypsum, supplied by a local retail store, Isparta, Turkey. The detailed description of gypsum and its specifications could be found elsewhere **(Demir, 2019).** After 15 to 20 minutes of mixing gypsum with cellulosic additives in water, the composite paste 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 5.0 MPa, to reach 10 mm thickness, after which the boards was retained in compression for 24 hours. The target densities of the manufactured boards were; 1.0 (± 0.1) gr/cm^3.

A total of 36 experimental gypsum-based boards were made. The experimental procedure for manufacturing experimental particle boards as;

- **Press temperature (ºC):** Ambient temperature,
- **Pressing and curing time (day):** up to 28,
- **Press pressure (N/mm^2):** 0.1-1.0,
- **Gypsum-waste paper/OCC/secondary fiber ratio (%):** 100-0/0-50
- **Board dimensions (mm):** 400x400x10 cm.

In order to limit the study to a certain level and to investigate the effects of cellulosic additives to gypsum structure, it is not considered to include any other substance rather than cellulosic additives and gypsum, since only the effect of gypsum/cellulosic compatibility are considered.

After manufacturing, the experimental panels, they were conditioned at 20 ºC and 65 % relative humidity and samples were cut to determine the IB (Internal Bond), MOE and MOR (Modulus of Elasticity and Rupture), TS (Thickness Swelling after 24 hours immersion in water), in accordance with TS EN 310 (1999), TS EN 319 (1999) and TS EN 317 (1999) standards, respectively.

The board's code numbers and gypsum/cellulosic additive proportions (waste paper (A); OCC (B) and secondary fiber (C) are given in Table 1.

The natural weathering tests were conducted on 50x50x10 mm samples were exposed to natural outdoor process for two months. The comparative hardness tests were conducted only for those samples. The surface hardness properties of both control and wheathered samples were measured with a Shore Hardness (Scale D) instrument, according to test method of ASTM D2240 standard.

An 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. The code numbers and mixture proportions of gypsum based experimental panels

Code	Cellulosic additive (gr)	Gypsum (gr)	Cellulosic additive (%)	Gypsum (%)
A1-B1-C1	0	1600	0	100
A2-B2-C2	160	1440	10	90
A3-B3-C3	320	1280	20	80
A4-B4-C4	480	1120	30	70
A5-B5-C5	640	960	40	60
A6-B6-C6	800	800	50	50
C7	960	640	60	40
C8	1120	480	70	30

3. Results and Discussions

The comparative Thickness Swelling (TS) properties of boards immersed in water for 24 hours are shown in Figure 1. The highest TS found for A6 (23.32%) and B6 (12.76%) experimental panels at similar proportions in gypsum structure (50:50, waste paper & OCC into gypsum) while the lowest with control sample (A1 & B1). In general, it was observed that the amount of waste paper or OCC particles in the gypsum structure adversely affected the TS increases. This could be expected considering addition of a hydrophilic cellulosic material (waste paper & OCC) into the hydrophobic gypsum structure. It is clear that those panels with having some cellulosic additives exhibit higher hydrophilic properties than gypsum alone, and that it is inevitable. However, more less similar trend was also found in C-type experimental panels at similar level of additives that the highest TS value of 7.79% was also found in C6. It is clearly seen that there is a close relationship between the increase in the ratio of the secondary fiber (cellulosic) and the TS of the boards in the water, and in contrast to the increase in the ratio of the gypsum. Moreover, except B2 board, in all similar level of proportions, A-type experimental panels show higher TS properties while C-type panels show lowest. It is important to note that only cellulose based hydrophilic substances added to gypsum structure but some hydrophobic substances could be added (e.g. wax) together to improve thickness swelling properties that could be utilized in industrial level of productions. Furthermore, it was proposed for isocyanate bonded paper based panels that even %0.7 addition of wax into cellulosic panel structure significantly reduced TS values (Grigoriou, 2003). The similar approach might be applied to our experimental panels for improving TS properties.

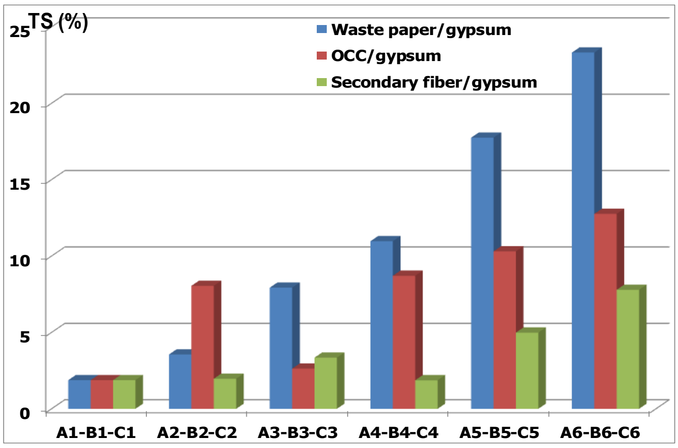

Figure 1. The thickness swelling properties of experimental panels.

Internal Bond (IB) strength properties of the experimental panels are given in Table 2. It has already realized that addition of waste paper and OCC into gypsum significantly affected the IB strengths and higher that content resulted in lower IB strengths of experimental panels. Thereby, highest IB value of 0.27 N/mm^2 was found for those in control sample. However, the highest IB values of boards produced by the waste paper and OCC addition to gypsum was found on the A5 and B3 experimental panels (0.22 N/mm^2) that are approximately, 18.5% lower than control panels. These results clearly indicate poor compatibility between waste paper and OCC particles with gypsum. In contrast, markedly different IB strengths were found for C-type experimental panels that all boards produced from the secondary fiber/gypsum mixture were higher IB values than the control (C1) in all conditions. The highest IB strength value of 0.60 N/mm^2 found for C3 experimental panel. It is important to note that the ratio of the secondary fiber in the mixture to be more than 20% while reducing the effects on IB values to a certain extent. But still IB values of panels are higher than control (C1) in all conditions. This is probably related to better fiber arrangement that is considerably softer and well organized could be the lowering the void volume in gypsum matrix system. In addition, it is well known that wood-based composite materials produced from fibers (fiberboards) at the same density level are usually higher strength properties than those produced from chip or particles (chipboards) (Maloney, 1977; FPL, 2010). In this study, the results found for C-type experimental panels support this hypothesis that secondary fibers could be more flexible and adaptive to gypsum structure than waste paper or OCC particles.

The Duncan's multiple range test results (Table 2) also showed that the OCC and secondary fibers addition into gypsum had some statistically different IB values, while it was in the two groups in B-type and four groups in C-type experimental boards.

Table 2. The Internal Bond (IB) strengths of experimental panels*

Board code	Density (kg/m³)	Internal bond strength (IB) (N/mm²)	Difference from control (%)
Waste paper/gypsum-based experimental panels			
A1	1107.61	0.27 (G)	0,0
A2	938.65	0.21 (G)	-22.2
A3	885.58	0.16 (G)	-40.8
A4	837.03	0.14 (G)	-48.1
A5	823.49	0.22 (G)	-18.5
A6	861.01	0.16 (G)	-40.7
OCC/gypsum-based experimental panels			
B1	1107.61	0.27 (A)	0.0
B2	952.22	0.19 (B)	-2.6
B3	930.47	0.22 (B)	-18.5
B4	825.46	0.15 (B)	-44.4
B5	884.30	0.13 (B)	-51.9
B6	840.91	0.11 (B)	-59.3
Seconder fiber/ gypsum-based experimental panels			
C1	1107.61 A	0.27 (Ax)	0.0
C2	1136.10 B	0.52 (Bx)	9.6
C3	1050.25 B	0.60 (Bx)	122.2
C4	1033.63 C	0.44 (Cx)	62.9
C5	962.92 C	0.35 (Cx)	19.6
C6	939.93 D	0.28 (Dx)	3.7
C7	966.67 D	0.30 (Dx)	11.1
C8	951.49 D	0.28 (Dx)	3.7

* Groups with the same letters in each column indicate that there is no statistical difference ($P< 0.05$) between the samples according to the Duncan's multiple range test.

With using the data in Table 2, the effect of cellulosic additives on gypsum for IB strengths at similar conditions are comparatively shown in Figure 2. It can be clearly seen that the experimental panels produced by secondary fibers/gypsum mixture under the same conditions (weight/weight) were found to significantly higher than the other two types of panels. In this situation, one could be said that the dimensions of the cellulosic material added to the gypsum structure are effective. Because paper and corrugated cardboard particles (2-5 cm) were used in A- and B-type experimental panels, but secondary fibers (1-3 mm) were used in C-type panels. In this case, it is assumed that the fibers are more compatible with the gypsum than the particles that could be set in gypsum matrix structure with having positive effect on the IB strengths.

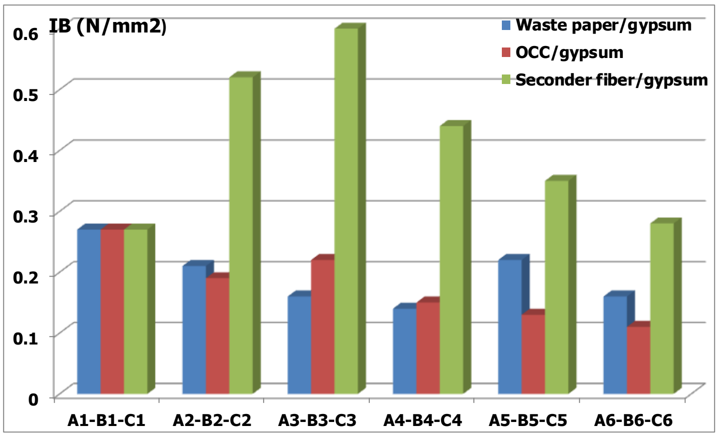

Figure 2. The Internal Bond (IB) properties of experimental panels.

The comparative Modulus of Ruprure (MOR) or Bending Strength and Modulus of Elasticity (MOE) values of boards with statistical results are shown in Table 3. When the bending strengths of boards were examined, it was found that all three experimental panel types had higher strength values than control samples (A1, B1 & C1: 2.22 N/mm²). In this sense, those all three additives into gypsum adversely influenced the strength properties compared with those of panel from only gypsum. The highest bending strength value was calculated 6.59 N/mm² in A-type boards (A2), 4.92 N/mm² in B-type boards (B5) and 6.98 N/mm² in C-type boards (C3). These values are approximately 196.8%, 121.6% and 214.4% higher than control, respectively. Thus, it is clear that the addition of all these cellulosic materials to the gypsum structure positively influence the bending strengths. In this regard, it could be suggested that a hard and brittle (rigid) matrix structure of gypsum may be modified by adding lower specific gravity materials which is more resistant and having high specific gravity/strength properties.

Table 3. The Bending Strength (MOR) and Moduclus of Elasticity (MOE) of experimental panels.

Board code	Modulus of Ruprure (MOR) (N/mm^2)	Diffrence from control (%)	Modulus of Elasticity (MOE) (N/mm^2)	Diffrence from control (%)
Waste paper/gypsum-based experimental panels				
A1	2.22 (Az)	0.0	1373 (A)	0.0
A2	6.59 (Cz)	196.8	2274 (A)	65.6
A3	4.27 (Az)	92.3	806 (BC)	-99.4
A4	5.71 (BCz)	157.2	154 (AB)	12.5
A5	3.72 (ABz)	67.6	802 (ABC)	-41.6
A6	6.44 (BCz)	190.1	1423 (AB)	3.6
OCC/gypsum-based experimental panels				
B1	2.22 (At)	0.0	1373 (Cx)	0.0
B2	2.46 (At)	10.8	1536 (Ax)	11.9
B3	2.99 (ABt)	34.7	1603 (BCx)	16.8
B4	4.45(BCt)	100.5	1536 (ABx)	11.9
B5	4.92 (Ct)	121.6	1798 (ABCx)	30.9
B6	2.23 (At)	0.45	522 (ABx)	61.9
Secondary fiber/gypsum-based experimental panels				
C1	2.22 (Af)	0.0	1373 (ABy)	0.0
C2	5.32 (BCf)	139.6	3819 (ABy)	178.2
C3	6.98 (Cf)	214.4	6117 (ABy)	345.5
C4	6.11 (Cf)	175.2	4881 (ABCy)	255.5
C5	3.47 (ABf)	56.3	5437 (BCy)	295.9
C6	3.97 (ABf)	78.8	1294 (Ay)	-5.8
C7	5.17 (BCf)	132.8	870 (Ay)	-36.6
C8	4.93 (Bf)	122.1	1002 (Ay)	-27.1

*Groups with the same letters in each column indicate that there is no statistical difference ($P< 0.05$) between the samples according to the Duncan's multiple range test.

Similar to MOR, the highest MOE value of 2274 N/mm^2 was found on A2 board, while the lowest value of 802 N/mm^2 for A5 board. For B-type experimental panels, the highest MOE values of 1603 N/mm^2 found for B3 board while the lowest of 522 N/mm^2 for B6 board. However, the MOE values of the C-type panels were found to be higher than the control sample (C1: 1373 N/mm^2) until the addition of 40% secondary fiber level. Further addition of secondary fibers in the gypsum matrix resulted in significant reduction in the MOE values and even lower than the control. These is important considering compatibility between secondary fibers with gypsum up to certain level.

However, Duncan's multiple range test results showed that the waste paper, OCC and secondary fibers effects statistically different MOR and MOE values, while it was in the four groups in A- and B type and five groups in C-type experimental panels for MOR properties. Moreover, for MOE properties four groups in A- and C type experimental panels while five groups in B-type experimental panels, respectively.

In order to comparatively investigate the effect of these cellulosic additive's impacts on gypsum-matrix at similar manufacturing (proportions) conditions, Figure 3 and Figure 4 were formed by using the data in Table 3. As mentioned above, it was found that all three types of cellulosic sources provided a higher bending resistance characteristic than the control sample in all conditions (Figure 3). However, at 10% and 50% proportion level, waste paper/gypsum based experimental panels show higher bending strengths than the other two panels types (A2: 6.59 N/mm^2 and A6: 6.44 N/mm^2). Moreover, at 40% proportion level, the B5 board was observed to be higher MOR values (B5: 4.92 N/mm^2) than the other two board types (A5: 3.72 N/mm^2 and C5: 3.47 N/mm^2) under the similar conditions. On the other hand, the highest MOR values of 6.98 N/mm^2 was found for C2 type board. It could be concluded that the addition of these cellulosic sources to the gypsum matrix structure increases the bending strength properties of the experimental panels that is important considering these raw materials are compatible with gypsum and could be useful in composite structure at controlled level of proportions.

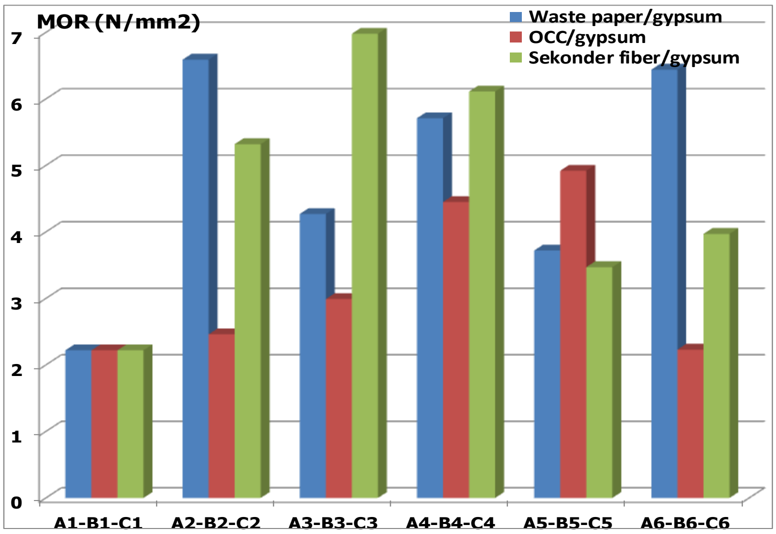

Figure 3. The bending strength (MOR) properties of experimental panels.

It is also realized that the boards produced from the secondary fiber/gypsum mixture (C-types) show higher MOE properties in all conditions than those produced by the waste paper (A-types) and OCC (B-types) experimental panels (Figure 4). However, only A3, A5, A6 and B6 boards show lower MOE values than control samples (A1-B1-C1: 1373 N/mm^2).

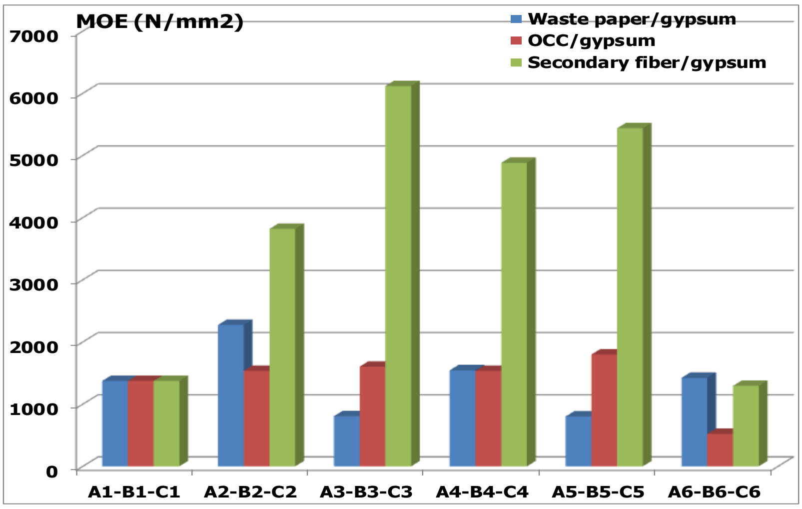

Figure 4. The Modulus of Elasticity (MOE) properties of experimental panels.

It was well known that additive type and particle size are two of the most important factors that affect strength properties of composite materials. However, the better arrangement of particles or fibers and compatibility with gypsum matrices should also positively effects on strength of panels. On the other hand, gypsum could effectively wet the outer surface of additives to form better mechanical bonding, which resulted in improved strength properties and dimensional stability. In our study, it looks like gypsum has better compability with secondary fibers rather than waste paper and OCC particles. The results found in above support this hypothesis. Moreover, some approaches could be suggested for improving the compatibility of cellulosic additives with gypsum that may increasing the strength of panel products. In addition the elimination of gypsum hardening inhibition could be overcome either reducing the amount of inhibitory substances into gypsum paste or accelerating the gypsum hydration by external force. Thereby, an pre-treatment of the furnish with various solution may be improve the compatibility due to change of structure of hydrated products and just cold or hot water was enough for some contaminants although some sources may require a more severe treatments.

The comparative surface hardness values (Shore D) of the experimental boards with statistical results and same samples keeping external atmospheric conditions for 60 days, are given in Table 4. It has been found that the increase in the ratio of the waste paper, OCC and secondary fibers in gypsum (A-, B- and C-type boards) has a positive effect on the hardness improvements.

Table 4. Surface hardness properties of experimental panels (Shore D hardness; metric)

Board code	Hardness (Metric)	Diffrences from control (A1, B1, C1) (%)	Hardness after wheathering (Metric)	Difference (%)
Waste paper/gypsum mixture				
A1	31 (Ax)	0.0	27	-12.9
A2	39 (Bx)	25.8	35	-10.3
A3	44 (Cx)	41.9	40	-9.1
A4	53 (Ex)	70.9	52	-1.8
A5	46 (BCx)	48.3	38	-17.4
A6	49 (Dx)	58.1	46	-6.1
OCC/gypsum mixture				
B1	31 (CDy)	0.0	27	-12.9
B2	56 (Dy)	48.3	54	-3.5
B3	58 (CDy)	87.1	51	-12.6
B4	44 (ABy)	41.9	43	-2.3
B5	49 (BCy)	58.1	46	-6.1
B6	40 (Ay)	29.1	39	-2.5
Seconder fiber/gypsum mixture				
C1	31 (Ez)	0.0	27	-12.9
C2	56 (Bz)	80.6	45	-19.6
C3	57 (Az)	83.8	37	-35.1
C4	55 (DEz)	77.4	54	-1.9
C5	47 (BCz)	51.6	42	-10.6
C6	51 (DCz)	64.5	47	-7.8
C7	48 (Bz)	87.1	44	-8.3
C8	52 (BCz)	67.8	47	-9.6

In all conditions, the higher hardness values were found with these rather than control samples. However, the highest hardness values for each type boards are; 53 in A-types (A4), 58 in B-types (B3) and 57 in C-types (C3) experimental boards that these are approximately 70.9%, 87.1% and 83.9% higher than control (A1-B1-C1: 31), respectively.

However, the panels that exposed to atmosphere for natural wheathering were affected significantly average surface hardness of the panels. In this sense, the natural weathered boards have always shown lower hardness properties than counterpart samples. The highest hardness value decrease was measured as 35.1% in C3 while the lowest was determined as 1.8% in the A4 board. It may be concluded that in the additive properties (cellulosic) effects the hardness properties but there is no direct correlation found between cellulosic additive type and surface hardness properties for both control and weathered samples.

Duncan's multiple range test results showed that the waste paper, OCC and secondary fibers effects statistically different hardness values, while it was in the six groups in A- and C type panels and five groups in B-type panels for surface hardness properties.

The combine effects of panel density and cellulosic additive level on surface hardness properties shown in Figure 5. As seen in Table 4, all cellulosic additives positively effects on panels hardness properties some level. However, increasing panels density had negative impact on surface hardness for A- and B-type boards (Fig. 5 A and B). Moreover, for C-type experimental boards, both board's density and secondary fiber content improvement effects on surface hardness some level (Fig.5 C). More less similar trend was also realized for weathered samples (Fig.5).

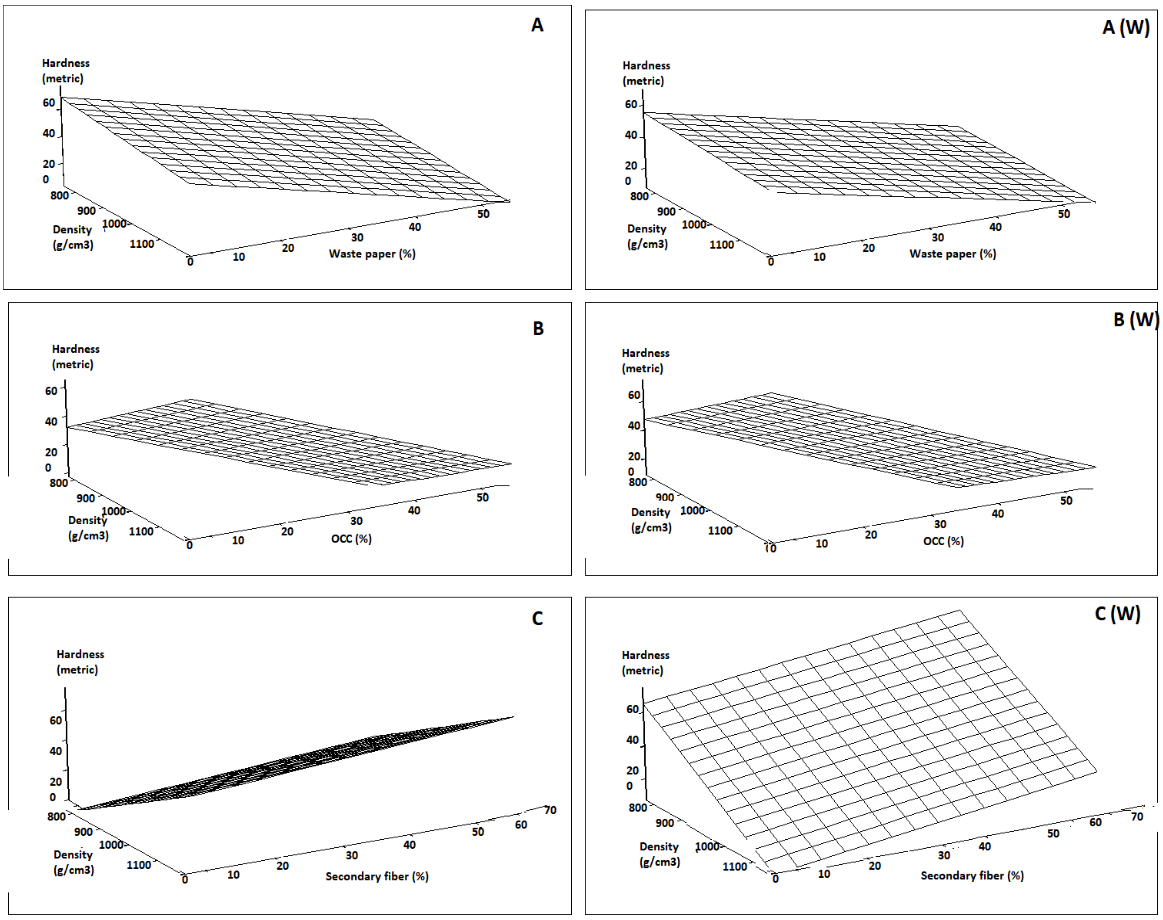

Figure 5. Cellulosic additive and board's density effects on hardness properties of boards (**A:** A-types; AW: Wheathered of A-types, **B:** B-types; BW: Wheathered of B-types, **C:** C-types; CW: Wheathered of C- types)**.**

4. Conclusions

Post-consumer waste paper and paperboards products have already close attention throughout the world due to ready to use cellulose in sheet structure. However, considerably high level of cellulose fibers has lost or not sufficient quality for paper production. Although these could be decreased by appropriate collection, transportation, and processing during careful recycling process, in other approaches for effective utilization of those waste materials to direct use for composite panel manufacturing.

In this study, gypsum-based experimental panels were produced by increasing 10% cellulosic raw materials (waste paper, OCC and secondary fiber) at each production stage, limit to compatibility level with gypsum. Hence, the effect of the ratio of these materials in the mixture of the known proportions has been studied. It is clear that some level of proportions, it is possible to produce acceptable level of gypsum-based panels with these additives at controlled conditions. In this sense, it may be introduced to market with better mechanical and physical properties.

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