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Properties of Gypsum Boards Made with Cedrus Tree (*Cedrus libani*) Components. Part 1. Physical and Mechanical Properties

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Research Article

Abstract − In this study, it was found that the addition of wood had a reducing effect on water absorption (WA) and thickness swelling (TS) properties in gypsum-based boards. The lowest WA value of 41.56% was found sample prepared with cedrus's bark/needle mixture (KaI_3; 3:2 by weight). It has also been realized that experimental boards made only bark-gypsum (SKa_6), cone-gypsum (SKo_6) and needle-gypsum (SI_6) proportions show Thickness Swelling (TS) values of 33.70%, 21.70% and 18.85%, respectively. However, the surface hardness (Shore D) has usually correlated with wood content but natural weathering negatively effects hardness that lowering from -6.9% (SKa_1) to -30.3% (SKa_2) in all typse experimental boards. It was found that panels produced with cedrus wood/cone (SKo); cedrus wood/needle (SI) and cedrus cone/needle (KoI) proportions have no higher values than standard Internal Bond (IB) value of 0.28 N/mm^2. But the highest IB value of 0.48 N/mm^2 was observed for a sample of SKa_5 that produced with a ratio of 1:4 by cedrus wood/bark proportions (w/w). Moreover, the highest bending strength (MOR) values of 1.32 N/mm^2 were calculated with SKa_2 sample that produced with ratio of 4:1 by cedrus wood/bark proportions (w/w). These mechanical properties are probably related to experimental board manufacturing process, which consists of multi stage processing (slushing, soaking, formation, pressing and drying) may effect hindering reinforcement elements to develop the network matrix strength properly.

Keyword − *Cedrus wood, cone, needle, gypsum board, internal bond, MOR, MOE*

Sedir Ağacının (*Cedrus libani*) Farklı Kısımlarından Üretilmiş Alçı Esaslı Levhaların Özellikleri. 1. Bölüm. Fiziksel ve Mekanik Özellikler

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Araştırma Makalesi

Öz− Bu çalışmada, odun ilavesinin, alçı esaslı levhalarda su alma (WA) ve kalınlığına şişme (TS) özelliğini azaltıcı etki gösterdiği bulunmuştur. En düşük su alma oranı %41,56 ile sedir kabuk/ibre karışımından (KaI_3; 3:2, ağırlık: ağırlık) üretilmiş levhalarda gözlemlenmiştir. Sadece kabuk-alçı (SKa_6) ve kozalak-alçı (SKo_6) ve ibre-alçı (SI_6) karışımından üretilmiş deneme levhalarının kalınlığına şişme oranları sırasıyla %33,70, %21,70 ve %18,85, hesaplanmıştır. Ayrıca, yüzey sertlik (Shore D) değerleri genellikle levha karışımındaki odun oranı ile pozitif, fakat doğal yaşlandırma işlemine tutulmuş levhalarda ise negatif ilişkisi olduğu ve % -6.9 (SKa_1) ile %-30.3 (SKa_2) arasında azalmalar belirlenmiştir. Sedir odun/kozalak, (SKo); sedir odun/ibre (SI) ve sedir kozalak/ibre (KoI) karışımlarından üretilmiş levhaların yapışma direnç değerleri (IB), standart değer olan 0.28 N/mm^2 den daha düşük hesaplanmıştır. En yüksek yapışma direnci 0.48 N/mm^2 olarak 1:4 (ağırlık/ağırlık) oranında sedir odun/sedir kabuk (SKa_5) örneğinde belirlenmiştir. En yüksek eğilme direnci ise (MOR) 1.32 N/mm^2 olarak 4:1 (ağırlık/ağırlık) oranında sedir odun/sedir kabuk (SKa_5) örneğinde belirlenmiştir. Bu mekanik değerler deneysel levha hazırlama aşamaları ile yakından ilişkili olduğu zira çok basamaklı proseslerde (ıslatma, taslak oluşturma, presleme ve kurutma), ilave edilen güçlendirme elamanlarının etkisini engelleyerek matris yapıda uygun direnç oluşumunu etkileyebilirler.

Anahtar Kelimeler − *Sedir odunu, kozalak, ibre, alçı levha, yapışma direnci, MOR, MOE*

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1. Introduction

Since gypsum-based boards began to use in the construction industry in 1950s, there has been growing interest in that composite manufacturing worldwide. However, a significant portion of recent literature on those products has focused on natural fillers to determining effects of variables (Cam, 2019; Herhández et. al. 1999; Van Elten, 1996). It has been reported by several scientist that the use of bio-material as reinforcement element in gypsum network has been beneficial in many aspects (Cam, 2019; Shiroma et al. 2016; Youngquist, 1999). De Araújo and his group (2011) studied the feasibility of gypsum- and cement-based composites made from bamboo species. It has been reported that the bamboo-cement boards presented higher bending strength and lower moisture content than bamboo-gypsum boards. Dai and Fan (2015) prepared a bio-composite from wood sawdust and gypsum. They proposed that there was a positive effect of sawdust on gypsum was achieved by the addition of an antifoam agent. They reported that water-based epoxy (WEP) could be coated on the surface of sawdust, which resulted in a reduction of the water absorption up to 25.6% and water content inside composite up to 35.8%. They suggested that 20% sawdust addition into gypsum gave reasonable flexural- and compressive strength values of the composite are 4.59 MPa and 13.25 MPa, respectively. Morales-Conde and his friends (2016) prepared a composite material from wood shavings and sawdust from wood waste mixed in various proportions with gypsum. It was found that increasing wood proportions in mixture reduced density and Shore C hardness while slightly lowered thermal conductivity. In addition, wood content and mechanical properties of the composite material were correlated to each other that lowered with increasing wood content in the mixture. In more recent study, the effects of red pine wood/rice straw particles in the mixture up to 60:40 (ratio, w/w) in gypsum-water mixture were investigated. It has been reported that the addition of rice straw to the wood/gypsum mixture has a lowering effect on the thickness swelling, internal bond (IB) and bending strength (MOR) properties of experimental boards at some level (Sahin et al. 2019). The similar results were also realized with post-consumer waste paper, old corrugated container (OCC) and secondary fiber addition (cellulosic additives) to gypsum in panel structure negative impact on Thickness Swelling values in water. Interestingly, the addition of all three cellulosic sources to the gypsum structure increases the bending strength properties on some level (Sahin and Demir, 2019). Cedrus libani, commonly known as the Lebanon cedar, is an evergreen conifer that is native to the mountains of the Eastern Mediterranean basin. Cedar wood is very prized for its fine grain, attractive yellow color, and fragrance. It is exceptionally durable and immune to insect ravages.

The aim of the complimentary laboratory-scale investigations is to study the effects of cedrus tree's components (bark, cone, needles, wood) as reinforcenent elements on gypsum-based boards. In this respect, experimental composite panels were produced from a combination of various proportions with cedrus tree's components in controlled conditions. Thus, it is possible to produce gypsum-lignocellulosic based (cedrus tree components) experimental panels by selecting the most suitable processing conditions. In order to limit the study to a certain level and to investigate the effects of lignocellulosic reinforcement elements to gypsum structure, it is not considered to include any other substance rather than cedrus tree components and gypsum, since only the effect of gypsum/lignocellulosic compatibility is considered.

2. Material and Method

The reinforcement filler materials used in gypsum-based boards are cedrus tree (*Cedrus libani*) and its components. The cedrus wood, bark, cones, and needles used in the study were collected from a local forest office in Isparta, Turkey. All these raw materials were turned into particles through a hammer mill and screened. Particles remaining on the 2-3 mm were used in gypsum-based experimental panel production. The particles were then dried at atmospheric conditions until air dried (12-15%) moisture content. Commercially available gypsum that carried TS EN 13279-1 B4/20/2 standard form as provided and without further processing was used. Some reported specification of that Gypsum material as follows; initial hardening time:> 20 min; full hardening time: 150 min; useability time after mixture prepared, 60 min; water (lt)/gypsum content (gr): 6.0-6.5/10; heat coefficient: 0.34 W/mK; Fire performance: A1; Bending strength (at least): 10 kgf/cm^2; Crushing strength (at least 4x4 block): 25 kgf/cm^2. After 15 to 20 minutes of mixing gypsum with cedrus tree's components in water, the paste was screened onto a metal plate that 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 were retained in compression for 24 hours. The target densities of the manufactured boards were; 1.2 (± 0.5) gr/cm3. A total of 62 (31x2) experimental gypsum-based boards were made. Six different types of boards were prepared with various proportions with 1000 gr (constant) gypsum and 500 gr (constant) lignocellulosic additives. The experimental boards were prepared with given codes in this study was summarized in Table 1. 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-cedrus's wood/bark/cone/needle ratio (gr): 1000 gr/500 gr.
- Board dimensions (mm): 400x400x10 cm.

Table 1
Code numbers and mixture proportions (gr) of reinforcement elements (S: cedrus wood, Ka: cedrus bark, Ko: cedrus cone, I: cedrus needle).

Board Code	**Wood (gr)**	**Bark (gr)**	**Cone (gr)**	**Needle (gr)**
Type 1 (Gypsum-cedrus' wood/bark based boards)				
SKa$_1$	500	0	0	0
SKa$_2$	400	100	0	0
SKa$_3$	300	200	0	0
SKa$_4$	200	300	0	0
SKa$_5$	100	400	0	0
SKa$_6$	0	500	0	0
Type 2 (Gypsum-cedrus' wood/cone based boards)				
SKo$_1$	500	0	0	0
SKo$_2$	400	0	100	0
SKo$_3$	300	0	200	0
SKo$_4$	200	0	300	0
SKo$_5$	100	0	400	0
SKo$_6$	0	0	500	0
Type 3 (Gypsum-cedrus' wood/needle based boards)				
SI$_1$	500	0	0	0
SI$_2$	400	0	0	100
SI$_3$	300	0	0	200
SI$_4$	200	0	0	300
SI$_5$	100	0	0	400
SI$_6$	0	0	0	500
Type 4 (Gypsum-cedrus' bark/cone based boards)				
KaKo$_1$	0	500	0	0
KaKo$_2$	0	400	100	0
KaKo$_3$	0	300	200	0
KaKo$_4$	0	200	300	0
KaKo$_5$	0	100	400	0
KaKo$_6$	0	0	500	0
Type 5 (Gypsum-cedrus' bark/needle based boards)				
KaI$_1$	0	500	0	0
KaI$_2$	0	400	0	100
KaI$_3$	0	300	0	200
KaI$_4$	0	200	0	300
KaI$_5$	0	100	0	400
KaI$_6$	0	0	0	500
Type 6 (Gypsum-cedrus' cone/needle based boards)				
KoI$_1$	0	0	500	0
KoI$_2$	0	0	400	100
KoI$_3$	0	0	300	200
KoI$_4$	0	0	200	300
KoI$_5$	0	0	100	400
KoI$_6$	0	0	0	500

After manufacturing, the experimental panels, were conditioned at 23 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 2- and 24-hours immersion in water) and The Water Absorption (WA, %), in accordance with TS EN 310 (1999), TS EN 319 (1999) and TS EN 317 (1999) standards, respectively. The natural weathering tests were conducted on 50x50x10 mm samples were exposed to natural outdoor process for two months, the surface color changes and surface hardness were determined with X-Rite SP68 Spectrophotometer using CIE L*, a*, b* standard (1976), and a Shore Hardness (Scale D) instrument, according to the 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.

3. Result and Discussion

Although many variables and mechanisms effects liquid uptake, the water absorption experiments are valuable in predicting moisture absorptiveness regardless of the mechanisms (Khazaei, 2008). The comparative water absorption (WA) properties of six different types of gypsum based boards are presented in Table 2.

Table 2
Water absorption (%) properties of boards

Board Codes	**WA (%) (2 h)**	**WA ratio (%) (2/24 h)**	**WA (24 h, %)**
SKa_1	56.74	95.3	59.49 (1.42) **A**
SKa_2	51.62	90.3	57.18 (1.57) **A**
SKa_3	48.64	83.9	57.89 (0.48) **A**
SKa_4	40.00	78.8	50.76 (3.30) **B**
SKa_5	42.06	78.6	53.51 (3.92) **C**
SKa_6	32.58	69.4	46.93 (3.93) **D**
SKo_2	47.08	84.1	56.04 (5.35) **A**
SKo_3	43.24	86.5	50.04 (0.99) **B**
SKo_4	46.38	94.4	49.12 (1.49) **B**
SKo_5	48.13	96.5	49.96 (3.62) **B**
SKo_6	44.45	90.8	48.91 (4.42) **B**
SI_2	50.70	94.1	53.89 (5.25) **AB**
SI_3	43.15	74.1	58.03 (4.31) **A**
SI_4	49.17	93.9	52.39 (3.16) **B**
SI_5	49.80	82.2	59.59 (6.16) **A**
SI_6	50.24	86.5	58.08 (3.79) **A**
$KaKo_2$	39.33	85.5	46.01 (2.32) **A**
$KaKo_3$	37.07	76.1	48.73 (0.04) **A**
$KaKo_4$	34.65	74.5	46.52 (2.09) **A**
$KaKo_5$	40.94	86.1	47.54 (5.32) **A**
$KaKo_6$	41.43	84.7	48.91 (4.42) **A**
KaI_2	36.80	76.8	47.94 (6.07) **B**
KaI_3	35.80	86.1	41.56 (2.24) **A**
KaI_4	37.36	87.9	42.48 (0.84) **AB**
KaI_5	43.87	77.2	58.63 (1.64) **C**
KaI_6	54.33	93.5	58.08 (3.79) **C**
KoI_2	33.48	74.6	44.85 (3.33) **B**
KoI_3	33.85	81.2	41.69 (1.35) **C**
KoI_4	37.10	72.6	50.97 (2.72) **A**
KoI_5	36.04	81.2	44.39 (0.53) **B**
KoI_6	39.22	67.7	58.08 (3.79) **D**

**The numbers in parenthesis are standard deviations. Values sharing the same capital letter (s) within a column are not statistically different at a 0.05 level of confidence.*

The boards made with wood in proportions (Type 1-3) exhibited an initial high rate of moisture sorption followed by lowering trend while the other components (bark, cone and needle) increases in the mixture. However, boards made without wood show various levels of WA properties. The highest WA value of 59.49% was found for the SKa1 sample that was only made with cedrus wood-gypsum. But the lowest WA value of 46.93% was found with a sample made only with cedrus' bark-gypsum for Types 1-3 boards. Moreover, the lowest WA value of 41.56% was found sample made with cedrus's bark/needle mixture (KaI3; 3/2 by weight) in gypsum.

It is clear that lignocellulosic fillers in gypsum rather than wood lowering effects on WA of experimental boards. It could also be realized that boards prepared with various proportions with wood/bark, cone and needle show lowering water absorption as wood content reduced in proportions. It may be expected considering these non-wood substrates has usually higher hydrophobic constituents (lignin and extractives) rather than wood. It may effect lowering water intake. It has well known that the rate of water absorption depends on the difference between the saturation moisture content and the water content at a given time, which is called the driving force. As hydration proceeds, the water content increases, decreasing the driving force and consequently the sorption velocity. The water absorption process ceases when the sample attains the equilibrium in water content (Siau, 1995). It may be another evidence that cone, bark and needle particles could be better alignment in the gypsum network resulting in resistance against water diffusion in some level. Moreover, Wilson and his group (1995 a and b) proposed that the absorption of water into a composite (two different materials) was due to hydraulic contact that the absorption of water into two-layer composites is ultimately controlled by the properties of the second material.

Table 3 shows the comparative Thickness Swelling (TS, %) properties of experimental boards. Except for the boards of SKa_6 and SI_3 which shows the 33.70% and 30.34% TS values, the lowering wood content and/or increasing bark (Type 1), cone (Type 2) and needle (Type 3) proportions in the mixture have usually lowering effects on TS properties of experimental boards in water. The lowest TS values have been observed at the lowest cedrus wood content (100 gr) while the highest amount of bark (10.69% for SKa_5, in Type 1); cone (7.67% for SKo_5, in Type 2) and needle (9.48% for SI_5, in Type 3) reinforcement particles with in gypsum. On the other hand the lowest TS values of 12.34% ($KaKO_2$, in Type 4); 11.03% (KaI_4, in Type 5); and 9.9% (KoI_2, in Type 6) were found, respectively. Although boards made only bark-gypsum (SKa_6), cone-gypsum (SKo_6) and needle-gypsum (SI_6) show TS values of 33.70%, 21.70% and 18.85%, respectively. It can be hypothesized that although cedrus's tree components rather than wood have higher hydrophobic constituents that lowering effects on hydrophilic properties of gypsum boards (Table 2), it is very difficult to predict the TS values for proportions to each other with in gypsum network. In addition, it has already predicted that water diffusion is the process by which a fluid migrates and spreads itself through openings (capillaries, vessels and cellular walls) of network structure. In this way, a difference in concentration between the various cellular layers effects water migrations from the more concentrated medium towards the less concentrated one.

Sahin et al. (2019) found that the addition of rice straw to red pine/gypsum-based boards negative impact on thickness swelling (TS) properties of boards in water. They reported the highest TS value of 47.66% for the board that produced from 60:40 (ratio) (w/w) wood/rice straw mixture. It was also found that the addition of post-consumer waste paper, old corrugated container (OCC) and secondary fiber to gypsum in panel structure negative impact on Thickness Swelling (TS) values in water (Sahin and Demir, 2019). Contrary to these results, we found that increasing bark (Type 1), cone (Type 2) and needle (Type 3) proportions in the mixture have usually lowering effects on TS properties of experimental boards.

Figure 1 show the comparative hardness (Shore D) properties of both control and naturally, two months weathered samples. It could be seen that surface hardness has usually correlated with wood content that it decreased while cone (Type 2) and needle (Type 3) content increased in the mixture. Similar trend is also found for Type 4 and 5 boards that increase cone and needle content while decreasing bark positively effects hardness value of samples. However, there is no correlation was observed with Type 6 boards (cone/needle boards).

Table 3
Thickness Swelling (%) properties of boards

Board Codes	TS (2 h)	TS (2/24 h ratio %)	TS (24 h, %)
SKa_1	13.69	61.2	22.35 (5.88) **A**
SKa_2	4.86	24.8	19.56 (2.20) **A**
SKa_3	7.00	58.4	11.98 (6.11) **B**
SKa_4	3.92	33.3	11.75 (1.59) **B**
SKa_5	3.22	30.1	10.69 (2.69) **B**
SKa_6	4.56	13.5	33.70 (8.35) **C**
SKo_2	8.88	70.4	12.61 (4.14) **AB**
SKo_3	5.42	25.4	21.34 (5.25) **CD**
SKo_4	7.49	44.2	16.95 (5.21) **BC**
SKo_5	5.99	78.1	7.67 (2.19) **A**
SKo_6	8.17	37.6	21.70 (4.10) **CD**
SI_2	6.49	33.3	19.49 (4.76) **C**
SI_3	12.47	41.1	30.34 (6.79) **D**
SI_4	9.11	69.0	13.20 (2.51) **AB**
SI_5	4.40	46.4	9.48 (7.19) **A**
SI_6	9.78	51.9	18.85 (6.34) **BC**
$KaKo_2$	6.91	55.9	12.34 (1.19) **A**
$KaKo_3$	5.32	40.1	13.01 (5.41) **AB**
$KaKo_4$	8.13	62.2	13.08 (4.99) **AB**
$KaKo_5$	8.07	44.4	18.17 (11.92) **AB**
$KaKo_6$	8.17	37.6	21.70 (4.10) **B**
KaI_2	3.35	25.1	13.37 (2.20) **A**
KaI_3	7.24	62.7	11.54 (2.66) **A**
KaI_4	5.37	48.6	11.03 (4.18) **A**
KaI_5	4.82	38.7	12.44 (5.87) **A**
KaI_6	9.78	51.9	18.85 (8.35) **A**
KoI_2	3.19	31.9	9.99 (5.48) **A**
KoI_3	4.32	30.2	14.29 (2.87) **AB**
KoI_4	5.48	52.4	10.46 (6.30) **A**
KoI_5	6.44	40.1	16.08 (2.78) **B**
KoI_6	9.78	51.9	18.85 (8.35) **BC**

**The numbers in parenthesis are standard deviations. Values sharing the same capital letter (s) within a column are not statistically different at a 0.05 level of confidence.*

The highest shore hardness value of 51 (metric9 was found for the SKa5 sample while the lowest value of 21 (metric) was found in $KaKo_6$ boards. However, as expected two month weathering negatively effects all experimental boards' hardness properties. It reduced from -6.9% (SKa_1) to -30.3% (SKa_2) in all types of experimental boards. It has been noted that boards made with only wood (SKa_1), bark (SKa_6), cone (SKo_6 and needle SI_6) show approximately lowering hardness of-6.9%; -10.6%; -14.3% and -14.6%, respectively. The hardness properties deteriorated with the progress of weathering is probably due to the deformed and loosening of particles in board structure. This is an important finding, in regard to weathering performance of composite materials.

As mentioned above, increasing wood shavings and sawdust proportions in gypsum-based mixture impact on reducing Shore C hardness (Morales-Conde et al. 2016). However, the natural weathering of boards made with some cellulosic filler in gypsum had shown lowering hardness (Shore D) properties (Sahin and Demir, 2019). The results found in this study show similar results that addition of some lignocellulosic fillers (reinforcement elements) on gypsum has no any improvement effects for hardness properties of experimental boards.

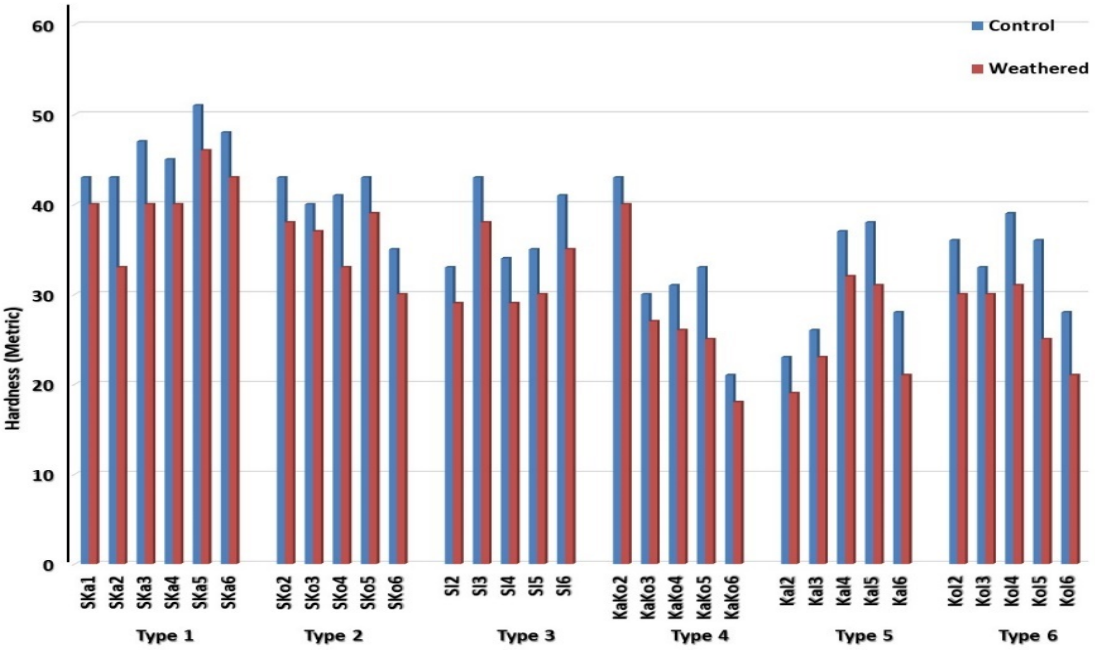

Figure 1. Hardness (Shore D) properties of experimental boards

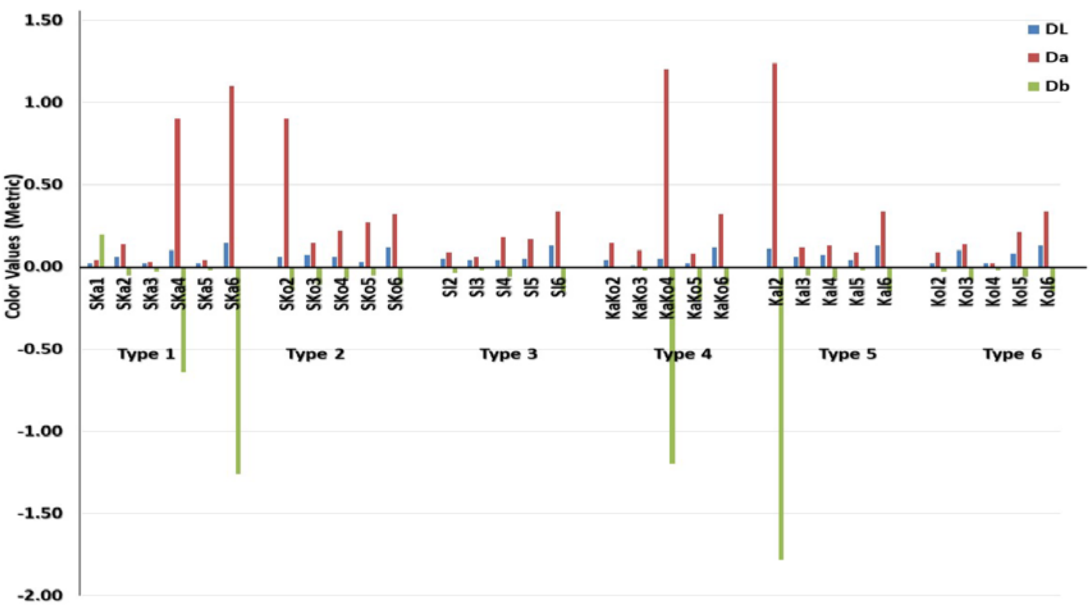

Figure 2. Color (CIE L,a,b) properties of experimental boards

Figure 2 show the weathering modified lightness (ΔL), redness (Δa) and yellowness (Δb) of colour coordinates. However, it appears that outdoor exposure marginally effects on lighter tone (ΔL) of samples in all manufacturing conditions. It is usually changed of 0.01-0.15 level of increasing (reducing darkness). Moreover, it looks like both green-red (a*) and yellow-blue (b*) colour coordinates better correlated with weathering. Interestingly all samples show increasing redness (+a) and yellowness (-b) colour coordinate values in all conditions. The highest redness of Δa =1.1, 0.32 and 0.34 and yellowness of Δb= -1.26, -0.16 and -0.15 were observed in Types 1-3 boards that made from without cedrus's wood that only cedrus's bark (Ska_6), cone (SKo_6) and needle (SI_6) particles in experimental boards, respectively. It is interesting to note that boards made with needle/wood and needle/cone in proportions (Type 3 and 6) in gypsum show only marginally changed color values. These marginal changes in those boards may be attributed to the chemical constituents of filler (lignocellulosic elements). It could also be hypothesed that among fillers even with the same level of extractive content, different levels of resistance against weathering could be possible. This should be case for gypsum-cedrus tree components' compability that the chemical composition and types of fillers particularly different one to another. The comparative three important mechanical strength (IB, MOR, and MOE) properties of experimental samples are shown in Table 4.

Table 4.
The strength properties of experimental boards

Board Code	**Density (g/cm³)**	**IB (N/mm²)**	**Δ (Std. %)**	**MOR (N/mm²)**	**Δ (Std. %)**	**MOE (N/mm²)**	**Δ (Std%)**
SKa_1	1.29	0.22 (0.07) **B**	-21.4	1.06 (0.13) **AB**	-91.57	206.72	-88.5
SKa_2	1.33	0.27 (0.06) **B**	-3.6	1.32 (0.27) **C**	-89.4	348.64	-80.6
SKa_3	1.30	0.33 (0.05) **A**	17.9	1.13 (0.19) **B**	-90.9	337.92	-81.2
SKa_4	1.28	0.41 (0.04) **A**	31.7	0.9 (0.22) **A**	-92.3	505.68	-71.9
SKa_5	1.29	0.48 (0.04) **A**	71.4	1.03 (0.25) **A**	-91.8	312.77	-82.6
SKa_6	1.23	0.44 (0.06) **C**	57.1	1.05 (0.17) **AB**	-91.6	513.84	-71.5
SKo_2	1.43	0.19 (0.05) **AB**	-32.1	1.09 (0.30) **C**	-91.3	325.37	-81.9
SKo_3	1.12	0.18 (0.02) **CD**	-35.7	0.97 (0.21) **C**	-92.2	274,72	-84.8
SKo_4	1.08	0.17 (0.02) **BC**	-39.3	0.65 (0.10) **B**	-94.8	< 150**	-
SKo_5	1.22	0.06 (0.03) **A**	-78.6	0.4 (0.08) **A**	-96.8	< 150**	-
SKo_6	1.30	0.1 (0.02) **CD**	-64.3	0.5 (0.04) **A**	-96.0	< 150**	-
SI_2	1.37	0.27 (0.07) **C**	-3.6	0.98 (0.13) **CD**	-92.2	293.77	-83.7
SI_3	1.45	0.13 (0.02) **D**	-53.6	0.81 (0.14) **B**	-93.5	< 150* *	-
SI_4	1.26	0.17 (0.07) **AB**	-39.3	0.79 (0.22) **B**	-93.7	314.9	-82.5
SI_5	1.27	0.15 (0.01) **A**	-46.4	0.88 (0.16) **BC**	-92.9	330.64	-81.7
SI_6	1.19	0.05 (0.05) **BC**	-82.2	0.55 (0.10) **A**	-95.6	< 150* *	-
$KaKo_2$	1.19	0.31 (0.01) **A**	10.7	0.84 (0.25) **BC**	-93.3	< 150* *	-
$KaKo_3$	1.24	0.27 (0.01) **AB**	-3.6	0.88 (0.22) **C**	-92.9	582.04	-67.7
$KaKo_4$	1.41	0.27 (0.03) **AB**	-3.6	0.71 (0.15) **B**	-94.3	< 150**	-
$KaKo_5$	1.10	0.26 (0.06) **AB**	-7.1	0.73 (0.07) **BC**	-94.4	< 150**	-
$KaKo_6$	1.30	0.1 (0.02) **B**	-64.3	0.5 (0.04) **A**	-96.0	< 150* *	-
KaI_2	1.13	0.35 (0.05) **A**	25.1	1.26 (0.37) **C**	-89.9	188.6	-89.5
KaI_3	1.24	0.42 (0.07) **A**	50.1	1.02 (0.50) **BC**	-91.8	294.42	-83.7
KaI_4	1.27	0.27 (0.03) **A**	-3.6	0.95 (0.44) **B**	-92.4	< 150**	-
KaI_5	1.10	0.12 (0.03) **A**	-57.1	0.55 (0.09) **A**	-95.6	< 150**	-
KaI_6	1.19	0.05 (0.02) **A**	-82.2	0.55 (0.10) **A**	-95.6	< 150**	-
KoI_2	1.23	0.19 (0.05) **A**	-32.1	0.33 (0.16) **A**	-97.4	< 150**	-
KoI_3	1.37	0.15 (0.04) **AB**	-46.4	0.33 (0.11) **A**	-97.4	< 150**	-
KoI_4	1.15	0.2 (0.03) **A**	-28.6	0.79 (0.17) **C**	-93.7	< 150**	-
KoI_5	1.20	0.28 (0.02) **B**	0.0	1.11 (0.38) **D**	-91.1	535.42	-70.3
KoI_6	1.19	0.05 (0.02) **BC**	-82.2	0.55 (0.10) **B**	-95.6	< 150* *	-
According to EN 312 standard For Type 1 boards							
	0.28			**12.5**		**1800**	

**The numbers in paranthesis are standard deviations.* * *measurement limit of instrument, *Values sharing the same capital lette(s) within column are not statistically different at 0.05 level of confidence.*

For IB properties, it can be seen that only a few samples (SKa_3-6; KaI_2; $Kako_2$; KaI_{2-3}) show higher IB values than standart values of 0.28 N/mm^2. The highest IB value of 0.48 N/mm^2 was found for sample SKa_5 that produced with ratio of 1/4 by cedrus wood/bark proportions (w/w). It was also found that panels produced with cedrus wood/cone (SKo); cedrus wood/needle (SI) and cedrus cone/needle (KoI) proportion have no any higher values than standard. The results might not be surprise, when considering the structure of gypsum. One could be said that most of the gypsum might be absorbed by this bulky matrix elements and that not sufficient glue remains in reinforcement elements (cedrus's tree) in strucuture. Thereby, the amount of glue used in this study (1000 gr by weight) probably is not sufficient for this type of boards.

For Bending strength (MOR) and Modulus of Elasticity values (MOE) of the six types boards, in general, it has been understood that the both MOR and MOE values of the mixture produced with the cedrus tree and its components considerably lower than standard value of 12.5 N/mm^2 for MOR and 1800 N/mm^2 for MOE. The highest MOR values for Type 1 boards was calculated as 1.32 N/mm^2 (SKa_2); 1.09 N/mm^2 for Type 2 boards (SKo_2); 1.26 N/mm^2 for Type 5 (KaI_2); and 1.11 N/mm^2 for Type 6 (KoI_5) boards, respectively. These values approximately -89.4%; -91.3%; -89.9% and -91.1% lower than standard value of 0.28 N/mm^2.

Like MOR properties, the similar results was also found for MOE values of boards. The MOE values of the all six types boards were found to be significantly lower in all proportions and conditions. This situation was expected when considering the properties of experimental boards. This is because, the gypsum boards produced in the industry generally have lower elastic properties. It can be seen that increasing lignocellulosic additives in panel matrix for all type panels effects strength and elastic properties. It has already well presented that although strength properties are dependent on the size and distribution of fibers within the matrix system, low adhesive ratio or insufficient mixing procedure might lowering effects on the strengths of experimental panels. In addition, these non-wood substance that has considerably lower self strength and flexible than wood fibers that may resulting lowering strength properties. In addition, loss in fibre flexibility could also happen because of loss in bonding agents of fibre. For instance, loss in hemicelluloses component of fibre wall results in poor fibre swelling, thus fibre stiffness. It has alreday reported by Sahin and et al (2019) that the addition of rice straw to the red pine/gypsum mixture has a lowering effect on the internal bond (IB) and bending strength (MOR) properties of experimental boards some level. In contrast, the experimental boards produced by secondary fiber/gypsum mixture increases the IB and bending strength properties some level. However, the strengths are sensitive to fillers that the flexible fillers conform well on the plane of board, and by doing so flexible fillers contribute in enhancing the relative bonded area. This may a clear evidence that fibrous filler or reinforcement elements (secondary fibers) has better align and/or adopt to gypsum in network structure than lignocellulosic particles (wood, cone, bark, needle) resulting better strength properties as reported in literature (Sahin and Demir, 2019).

Figures 3-4 show the Internal Bond (IB) and Bending strength (MOR) properties of boards respectively. The dependence of IB strength to reinforcement element as a function of proportions shows that IB strength has a directly proportional to filler type and content. It is interesting to note that boards made with cedrus wood/cone (Type 2), cedrus wood/needle (Type 3) and cedrus cone/needle proportions have lower IB values that standard of 0.28 N/mm^2 (Figure 3).

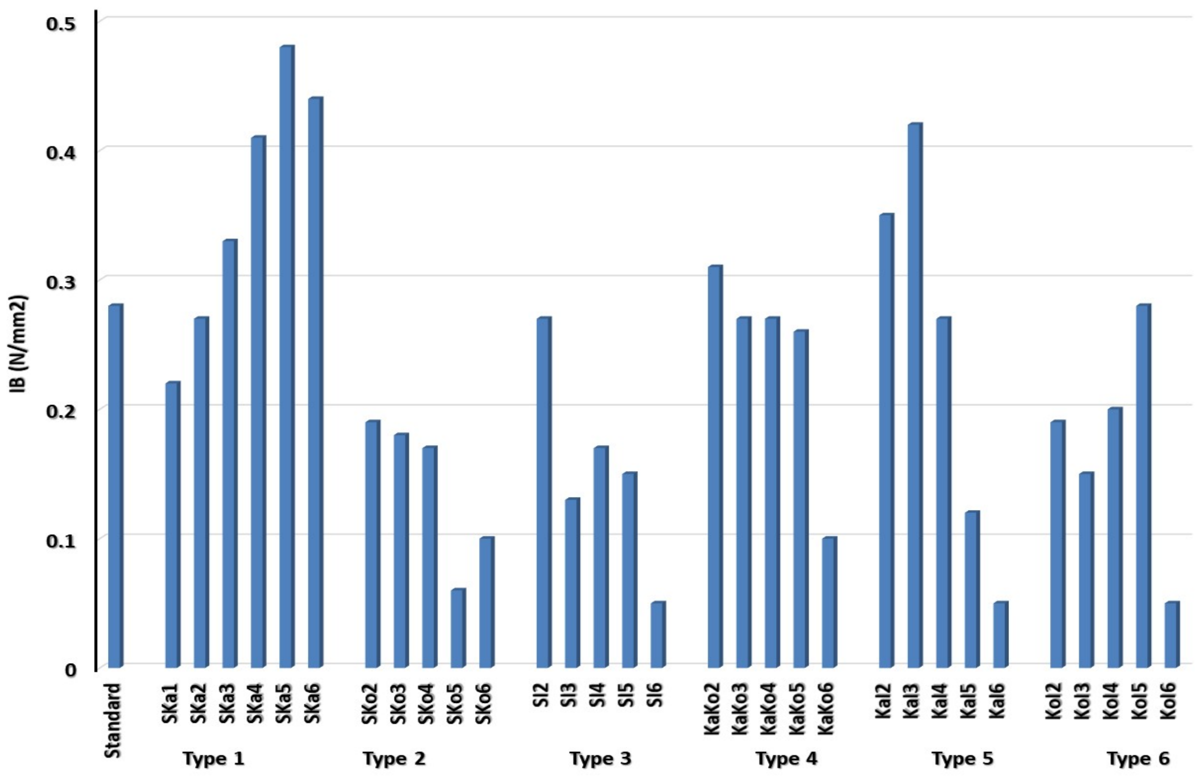

Figure 3. The Internal Bond Strength (IB) properties of boards

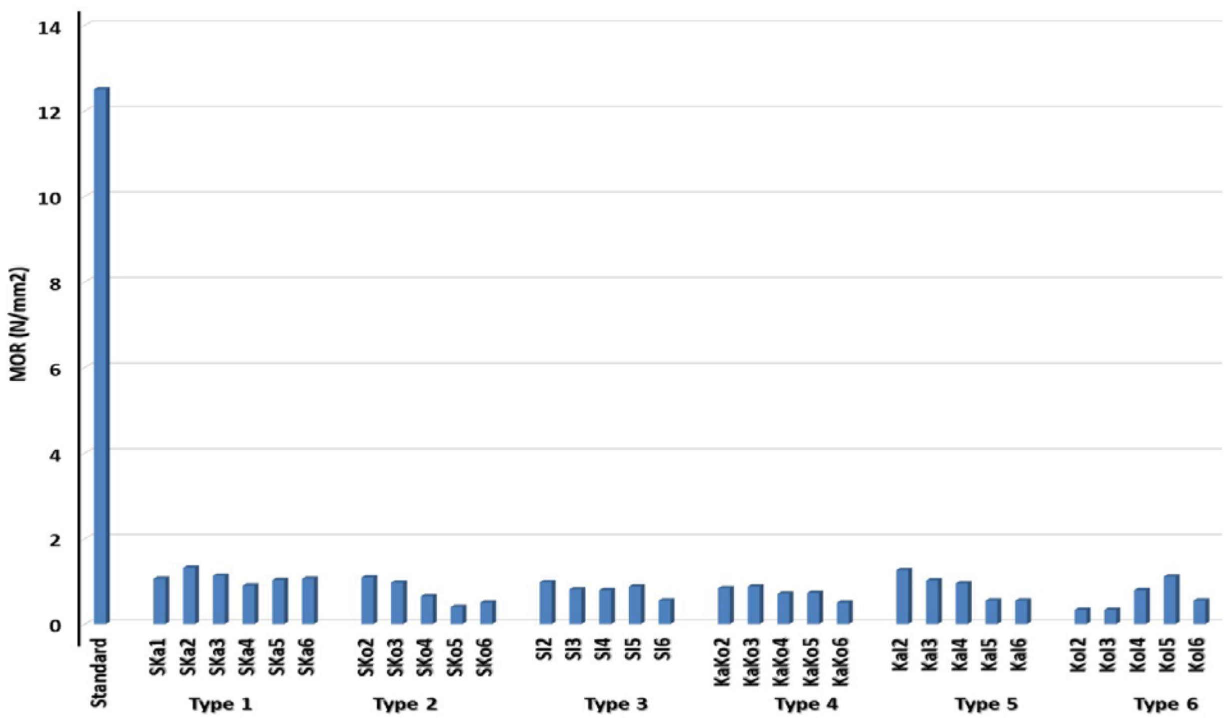

Figure 4. The Bending Strength (MOR) properties of boards

The bending strength is a important property to describe the general strength of materials. As seen in Figure 4, experimental boards manufacturing in all conditions show lower MOR values than standard value of 12.5 N/mm^2. Boards made with only wood (SKa_1), bark (SKa_6), cone (SKo_6) and needle (SI_6) show the MOR values of 1.06 N/mm^2; 1.05 N/mm2; 0.5 N/mm^2 and 0.55 N/mm^2), respectively. It has already well established that the bending strength of hybrid materials (composites) related to the bonding potential of reinforcement elements and bonded area, which originates from the surface properties of fillers and the fibre flexibility, assuming that the other properties (fibre- length, strength) remain intact. As mentioned above, due to bulkiness of lignocellulosic reinforcement elements in gypsum mixture, the gypsum content (1000 gr constant by weight) may not sufficient for this type of raw materials. However, during gypsum drying, network shrink laterally creating drying stresses in the structure. If reinforcement element is not compatible with gypsum or some chemical that against hydration properly, these stresses could not be straighten segments enough to enhance the network load carrying capacity. Because during experimental board manufacturing process, which consists of slushing, soaking, formation, pressing and drying may effects hindering reinforcement elements to develop the network strength properly. The results found in this study consisted with these suggestions.

4. Conclusion

Gypsum-based boards have been a common material and can be used various type of construction purposes. However, those have usually utilized non-strength required areas due to their specific structural properties. There have been many approaches have already predicted with valuable results, but there is no standardized method to produce gypsum/lignocellulosic hybrid products that suitable to all wood species. In this study, the useability of cedrus tree’s components (wood, bark, cone, needle) as reinforce elements with gypsum as mineral bonding agent in matrix composite system was investigated. The measured results clearly indicates that the selected lignocellulosic components have influenced boards mechanical properties some level. Although, experimental board’s MOR strength properties are lower than standard value, but it is possible to find some level of mechanical properties at certain conditions. Moreover, these products could be utulized in not strength necessity applications. In general, the results of this study on the effect of cedrus tree components as reinforce element on gypsum bonded experimental boards are compatible with the findings in the literature.

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