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Physical, Mechanical and Thermal Properties of Red Pine Wood-Gypsum Particleboard

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Abstract: Physical, mechanical and some thermal properties of gypsum-wood mixture particleboards were analyzed for specimens which were prepared in different proportions previously conditioned at 23 ˚C and 65% relative humidity. Water absorbtion (WA) and thickness swelling (TS) properties were measured after being soaked in water for 24 hours. Furthermore, the increment of wood particle was increased the water absobtion values around 28.5 % and 2.1% thickness swelling values, respectively. However, the reduction of gypsum ratio was negatively effected the mechanical resistance of the boards. The highest MOR, MOE and internal bond (IB) values were observed in the C1 code board with 4.73 MPa, 27.04 MPa and 0.97 N/mm^2 respectively. The thermal conductivity of wood-gypsum boards were ranged from 0.7404-0.5021 W/mK. The highest density was found in C1 type board as 1.333 kg/m^3 and also the highest thermal coductivity was observed at the same sample. Besides, the highest surface temprature which was passed to opposite side of flame source, was found in C5 as 141.7 ºC after 300 seconds. However, the lowest value was observed in C1 type board as 93.3 ˚C after 300 seconds.

Keywords: Physical properties, mechanical properties, thermal properties, gypsum, wood, particleboard.

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1. INTRODUCTION

Gypsum is known to be one of the oldest building material that uses from ancient times. It is an environmentally friendly building material, with energy-saving, constructability, sound insulation, thermal insulation, decoration materials, availability, low price, ease of production and other advantages. (Martias et al. 2014; Han et al. 2017). Gypsum has been used as an insulation material in buildings since the 1900s. The new insulation materials and systems provide many advantages in the structures (Binici et al. 2016).

It was indicated that worldwide energy consumption has been increasing in the buildings more than 30%. But this rate is up to 40% in some countries such as in Turkey on the buildings in recent years. Therefore, reducing the energy consumption in structures by improving their thermal performance can dicrease mentioned rate above (Sharifi et al. 2017).

However, the insulation properties of gypsum boards are improved by increasing the porosity. In order to improve physical properties of gypsum board such as high permeable to water, porous nature, low compressive strength, low flexural and tensile strength can be added different fillers that reinforcing materials that polypropylene fibres, jute fibres, coconut fibres, hemp fibres and wood fibre to gypsum boards. So, physical and thermal conductivity can be improved by some additives (Regulska and Repelewicz, 2019; Beram and Yasar, 2020; Herrera, and Cloutier, 2010; Sophia and Sakthieswaran, 2016; Amiandamhen et al. 2016). The presence of wood materials in these boards improves the mechanical properties while retaining the great fire resistance on boards (El-Juhany, et al. 2003; Icel and Beram, 2017).

Therefore, Gypsum board as insulation material can be used to reduce building energy consumption (Kang et al. 2018). Otherwise, Gypsum boards and wood-based panels are the most common materials used as fire barriers in the

residental and building construction (Kolaitis et al., 2014; Cramer et al., 2003).
Most of the wood species and agricultural residues that are available for wood reinforced panels manufacturing (Nasser et al., 2016). Lignocellulosic materials are used in cementitious panels due to their low densities, low cost, nonabrasive natures, high specific properties, biodegradability, and the abundant availability in the world (Ashori et al., 2011).

There is limited researches on the properties of boards which made with lignocellülosic material under the gypsum existence as binder. The aim of this study was to determine the physical, mechanical and thermal properties of red pine wood and gypsum mixture board.

2. MATERIAL AND METHODS

Red pine wood samples were obtained from a chipboard production facility in Isparta. Wood chips were cut into pieces using a 5-8 mm sieve with the help of a hammer mill. Wood chips were dried in natural atmospheric conditions until they had a humidity of 10-12%. The plaster used in the study was obtained from a company in Isparta.The method followed for the preparation of the samples is given in Figure 1.

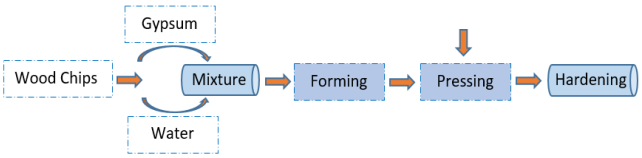

Figure 1. Sample preparation flow chart

The preparation of the samples for production was carried out at room temperature. Gypsum and red pine wood chips were mixed homogeneously with lab type mixer. Metal mold plates of 40 x 40 cm2 and 10 mm in size were used to prepare the sheet paste. It was pre-pressed under 80 kg/cm2 for 5 minutes then pressed under 1.5 N / mm2 at 20-24 ºC with laboratory type press 24 hours. The plates were acclimatized for 3 weeks after the pressing process was completed and kept between the metal plates. The image of the samples produced is shown in Figure 2.

Figure 2. Image of the samples produced

The experimental panels were conditioned at 23 ºC and 65% relative humidity and samples were sawn into 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 thermal conductivity of the test samples were examined in pursuance of the ASTM C 1113-90 standard and the Hot Wire Method by with the QTM 500 device. Flame combustion tests of the samples were made according to TS EN-ISO 11925-2 and DIN 4102-1. Thermogravimetric analysis (TGA), Perkin Elmer SII instrument was utilized in order to determine the thermal degradation changings. The experimental boards prepared with given codes in this study was summarized in Table 1.

Table 1. Code numbers and mixture proportions (%)

Board Code	Red pine wood (%)	Gypsum (%)
C1	10	90
C2	20	80
C3	30	70
C4	40	60
C5	50	50

Measurements were conducted in Isparta University of Applied Sciences, Forest Product Engineering Research and Application Laboratory. An ANOVA general linear model procedure was employed for data to interpret interaction of the panels manufactured. Duncan test was used to make comparison among board types for each property tested if the ANOVA found significant.

3. RESULTS AND DISCUSSION

Results of the water absorption and thickness swelling properties of boards in water (2.0 and 24 hours) are presented in Table 2. C1 type board gave the lowest water absorption values of 21%. The highest water absorption value was found in C5 type board as 45.5 % after 24h soaking in water.

It was seen that the best thickness swelling was observed from C1 with the thickness swelling 0.2%, while the worst thickness swelling given by board C5 with 2.2%. Therefore, all the boards were resulted in satisfactory thickness swelling level when compared to the standard value of 12.5%. It seems that water absorption (WA) and thickness swelling properties were improved depending on the increasing gypsum ratio by contrast with the decreasing woody content in the mixture (Yel et al., 2020).

It was seen from statistical data that F values of C type boards were found 13.703 (P=0.000) on water absorption properties. Likewise F values of boards was observed as 0.512 (P=0.729) on thickness swelling (TS) properties. According to these results, significant difference was found on C type boards on water intake properties. According to the ANOVA analysis results for TS values , IB bond properties and modulus of elasticity (MOE) values of boards were observed statistically insignificant. However, modulus of rupture (MOR) values of boards were found with 99% confidence level.

Table 2. The water absorption (%), thickness swelling (%) and mechanical strength properties of boards

Board Code	WA (2 h)	WA (24 h)	TS (2 h)	TS (24 h)	IB (MPa)	MOR (MPa)	MOE (MPa)
C1	15.1	17[b]	0.1	0.1[a]	0.97[a]	4.73[b]	27.04[a]
C2	18.9	21[a]	0.2	0.2[a]	0.73[a]	4.35[b]	18.24[a]
C3	21.6	23.8[b]	0.3	0.4[a]	0.67[a]	4.16[b]	17.06[a]
C4	22.3	25.6[b]	1.5	1.9[a]	0.18[a]	3.48[a]	8.34[a]
C5	41.2	45.5[c]	2.1	2.2[a]	0.07[a]	3.37[a]	8.06[a]
F value		13.703***		0.512(ns)	1.986(ns)	7.221**	1.724(ns)

Note: (***) means 99.9% confidence level, (**) means 99% confidence level, (*) means 95% confidence level (ns) is statistically insignificant and (a, b, c, d, e) means homogeneous groups

The internal bond (IB), modulus of rupture (MOR) and modulus of elasticity (MOE) properties of the experimental panels are shown in Table 2. It was found that the highest internal bond (IB) value was observed in the C1 code board as 0.97 N/mm^2 and the lowest IB in C5 as 0.07 N/mm^2. It appears that internal bond strength (IB) values were indicated higher than the standard value of 0.28 N/mm^2 in approximately all type boards without C4 and C5 type boards. So these panels could be used for heavy load-bearing requirements in terms of internal bond properties.

However, the highest MOR and MOE values of boards were observed in C1 type samples with 4.73 MPa and 27.04 MPa, respectively. These results were shown that all board samples could not met the standart values of particleboard on bending strength (12.5 N/mm^2) and modulus of elasticity (1600 N/mm^2) unless the internal bond strength.

The results suggest that MOE and MOR values increased with increasing board density. Therefore the increasing amount of gypsum in the mixture was caused to density increment from C5 (50% gypsum) to C1 (10% gypsum) type samples.

The thermal conductivity and the density values obtained from the various types of boards that prepared in the presence of gypsum as a binder are given in Figure 3. The thermal conductivity of wood-gypsum boards were ranged from 0.7404-0.5021 W/mK. It was resulted that thermal conductivity of C5 type board is lower than the C4 and C1 type board about 9% and 47%, respectively.

Furthermore, the highest thermal conductivity value (0.7404 w/mK) was found for C1 type board. The lowest thermal conductivity value (0.5021 w/mK) was obtained C5 type board (Figure 3). This thermal conductivity results show that all board samples had lower value than 0.065 w/mK value which was determined for building material and thermal insulation material (Yalcın, 2018). It seems that the amount of gypsum is increased in the mixture the thermal insulation propery of the material decreases.

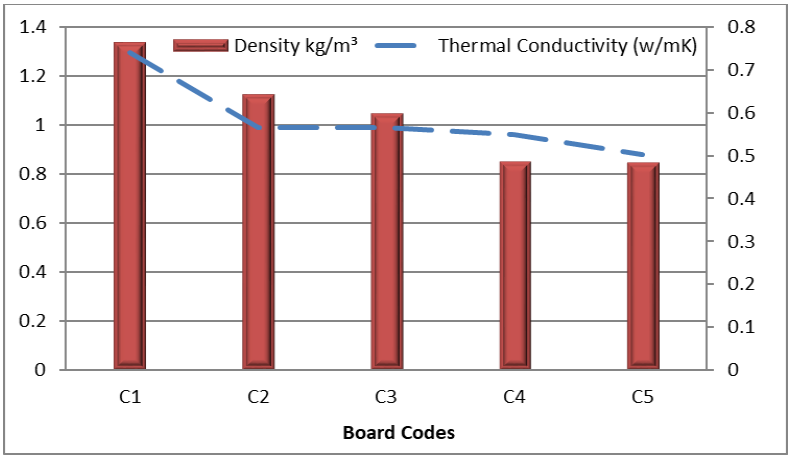

Figure 3. The thermal conductivity and the density properties of boards

It was understood that the density was increased depending on gypsum increment and density differences of samples were effected to thermal performance of board. The highest density was found in C1 type board as 1.333 kg/m³ and also the highest thermal coductivity was observed at the same sample. However, the lowest density was examined in the C5 type board which was 0% red pine wood/50% gypsum mixture board, as 0.845 kg/m³.

It was due to fact that the presence of the gypsum can caused the decrease on the thermal conductivity in wood - gypsum boards. So the increment of particle content and amount of space between particles can lead to lower thermal conductivity (Bekhta and Dobrowolska, 2006).

Figure 4 shows that the results of combustion experiments which was carried out with a single flame source. The temperature values were measured every 30 seconds with heat measuring device from the back side of the board surface till 300 seconds according to the DIN 4102-1 standard. As seen in Figure 3, the highest surface temprature which was passed to opposite side of flame source, was found in C5 as 141.7 ˚C after 300 seconds. However, the lowest value was observed in C1 type board as 93.3 ˚C after 300 seconds.

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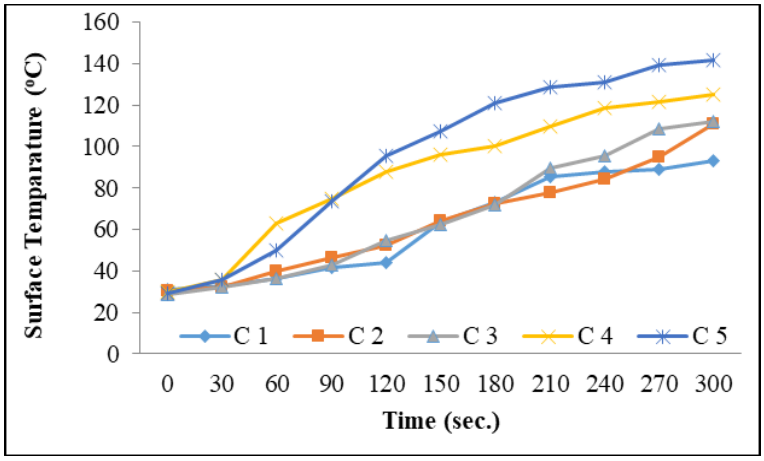

Figure 4. Surface temprature properties related to time with a single flame source

In Figure 5, the shape (flame spread property) formed on the surfaces of the boards as a result of the combustion tests performed with a single flame source is shown comparatively (Beram et al., 2020). When Figure 6 was examined carefully, it was observed that the burning shape on the surface of the gypsum added boards trial samples did not reach the 150 mm threshold limit.

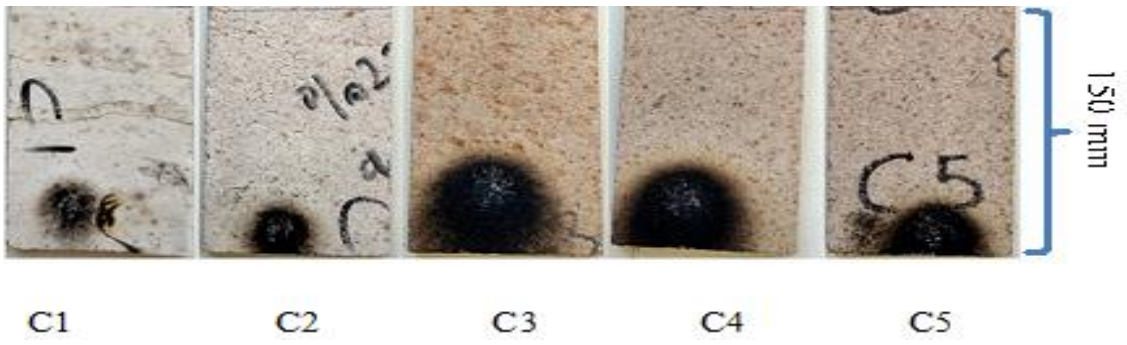

Figure 5. The behavior of gypsum boards exposed to single flame source

Detailed results of TGA – DTG curves analysis (N_2 environment) are given in Figure 6 and Table 3 respectively. Degradation took place in four phases in the samples consisting of a mixture of gypsum and wood in different proportions by weight. In the first phase, dehydration caused by the removal of water in 108 ˚C (C1), 110 ˚C (C2-C5), 111 ˚C (C3), 112 ˚C (C4) structure causes. In the second phase, 351 ˚C (C1), 359 ˚C (C2), 370 ˚C (C3), 358 ˚C (C4), 350 ˚C (C5) are formed as a result of the decomposition of the composition of wood. Kim et al. (2006) stated that hemicellulose, cellulose decomposed at 275˚C - 350˚C and lignin at 250 ˚C-500 ˚C at 180 ˚C -350 ˚C. Gao et al. reached similar results in their 2006 study.

Ca (OH) $_2$ dehydration (1) occurred in the samples of the third phase 740 ˚C (C1), 735 ˚C (C2), 701 ˚C (C3), 748 C (C4), 751 ˚C (C5) (Shafiq and Nuruddin, 2010).

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$ (1)

$CaCO_3$ decarbonation in samples of the fourth phase 748 ˚C (C4), 751 ˚C (C5) (2). A similar reaction occurred in the studies in Cabrera and Lynsdale, 1996.

$CaCO3 \rightarrow CaO + CO2$ (2)

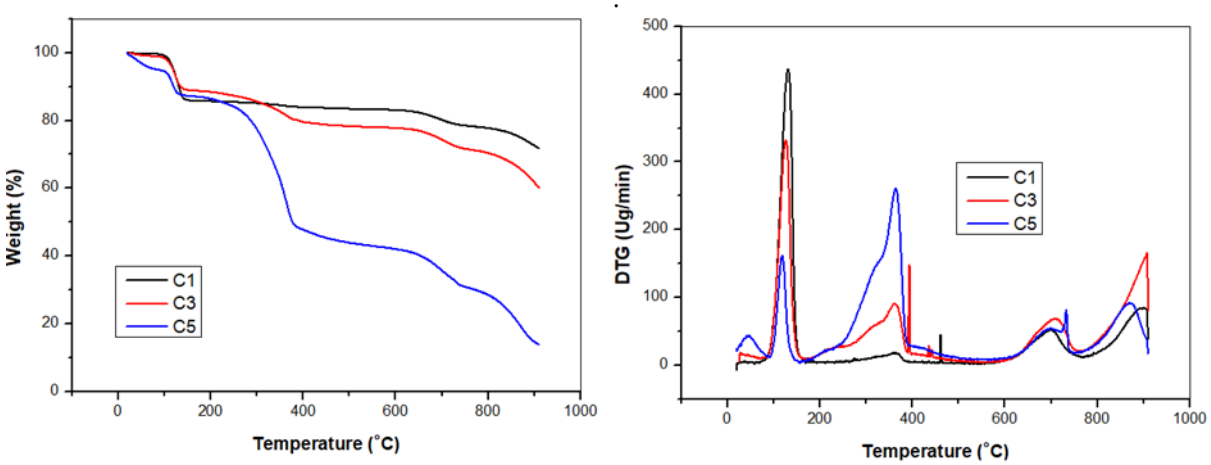

Figure 6. The results of TGA – DTG curves analysis

According to Table 3, as the percentage of wood increases in the composite structure, which consists of a mixture of gypsum and wood in different proportions by weight, the thermal stability is adversely affected. The highest mass loss was 86.13 (wt.%) in the C5 sample, while 26.17 (wt.%) in the lowest sample C1.

Table 3. The different thermal decomposition temperatures and final residue percentage

	T5 wt% (ºC)	T10 wt% (ºC)	T50 wt% (ºC)	T_1max (ºC)	T_2max (ºC)	T_3max (ºC)	T_4max (ºC)	900 ˚C Residue (wt.%)
C1	120	131	-	108	351	740	-	73.83
C2	118.5	132	-	110	359	735		65.84
C3	118	134	-	112	370	701	-	60.22
C4	91	125	360	111	358	748	841	15.68
C5	86.25	119	377	110	350	751	850	13.87

Note: T5 wt%: thermal decomposition temperature at 5% weight loss; T10 wt%: thermal decomposition temperature at 10% weight loss; T50 wt%: thermal decomposition temperature at 50% weight loss; T1max: the temperature of the peak maximum at the first step of degradation (ºC); T2max: the temperature of the peak maximum at the second step of degradation (ºC); T3max: the temperature of the peak maximum at the third step of degradation (ºC). T4max: the temperature of the peak maximum at the four step of degradation (ºC).

After single and dual component varnish applications of chestnut wood; lowest adhesive resistance was seen in specimens performed single component varnish application and waited for 6 hours in 150 ˚C, while highest adhesive resistance was seen in specimens performed dual component varnish application and waited for 2 hours in 100 ˚C according to heat treatment temperature and time conditions. As a result of comparing adhesive resistance values of non-heat-treated specimens subjected to single component varnish application and heat-treated specimens, specimens waited for 2, 4, 6 hours in 100 ˚C have higher adhesive resistance than specimens varnished as without heat treatment, and it was seen that adhesive resistance values decreased in other heat treatment temperatures and times. As a result of comparing dual component varnished non-heat-treated specimens and heat-treated specimens, specimens waited for 2, 4, 6 hours in 100 ˚C and waited for 2 hours in 125 ˚C have higher adhesive resistance, and it was observed that adhesive resistance values decreased in other heat treatment temperatures and times.

4. CONLUSION

In this study, the gypsum and wood incorporation in the different proportions were investigated. For this purpose, water absorption (WA), thickness swelling (TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) and thermal conductivity properties were conducted. All boards were resulted in satisfactory thickness swelling level when compared to the standard value of 12.5 %. Meanwhile, the reduction of gypsum was decreased the water absobtion values around 28.5 % and 2.1% thickness swelling values, respectively. The water absorption and thickness swelling properties were improved depending on the increasing gypsum ratio by contrast with the decreasing woody content in the mixture.

Although, the increment of gypsum ratio was positively effected the mechanical resistance of the boards. The internal bond strength (IB) values were indicated higher than the standard value of 0.28 N/mm^2 in approximately all type boards. So these panels could be used for heavy load-bearing equirements in terms of internal bond properties. However, board samples could not met the standart values of particleboard on bending strength (12.5 N/mm^2) and modulus of elasticity (1600 N/mm^2) unless the internal bond strength.

It is understood that the amount of gypsum is increased in the mixture the thermal insulation properties of the material decreased. So the increment of particle content and amount of space between particles can lead to lower thermal conductivity.

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REFERENCES

Amiandamhen, S.O., Meincken, M., Tyhoda, L. (2016). Magnesium based phosphate cement binder for composite panels: Aresponse surface methodology for optimisation of processingvariables in boards produced from agricultural and wood processingindustrial residues. Industrial Crops and Products, 94, 746-754.

Ashori, A., Tabarsa, T., Azizi, K., and Mirzabeygi, R. (2011). Wood–wool cement board using mixture of eucalypt and poplar. Industrial Crops and Products, 34, 1146-1149.

ASTM C 1113-90: 1990. Standard test methods for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique). Annual Book of ASTM Standards.

Bekhta, P. and Dobrowolska, E. (2006). Thermal properties of wood-gypsum boards. Holz als Roh- und Werkstoff, 64, 427-428.

Beram, A. and Yasar, S. (2020). Performance of brutian pine (pinus brutia ten.) fibers modified with low concentration naoh solutions in fiberboard production. Fresenius Environmental Bulletin, 29(1), 70-78.

Beram, A., Yaşar, S. and Aytaç, U. Z. (2020). Kızılçam (Pinus brutia Ten.) Yongalarına Uygulanan Isıl İşlemin Üretilen Levhaların Formaldehit Emisyonu ve Yanma Özellikleri Üzerine Etkileri. Bilge International Journal of Science and Technology Research, 5(1), 86-90.

Binici, H., Orhan Aksogan, O., and Demirhan, C., 2016. Mechanical, thermal and acoustical characterizations of an insulationcomposite made of bio-based materials. Sustainable Cities and Society, 20, 17-26.

Cabrera, J.G. Lynsdale, C.J. (1996). The effect of super-plasticisers on the hydration of normal Portland cement (in Italian). L'industria Italiana del Cemento, 66 (712), 532-541.

Cramer, S. M., Friday, O. M., White, R.H., Sriprutkiat, G. (2003). Mechanical Properties of Gypsum Board at Elevated Temperatures. Proceedings of the Fire and Materials Conference. San Francisco, CA, USA. London: Interscience Communications Limited, c2003: pp 33-42.

DIN 4102-1:1998. Fire behaviour of buildings materials and buildings components—part 1: buildings materials, concepts, requirements and tests.

El-Juhany, L. I., I. M. Aref and A. O. Wakeel (2003). Evaluation of using some available lignocellulosic agricultural residues in manufacturing wood-cement boards in Saudi Arabia. In:the Proceedings of the International Conference on Date Palm, pp 281-291.

Gao, M, Niu, J., Yang, R. (2006) Synergism of gup and boric acid characterized by cone calorimetry and thermogravimetry. J Fire Sci, 24(6), 499 - 511.

Han, FQ., Tan, X., Zhao, FQ. (2017). Modification of Wood Fiber for Use in Cement Board, 1st International Workshop on Materials Science and Mechanical Engineering, 281(1), 012020.

Herrera, R.E., and Cloutier, A. (2010). Physical and mechanical properties of gypsum particleboard reinforced with Portland cement. Eur. J. Wood Prod. European Journal of Wood and Wood Products, 69(2), 247-254.

Icel, B. and Beram, A. (2017). Effects of industrial heat treatment on some physical and mechanical properties of iroko wood. Drvna industrija: Znanstveni časopis za pitanja drvne tehnologije, 68(3), 229-2369.

Kang, Y., Chang, S.J., Kim, S. (2018). Hygrothermal behavior evaluation of walls improving heat and

moisture performance on gypsum boards by adding porous materials. Energy & Buildings, 165, 431–439.

Kim, H.S., Kim, S., Kim, H.J., Yang, H.S. (2006). Thermal properties of bio-flour-filled polyoefin com¬posites with different compatibilizing agent type and content. Thermochim Acta, 451(1-2), 181-188.

Kolaitis, D. I., Asimakopoulou, E. K., and Founti, M.A. (2014). Fire protection of light and massive timber elements using gypsum plasterboards and wood based panels: A large-scale compartment fire test. Construction and Building Materials, 73, 163–170.

Martias, C., Joliff, Y., and Favotto, C. (2014). Effects of the addition of glass fibers, mica and vermiculite on the mechanical properties of a gypsum-based composite at room temperature and during a fire test. Composites: Part B, 62, 37–53.

Nasser, R.A., Salem, M.Z.M., Al-Mefarrej, H.A., and Aref, I.M. (2016). Use of tree pruning wastes for manufacturing of wood reinforced cement composites Cement and Concret Composites, 72, 246-256.

Regulska, K., and Repelewicz, A. (2019). Properties of gypsum composites with sawdust. E3S Web of Conferences, 97, 02037.

Shafiq, N., Nuruddin, M.F. (2010). Degree of hydration of OPC and OPC/FA pastes dried in different relative humidity. J Concr Res Lett, 1(3), 81-89.

Sharifi, N. P., Shaikh, A. A. N., and Sakulich, A. R. (2017). Application of phase change materials in gypsum boards to meet building energy conservation goals. Energy and buildings, 138, 455-467.

Sophia, M., Sakthieswaran, N. (2016). Gypsum as a Construction Material- A Review of Recent Developments IJIRST –International Journal for Innovative Research in Science & Technology, 2(12), 1-9.

TS EN 310: 1993. Wood based panels: Determination of modulus of elasticity and modulus of rupture in static bending.

TS EN 317: 1999. Particleboards and fibreboards-Determination of swelling in thickness after immersion in water.

TS EN 319: 1999. Particleboards and fiberboards: Determination of tensile strength perpendicular to plane of the board.

TS EN ISO 11925-2: 2002. Reaction to fire tests: Ignitability of building products subjected to direct impingement of flame - Part 2: Single-flame source test.

Yalcın, O.U. Investigation of performance properties of panels produced from some lignocellulosic sources with mineral (Dolomite and olivine) additives. 2018. 184 p. PhD thesis Isparta University of Applied Sciences, Isparta.

Yel, H., Cavdar, A. D., Torun, S. B. (2020). Effect of press temperature on some properties of cement bonded particleboard. Maderas. Ciencia y tecnología, 22(1), 83-92.