Original Research Article

PROPERTIES OF GYPSUM BOARDS MADE OF MIXTURES OF WOOD AND RICE STRAW

.

ABSTRACT

Aims: **I**t was investigated to produce gypsum-based experimental composite panels with red pine wood/rice straw particles in the mixture up to 60:40 (ratio) (w/w) in gypsum-water mixture. In this case, the fillers (additives) could be observed more closely.
Methodology: The red pine wood chips and the rice straw (stalks) have been turned into suitable particle dimensions. The experimental boards were cut to determine the IB (Internal bond), MOE–MOR (Modulus of Elasticity and Rupture), and TS (thickness swelling after 24 hours immersion in water). A standard flame combustion test system was conducted according to TS EN-ISO 11925-2. For surface chemical analyses, FTIR was used to evaluate the chemical groups present in the board surface. The thermogravimetric analysis (TGA) was conducted for measuring changes in boards as a function of increasing temperature. The natural weathering tests were conducted that were exposed to outdoor for two months then color and surface hardness tests conducted for determining property changes.
Results: The rice straw had negative impact on thickness swelling (TS) properties of boards in water. The highest TS value of 47.66% was observed in the board that produced from 60:40 (ratio) (w/w) wood/rice straw mixture (DE4). However, the addition of rice straw to the wood/gypsum mixture has a lowering effect on the internal bond (IB) and bending strength (MOR) properties of experimental boards some level. The maximum IB strength of 0.06 N/mm^2 and MOR of 2.77 N/mm^2 found control sample (DE0). However, the highest MOE value of 553 N/mm^2 was calculated on the DE4 board, which was produced by adding 40% rice straw to the wood/gypsum mixture. The addition of rice straw and wood particles to the gypsum structure has a positive effect on the heat transfer properties.
Conclusion: It is clear that the addition of rice straw to the wood/gypsum mixture adversely affected the strength properties negatively. However, rice straw in wood chip/gypsum mixture helps to improve heat resistance (insulation) properties of panels at some level. Moreover, the addition of rice straw to wood/gypsum mixture effects on extending hardening time.

Keywords: Rice straw, gypsum board, red pine, strength properties, heat insulation

1. INTRODUCTION

Wood has been important raw material sources for housing, energy and decorative purposes. However, in modern times it has become utilized in the fabrication of different products such as paper products, composite panels, furniture and some chemicals [1, 2]. Due to the excessive use of wood, natural forests have become depleted and of scarcity value. The consumers have also become more aware of the importance of preservation and destruction of the natural forests. Thereby, other alternatives have been studied throughout the world such as agricultural residues or wastes, forest residues, low value woody materials, non-wood materials (annual plants), etc. have been found to be useful as added products instead of wood [3-5]. Moreover, there are numerous literature information for utilization of non-wood sources into processing of products [6-11]. The chemical and physical information on those raw materials and processing into composite manufacturing could be found elsewhere [3, 8, 9].

Rice stalk or straw is one of the abundant lignocellulosic waste materials in the world. It was stated that 709.2 million tons of wheat straw and 673.3 million tons of rice stalks were exposed worldwide and that large amount of lignocellulosic raw material could be used in the production of composite panels [4]. In more recent study, it was proposed that rice is the third most important grain crop in the world behind wheat and corn. According to FAO statistics, world annual rice production in 2007 was about 650 million tons while every kilogram of grain harvested is accompanied by production of 1–1.5 kg of the straw [12].

Amini and his group (2018) proposed modified corn starch with urea formaldehyde resin could have a potential to be used as a binder to produce particleboard panels with accepted properties [13]. In recent study, the urea-formaldehyde glue was used as a binder for producing cotton waste-based panels with red pine chips and fibers, separately. It was concluded that in some preparation conditions, it is possible to produce particle- and fiberboards with cotton-based waste materials at acceptable level [14].

However, gypsum is one of the oldest construction materials throughout human beings. The gypsum based construction and ornamental materials were found ancient civilizations (i.e. Sumerian, Seljuk, Ottoman Aztec, Egyptian, Greek and Roman so on). It was used intensively in Renaissance architecture period in Europe due to its easy shape in interior and exterior spaces by architects and painters [15].

In this study, gypsum-based experimental composite panels was produced with red pine wood/rice straw particles in the mixture up to 60:40 (ratio) (w/w) in gypsum-water mixture. Thus, it is possible to produce gypsum-based experimental panels by selecting the most suitable processing conditions.

2. MATERIAL AND METHODS

The red pine wood chips were supplied from a local timber company where processing log to timber, Isparta-Turkey. The rice straw (stalks) was supplied from Can-Biga region of Turkey. Both raw materials have been carefully cleaned from dust, bark and other substances then turned into particles using scissors and screened to suitable particle dimensions. The 10-50 mm particles were utilized for mixing with gypsum/water. They were then dried at atmospheric conditions until at least a 10-12% moisture content was obtained.

The commercial grade perlite plaster type Gypsum, used as binder agent, supplied by a local company, Isparta Turkey. After manufacturing, the experimental boards, they were conditioned at 20 ºC and 65% relative humidity. The detailed description of cellulosic raw materials, gypsum with their specifications, and manufacturing process could be found elsewhere [15].

A total of 14 boards (two for each condition) were made. The experimental procedure for manufacturing experimental particle boards as follows:

- Press temperature (ºC): Ambient temperature
- Pressing time (day): up to 14
- Press pressure (N/mm^2): 0.1-1.0
- Wood particles/rice stalk ratio (w/w,%): 100-40/0-60
- Board dimensions (mm): 400x400x10 cm.

- Target density (gr/cm^{-3}): 0.75 (± 0.1).

It is important to note that the compatibility of gypsum, red pine particles and rice straw are important but not considered in this study. However, some certain chemicals may also be used to shorten the curing time and improve compatibility of these substances into gypsum. Therefore, only the pure effects of wood/gypsum/rice straw compatibility are considered.

After reaching full strength at ambient temperature, the experimental boards were conditioned at 20 ºC and 6-8 % relative humidity and samples were cut to determine the IB (Internal bond), MOE–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), ASTM D 1037, respectively [16-18].

A standard flame combustion test system was conducted according to TS EN-ISO 11925-2. A visual observation of the sample was made either or not the flame spreads in the vertical direction more than 150 mm above from the flame application point [19-22]. For surface chemical analyses, FTIR spectrophotometer (A Shimadzu (IR Prestige-21) was used to evaluate the chemical groups present in surfaces. For thermogravimetric analysis (TGA), Perkin Elmer SII instrument was utilized for measuring changes as a function of increasing temperature.

The natural weathering tests were conducted on 50x50x10 mm samples were exposed to outdoor for two months then color and surface hardness tests conducted for determining property changes. The total color differences (ΔE) of the samples were measured by X-Rite SP 68 Spectrophotometer using CIE L*, a*, b* standards (1976). The surface hardness properties of both control and weathered samples were measured with a Shore D hardness tester, according to test method of ASTM D2240 standard [23]. The board's code numbers (wood chip and rice straw ratios) with constant gypsum content (800 gr) at various proportions are given in **Table 1.**

Table 1. The proportions and code numbers of gypsum boards

Board code	Wood (gr)	Rice straw (gr)	Wood (%)	Rice straw (%)
DE0	1000	0	100	0
DE1	900	100	90	10
DE2	800	200	80	20
DE3	700	300	70	30
DE4	600	400	60	40
DE5	500	500	50	50
DE6	400	600	40	60

3. RESULTS AND DISCUSSION

The thickness swelling properties of experimental boards after immersing in water are shown in Figure 1. It was realized that the lowest thickness swelling of 24.85% was observed in the panels produced from only the mixture of wood/gypsum (DE0) (no rice straw added). The addition of rice straw to the mixture had adversely affects the thickness swelling properties. The highest thickness swelling value of 47.66% found at 60:40 wood/rice straw (w/w) mixture (DE4) condition. Interestingly, it was found that the panels include rice straw was equal and/or higher than the wood chips (DE5 and DE6 boards), the thickness swelling values of 27.18 and 26.45% were found that only marginally similar to control sample (DE0), respectively.

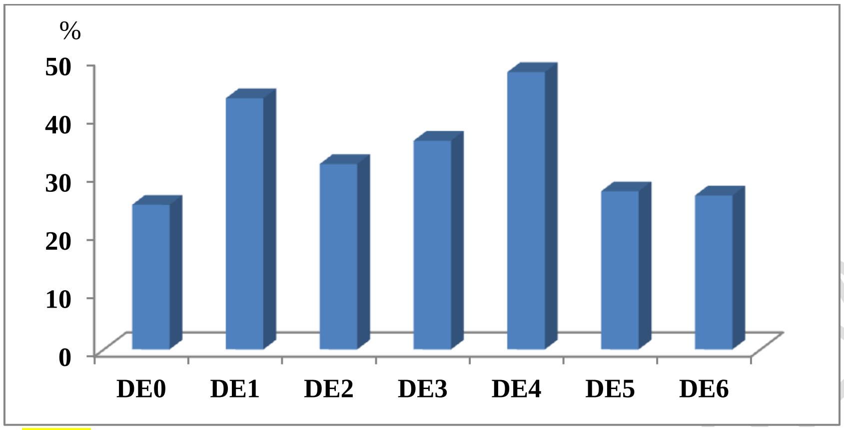

Fig. 1 Thickness swelling properties of experimental boards in water

The comparative internal bond (IB) strength properties of experimental boards are shown in Table 2. The test boards produced from wood/rice straw-gypsum boards were lower than those of the board produced only with wood/gypsum mixture (DE0). That is, the addition of rice straw to the wood/gypsum mixture has a negative effect on the IB strengths in all conditions. The maximum IB strength was calculated as 0.06 N/mm^2 for control sample.

Table 2 The IB strength properties of gypsum boards

Board code	Density (kg/m^3)	Internal bond (IB) (N/mm^2)	Difference from control (DE0) (%)
DE0	709.99	0.06	0.0
DE1	747.94	0.012	-80.0
DE2	717.94	0.014	-76.7
DE3	719.31	0.015	-75.0
DE4	705.89	0.013	-78.3
DE5	699.70	0.012	-80.0
DE6	697.48	0.011	-81.7

The combined effects of panel density and rice straw additive level on IB properties shown in Fig. 2. As seen**,** all rice straw addition negatively effects on IB properties some level. However, increasing panel's density had not much impact on IB of boards.

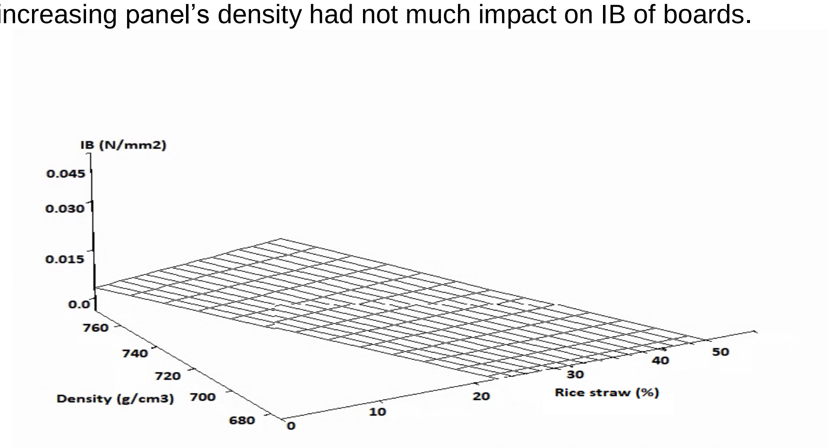

Fig. 2 IB properties of experimental boards.

The bending strength values of the experimental panels (MOR) produced with various proportion additions to rice straw (D1 to D6) was found to be lower than those produced from only wood/gypsum mixture (DE0) (Table 3). This is obviously important in that the introduction of rice straw into the wood/gypsum mixture has the reducing effects on bending strength properties. However, the lowest MOR value was calculated as 0.97 N/mm^2 in the DE3 panel (70:30; wood chip/rice straw mixture).

The elastic modulus characteristics (MOE) of the boards are also show similar trend (Table 3). The highest MOE value of 553 N/mm^2 was calculated on the DE4 board, which was produced by adding 40% rice straw to the wood/gypsum mixture. It was clearly seen that the elastic modulus values of all boards produced by the addition of rice straw into wood/gypsum mixture were improved up to 60:40 wood/rice straw level (w/w), beyond this level, the MOE values of experimental panels significantly reduced. In this sense, except a few conditions, the similar situations were also observed for internal bond strength (IB) and bending strength (MOR) properties. It could be summarize that the compatibility of rice straw with gypsum is low and should be useful only in controlled conditions.

The Duncan's multiple range test results also showed that the rice straw and wood chips ratio had some statistically different MOR values that it was in the two groups for MOR while no statistically difference in MOE values.

Table 3 Bending strength and modulus of elasticity of experimental panels

Board Code	**MOR** (N/mm^2)	**Diffrence from control** (%)	**MOE** (N/mm^2)	**Diffrence from control** (%)
DE0	2.77 (B)	0.0	445	0.0
DE1	1.21 (A)	-56.3	113	-74.6
DE2	1.22 (A)	-55.9	192	-56.9
DE3	0.97 (A)	-64.5	443	-0.23
DE4	1.07 (A)	-61.4	553	24.3
DE5	1.16 (A)	-58.1	360	-19.1
DE6	2.30 (B)	-16.9	138	-68.9

***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.

The combined effects of both panels density and rice straw ratio impact on bending strength properties of experimental boards are shown in Figure 3. It could be seen that increasing rice straw ratio and panel's density has only marginally effects on panel's MOR values.

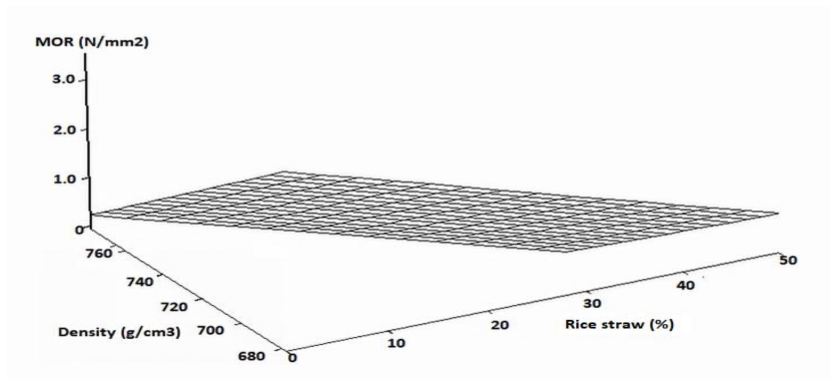

Fig. 3 Panel density and rice straw ratio effects on bending strength of experimental boards

The comparative surface hardness values (Shore D) of the test panels are given in Table 4. The highest Shore D value of 44 (metric) was observed on the DE0 board while the lowest value of 22 found for DE5 board produced from the mixture of 50:50 wood/rice straw. In general, it has understood that the hardness values of the boards produced with the increase in rice straw or the decrease in the wood ratio (at fixed the gypsum ratio) are affected negatively on hardness properties. However, an interesting situation was encountered that the hardness values of the boards kept under external atmospheric conditions were found to decrease less than the DE0 sample. The lowest hardness value reduction in the boards that were kept under external atmospheric conditions was calculated as 3.2% in DE3 and 4.3% in DE1 type boards, respectively. The increase in the ratio of rice straw in the mixture adversely affects the hardness values, but it is important to ensure that the hardness properties of the panels against external atmospheric conditions remain at a lower trend than control sample (DE0).

However, according to Duncan's multiple range test result, rice straw and wood chips ratio had some statistically different hardness values that it was in the six statistically different groups for this study.

Table 4. Surface hardness properties of boards

Board code	**Hardness** (metric)	**Diffrence from control (DE0)** (%)	**After weathering hardness** (metric)	**Changes** (%)
DE0	44 (D)	0,0	33	-25
DE1	45 (E)	2.2	43	-4.4
DE2	32 (BC)	-27.2	27	-15.6
DE3	31 (CD)	-29.9	30	-3.2
DE4	23 (A)	-47.8	21	-8.7
DE5	22 (A)	-50.0	20	-9.1
DE6	26 (AB	-40.9	25	-3.8

***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.

The effects of wood and rice straw ratio on both control and weathered experimental panels are shown in Figure 4. It was realized that the similar trend was found for both panels that increasing rice stalk ratio or (decreasing wood ratio) negatively effects on experimental panels.

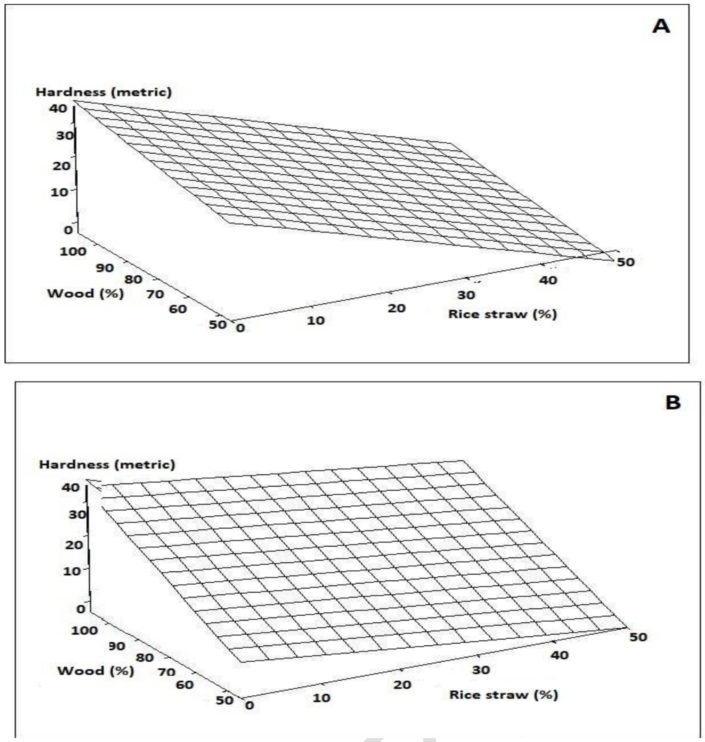

Fig. 4 **H**ardness properties of boards (A: Control samples, B: Weathered samples)

The comparative surface optical (color) properties of boards are shown in Table 5. In general, it was proposed in literature that total color difference (ΔE) of samples are more useful for explain materials surface color changes rather than other CIE L*, a*, b* parameters [23]. The highest ΔE value of 8.15 was observed in the control sample (DE0) while the lowest in DE6 sample (0.63). It was also found that the highest whiteness color value of -35.48 (in metric) and the corresponding increase in the yellowness color value of 7.03 (in metric) were found in the DE0 board as well.

Table 5 The surface color properties of experimental panels

Board codes	ΔL	Δa	Δb	ΔE	CIE Whiteness	E313 Yellowness
DE0	-7,19	1,55	3,51	8,15	-35,48	7,03
DE1	-2,78	0,48	0,3	2,84	-8,09	1,01
DE2	1,26	-0,35	1,17	1,75	-3,48	1,56
DE3	-1,12	-0,16	0,8	1,39	-6,9	1,48
DE4	0,17	1,81	-1,46	2,33	8,79	-2,42
DE5	0,98	-0,44	1,27	1,67	-5,13	1,85
DE6	0,47	-0,39	-0,15	0,63	1,91	-0,38

The comparative Fourier Transform Infrared Spectroscopy (FTIR) analysis of DE0 and DE5 boards are shown in Fig. 5. Generally, bands in the range of 1500-1610 cm^{-1} are considered as a characteristic peak for lignin components and composed of C=O and COO- symmetric tension vibrations in aromatic rings of lignin structure [15, 25]. However, the bands in the range of 1360-1380 cm^{-1} were generally showing C-H degradation in polysaccharides. The change in the bands at 1230-1270 cm^{-1} was reported to explain the vibration in the guayacil ring with CO groups in lignin and hemicellulose. Although some chemical groups could be modified under the water/gypsum environment that might be deteriorated to some extent (alkaline environment). In this sense, some bands are modified to some extent but all these groups observed on the surface of boards.

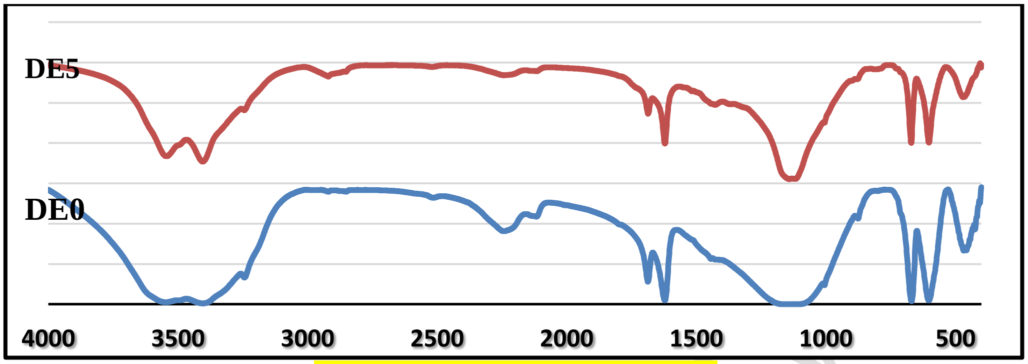

Fig. 5 The FTIR spectra of boards

TGA (Thermal Gravimetric Analyzer) analysis based on temperature-time variables at range of 25-900^{o}C is shown in Fig. 6. The TGA thermographs has divided four different regions as; heating zone (Tb); (the water assumed to remove) up to 120 ^{o}C; cell wall degradation zone (Tm1); above 120 to 370^{o}C; completely break down zone (Tm2); cell wall organic constituents completely break down up to 700^{o}C; non-organics degraded zone (Ts) up to 900^{o}C, on-organics have degraded and char residues obtained. In this approach, the mass loss of in that zones were found to be 2.5, 27.7, 49 and 55% for DE5 sample, respectively.

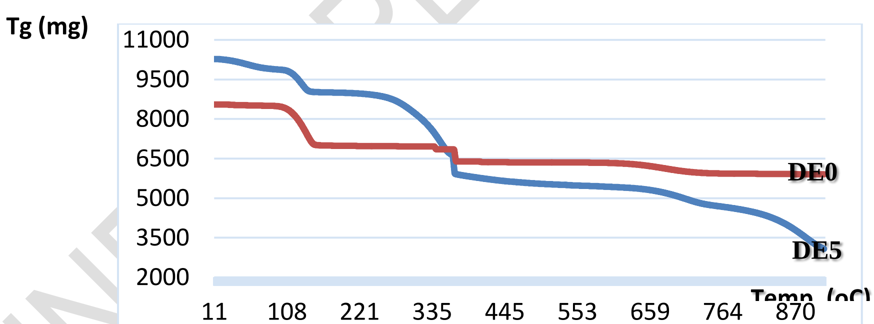

Fig. 6 The TGA micrographs of experimental panels

According to the TS EN-ISO 11925-2 standard, the flame spreading characteristic of the boards was conducted. However, the flame spreading pattern of all test boards produced by adding wood/rice straw-gypsum based boards show that the flame did not reach the threshold limit of 150 mm. This is a well indication of boards that could be classified as class A1 (non-flammable material).

For determining heat insulation properties, the temperature values passed to the back surfaces were measured in accordance with DIN 4102 for 30 seconds intervals and for a total of 300 seconds. The measured values were shown in Table 6. It has been observed that the addition of rice straw and wood particles to the gypsum structure has a positive effect on the heat transfer properties. It was measured as 39.1^{o}C in the DE6 panel. When

Table 6 is carefully examined, the addition of rice straw has improving effects on heat insulation properties of boards. However, the lowest mass loss was also measured as 2.01% on the DE6 boards that produced with the highest rice straw ratio (60:40, rice straw/wood chips by weight).

Table 6 The heat insulation properties of boards

	0 (sec.)	**60** (sec.)	**120** (sec.)	**180** (sec.)	**240** (sec.)	**300** (sec.)	**Total Mass loss** (%)
DE0	20.2	20.2	24.3	41.9	58.8	66.0	4.15
DE1	20.0	22.7	32.4	45.1	52.0	62.9	3.90
DE2	12.9	15.2	16.3	20.5	30.4	40.9	3.04
DE3	14.2	15.3	23.1	35.0	45.3	56.1	6.21
DE4	10.8	12.9	14.6	19.3	28.7	40.3	2.66
DE5	13.8	14.4	16.0	25.6	32.5	45.3	2.65
DE6	11.8	12.1	15.4	25.1	34.6	39.1	2.01

4. CONCLUSIONS

In this study, the fundamental knowledge and approaches for producing gypsum based boards from wood/rice straw was investigated. Thus could help researchers to this area gain the understanding and to make meaningful contributions to this field of study. However, it is clear that in order to be an composite panel has efficient mechanical and technological properties, there must be a hydrophobic substances added to mixture for improvement thickeness swelling properties in water. Moreover, although the addition of rice straw to the wood/gypsum mixture adversely affected the strength properties negatively, with using some longer fibers may improve the strengths of panels. On the other hand, rice straw in wood chip/gypsum mixture helps to improve heat resistance (insulation) properties some level. It was also realized that the addition of rice straw to wood/gypsum mixture effects on extending hardening time. It is probably gypsum-rice straw interaction that could not effectively wet and penetrate the rice straw surface due to the hydrophobic wax and inorganic silica on the outer surface of rice straw.

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