MECHANICAL PROPERTIES OF PARTICLEBOARD PANELS MADE FROM AGRICULTURAL WASTES

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ABSTRACT

The aim of this study is to characterize the mechanical properties of particleboard (tensile strength (TS), compressive strength (CS), modulus of rupture (MOR) and modulus of elasticity (MOE)) as affected by various parameters. The effects of waste type, particleboard density and resin content on the mechanical properties of the particleboards were investigated. Also, the possibility of using treated rice straw to improve the properties of the particleboards was evaluated. The results showed that an improving in the mechanical properties of rice straw particleboards with increasing the density of particleboard and the added resin content in the mixture. While the internal bond (IB) initially increased then decreased with increasing particleboard density. Finally, the MOR and MOE decreased with increasing resin content. Hot-water treatment induced better performance on the properties of particleboards.

Keywords: *particleboards, rice straw, flax shives, Urea formaldehyde, mechanical properties.*

1.   INTRODUCTION

Heating costs in the winter and cooling costs in the summer are very high. As building insulation reduces heating costs in the winter and cooling costs in the summer. Therefore, the use of insulation materials has become a necessity. The production of appropriate materials for insulation materials is of great importance.

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Insulation materials are usually produced from inorganic materials. In recent years, these materials have been prohibited due to the suspicion of health risks Thus, it is important to investigate organic-based insulation materials. On the other hand, large quantities of agricultural residues are available that have potential alternative uses for some inorganic materials such as particleboard production. Although rice production in Egypt is significant, after the production the rice straw is a serious problem for farmers. Rice straw are cleaned, burned or used for temporary heating purposes. This type of use is causing serious problems to the environment. Consequently, rice straw is the renewable resource that can be utilized as raw materials for making insulated particleboard. Particleboard is one instance from the applications of wood. Particleboard is a panel product manufactured under pressure from particles of wood or other lignocellulosic materials and an adhesive. Particleboard historically has been made with forest products. However, due to government restriction; wildlife protection, and other environmental concerns, the availability of these raw materials has been decreasing. The demand for particleboard products continues to increase, leaving an increasing gap between raw materials and products demand. This researcher will use rice straw as alternative to fill this gap. Rice is the primary food for more than 40% of the world's population, with about 596 million tons of rice and 570 million tons of rice straw produced annually in the world **(Pathak *et al.,* 2006; Mohdy *et al.,* (2009)**. Currently, 12 million MTs of rice straw is produced annually in Egypt **(CAPMAS, 2013)**, most of which returns back to field by burying or burning, or serves as an on-farm fuel source. **Tong *et al.,* (2001)** found that Straw is rich in resources, with low density, renewable nature and lustration. Rice straw is an annually renewable agricultural by-product. Its unique characteristics have drawn attention of researchers throughout the world. Particleboard performance is mostly related to the properties of adhesives and their compatibility with fibres. Several types of adhesive resins have been used to make straw particleboard. Urea-formaldehyde (UF) has been the major adhesives for wood-based particleboard. The manufacture of particleboards from eggplant stalks using UF adhesive is technically viable **(Guntekin and Karakus 2008)**.

Researchers have succeeded in studying some parameters such as resin content, particleboard density and straw treatment to improve the mechanical properties of the particleboard. The mechanical properties of particleboard made of mesquite, salt cedar and date palm were improved as the Urea–formaldehyde (UF) resin content increased from 9 to 11% (**Ashori and Nourbakhsh 2008**). The qualities of particleboard were improved as the content of UF resin increased from 7% to 16% (**Pan *et al.,* 2007**). The mechanical properties of the saline Jose Tall Wheatgrass (JTW) particleboards improved with the increase of particleboard density from 0.71 to 0.75 g/cm^3 (**Zheng *et al.,* 2007**). Values of the mechanical properties showed that hot-water treatments on RS induced better performance on the obtained composites (**Junjun and Chuanhui 2013**). Steam and short durations of OA-treatment resulted in significantly improved mechanical properties of UF-bonded rice straw particleboards (**Li *et al.,* 2011**). The treatment of oil palm particles before board making gives a positive effect by improving the mechanical properties of board. As resulted, the treatment with hot water improved for board properties (**Jumhuri *et al.,* 2014**). The mechanical properties of the corn-stalk-based fiberboard without adhesive were improved by pretreatment with the white-rot fungus T. hirsute. Pretreatment increased the mechanical properties of the fiberboard (**Wu *et al.,* 2011**). Because of a little information is available on use of rice straw for particleboard in combination with adhesives and effect of resin content, particleboard density and rice straw treatment on the mechanical properties of particleboard. To achieve that the specific objectives of this work are to utilize rice straw for making insulation particleboards and evaluate the effect of different waste type, resin content, particleboard density and rice straw treatment on the mechanical properties of particleboard.

2.   EXPERIMENTAL PROCEDURES

2.1. Materials

Rice straw was cultivated on the Shubra Millis, Zifta, Al Gharbiyah Governorate, Egypt. At maturity, the straw was harvested and left in the open field for two weeks to dry and then moisture content (MC) of the straw was about 5%. The commercial UF resin adhesive (65 wt.% of

solid content) was used as a composite binder. Ammonium chloride (NH$_4$Cl) solution (10 wt.%) was added to the UF as a hardener material. These two materials and flax shives were obtained from Tanta Company of Flax and Oils, Tanta.

2.2. Sample preparation

Rice straw was obtained from local farming operation. After received, the rice straw was broken down into different particle sizes from 10-40 mm using a hammer mill. The hammer milling reduced the straw particles size, and then the straw particles were screened to remove fines and dust from the straw stream. Treatment of rice straw was carried out according to **Junjun *et al.,* (2012)**. A desired amount of straw was sprayed with resin material. After spraying, the straw particles were sufficient mixing for 8 minutes. The mixture was poured into a steel mold placed on a wood board. The steel mold dimensions are 700 x 350 mm. For one layer, it was put into the mould and press by hands for making mat forming. The mould was pulled from around straw particles before primary press. The particleboards were manufactured using a Primary press with a manually controlled hydraulic press system. The time period of press was approximately 2 min. After Primary press, the boards were placed in between the heated platens of the hot press. The platens of the press were heated to a constant temperature of 180 ℃ to ensure optimal curing of the resin material. The platens compressed the boards; the load applied to the boards was set to 210 Bar. The total time from the press closing to opening was approximately 12 min. The edges of the particleboard were trimmed with a utility knife. The finished boards were cut to desired length, width and to square the edges.

Different recipes of particleboards with different parameters were prepared for testing. These parameters include resin ratio (10, 12 and 14 %), waste type (rice straw and flax shives), particleboard density (0.3, 0.5 and 0.7 g/cm^3) and straw treatment (hot water and Sodium hydroxide (NaOH)). Different recipes are given in Table (1).

2.3. Test Procedure

The particleboard was cut into various specifications according to **the ASTM standard method, D1037-06 (American Society of Testing and**

Materials, 2006). Prior to property evaluation, specimens were conditioned for 72 h in a Fisher-brand Desiccators Cabinet maintained at 65% RH and 20±1°C to achieve stable conditions.

Table 1: Recipes of designed particleboards.

Recipes	Type of waste	Ratio of resin (%)	Density of Particleboard (g/cm³)	Treatment of straw
1	Rice straw	10 12 14	0.7	Untreated
2	Rice straw	12	0.3 0.5 0.7	Untreated
3	Rice straw	12	0.5	NaOH Hot water Untreated
4	Rice straw Flax shives	12	0.5	Untreated

2.3.1. Flexural strength (Static bending)

Static bending tests shall be made to determine the flexural properties, such as modulus of rupture (MOR) and apparent modulus of elasticity (MOE). Static bending tests were conducted on samples in accordance with **ASTM D1037-06 section 9**. The test involves utilizing a three-point bending test to obtain the modulus of elasticity (MOE) and the modulus of rupture (MOR) for the particleboards (Figure 1). The flexural strength was measured by using specimens with dimension of $530 \times 76 \times 20$ mm (rectangular pieces). Each flexural strength result was the average of strength for three specimens as replicates. Each sample was loaded with a central loading nose and two support noses, each having a radius of 25.4 mm. The two support noses were placed such that the span between them was as suggested in the ASTM D1037, 24 times the nominal board thickness. Loading of the samples was achieved by lowering the central loading nose at a constant crosshead rate determined by the sample geometry, given by equation (1):

$$N = \frac{zL^2}{6d} \tag{1}$$

where N is the crosshead rate (mm/min), L and d are the length and thickness of specimen (mm), respectively and z is the unit rate of fibre strain of outer fibre length per minute (z=0.005 according to ASTM D1037).

The maximum load achieved during the test and the corresponding vertical deflection were recorded in order to calculate the MOE and MOR of the samples. The modulus of rupture and the modulus of elasticity are calculated by Eqs. (2) and (3), respectively:

$$MOR = \frac{3P_{max}L}{2bd^2} \tag{2}$$

$$MOE = \frac{L^3}{4bd^3}\frac{\Delta p}{\Delta y} \tag{3}$$

Where MOR is the modulus of rupture (MPa), P_{max} is the maximum load (N), b is the width of specimen (mm), MOE is the modulus of elasticity (MPa) and $\frac{\Delta p}{\Delta y}$ is the slope of the straight-line portion of the load deflection curve (N/mm) (slope between 10% and 40% of P_{max} as suggested in note 16 of ASTM D1037).

a)   b)

Fig. 1: samples for static bending test, a) before the test. b) after the test.

2.3.2. Internal Bond strength (Tension Perpendicular to Surface)

The tension test perpendicular to the surface shall be made to determine cohesion of the panel in the direction perpendicular to the plane of the panel. Internal bond was measured according standard of **ASTM D1037-06 section 11**. In the standard test for IB, the internal bond strength was measured by using specimens with dimension of 50×50×20 mm (square

pieces). Each internal bond strength result was the average of strength for three specimens. Samples were adhered to the faces of aluminium loading blocks by first heating the loading blocks and melting a hot melt adhesive on the face, then placing individual samples between two loading blocks and letting the adhesive set in room temperature with no pressure applied to the samples. A minimum of 24 h was allowed to pass after adhering to the loading blocks before samples were tested. Each sample was loaded into the testing fixture by placing the loading blocks such that the slots in each block made sufficient contact with the fixture arms (Fig. 2). Samples were loaded perpendicular to the panel face until specimen failure occurred. The rate of loading was kept at a constant 1.6 mm/min rather than keeping the speed of testing at a rate of 0.08 cm/cm as was specified in ASTM D1037. The maximum load achieved during the test before specimen failure occurred was recorded and used to calculate the internal bond strength, where the internal bond strength is calculated as follows:

$$IB = \frac{P_{max}}{bL} \qquad (4)$$

where IB is the internal bond strength (MPa).

a)   b)

Fig. 2: samples for tension test, a) before the test. b) after the test.

2.3.3. Compression strength

The compression test shall be made to determine the compressive strength in the plane of the panel. Compression was measured according standard of **ASTM D1037-06 section 12**. The compression strength was measured by using specimens with dimension of $102 \times 25 \times 20$ mm

(rectangular pieces). Each compression strength result was the average of strength for three specimens. The specimen was entered carefully through a spherical loading blocks in the testing machine in a vertical plane for unsupported (102 mm) specimen. The specimen was loaded parallel to the panel face until specimen failure occurred. The rate of loading was kept at a constant 0.5 mm/min rather than keeping the speed of testing at a rate of 0.005 mm/mm as was specified in ASTM D1037. The maximum load achieved during the test before specimen failure occurred was recorded and used to calculate the compression strength, where the compression strength is calculated as follows:

$$CS = \frac{P_{\max}}{bd} \tag{5}$$

where CS is the compressive strength (MPa).

a)   b)

Fig. 3: Compressive strength test samples, a) before the test. b) after the test.

3. <u>RESULTS AND DISCUSSION</u>

3.1. Effect of waste type on the mechanical properties of particleboard

3.1.1. Flexural strength (Static bending)

Fig. 4 illustrates the modulus of rupture (MOR) and modulus of elasticity (MOE) as a function of waste type. The results reveal that, boards made with flax shives exhibited superior bending properties compared to the rice straw particles. For example, the maximum values of the MOR and MOE were 13.85 MPa and 1722 MPa for flax shives, respectively, while the values for rice straw were 1 MPa and 181.9 MPa, respectively. The results also proved that MOR and MOE values for flax shives were

higher than rice straw. This may be due to use of light particles improve bending properties of particleboard due to high compaction ratio. These results trend agreed with those obtained by **Tabarsa *et al.*, (2011)**.
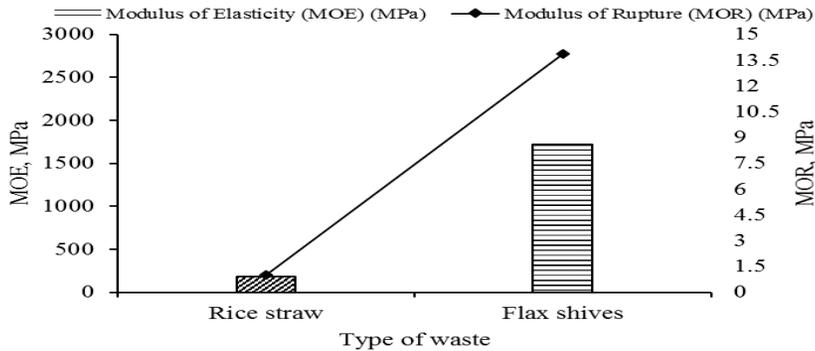

Fig. 4: The effect of waste type on bending properties of particleboard.

3.1.2. Internal Bond strength

The results are shown in Fig. 5 demonstrate the influence of waste type on the internal bond property of experimental rice straw particleboard. Bending properties such as MOR and MOE, boards made with flax shives showed higher internal bond than those made from rice straw particles. The internal bond value increases from 0.02 to 0.6 MPa. The possible reason proposed for this kind of behavior may be due to the high compaction of flax shives furnish which caused faster heat transfer to the core layer resulted more curing of resin. These results trend agreed with those obtained by **Tabarsa *et al.*, (2011)**.
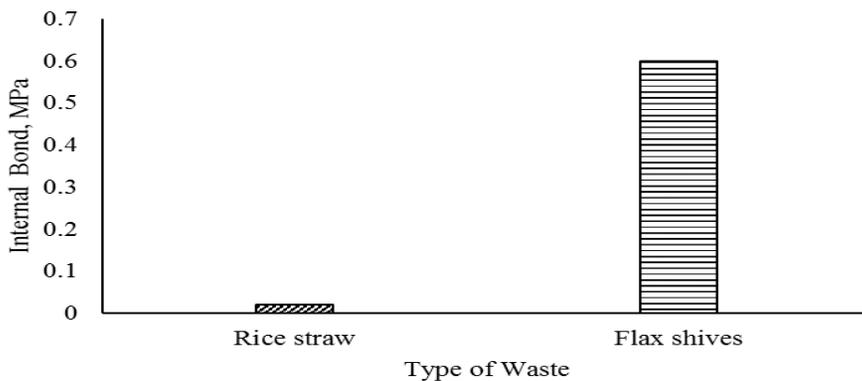
Fig. 5: Internal bond of particleboard as a function of waste type.

3.1.3. Compression strength

The particleboard made from rice straw particles is much weaker in compression strength than that from flax shives as shown in Fig. 6. Where, the compression strength value of untreated rice straw is 1.7 MPa and is 12.4 MPa for untreated lax shives. This was due to the particleboard prepared with flax shives had smaller size than that rice straw particles, which increase the compaction of flax shives particleboard. The mechanically split of flax shives result in the best compression strength of composites compared to rice straw. This is may be due to the increasing of surface area of flax shives compared with rice straw. These results trend agreed with those obtained by **Yi *et al.,* (2010)**.
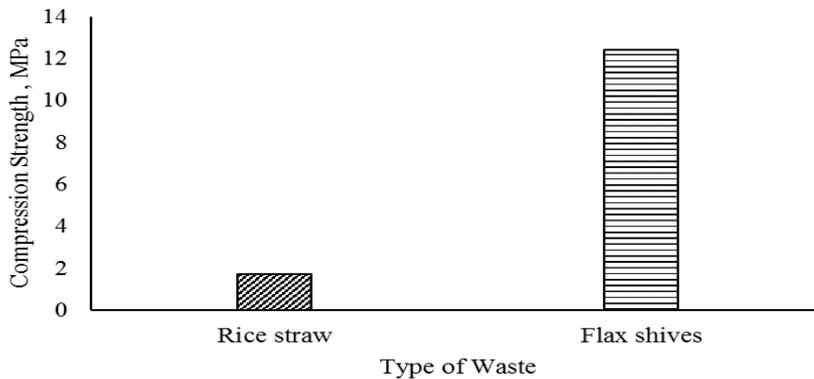
Fig. 6: The influence of waste type on Compression strength of particleboard.

3.2. Effect of particleboard density on the mechanical Properties
3.2.1. Flexural strength (Static bending)

The bending properties of the particleboards were strongly dependent on the density, and two regions of MOR and MOE are shown in Figs 7. Increased density resulted in significant improvement of the bending properties. The higher density of the particleboards generates a higher number of contact points (inter-bonding between fibers), which consequently improve the bending strength. For particleboard produced at the lower density had MOR value reached 0.6 MPa, the corresponding MOE value reached 91.8 MPa. Higher density in the produced particleboard resulted in improved bending properties, causing MOR to increase to 1.95 MPa and the corresponding MOE value to reach

approximately 244 MPa. These results agreed with those obtained by **Khristova *et al.,* (1996)** and **Zheng *et al.,* (2007)**.
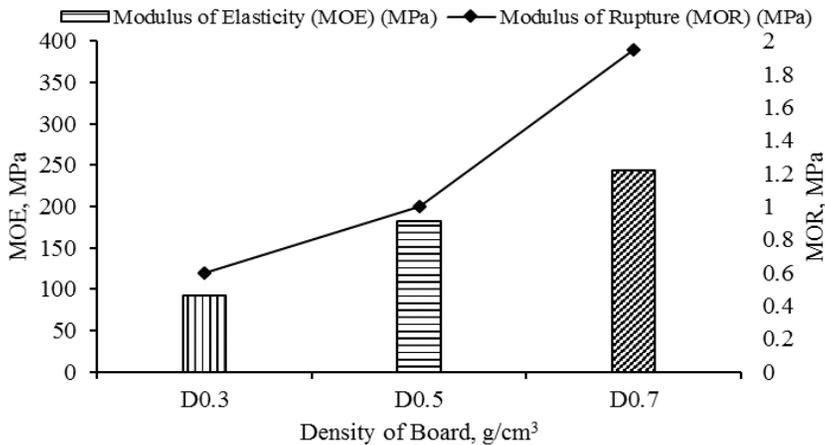

Fig. 7: The effect of board density on bending properties of particleboard.

3.2.2. Internal Bond strength

The results presented in Fig. 8 demonstrate the influence of board density on the internal bond property of experimental rice straw particleboard. The results mentioned that internal bond increased and then decreased with increasing of particleboard density, and reached to the peak value at particleboard density of 0.5 g/cm^3. The internal bond property decreased with increasing of particleboard density above 0.5 g/cm^3. At a board density of 0.3 - 0.5 g/m^3, the internal bond significantly increased from 0.003 to 0.02 MPa. At a board density of 0.5–0.7 g/m^3, the internal bond slightly decreased from 0.02 to 0.008 MPa. This could be accounted for looser internal structure, more moisture content of particleboard and weakened adhesive solidification, and the internal bond property was lower at density below 0.5 g/cm^3. When density was 0.5 g/cm^3, moisture content was appropriate, adhesive material diffuses uniformly and could glue the rice straw completely, internal bond strength reached the peak value. The internal bond property decreased with increasing of density above 0.5 g/cm^3, this was due to more compact internal structure and more difficult adhesive material diffusion. These results trend are similar to those obtained by **Junjun *et al.,* (2012)**.
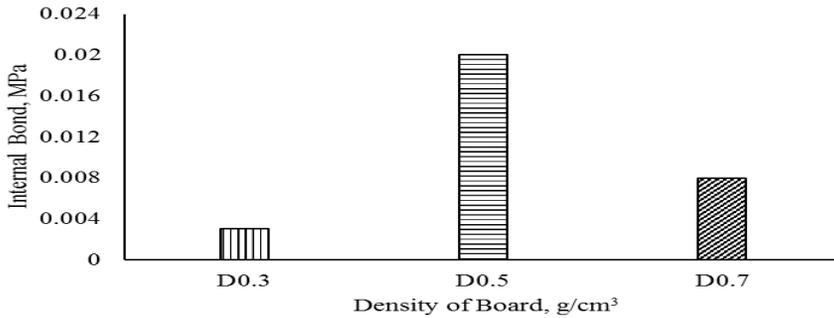
Fig. 8: Internal bond of particleboard as a function of board density.

3.2.3. Compression strength

Fig. 9 plots the effect of board density on the compression strength of rice straw particleboards. Increasing of density of particleboard positively affects the compression property, which compression strength increased with increasing of particleboard density. The high density of particleboard showed high compressive strength due to their low porosity. It appears that for the compression strength was increased from 0.7 to 1.7 MPa with increasing the board density from 0.3 to 0.5 g/cm^3. The peak value of compressive strength reached 2.5 MPa at particleboard density of 0.7 g/cm^3. These results trend agreed with those obtained by **Donghai and Xiuzhi (2002)**.
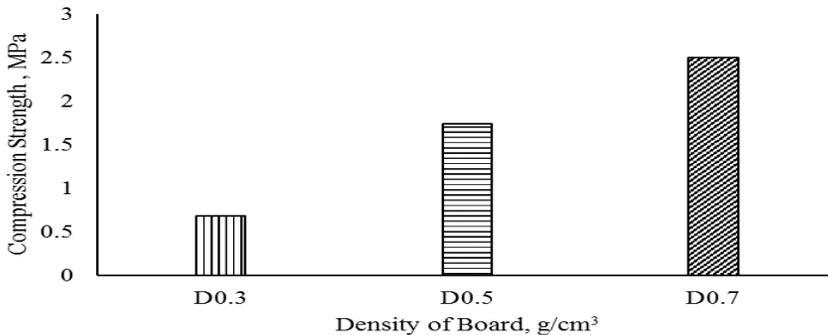

Fig. 9: The effect of board density on compression strength of particleboard.

3.3. Effect of resin content on the mechanical Properties of particleboard

3.3.1. Flexural (Static bending)

Fig. 10 presents the modulus of rupture (MOR) and modulus of elasticity (MOE) as a function of resin content. The bending properties of the

particleboards were strongly dependent on the resin content, and two regions of MOR and MOE are shown in Figs. 13. The results revealed that decreasing of resin content lead to significant improvement of the bending properties. The lower resin content of the particleboards generates a higher number of contact points (inter-bonding between fibers), which consequently improve the bending strength. For particleboard produced at the higher resin content (14%) had MOR value reached 1.3 MPa, the corresponding MOE value reached 213.6 MPa. Lower resin content (10%) in the produced particleboard resulted in improved bending properties, causing MOR to increase to 2.1 MPa and the corresponding MOE value to reach approximately 344.97 MPa. The bending properties decreased with increasing of resin content, this was due to increase solidification of particleboard.
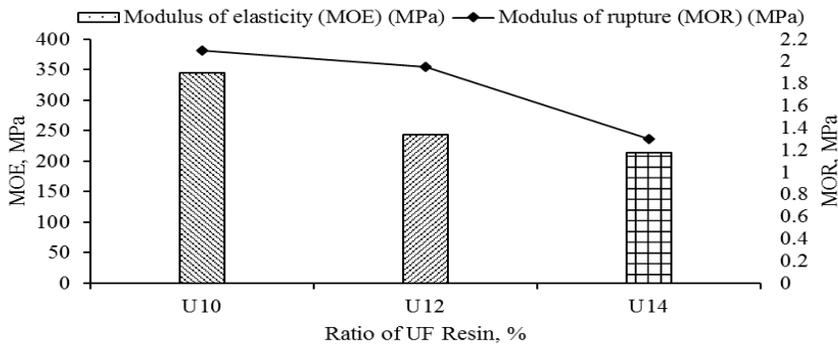

Fig. 10: Bending properties of particleboard as a function of resin ratio of Urea formaldehyde.

3.3.2. Internal bond strength

Fig. 11 shows a definitive relationship between the resin content of the produced particleboard and internal bond property. While, Increasing of UF resin ratio in the produced particleboard gives a positive influenced by improving the internal bond property of particleboard. Additionally, increasing the resin content of the produced particleboard from 10% and 12% to 14% improved the internal bond significantly. For example, the internal bond value of particleboards at the lower resin content was 0.002 MPa, whereas that of particleboards produced at the higher resin content was 0.016 MPa. These results trend agreed with those obtained by **(Guntekin and Karakus 2008)**.
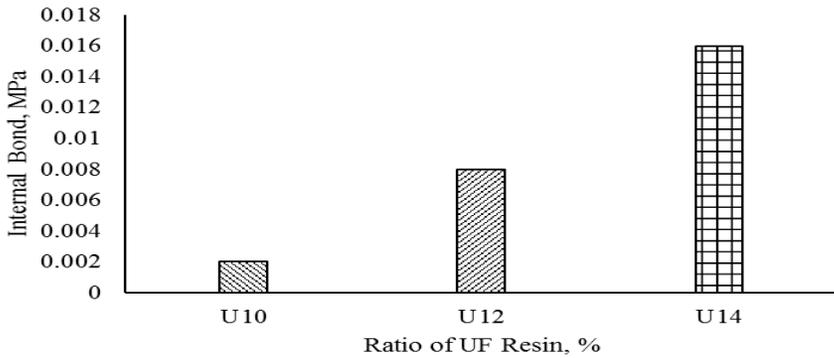
Fig. 11: The influence of resin ratio of Urea formaldehyde on internal bond of particleboard.

3.3.3. Compression strength

The compression strength was plotted as a function of resin content for all produced particleboard in Fig. 12. The results reveal that, the influence of resin content on compression strength is very important. While Increasing of UF content lead to improve compression strength of the produced particleboard. At particleboard density 0.7 g/cm^3, increasing the resin content from 10% to 14% lead to increase the compression strength from 1.55 to 4.46 MPa.

A linear regression was made to obtain a relationship between the compressive strength (CS) and the resin ratio of UF as follows:

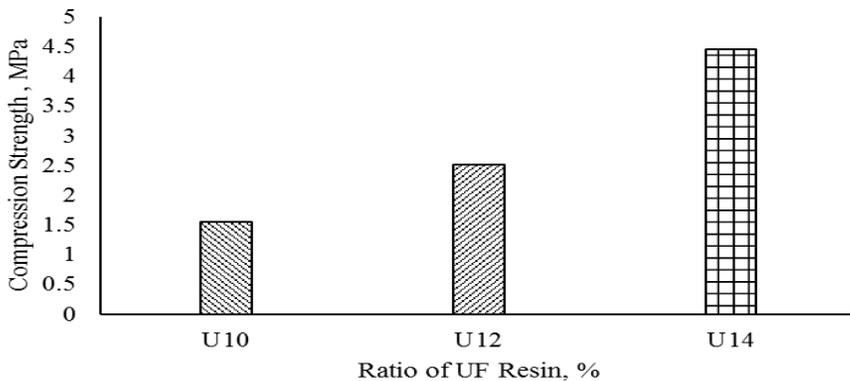$$CS = 1.458R_c - 0.0753 \qquad (R^2 = 0.963) \qquad (13)$$

Fig. 12: Compression strength of particleboard as a function of resin ratio of Urea formaldehyde.

3.4. Effect of treated straw on the mechanical Properties of particleboard

3.4.1. Flexural (Static bending)

Fig. 13 presents the bending properties modulus of rupture (MOR) and modulus of elasticity (MOE) as a function of chemical treatment of straw. The bending properties of the particleboards were strongly dependent on the chemical treatments of straw, and two regions of MOR and MOE are shown in Figs. 16. For particleboard made from untreated straw had MOR value reached 1 MPa, while the MOE value reached 181.9 MPa. Particleboard made from NaOH treated lead to improve bending properties, while MOR increase to 2.1 MPa and the corresponding MOE value to reach approximately 221 MPa, while particleboard from hot-water treated resulted in improved MOR, causing to increase to 2.8 MPa and worse MOE, causing to decrease to 163.6 MPa.
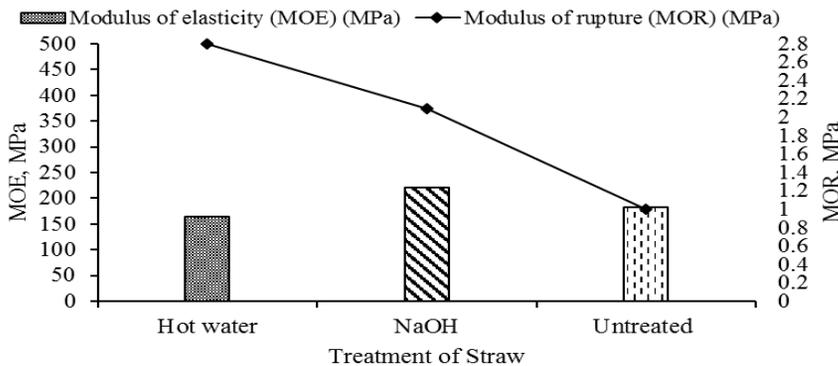

Fig. 13: The effect of treated rice straw on bending properties of particleboard.

3.4.2. Internal bond strength

Fig. 14 shows the effect of treated straw on internal bond strength of rice straw particleboard made by using 12% UF resin. IB value showed that hot-water treatments on RS induced better performance on the produced particleboards. In contrast, NaOH treatments on RS reduced IB of the particleboard slightly. It appears that for particleboard made from hot water-treated straw, the internal bond strength initially increases from 0.02 to 0.045 MPa and then decreases to 0.005 MPa when the straw treatment changes to NaOH treated straw. This could be attributed to the

higher content of silica, which existed in the form of non-polar surface structure, resisting the adsorption of rice straw with UF adhesive. Hot-water treatments on RS removed the silica and wax on the surface partly, which reduced the contact angle on straw surface and increased infiltration with UF adhesive, making higher interface bonding strength between rice straw and adhesives. These results trend agreed with those obtained by **(Junjun and Chuanhui 2013).**
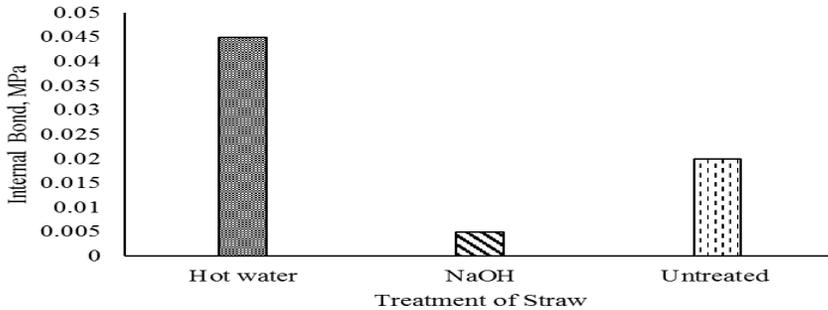

Fig. 14: Internal bond of particleboard as a function of treated rice straw.

3.4.3. Compression strength

Fig. 15 shows the effect of pre-treatment on the compression strength of rice straw particleboards. In comparison with the rice straw untreated particleboard, a significant improvement was observed in hot water treated rice straw particleboards, where compression strength increased from 1.7 to 3.4 MPa. For the NaOH treated rice straw particleboards, the compression strength increased to 1.8 MPa. The increase of compression strength could be mainly due to the extraction of hemicelluloses, wax like substances, and other non-polar extractives from rice straw in pre-treatment resulting in improved compatibility between rice straw and UF resin. These results clearly indicate that the addition of NaOH in pre-treatment has a negative effect on comparison strength of particleboards compared to hot water treatment. The results revealed that the compression strength of particleboards decreased after the NaOH pre-treatment. This could be caused by the NaOH treatment may be lower the pH-value of particles because of residual NaOH on the surface and interior of rice straw particles, which lead to a pre-curing of the UF resin.
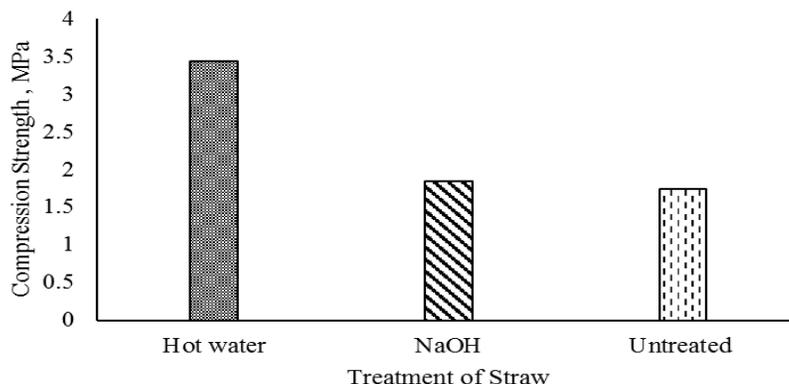
Fig. 15: The effect of treated rice straw on compression strength of particleboard.

4. CONCLUSIONS AND RECOMMENDATIONS

Particleboards made with flax shives had superior properties compared to the rice straw particles. The mechanical properties of the particleboards increase with increasing resin content except for the MOR and MOE decreases with increased resin content, and reached to the peak value at resin content of 10 %. Additionally, increasing particleboard density significantly improved the mechanical properties of the particleboards except for the IB initially increases then decreases with increased particleboard density, and reached the peak value at particleboard density of 0.5 g/cm^3. Maximum mechanical strength was obtained at 0.7 g/cm^3 particleboard density and at 14 % resin content with UF. Finally, rice straw treated by hot water induced better performance on the mechanical properties of produced particleboards except for modulus of elasticity (MOE) which that reach to peak value with NaOH treatment.

5. ACKNOWLEDGEMENTS

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الملخص العربى

الخصائص الميكانيكية للألواح الحبيبية المصنوعة من المخلفات الزراعية

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الهدف الرئيسى لهذه الدراسه هو تحقيق بعض خواص الالواح الحبيبيه المصنوعه من قش الارزكماده ليفيه بديله. تم تقيم وتحليل الخصائص الميكانيكية والتى تشمل معامل المرونه ومعامل الكسر وقوة الترابط الداخلى وقوه الضغط كدالة فى جميع المتغيرات. شملت متغيرات الدراسة نوع المخلف المستخدم (قش الارز وساس الكتان) ونسبة المادة اللاصقة (۱۰، ۱۲، ۱٤ %) وكثافة اللوح الحبيبى المنتج (۰.۳، ۰.٥، ۰.۷ جم/سم³) ومعاملة قش الارز (هيدروكسيد الصوديوم، الماء الساخن) والتى اثرت معنويا فى خصائص الألواح الحبيبيه والنتائج المتحصل عليها يمكن تلخيصها كالتالى:

- الألواح الحبيبيه المصنوعه من ساس الكتان لها خصائص ميكانيكية فائقه مقارنة بتلك المصنوعه من قش الارز.

- بزيادة كمية المادة اللاصقة تزداد الخصائص الميكانيبية للالواح الحبيبية فيماعدا معامل المرونه ومعامل الكسر حيث يقل قيمتهما بزيادة كمية المادة اللاصقة ويصلان الى اقصى قيمة لهما عند كمية مادة لاصقة ۱۰ % ومن ناحية اخرى تحسنت الخصائص الميكانيكية للالواح الحبيبية معنويا بزيادة كثافة اللوح الحبيبى فيماعدا قوة الترابط الداخلى حيث زادت قيمتها ثم قلت بزيادة كثافة اللوح وتصل الى اقصى قيمة لها عند كثافة اللوح ۰.٥ جم/سم³ وتم الحصول على اقصى قيم للخصائص الميكانيكية عند كمية مادة لاصقة لليوريا فورمالدهيد ۱٤ % و كثافة اللوح الحبيبى ۰.۷ جم/سم³.

- احدثت معالجه قش الارز بالماء الساخن اداء افضل على الخصائص الميكانيكية للالواح الحبيبية المنتجة فيماعدا معامل المرونه حيث يصل الى اقصى قيمة له عند معالجه قش الارز بهيدروكسيد الصوديوم.

الكلمات الدالة: *الالواح الحبيبية، قش الارز، ساس الكتان، يوريا فورمالدهيد، الخصائص الميكانيكية.*

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