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Correlation of density and properties of particleboard made from polyester resin and date palm waste fibers

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ABSTRACT

The goal of this study is to use date palm wastes (DPWs) and polyester resin as a binder to produce inexpensive particleboards. The DPWs were blended with polyester resin, then hot-pressed at 90°C for 45 min. Particleboards with varying compositions were prepared in order to attain boards with varying densities. The particleboards were tested to certify their physical (e.g. density, moisture content (MC), water absorption (WA) and thickness swelling (TS)) and mechanical properties (e.g. bending strength and impact strength). Furthermore, the correlation of density and the studied properties were investigated. The results showed that the densities ranged from 0.63 to 0.96 g/cm^3. Increasing the amount of polyester resin and lowering the amount of DPWs resulted in an increase in the density. As the density increased, the produced boards' MC, WA, and TS decreased. The MC ranged from 0.2 to 2.9%. After 24 hours of immersion in water, WA ranged from 10.71 to 32.48%, while the TS ranged from 1.02 to 1.09%. The correlation coefficients for the density and MC, WA, and TS were 0.6969, 0.9625, and 0.9823, respectively. This indicates that there is a strong and positive correlation between density and these properties. In contrast to physical properties, the bending and impact strength increased with increasing the density. The bending strength ranged from 0.094 to 0.370 N/mm^2, while the impact strength was increased from 1.726 to 6.496 KJ/m^2. It was found that density and bending and impact strength displayed considerable linear relationship. The correlation coefficients for the densities and bending and impact strength were 0.9936 and 0.9740, respectively. The majority of the physical and mechanical characteristics results were consistent with certain International Standardization for particleboards. However, DPWs have the potential to be a promising industrial feedstock, especially in the field of polymer reinforced composites, replacing virgin wood fiber. Moreover, making particleboards from DPWs might be a useful solution for these wastes and also provide an opportunity to enhance their utilization.

دراسة العلاقة بين كثافة وخصائص الألواح الخشبية المصنوعة من راتنج البوليستر ومخلفات ألياف النخيل

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الكلمات المفتاحية:
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الخصائص الفيزيائية
الخصائص الميكانيكية

الملخص

تهدف هذه الدراسة إلى استخدام مخلفات ألياف نخيل التمر وراتنج البوليستر كمادة رابطة لإنتاج ألواح خشب مضغوطة منخفضة التكلفة. خُلطت مخلفات ألياف النخيل مع البوليستر، ثم كُبست حراريًا عند درجة حرارة 90 درجة مئوية لمدة 45 دقيقة. حُضِّرت الألواح بتركيبات متنوعة للحصول على ألواح بكثافات متفاوتة. خضعت الألواح لعدد من الاختبار للتحقق من خصائصها الفيزيائية (مثل الكثافة، ومحتوى الرطوبة، وامتصاص الماء، والتغير في الابعاد)، والميكانيكية (مثل قوة الانحناء ومقاومة الصدمة). علاوةً على ذلك، تم فحص العلاقة بين الخصائص الفيزيائية والميكانيكية مع الكثافة. أظهرت النتائج أن كثافة الالواح المُنتجة تراوحت بين 0.63 و 0.96 غ/سم^3. أدت زيادة كمية البوليستر وخفض كمية ألياف النخيل إلى زيادة الكثافة. من جهة أخرى، انخفض

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محتوى الرطوبة، وامتصاص الماء، والتغير في السُمك للألواح مع زيادة الكثافة. تراوحت المحتوى الرطوبي للألواح بين 0.2 و 2.9%. بعد 24 ساعة من الغمر في الماء، تراوحت نسبة امتصاص الماء بين 10.71 و 32.48%، بينما تراوح التغير في السمك بين 1.02 و 1.09%. بلغت معاملات الارتباط للكثافة والمحتوى الرطوبي وامتصاص الماء والتغير في الابعاد 0.6969 و 0.9625 و 0.9823 على التوالي. هذا يشير لوجود ارتباط إيجابي وقوي بين الكثافة وهذه الخصائص. على عكس الخصائص الفيزيائية، ازدادت قوة الانحناء ومقاومة الصدمة للألواح مع زيادة الكثافة. تراوحت قيم قوة الانحناء للألواح بين 0.094 و 0.370 نيوتن/مم^2. كما زادت مقاومة الصدمة من 1.726 إلى 6.496 كيلوجول/م^2. كما وجد أن هناك علاقة خطية واضحة بين الكثافة ومقاومة الانحناء ومقاومة الصدمة. فقد بلغت معاملات الارتباط للكثافة ومقاومة الانحناء ومقاومة الصدمات 0.9936 و 0.9740 على التوالي. معظم نتائج الخصائص الفيزيائية والميكانيكية متوافقة مع المعايير الدولية للألواح الخشبية المضغوطة.
الخلاصة: تتمتع مخلفات الياف النخيل بخصائص جيدة تجعلها مادة خام واعدة، لا سيما في مجال البوليمرات المركبة، لتحل محل ألياف الخشب الخام. علاوةً على ذلك، قد يُمثّل تصنيع الألواح الخشبية من مخلفات النخيل حلاً مُجديًا لهذه النفايات، كما يُتيح فرصةً لتعزيز استخدامها.

1. Introduction

Agriculture wastes, such as palm wastes, might be potential alternative raw materials for the wood industry since they come from renewable resources and are readily available [1]. In certain countries, agricultural wastes such as stalks, grasses, leaves, and husks are burnt without any benefit. This is because burning is the simplest and affordable technique to decrease or eliminate the volume of materials produced by agricultural processes [2]. In fact, burning these wastes is not an environmentally sustainable practice. Moreover, agriculture wastes are frequently burnt to generate electricity or utilized as animal feed and natural fertilizer in the fields. Furthermore, some emerging uses include creating biochar, biochemical, and medicinal materials, with an emphasis on extracts from particular agro-waste products for therapeutic purposes. Some wastes have recently been employed in water treatment processes [3]. As a lignocellulosic material, agricultural waste has the potential to be used efficiently in the manufacturing of polymer composites such as particleboards [4]. Date palm fiber (DPF) have gained popularity because to their ease of obtain, low cost, and biodegradability [5].

DPF is a readily accessible natural fiber in North Africa and the Middle East that may be used as a reinforcement in polymers [6-7]. According to various studies [8-9], utilizing DPF as a reinforcing agent improves the strength and stability of structures. According to Perera and Banu [9] DPFs are becoming a popular choice for reinforcing polymeric matrices due to their environmental benefits. According to them date palm fibers reinforced composites (DPFRCs) have been used in three main areas include; building and construction, automotive, and packaging. For all of these, date palm wastes (DPWs) appears to be a promising choice for usage as a reinforcement in the polymer matrix. One of the most important wood based composites is particleboard.

Particleboards are products made from wood particles or lignocellulosic raw materials that are bound together with a polymer resin (binder). The process for producing these boards involves combining dried wood with synthetic resin, then placing the material in a mold and applying pressure and heat. A wide variety of agricultural wastes, including sugarcane bagasse, rice husks, maize stover, peanut shells, wheat straws, and coconut fibers, have been effectively employed as raw materials for the production of particleboards [10]. The only attempt to produce particleboards in Libya is what our team did [11-12], which involved making these boards out of olive stone waste. In these studies, particleboards were successfully created from olive stone by using polyester resin as a binder. The results of these studies showed that the physical, mechanical and biological properties of the produced particleboards are in good agreement with international standard. in fact, to guarantee their quality and performance, particleboards must meet very specific standards. These standards, which specify the requirements for different facets of particleboard manufacturing and usage, are created by entities such as International Organization for Standardization (ISO), national standards bodies and many others.

Therefore, this study's objectives were to investigate the acceptability of using DPWs as a particleboard raw material and evaluate their physical and mechanical properties. One of the goals of this study was also to make sure that the properties of the boards met the standard requirements. Above all, to ascertain the relationship between density and the properties under study.

2. Experimental work

Materials

DPWs were gathered from the city of Sabratha. Mesh fibers from these DPWs were utilized in this study as a raw material for particleboard production, as shown in Fig. 1. Commercial polyester (EKER POLYESTER EK) orthophthalic based polyester was used as a binder. Accelerator agent (cobalt octanone) and hardener (methyl ethyl ketone peroxide MEKP) were used to accelerate the process of binding. these materials were donated from Marble factory, Tajoura – Libya.

Fig. 1: DPWs collected for this study.

Mould manufacturing

The mold used in this study to produce particleboards was designed at Libyan Polymer Research Center and manufacturing at Advance Centre for Technology, Tripoli-Libya. As shown in Fig. 2, the mold made from saint steel with dimensions of 14.6 X 8.6 X 1.9 cm.

Fig. 2: The used mold for particleboard production.

Methods

Treatment of DPWs

DPWs were washed well with distilled warm water and soap first, and then they washed again with distilled. Afterward, they dried at room temperature for more than three days. Finally, the fibers were grounded in small fibers by milling process. The shape of fibers after milling is presented in Fig. 3.

Fig. 3: The final shape of the DPWs used for particleboard production.

Preparation of polyester resin

The resin was prepared with the addition of 4 wt.% accelerator agent to the polyester with stirring. Then 10 wt.% hardener was added to the mixture with stirring as well.

Preparation of particle board

Different mounts of palm fiber were mixed with various amounts of polyester resin, manually in stainless steel container. The mixture after that were transferred into the mould coated with thin layer of Vaseline. Vaseline was used as a releasing agent. The mold was pressed at about 8 tons using clamps for 10 min, then the mold was placed into an oven at 90 ºC for 45 min. The particleboard was removed from the mould to cooled down in dissector. Table 1 demonstrates the compositions and codes of the prepared particleboards.

Table 1: Compositions and codes of the prepared particleboards.

Sample number	Sample code	Polyester resin, %	Palm fiber, %
1	PB1	53	47
2	PB 2	56	44
3	PB 3	59	41
4	PB 4	62	38

Characterization

Physical properties

Density

The densities (D) of the four prepared boards were calculated using the following equation:

$$D = M/V$$

Where, M is the weight of the particle board and V is the volume of the particle board (length × width × depth).

Moisture content

The moisture content (MC) measurements were performed using moisture measuring device (PCE moisture analyzer). Four samples were weighted (for each type of particleboard) (m_1), then dried in an oven at 110 ºC for 2 h. Afterward, the samples weighted again (m_2). The MC was calculated using the following equation: -

MC (%) = $((m_1 - m_2) / m_2) \times 100$

Water Absorption

Three boards (for each type of particleboard) were weighted (w_1) and then immersed in water at room temperature for 24 h. After that, the boards were remove from the water and cleaned in order to remove the excess water. The boards were weighted again (w_2). The water absorption (WA) was calculated by using the following equation: -

WA (%) = $(\frac{W_2 - W_1}{W_1}) \times 100$

Thickness swelling

Thickness swelling (TS) was measured using micrometre with sensitivity of 1µm. The thickness (TS) of three boards (for each type of particleboard) were weighted before immersion in water (t_1). Then they placed in water at room temperature. After 24 h, the thickness (t_2) was measured again. The TS was calculated by using the following equation: -

TS (%) = $(\frac{t_2 - t_1}{t_1})\ x\ 100$

Mechanical properties

Bending strength

Static bending test was performed to determine according to EN310. The samples in Figure 3.9 was labelled in the center. The bending strength of the tested samples was calculated by using the following equation: -

σ = $100\ x\ (\frac{3FL}{2bh^2})$

Where, F is the load (force) at the fracture point (N), L is the length of the support span (mm), b is the sample width (mm) and is the thickness of the sample (mm). Average of minimum three specimens were tested for each particleboard.

Impact strength

The impact strength test was performed using CEAST Resil Imactor tester with impact energy of 15 J. The specimens of impact test were notched according to ASTM (D256-87). All the particleboards were in dimensions of (thickness 4 mm, width 10 mm and length 100 mm). Average of minimum three specimens were tested for each particleboard.

3. Results and discussion

Physical properties

The results of the main physical properties of the produced particleboards are given in Table 2. These boards' physical properties varied depending on their density. One of the most important variables influencing the properties of particleboard and other wood composites is board density; in fact, many of the boards' properties are enhanced by increasing their density [13].

Table 2: The main physical properties of the particleboards.

Sample code	Density, g/cm^3	MC, %	WA after 24h, %	TS after 24h, %
PB1	0.63 ± 0.02	2.90 (0.05)*	32.48 (0.9)*	1.09 (0.01)*
PB 2	0.73 ± 0.02	0.70 (0.06)*	22.76 (0.8)*	1.07 (0.02)*
PB 3	0.81 ± 0.03	0.50 (0.05)*	21.58 (0.5)*	1.06 (0.02)*
PB 4	0.96 ± 0.03	0.20 (0.06)*	10.71 (0.8)*	1.02 (0.01)*

*Standard deviation are given in parentheses

Particleboard density

Density is an important factor effecting the quality and performance of the particleboards. Moreover, it is an important physical parameter for assessing the sustainability of reinforcing properties in composite materials [14]. The shape of the produced particleboard is shown in Fig. 4. The density of the four particleboards prepared is shown in Table 1. It should be declared that decreasing the palm content and increasing the resin content resulted in an increase in the densities of the prepared particleboards. The densities of the prepared particleboard ranged from 0.63 to 0.96%. According to Vinny et al. [15], an increase in the amount of resin led to produce a particleboard with a higher density. The density of particleboard can be influenced by factors such as the filler size and content, binder type and content, manufacturing process, and measuring method [16]. However, higher density particleboards tend to offer superior mechanical and physical properties [17]. For example, as density increases, particleboard's mechanical properties such as strength and stiffness also increase.

Fig. 4: The shape of the produced particleboard.

Moisture content

The moisture content (MC) of the four particleboards prepared in this study is shown in Table 1 and Fig. 5. It important to state that the presence of moisture could be due to existence of cellulosic materials in DPWs. As the binder content increased and the palm content decreased, the MC decreased, according to the results presented in Table 2 and Fig. 5. The MC of the prepared particleboards ranged from 0.2 to 2.9%. These values are in agreement with International Organization for Standardization (ISO 3087) for particleboards [18]. According to ISO standards, the values of moisture content should be in the range of 5-15%. The values of MC for particleboard in European Standards (EN) [19] should be in the range of 5-11%. The standard value of MC for particleboard in Japanese Industrial Standard specifies JIS A 5908 [20] should be between 5 to 13%.

In fact, MC could affect the properties and performance of particleboard. For example, a higher moisture content could affect the board's strength, whereas a lower content can cause irregular bending [18]. In general, MC could be used to determine the board's overall strength and durability. Moisture distribution also affects the board's surface quality and appearance. Moreover, boards with higher density showed to have less MC, as revealed in Table 1 and

Figure 1. Higher resin content tends to reduce the susceptibility of the board to moisture and WA [21]. Higher resin content provides more adhesion between the filling particle with no or low existence of voids. It is important to declare that the MC can be influenced by factors like density, type and content of binder, and surrounding humidity [22].

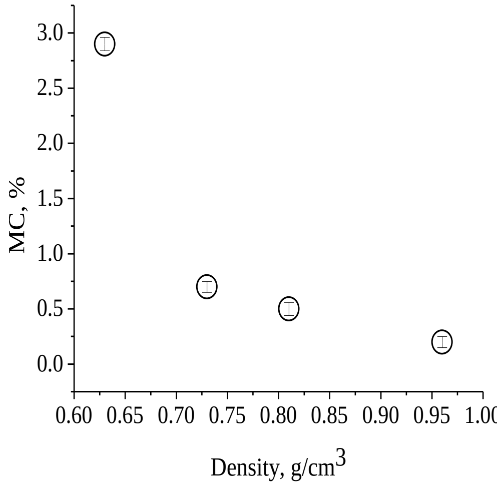


Fig. 5: The variation in MC with density.

Water absorption

Natural fibers such as DPF could easily absorb water due to the presence of cellulosic materials. For this fact, the particleboard's ability to absorb water become the most crucial characteristic [11-12]. This is because water has a highly negative impact on characteristics like bending stiffness and strength. The main obstacle to using lignocellulosic in composite materials is that it is extremely sensitive to water, which affects both its long-term durability and mechanical performance, especially when used outdoors [23]. The water absorption (WA) results of the four prepared particleboards after 24 h immersion in water are illustrated in Table 2 and Fig. 6. As it can be seen in Table 2 and Fig. 6, the WA was decreased with increasing the density and resin content. These findings align with the findings on moisture content. As stated above, a higher resin content generally decreases the board's sensitivity to moisture and WA. Most importantly, several standard specifications for particleboards are met by those results. According to ISO 3087 [18] and EN Standards [19] the maximum value of WA for particleboard is 40% after 24 h immersion in water.

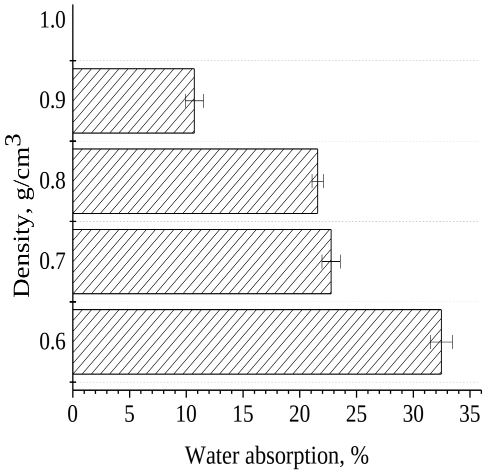


Fig. 6: The variation in WA with density.

Thickness swelling

The thickness swelling (TS) values of the four prepared particleboards are shown in Table 2 and Fig. 7. The TS (dimensional stability) of the boards was evaluated through WA tests. As shown in Table 2 and Fig. 7, the results showed that the TS values of the four boards were decreased with increasing the density. The TS ranged from 1.02% to 1.09% for 24 immersions in water. Since a decrease in WA may induce a decrease in dimensions, these results are in line with the above WA results. The TS of composite materials can be caused by WA, especially when hydrophilic plant fibers are encompassed [24].

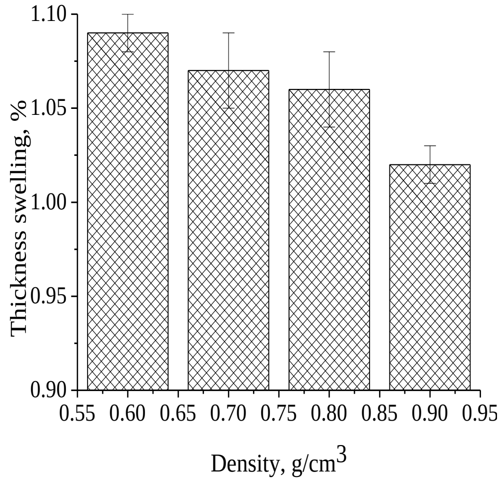


Fig. 7: The variation in TS with density.

All of these particleboards had TS that was deemed sufficient because it was less than what American Natural Standards (ANSI A208.1) [25], ISO 3087 [18], JIS A 5908 [20] and EN Standard (EN 312-2005) [26] specified for particleboards. According to ANSI [25], commercial particleboard shouldn't undergo TS of up to 35% during a 24 h water immersion. Particleboard TS should not exceed 15% for 24 h water immersions, in accordance with EN standards [26]. On the other hand, the TS of particleboard should not exceed 12% according to ISO 2087 [18]. The TS value for particleboard according to JIS A 5908 should be less than 12% [20]. It is evident from Figure 6 that as density increases, TS decreases. However, these findings indicated that a higher particleboard density led to less WA and TS performance. These findings agreed with the reported by Radzi et al. [27]. However, the TS and WA are clearly correlated with the density, presence of voids, and fiber-matrix interface [28].

Correlation of density and physical properties

A correlation made between the density and the above physical properties is presented in Fig. 8. From Fig. 8, it is evident from the correlation that there exists a good linear relationship between the density and the studies physical properties such as MC, WA and TS. The correlation coefficients for the densities and MC, WA, and TS were 0.6969, 0.9625, and 0.9823, respectively. This means that there is a strong and positive relationship between the density and the studied physical properties. The obtained correlation coefficient values indicate that there appears to be a relatively stronger goodness of fit between density and WA and TS than between density and MC.

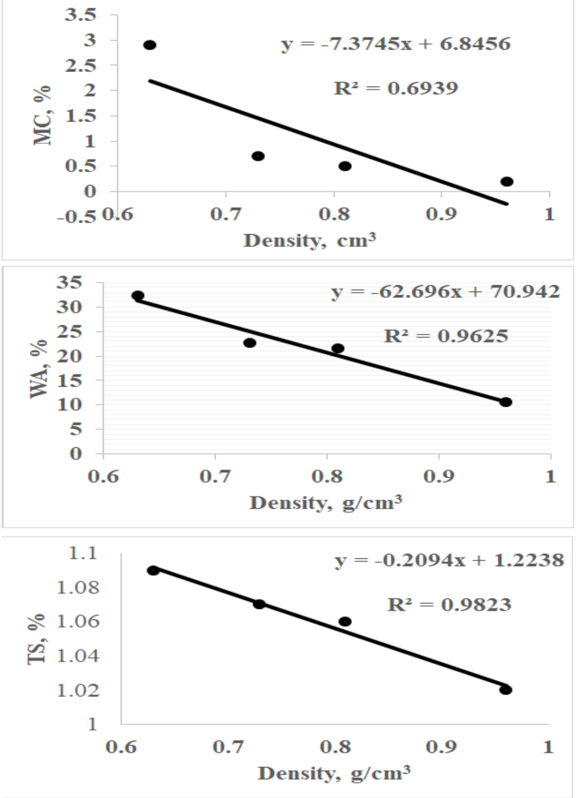


Fig. 8: Correlation of density and the studied physical properties.

Mechanical properties

The results of the studied mechanical properties of the produced particleboards are given in Table 3. Similar to physical properties, mechanical properties of these boards varied according to their densities. As mentioned above, one of the key variables influencing particleboard and other wood composites' properties is board density; in fact, many of the boards' practical properties are enhanced by increasing this component.

Table 3: The studied mechanical properties of the produced particleboards.

Sample code	Density, g/cm³	Bending Strength ,N/mm²	Impact Strength ,KJ/m²
PB1	0.63 ± 0.02	0.094 (0.01)*	1.726 (0.49)*
PB 2	0.73 ± 0.02	0.172 (0.02)*	3.631 (0.69)*
PB 3	0.81 ± 0.03	0.260 (0.01)*	3.993 (0.607)*
PB 4	0.96 ± 0.03	0.370 (0.04)*	6.496 (0.97)*

*Standard deviation are given in parentheses

Bending Strength

Bending strength is the maximum stress an object can withstand before breaking or attaining a particular moment of bending. When using particleboards for furniture or interior design, their bending strength is the most crucial characteristic. For example, office and home furnishings are impacted by both direct and indirect causes. These pressures manifest as tension or compression stress at the furniture's components and joints, leading to deformations such as cracking, bending, or openings [29]. According to the data in Table 3 and Fig. 9, increasing density enhanced the bending strength. The bending strength values for the produced particleboards varied from 0.094 to 0.370 N/mm2 as the density increased from 0.63 to 0.96 g/cm³. The highest bending strength (0.37 N/mm²) was obtained by board with the highest density contained more resin and less palm fiber. Bending resistance varies based on board density, thickness, resin type and binding rate [30-31]. As stated by Hegazy and Ahmed [32], increasing the density of particleboard could improve its mechanical properties, particularly bending strength. The findings of this investigation were comparable to those of Hegazy and Ahmed [32] and Nur et al. [33].

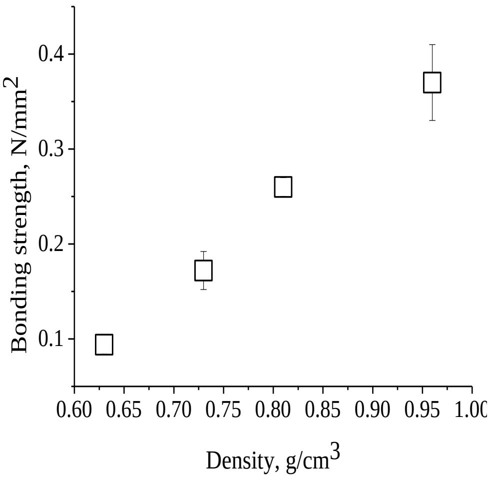


Fig. 9: The variation in bonding strength with density.

Impact Strength

The impact strength results of the produced particleboards with different densities are tabulated in Table 3 and plotted in Fig. 10. The impact strength of these particleboards increased as their density increased. More accurately, as density and resin content increased, impact energy increased as well. Several studies revealed similar findings [34-35]. Moreover, a high impact strength suggests low brittleness [36]. This points out that as density increased, the brittleness of the particleboards produced was considerably reduced. In another context, adding more resin improved the particleboard's bending qualities by reducing brittleness [37]. However, an improvement in impact strength with a higher resin content may be explained by the material's increased elasticity brought on by the decrease of palm fibers, which increases the matrix's deformability [38]. On the other hand, lower resin content results in poor interfacial adhesion between the reinforcement and the resin, which weakens the resistance to crack and reduces impact strength [35].

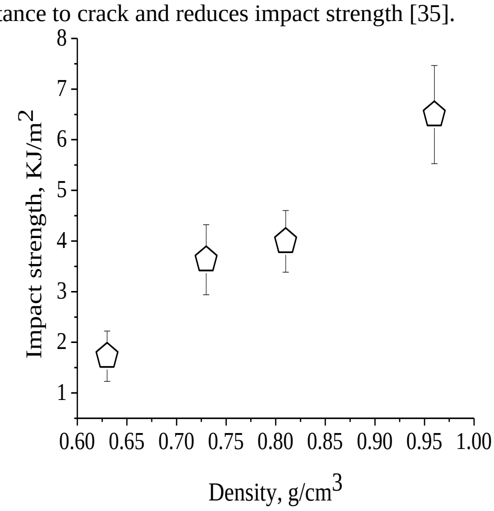
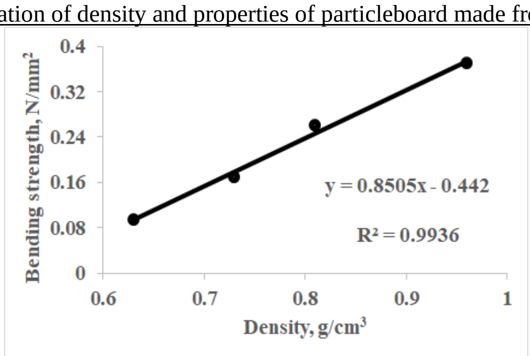


Fig. 10: The variation in impact strength with density.

Correlation of density and mechanical properties

The correlation of density and the studied mechanical properties are potted in Fig. 11.



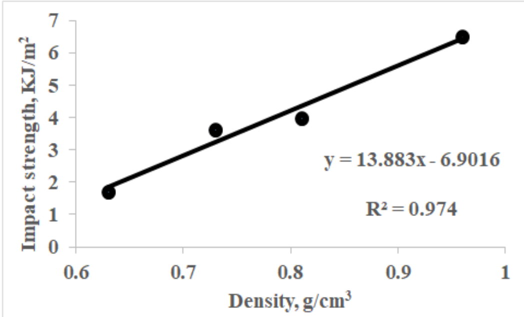


Fig. 11: Correlation of density and the studied mechanical properties.

The density was significantly positive with each studied mechanical properties. Fig. 11 makes it clearly that there is a strong linear relationship among density and mechanical characteristics (bending and impact strength). The correlation coefficients for the densities and bending and impact strength were 0.9936 and 0.9740, respectively. This means that there is a strong and positive relationship between the density and the studies mechanical properties. The obtained correlation coefficient values indicate that there appears to be a relatively stronger goodness of fit between density and mechanical properties like bending and impact strength.

4. Conclusion

This study aims to ascertain the feasibility to produce particleboards from DPWs and polyester resin as a binder and to assess their physical and mechanical properties. This study aims also to correlate the densities of different particleboards to their physical and mechanical properties. The overall results indicated that DPWs could be used to produce affordable and eco-friendly particleboard that satisfies global standards. Particleboards with varying densities were produced by varying the quantity of DPWs and polyester resin. Increasing the amount of polyester resin and lowering the amount of palm water fibers resulted in higher particleboard densities. The densities ranged from 0.63 to 0.96 g/cm^3. The boards' physical and mechanical properties varied depending on their density.

Physical properties such as MC, WA and TS were decreased with increasing the density. The MC of the prepared particleboards ranged from 0.2 to 2.9%. After a 24 h immersion in water, the prepared particleboards' WA varied from 10.71 to 32.48%, while their TS ranged from 1.09 to 1.02%. The results showed that there is a strong and positive relationship between the density and the studied physical properties. The correlation coefficients for the densities and MC, WA, and TS were 0.6969, 0.9625, and 0.9823, respectively.

Mechanical properties like bending and impact strength improved as density increased. With increasing density, the produced particleboards' bending and impact strengths ranged from 0.094 to 0.370 N/mm^2 and 1.726 to 0.6.496 KJ/m^2, respectively. The results demonstrated a strong linear correlation between density and the studied mechanical properties. The correlation coefficients for the density and bending and impact strength were 0.9936 and 0.9740, respectively.

Prospective studies should focus on examining the surface, biological, and other mechanical properties. Furthermore, it is necessary to assess the carpentry work for these boards, such as sawing, drilling, painting, and nailing, in order to determine their durability for use in carpentry. This is because particleboards are a prevalent material in carpentry and building, and understanding their particular features is critical for identifying suitable applications for them. As a result, further study into this kind of particleboards should involve identifying acceptable uses for them. However, the use of DPWs to make particleboards may assist ease material scarcity difficulties in the wood industry while also cutting waste disposal expenses and providing additional financial advantages through the sale of these wastes to the furniture and.

6. Acknowledge

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7. References

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