Cogent Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaen20

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To cite this article: Tabitha Kibet, David, R. Tuigong, Obadiah Maube & Josphat I. Mwasiagi | (2022) Mechanical properties of particleboard made from leather shavings and waste papers, Cogent Engineering, 9:1, 2076350, DOI: 10.1080/23311916.2022.2076350

To link to this article: https://doi.org/10.1080/23311916.2022.2076350

Published online: 29 May 2022.

Kibet et al., *Cogent Engineering* (2022), 9: 2076350
https://doi.org/10.1080/23311916.2022.2076350

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MATERIALS ENGINEERING | RESEARCH ARTICLE

Mechanical properties of particleboard made from leather shavings and waste papers

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Received: 09 February 2022
Accepted: 05 May 2022

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Reviewing editor:
Manoj Gupta, Mechanical Engineering, National University of Singapore, Singapore

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Abstract: The demand for particleboard has been increasing over the years. Currently, most particleboards are produced from wood which may not be sustainable in the long term. Therefore, there is need of exploring alternative materials such as making particleboards from waste materials. This study investigated the mechanical properties of particleboard consisting of waste leather shavings and waste papers blended together by unsaturated polyester. A single-layered particleboards were manufactured using compression method. Different resin contents (60%, 70%, 80%, and 90%) and leather/paper ratios (100:0, 25:75, 50:50, 75:25) were used to determine the effects on the mechanical properties (internal bond, bending strength, compression, and impact strength) of fabricated boards. From the results of this study, it was found that leather shavings and waste papers can be used as alternative raw materials for particleboard production and that mechanical properties were depended on the resin content and the blend ratio. Also, mechanical properties were reduced with resin content increment, except for impact strength, and improved by high paper blend ratio. It could be concluded that the produced particle panels could be used for indoor application or interior equipping. Additionally, it is recommended that further studies can be done on morphological analysis to establish the bonding between the particles and matrix.

ABOUT THE AUTHOR

Tabitha Kibet is a scholar who has successfully finalized her Master of Science degree in Industrial Engineering from Moi University. She holds a Bachelor's degree in Industrial and Textile engineering from the same university. Her research work is about environmental conservation as well as adding value to waste material. Currently, she is pursuing PhD in Industrial Engineering, Moi University, Kenya. The current study is concerned with the issues of waste management, pollution control and value addition. It shows the viability of utilising waste to produce wealth at the same time protecting the environment. It also provide a baseline study for future research.

PUBLIC INTEREST STATEMENT

The demand for slabs has been increasing over the years. Presently, most slabs are produced from wood which may not be sustainable in the long term. Therefore, there is need of exploring alternative materials such as making slabs from waste materials. This study investigated the properties of the slabs consisting of waste materials combined together by a binder. The slabs were manufactured using compression method with different contents of binder and wastes to establish the relation between the properties and raw materials. From the results of this study, it was found that the waste materials can be used as alternative raw materials for slab production and that the properties were dependent on the binder and waste content. It could be concluded that the produced slabs could be used for indoor application or interior equipping, thus contributing to affordable housing agenda. Additionally, the use of these wastes will reduce environmental pollution as well as conservation of natural resources such as wood materials.

Subjects: Environmental Management; Conservation - Environment Studies; Material Science

Keywords: leather shavings; waste papers; unsaturated polyester; particleboards; mechanical properties

1. Introduction

Particleboard is a panel composite developed as an alternative building material whose demand is increasing throughout the world (Batiancela & Acda, 2014; San et al., 2014). For many years, industries have been using traditional wood fibres such as sawmill residues, wood chips, and logs in the manufacture of wood panel products. On the other side, increasing demand for these products as well as depletion of forest resources has led to a shortage of raw material (Nourbakhsh, 2009). Leather solid waste (LSW) can play a major role in providing the balance between supply and demand. Solid wastes from the leather industry are inevitable since leather processing is primarily associated with conversion of a multi-component skin to a single protein, collagen (Ponsubbiah et al., 2018). Globally, leather industry is one of the most polluting industries, which is considered to be responsible for unfavourable impact on environment (Mushahary, 2017). More waste generation is experienced as a result of increase in meat consumption and more production of leather goods and shoes. The other type of waste which is abundant and usually thrown away is paper. The amount of papers thrown in domestic places is high, causing threat to environment (Aksogan et al.,). Thus, pollution to the environment will inevitably occur. How to treat these pollutants is attracting much attention calling for urgent strategies.

According to Mitchual and Mensah (2020), characterisation of particleboards produced from residues of plantain pseudostem, cacao pod and stem, and ceiba were investigated, and the results indicated that the modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength, and hardness of the particleboards produced were satisfactory. However, these particleboards from agro-waste could only be used for indoor application or interior furnishings, under dry conditions due to their water absorption. Properties of particleboard made from recycled polystyrene and cocos nucifera stem particles were studied by Adeniran (2021), and the results revealed that senile coconut stem particle and polystyrene wastes could act as raw materials for particleboard production, and recycled polystyrene can substitute formaldehyde-based resin commonly used in particleboard industries.

In another investigation, Marta et al. (2022) reported enhanced mechanical properties of the particleboard produced from walnut wood residues, and those manufactured with 50% walnut wood residues presented better flexural properties as well as internal bond strength. Suwan et al. (2020) investigated the potential of using waste bamboo together with modified recycled palm oil as adhesive to produce a particleboard. In their study, adhesive content was varied from 15wt% to 60 wt%. From their study, they reported an increase in flexural strength, elastic modulus, and water absorption resistance as the adhesive was increased. The mechanical properties and water absorption resistance of the particleboard were also improved by coating the particleboard with modified recycled palm oil. Several researchers (Hernández et al., 2020; Nurdin et al., 2019; Reinprecht, 2020, 1597; Risnasari et al., 2019) investigated the use of different wastes such as waste tea leaves, fruit waste, recycled wood, and recycled pellets as raw materials for particleboard production, and from all these studies, the results demonstrated the possibilities of making particle panels from these wastes.

In the literature, there are few studies on the treatment of chromium containing wet blue leather wastes through extraction of chromium from wastes for reuse in the tanning process and isolation of protein fractions (Rahaman et al., 2016). As an alternative to this exercise, the thermal treatment of leather waste for energy generation and other useful products through combustion, pyrolysis, and incineration was also reported (Agustini et al., 2018; Priebe et al., 2016; Sethuraman et al., 2013). Transformation of this leather waste into lightweight constructional materials and hierarchical porous carbons was stated by Mushahary and Konikkara, Kennedy, & Vijaya (Konikkara et al., 2016; Ponsubbiah et al., 2018). LSWs were also used by Ponsubbiah et al., Teklay et al., Członka et al., and Moses, Sumathi, and Bright (Cruz et al., 2011; Członka et al., 2018; Nourbakhsh, 2009; Teklay et al., 2018) as precursor for making composite materials for various applications.

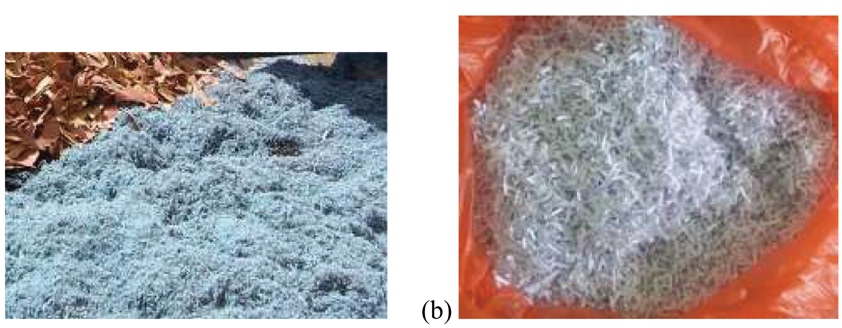
The conventional recycling methods cannot be considered a solution to the waste management process for leather wastes with Cr content in ecological way. The same way by-product of the meat industry becomes the raw material for leather, the by-product of leather industry shall thus become the raw material for board industry. Conversion and utilisation of LSWs by cleaner methods such as making particleboard can reduce the problems of environmental pollution and compliment the challenges of wood sector. Not only this kind of process will demand the low quality thrown away waste, but also it will generate value added products, connecting the way between the leather and board sectors.

The recycling of waste products and its use for production of new products is advantageous from both sustainable and economic point of view. The quantities of waste product originating from leather industries as well as paper wastes represent really large numbers, thus strongly signifying the need for efficient waste management. On the other hand, increasing demand for particleboards as well as depletion of forest resources has led to a shortage of raw materials. Therefore, there is need of exploring alternative materials for making particleboards at the same time proposing new route for solid waste management. Hence, this research was conducted to figure out the fitness of leather shavings and waste papers as raw material for particleboard and also to investigate the effects of resin content and blend ratio on properties of particleboard

2. Materials and methods

2.1. Materials

The raw materials of this study consisted of leather shavings and waste papers (newspapers, office papers), which were collected from Kenya Industrial Research and Development Institute. The leather shavings were air-dried and shredded using a 2 mm mesh network. The particles which went through the sieve were used for the development of the particleboard. The waste papers were also shredded in the same manner as leather wastes. Unsaturated polyester (UP) (viscosity 90–120°C, acid value 22–23 Mg koh/g, purity 98 %, density 1.23 g/cm^3) was used as a resin and methyl ethyl ketone peroxide (MEKP) as a catalyst. These products were sourced from Henkel Chemicals Ltd., Industrial Area, Kenya. Figure 1 shows leather shavings and shredded waste papers.



(a) (b)

Figure 1. (a) Leather shavings. (b) Shredded waste papers.

2.2. Methods

2.2.1. Preparation of leather shavings and waste papers

The leather shavings were collected from Kenya Industrial Research and Development Institute using manual process. The waste were then dried at 80°C in an oven for 1 hour to remove excess moisture (to around 10%) facilitate shaving-resin adhesion. The air-dried leather shavings were shredded using laboratory mill machine model 4 and sieved using a 2 mm mesh. The particles which went through the sieve were used for the development of the particleboard. The waste papers (newspapers, office papers) were also collected from the same institution and prepared in the same manner as the leather wastes.

2.2.2. Particleboard manufacture

A single-layer particleboards measuring 300 mm × 300 mm × 6 mm were fabricated using compression moulding method as described by Cruz et al. (Risnasari et al., 2019) but with some modification. A mould made of mild steel measuring 310 mm × 310 mm was utilised during the board production. The mould was cleaned and the inner surface was covered with aluminium foil to prevent the particleboard from sticking onto the mould. The amount of matrix material used in the particleboard as well as the blend ratio is depicted in Table 1. Production of particleboards at varied blend ratios was done at constant matrix weight fraction of 70%. This percentage was selected since it was in line with what Cruz et al. (2011) used in the production of a composite using polyester resin as a binder.

The resin (UP) was mixed with 2% catalyst (methyl ethyl peroxide) by mass as per Park (2011). Leather shavings and waste papers were weighed using electric balance before manual mixing. The particles were mixed with resin manually and stirred until homogenous mixture was obtained. The mixture was then poured into the mould, spread, covered with the lid, and conveyed to the hydraulic press with a pressing load of 50 kN. The particleboards were left to cure at room temperature for at least 4 hours before removal. After removal, the boards were finally trimmed into shapes (see Figure 2).

Figure 2. Fabrication process of the particleboard.

Table 1. The experiment design for matrix weight fraction and particle blending

Experiment No.	Matrix weight fraction (% wt. /wt.)	Particle blending (leather: paper)
1	60	100/0
2	70	100/0
3	80	100/0
4	90	100/0
5	70	0/100
6	70	25/75
7	70	50/50
8	70	75/25

2.2.3. Evaluation of mechanical properties of the particleboards

Before testing, the particleboards were conditioned for 4 days under ambient conditions (25 ± 2 °C and 65 ± 2% relative humidity). The following properties of the particleboards were determined according to JIS A 5908 (2003) standards: internal bond, MOE, and MOR. Compression property was determined according to ASTM D−1037 standards, while impact strength was carried out in accordance with ASTM D-256 standard. Five replicates were run for each test.

2.2.4. Statistical analysis

Statistical analysis was performed using Minitab software (version 17) at 95% confidence level. The significance of different blend ratios and matrix weight fraction were determined by variance analysis (regression) and least significant difference test ($\alpha \le 0.05$).

3. Results and discussion

3.1. Internal bond strength of particleboard at constant particle blend ratio

Figure 3 shows the graph of internal bond strength of the particleboard sample against its corresponding resin content. Internal bond strength decreases with an increase in resin content from 6.46 MPa (60% resin) to 2.82 MPa (90% resin). In other words, the highest tensile strength corresponded to 40% particle weight fraction. Several studies have shown that tensile strength of a composite is dependent on the weight fraction of the reinforcement and its strength. However, there is a level over which increase in fibre fraction decreases the strength due to poor bonding (Madueke & Bolasodun, 2017; Njoku et al., 2011; Tezara et al., 2016).

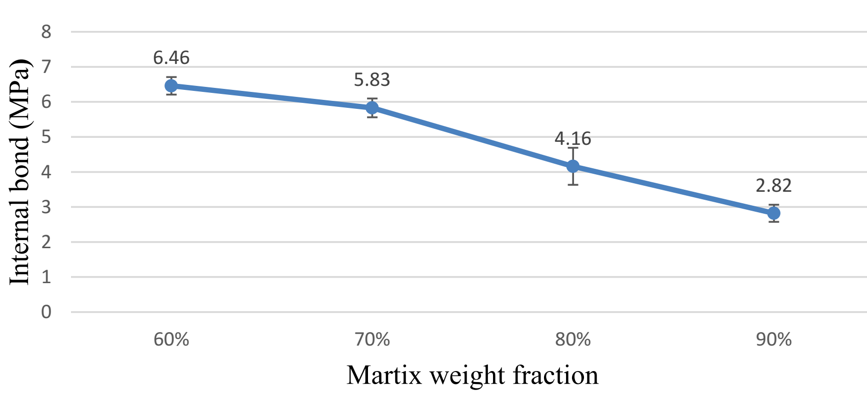


Figure 3. Internal bond strength of particleboard at constant blend ratio of 100% leather with varying resin contents.

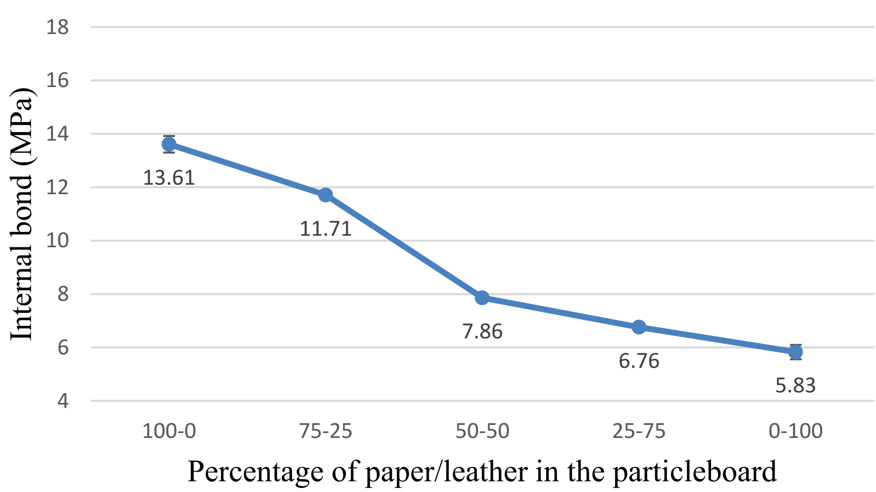
From the literature, the internal bond strength of neat cured polyester is 5.11 MPa (Daramola et al., 2017), but when compared with composite reinforced with particles, the strength decreased (Rodrigues et al., 2011). Similar results were obtained in this study. The decrease in internal bond strength of the particleboard as resin content was increased could be attributed to poor stress transfer between the filler and matrix, poor dispersion of reinforcement in polyester resin matrix, and poor interfacial bond since the particle mass fraction was reduced.

There was significant difference in internal bond strength of the particleboards ($p < 0.05$) as the resin content was increased. This means that resin increment had effects on internal bond strength.

3.2. Internal bond strength of particleboard at constant matrix weight fraction

The results of internal bond strength against blend ratio of waste paper to leather (see Figure 4) indicated that 100% waste papers had the highest strength (13.61 MPa) and 100% leather wastes had the lowest (5.83 MPa). The reason behind these values could be due to good bonding with the resin where waste papers bonded well with polyester resin compared to the leather shavings. From raw material values, the moisture content of waste papers was much lower than those of leather shavings; thus, this could also have contributed to poor bonding in the case of leather wastes. This is in agreement with a study by Daramola et al. (2017). When paper was mixed with leather shavings, 75:25 paper to leather ratio exhibited the highest tensile strength and could be attributed to high bonding sites with the polyester resin as leather particles were in low levels.

Figure 4. Internal bond strength of particleboard at constant matrix weight fraction of 70% with varying blend ratio.



From the analysis, the p-value of 0.007 was obtained which is lower than 0.05, thus suggesting significant impact on the particleboards.

3.3. MOR and MOE of particleboard at constant blend ratio

The outcome of MOR (bending strength) and MOE with resin content is displayed in Figure 5. The maximum bending strength (14.31 MPa) of the particleboard was at 60 wt% resin content after which it continually dropped because of a decrease in particle mass concentration. This is in agreement with Shamszadeh et al. (2013) who mentioned that reinforcement quantity is the main cause of dissimilar flexural strengths in composites. The composites with higher particle weight fraction showed higher flexural strength.

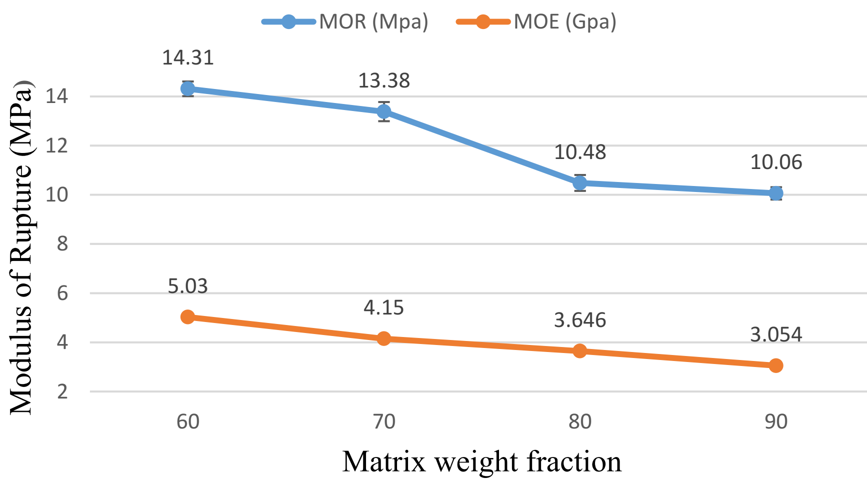


Figure 5. MOR and MOE of particleboard at constant blend ratio of 100% leather and varying matrix weight fraction.

In a study by Madueke and Bolasodun (2017), the maximum bending strength was noted at 20 wt% reinforcement concentration, and the reduction of this strength was caused by controlled mobility of matrix by the particles. Also according to Al-mosawi et al. (2014) and Durowaye et al. (2014), the flexural strength increased with increased fibre addition until a maximum level where further increase caused reduction in bending strengths. The flexural properties of composites depend mainly on the interfacial bonding and microstructure between the matrix and reinforcement. The decrease in flexural strength in this study could be attributed to the fact that there was a reduction in the total surface area available for matrix–filler interaction, leading to a poor load transfer between the matrix and the reinforcement. As the resin content was added, the number of particles responsible for load bearing was reduced thus causing a reduction in flexural strength.

From the graph, the MOE decreased with increase in resin content. Factors which affected the flexural strength also affected the flexural modulus in the same manner since flexural modulus is a function of flexural strength (Durowaye et al., 2014). Therefore, as the resin content was increased from 60 wt% to 90 wt%, the flexural modulus was reduced from 5.03 GPa to 3.054 GPa. Increase in resin content could have created defects due to an incomplete cure of the matrix and void (places unfilled by matrix and particles) reducing restraint strength, thus leading to lower MOE (Nurul et al., 2019).

Analysis of variance for MOR and MOE of particleboards manufactured from leather shavings at varying matrix weight fraction showed significant difference ($p < 0.05$). The null hypothesis was thus rejected and other alternatives were accepted.

3.4. MOR and MOE of particleboard at constant matrix weight fraction

Figure 6 shows the values of MOR (bending strength) and MOE of particleboard against the mixing ratio of the particles. The highest value (20.11 MPa) of MOR was at 100 wt% waste papers, while the lowest value (11.44 MPa) was at 50 wt% waste papers. The high value of bending strength at 100 wt% waste papers could be explained by the reason that good bonding between the particles and polyester resin was experienced. The fact that the waste papers had lower moisture could have contributed to less trap voids in the board resulting into greater adhesion. At 50 wt% level, there was poor bonding between the two types of particles and polyester resin resulting into lower bending strength. The increase in strength at 25 wt% waste paper content could be due to good bonding compared to the 50 wt% ratio.

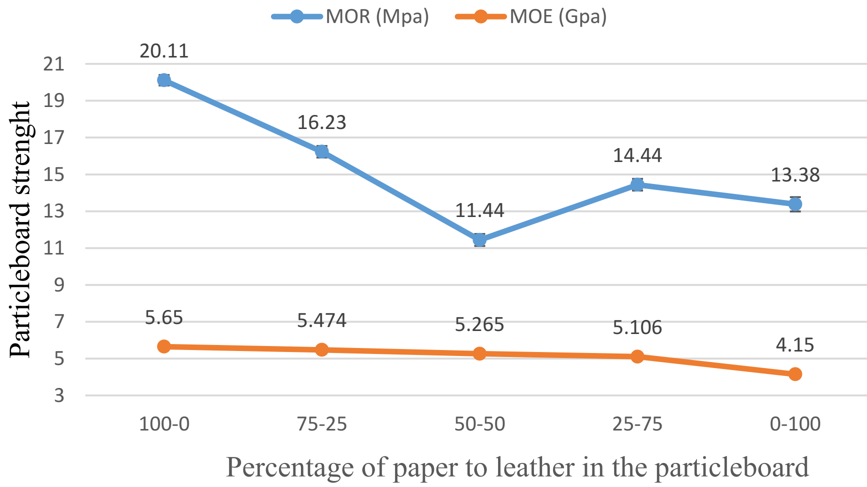


Figure 6. MOR and MOE of particleboard at constant matrix weight fraction of 70% and varying blend ratio.

On the case of bending modulus, the particleboard made up of 100% paper had maximum bending modulus of 5.65 GPa, while at 100 wt% leather ratio, the modulus value was minimum at 4.150 GPa. 100 wt% waste paper had a high value, and this could be due to good adhesion between the resin and particles. Since waste papers had lower moisture content, less moisture could have been trapped during pressing resulting in a strong particleboard (Nurul et al., 2019). The low modulus value at 100% leather could be due to low density and high moisture content since low density causes reduction in MOE (Mehdi & Maraghi, 2018). Similar results were obtained by Wieland et al. (2020) in assessment of mechanical properties of wood-leather panel.

There was no significant difference in MOR of particleboards ($p > 0.05$) as blend ratio was varied. This could be due to errors in measuring and testing. On the case of MOE, there was significant difference as blend ratio was varied.

3.5. Compressive strength of particleboard at constant particle blend ratio

The compressive strength of fabricated particleboard with change in resin content is displayed in Figure 7, and from the graph, the compressive strength decreases with increase in resin content up to 80% resin content where it starts to rise again. 60% resin content had compressive strength of 18.57 MPa, while that of 90% had 13.41 MPa.

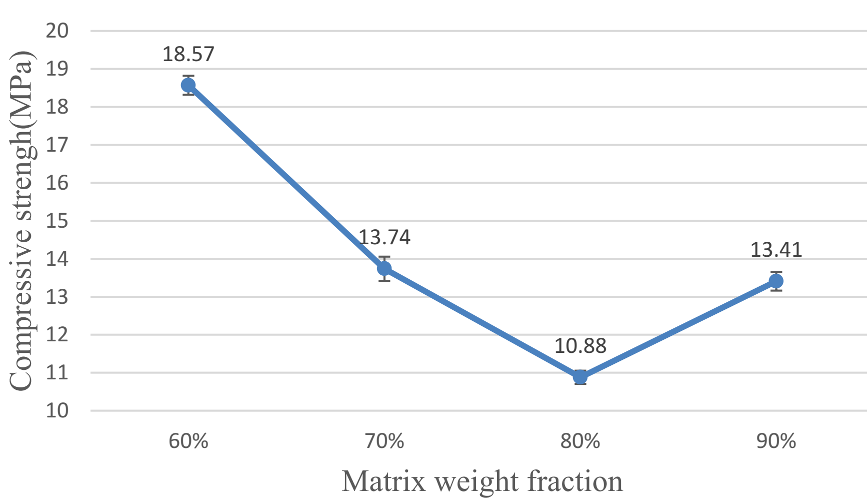


Figure 7. Compressive strength of particleboard at constant blend ratio of 100% leather with varying resin contents.

According to Wu et al. (2018), the reinforcement and resin in the composite assume the force when subjected to a compressive loading; thus, this strength is determined by both reinforcement and the matrix. The most common failure mode under compressive force in a composite is kinking of load-bearing reinforcement. This kinking mode involves buckling of fibres over a small region causing instability and fibre fracture. The instability which is created by voids and resin-rich regions will provide insufficient restraint to fibres under compression loading (Limited, 2012).

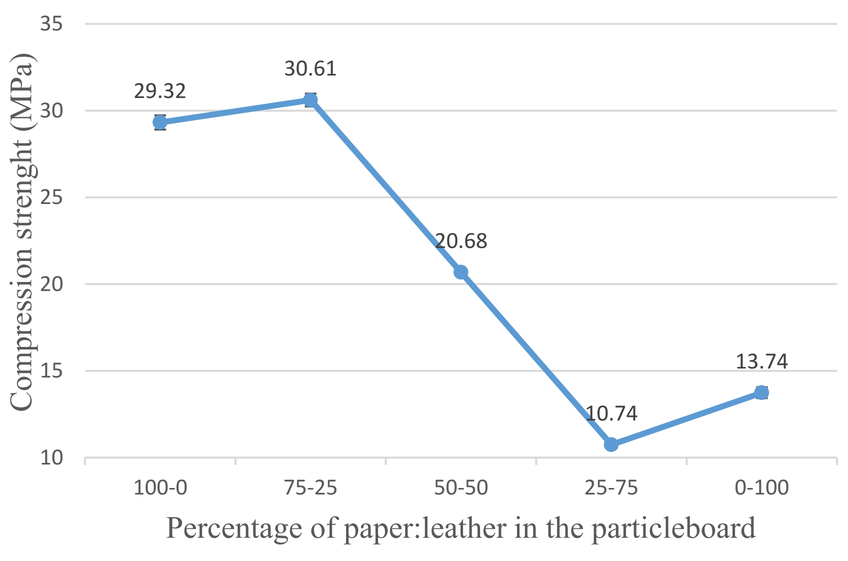
The decrease in compressive strength with decrease in resin content could be attributed to an unfavourable deformation process aided by filler reduction in the matrix (Bhagyashekar, 2014). In addition, the fact that in the compressive test, any crack or flaws introduced by dispersion of particles will be closed and made ineffective resulted in this trend. Therefore, 60% resin content had the highest value because of higher particle content, which provided sufficient restraint to compressive loading. Increase in compressive strength at 90% resin content could be due to errors during manufacturing and measurement processes.

Analysis of variance showed that there was insignificant difference in compressive strength as matrix weight fraction was varied. This could be due to systematic and random errors during measurements.

3.6. Compressive strength of particleboard at constant matrix weight fraction

Figure 8 shows the compressive strength of the particleboard against the paper-leather blend ratio. It can be observed that the compressive strength of 75:25 untreated paper to leather waste (30.61 MPa) was the highest, while 25:75 ratio was the lowest (10.71 MPa). The high values in 75:25 blend ratios could be due to crack deflection by the particles thus providing great restraint to compressive loading, hence resulting in higher values. On the other hand, combining 25% waste paper and 75% leather waste could have resulted in the creation of voids and instability in the composite thus lower restraint to particles during loading, hence, low compressive strength values (Limited, 2012).

Figure 8. Compressive strength of particleboard at constant matrix fraction of 70% with varying particle blend ratios.



In this study, statistical analysis indicated significant difference ($p < 0.05$). As the blend ratio was varied, there was changes in the compression strength.

3.7. Impact strength of particleboard at constant particle blend ratio

The amount of energy that the fabricated sample absorbed before fracture is shown in Figure 9. It was observed that the particleboard absorbed maximum energy at 80 wt% resin content (64 kJ/m^2) and minimum energy at 60 wt% resin content (48.33 kJ/m^2). There was an increase in impact energy as resin content was increased up to 80 wt%. Similar results were obtained by Madueke & Bolasodun (2017) and Durowaye et al. (2014) where impact strength was reduced by high reinforcement content. Increase in impact strength with increase resin content could be attributed to addition of elasticity of the material due to particle reduction increasing deformability of the matrix. The matrix was able to absorb energy thereby increasing the toughness and hence impact strength increased.

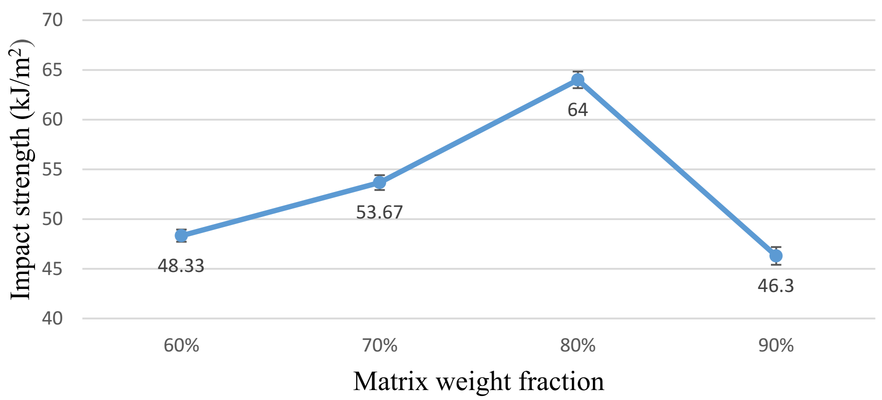


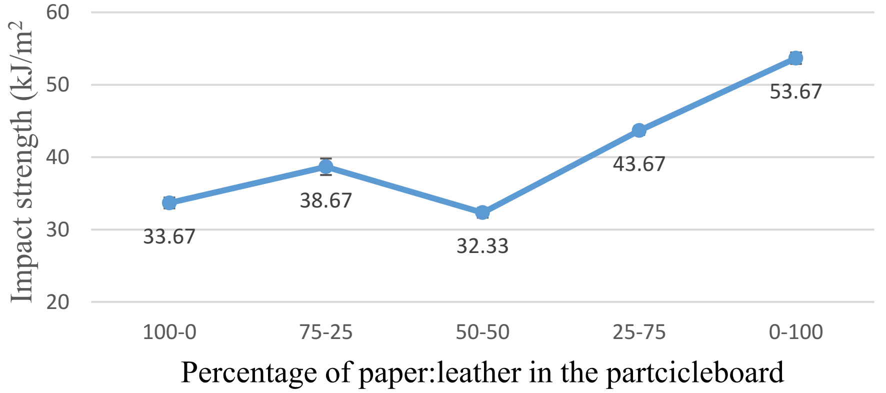
Figure 9. Impact strength of particleboard at constant blend ratio of 100% leather with varying resin content.

At lower resin content, there is poor interfacial adhesion between the polymer matrix and the reinforcement, and this would cause occurrence of micro-cracks at impact point thus decreasing the impact strength. The reinforcement will not be able to block the propagation of cracks leading to lower impact strength (Durowaye et al., 2014). Analysis of variance showed that there was no significant difference in impact strength when resin content was varied, and this could be due to errors during measurements.

3.8. Impact strength of particleboard at constant matrix weight fraction

The impact strength of particleboard against blend ratio of raw materials is illustrated in Figure 10. 100 wt% leather waste had the highest impact strength, while 50 wt% leather had the lowest impact value. Maximum impact strength in leather particleboard could be explained by the fact that leather fibres promoted deformation and ductile mobility of polyester molecules, which increased the capability of composites to absorb energy during crack propagation. When the ratio was reduced to 50–50 ductile mobility of the polymer, energy absorption during crack propagation was reduced (Durowaye et al., 2014). Analysis of variance shows that there was no significant difference in impact strength of particleboards produced from varying blend ratios of leather and paper. The p-value of 0.075 was obtained which was higher than the α-value. Systematic and random errors could have occurred during measurements resulting in the observed output.

Figure 10. Impact strength of particleboard at constant matrix fraction of 70% with varying particle blend ratio.



4. Conclusions

The current study investigated the effects of matrix weight fraction and blend ratio on the properties of leather shavings/waste papers particleboard bonded together with polyester resin. Based on the results obtained from this study, the use of leather shavings was proved as promising raw material for production of particleboard either alone or in combination with waste papers using polyester resin as a binder. UP resin of 60 wt% and higher amount of waste paper in the blend showed the highest resistance before failure by bending, tensile loading, and compression. Therefore, mechanical properties of the board were decreased by increase in resin content exception of impact strength. Since the properties of leather and paper are different, it is recommended that one type of waste is to be used a time and not by mixing. However, the best matrix weight fraction that can be adopted is 60 wt% for both the leather shavings and waste papers. Research on possibility of modifying the particles is to be done in order to investigate the effects on board's properties. In addition, it is recommended that further studies can be done on morphological analysis to establish the bonding between the particles and matrix.

Abbreviation

UP: Unsaturated Polyester
IB: Internal Bond
MOR: Modulus of Rupture
MOE: Modulus of Elasticity
ASTM: American Society for Testing and Materials
JIS: Japanese Industrial Standards
wt%: Weight percentage.
GPa: Gigapascals (10^9 Pascals)
MPa: Megapascals (10^6 Pascals)

Acknowledgements

The authors would like acknowledge the staff of Moi University, Kenya; Multimedia University, Kenya; and Kenya Industrial Research and Development Institute for their technical support throughout this research. Tabitha is indebted to Africa Centre of Excellence II in Phytochemicals, Textiles and Renewable Energy (ACE II PTRE), Moi University, Kenya, for the scholarship awarded to her which led to this announcement. The authors would also like to thank Alvin, Department of leather, KIRDI, and Musyoki, Multimedia University, for their assistance in the laboratory services. Financial support in this project was awarded by Africa Centre of Excellence II in Phytochemicals, and Renewable Energy (ACE II PTRE), Moi University (Credit no. 5798-KE).

Funding

This work was supported by the ACE II PTRE [Credit no. 5798-KE].

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Disclosure statement

The funders of this research did not participate in the experimental design, collection of data, nor direct influence on the decision to publish this work.

Data availability statement

The data arrangements supporting the conclusions of this article are included within the article).

Citation information

Cite this article as: Mechanical properties of particleboard made from leather shavings and waste papers, Tabitha Kibet, David, R. Tuigong, Obadiah Maube & Josphat I. Mwasiagi, *Cogent Engineering* (2022), 9: 2076350.

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Cogent Engineering **(ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.**