Bending strength analysis of HDPE plastic reinforced wood waste and thermoplastic polymer to replace ceramic tile composites

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Abstract. Commercial products made from plastics, papers, and various other materials are always in high demand in this day and age. The waste products also increase with time accumulating becomes very high that it impacts the environment. Recycling waste products can reduce waste and improve the development of manufacturing products as the materials are readily available as waste especially plastic waste. This project research presents bending strength analysis of HDPE plastic waste reinforced wood waste and thermoplastic polymer. The waste materials of HDPE plastic waste and wood waste potential to replace ceramic tile composites. Four samples were prepared to produce ceramic tile samples at different composition ratio of HDPE plastic waste: 1.0, 2.0, 3.0, 4.0 weight by weight (wt/wt%) reinforced composition ratio of wood waste at 2.0 (wt/wt%) and thermoplastic polymer. It is revealed the higher bending strength test for composition ratio of 3.0 HPDE plastic waste produce 8.28 MPa with the density at 0.83 g/cm³ and a porosity value of 0.05%. The image microstructure by using Optical Microscope (OM) analysis shows the 10x magnification of matrix reinforcement bonding between HDPE plastic waste reinforced wood waste and thermoplastic polymer has a good matrix-reinforcement bonding and suitable to replace ceramic tile applications.

1. Introduction

The need for recycled products such as plastics, papers, metals, and alternative materials will rise as a result of their diverse applications, particularly in the corporate world. In 2007, world production of plastics rises to approximately 260 million tonnes. In Europe, this resulted in the generation of 24.6 million tonnes of post-consumer plastics waste concentrated in the packaging, construction, automotive and electrical and electronic equipment sectors [1]. Half of this waste was disposed of in landfills, whilst 20% was recycled and 30% was recovered as energy [2]. The growth of the Indian plastic industry has been phenomenal equal to 17% is higher than for the plastic industry elsewhere in the world [3]. India has a plastic consumption of 3.2 million tonnes during 2000 and is expected to reach nearly 12.5 million tonnes by 2010. It is revealed India will be the third-largest plastics consumer by 2010 after the United State of America (USA) and China [4]. The reason for the highest growth rate in
the last few years in India is due to one-third of the population is destitute and may not have the disposable income to consume much in the way of plastics or other goods. The virgin industry does not target this population to expand its markets [5].

A current application for plastic waste and wood waste industries and polymers, that has been gaining ground within the international market, is its use as reinforcement within the manufacture of composites that are fabricated from a compound section. Wood waste is suitable for composite materials and as the alternative within the matrix and reinforcing section, typically within the kind of fibers [6]. The composites can be used as a bulk material to replace for structural applications such as partition, ceramic tile, flooring vinyl and others. Ceramic tiles are composed of natural materials like clay, feldspar, and quartz. However, contain toxic additive in their pigments, frits and glazes. Historically, one major health concern has been the use of heavy metals such as lead in glazes [7]. According to Becerril-Arreola et al. (2021) is very important to test the positive matrix such as fiber protection, enhanced cross section besides rising the impact resistance and failures [8]. Gupta et al. (2021), the utilization of fiber-matrix combination additional aims to cut back the price of the reinforcements used, it's important that the fiber-matrix composite exhibit appropriate mechanical properties and sensible compatibility with alternative materials [9].

A composite material is made by combining two or more materials often ones that have very different properties. The two materials work together to give the composite unique properties [10]. However, within the composite can easily investigate the different materials apart as do not dissolve or blend into each other [11]. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibers or fragments of the other material, which is called the reinforcement [12]. Basically, these materials are good physical and mechanical properties include it can be lighter and stronger than single materials [13]. Therefore, this project research highlight HDPE plastic waste reinforced wood waste and thermoplastic polymer to replace ceramic tile composites due to adequate bending strength properties and achieved characteristic in density, porosity and microstructure bonding between HDPE plastic waste, wood waste and thermoplastic polymer. The use of waste materials also will improve the sustainability of the environment.

2. Methodology

2.1. The preparation of samples

The preparation of samples of raw materials was involved different composition ratio of HDPE plastic waste reinforced wood waste and thermoplastic polymer to replace ceramic tile. The different composition ratio of HDPE plastic waste is tabulated in Table 1. The selection of composition ratio is referring recent studies of municipal plastic and wood waste. In the study, they use of thermoplastic polymer and wood waste remain 2.0 (wt/wt%) and 3.0 (wt/wt%), respectively [14]. There are three main process including chopping process, mixing process and curing process. The HDPE plastic waste and wood waste were chopped into small particles sizes of 0.5 – 0.1 mm by using grinder machine. The raw materials are measure the weight using Mettler Toledo electronic precision balance. The final mixture was completely mixed until raw material became viscous.

| Samples | HDPE plastic waste (wt/wt%) | Wood waste (wt/wt%) | Thermoplastic polymer (wt/wt%) |
|---------|-----------------------------|---------------------|-------------------------------|
| A       | 1.0                         | 2.0                 | 3.0                           |
| B       | 2.0                         | 2.0                 | 3.0                           |
| C       | 3.0                         | 2.0                 | 3.0                           |
| D       | 4.0                         | 2.0                 | 3.0                           |
2.2 The curing process

For curing process, the final mixture was distributed over the mould for bending strength test, density and porosity test. The mould of bending strength test has dimensions of 20 mm in width, 100 mm in height and 5 mm in thickness is designed in accordance with ASTM Standard ASTM D7264 - Standard Test for Bending Properties of Polymer Matrix Composite Materials. Next, the final mixture was post-curing process to replace ceramic tile samples for 24 hours in room temperature of 27°C ± 0.5. Figure 1 shows the sample of ceramic tile based on different composition ratio of HDPE plastic waste reinforced wood waste and thermoplastic polymer.

![Figure 1](image)

**Figure 1.** The different ratio of HDPE plastic waste reinforced wood waste and thermoplastic polymer to preplace ceramic tile; (a) 1.0; (b) 2.0; (c) 3.0 and (d) 4.0 (wt/wt%)

3. Results and discussions

3.1. Bending strength test

Figure 2 depicts the bending strength test study of different composition ratio HDPE plastic waste reinforced wood waste and thermoplastic polymer to replace ceramic tile. It is clearly demonstrated that a composition ratio of 3.0 HDPE plastic waste can withstand a higher maximum bending strength test with a value at 8.28 MPa, followed by the composition ratio of 4.0 HDPE plastic waste at 4.75 MPa, then the composition ratio of 2.0 HDPE plastic waste at 3.65 MPa and lastly, the composition ratio of 1.0 HDPE plastic waste at 3.16 MPa. It is found that the bending strength test was increased incredibly with increasing HDPE plastic waste up to composition ratio of 3.0, however the bending strength dropped from 8.28 kN to 4.75 MPa at the composition ratio of 4.0 HDPE plastic waste.

![Figure 2](image)

**Figure 2.** Bending strength results at different ratio of HDPE plastic waste reinforced wood waste and thermoplastic polymer for replace ceramic tile samples.
It is also support finding from force analysis which is the trend is same as shown in Figure 3. Significant decrease in the bending strength value from 3.0 HDPE plastic waste to 4.0 HDPE plastic waste may be a results of lower bond strength between thermoplastic polymer and wood waste due to higher composition of HDPE plastic waste. An additional ratio in the composition of HDPE plastic waste may increase the porosity of material which also negatively affects its bending strength [15]. Another possible reason of the higher bending strength of composition ratio 3.0 HDPE plastic waste might be related to the formation of strong bonds between thermoplastic polymer and wood waste. It can be proved with the similar results have been studied the development of a composite material based on wood waste stabilized with recycled expanded polystyrene [16]. The mechanical behaviour of HDPE plastic waste reinforced wood waste and thermoplastic polymer influenced by the uniformity of lignocellulosic materials dispersed in the polymeric matrix and surface area increases with increasing particle size. As a result, less energy is required to break a specimen containing larger particles. Also, bigger particles can create bigger flaws in the composites contrary to smaller flaws created by smaller particles, thus reducing composite strength [17].

![Figure 3](image3.png)

**Figure 3.** Force vs time results at different ratio of HDPE plastic waste reinforced wood waste and thermoplastic polymer for replace ceramic tile samples.

### 3.2. Density and porosity test

The results of density study are shown in Figure 4. The bar chart shows the rate of density decreases with the increases of composition ratio of HDPE plastic waste. The highest value of density is 1.09 g/cm³ for composition ratio of 1.0 HDPE plastic waste followed by 2.0 HDPE plastic waste at 0.94 g/cm³. Next, the composition ratio of 3.0 HDPE plastic waste is 0.83 g/cm³ and the lowest value of density is 0.75 g/cm³ with the composition ratio of 4.0 HDPE plastic waste. It is observed that the results of porosity show the opposite trend in Figure 5. The rate of porosity increases with the increases of composition ratio of HDPE plastic waste. The highest value of porosity is 0.37% for composition of 4.0 HDPE plastic waste followed by 3.0 HDPE plastic waste at porosity of 0.22%. Then, the composition ratio of 2.0 HDPE plastic waste is 0.15% and lastly the lowest value of porosity is 0.1% for 1.0 HDPE plastic waste. It can be concluded that the higher composition ratio of HDPE plastic waste produces lower density and higher porosity.

This is may be due significant amounts water cannot entrap inside those empty spaces and generally the present of higher HDPE plastic waste are non-porous materials. It is observed that the presence of higher HDPE plastic waste reinforced wood waste and thermoplastic reduces the density, hence makes it lightweight [18]. Krauklis et. al. (2021) stated this significant increase in porosity is due to the presence of fiber reinforced which caused creation of fiber–matrix interfacial areas and thus the concomitant formation of voids in the sample [19]. Balas et. al. (2020) stated the increase in porosity with rising fiber content tended to make fibers clumping together during mixing, which resulted in entrapped of water-filled spaces that subsequently turned into voids [20]. This result is obtained from
the method uses the Archimedes principle to calculate the samples actual density, and then by using the theoretical density of the sample with no voids present, the void volume fraction or apparent porosity can be calculated. This technique however relies on accurate knowledge of the fiber and matrix density and weight fraction values of the specimen, hence it might not so accurate. The size of particle diameter also offers more surface area of contact that affect the density and porosity of the samples of different composition ratio of HDPE plastic waste reinforced wood waste and thermoplastic polymer [21].

![Figure 4. The density results of different ratio HDPE plastic waste reinforced wood waste and thermoplastic polymer](image1)

Figure 4. The density results of different ratio HDPE plastic waste reinforced wood waste and thermoplastic polymer

![Figure 5. The porosity results of different ratio HDPE plastic waste reinforced wood waste and thermoplastic polymer](image2)

Figure 5. The porosity results of different ratio HDPE plastic waste reinforced wood waste and thermoplastic polymer

4. Conclusion

In conclusion, the composition ratio of 3.0 HDPE plastic waste reinforced wood waste and thermoplastic polymer in term of the higher value of bending strength at 8.28 MPa is adequate to be used to replace ceramic tile. It is also revealed the optimum porosity dan density value at 0.83 g/cm³ and porosity of 0.22% demonstrated the material is lightweight. The important of the study to produce new composition ratio from waste material to produce bio-products in this research is to replace ceramic tile. This may help the government and industry to reduce environmental pollution caused by land filling, incineration and haphazard littering in the world. It also can increase the level of economic which turn waste into added value product and promote zero waste concept.

5. References

[1] Zhao, C., Liu, M., Du, H. & Gong, Y. (2021) The evolutionary trend and impact of global plastic waste trade network. *Sustainability MDPI* vol.13(3662), pp 1-19.
[2] Metteb, Z.W., Abdalla, F.A. & Ehsan S.A. (2020) Mechanical properties of recycled plastic waste with polyester. *AIP Conference Proceedings*, vol.2213(1), pp 1-7.
[3] Fodzi, M.H.M., Marsi, N., Rus A.Z.M., Hassan, N.N.M., Mahmood, S., Hazaisham, N.A. & Singam R.T. (2020) Izod impact behaviour of polymer composite solid waste disposal with epoxy-matrix. *Test Engineering and Management*, vol.81, pp.607-612.
[4] Zaman, A. & Newman, P. (2021) Plastics: are they part of the zero-waste agenda or the toxic-waste agenda? *Sustainable Earth*, vol.4(4), pp 1-16.
[5] Atmakuri, A., Palevicius, A., Vilkaskas, A. & Janusas, G. (2020) Review of hybrid-based composites with nano particles – material properties and applications. *Polymer MDPI*, vol.12(9) pp 1–30.
[6] Ugochukwu S., Ridzuan, M.J.M., Abdul Majid, M.S., Cheng E.M., Razlan, Z.M. and Marsi, N. (2021) Effect of thermal ageing on scratch resistance of natural-fibre-reinforced epoxy composites *Composites Structure*, vol.261, pp 1-20.
[7] Kesikisaari, A. & Karki, T. (2018) The use of waste materials in wood-plastic composites and their impact on the profitability of the product *Resources, Conservation and Recycling*, vol.134 pp 257-261.
[8] Becerril-Arreola, R. & Bucklin, R.E. (2021) Beverage bottle capacity, packaging efficiency, and the potential for plastic waste reduction Scientific Reports, vol.11(3542), pp 1-11.
[9] Gupta, A., Misra, M. & Mohanty, A.K. (2021) Novel sustainable materials from waste plastics: compatibilized blend from discarded bale wrap & plastic bottles RSC Advances, vol.15, pp 1-7.
[10] Kassim, N., Marsi, N., Johari, N.M. & Fodzi M.H.M. (2020) The characterization of HDPE plastic waste producing polyurethane foams (PUFs) International Journal of Emerging Trends in Engineering Research, vol.8(19), pp 139-144.
[11] Qinxin, X., Chaoji, C., Yonggang, Y., Jianguo, L., Shuaiming, H., Yubing, Z., Teng, L., Xuejun, P., Yuan, Y., & Lianghing, H (2021). A strong, biodegradable and recyclable lignocellulosic bioplastic Nature Sustainability, vol.1, pp.1-10.
[12] Cresnar, K.P., Zemljic, I.F., Perse, L.S. & Bek, M (2020) Effect of wood fiber loading on the chemical and thermo-rheological properties of unrecycled and recycled wood-polymer composites. Applied Sciences MDPI, vol 10(8863), pp 1-17.
[13] Pizzi, A., Papadopoulos, A.N. & Policardi, F. (2020) Wood composites and their polymer binders Polymers MDPI, vol 12(5), pp 1-27.
[14] Basalp, D., Tihminlioglu, F., Sofuoglu, S.C., Inal, F. & Sofuoglu, A. (2020). Utilization of municipal plastic and wood waste in industrial manufacturing of wood plastic composites. Waste and Biomass Valorization. Springer, vol.11, pp.5419-5430.
[15] Marsi, N., Subramaniam, L., Rus, A.Z.M., Sulong, N., Fodzi, M.H.M., Huaizhimi, N.A., Yusuf,N.A.A.N., Mahmood, S., Shaari, M.F. & Shariff, H.H. (2020) The mechanical performance of pipe base on fiberglass reinforced with plastic waste (FRPW) IOP Conference Series: Materials Science and Eng. vol 854(1), pp 1-7.
[16] Kaho, S.P., Kaouadida, K.C., Kouakou, C.H. & Emeruwa, E. (2020) Development of a composite material based on wood waste stabilized with recycled expanded polyethylene. Open Journal of Composite Materials, Scientific Research An Academic Publisher, vol.10, pp 66-67.
[17] Hubbe, M.A. & Grigsby, W. (2020) From nanocellulose to wood particles: A review on particle size vs. the properties of plastic composites reinforced with cellulose-based entities. BioResources, vol.15(1),pp 2030-2081.
[18] Amer, A.A.R., Abdulliah, M.M.A.B., Ming, L.Y. & Tahir, M.F.M. (2018) Performance and properties of glass fiber and its utilization in concrete – a review. AIP Conference Proceedings, vol.2030 pp 1-6.
[19] Alzomor, A., Rus, A.Z.M., Wahab, H.A., Salim, N.S.M., Marsi, N., Zulhakimie, M.A. & Farid, M.M. (2021) Dynamic mechanical analysis and morphology of petroleum-based and bio-epoxy foams with wood filler. AIP Conference Proceedings, vol.2339, pp 1-6.
[20] Krauklis, A.E., Karl, C. W., Gagani, A. I. & Jergensen, J.K. (2021) Composite material recycling technology state of the art and sustainable development for the 2020s. Jornal of Composites Science, vol 5(28), pp 1-23.
[21] Basalp, D., Tihminlioglu, F., Sofuoglu, S.C., Inal, F. & Sofuoglu, A. (2020) Utilization of municipal plastic and wood waste in industrial manufacturing of wood plastic composites. Waste and Biomass Valorization, vol.11, pp 5419-5430.
[22] Marsi, N., Huaizhimi, N.A., Rus, A.Z.M., Lethumanan, T., Mahmood, S., Masrol, S. R., Rashid, A.H.A., Fodzi, M.H. & Singam, R.T. (2020) The mechanical performance of tile based on plastic waste (ww) mixed wood waste (mww). Journal of Computational and Theoretical Nanoscience, vol 17(2-3), pp.795-802.

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