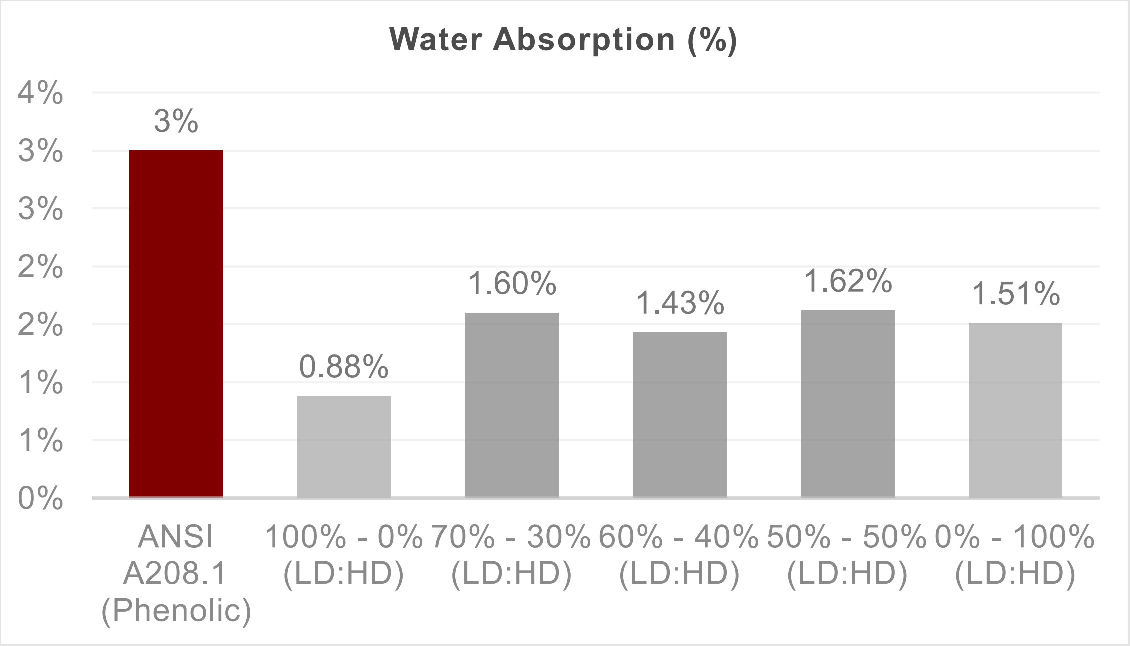

Fig. 4 Water Absorption Test Results & Remarks

Fig. 4 presents the water absorption of all the specimen based on the test methods provided by PNS 230:1989. Composite materials presented a higher water absorption compared to the control specimens. The water absorption results passed the minimum requirements of ANSI A208.1 for phenolic board materials with water absorption of not greater than 3% and ultimately passed the minimum requirements for hard board materials with water absorption of not greater than 25% (ANSI_A208.1, 2016). The typical water absorption of plastic ranges from 0.5% to 2% (AIP, 2021).

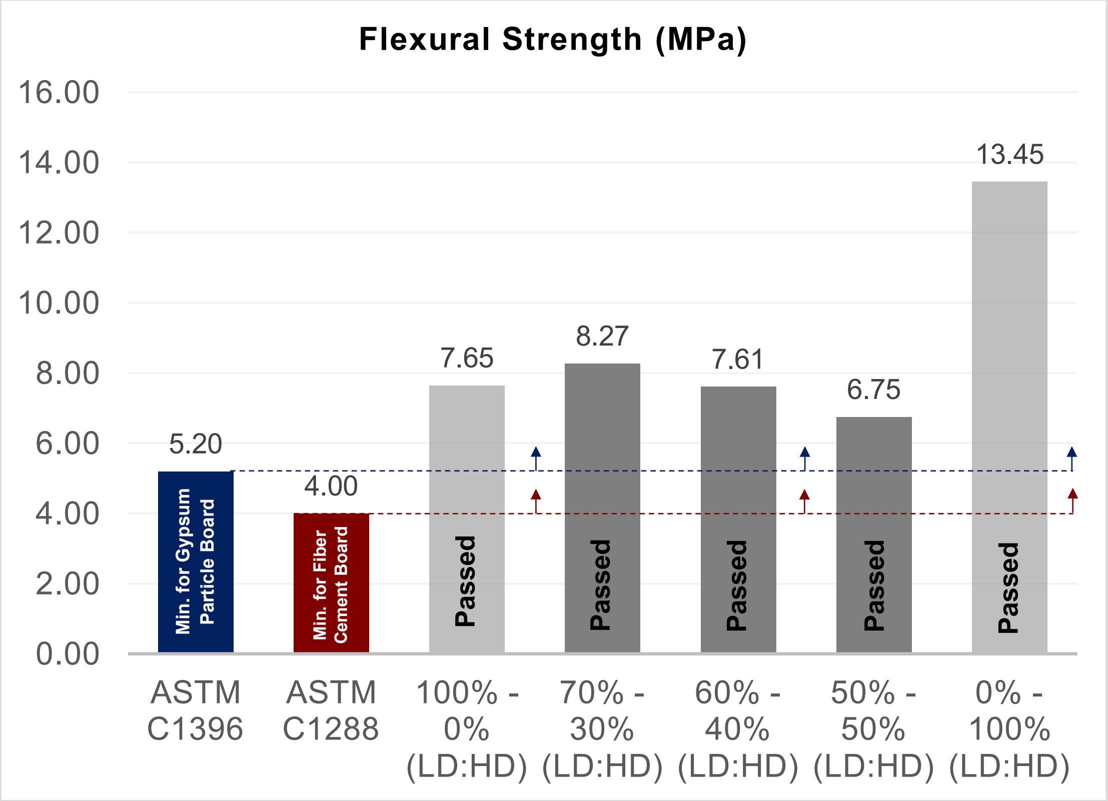

Fig. 5 Flexural Strength Test Results

Fig. 5 presents the values of the flexural strength of the specimens. Control specimens pure LDPE and pure HDPE served as the basis of the comparison. Even though flexural strength is controlled by the content of HDPE (Nwapa et al., 2020), experimental specimens presented a downward trend. From the study by Techawinyutham et al. (2021), polymer compatibilizers will improve the bonding of these polymers and ultimately improve its mechanical properties. However, the results can still be compared to the minimum requirement of gypsum particle boards at 5.20 MPa from ASTM C1396 as reported by Catapang et al. (2020) and to the minimum requirement of fiber-cement interior sheets at 4.00 MPa from ASTM C1288 as reported by Andales et al. (2019). The results surpass the minimum requirements as stated from these previous studies.

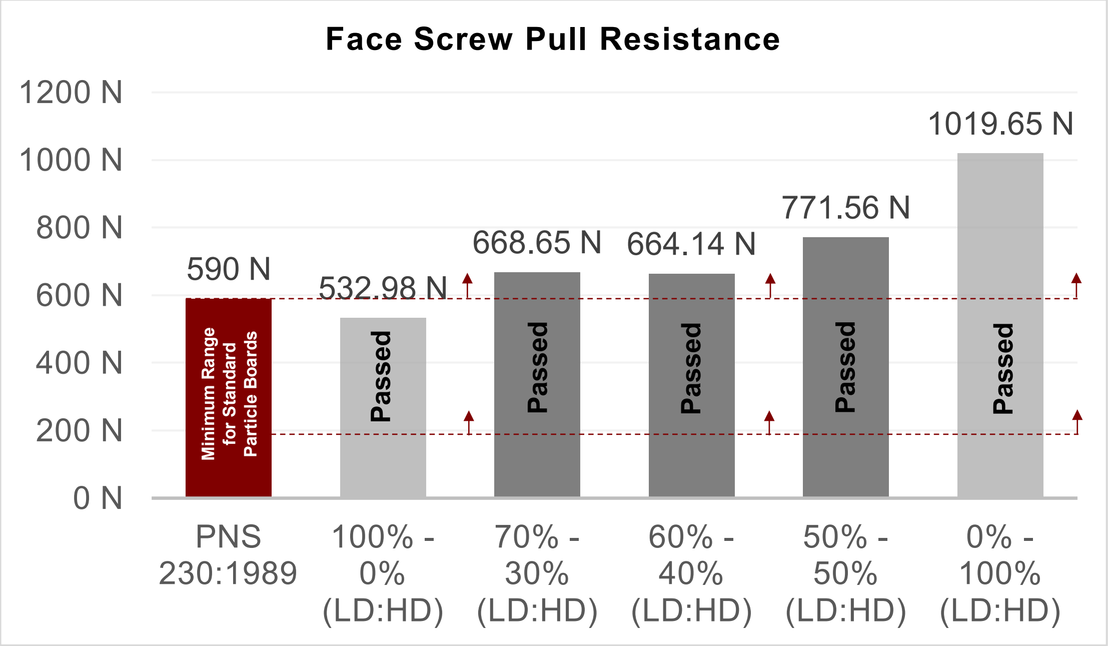

Fig. 6 Face Screw Pull Resistance Test Results

Fig. 6 presents the test results for the face screw pull resistance of the specimens. With the values of the control specimen, the value of the face screw pull resistance is majorly influenced by the content of HDPE. However, both ASTM D1037 and PNS ISO:16893 has no specific minimum values for the face screw withdrawal of particle boards. The researcher compared the results to PNS 230-1989 as used by Andales et al. (2019) which requires a range of screw holding force of 195 N to 590 N for standard particle boards. Only control specimen 1 did not reach the upper minimum requirements of 590 N.

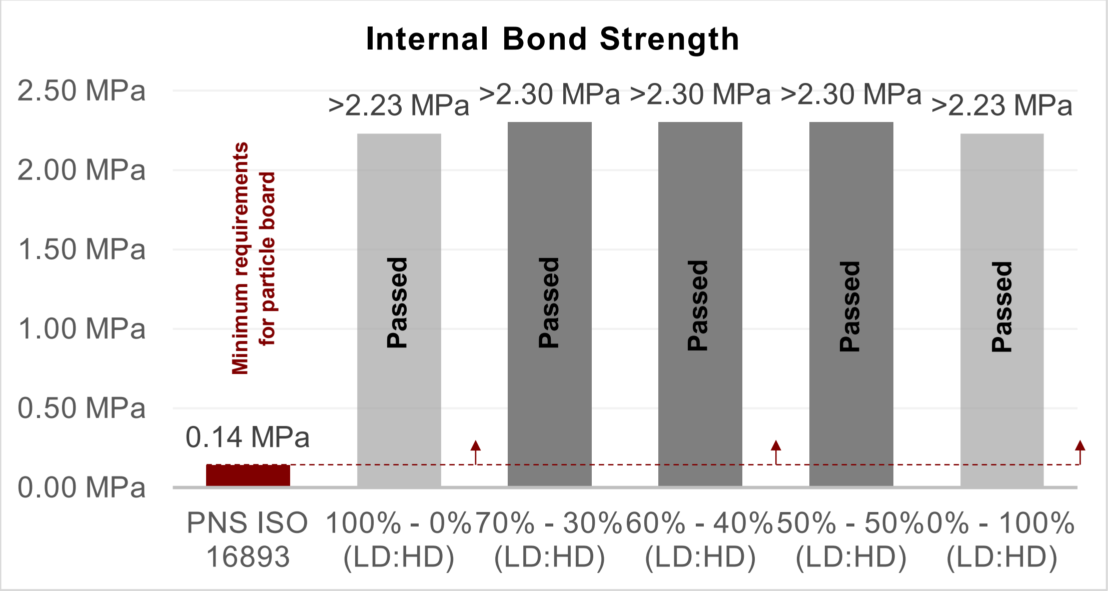

Fig. 7 Internal Bond Strength Test Results

Fig. 7 presents the values of minimum internal bond strength. The minimum requirement by PNS ISO 16893:2017 for internal bond strength of general-purpose particle boards is 1.43 kg/cm^2 or 0.14 MPa, which is surpassed by any of the specimen presented. Plastic, when melted, is an effective polymer binder applied on wood-plastic composites (Sherali, 2024) and is expected to have a superior value when used without the presence of any other materials. The tensile break stress of the following values is presented: 70LD:30HD at 170 MPa, 60LD:40HD at 175 MPa, 50LD:50HD at 177 MPa, far beyond the minimum requirements of PNS ISO 16893:2017 (Dzulfikar et al., 2022).

Table 3 *Pair-wise comparison matrix*

	Modulus of Rupture	**Face Screw Withdrawal**	**Internal Bond**	**Relative Density**	**Water Absorption**	**Criteria Weight**
Modulus of Rupture	1	0.25	0.2	4	1/6	**0.0809**
Face Screw Withdrawal	4	1	1	5	1/3	**0.2193**
Internal Bond	5	1	1	6	2	**0.3316**
Relative Density	0.25	0.2	1/6	1	1/6	**0.0402**
Water Absorption	6	3	0.5	6	1	**0.3279**
Sum	**16.250**	**5.450**	**2.867**	**22**	**3.667**	

From the presented values on Table 3, the value of the consistency index (CI) is 0.11 and the value of the consistency ratio (CR) is 9.70% which is less than the required 10%.

Table 4 *Properties of experimental composites*

Sample	**MOR (MPa)**	**FSW (N)**	**IB (MPa)**	**RD**	**WA (%)**
70LD:30HD	8.27	668.65	2.3	0.95	1.6
60LD:40HD	7.61	664.14	2.3	0.96	1.43
50LD:50HD	6.75	771.56	2.3	0.9	1.62

Experimental specimens presented in Table 4 will undergo parametric optimization. The physical and mechanical properties are presented in the table. Modulus of rupture or flexural strength, face screw withdrawal, and internal bond strength are characterized as beneficial parameters while relative density and water absorption are non-beneficial parameters.

Table 5 *Decision matrix for criteria*

Sample	MOR (MPa)	FSW (N)	IB (MPa)	RD	WA (%)
70LD:30HD	8.27	668.65	2.3	0.95	1.6
60LD:40HD	7.61	664.14	2.3	0.96	1.43
50LD:50HD	6.75	771.56	2.3	0.9	1.62
$\sqrt{\sum x_{ij}^2}$	13.110	1217.982	3.984	1.623	2.689

Table 5 presents the decision matrix of the proportional criteria where the MOORA technique starts its process. Performance of different design mixes or alternatives corresponding to each criterion is outlined in the table.

Table 6 *Normalized decision matrix*

Sample	MOR (MPa)	FSW (N)	IB (MPa)	RD	WA (%)
70LD:30HD	0.6308	0.5490	0.5774	0.5853	0.5951
60LD:40HD	0.5805	0.5453	0.5774	0.5915	0.5318
50LD:50HD	0.5149	0.6335	0.5774	0.5545	0.6025

Decision matrix is normalized and is dimensionless to be comparable. Elements are normalized regardless of being beneficial or non-beneficial. Table 6 presents all the normalized decision matrix.

Table 7 *Weighted normalized decision matrix*

Sample	MOR (MPa)	FSW (N)	IB (MPa)	RD	WA (%)
Weight	**0.0809 (+)**	**0.2193 (+)**	**0.3316 (+)**	**0.0402 (-)**	**0.3279 (-)**
Remarks	Beneficial	Beneficial	Beneficial	Non-Beneficial	Non-Beneficial
70LD:30HD	0.0510	0.1204	0.1915	0.0235	0.1951
60LD:40HD	0.0470	0.1196	0.1915	0.0238	0.1744
50LD:50HD	0.0416	0.1389	0.1915	0.0223	0.1976

The weights acquired from the AHP method in Table 3 were used to evaluate the weighted normalized decision matrix. The sum of the non-beneficial criteria is subtracted from the sum of the beneficial criteria as shown in Table 7. The result for the overall performance, priority value, and ranking are presented in Table 8. The one with the highest priority value is regarded as the best alternative.

Table 8 *Alternatives ranking through MOORA technique*

Specimen	Sample	Priority Value	Rank
Experimental	70LD:30HD	0.14423028	3
Experimental	**60LD:40HD**	**0.15983079**	**1**
Experimental	50LD:50HD	0.15218353	2

The specimen with 60LD:40HD was found to have the best rank out of the three experimental members. The results of this parametric optimization technique are also in-lined with the results of the research by Shebani et al. (2018) on polyethylene composites where 60% LDPE and 40% HDPE also had the better overall mechanical properties.

Table 9 *Correlation between mechanical and physical properties of LDPE-HDPE Composites using Pearson Correlation*

Mechanical Properties	Physical Properties	Pearson Correlation Coefficient	p-value	Decision	Verbal Interpretation
MOR vs	WA	0.158*	0.800	Accept H_0	Not Significant
	RD	-0.439*	0.459	Accept H_0	Not Significant
IB vs	WA	0.629*	0.256	Accept H_0	Not Significant
	RD	-0.170*	0.785	Accept H_0	Not Significant
FSW vs	WA	0.582*	0.303	Accept H_0	Not Significant
	RD	-0.870*	0.055	Accept H_0	Not Significant

*Note: ** - Relationship is Significant at the 0.05 level (2-tailed). ** - Relationship is Not Significant at the 0.05 level (2-tailed) For the interpretation of the value of the level of relationship, 1.00 – 0.70 for Very Strong Relationship, 0.69 – 0.40 for Strong Relationship, 0.39 – 0.30 for Moderate Relationship, 0.29 – 0.20 for Weak Relationship, and 0.19 – 0.01 for No or Negligible Relationship.*

Table 9 presents the correlation between mechanical and physical properties of composite materials. Despite some moderate to strong correlations, such as the negative relationship vs FSW and RD (-0.870) and the positive relationship between IB and WA (0.629), all p-values exceed 0.05 leading to the acceptance of null hypothesis. A verbal interpretation of non-significant between the mechanical properties and physical properties were accepted. Similar research was done where the physical and mechanical properties of wood boards from pine do not correlate (Cherry et al., 2022).

4. CONCLUSIONS

The relative density of the LDPE/HDPE composite materials were found to be between 0.90 – 1.00 depending on the design mix. The water absorption of all the specimen was below the maximum allowable water absorption for hardboards (<25%) and phenolic board (<3%) (ANSI_A208.1, 2016). The flexural properties of the specimens also surpassed the minimum requirement of gypsum particle boards for 12.7 mm thick specimens at 5.20 MPa from ASTM C1396 as reported by Catapang et al. (2020). It also surpassed the minimum requirement for fiber-cement interior sheets at 4.00 MPa from ASTM C1288. For the face screw withdrawal, all the specimen were within the required minimum range for screw holding force of 195 N to 590 N from PNS 230-1989 (Andales et al., 2019). Since plastic is known as a binder, its internal bond strength surpassed the minimum 0.14 MPa of PNS ISO 16893:2017 and is believed to have a tensile strength of 170 MPa (Dzulfikar et al., 2022). However, all of the physical and mechanical properties show no direct correlation with each other similar to the reports found in wood and wood particle materials (Cherry et al., 2022).

The optimum mix ratio was determined with the use of MOORA method and was found to be the experimental specimen 60% LDPE – 40% HDPE, in line with the study of Shebani et al. (2018) on composite polyethylene materials. Acquired data are presented to the company and was found to have a positive cost-benefit ratio. Utilizing plastic manufacturing byproducts for particle boards is feasible for construction applications.

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