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Potential utilization of reinforced mortar and dissolved high-density polyethylene (HDPE) plastic waste with used cooking oil as floor tiles: An eco-friendly approach to alternative building material

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Abstract

The world is currently confronting a pressing environmental challenge: solid waste management. Among various waste types, plastic particularly high-density polyethylene (HDPE), is of major concern due to its resistance to degradation, often persisting for hundreds or even thousands of years. This accumulation poses significant threats to ecosystems and human health. Recycling presents a viable, sustainable solution. The primary objective of this research is to tackle the issue of plastic waste by developing a practical product that reduces the reliance on mined raw materials in construction. Specifically, the goal was to develop reinforced mortar with Galvanized Wire Mesh (GWM) tiles suitable for construction by incorporating High-Density Polyethylene (HDPE) plastic waste and Waste Cooking Oil (WCO). This study sought to evaluate the feasibility of the experimental product by assessing its physical (water absorption and breaking strength and modulus of rupture), mechanical (surface quality), and chemical (stain resistance) properties prescribed by ISO-13006/EN176 standards. Each of the treatments (1, 2, and 3) exhibited positive results in water absorption with the standard of >10%, breaking strength of >600N, modulus of rupture of >35N/mm^2 and stain resistance test minimum of class 3. Unfortunately fail to surface quality test due to volumetric shrinkage of the plastic material. The results indicated that Treatment 2 and 3, having treatment ratios of 5.0% WCO, 45.0% HDPE plastic waste, 2.5% GWM, 47.5% mortar, and 10.0% WCO, 40.0% HDPE plastic waste, 2.5% GWM, 47.5% mortar, respectively, where higher proportions of waste cooking oil were utilized, align with the observed improvements in homogeneity and compactness of the samples. Additionally, there doesn't appear to be a significant difference in the results for each treatment across these different testing characteristics, suggesting that each treatment offered environmental benefits while also presenting a cost-effective option. Further research and development are essential to optimize the performance and suitability of plastic tile materials for broader applications.

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Introduction

Plastic waste is a significant solid waste environmental challenge. Its durability and resistance to degradation mean that once produced, plastic can persist in the environment for hundreds, if not thousands, of years. The sheer volume, on average, of the annual generation of plastic waste globally is around 380 million tons (Ritchie and Roser, 2018), which is staggering and puts immense pressure on ecosystems, wildlife, and human health.

Conventionally, producers utilize plastic as their prime packaging component due to its good properties and thermally stable characteristics, substantial ultimate strength, high degree of process ability, lightweight nature, and cost-effectiveness Sangroniz *et al.* (2019). However, plastic packaging is commonly single-use in nature; thus, single-use plastic packaging, which constitutes a large portion of plastic waste, is often disposed of after just one use, leading to massive accumulation in landfills, waterways, and the environment. Due to their properties, plastics possess the merit of being recycled; however, in the country, the recycling rate is 9%, which is considerably low (World Wide Fund for Nature [WWF], 2020).

Plastics possess the potential to be recycled, and increasing recycling rates can help reduce the demand for virgin plastic production, conserve resources, and mitigate environmental impacts. Its application to plastic waste is crucial for reducing the environmental impact caused by plastic accumulation and conserving raw materials used in plastic product manufacturing (Hopewell *et al.*, 2009). The depletion of natural resources and the growing need for building materials have aided scientific research into alternative building materials, which has been aided by strict environmental regulations.

One of the top ten environmental threats in the world, plastic pollution has a substantial and pervasive negative influence on wildlife and ecosystems worldwide. Plastic packaging materials account for 28.1% of total Municipal Solid Waste, according to the (US EPA, 2017). This includes items like soda and water bottles, detergent bottles, milk jugs, and plastic bags made primarily of PET, HDPE, and LDPE, which are often deemed as single-use plastics. Clay is the primary raw material used in the ceramic tile industry, and its remarkable growth indicates a rise in demand for these resources. Waste cooking oil poses another significant concern, particularly in the Philippines as many sectors such domestic and small-scale commercial units dispose of it inadequately. Improper disposal can result to issues such as pipeline blockages and negative environmental impacts, including the disruption of aquatic ecosystems and the degradation of water quality (Azahar *et al.*, 2016).

Zamboanga City's waste composition comprises 61% biodegradable waste and 39% non-biodegradable waste (OCENR, 2023). However, only a single type of waste, Polystyrene, is being recycled, resulting in a significant accumulation of recyclable plastic waste such as PET, LDPE, and HDPE plastics in the Materials Recovery Facility. Thus, the primary objective of this research was to create a usable product using plastic waste to reduce litter or plastic waste directly disposed to sanitary landfill and lessens the use of mined raw construction materials. Specifically, to develop a reinforced mortar tiles suitable for construction by utilizing High Density Polyethylene (HDPE) plastic waste, galvanized wire mesh (GWM) and Waste Cooking Oil (WCO).

This research will offer a cost-effective alternative: using waste HDPE plastic for tile production, reducing dependence on finite resources like oil and petroleum. It addresses plastic waste accumulation while promoting sustainable practices in construction by lowering costs and conserving raw materials. The success of this approach could encourage industries and governments to adopt proactive measures for waste disposal and environmental improvement.

Materials and methods

Production of experimental tile specimen

The mixture and set-up are processed to attain tile forms. The specifications for the tile specimens are derived from ASTM Tile Standards Referenced in ANSI A137.1. Presented in Fig. 1, there are the experimental tile layout, the cross-sectional, and the 3D isometric view. The upper part layer was the dissolved HDPE with waste cooking oil; the bottom part layer was the mortar with galvanized wire mesh in the middle part as reinforcement.

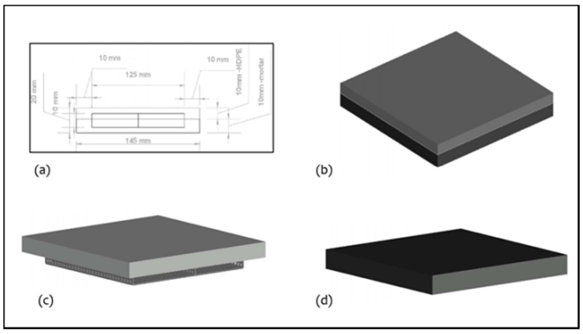

Fig. 1. Experimental Tile layout, (a) Side view with labels and dimensions of actual average size of experimental tile, b.) Expected output-3D SW Isometric View, (c) 3D Isometric View of HDPE with Galvanized wire mesh, (d) Mortar 3D Cross sectional view

Preparation of the experimental tile treatment ratios

For the purpose of this experiment, a total number of specimens needed for testing was 51 pcs. As per PNS ISO 13006, seven (7) for breaking strength test and ten (10) for stain resistance test, water absorption test and surface quality test. As per ASTM D695 and ASTM D638 for compressive and tensile strength, the mortar should have a mixing ratio of 1:2 to 1:4 cement-sand by volume, using the richer mix for thinnest structures having 7 to 14 MPa and tensile strength of 1.6 MPa respectively and the water-cement should be below 0.5:1 by volume (Mortar cement-sand-water Ratio: 1:4:0.5).

Table 1 showed all treatments of the entire tile specimen with a total volume of 632.26 cm^3, divided equally between dissolved HDPE plastic waste (50%) and reinforced mortar (50%). The proportion of used oil in the dissolved HDPE plastic waste varies across treatments, with Treatment 1 having 1% used oil and 99% HDPE plastic, Treatment 2 having 10%used oil and 90% HDPE plastic, and Treatment 3 having 20% used oil and 80% HDPE plastic. The composition of the reinforced mortar 95%, including the galvanized wire mesh 5%, remains the same across all treatments.

Table 1. Overall specific material proportions per tile specimen

Treatment ratio distribution		Total volume (cm^3), 632.26			
		Dissolved HDPE, 316.13 (50%)		Reinforced mortar, 316.13 (50%)	
		WCO	HDPE	GWM	Mortar
Specific % mixture	Treatment 1	1%	99%	5%	95%
	Treatment 2	10%	90%	5%	95%
	Treatment 3	20%	80%	5%	95%

Research procedure

The following tasks were undertaken in this study. First, equipment and materials were procured; including the melter (oven) and tile molder from Sta. Cruz, Zamboanga City, while HDPE waste was sourced from laundry shops and the Material Recovery Facility in Zamboanga City. Second, HDPE waste was chopped, washed, and drained, then additional materials such as sand, cement, and galvanized wire mesh (GWM) were obtained from a local hardware store, with GWM shaped into cuboids (100 mm × 100 mm × 10 mm), and waste cooking oil was collected from street food vendors.

The following steps were considered in experimenting: For initial melting and molding, 100 grams of HDPE plastic and oil were placed into the molder. Heat the molder in the oven at 230 degrees Celsius for approximately 20 minutes to allow the plastic to melt. Remove the molder from the oven and apply pressure using the tile presser. Repeat this procedure three times to form a single tile, using a total of 300 grams of plastic with oil.;

b.) Incorporating the Wire Mesh, while the plastic is still in its melted form, insert the cuboid galvanized wire mesh into the plastic. Press continuously until the desired shape was achieved. Allow the experimental tile to cool for 60 to 120 minutes.; c.) Finally, for the tile formation, assemble a square tile-shaped mold and tape around the sides of the tile to serve as the molder for the mortar. Pour the mortar, having a ratio of water-cement-sand (0.5:1:2), into the mold. Let the tile set for 48 hours to solidify and reach its cure strength.

The formed plastic tiles underwent testing procedures to evaluate their physical, mechanical, and chemical properties. The results obtained from these experiments were compared with those of commercially available tiles using both descriptive and inferential statistics.

Physical, mechanical, and chemical testing

The Standard as per ISO-13006/EN176, the corresponding common ceramic tile value available commercially, and the test method, which provides standard procedures for testing for tile specimens, are presented in Table 2 below.

Table 2. Characteristics required for different applications and common ceramic tile result

Characteristics	Standard as per ISO-13006/EN176	Common ceramic tile value	Test method
Structural properties (physical)			
Water absorption	> 10%	>12-18%	ISO-10545-3
Breaking strength (BS)	> 600 N	> 800 N	ISO-10545-4
BS Modulus of rupture	> 35 N/mm²		ISO-10545-4
Surface mechanical properties			
Surface quality	Min. 95% defect free	> 96%	ISO-10454-2/ EN 154
Chemical properties			
Stain resistance	Min. class 3	Class 5	ISO-10545-14

Source: ISO-13006

The specimen's physical changes following exposure to loads, chemicals, and water may impact the tile installation's stability and integrity. To evaluate the physical property in terms of water absorption, the basis is ISO-10545-3; for breaking strength and modulus of rupture, the basis is ISO-10545-4; for mechanical property in terms of surface quality, the basis is ISO-10454-2 and for chemical properties in terms of stain resistance, the basis is ISO-10545-14 of the tile specimens are various testing methods employed.

Statistical analysis

The outcome was computed and evaluated using data from tests on water absorption, breaking strength, modulus of rupture, surface quality, and stain resistance. The experimental specimens were compared to the ISO standard, serving as the control for each test, to assess whether they could provide a viable alternative to commercially available tiles.

The test results for various tile treatments were summarized using descriptive statistics in tables and graphs. At a 5% significance level, One-Factor ANOVA was applied to determine differences between commercially available ceramic tiles and experimental plastic tiles with varying raw material ratios. The results were interpreted according to ISO-13006/EN176 standards, assessing the viability of using HDPE plastic waste, waste cooking oil, galvanized wire, and mortar for plastic tile production.

Results and discussion

Experimental tile quality in terms of physical test (water absorption)

Table 3 shows the summary result for quality in terms of physical property for water absorption. The Control, having 10% water absorption, showed relatively higher water absorption compared to the treatment variations. Treatment 2 exhibits a significantly lower maximum absorption of only 5.72% by mass, followed by treatment 3 with 6.23%, and treatment 1 with 6.67%; this is attributed to the volume distribution of the reinforced mortar.

Among the various experimental tile treatments presented at Table 3, a notable observation was the comparatively lower water absorption value, when compared to the control treatment standards provided by ISO-10545-3 classification for Group III with water absorption of > 10%. The experiments result ranges from 5-8% only. As a result, the commercially available common ceramic tile with water absorption of approximately >12–18% was surpassed by the reinforced mortar and HDPE plastic with used cooking oil, which met all standards.

Table 3. Quality of physical property (water absorption) result summary

Water absorption (%)				
	Control	Treatment1	Treatment2	Treatment3
Mean	10	6.67	5.72	6.23
Remarks for quality		Surpassed group III tile standard	Surpassed group III tile standard	Surpassed group III tile standard

Table 4. Results of physical property (breaking strength)

Breaking strength, in N				
Item	Control	Treatment1	Treatment2	Treatment3
Mean	600	2365.93	2357.64	2364.22
Remarks for quality		Surpassed ISO standard	Surpassed ISO standard	Surpassed ISO standard

The classification system for ceramic tiles based on water absorption, as defined by PNS ISO-10545-3 and PNS 145:2005 are: Group I, tiles with low water absorption of maximum 0.5% for impermeable, unglazed floor tiles; Group II, tiles with medium water absorption (3 < Ev ≤ 10%); and Group III, tiles with high water absorption (Ev > 10%). According to ISO-10545-3, common ceramic tiles are classified under Group III, which typically have water absorption rates ranging from 12% to 18%.

Additionally, as per ISO 62 and (MatWeb, n.d.), HDPE plastic typically exhibits very low water absorption, with values ranging from 0.005-0.01% and 0.00-0.07% by weight respectively. This indicates that HDPE plastic is highly resistant to water absorption, which makes it an excellent choice for applications where moisture resistance is essential. Moreover, water absorption of mortar was noted that it plays a crucial role in determining its longevity. A good mortar mix typically has water absorption well below 10% by mass. The increase in mortar volume correlates with a higher percentage of water absorption, suggesting that the experimental tiles' mortar component is responsible for absorbing water (Borhan and Mohamed, 2011).

Experimental tile quality in terms of physical testing (breaking strength)

Table 4 showed the summary result in terms of physical property for breaking strength. Control having the mean of 600 N, as a standard, showed relatively lower value compared to Treatment 1 that yielded the highest average breaking strength of 2365.93N, followed by Treatment 3 with 2364.22N, and Treatment 2 with 2357.86N.

Tiles breaking strength standard was greater than 600 N as prescribed by ISO-13006/EN176. Reinforced mortar and HDPE plastic waste with used cooking oil as tiles have surpassed the breaking strength standard, as evidenced by the average breaking strength values obtained from the various treatment.

The differences in breaking strength among the treatments and attributing it to the volume of cement attached beneath the experimental tile was insightful. The additional support provided by the cement volume contributed to the higher breaking strength observed in Treatment 1 and Treatment 3 compared to Treatment 2. This analysis showcases a keen understanding of how variations in experimental conditions, such as the amount of support provided by cement, can impact the performance of the tiles, validating the effectiveness of the support provided by the cement volume.

The observation regarding the behavior of the cement under load, where it breaks into halves but does not crumble into pieces due to reinforcement made by wire mesh, compressive strength and mortar is a material with wide range of applications in the construction industry aligns with findings from (Aho and Ndububa, 2015) study. This study highlights the benefits of reinforcing mortar with wire mesh to prevent sudden failures and increase durability. Reinforced mortars, as demonstrated by the study, exhibit improved resistance to cracking and sudden failures.

Experimental tile quality in terms of physical testing (modulus of rupture)

In Table 5, the result in terms of physical property for modulus of rupture, when compared to the Control, which had a modulus of rupture of 35 N/mm^2, all of the experimental tile treatment ratios passed for modulus of rupture. Treatment 2 had 37.18 N/mm^2, yielded the highest mean value, followed by Treatment 3, which had 36.73N/mm2, and Treatment 1 had 36.20N/mm^2, indicating that the experimental tile treatments had achieved good flexural strength.

Table 5. Results of physical property (modulus of rupture)

Modulus of rupture, in N/mm^2				
Item	Control	Treatment1	Treatment2	Treatment3
Mean	35	36.20	37.18	36.73
Remarks for quality		Passed ISO Standard	Passed ISO Standard	Passed ISO Standard

The reference (ISO, 2019) and (ASTM C648-04) standards for determining the modulus of rupture and breaking strength further emphasizes the importance of standardized testing procedures in assessing tile performance. Furthermore, for HDPE plastic's behavior, bending rather than breaking under load due to its high ultimate tensile strength of 30 MPa and flexural modulus of 1.86 GPa, contrasts with the behavior of ceramic materials of approximately 0.0007 GPa- 0.17 GPa (Forquin *et al.*, n.d.). Ceramic materials possess lower tensile strength values compare with the HDPE. This comparison highlights the diverse mechanical properties of different materials and their implications for various applications in the construction industry.

Additionally, in comparing the flexural modulus of HDPE plastic, which falls within the range of 0.280-1.86 GPa with an average value of 1.13 GPa Grade Count:398 stated from (MatWeb, n.d.) database for the category "High Density Polyethylene (HDPE), Injection Molded, to the standard flexural modulus for tiles, which is stated as 0.035 GPa according to the PNS ISO 10545-4. This suggests that the experimental tiles, reinforced mortar and HDPE plastic with used cooking oil, being tested have a significantly higher flexural modulus compared to the standard.

Experimental tile quality in terms of mechanical property test (surface quality testing for measurement of length and width)

Presented in Table 6 is the quality summary result in terms of mechanical properties for surface quality, in particular, the measurement of the length and width. The Control exhibited the highest mean value of 177.8 mm compared to the treatment variations; treatment 1 exhibited the average dimension of 146.58 mm, Treatment 2 with 145.113 mm and Treatment 3 with 145.522 mm.

When in the measurements was gathered the average dimension of square tiles was the average of four measurements and the average dimension of the sample was the average of forty measurements. ISO 10454-2 specifies methods for assessing the surface quality and dimensional properties of ceramic tiles, including parameters such as length, width, thickness, straightness of sides, and surface flatness. This standard ensure that ceramic tiles meet certain quality and dimensional, abrasion resistance and durability of ceramic tiles, particularly in terms of their ability to withstand normal wear and tear under typical usage conditions.

Experimental tile quality in terms of mechanical property test (surface quality testing for percent defect free)

Table 7 shows the surface quality findings, assessing defects like cracks, unevenness, and nipped edges. The Control group had the highest percentage of defect-free tiles. Treatment 3 showed the best results for length and width accuracy (90.27%) and defect-free tiles (90%), followed by Treatment 2 (85.33% accuracy and 90% defect-free). Treatment 1 had the lowest performance with 65.87% accuracy and 80% defect-free tiles.

The improved results for Treatment 3 suggest that adding used cooking oil, acting as a plasticizer, enhanced the mixture's flow, leading to better homogenization and surface quality.

The criteria for assessing the surface quality of glazed, engobe, and unglazed tiles per ISO-13006/EN176 standards include cracks, crazing, unevenness, pinholes, nipped edges, and specks. Tiles must be 95% defect-free to meet the standard. Though Treatment 3 did not meet the ISO-13006/EN176 standard, it had the best results for length, width, and defect-free tiles.

Table 6. Measurements of length and width of the experimental tile

Surface quality (Measurements of length and width)				
Item	Control	Treatment1	Treatment2	Treatment3
Mean	177.8	146.58	145.113	145.522
Remarks for quality		Unequal size	Unequal size	Unequal size

Table 7. Surface defects and intentional effects

Summary for surface quality, in %						
Specific	No. of tiles	No. of defectives	% of tiles with defect	% of tiles without defect	% by observer (surface defect)	Remarks for quality
Control				95	95	
T1	10	2	20	80	65.87	With visible defect
T2	10	1	10	90	85.33	With visible defect
T3	10	1	10	90	90.27	With visible defect

The visible defects observed were attributed to the cooling process, which caused shrinkage due to factors like temperature changes and material properties. As the material cools, it contracts, reducing its dimensions. In the experiment, shrinkage from 177.8 mm to 146 mm was significant. Controlling shrinkage is crucial in ceramic manufacturing to meet desired specifications. Shrinkage is common in materials like plastics (Swan, n.d., p. 177), which can experience up to 25% shrinkage when cooling. In injection molding, high pressure can reduce but not eliminate this shrinkage, requiring adjustments to the mold or post-molding processes to ensure accurate dimensions.

Experimental tile quality in terms of chemical testing (stain resistance)

Table 8 showed the experimental tile quality result in terms of chemical property for stain resistance. The Control with the standard of minimum of class 3 showed relatively lower result compared to experimental tile treatment variations. Treatment 1,2 and 3 exhibited the same result of class 4.

ISO-13006/EN176 sets a minimum staining resistance of Class 3. Both the common and experimental tiles were affected after Procedure A but showed no visible effects after Procedure B, placing them in Class 4, which indicates higher staining resistance. Procedure B likely involves treatment or cleaning that removes stains, showing the tiles' ability to resist staining. Both tiles passed the staining resistance test.

ISO (2019) and ASTM standards, particularly ASTM C650-04, assess ceramic surface durability, including resistance to stains and harsh chemicals. "Chemical resistance" refers to a ceramic surface's ability to withstand corrosive effects. This is crucial in environments like kitchens, labs, and industrial settings where exposure to chemicals is common. High chemical resistance ensures the tile's longevity and aesthetic appeal.

The stain resistance test used olive oil, iodine, and benzalkonium chloride to evaluate ceramic tiles, reinforced mortar, and HDPE plastic with used cooking oil. Benzalkonium chloride replaced the originally intended Propanetriol tributanoate, demonstrating flexibility in the experiment. Comparing experimental and commercial tiles under the same conditions allows for meaningful quality assessments by evaluating their stain resistance and material effectiveness.

ISO 10545-14 classifies stain resistance into several classes, with Class 1 representing the lowest resistance and Class 5 representing the highest. Class 3 is typically considered the minimum acceptable level for stain resistance in ceramic tiles, indicating moderate resistance to staining.

Table 8. Stain resistance result

Stain resistance				
Item	Control	Treatment1	Treatment2	Treatment3
1-10	Min. of Class 3	Class 4	Class 4	Class 4
Remarks for quality		Resistant	Resistant	Resistant

Statistical analysis of experimental tile quality

The Kruskal-Wallis H test revealed significant differences in water absorption between the groups (Table 9). The Control group had the highest mean rank, suggesting higher water absorption compared to the treatment groups. Treatments 1 and 3 had higher mean ranks than Treatment 2, indicating differences in water absorption effects. Post-hoc Dunn's test with a Bonferroni correction (alpha = 0.0083) showed significant differences between the Control and all treatment groups (1, 2, and 3) and between Treatment 1 and Treatment 2. No significant differences were found between Treatment 1 and 3, or between Treatment 2 and 3.

Treatment 2 had the lowest water absorption, followed by Treatments 3 and 1. The results show that adding reinforced mortar and dissolved HDPE plastic with used cooking oil to the tile composition improves water resistance, with Treatment 2 being the most effective, exceeding ISO-10545-3 standards for Group III tiles. This highlights the importance of water absorption testing for tile suitability, especially in moisture-prone environments, and points to promising uses of these materials in sustainable construction.

Table 9 further shows the mean breaking strength values, with the Control (600N) having the lowest strength compared to the treatments. Treatment 1 had the highest mean (2365.93N), followed by Treatment 3 (2364.22N) and Treatment 2 (2357.64N). The Kruskal-Wallis H test found significant differences between groups, with Treatment 1 having the highest rank and Control the lowest. Post-hoc Dunn's test (alpha = 0.0083) showed significant differences between Control and all treatments, but no significant differences between the treatments themselves. These results suggest that the treatments, incorporating reinforced mortar and HDPE plastic with used cooking oil, significantly improve breaking strength compared to the Control and exceed ISO standards, making them suitable for high-demand applications.

Table 9. Summary table on statistical analysis of experimental tile quality

Characteristics	Control	Treatment 1	Treatment 2	Treatment 3	p-value
Physical property					
Water absorption (%)	10.00[a]	6.67[b]	5.72[c]	6.23[bc]	0.000**
Breaking strength (Newton)	600.00[a]	2365.93[b]	2357.64[b]	2364.23[b]	0.000**
Modulus of rapture (N/mm^2)	35.00[a]	36.20[a]	37.18[a]	36.73[a]	0.5425[ns]
Mechanical property					
Surface quality (mm)	177.80[a]	146.58[b]	145.11[c]	145.52[bc]	0.000**

Note: ns not significant, *significant, **highly significant, abc different letters denote significant differences

Table 9 presents the mean values and statistical results for the modulus of rupture, showing that the Control (35N/mm²) had a lower value compared to the treatment variations. Treatment 2 (37.18N/mm²) had the highest mean value, followed by Treatment 3 (36.73N/mm²) and Treatment 1 (36.20N/mm²). ANOVA test results indicate no statistically significant differences in breaking strength between the control and treatment groups, nor among the treatments themselves. This suggests that the sample averages are not large enough to show significant variation. A higher modulus of rupture indicates greater durability, with all treatments exceeding the ISO standard (PNS ISO 10545-4), making the experimental tiles suitable for applications requiring high mechanical strength and durability, offering a sustainable alternative to traditional materials.

The table shows that the Control group (177.8 mm²) has a higher surface quality than the treatment variations, with Treatment 1 (146.58 mm²) being closest to the mold size average, followed by Treatment 3 (145.22 mm²) and Treatment 2 (145.11 mm²). Significant differences in surface quality were found among the groups, with between-group variation being greater than within-group variation. Notable differences in length and width exist between the Control and each treatment group, but no significant differences were observed between Treatment 1 and Treatments 2 or 3. The results indicate significant differences for Control-Treatment 1, Control-Treatment 2, Control-Treatment 3, and Treatment 1-Treatment 2, while Treatment 1 performed best in dimensions, followed by Treatment 2 and Treatment 3. Treatment 3's improved surface quality suggests that used cooking oil effectively acts as a plasticizer, enhancing the melt flow properties of the plastic during production.

Comparison in cost between reinforced mortar and dissolved high-density
Polyethylene (HDPE) plastic waste with used cooking and the commercial sample

Based on the information provided in the Table 10 for the unit cost of experimental and common ceramic tile, the experimental plastic waste tile, which cost amounting 7.8 pesos each and has dimensions of 146 × 146 mm, was cheaper than the commercially available ceramic tile, which cost amounting 11 pesos each and has dimensions of 152.4 × 152.4 mm. Therefore, in terms of cost, the experimental tile presents a more economical option.

To develop a comprehensive cost estimate for producing experimental tiles, all relevant production costs must be considered, including equipment, materials, labor, and overhead.

Table 10. Unit cost of experimental and common ceramic tile

Tile	Unit	QTY	Amount (Php)
Common ceramic (7×7in)	Piece	1	11
Experimental tile	Piece	1	7.8

For equipment, such as the oven used for melting tiles, the initial cost is divided by its expected lifespan, assuming daily operation. The costs for reinforced mortar, including sand and cement, are calculated per kilogram, while wire mesh costs are computed per 100 mm².

No expenses are incurred for HDPE plastic waste and used cooking oil, as these are the main materials for the experiment. Labor costs are determined by calculating the daily wage based on the number of workers, their hourly rate, and total hours worked. Utilities and overhead costs include water, soap, and maintenance. The production rate is calculated by dividing the total cost (approximately 376.185 PHP) by the number of tiles produced (48), resulting in a cost of about 7.84 PHP per tile. Utilizing HDPE plastic waste and used cooking oil as raw materials not only reduces costs but also offers environmental benefits. This approach conserves natural resources by decreasing the need for raw materials like clay and addresses the issues of improper disposal, as both plastic waste and cooking oil contribute to pollution. By repurposing these materials in tile production, we can prevent them from contaminating landfills or oceans and give them a new life as valuable construction materials.

Conclusion

The study led to several conclusions. First, the experimental tiles were tested for physical properties (water absorption, breaking strength, and modulus of rupture), mechanical properties (surface quality), and chemical properties (stain resistance) following ISO-13006/EN176 standards. All treatments exceeded the standards for water absorption, breaking strength, and modulus of rupture. However, while Treatment 3 achieved the best surface quality, none of the treatments met the minimum requirements set by ISO 10545-2 due to volumetric shrinkage of the HDPE material, which has a shrinkage ratio of 2-6% Kruse Training (2017) and 25% volumetric shrinkage (Swan, n.d., p. 177). All treatments passed the stain resistance tests according to ISO 10545-14 standards.

Additionally, Treatments 2 and 3, which included dissolved HDPE plastic, showed the greatest potential for plastic tile production, outperforming Treatment 1. The higher proportion of waste cooking oil in the mixtures resulted in a more homogeneous blend, enhancing the uniformity and mechanical properties of the tiles. Furthermore, all treatments demonstrated positive outcomes in water absorption, breaking strength, modulus of rupture, surface quality, and stain resistance. The significant differences between the control and treatment groups indicate that the experimental tiles exceeded ISO standards. However, no significant differences were found among the treatment results across various testing characteristics, suggesting multiple effective options for producing high-quality plastic tiles.

Finally, the experimental plastic waste tiles, particularly those incorporating used cooking oil, provide environmental benefits and are a more economical alternative to commercially available ceramic tiles, contributing to waste reduction and promoting sustainable practices.

Recommendation(s)

After a thorough analysis of the data, identifying research gaps is crucial for pinpointing areas needing further investigation or where knowledge is lacking. Therefore, it is recommended to adjust factors such as material composition, firing temperature, and cooling rate to reduce shrinkage and ensure dimensional stability in tile manufacturing. This may involve investing in specialized equipment, like customized heating machines and tile molders with pressers. Additionally, exploring extrusion or injection methods in the production process and incorporating HDPE (High-Density Polyethylene) plastic waste pellets could enhance tile manufacturing. Further testing on tiles should include thermal shock resistance, crazing resistance, thermal expansion, and frost resistance. Lastly, in-depth research should focus on fine-tuning the composition of HDPE plastic waste tiles, particularly the ratios of waste cooking oil and other additives.

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