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A study on the behavior of pulling power and flammability of mold walls mixed with high-density polyethylene plastic waste

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ABSTRACT

Currently, materials used in construction have been continuously developed in terms of quality and efficiency, especially fiber reinforcement in mortar, a form of development used in construction. The development aims to enhance concrete's tensile properties and performance for higher flexibility. Most plaster walls are ordinary mortar and have low elasticity, which is a weak point. Therefore, attempts are being made to improve their properties by using a rigid material as a concrete mixture, namely high-density polyethylene plastic, to increase its ability to bear tensile force. This study examines the tensile strength and flammability tests of walls plastered with mortar, with which high-density polyethylene plastic waste is mixed. The tensile strength of mortar plaster walls mixed with high-density polyethylene plastic is tested by replacing at 2.5%, 5%, and 10% proportions and cured at 7, 14, and 28 days. By comparing general mortar and high-density polyethylene plastic mortar, it is found that the general mortar had the highest tensile strength at 28 days of curing. The obtained value is 45 ksc, and the mortar mixed with polyethylene plastic in the amount of 2.5% at 28 days of curing can withstand the strength of 45 ksc. In addition, the general mortar can produce the same tensile strength as mortar mixed with high-density polyethylene plastic. The flammability test shows that general mortar develops red marks after being burned with fire, while the mortar combined with high-density polyethylene plastic develops black marks. However, neither type of wall is in flames nor spread.

Keywords: High-density polyethylene plastic waste, Pulling power, Ignition

INTRODUCTION

Mortar is made from a cement mixture with fine sand and water as a binder. It is trendy for constructing all types of buildings and valuable for plastering the surface of building walls and covering the surface of building structures such as beams and columns to create a neat surface before painting or decorating the surface with other materials. In addition to the benefits of covering walls and structures, mortar can be used for different construction purposes, such as laying bricks or block walls, and as an adhesive for bonding ceramic tiles. Mortar has the highest amount of sand as an ingredient, causing the demand for sand to increase along with the popularity of mortar used in construction [1].

Today's society is interested in environmental conservation. Waste in one industry is used to benefit another sector. The idea for this research is to use waste from the recycled plastic production process in the construction industry. Because plastic is a material that plays a massive role in our daily lives, the trend of its use is increasing to replace the use of natural resources [2]. Reusing plastic waste by forming it into new products is a prevalent method. The plastic recycling process begins with separating different types of plastic from each other because different types have various properties, such as melting points, density, hardness, softness, and clarity. When each type of plastic is separated, it will be squeezed, flattened, and then bundled into bales to be sent to a plastic recycling factory. Each type of plastic is crushed into small pieces and washed in a large pond during this step. Dust and dirt are removed, and the plastic pieces are dried in the sun or hot air. The paper or film tag attached to the plastic piece will be blown apart and enter the process of melting plastic pieces through an extruder into strips before cutting them into small

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pellets and packing them into boxes to go to a plastic molding factory to make new products. When all recycled plastic pellets are used and molded into new products, the new plastic products will have reduced physical properties. Sometimes, factories mix new plastic pellets to give the product better properties. This recycled plastic production process creates waste, including a large amount of solid waste. In 2017, the amount of solid waste throughout the country was 27.40 million tons, an increase from 2016, which had 27.06 million tons, accounting for 1.26 percent or 120,000 tons, while the rate of solid waste generation per person decreased from 1.14 kilograms/person/day in 2016, to 1.13 kilograms/person/day in 2017. The correct waste disposal increased from 9.57 million tons in 2016 to 11.70 million tons in 2017 and increased for use from 5.80 million tons to 8.52 million tons.

Due to the problems mentioned above, the researchers, therefore, had an idea to study the behavior of the tensile strength and flammability of mortar walls mixed with high-density polyethylene plastic waste [3]. The purposes are to examine the possibility of using plastic scraps instead of sand in producing plaster walls and to form a guideline for managing plastic waste for engineering benefits. The reason for choosing plastic waste is to put unused materials to good use and to manage pollution and the environment, reducing the amount of plastic waste that is often difficult to decompose [4].

MATERIALS AND METHODS

Materials used for testing

1. Portland cement type 1
2. Clean water
3. Plastic waste: high-density polyethylene (HDPE) plastic, as shown in Figure 1.

High-density polyethylene (HDPE) has a linear molecular structure. It is cheap, relatively hard but stretchable, and easy to mold. Commonly used to make packaging for cleaning liquids, shampoo, baby powder, and bags with handles, HDPE does not break easily and is resistant to chemicals. In addition, containers made from HDPE also have good properties for preventing moisture transmission [5, 6]. Therefore, this research chose to mix HDPE with mortar to reduce water absorption, increase mortar strength, and help with sound absorption.

4. fine river sand
5. Brick block size 0.07 x 0.19 x 0.39 m
6. Ready-made cement

Figure 1 High-density polyethylene plastic waste.

Test procedure

1. Testing the specific gravity of Type 1 Portland cement according to ASTM C188 [7].
2. The proportion of mortar, cement, sand, and water equals 1: 2.75: 0.485. Then, the high-density polyethylene (HDPE) plastic is mixed in the ratio of 2.5%, 5%, and 10% by weight to replace some amount of sand, as shown in Table 1.

Table 1 The ratio of mixing mortar and plaster.

Sample	Cement (g)	Sand (g)	HDPE waste (g)	Water (g)
Mortar Sand 100%	125	344	0	88
Mortar HDPE 2.5%	125	335	9	88
Mortar HDPE 5%	125	327	17	88
Mortar HDPE 10%	125	310	34	88

3. Analyzing the mix size and fineness modulus of fine aggregate according to ASTM C136 standard [8].
4. Testing the specific gravity value and absorption of fine aggregate according to ASTM C642 standards [9].
5. Test the flow of mortar (Flow Table) to find the flow rate of cement mortar and cement paste using a flow test table with accessories according to ASTM C230 standards [10].
6. A sample block of mortar was cast to test its tensile strength using a briquette mold measuring 7.5 cm x 2.5 cm x 4.5 cm and 2.5 cm thick according to the ASTM C190 standard [11], as shown in Figure 2.

Figure 2 Briquette mold.

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7. Density test of mortar mixed with plastic waste according to the standard test method of ASTM C642.

8. Curing 6 mortar blocks of every ratio of each type at the test ages of 7 days, 14 days, and 28 days.

9. Comparing the results of the study of mechanical properties with a tensile tester of concrete test samples at various mixed ratios to find the best and most appropriate properties.

10. Fire test according to the ASTM E119 standard for plaster mortar walls mixed with High-Density Polyethylene (HDPE) plastic [12].

Test method

1. Testing the physical properties of cement, fine sand, and HDPE plastic waste.

1.1 Testing the specific gravity of cement

The specific gravity of cement is the ratio of the weight of cement to the weight of water with an equal volume of cement. The specific gravity of Portland cement has a value of approximately 3.00 to 3.20, depending on the composition and fineness of the cement. In general, Portland cement type 1 has a value of approximately 3.15. The specific gravity of the cement indicates its composition and fineness [13].

1.2 Analyzing mix size and the fineness modulus of fine aggregate according to the ASTM C136, as shown in Figure 3 [14].

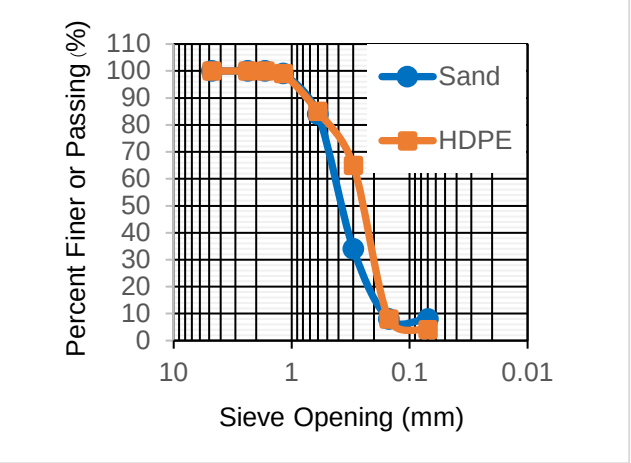

Figure 3 Mix size and fineness modulus of fine aggregate.

1.3 Testing the specific gravity and absorption of fine aggregate (Specific Gravity and Absorption of Aggregate) according to the ASTM C642 [15].

1.4 Testing the flow of mortar (Table 2) to find the flow rate of cement mortar and cement paste using a flow test table with accessories according to ASTM C230 standards.

1.5 Density test for mortar mixed with plastic waste (Table 2) according to the ASTM C642 standard [16].

Table 2 Density, water absorption, and fluidity values of mortar.

Sample	Plastic percentage (%)	Density value (g/cm^3)	water absorption (%)	Mortar flow (mm)
Reference	0.00	2.04 + 0.09	1.98	101.18 + 0.59
HDPEM2.5	2.50	1.10 + 0.05	6.83	104.23 + 2.68
HDPEM5	5.00	1.69 + 0.03	7.42	102.16 + 0.57
HDPEM10	10.00	1.65 + 0.02	7.91	106.26 + 1.93

2. Testing for tensile strength

The American standard test for tensile strength is the briquette of mortar, which consists of 1 part of cement and 3 parts of standard sand by weight. The sample briquette block used for this test is large at both ends and has a middle cross-section of 1 square inch. The amount of water used in the mix is calculated from the normal consistency of that type of cement.

Figure 4 Mortar tensile strength test.

After casting the mold and curing according to specified standards, testing was done to determine the tensile strength when the test blocks were of different ages, namely 7, 14, and 28 days. The tensile force used in the test must be applied uniformly at a rate of approximately 265 -285 kg/min. The average value of the tensile strength obtained must not be less than the values specified in the standard (which are 10, 20, and 25 kilograms per square centimeter) when the test bars are 7, 14, and 28 days old, respectively, as shown in Figure 4 [17].

where

$$F_c = \frac{P}{A} \quad (1)$$

Fc = ultimate tensile strength; the unit is kc.

P = tensile force, the units are kg.

A = Cross-sectional area of the sample bar, the unit is cm^2.

3. Plastered Wall Flammability Test

Combustion is a chemical reaction in which combustible material oxidizes with oxygen, releasing heat and converting it to oxide compounds or by-products. The complete combustion of fuel includes carbon dioxide and water. Incomplete combustion

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causes wasted fuel and air pollution. Therefore, knowing the principles of the combustion process and how to control complete combustion is very important for energy conservation and environmental protection. In addition, understanding the causes of heat loss in various forms of heat systems and equipment, along with prevention guidelines, will help improve the system's overall thermal energy efficiency to a higher level as well.

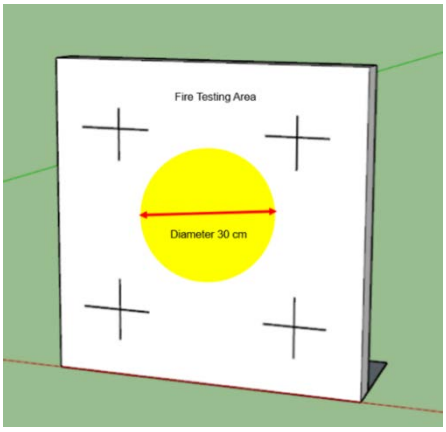
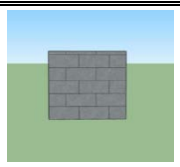
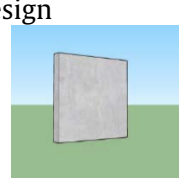
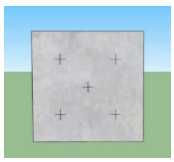


Figure 5 Components of fire testing of plaster walls.

Table 3 Procedures for fire testing of plaster walls.

No.	Model	Working characteristics
1	 Concrete block brick design	 Laying concrete blocks size 1 x 1 meter.
2	 Front-back concrete block plastering pattern	 They are plastering the front and back concrete block walls.
3	 Finding the intersection point to find the center of the circle.	 Drawing the center of a circle of radius 30 cm.
4	 Designing to burn with a gas torch.	 Burning the walls with a gas torch.

4. Procedure for testing the flammability of plaster walls

4.1 Building a 1 meter x 1 meter concrete block wall [18].

4.2 Plastering the walls with plaster mortar mixed with plastic waste in ratios of 0%, 2.5%, 5%, and 10% by weight instead of some sand.

4.3 Measuring in a circle with a diameter of 30 centimeters, as shown in Figure 5.

4.4 Installing gas torch burning equipment by measuring the plaster mortar wall to a distance of 5 centimeters.

4.5 Burning standard plaster mortar walls and mortar mixed with 2.5, 5, and 10 percent HDPE plastic waste by burning and analyzing the flammability of plaster walls at 30, 60, 90, and 120 seconds.

4.6 Comparing the fire characteristics of a standard mortar plaster wall with a plaster wall mixed with HDPE plastic waste. Details are as shown in Table 3 [19].

RESULTS AND DISCUSSION

Test results and discussion

This experimental study investigates investigate the possibility of using plastic waste, including high-density polyethylene (HDPE), for engineering purposes. The research results were obtained by collecting relevant information and conducting experiments in a laboratory.

Test results

1. Tensile strength test results

The tensile strength properties of mortar mixed with HDPE plastic waste decreased proportionately with increased plastic waste. This is because HDPE plastic particles are of various sizes and shapes, primarily small and delicate. The tensile strength of HDPEM2.5, HDPEM5, and HDPEM10 are equal to 45 ksc, 42 ksc, and 28 ksc, respectively, by the calculation formula (1). However, after 28 days, the tensile strength of HDPEM2.5 containing the lowest HDPE amount is equivalent to that of standard mortar, as shown in Table 4 and Figure 6.

From the test results of the tensile strength of mortar mixed with high-density polyethylene plastic in various amounts, it was shown that when comparing the general mortar with the mortar mixed with polyethylene plastic, the sample of 2.5% plastic mixed at the age of 28 days, was able to bear a tensile strength of 45 ksc, which has the same tensile test value as that of most common mortars. The high-density polyethylene plastic waste in the amount of 2.5% mixed in place of sand does not reduce its strength and helps to reduce the amount of sand used.

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Table 4 Examples of tensile strength test averages.

Sample	Tensile strength (ksc)		
	7 Day	14 Day	28 Day
Mortar Sand 100%	40	42	45
Mortar HDPE 2.5%	33	37	45
Mortar HDPE 5%	35	35	42
Mortar HDPE 10%	21	26	28

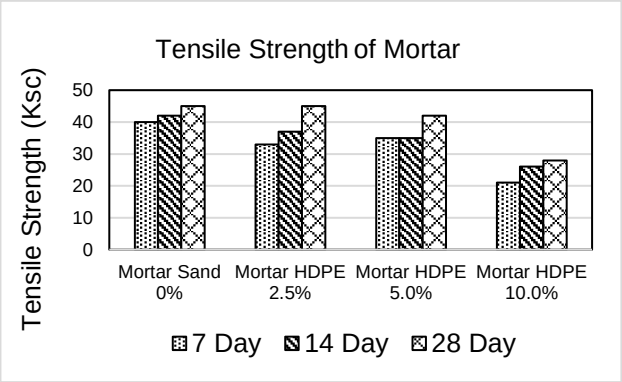

Figure 6 Tensile strength of plaster mortar mixed with HDPE plastic waste.

2. Results of the fire test of mortar walls

The flammability test of mortar walls mixed with high-density polyethylene plastic waste was performed with a gas torch by burning for 30, 60, and 120 seconds. The flammability characteristics of standard plastered mortar walls with mortar mixed with high-density polyethylene plastic waste are compared, as shown in Table 5 [20].

Table 5 Mortar wall flammability test.

Sample	Time		
	30 seconds	60 seconds	120 seconds
Mortar Sand 100%			
Mortar HDPE 2.5%			
Mortar HDPE 5%			
Mortar HDPE 10%			

The flammability test of the wall of mortar mixed with high-density polyethylene plastic in quantities of 2.5%, 5%, and 10%, was done with a burning period of 30 seconds, 60 seconds, and 120 seconds and with a 5 cm distance from the fire head to the wall. Images were taken, indicating that red stains began to appear during the first 30 seconds of burning. The red stains would expand only slightly until dark stains appeared. The higher the ratio of plastic used in place of sand and the longer the burning time, the more black marks appeared on the wall. However, there was no evidence of ignition or flames in the mortar plaster wall mixed with polyethylene plastic waste in all the ratios.

Discussion

The number of fine particles passing through sieves 50 and 100 affects fresh concrete's pourability, make-up, and greasiness (Bleeding), where the small particles allow the mortar to mix well. Therefore, the appropriate amount of fine particles is at least 15 percent passing through a No. 50 sieve and at least 5 percent through a No. 100 sieve. An amount greater than 5 percent of the particles to pass through a No. 200 sieve is not recommended because more water is used for mixing, and there is a high rate of change and contraction. The fineness of the aggregate can be seen from the fineness modulus (Fineness Modulus, F.M.) value. The fine aggregate suitable for the concrete mixture is between 2.30 - 3.20, with a lower value indicating more excellent fineness. According to the tests and analyses of the mixed sizes of two types of aggregate, namely sand and HDPE plastic, it is found that the F.M. values of sand and HDPE plastic are equal to 2.75 and 2.39, respectively, which are values within the excellent range [21].

The water absorption value affects the pourability of the mortar, as the dry aggregate absorbs water from the mortar mix, causing the mortar to lose some water and the pouring ability to be lower than designed. On the other hand, if the moisture content of the aggregate exceeds the saturation level, the dry surface will dehydrate the mortar mixture, causing the mortar to become too watery and making the water-to-cement ratio (w/c ratio) higher than designed, resulting in a low strength of the mortar. The experiment suggests that the water absorption value of the mortar mixed with HDPE plastic waste is higher than the standard. The water absorption values of HDPEM2.5, HDPEM5, and HDPEM10 are equal to 6.83%, 7.42%, and 7.91%, respectively, which is higher than standard mortar, which is equal to 1.98%. It can be seen that there is higher water absorption when the amount of HDPE plastic in the mortar increases; this is because the crushed HDPE plastic particles are small and spherical, causing the structure of the mortar to be porous despite the HDPE plastic properties, which have a low water absorption value. As a result of particle characteristics and the ability to absorb water, which is a unique property of each type of plastic, mortar mixed with HDPE plastic has higher water absorption than standard mortar [22].

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The density of the material affects the strength and performance of mortar mixed with plastic waste. This is because the density value decreases in proportion to the percentage of plastic replacing sand, which in turn varies with the amount of HDPE plastic waste. The density value of mortar mixed with HDPE plastic waste increases proportionally due to the mixed size of the aggregate, as the aggregate has excellent and weighty particles. The densities of HDPEM2.5, HDPEM5, and HDPEM10 are equal to 1.10 g/cm^3, 1.69 g/cm^3, and 1.65 g/cm^3, respectively, and affect the mortar's strength properties. The density of mortar mixed with HDPE plastic waste is noted to be lower than that of standard mortar [23].

The mortar flow test is the first step in designing the mix for casting the mortar sample. This gives an idea of the liquidity of the mixture ratio for use. The flow rate value in the test aligned with the standard. It was found that the value went between 100 - 115 percent of the water used, indicating the appropriate amount of water used in casting the mortar samples. The appropriate spread rate of the mortar mixed with HDPE plastic waste was within the specified standards. The flow spread values of HDPEM2.5, HDPEM5, and HDPEM10 mortars equal 104.23 percent, 102.16 percent, and 106.29 percent, respectively.

Briquette mold mortar samples mixed with HDPE plastic waste of size 7.5 cm x 2.5 cm x 4.5 cm, thickness 2.5 cm, were tested for tensile strength. Six samples of each type of mixture, at 7, 14, and 28 days of curing, were sampled and tested for the tensile strength exerted on the cross-sectional area of the mortar sample. The results suggest that the mortar mixed with HDPE plastic waste decreases tensile strength properties because HDPE plastic particles are of mixed sizes have small particles and acceptable density. From the tensile strength test at 28 days, the tensile strengths of HDPEM2.5, HDPEM5, and HDPEM10 were 45 ksc, 42 ksc, and 28 ksc, respectively. It should be noted that the HDPEM 2.5 mortar at 28 days (45 ksc) has the same value as standard mortar, showing the efficiency in supporting lateral loads and the cracking behavior of the mortar that will be used in construction. Another facet of the experiment showed that replacing sand with high-density polyethylene plastic waste could increase the tensile strength, as shown in Table 4. Still, it is recommended that the amount not exceed 10% to comply with the mortar tensile strength standards. (Cement mortar samples aged 28 days must not be less than 25 kg/cm^2 (ksc). The trend indicates that replacing high-density polyethylene plastic waste decreases the tensile strength [24].

Comparing the fire characteristics of standard mortar plaster walls with mortar mixed with HDPE plastic waste, it was found that the flames on the standard mortar plaster walls did not change their original color from the gas torch, but the flame characteristics of the mortar wall mixed with HDPE plastic waste had a spreading characteristic. The color of the flame turned orange. This is because the mixture is explosive and easily creates heat around the walls, resulting in the color change. As the proportion of plastic waste increased, the walls got more serious burns and were left with more black stains on the surface. Various proportions of sand replacement and the duration of the fire test at the same distance did not affect the flammability time or the damage from burning on the cement surface [25].

CONCLUSIONS

The study's findings indicate that the inclusion of HDPE plastic waste has an impact on both the tensile strength and flammability of mortar walls. The selection of HDPE plastic was based on its high density, chemical resistance, and heat resistance, which make it well-suited for the intended uses. The research suggests the potential for using different types of plastic waste to further investigate their effects on the tensile strength and flammability of plastered mortar walls. This approach aligns with efforts to enhance the physical and mechanical properties of cement while promoting environmentally friendly construction materials by reducing natural sand usage and plastic waste in the environment.

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