A Cost-Benefit Analysis of Roof Tiles with Polyethylene Terephthalate and Concrete Waste in Construction Industry

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Abstract— **Roofing is an essential aspect in construction as it acts as the cover in between the interior and exterior of the structure. With the growing concern in sustainability and affordability in the construction industry, the utilization of recycled materials is becoming rampant. That said, the use of Polyethylene Terephthalate (PET) and concrete waste in the form of fine recycled concrete aggregates are employed in the formulation of roof tiles. This study observed three (3) ratios consisting of 50% PET and 50% concrete waste, 60% PET and 40% concrete waste, and 40% PET and 60% concrete waste. This experimental research aimed to determine the drop resistance, water absorption rate using American Society for Testing Materials (ASTM) C140 and ASTM D570, heat resistance using Differential Scanning Calorimetry in compliance to ASTM D3418, and scratch resistance using Mohs Hardness Scale of the roof tiles with PET and concrete waste. The 50% PET and 50% concrete waste governed with positive results on the implemented testing methods. A simple cost-benefit analysis was created based on the findings on the 50% PET and 50% concrete waste, with the selected concrete roof tiles, clay roof tiles, and galvanized roof which aims to initiate the use of roof tiles with PET and concrete waste in the manner of achieving sustainability and affordability of materials in the construction industry.**

Index Terms— **Roofing, Polyethylene Terephthalate, concrete waste, fine recycled concrete aggregates, sustainability, cost-benefit analysis.**

1. Introduction

The construction industry continues to expand due to the increasing standard of living and population, with that, the construction waste also continues to grow which greatly impacts the environment.

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Construction waste is still affecting the environment in terms of soil, agricultural land and air pollution. It also has a negative impact on the generation of waste. This waste came from the structures and buildings of the projects, and the materials that were used during and after the construction of projects. Approximately, 10-30% of these materials are being disposed of on landfill sites all over the world. Construction and demolition waste are difficult to dispose of since they contain other hazardous matters such as asbestos, heavy metals, persistent organic compounds, and volatile organic compounds [1].

As modern concrete buildings will be facing the end of their useful life, there will be no use that can be found for them as their concrete may fail due to its age. With the flexibility and adaptability of the concrete, demolished structures may provide potentially a rich source of recycled aggregate for a wide array of applications. That said, recycled concrete has been proven with a feasible source of aggregate that can be used in granular subbases, soil-cement, and in as new concrete form. In line with that, recycled aggregates can be classified into two ways, which are a.) Recycled Aggregate (RA), and b.) Recycled Concrete Aggregate (RCA). Moreover, with the growing rate of the usage of recycling construction waste materials, recycled and secondary aggregates are found to have accounted for 28 percent of the total market — highest in Europe. As stated, recycled concrete is applicable for aggregate for new concrete, mainly on the coarse portion [2].

In recent times, there is an extensive development of numerous sustainable materials that are being integrated with building structure designs. As a result, an increase of sales as well as competitions in building industry companies is prominent. On the other hand, while achieving the goal of being a modern and lavish society, people are unaware of its negative effect on the environment. Designing the structure of a building is very crucial. Aside from being convenient to users, it must also implement the notion of environmental preservation.

In all intents and purposes of sustainable concepts, a variety of determinants on present roof tiles have been examined. As an outcome, there were nine (9) elements of roof tile options that went through tests [3].

Polyethylene Terephthalate (PET), a semi-crystalline thermoplastic polyester, has become a major source of plastic pollution. The vast majority of PET consumption worldwide is for synthetic polymers. PET bottles are frequently used for carbonated beverages. PET is an extremely compact material that can be semi rigid or rigid. The most important polyester is Polyethylene Terephthalate (PET). When subjected to quick cooling, PET behaves as a transparent, amorphous thermoplastic, but when cooled slowly or cold-drawn, it behaves as a semi-crystalline plastic. PET is made by polycondensation ethylene glycol and terephthalic acid. PET can be molded using standard techniques such as injection molding, blown molding, and extrusion. It can also be used to make thin layer items like stretched film and thermoforming. Because of its high strength and toughness, outstanding abrasion and heat resistance, low creep at elevated temperatures, superior chemical resistance, and excellent dimensional stability, PET is frequently utilized to manufacture carbonated beverage bottles [4].

Creating a roof tile that is cheaper, stronger, and way more environmentally friendly is needed to lessen the negative effects of creating traditional roofing to the environment and to reduce the cost in the roofing construction of residential and commercial buildings.

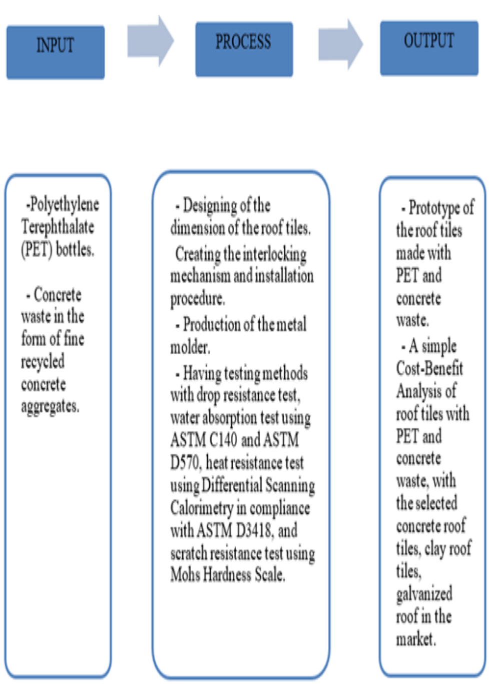

Fig.1. Conceptual Framework

2. Methodology

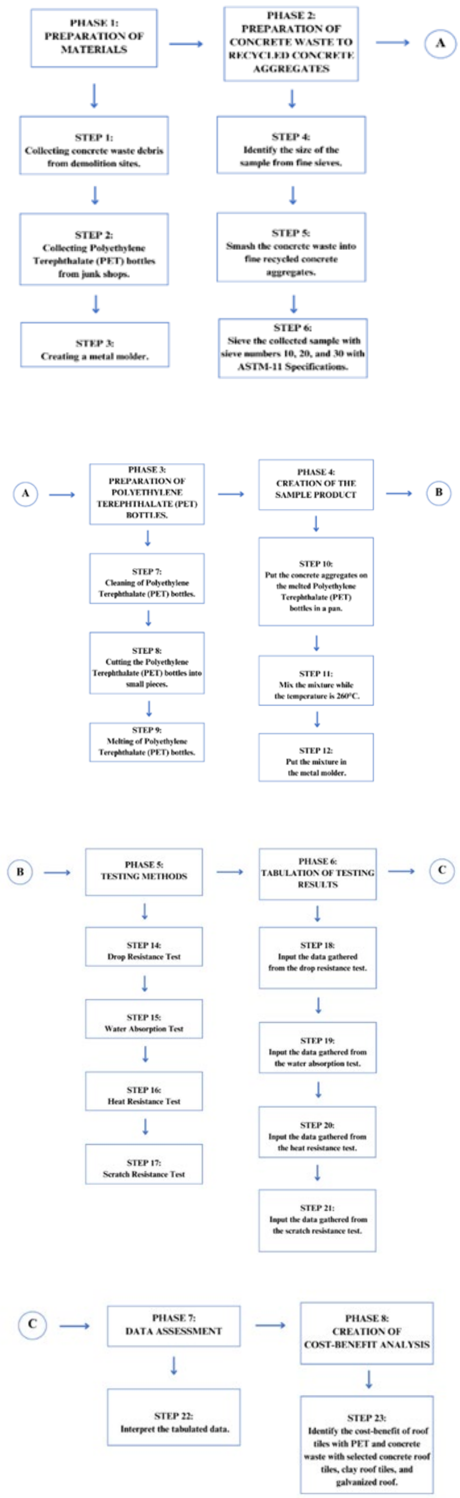

Fig.2. Process Flowchart

A. Formulation of Samples

In creating the sample product, it is identified the specific material ratio of Polyethylene Terephthalate and Recycled Concrete Aggregates including the reinforcement of the sample. The table below shows the number of materials used.

Sample	Polyethylene Terephthalate (grams)	Fine Recycled Concrete Aggregate (grams)	Reinforcement
Sample 1	1,200	800	SS304 Stainless Steel Welded Wire Mesh
Sample 2	800	1,200	SS304 Stainless Steel Welded Wire Mesh
Sample 3	1,000	1,000	SS304 Stainless Steel Welded Wire Mesh

Fig.3. Sample Ratio

B. Proposed Design of the Roof Tile

Fig.4.1. Top View

Fig.4.2. Side View

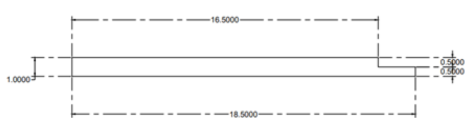

Fig.4.3. Rear View

C. Preparation of Roof Tiles Metal Molder

The created a design of the molder based on the existing dimensions of a roof tile in the market. The design of the interlocking mechanism of the molder is based on the desired mechanism, as well. The dimension of the metal molder is 265 mm. x 165 mm. with a 20 mm. interlocking mechanism.

Fig.5. Metal Molder

D. Preparation for wire mesh reinforcement

The SS304 Stainless Steel Welded Wire Mesh is used due to its economic value as the steel reinforcement of the roof tile. It is cut into the exact dimension of the metal molder and placed in the middle.

Fig.6. Installation of Wire Mesh

E. Sieving of the crushed recycled concrete aggregate

The sieve used falls under the ASTM-11 specifications. The sieve numbers used are smaller than 5 millimeter as per the classification of fine recycled concrete aggregates. Therefore, the accustomed sieve numbers are as follows: a.) Sieve No. 10, b.) Sieve No. 20, and c.) Sieve No. 30. The retained weight of each sieve is taken into record in the determination of the particle size distribution of the sample products.

Fig.7. ASTM-11 Sieve Set

F. Melting Polyethylene Terephthalate in a shack

The melting of PET bottles must be done outside with a well-ventilated shack primarily away from residential areas to minimize the health risk imposed by melting Polyethylene Terephthalate. PET is classified as a linear thermoplastic polyester made after the condensation reaction of ethylene glycol and terephthalic acid known to be as the purified terephthalic acid (TPA). PET has no carbon atoms with its main chain, and during the condensation reaction, PET may come in both amorphous and a semi-crystalline polymer. On that note, the glass-transition of amorphous PET is up to 67 degrees Celsius and 81 degree Celsius for crystalline PET, given the melting point to be 260 degree Celsius [5]. Kerosene, gasoline, and other flammable chemicals are not used in the process; instead leaves, tree branches, and other materials such as used papers are used in making the small base fire for melting procedure. The following are considered for safety measures to avoid health conflict:

- The use of fire-resistant gloves to ensure that there is no direct contact on the substances.
- The use of eye protective goggles to prevent chemicals from damaging the eyes.
- The use of industrial face masks against harmful gas and to make sure that no one will breathe hazardous substances.
- The use of a lab gown to give protection to the shirt from dirt and splashes.

G. *Pouring the mixture in the molder*

The melted mixture of Polyethylene Terephthalate and fine recycled concrete aggregate will then be placed right after to the metal molder with the steel reinforcement.

Fig.8. Pouring the mixture

H. *Curing of the Sample*

The sample will be left for 15 to 20 minutes in the molder to let the mixture cool down and to keep the steel reinforcement compressed, preventing it from further bending.

Fig.9. Curing of Sample

3. Results And Discussions

A. *Drop Resistance Test*

The drop resistance test is performed in order to determine the fall off capacity of a roof tile with Polyethylene Terephthalate and recycled concrete aggregate. It is identified the height of the fall as 1 meter, 2 meters, and 3 meters. The physical evaluation describes the situation of the roof tile after a specific fall.

The sample with 60% Polyethylene Terephthalate and 40% recycled concrete aggregates. The physical evaluation for the sample which underwent the 1-meter drop, few destructions on the edge of the sample has been observed. After experiencing a 2-meter drop, the reinforcement on the edge of the sample has become visible, implying more damage within the area with reinforcement. For the 3-meter drop, severe damage has been observed, small particles are scattered after the sample has been dropped.

The sample with 40% Polyethylene Terephthalate and 60% recycled concrete aggregates. The physical evaluation for the sample which underwent the 1-meter drop, minimal damage on the edge of the sample has been observed. After experiencing a 2-meter drop, destruction on the side of the sample for interlocking mechanism has been seen since it has much thinner width compared to the main body of the sample. For the 3-meter drop, damages on the edge have been observed. Reinforcement has not become exposed with all the height of drop falls.

The sample with 50% Polyethylene Terephthalate and 50% recycled concrete aggregates. The physical evaluation for the sample which underwent the 1-meter drop, no damage has been observed. After experiencing a 2-meter drop, minor damages on the edge have been observed. For the 3-meter drop, the sample has experienced few minor damages which are present on the tip edge.

B. *Water Absorption Test*

The water absorption test is performed to determine the amount of the quality moisture that a roofing material will be able to absorb. As such, it is being expressed in percent form and it indicates the water weight in relation to the dry weight of the roofing tile [6]. The samples' dimensions have been measured along with their received weight, saturated weight, immersed weight, oven-dry weight, density, net volume, net area, absorption, and moisture content after being soaked with water for 24 hours and oven-dried for another 24 hours. The testing is conducted at the Smart K Materials Testing Laboratory, Inc. at Sindalan, City of San Fernando, Pampanga, Philippines following the ASTM C140 and ASTM D570.

The results for water absorption of the 3 samples with 60% Polyethylene Terephthalate and 40% concrete waste ratio. The lengths have been noticeably seen that vary with minimal amount while the width and height remain all the same. The received weight of the first sample is 0.709 kilogram followed by 0.755 kilogram and 0.762 kilogram of the second and third sample, respectively. For the saturated and immersed weight of the samples in kilograms, the results are 0.727 kilogram and 0.705-kilogram, 0.764 kilogram and 0.689 kilogram, and 0.775 kilogram and 0.713 kilogram for samples 1, 2, and 3, respectively. The oven-dry weight of sample 1 is 0.677 kilogram, for sample 2, 0.693 kilogram, and 0.696 kilogram for sample 3. The calculated density of the samples 1, 2, and 3 are 30,773 kilograms per cubic meter, 9,240 kilograms per cubic meter, and 11,226 kilograms per cubic meter, successively. For the net volume, sample 1 has 22 cubic centimeters, sample 2 has 75 cubic centimeters, and sample 3 has 62 cubic centimeters. Meanwhile, the computed net area of sample 1 is 122 square millimeters, for sample 2, 417 square millimeters, and sample 3 with 344 square millimeters. The absorption rate of the samples 1, 2, 3 in percentage are 7.39%, 10.25%, and 11.35%, consecutively. Lastly, for the moisture content in percentage of the total absorption, sample 1 has 64.00%, sample 2 obtained 87.32%, and sample 3 has 83.54%.

The average percentage of absorption rate of the 60% Polyethylene Terephthalate and 40% concrete waste ratio is 9.66% and the average percentage of the moisture content is 78.25%.

The results for water absorption of the 3 samples with 40% Polyethylene Terephthalate and 60% concrete waste ratio. The lengths have been noticeably seen that vary with minimal amount while the width and height remain all the same. The received weight of the first sample is 1.69 kilograms followed by 1.28 kilograms and 1.29 kilograms of the second and third sample, respectively. For the saturated and immersed weight of the samples in kilograms, the results are 1.86 kilograms and 1.23 kilograms, 1.23 kilograms and 1.195 kilograms, and 1.24 kilograms and 1.199 kilograms for samples 1, 2, and 3, respectively. The oven-dry weight of sample 1 is 1.07 kilograms, for sample 2, 1.21 kilograms, and 1.22 kilogram for sample 3. The calculated density of the samples 1, 2, and 3 are 1,685 kilograms per cubic meter, 34.629 kilograms per cubic meter, and 29,756 kilograms per cubic meter, successively. For the net volume, sample 1 has 635 cubic centimeters, sample 2 has 35 cubic centimeters, and sample 3 has 41 cubic centimeters. Meanwhile, the computed net area of sample 1 is 3,969 square millimeters, for sample 219 square millimeter, and sample 3 with 256 square millimeters. The absorption rate of the samples 1, 2, 3 in percentage are 73.83%, 1.49%, and 1.64%, consecutively. Lastly, for the moisture content in percentage of the total absorption, sample 1 has 78.48%, sample 2 obtained 377.78%, and sample 3 has 350.00%.

The average percentage of absorption rate of the 40% Polyethylene Terephthalate and 60% concrete waste ratio is 1.565% excluding the failed sample and the average percentage of the moisture content is 363.89% excluding the failed sample.

The results for water absorption of the 3 samples with 50% Polyethylene Terephthalate and 50% concrete waste ratio. The lengths have been noticeably seen that vary with minimal amount while the width and height remain all the same. The received weight of the first sample is 0.920 kilogram followed by 0.947 kilogram and 0.948 kilogram of the second and third sample, respectively. For the saturated and immersed weight of the samples in kilograms, the results are 0.933 kilogram and 0.890-kilogram, 0.962 kilogram and 0.903 kilogram, and 0.971 kilogram and 0.910 kilogram for samples 1, 2, and 3, respectively. The oven-dry weight of sample 1 is 0.884 kilogram, for sample 2, 0.934 kilogram, and 0.942 kilogram for sample 3. The calculated density of the samples 1, 2, and 3 are 20,558 kilograms per cubic meter, 15,831 kilograms per cubic meter, and 15,443 kilograms per cubic meter, successively. For the net volume, sample 1 has 43 cubic centimeters, sample 2 has 59 cubic centimeters, and sample 3 has 61 cubic centimeters. Meanwhile, the computed net area of sample 1 is 246 square millimeters, for sample 2, 337 square millimeters, and sample 3 with 349 square millimeters. The absorption rate of the samples 1, 2, 3 in percentage are 5.54%, 3.00%, and 3.08%, consecutively. Lastly, for the moisture content in percentage of the total absorption, sample 1 has 73.47%, sample 2 obtained 46.43%, and sample 3 has 20.69%.

The average percentage of absorption rate of the 50% Polyethylene Terephthalate and 50% concrete waste ratio is 3.87% and the average percentage of the moisture content is 46.86%.

C. Differential Scanning Calorimetry (Heat Resistance Test)

The Differential Scanning Calorimetry (DSC) is performed in the determination of thermal analysis with the presence of endothermic processes with melting and solid-solid phase transmission, and exothermic processes with crystallization and oxidative decomposition [7]. The testing method used follows ASTM D3418, the standard test method for transition and enthalpies of fusion and crystallization of polymers. The measuring cell is Perkin Elmer DSC 4000, the sample holder is a crimped standard aluminum pan, the temperature program is heating from 30 degree Celsius to 400 degree Celsius at 20 degree Celsius per minute, and the atmosphere is nitrogen at 20 milliliter per minute. The testing method is conducted at Advanced Device and Materials Testing Laboratory at the Department of Science and Technology, Taguig City, Philippines.

The results of the differential scanning calorimetry of the 50% Polyethylene Terephthalate and 50% concrete waste ratio. The observed glass transition temperature is 70.43 degree Celsius. The peak temperatures and enthalpies are done with 3 points of observations. With an area of 0.543 millijoule, and delta H of 0.1055 Joule per gram, the peak temperature is 129.58 degree Celsius. With an area of 4.238 millijoules and delta H of 0.8233 Joule per gram, the peak temperature is 172.91 degree Celsius. With an area of 134.514 millijoules and delta H of 26.1344 Joule per gram, the peak temperature is 228.20 degree Celsius.

The results of the differential scanning calorimetry of the 60% Polyethylene Terephthalate and 40% concrete waste ratio. The observed glass transition temperature is 67.63 degree Celsius. The peak temperatures and enthalpies are done with 3 points of observations. With an area of 3.191 millijoule, and delta H of 0.6017 Joule per gram, the peak temperature is 130.55 degree Celsius. The peak temperature of 213.54 degree Celsius has no value of enthalpy. With an area of 253.481 millijoules and delta H of 47.7995 Joule per gram, the peak temperature is 235.76 degree Celsius.

The results of the differential scanning calorimetry of the 40% Polyethylene Terephthalate and 60% concrete waste ratio.

The observed glass transition temperature is 70.29 degree Celsius. The peak temperatures and enthalpies are done with 3 points of observations. With an area of 1.075 millijoule, and delta H of 0.1930 Joule per gram, the peak temperature is 129.60 degree Celsius. With an area of 6.376 millijoule, and delta H of 1.1445 Joule per gram, the peak temperature is 176.59 degree Celsius. With an area of 115.009 millijoules and delta H of 20.6443 Joule per gram, the peak temperature is 225.89 degree Celsius.

D. Mohs Hardness Scale (Scratch Resistance Test)

The Mohs Hardness Scale is used to determine the hardness of an object to its relative resistance to scratching that is measured by scratching minerals of common objects. The common objects that are used with scale numbers are the following: a.) masonry drill bit with 8.5, b.) steel nail with 6.5, c.) knife with 5.5, d.) copper with 3.5, and e.) finger nail with 2.5 [8].

The test report for 50% Polyethylene Terephthalate and 50% Concrete Waste ratio using Mohs Hardness Scale. The sample is seen with visible and minimal holes on the surface after being scratched by a masonry drill bit with a correspondent scratch rate of 8.5. Upon scratching a steel nail with a 6.5 scratch rate, the sample is seen with light depth, visible scratches on its surface. Meanwhile, for the knife and copper, having scratch rate of 5.5 and 3.5, respectively, the sample is seen with visible scratches, and light scratches on the exposed surface, correspondingly. After scratching a fingernail with a scratch rate of 2.5, the sample has been seen with no scratches.

The test report for 60% Polyethylene Terephthalate and 40% Concrete Waste ratio using Mohs Hardness Scale. The sample is seen with more in depth, visible scratches on the surface after being scratched by a masonry drill bit with a correspondent scratch rate of 8.5. Upon scratching a steel nail with a 6.5 scratch rate, the sample is seen with visible scratches on its surface. Meanwhile, for the knife and copper, having scratch rate of 5.5 and 3.5, respectively, the sample is seen with visible minimal scratches, and light scratches on the exposed surface, correspondingly. After scratching a fingernail with a scratch rate of 2.5, the sample has been seen with no scratches.

The test report for 60% Polyethylene Terephthalate and 40% Concrete Waste ratio using Mohs Hardness Scale. The sample is seen with slightly deep visible scratches on the surface after being scratched by a masonry drill bit with a correspondent scratch rate of 8.5. Upon scratching a steel nail with a 6.5 scratch rate, the sample is seen with visible light in deep scratches on the surface. Meanwhile, for the knife and copper, having scratch rate of 5.5 and 3.5, respectively, the sample is seen with visible minimal scratches, and light scratches on the exposed surface, correspondingly. After scratching a fingernail with a scratch rate of 2.5, the sample has been seen with no scratches.

4. Cost-Benefit Analysis

The cost breakdown of roof tiles with Polyethylene Terephthalate and concrete waste. The materials under capital costs are PET bottles, concrete waste, SS304 Stainless Steel Welded Wire Mesh amounting to PHP 20.00 per kilogram, PHP 10.00 per kilogram with the crusher included, and PHP 4.00 per 250mm x 150mm. In terms of equipment under capital costs, are metal molder, fire-resistant gloves, eye protective goggles, industrial face mask, and laboratory gown amounting to PHP 400.00, PHP 150.00, PHP 180.00, PHP 130.00, and PHP 169.00, accordingly. As per the labor costs under implementation cost, the man hour per day is PHP 650.00. For the installation costs under implementation cost are underlayment, drip edges, nails, batten, board, silicone based-sealant, and ordinary gutter amounting to PHP 1,000.00 per linear meter, PHP 560.00 per linear meter, PHP 0.82 per 12 pieces, PHP 480.00 per piece, PHP 425.00 per piece, PHP 130.00, and PHP 107.00 per linear meter, respectively. For the maintenance cost, the labor is amounting to PHP 650.00-man hour per day, and repairs with downtime amounting to PHP 5,000.00 - PHP 20,000.00 per square meter.

COST				
	Roof Tiles with PET and Concrete Waste	Concrete Roof Tiles	Clay Roof Tiles	Galvanized Roof
Capital Costs				
Materials	PHP 35.00 per piece	PHP 120.00 per piece	PHP 180.00 per piece	PHP 210.00 per piece
Equipment	PHP 65.00 per piece	PHP 300.00 per piece	PHP 150.00 per piece	PHP 115.00 per piece
Implementation Costs				
Labor	PHP 650.00 man hour per day	PHP 650.00 man hour per day	PHP 650.00 man hour per day	PHP 650.00 man hour per day
Installation	PHP 150.00 per piece	PHP 250.00 per piece	PHP 350.00 per piece	PHP 225.00 per piece
Maintenance Costs				
Labor	PHP 650.00 man hour per day	PHP 650.00 man hour per day	PHP 650.00 man hour per day	PHP 650.00 man hour per day
Repairs with downtime	PHP 5,000 – PHP 20,000	PHP 10,000 - PHP 350,000	PHP 10,000 - PHP 350,000	PHP 5,000 – PHP 20,000

Fig.10. Cost

The cost breakdown of concrete roof tiles. The materials under capital costs are cement and sand amounting to PHP 6.00 per kilogram and PHP 2.50 per kilogram, respectively. For equipment under capital costs are one unit of concrete roof machine, one unit of wet mixer standard, one set of ridge mold, and one unit sand sieve amounting to PHP 560,000.00, PHP 196,000.00, PHP 196,000.00, and PHP 84,000.00, correspondingly. In results for the total computation cost of the equipment is based on the production rate of 3360 per day and divide it by the total amount of PHP 1,036,000.00 is equivalent to PHP 310.00 per piece. For labor cost under implementation cost is worker amounting to PHP 650.00 man hour per day. Under installation costs amounting to PHP 4,000.00 is, then, divided by 16 pieces per linear meter equated to PHP 250.00 per piece. For the maintenance cost, under labor cost is worker amounting to PHP 650.00 per day, and repairs with downtime amounting to PHP 10,000.00 - PHP 350,000.00.

The cost breakdown of clay roof tiles. Under capital costs is material with clay amounting to PHP 180.00 per piece. With equipment are one unit of industrial kiln, and molder amounting to PHP 500,000.00 and PHP 40,000.00, respectively. The computation for the equipment is also based on the production rate of 3,360 per day and divide it by the total amount of PHP 540,000.00 which is equal to PHP 160.00 per piece. The labor cost under implementation cost is worker amounting to PHP 650.00 man hour per day. For installation cost under implementation cost amounting to PHP 6,000.00 which is, then, divided by 18 pieces per linear meter equated to PHP 340.00 per piece. Under labor cost in maintenance cost is worker amounting to PHP 650.00 man hour per day, and repairs with downtime amounting to PHP 10,000.00 - PHP 350,000.00.

The cost breakdown for galvanized roofs. Under capital costs is material with a galvanized roof amounting to PHP 210.00 per linear meter. For equipment under capital costs is a high speed galvanized corrugated iron sheet making machine amounting to PHP 804,127.50. In results for the total computation cost of the equipment is based on the production rate of 15 pieces per minute which is multiplied by 60 minutes or 1 hour and multiply by 8 hours is equal to 7,200 per day, then divide it by the amount of the equipment of PHP 804,127.50 is equivalent to PHP 115.00 per piece. Under labor cost in implementation cost is worker amounting to PHP 650.00 man hour per day. For the installation costs under implementation cost amounting to PHP 750.00 per linear meter is multiplied by 30% is equal to PHP 225.00 per piece. In labor cost under maintenance cost is worker amounting to PHP 650.00 man hour per day, and repairs with downtime for PHP 5,000.00 - PHP 20,000.00 per square meter.

BENEFIT				
	Roof Tiles with PET and Concrete Waste	Concrete Roof Tiles	Clay Roof Tiles	Galvanized Roof
Cost	Materials are accessible and the materials that are being used are cheap and recyclable.	Materials are easy to find and affordable.	Materials are accessible but quite expensive.	Materials are accessible and can save up for the long run.
Durability	After conducting the different testing, the durability of this product is strong since it just had minimal cracks and light scratches, low in water absorption of 3.87% and lastly, it obtained a glass transition temperature of 70.43 degrees Celsius.	The durability of this product is it can easily break after conducting drop tests, cracks and light scratches are visible, low in water absorption of 3% and lastly, it can withstand different weather conditions.	It can withstand different weather conditions, it can break easily after the drop test and obtained a water absorption rate of 17.26%.	It is more durable and it can also withstand extreme weather.
Installation	Can be installed easily because it has an interlocking mechanism.	Safe and can be installed easily.	Can be installed easily.	Installed with the use of welding assuring that it was all safe.
Maintenance Cost	Less in maintenance cost since it was made in a mix of concrete and PET.	Does not require heavy maintenance procedures.	Requires less materials which makes it low maintenance cost.	Maintenance procedure is easy to conduct.
Aesthetic	Much more aesthetically appealing due to its shape.	Can be used for traditional structures.	Can be placed in different styles, positions and can create multiple designs.	Had different options in terms of shape and colors.
Environmental Impact	Helps the environment to lessen the usage of the plastic and promotes reduce, reuse and recycle program.	Produced without any other chemicals and can be recycled.	Does not harm the environment since its main material is clay.	Recyclable and in the long run, can save other resources.

Fig.11. Benefit

5. Conclusion

In coming up with the conclusion, it was found out that the 50% PET and 50% concrete waste had the best resistant to 1-, 2-, and 3-meter drop as it had no physical damage upon experiencing 1 meter drop, minor damages on the edge for a 2-meter dropping, and few minor damages on the edge for the 3-meter damage. That said, the composition of this sample is suitable for the roof tiles in order for it to be resistant enough for drop in comparison to the other two samples.

In terms of the water absorption test, it has been found that the 60% PET and 40% concrete waste has the lower water absorption average percentage of 1.565. On that note, the governing sample is classified as an impervious tile due to it is less than 5% of water absorption rate.

For the differential scanning calorimetry, it has been found that the 50% PET and 50% concrete waste has a glass transition temperature of 70.43 degree Celsius, and peak temperatures of 129.58 degree Celsius, 172.91 degree Celsius, and 228.20 degree Celsius, with enthalpies of 0.1055 Joule/gram, 0.8233 Joule/gram, and 26.1344 Joule/gram governs. The 50:50 ratio had the highest glass transition temperature due to the balance ratio of PET and concrete waste which equalizes the amount of crystallized volume and concrete volume of the sample leading to higher glass transition temperature.

In terms of the scratch resistance using Mohs hardness scale, the 50% PET and 50% concrete waste ratio, and 40% PET and 60% concrete waste ratio has almost the same scratch resistance. The results determined the scratch resistance of these two samples, from visible scratches, light-depth scratches, visible scratches, light scratches, and no scratches at all, respectively.

With the conducted testing methods, the 50% PET and 50% concrete waste ratio governs and is used in the formulation of a simple cost-benefit analysis in comparison to the selected concrete roof tile, clay roof tile, and galvanized roof in the construction industry. It was found that in the cost-benefit analysis, in terms of costing, the roof tile with PET and concrete waste has much lower costs — cheaper compared to the other roofing materials in terms of materials, equipment, installation cost, and maintenance cost.

For the benefit, roof tile with PET and concrete waste is more durable after conducting different testing. It can be easily installed and importantly, it has a positive impact on the environment. Moreover, it can potentially lessen the pollution with the use of PET as it also promotes the conduct of the 3R Project (Reduce, Reuse and Recycle) since the materials used are to be disposed of.

With all the testing methods and analysis conducted, it is concluded that the roof tile with PET and concrete waste performed better in its respective testing methods. In terms of the costing, galvanized roof has been proven to be cheaper, but in the overall strength and capacity, the roof tile with PET and concrete waste demonstrates cost effectiveness.

That said, the production of roof tiles with PET and concrete waste in the form of fine recycled concrete aggregates must be introduced to conserve materials and produce a better composited roof tiles in the construction industry.

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