CREATING POLYMER MATRIX CERAMIC REINFORCED ROOF TILES UTILIZING RECYCLED PLASTIC MATERIALS

PhD. Indrit Vozga, Prof. Vladimir Kasemi

Production and Management Department, Mechanical Engineering Faculty,
Polytechnic University of Tirana

DOI <10.26821/IJSHRE.9.1.2021.9105>

Abstract: The aim of this paper is to show improved roof tile constituents to achieve the desirable engineering properties of low weight, high strength, and low water adsorption. Plastics are non-biodegradable materials, so nature cannot dissolve them as other waste. The purpose of this research is to provide an alternative to other traditional building technologies that consume non-renewable resources, or produce negative environmental impact. We also open a way for the utilization of Polyethylene plastic as substitute for concrete in developing roof tiles that will meet the ASTM requirements in order to help contribute to the industry in saving the environment. We encourage the government to grand solutions regarding the disposal in landfills of solid waste materials, to provide new knowledge to the contractors and developers on how to improve the construction industry methods and services by using recycled plastic material.

Keywords: Polyethylene, low weight, Composite Roof Tile

1. INTRODUCTION

Roof is one of the most important part of a building and many efforts have been made to create practice and innovative solutions for their creation. Roofing materials and techniques have significantly developed time after time; as architecture has progressed, so has the design and production of roofs and the architectural influences of each era can be clearly identified.

Tile roofing has long been considered a prevalent technique when installing a new roof to your home because of its aesthetic appeal. Most importantly, a tile roof is great for insulation and protection against the elements which include strong winds, inclement weather, fires, and earthquakes.

The fundamental function of roof tiling is to keep the building watertight, to give it a decent cap on the off chance that you like. But tiling is about significantly more than that. They are highly visual parts of a building, which add to the character of our townscapes in each viewpoint, from domestic dwellings to buildings of high historical importance (Taylor, 2008).

Scope and Limitation

The scope of this study aims to determine the capability of recycled PE plastic waste to act as a binder for roof tile aggregates as a substitute for cement. Due to high cost of cement in the market, the analysis of PE plastic waste will reveal that this could be a substitute material to help reduce the cost of the construction. Also, this research includes the determination and computation of the cost of materials.

The product of this study is limited only to the material itself, to investigate the potential of PE plastic waste for being used as a roof tile, and does not concern the type, design and installation process of the roofing tiles.

This study also includes testing and identifying the water absorption, compressive strength, flexural strength and density of the roof tile but not to guarantee to attain the minimum required strengths for roof tiles.

2. LITERATURE REVIEW

Polyethylene (PE)

Polyethylene is of low strength, hardness and rigidity, but has a high ductility and impact strength as well as low friction. It shows strong creep under persistent force, which can be reduced by addition of short fibers. It feels waxy when touched.. It is known as a long-chain hydrocarbon. The unique property that polyethylene has is that it can be in rigid form or foamed, and can be shaped and moulded very easily because it is a thermoplastic [1].

Polyethylene (PE) is a clear, amorphous, nonpolar commodity thermoplastic that is easy to process and that can be easily converted into a large number of semi-finished products like foams, films, and sheets. It is the most common preferred material used for packaging, appliances, consumer electronics, medical and many other applications. PE is a very good electrical insulator, has excellent optical clarity due to the lack of crystallinity, and has good chemical resistance to diluted acids and bases. It is also easy to fabricate into a large number of finished goods since it is a viscous liquid above its glass transition temperature (T_g) that can be easily moulded. However, PE has several limitations. It is attacked by hydrocarbon solvents and it has poor impact strength (15-20 J/m) due to the stiffness of the polymer backbone. Furthermore, its upper temperature limit for continual use is rather low due to the lack of crystallinity and its low glass transition temperature of about T_g = 100 °C. Despite all these weaknesses, ethylene polymers are very attractive large-volume commodity plastics (Bayer, 2015).

Polyethylene is a not biodegradable plastic and resistant to photolysis. It is a major contributor to the debris in the ocean. Although recyclable, polyethylene is not recycled in many parts of the world. The biggest problem is Low Density Polyethylene (LDPE); due to its low density, it takes up a relative large amount of space in landfills.

About 200 tons of PE plastic waste is generated per month in the country. Almost 85% of which, amounting to 140 tons per month, is generated in Tirana [2].

Characteristics of Polyethylene

Polyethylene is typically a homopolymer meaning that it is composed only of the monomer ethylene in combination with itself. Depending on the type of PE it could be classified as a “thermoplastic” or a “thermoset” material. The name has to do with the way the plastic responds to heat. Thermoplastic materials become fully liquid at their melting point (210-249 0C in the case of Polyethylene), but they begin to flow at their glass transition point (100 ^{0}C for PE). A major useful attribute about thermoplastics is that they can be heated to their melting point, cooled, and reheated again without significant degradation.

Instead of burning, thermoplastics liquefy, which allows them to be easily injection moulded and then subsequently recycled. Thermoset plastics, by contrast, will not reliquefy once they are set in solid form.

Polyethylene is exceptionally useful for its application as a foam. It is the runaway leader in the packaging industry but it also has an extensive variety of uses as a customary plastic. For many years, PE was utilized as the go-to prototyping material. It's inexpensive, readily available, white in colour, and it glues, sands, cuts, and paints well.

Types of Polyethylene

Three major types of polyethylene include low density polyethylene, regular polyethylene plastic, and high density polyethylene. Some types of polyethylene plastic are copolymers. PE is fairly brittle and can be made more impact resistant if combined with other materials. While polyethylene film can also be vacuum formed and utilized as a part of packaging purposes.

Hydrophobic Effect of PE

Moisture absorption, also known as water absorption, is the capacity of a material to absorb moisture from its environment. Plastics absorb water to a limited degree. The degree of moisture absorption depends on the type of plastic and the ambient conditions such as temperature, humidity and contact time. Not only can dimensions change due to moisture absorption, but also material properties, such as mechanical strength, electrical conductivity and the dielectric loss factor, can be also affected.

This hydrophobicity is an essential characteristic for the production of HDPE roof tile because this will help to make the roof tile tough, long lasting and will greatly help cut expenses on unnecessary repairs

Resin

Most people do not recognize that plastic is a blanket term. There are many different types of plastic, and each plastic is made differently. Different chemicals and chemistry are needed in order to achieve this.

Plastic resins are the main base of all plastics. However, through different processes these resins can be transformed to fit specific needs. First, the resins are created with heat that cracks the hydrocarbons; this is called the cracking process. The larger molecules of the resin are broken down to different hydrocarbons such as, ethylene and propylene. The temperature used during cracking is largely responsible for the amount and types of hydrocarbons.

Zinc Oxide

Zinc oxide is an inorganic compound with the formula ZnO . ZnO is a white powder that is insoluble in water, and it is widely used as an additive in numerous materials and products including rubbers, plastics, ceramics, glass, cement, lubricants, paints, ointments, adhesives, sealants, pigments, foods, batteries, ferrites, fire retardants, and first-aid tapes. It occurs naturally as the mineral zincite, but most zinc oxide is produced synthetically.

Various amounts of nano- and micro- scale zinc oxide, also called as Calcimine, particles were systematically introduced into an epoxy resin matrix for reinforcement purposes.

In this study, zinc oxide was used as an admixture for the roof tile. It is also an important ingredient as it actively participates in the chemical reaction with the HDPE. It helps to make significant improvements in the breakdown resistance.

Roof Tile

Roof tile is a manufactured piece of hard-wearing material such as ceramic, stone, metal, or even glass, generally used for covering roofs, floors and walls. The word is derived from the Latin word "tegula". Roof tiles are designed primarily to keep out rain, and are traditionally produced using locally available materials such as terracotta or slate. An extensive number of shapes of roof tiles have developed. With modern technology, modern materials such as concrete and plastic are also used and some clay tiles have a waterproof glaze.

Concrete roof tiles are made of mixture of sand, cement and water, which are moulded under heat and high pressure. The exposed surface of a tile may be finished with a paint like material. Concrete tiles have additional water locks, or interlocking ribs on the edges that prevent water infiltration. Concrete tiles can simulate the appearance of traditional clay tiles, wood shake, slate and stone. Like clay, concrete tile surfaces can be textured or smooth, and tile edges can be ragged or uniform. They are resistant to hail, wind, and fire, making them a very safe roofing material when properly installed [3].

Synthesis

It is clearly true that in just a few decades, plastic has become a staple of most human societies. The creation of plastic and its wide sweeping applications, has allowed for people to acquire products much cheaper than they could in the past. In spite of being an essential material, the production of plastic is continuously increasing in recent years, which has led to a big environmental problem. Increased demand for plastic resulted to the increased volume of waste disposed in dumpsites, and remains visible in waste streams and alleged clogging drainage canals.

Plastic waste, like HDPE, is non- biodegradable but being a thermoplastic, it is a hundred percent recyclable. Therefore in this study, the researchers are pursuing for the solutions to develop a recycling technology for HDPE plastic waste; and to start converting this waste into functional and affordable products like roofing tiles [4].

3. METHODOLOGY

Research Design

The method used in this study is the experimental method of research. This research mainly focused on the development of an alternative construction material that will contribute to the environmental decontamination. The goal is to determine the material, its properties and proportion to attain the desired compressive strength of the roof tiles; and experiment to test some of the properties of the roof tiles such as water absorption, compressive strength of the structure.

Recyclable materials were used in this research like waste high density polyethylene (HDPE) plastic. Sand, zinc oxide, and laboratory extruder for liquefying were also used and complements the materials needed to manufacture the roof tile.

System Model

Fig. 3.1: System Model

Project Construction Procedure Fabrication Process Details

The first process is the cutting of HDPE waste into small pieces that is enough to fit inside the metal container. This process is done by using a shredder provided in Material Science Laboratory in Mechanical Engineering Faculty. After preheating the extruder, the HDPE waste pieces were poured and allowed to liquefy [5].

All the raw materials, which are sand and zinc oxide as aggregate were mixed together with an exact composition.

The sand, together with the zinc oxide, were poured and mixed until it all blended in. The fifth process is the preparation and setting up of mould into a level surface. The mould was initially brushed with oil so that product can be easily removed from the mould.

Next, the mixture is poured into the mould gradually, to ensure that it is closely and neatly packed together, some small forces has been applied on it using flat wood to make it compacted.

HDPE roof tile was left for 2 days. The last process is removal of solidified plastic roof tile from the mould.

Project Testing, Evaluation and Validation

Compressive Strength Test

A Universal Testing Machine (UTM) was used to determine the compressive strength of the material as shown in figure 3.4-1.

Fig. 3.2: Compression Test for HDPE Roof Tile Specimen

ASTM 579 – 96 and ASTM 695 – 96 were used as a reference for the testing methods for the determination of compressive strength of HDPE roof tile. The researches provided cube samples for the three different proportions since it was indicated that test specimen shall be cubes with dimensions of 50 mm.

Table 3.1: Property Specification Requirements for Compressive Strength

Type	Average Compressive Strength psi(MPa)
M	2500 (17.2)
S	1800 (12.4)
N	750 (5.2)
O	350 (2.4)

Where: M- High compressive-strength mortar, but not very workable

S- General all-purpose mortar with higher flexural bond strength

General all-purpose mortar with good bonding capabilities and workability

Low-strength mortar, used mostly for interior applications and restoration

Specification requirements for compressive strength of concrete roof tiles were carried out according to ASTM C270 – 14a. Table 3.1 indicates the values corresponding to the type of mixture used for concrete roof tiles. Roof tiles were classified as type M which has high compressive- strength mortar, but not very workable type of characteristics. The average compressive strength of concrete roof tiles which is about 2500 psi were used as a reference for the design strength of the HDPE roof tile.

Water Absorption Test

Figure 3.3: Water Absorption Test

The water absorption was measured according to ASTM D570 - 98. The test based on cutting the roof tile to pieces since the test specimen for molded plastics shall be in the form of a disk 50.8 mm in diameter and 3.2 mm in thickness. The procedure used was the Twenty-Four Hour Immersion where the conditioned specimens were placed in a container of distilled water, rested on edge and were entirely immersed. At the end of 24h, the specimens were removed from the water, all surfaces wiped off with a dry cloth and weighed to the nearest 0.001 g immediately. The water absorption is calculated as follows:

$$W = \frac{M2 - M1}{M1} \times 100$$

where: M1 = conditioned weight M2 = immersed weight

Table 3.2: Standard Requirements for Water Absorption

Weight Classification	Max % Absorption
Normal	12.50%
Medium	16.50%
Lightweight	20.00%

In accordance with ASTM C1492 – 03, table 3.4-2 shows the requirements for the water absorption that tiles should be classified as normal, medium or lightweight with the corresponding standards for the maximum absorption for roof tiles.

Density Test

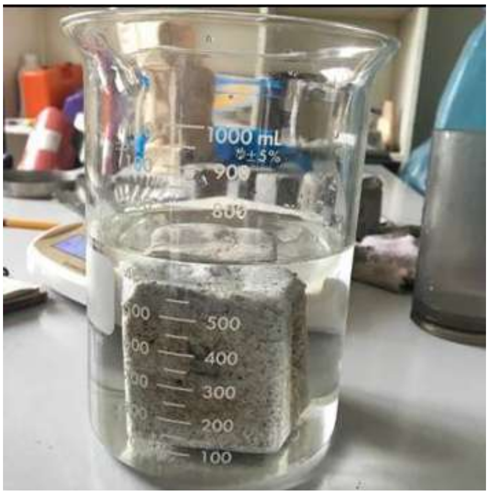

Figure 3.4: Density Test

The test was carried out according to ASTM D792 – 98. This test method was used to determine the specific gravity and density. It was indicated that the test specimen shall be a single piece of the material under test of any size and shape that can conveniently be prepared and tested.

Weight Classification

Table 3.3: Weight Classification for Roof Tiles

Weight Classification	Dry weight (kg/m^3)
Normal	Greater than 2002.30
Medium	1681.93 to 2002.30
Lightweight	Less than 1681.93

Table 3.4-3 was carried out according to ASTM C1492 – 03. It indicates the weight variation for the roof tiles to be classified as normal, medium or lightweight.

4. RESULTS AND DISCUSSION

The design requirement of this study is to use High Desnity PolyEthylene (HDPE) plastic waste to act as a binder for roof tiles as a substitute for cement; and to reduce the weight of roof tiles. HDPE as it proved an abundant waste in Albania, findings revealed that the use of it in construction can be beneficial economically and environmentally [6].

Presentation of Project Design

The HDPE plastic roof tile was made up having a dimension of 333 mm by 420 mm. A precast concrete mould was prepared which followed the dimensions and the form of a Standard Roman Tile; and is composed of male and female moulds. The detailed design was done using the AutoCAD software shown in figures 4.1 and 4.2.

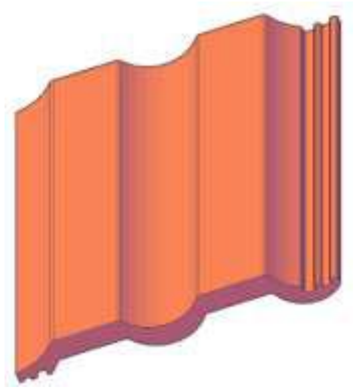

Figure 4.1: Standard Roman Tile

In making concrete roof tiles, the mix ratio between cement and sand varies from 1:2.5 – 1:4 by weight. Since experimental method of research was used in this study, the researchers conducted the experiment starting with the proportion 1:2.5. The proportions having greater amounts of sand than 1:2.5 failed to bind the mixture altogether because of the insufficient amount of resin (binder) necessary so that the mixture adhere.

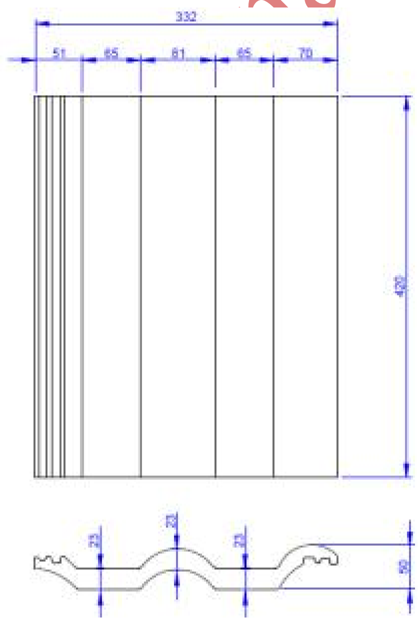

Figure 4.2: Dimensions of a Standard Roman Tile

In this research, three mixtures were studied. The compositions of the plastic roof tile are characterized by their proportion by weight. The compositions of the three proportions of roof tile are presented in the Table 4.1.

Table 4.1 Compositions of the Mixtures

Components	Proportion 1	Proportion 2	Proportion 3
HDPE (kg)	1.2	1.75	2
HDPE (% of roof tile composition)	30	50	60
Aggregate (kg) (Sand and Zink Oxide)	3	1.75	1.5
Aggregate (% of roof tile composition) (Sand and Zink Oxide)	70	50	40

Result of Testing, Evaluation and Validation

Compressive Strength

The results of the compression tests from different samples are tabulated below.

Table 4.2: Proportion 1 (1:2:0.5) for Compression Test

Sample Mark	Actual Dimensions			Surface Area (mm^2)	Total Load (kg)	Compressive Strength (MPa)	Standard Compressive Strength (MPa)	Remarks
	Length (mm)	Width (mm)	Height (mm)					
1	52	49	49	2553	4680	17.99	17.24	Passed
2	55	54	52	2982	5272	17.34	17.24	Passed
3	54	54	52	2927	5730	19.21	17.24	Passed

Proportion 1

Average Compressive Strength (MPa) = (17.99 + 17.34 + 19.21)/3 = **41.73 MPa**

Table 4.3: Proportin 2 (1:1:0,5) for Compression Test

Sample Mark	Actual Dimensions			Surface Area (mm^2)	Total Load (kg)	Compressive Strength (MPa)	Standard Compressive Strength (MPa)	Remarks
	Length (mm)	Width (mm)	Height (mm)					
1	50	50	49	2504	5068	19.86	17.24	Passed
2	48	50	50	2402	5058	20.63	17.24	Passed
3	50	50	46	2504	5047	19.78	17.24	Passed

Proportion 2

Average Compressive Strength (MPa) = (19.86 + 20.63 + 19.78)/3 = **47.10 MPa**

Table 4.4: Proportion 3 (2:1:0.5) for Compression Test

Sample Mark	Actual Dimensions			Surface Area (mm^2)	Total Load (kg)	Compressive Strength (MPa)	Standard Compressive Strength (MPa)	Remarks
	Length (mm)	Width (mm)	Height (mm)					
1	51	51	49	2520	5220	19.85	17.24	Passed
2	50	52	50	2662	5185	20.64	17.24	Passed
3	51	52	49	2780	5174	19,07	17.24	Passed

Proportion 3

Average Compressive Strength (MPa) = (19.85 + 20.64 + 19.07)/3 = **48.84 MPa**

The following bar graphs show the compressive strength results that are presented in Psi values for the different samples in each ratio.

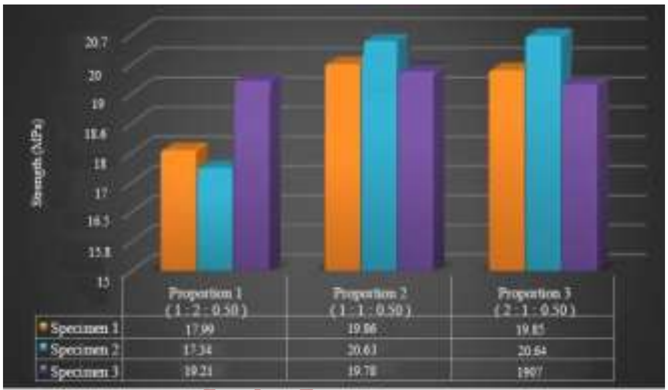

Figure 4.3: Summary of Compression Test Results

The results shown in figure 4.3 are the data gathered during the compression testing. Three sampling points for each ratio were used to test the compressive strength for the specimen of roof tile with HDPE waste. The compressive strength values of all mix proportions tend to increase with increasing of amount of HDPE as the binder. Although all the proportions passed the specified compressive strength for roof tiles of about 17.24 MPa, it can be seen that the maximum compressive strength of 20.64 MPa was achieved for the ratio of the Proportion 3 (2:1:0.50).

Water Absorption

The results of the water absorption tests from different samples are tabulated below.

Table 4.5: Proportion 1 (1:2:0.5) for Water Absorption Test

Specimen No	Weight Before Immersion (g)	Weight After Immersion (g)	Water Absorption (%)	Standard Maximum Absorption (%)	Remarks
1	61.1	61.9	1.31	20	Passed

Table 4.6: Proportion 2 (1:1:0.5) for Water Absorption Test

Specimen No	Weight Before Immersion (g)	Weight After Immersion (g)	Water Absorption (%)	Standard Maximum Absorption (%)	Remarks
1	40.1	40.4	0.75	20	Passed

Table 4.7: Proportion 3 (2:1:0.5) for Water Absorption Test

Specimen No	Weight Before Immersion (g)	Weight After Immersion (g)	Water Absorption (%)	Standard Maximum Absorption (%)	Remarks
1	55.2	55.3	0.18	20	Passed

The results shown indicate that Proportion 3, having 60% HDPE and 40% Aggregates has the lowest water absorption compared to other samples, although all the proportions passed the standards for the 20% maximum absorption of roof tiles.

Density Test

The results of the density tests from different samples are tabulated below.

Table 4.8: Proportion 1 (1:2:0.5) for Density Test

Sample	Initial Volume of Water (cc)	Final Volume of Water (cc)	Weight of Sample in Air (g)	Displacement (cc)	Unit Weight (kg/m^3)	Standard Lightweight Classification (kg/m^3)	Classification
1	500	660	228	160	1.575	<47.62	Lightweight

Table 4.9: Proportion 2 (1:1:0.5) for Density Test

Sample	Initial Volume of Water (cc)	Final Volume of Water (cc)	Weight of Sample in Air (g)	Displacement (cc)	Unit Weight (kg/m^3)	Standard Lightweight Classification (kg/m^3)	Classification
1	500	650	195	160	1.425	<47.62	Lightweight

Table 4.10: Proportion 3 (2:1:0.5) for Density Test

Sample	**Initial Volume of Water (cc)**	**Final Volume of Water (cc)**	**Weight of Sample in Air (g)**	**Displacement (cc)**	**Unit Weight (kg/m^3)**	**Standard Lightweight Classification (kg/m^3)**	**Classification**
1	500	650	173.5	150	1.157	<47.62	Lightweight

The test of density was carried out according to ASTM-D792. The density of a composite roof tile mixtures are presented in figure 4.4.

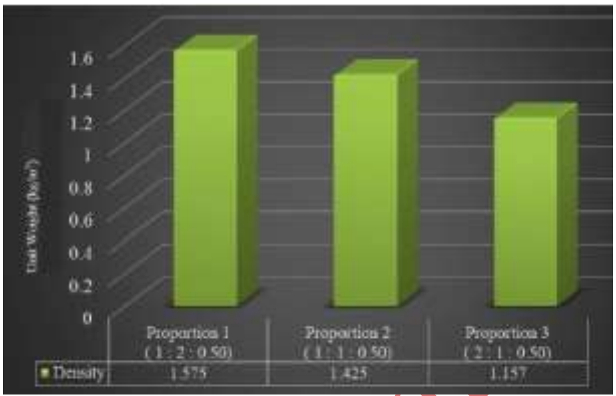

Figure 4.4: The Density of HDPE Roof Tile Specimen

Figure 4.4 indicates the results of density tests for HDPE roof tile specimen. It is noticeable that the density tends to decrease with the increasing HDPE ratio in each roof tile mixture and gets the roof tile to a lightweight condition [7].

Analysis and Interpretation of Data

Just as concrete mixes are prepared in ratios of weight, mix ratio by weight was initially adopted for this product development study. Thus a 1:2:0.5 mixture would contain one part of HDPE, two parts of sand, and a half part of zinc oxide by weight; because measurement by weight was found to be more feasible. In order to avoid wastage of materials in the initial trial mixes, smaller batch weights were used in the investigative study.

First trial (1:2:0.50): the first mix trial was 1 kg of HDPE waste to 2 kg of fine sand to 0.5 kg of zinc oxide. The aggregates and plastic were mixed together properly before pouring into the mould. Accurate quantity of mixture was placed in the mould. The mixture was moved from the mould and de-moulded after two days. The product formed properly but with a heavier weight than expected.

Second trial (1:1:0.25):Using 1 kg of HDPE waste to 1 kg of fine sand to 0.25 kg of zinc oxide, this proportion formed properly with a smooth surface and gives a lightweight product.

Third trial (2:1:0.50): Using 2 kg of HDPE waste to 1 kg of fine sand to 0.5 kg of zinc oxide. The product formed properly with a smooth surface and is the lightest weight among the three proportions but it has a low melting point due to the its high plastic content.

Since the Second Trial mix of (1:1:0.50) 1 kg of HDPE; to 1 kg of and fine sand; to 0.25 kg of zinc oxide gave the most optimal result, it was adopted for further development in this study.

5. CONCLUSION

All people deserve a decent roof over their heads. So the researchers aim to come up with a cheap but durable roofing solution. In this study, the researchers find another method to valorize the recycled HDPE and mix it with sand to produce a new material used as roofing tile. The researchers aim for those waste plastics that currently have no recycling value and are overlooked as being useful, for any kind of reason. With this process, the researchers also aim to provide job opportunities, a cleaner environment and durable end products.

An experimental test program is conducted on composite roof tile containing different proportions of the mixtures. The use of HDPE as substitute for cement gives a good advantage to greatly reduce the water absorption of it. The research revealed that the incorporation of HDPE plastic waste generally decreases the density, which makes the product lighter in weight. The results also show that the mechanical properties of HDPE roof tile, such as compressive strength, increases with increasing the waste plastic ratio; but gives lower flexural strength.

In this study, the researchers have successfully demonstrated that it is possible to manufacture a roof tile using waste HDPE plastic as substitute for cement. Plastic wastes are recycled and reused while ensuring environmental protection. This research effort has produced the expected outcome of weight reduction of Standard Roof Tile. HDPE Roof Tile was successfully developed at a reduced net product weight of 3.0 kg compared to the standard weight of 4.2 kg to 4.9 kg depending on its profile.

The detailed presentation of range of HDPE roofing material cost shows that a low cost price has been achieved from 90 Euro to 100 Euro per tile. However, it is not applicable for the researchers to compare the cost advantage in the production of HDPE Roof Tile with the other competing Standard Roman Tiles since those tiles are being mass produced and manufactured with an advanced system and equipment.

All the HDPE roof tile mixes give good results according to the standards, but the roof tile containing 40% HDPE with 60% Aggregates gives the best quality. The First and Second Trial Mix formed properly with a smooth surface and a high melting point but the First Trial Mix produced a higher density than expected. While the Third Trial Mix also formed properly but has a low melting point due to its high plastic content. Since the Second Trial mix, Proportion 2 (1:1:0.50) gave the most optimal result, it was adopted for further development in this study.

6. RECOMMENDATION

There are some improvements that can be done and be implemented for this project. First and foremost is the quality of the roof tile mould. Future researchers may improve and use a better roof tile mould since the researchers encountered a deformation in the pre-casted mould after using it several times that also causes deformation to the product's surface.

Secondly, future researchers may investigate other ratios of HDPE and sand to determine if there is a better proportion in achieving the best quality roofing tiles.

Next, future researchers may conduct economic study regarding the production of HDPE roof tiles.

Lastly is the investigation of the deformation of HDPE roof tile due to high temperature. Since the current researchers mainly focuses on the material of the roof tile, future researchers may conduct additional testing with regards to heat resistivity of HDPE roof tile when exposed to fire.

7. REFERENCES

[1] Bayer, D. (2015). Polymer Properties Database. Retrieved from http://polymerdatabase.com/polymer%20classes/Polyethylene%20type.html

[2] (2018). Status of Solid Waste Management in Albania.

[3] Dubey, Prem. (2012). Concrete Roof Tile Manufacturing. Retrieved from http://365days365businessideas.blogspot.com/2012/08/start-concrete-roof-tile-manufacturing.html

[4] Loberiano, R., de Chavez, E., Redondo, M., Cerbito, R., Tolentino, M., and Bernardo, S. (2009). Polyethylene Waste Treatment and Recycling. Retrieved from http://www2.gec.jp/gec/en/Activitie s/EST/2009/wasteplatics/TP2_Tony Chiong.pdf

[5] Makai, A., Kiss, J., and Mucsi, G. (2015). The Possibilities of Polyethylene Waste Recycling. Retrieved from http://www.unimiskolc.hu/~microcad/publikaciok2016/A_9_Makai_honlapra.pdf

[6] Sims, Bart. (2010). The Dangers of Polyethylene. Retrieved from http://businessbarbados.com/trending/green-business/the-dangers-of- polyethylene/

[7] Taylor, Kevin. (2008). Roof Tiling and Slating: A Practical Guide. Crowood Press Publisher. ISBN: 9781847970237.