Valorization of post-consumer plastic packaging into a composite material

Rafenomananjara Tsinjo Nirina
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Sekito, Tomoo
Department of Civil and Environmental Engineering Program, University of Miyazaki

Andrianarimanga Hery Mamisoa Clement
Ecole Supérieure Polytechnique d’Antananarivo, University of Antananarivo

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Valorization of post-consumer plastic packaging into a composite material

Rafenomananjara Tsinjo Nirina[1*], Sekito Tomoo[2], Andrianarimanga Hery Mamisoa Clement[3]

[1.] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University,
[2.] Department of Civil and Environmental Engineering Program, University of Miyazaki
[3.] Ecole Supérieure Polytechnique d'Antananarivo, University of Antananarivo
*Corresponding author email: rafeno.tsinjo@gmail.com

Abstract: *Because of its strength and simplicity, many producers prefer to package their products with various forms of plastic. The use of plastic for packaging has increased significantly due to the change in lifestyle, which has subsequently led to an increase in plastic packaging waste. However, approximately 50% of plastics are produced in disposable single-use applications. Meaning, most of them are used as once-of products and in a short space of time, they become solid waste. From the environmental preservation perspective, recycling plastic waste can save natural resources and decrease energy consumption. Among the various types of recycling management approaches, the reuse of recycled plastic material in the construction sector is considered one of the environmentally friendly recycling methods. This approach will help reduce the depletion of natural resources used as raw materials for cement production.*

Keywords: environment-friendly material, plastic recycling, waste management, cement substitute, cementitious materials

1. INTRODUCTION

Approximately 50% of plastics are produced into single-use disposable applications, such as packaging and agricultural films in the world [1]. Its broad range of applications is in packaging films, wrapping materials, shopping and garbage bags, fluid containers, clothing, toys, household and industrial products, and building materials [2].

Landfilling of plastic waste is not desirable since plastic is non-biodegradable [3]. There are long-term risks of contamination of soils and groundwater by some additives and breakdown by-products in plastics, which can become persistent pollutants.

Previous works indicated that plastics had the potential to replace conventional cement for manufacturing a concrete composite [4,5,6]. Compared to the former methods, the usage of melted post-consumer PET bottles as a binding agent in a composite material preparation without adding any chemical products has an advantage because compared to the production of unsaturated resin, the process is simple. it only requires sorting, grinding, and heating. In addition, its reuse in concrete not only serves as an effective means of disposal but also helps in reducing the cost of concrete manufacturing. This technology is already running in the sub-Saharan regions, funded by the Academy of Research and Higher Education and in collaboration with the University of Liege [7]. Much work has been done on building flexible road pavements by incorporating waste plastic into the matrix in road construction to improve its properties [8]. This work was focused on managing the problem of thermoplastic waste material composed of PET, PP, and LDPE in an economically and environmentally viable manner. The plastic waste was coated with the aggregates to produce an eco-friendly composite material. It also has numerous benefits such as reduction in landfill cost, avoiding serious threats to the environment, saving in energy, and protecting the environment from possible pollution effects. The methodology is easy to implement and appropriate to the local context in Madagascar it seems a suitable option to eliminate these residues and reduce environmental damages.

The scope of the present work includes the following aspects: the binder phase for polymer concrete consists only of molten plastic instead of conventional Portland cement and water. So, the aggregates are strongly bound to each other by polymeric binders. The experimental study was divided into three parts. The first part is concerned with the comparative study between composites made from PP / PE and PET in terms of compressive behavior and physical properties. Then, depending on the results of the previous experiment, the second part assessed the mechanical properties of polymer concrete with different ratios of aggregates. The final part evaluated the durability of those composites.

2. MATERIALS AND METHODS

Three types of plastics such as polyethylene terephthalate (PET), polyethylene (PE) and polypropylene (PP) were used. The commercial styrene monomer was used as an additive to reduce the viscosity in melted plastics.

PET was obtained from post-consumer PET bottles. The bottles were washed before passing through a shedder to get PET flakes. Commercial PE and PP pellets were used instead of real plastic wastes. Sand and gravels were adopted to prepare the concrete composite: a single lot of coarse aggregates was used with 4–8 mm size from available crushed from crushed stones. Manufactured sand produced by the Japan cement Association, with a nominal maximum size between 0 mm to 4 mm, was used as the fine aggregate. Two different percentages of coarse and fine aggregates were mixed to determine the best mix ratio.

2.1 Mix design

The mix proportions of experiments 1, 2 and 3 were shown in Tables 1, 2 and 3, respectively.

Table 1. Mix proportions of the Experiment 1

Mortar types	Weight of sand (g)	Weight of PET or PP + PE (g)	Ratios PP: PE	Weight of Styrene monomer (g)
GROUP 1 (PP+PE/Sand)	250	25	1:1	10
	250	50	1:1	20
	250	75	1:1	30
	250	100	1:1	40
GROUP 2 (PET/Sand)	250	25		10
	250	50		20
	250	75		30
	250	100		40

Table 2. Mix proportions of the Experiment 2

Mortar types	Ratios Sand: Gravel	Weight of gravel (g)	Weight of sand (g)	Weight of PET (g)	Weight of Styrene monomer (g)
PET 1:1 *PET/Sand/ Gravel*	1:1	150	150	60	24
	1:1	150	150	90	36
	1:1	150	150	120	48
	1:1	150	150	150	60
PET 1:2 ***PET/Sand/ Gravel***	1:2	100	200	60	24
	1:2	100	200	90	36
	1:2	100	200	120	48
	1:2	100	200	150	60

Based on previous studies [10,11], the plastics were melted between 280°C and 320°C. The plastics were initially put in a steel container and put in the electric furnace for 45 minutes to 1 h.

Table 3. Mix proportions of the Experiment 3 (PET is 20 % by weight of sand)

Mortar types	Weight of sand (g)	Weight of PET (g)	Weight of Styrene monomer (g)
PET/Sand	450	90	36

Then, the aggregates were added little by little within the molten plastics and mixed for about 15 minutes using a mixing paddle. The mixing and heating continued until all aggregates were blended with the polymer for approximately two hours. The mixes were subsequently poured into molds, cast, and properly compacted by a steel plate after mixing. Before casting, the molds were carefully cleaned and oiled on all its contact surfaces. The samples were taken out from the furnace to cool to ambient temperature (approximately 25 ºC) for 36 hours before demolding. The compressive strength, the density, and the water absorption were determined on cylindrical samples of 100 mm x 50 mm dimensions. Thus, samples were prepared in prismatic form of 40 mm x 40 mm x 160 mm, to assess the flexural characteristics. In the case of Experiment 1, all samples were cut to a height of 47.5 mm. The details of the specimens are summarized in Table 4.

Table 4. Details of samples

Experiments	Tests	Dimensions of the moulds	Number of samples
1	Compressive strength	Cylinder form of 50 mm x 50 mm	12
	Density		12
	Water absorption		
2	Compressive strength	Cylinder form of 100 mm x 50 mm	12
	Density		12
	Water absorption		
3	Xenon-arc lamp	Prismatic form of 14 mm x 14 mm x 160 mm	5
	Freeze-thaw test		5

2.2 Laboratory test methods

The determination of the mechanical and physical properties was limited to physical observation and the mechanical properties for experiments 1 and 2. In case of the experiment 3, the freeze-thaw durability of concrete composites was studied using two factors accelerated

aging tests composed of ultraviolet radiation and freeze-thaw cycling. According to the specifications in standards ASTM C666 and EN 321, the test method covers the determination of the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing in the laboratory. The resistance to moisture and freeze-thaw was carried out under cyclic conditions.
The compressive strength was evaluated at 28 days of curing using a hydraulic loading machine with a maximum load capacity of 1500 kN.

3. RESULTS AND DISCUSSIONS

3.1 Experiment 1 results

Figures 1 and 2 indicated the variation of the compressive behavior and the physical strength of each sample PET / Sand PE+PP/Sand and versus the plastic content.

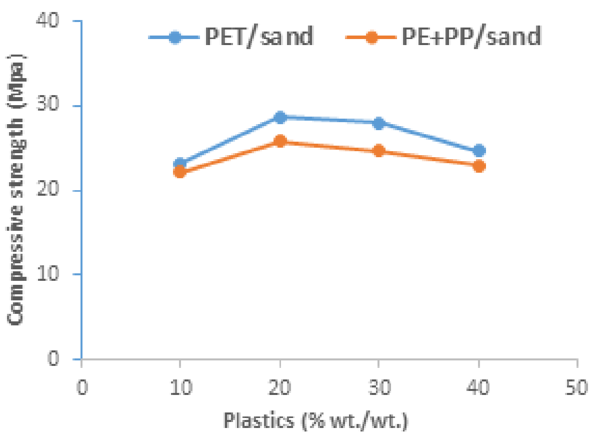

Figure 1. Compressive strength Measurement of the samples PET/Sand and PP+PE/Sand

The result indicated that PET/Sand specimen showed higher compressive strength than that of PE+PP/Sand specimens. The highest value of compressive strength of PET/Sand specimens was 28.59 MPa with 20% of PET. For the samples with PE+PP/Sand, the maximum value obtained was 25.78 MPa at the same percentages of plastics.

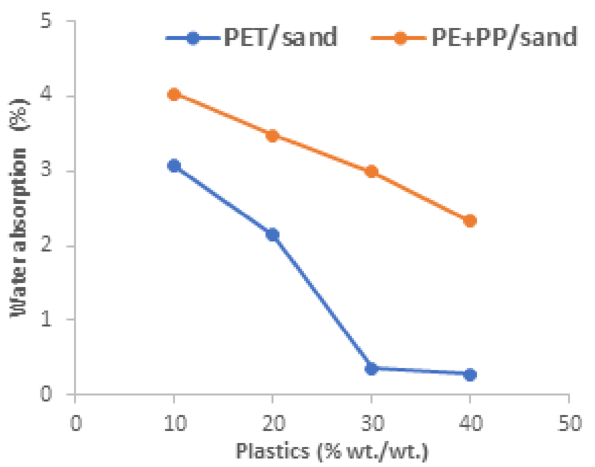

Figure 2. Water absorption measurement of the samples PET/Sand and PP+PE/Sand

It can be explained by the mechanical properties of the polymers themselves. The chemical structure such as the molecular carbon-hydrogen-oxygen bonds within the PET are more resistant than those carbon-hydrogen only for PP and PE, which leads to better mechanical properties for the PET when mixed with aggregates [12]. Based on the results, 20% of the plastics were enough to bind the melted plastic and the sand which made the samples to reach a maximum value of hardness.
Water absorption decreased with increasing plastic content because plastics are impermeable to water. At 20% of plastics, the water adsorption of the samples with PP/PE and PET were 3.48 % and 2.14 % respectively. That result showed that PP and PE are more permeable than the PET.

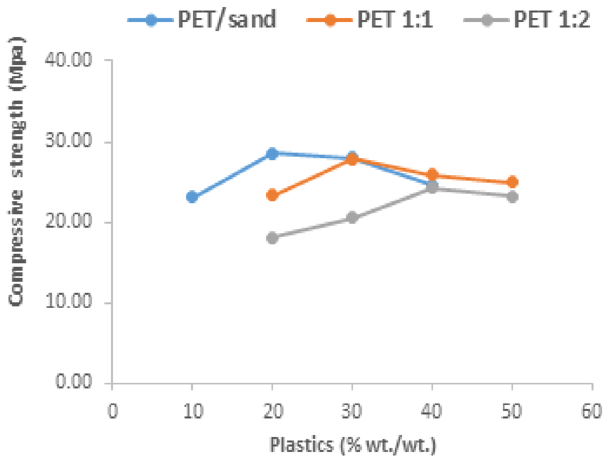

Figure 3. Compressive strength measurement of the samples PET/Sand, PET1:1 and PET1:2

3.2 Experiment 2 results

In the previous experiment, it was found the PET/Sand specimens demonstrated a higher compressive strength than PP+PE/Sand samples.
Thus, in the following study PET was used for a binder with different proportions of gravels. Similarly, compressive, and physical properties have been characterized.
The compressive strength of the sample with PET/Sand only was higher than those containing PET/sand/gravels. The highest value of compressive strength was 28.59 MPa obtained with the samples made off PET/sand at 20% plastic content. The maximum compressive strengths were 27.84 MPa at 30% and 24.23 MPa at 40% plastic content for the samples produced from PET 1:1 and PET 1:2, respectively.
This result agrees with a work using an epoxy Resin to produce polymer Concretes. In her research entitled “Optimal Mix Design for Epoxy Resin Polymer Concrete", 2015), Amy Beutel stated that the addition of aggregate has no effect on the strength of the sample. The mix design with no coarse aggregate had the best performance in terms of compressive strength. It might be due to air voids caused by the addition of gravel in the mixture, therefore reducing the strength. [13] stipulated

that these values were close to the compressive strength of conventional concrete. According to him, the standard strength values for hydraulic cement with moderate resistance are between 21 and 30 MPa at 28 days. Otherwise, according to Eurocode 2: Design of concrete structures EN1992-1-1 and EN 206, the samples belong to C20/25 and C25/30 based on the standard values of concrete classes [14].

Also, peak values of compressive strength of PET/Sand, PET1:1 and PET1:2 shifted according to the plastics percentage increased. It can be assumed that 28.59 MPa, 27.84 MPa, and 24.23 MPa, respectively for the samples PET/Sand, PET1:1, and PET1:2, represented the optimum values of plastic content that give the highest value of compressive strength. Less than 20 wt.%, 30 wt.%, and 40 wt.% of plastics, respectively for the samples PET/Sand, PET1:1 and PET1:2, the compressive strength was low. It may be due to the low bond strength within the matrix that agrees with other studies using unsaturated polyester resins [15,16,17]. Adding more plastics makes the compressive strength decrease, presumably because of the plasticity of the material which weakened the links between the sand and the binder. Hence, the results of compressive strength tend to decrease.

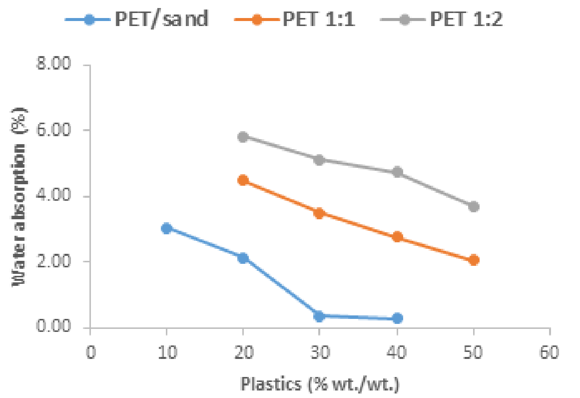

Figure 4. Water absorption measurement of the samples PET/Sand, PET1:1 and PET1:2

The measurement of the water absorption showed also the decreasing the values of density with increasing the percentage of the added plastic content to all types of aggregates. It can be explained by the hydrophobic nature of plastics which can restrict water movement within the matrix. This point should be considered as a good aspect of using PET in the production of polymer concrete.

3.3 Experiment 3 results

The effect of water immersion-freeze-thaw actions and UV exposure on the mechanical properties of the composites are presented in Figure 5 and Figure 6, respectively.

a. Freeze-thaw cycling

It was found that the mechanical properties declined by 12% and 39% for compressive and flexural strength, respectively. As it was already observed, the low permeability of the samples reduced the presence of water in the composites. However, the repeated actions of the freezing and heating caused microcracks which contributed to further water penetration into the composite. The presence of water within the matrix is the main reason for the performance reduction of the concrete composites. In accordance with this [18,19], one of the most common physical deteriorations of concrete in cold environments is freezing/thawing, which causes serious damage and induces cracks in concrete structures. Freezing/thawing damage comes with internal frost damage which is caused by water freezing inside the body of the concrete and manifests through changes of mechanical properties. Those processes are the most applied to generate microcracking differential alternation and, therefore, a significant loss of their engineering properties.

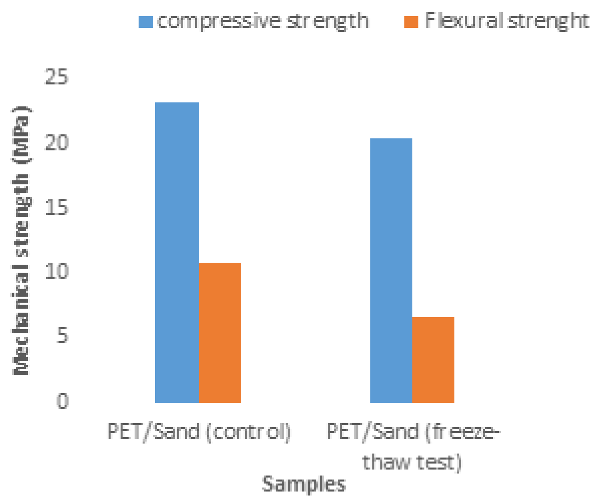

Figure 5. Measurement of freeze-thaw cycling behavior

b. UV exposure

The effect of UV radiation showed that the compressive and flexural properties were decreased by 5% and 14%, respectively. The changes in composite properties were lower than those obtained from the previous test on freeze-thaw cycling. The results indicated that a small loss of hardness was observed. [20] explained the insignificance changes of the tested samples compared to control concrete as a strong interfacial interaction within the composite. The UV radiation doesn't affect too much the bond between the binder and the aggregates [21,22].

4. CONCLUSION

Results showed that regardless of the type of Plastic/Aggregates prepared, the mechanical behavior decreased as the content of plastics increased, which were also reported in some references. Nevertheless, these values were satisfactory and close to the compressive strength of the conventional concrete with lies between 21 and 30 MPa according to some references. Besides, the incorporation of plastics can improve the permeability behavior of the manufactured concrete composites. On the other hand, the durability tests demonstrated that freeze-thaw cycles negatively influenced on the mechanical properties of composites than the UV exposure.

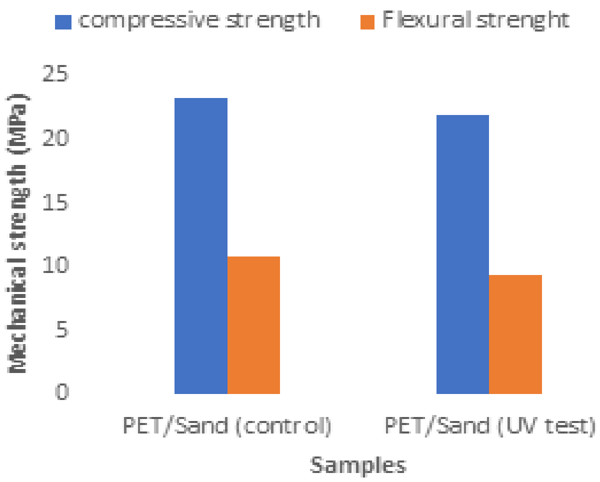

Figure 6. Measurement of the effect of UV radiation

The findings give a new approach for the recovery of the waste PET bottles and a new concrete composite material can be manufactured with low cost and improved properties. It has shown that melted plastics can be used as a binder to replace the conventional cement for manufacturing a concrete composite in low load bearing structures such as footpaths, walkways, etc.

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