Recovery of Post-Consumer PET Bottles in a Composite Material Preparation

Rafenomananjara Tsinjo Nirina, Tomoo Sekito, Andrianaivoravelona Jaconnet Oliva

Abstract**—**Manufacturing a composite material from post-consumer bottles is an interesting outlet since Madagascar is still facing the challenges of managing plastic waste on the one hand and appropriate waste treatment facilities are not yet developed on the other hand. New waste management options are needed to divert End-Of-Life (EOL) soft plastic wastes from landfills and incineration. Waste polyethylene terephthalate (PET) bottles might be considered as a valuable resource and recovered into polymer concrete. The methodology is easy to implement and appropriate to the local context in Madagascar. This approach will contribute to the production of ecological building materials that might be profitable for the environment and the construction sector. This work aims to study the feasibility of using the post-consumer PET bottles as an alternative binding agent instead of the conventional Portland cement and water. Then, the mechanical and physical properties of the materials were evaluated.

Keywords**—**PET recycling, polymer concrete, ecological building materials, pollution mitigation.

I. Introduction

SIMILAR in other developing countries, the municipal solid waste management in Madagascar remains a challenge especially the recovery of EOU plastic packaging waste for recycling [1]. A large range of plastics are produced into disposable single-use applications, then becoming solid waste in a short space of time. Hence, this kind of wastes creates environmental and waste management concerns.

A. Background

Malagasy government and environmental authorities become really concerned about this growing waste generation. The solid waste management (MSW) has been suffering from a lack of financial and technological resources, and a poor organization. Cities and towns in Madagascar face serious environmental degradation and health risks due to the weak MSW. Some cities with more than one million inhabitants still have only small landfills, while the size of the population involves huge amounts of waste.

Through the findings from the field surveys, it was identified that a variety of plastic packaging waste (PPW) and bags are the major component of plastic waste composition, including polypropylene (PP), polyethylene (PE) and PET which ended up in the waste stream. Plastic waste is difficult to separate from the waste stream, and too dirty to be recycled without a modern infrastructure. Due to lack of integrated MSW management, wastes from households are neither collected properly nor disposed of in appropriate manner by the municipalities [2].

Landfill and incineration in open air, are the main disposal method because it is cost-effective and it can accommodate large fluctuations in the amount and type of waste [3]. Much plastic waste is littered on public places or open dumped at illegal sites that blocks drainage and sewer systems [4]. Indeed, it affects public health, the sewerage services and the urban environment. Consequently, the environmental degradation associated with the existing dumps is directly affecting the population.

It becomes necessary to look at other strategies that can work in the recovery and management of PSW. The findings of researches indicated recycling as one of the best approaches for the waste management of this kind of waste. In fact, recycling is recognized as the most environmentally sound strategy for dealing with MSW following only the preventive strategy of source reduction and reuse. It also provides the opportunity to use recovered plastics to manufacture a new product [1].

Among the various types of recycling management approaches, the reuse of plastic material in the construction sector is considered as a the environmentally friendly aspect to dispose plastic waste [5]. Recycling of plastic waste to produce new materials, such as cement composites, appears as one of the best solutions for disposing of plastic waste, due to its economic and ecological advantages [6].

This research work will focus on recycling of PET wastes to produce a polymer concrete and to evaluate the mechanical and physical properties of the samples. By this method, post-consumer bottles were used as a binding agent in a composite material preparation without adding any chemical products which is quite different as using unsaturated polyester resin. Manufacturing a construction material from post-consumer plastic is an interesting outlet because waste PET can represent also a valuable resource. Besides, its reuse in concrete will not only serve as an effective means of disposal but also will help in reducing the cost of concrete manufacturing. It also has numerous benefits such as reduction in landfill cost, avoid serious threat to environment, savings in energy, and protecting the environment from possible pollution effects.

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II. Experimental Work

A. Material Selection

The composite material was prepared by mixing aggregates and melted plastics. 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.

Three types of polymer concretes were performed: PET/ sand (*Group 1*), PET/sand/gravels (*Group 2 and 3*) with different amounts of aggregates. Different ratios sand/gravels (1:1 and 1:2) were tested to assess the effect of aggregates on the behaviour of hardened polymer concrete properties.

- *Plastics*: we used PET obtained from beverage bottles, washed and crushed into 15 mm or smaller by a shredder.
- *Fine aggregates:* normally consists of natural, crushed, or manufactured sand. Standard sand produced by Japan Cement Association was used for the experiments and retained on 75 µm IS sieve.
- *Coarse aggregates*: obtained from available crushed stone aggregate. Single lot size has been used trough out the experiment. Japan Society of Civil Engineers (2007) reported smaller sized aggregates produce higher concrete strength [7].

B. Preparation and Samples Conditioning

Batching of materials as per mix design is done by weigh batching [8]. The use of weight system in batching, facilitates accuracy, flexibility and simplicity [9].

Molten plastics are blended with aggregates at a rate of 10 to 40% by weight of sand in steps of 10% for Group 1, and it varied from 20% to 50% of the weight of the sand and gravels for Groups 2 and 3. In this context, two different ratios of fine and coarse aggregates were carried out. Different mix ratios of sand and gravels (1:1 and 1:2) were mixed to determine the optimum one. Whatever may be the type of polymer concrete being prepared, the major work is determining the appropriate mix proportions.

For the mix design, shredded plastics and aggregates were put in a tubular mixing machine at 280 ± 20°C. It consisted of a furnace with a ceramic cylindrical tube, which was rotated with 30 ~ 50 rpm as shown in Fig. 1.

Fig. 1 Furnace used for the experiment

During two hours of heating, samples were mixing until obtaining homogeneity. Afterward, the mixture was poured into cylindrical molds and manually pressed into them, then allowed to harden, cooling to ambient temperature for 36 hours before demolding.

C. Test Procedures

The determination of the properties was limited to physical observation and the mechanical properties. The laboratory tests were done using the same procedures adopted for the conventional concrete.

The experimental study consisted of casting and testing of 36 cylinders for the determination of the compressive strength, the splitting tensile strength, the density and the water absorption. Polymer concrete cylinders of 100 mm height and 50 mm diameter were prepared using the cast iron molds which are normally employed for the conventional concrete.

The compressive strength and tensile splitting strength were evaluated at 28 days of curing using a hydraulic loading machine with a maximum load capacity of 1500 kN.

The dry density of the samples was measuring based on dry mass and the total volume. Besides, the water absorption test was carried out on the same samples which served for the determination of the density.

All test results were performed in triplicate, and averages were used for the study. These three samples for each mix design were done to ensure consistent and accurate results.

The experimental methods to determine the mechanical and physical properties of the polymer concrete are presented in Table II.

TABLE I
Test Methods to Proceed on the Determination of Concrete Properties

Properties	Methods
Hardened polymer concrete	
Compressive strength	ASTM C 39
Splitting tensile strength	ASTM C 496-86
Dry density	ASTM C138
Water absorption by capillarity	ASTM C 642-97

III. Results and Discussions

A. Mechanical Properties

It was seen from the results, the compressive strength of the mixture containing only PET/sand were higher than those containing PET/sand/gravels. The maximum compressive strength is 28.59 MPa obtained from the samples made off PET/sand at 20% plastic content; while it shows 27.84 MPa at 30% plastic content and 24.23 MPa for the samples produced from PET/sand/gravels (ratios 1:1) and PET/sand/gravels (ratios 1:2), respectively.

Fig. 2 shows the compressive strength of the three samples.

The test data indicate that at 20 wt.%, 30 wt.% and 40 wt.% of PET, respectively for the samples Group 1, Group 2 and Group 3, the values of compressive strength for mixture increased then decreased with the increasing proportion of the plastic. It can be assumed that these values represent the optimum values of plastic content that give the highest value of compressive strength. Less than 20 wt.%, 30 wt.% and 40 wt.% of PET, respectively for the samples Group 1, Group 2 and Group 3, the compressive strength were low. It may be due to the poor bond strength within the matrix. And adding more plastics makes the compressive strength decreasing, presumably because the plasticity of the material weakened the links between the sand and the binder. Hence, the results of compressive strength tend to decrease.

The laboratory results of the measurement of the compressive strength are synthesized in Table II.

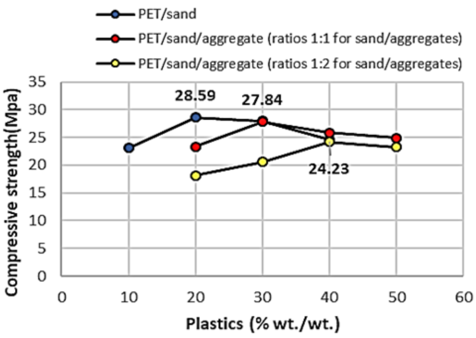

Fig. 2 Measurement of the compressive strength

TABLE II
TECHNICAL CHARACTERISTICS OBTAINED FOR THE COMPRESSIVE STRENGTH

Sample type	Ratios Sand/gravels	The maximum value of Compressive strength	Optimum values of the plastic content
GROUP 1 (PET/sand)		28.59 MPa	20 wt.%
GROUP 2 (PET/sand/gravel)	1:1	27.84 MPa	30 wt.%
GROUP3 (PET/sand/gravel)	1:2	24.23 MPa	40 wt.%

Thus, the mix design with no coarse aggregate was the strongest for all strength tests. It might be due to air voids caused by the addition of gravels in the mixture, therefore reducing the strength. Otherwise, these values were close to the compressive strength of conventional concrete using a cement and sand (28 MPa) in average [10].

This result agrees with some previous investigations in the same fields. Another research found the similar results and stipulated that the addition of aggregate and how much is added does not have a large impact on the strength of the sample [11].

The measurement of the tensile strength is shown in Fig. 3.

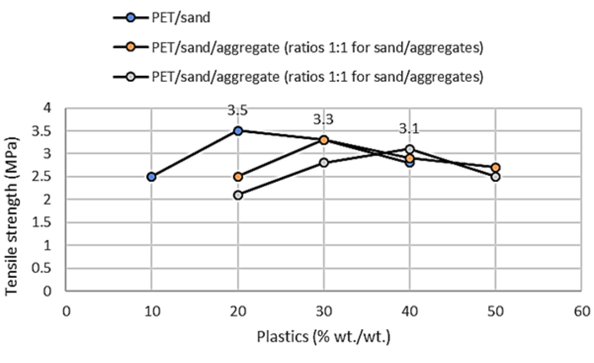

Fig. 3 Measurement of the tensile strength

The trend of the curves clearly indicates a worsening in the concrete performances with increasing of plastic proportions. The causes of the reduction observed in tensile strength are assumed similar to the reasons attributed to justify the decrease of the compressive strength, mentioned above.

The incorporation of plastics more than the optimum values (20 wt.%, 30 wt.% and 40 wt.% of PET, respectively for the samples Group 1, Group 2 and Group 3) has a declining effect on the tensile strength. Moreover, the tensile strength is highest in the mix with no aggregate.

TABLE III
TECHNICAL CHARACTERISTICS OBTAINED FOR THE TENSILE STRENGTH

Sample type	Ratios Sand/gravels	The maximum value of tensile strength	Optimum values of the plastic content
GROUP 1 (PET/sand)		3.5 MPa	20 wt.%
GROUP 2 (PET/sand/gravel)	1:1	3.3 MPa	30 wt.%
GROUP 3 (PET/sand/gravel)	1:2	3.1 MPa	40 wt.%

B. Physical Properties

The results of density and water absorption are presented in Figs. 4 and 5, respectively. This result shows the decreasing the values of density with increasing the percentage of the added plastic content to the all types of aggregates, which was mentioned in some previous studies [12].

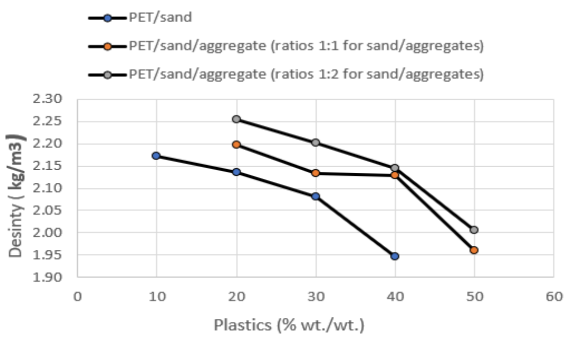

Fig. 4 Measurement of the density

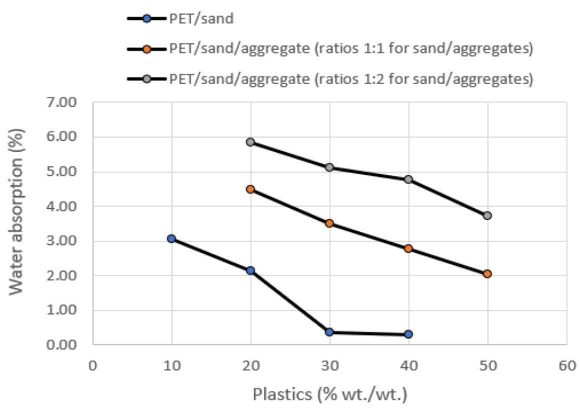

Fig. 5 Measurement of the water absorption

At the optimum values of the plastic content of each sample, the measured densities of the Groups 1, 2 and 3 are 2.14 g/cm^3, 3.18 g/cm^3 and 3.18 g/cm^3 respectively. Although these values were higher than that using lightweight aggregate (less than 1.1 g/cm3) [10], lower compared to conventional concrete using normal weight aggregate (2.4 to 2.9 g/cm^3 in average) for the sample Group 1 but higher for the samples Groups 2 and 3.

Similarly, water absorption decreased with increasing plastic content which can be explained by the hydrophobic nature of plastics which can restrict water movement within the matrix. Safi (2013) [13] found the same results and explained it as the filing effect of voids in the cementitious matrix. Indeed, pore spaces on the aggregate's surfaces provide the water absorption condition. This point then should be considered as a good aspect of using PET in the production of polymer concrete.

IV. Conclusion

The following conclusions can be drawn based on the laboratory test results.:

- Results show that regardless of the type of PET/aggregates prepared, both compressive strength and splitting tensile strength decreased as the content of PET increased, which were also reported in some references. Nevertheless, these values were satisfactory and close to the compressive strength of the conventional concrete.
- Reduction in the density was noticed as the plastic content increased. Low density can contribute to the production of light weight concrete.
- The use of molten plastics as a binding material lowers the water adsorption rate of concrete.

The findings of this investigation give a new approach for the recovery of the waste PET bottles and a new cementitious composite material can be manufactured with low cost and improved properties.

References

[1] Mwanza, B. G., & Mbohwa, C. (2017). Drivers to Sustainable Plastic Solid Waste Recycling: A Review. *Procedia Manufacturing*, *8*(October 2016), 649–656. https://doi.org/10.1016/j.promfg.2017.02.083.

[2] Chaerul, M., & Reza, A. (2014). *Recycling of plastic packaging waste in Bandung City , Indonesia*. 509–518. https://doi.org/10.1007/s10163-013-0201-2.

[3] Zhang, D. Q., Tan, S. K., & Gersberg, R. M. (2010). Municipal solid waste management in China: Status, problems and challenges. *Journal of Environmental Management*, *91*(8), 1623–1633. https://doi.org/10.1016/j.jenvman.2010.03.012.

[4] Oyake-Ombis, L., van Vliet, B. J. M., & Mol, A. P. J. (2015). Managing plastic waste in East Africa: Niche innovations in plastic production and solid waste. *Habitat International*, *48*, 188–197. https://doi.org/10.1016/j.habitatint.2015.03.019.

[5] Gu, L., & Ozbakkaloglu, T. (2016). Use of recycled plastics in concrete: A critical review. *Waste Management*, *51*, 19–42. https://doi.org/10.1016/j.wasman.2016.03.005.

[6] Saikia, N., & De Brito, J. (2014). Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate. *Construction and Building Materials*, *52*, 236–244. https://doi.org/10.1016/j.conbuildmat.2013.11.049.

[7] Japan Society of Civil Engineers. (2007). Standard Specifications for Concrete Structures "Materials and Construction." In *Concrete*. Retrieved from http://conc.civil.okayama-u.ac.jp/~tayano7/JSCE/publication.html.

[8] Lad, H., Shah, P., & Garasia, B. (2018). *Experiment Study On Strength Characteristics Of Concrete Using Bagasse Ash*. 3699–3703.

[9] G, G. S. R., Anil, G., & S, L. G. (2016). *Comparison of Compressive Strength of M25 , M30 Grades of Concrete by Partially Replacement of Fly Ash with Normal and Accelerated Curing*. *3*(1), 164–172.

[10] Nemati, K. N. (2015). Aggregates in concrete. *Modern Concrete Technology*, (13), 1–16. https://doi.org/10.1017/CBO9781107415324.004.

[11] *Optimal Mix Design for Epoxy Resin Polymer Concrete Miss Amy Beutel Course ENG4111 Research Project Part 1 & Bachelor of Civil Engineering (Honours)*. (2015). (October).

[12] Hameed, A. M., & Ahmed, B. A. F. (2019). Employment the plastic waste to produce the light weight concrete. *Energy Procedia*, *157*(2018), 30–38. https://doi.org/10.1016/j.egypro.2018.11.160.

[13] Safi, B., Saidi, M., Aboutaleb, D., & Maallem, M. (2013). The use of plastic waste as fine aggregate in the self-compacting mortars: Effect on physical and mechanical properties. *Construction and Building Materials*, *43*, 436–442. https://doi.org/10.1016/j.conbuildmat.2013.02.049.