BirEx JOURNAL
Budapest International Research in Exact Sciences
Medical, Biological, Argiculture, Engineering Science and other related areas
e-ISSN : 2655-7827
p-ISSN : 2655-7835
http://www.bircu-journal.com/index.php/birex

Process for Making Self-Locking Pavements from Madagascar River Sand and Plastic Waste

Rakotomamonjy L.[1], Rakotomamonjy P.[2], Razafindramanga A. W.[3], Rakotondramanana V. Henintsoa[4], Bakoarisoa Andrianina Cynthia[5], Ramahandry Jean Elidon[6], Koto-te-Nyiwa Ngbolua[7], Robijaona Rahelivololoniaina B.[8]

[1,2,3,4,5,6,8]*Engineering and Industrial Process, Agricultural and Food Systems, Polytechnic High School of Antananarivo, Madagascar*

[7]*Department of Biology, Faculty of Science, University of Kinshasa, Kinshasa, Democratic Republic of the Congo*

[7]*Department of Environmental Sciences, Faculty of Science, University of Gbado -Lite, Gbado-Lite, Democratic Republic of the Congo*

[8]*Laboratory for the valorization of natural resources, Polytechnic High School of Antananarivo, Madagascar*

valorena1357@gmail.com

Abstract: *This work focuses on the manufacture of self-locking pavement from a mixture of river sand and waste from the recovery of plastic film packaging of the cookie and confectionery JB and wastes plastic bags collected at the university campus of Vontovorona. The sand is sifted to select the appropriate granulometry, which is higher than 0.5 mm on the one hand, and that is lower than 0.5 mm on the other hand. The sand with a grain size greater than 0.5 mm is mixed with the plastic waste in accordance with the manufacturing dosage. Different proportions of sand/plastic waste ranging from 40/60 to 70/30 have been prepared. The absorption rate increases with the proportion of sand added. This is true for both types of plastic waste. This absorption rate is increased for the pavers with plastic bag waste as binders. For the latter, the lowest rate of 2.2 is close to the highest rate of 2.1 for paving stones with JB plastic packaging waste as binders. The obtained pavers have a good mechanical strength higher than 12,000 daN.*

Keywords: *waste; plastic; sand; granulometry; paving stone*

I. Introduction

The environment undergoes major problems due to various pollutions in our time. In Madagascar, the management and recovery of waste remain major challenges to achieve, it does not keep pace with the growth. Waste is poorly managed and constitutes a major source of pollution (Ndepete et *al.*, 2022). Garbage bins are overflowing and the places and surfaces of dumping are constantly increasing and scattered everywhere without any well-defined regulation. In particular, waste bags and plastic packaging are proliferating relentlessly in large cities and even in relatively large villages. This represents a great threat to our environment by preventing the drainage of wastewater and rainwater in the gutters. This leads to the spread of waterborne diseases (cholera, typhoid) and malaria (Rakotosaona et *al.*, 2014).

How can we manage this waste while making a profit? It turns out that the valorization of these resources is one of the solutions to remedy this. Opportunities for development have arisen and have aroused our interest in being able to valorize plastic waste.

In the case of the university campus of Vontovorona, these wastes are in large quantities, coming from daily use.

It is interesting to consider the transformation of this waste into interlocking paving stones and to try to optimize the parameters that can influence their performance (Tafitason, 2017). Interlocking paving stones are well known for their use in road construction and housing.

The chapters will explain the materials and methods for the manufacture of interlocking paving stones from plastic waste. Then the results and discussions.

II. Material and Methods

2.1 Particle Size Analysis

It allows to measure of the dimensional distribution in the mass of the elements of a material **(Ranarivelo, 2019)**. The tasks to be done are: drying the sand, sieving and weighing. First, the sand used was collected at the edge of the river Imerintsiatosika. Then, it is exposed for 72h to the open air to make sure that it is quite dry. A sample of 500 g of this sand is taken, and the sieves are weighed with vacuum to 1 g by constituting a column of clean and dry sieves whose opening of the meshes is respectively from top to bottom: 1.60; 0.50; 0.40; 0.20; 0.10; 0.063 and 0.04 mm.

Figure 1. *AFNOR Test Sieve and a Mechanical Vibration Device*

The column is capped by a bottom to collect the elements passing the last sieve and a cover to avoid the dispersion of dust. The dry sand is poured on the column and carefully fixed on the mechanical stirring machine which is stirred for 20 minutes. Stop the shaker, then carefully separate the different sieves and weigh each sample collected using the precision balance.

2.2 Manufacture of the Paving Stone

a. Raw Materials

The plastic waste used is used plastic bags, recovered in the household waste of the Regional University Campus (CUR) of Vontovorona, and packaging of the factory Joliment Bon (JB) in order to manufacture interlocking paving stones by adding sand.

The study allows for determining the optimal quantity of plastic bags to be added to the sand and the granulometry of the sand used (Rasolonjatovo, 2012).

In this sense, the methodology consists of carrying out different tests for each dosage to determine the optimal manufacturing parameters.

b. Processes

1. Sorting

First of all, manual sorting for the household waste of Campus Universitaire Régional Vontovorona in order to select the plastic bags and eliminate the maximum impurity.

2. Washing

After sorting, the plastic bags are washed in a basin filled with water to purify the selected raw materials (Dairon et *al.*, 2020).

It consists in purifying the plastic waste by removing all foreign bodies. Cleaning is essential to ensure the quality of the finished products.

Figure 2. *Washing Plastic Bags in a Bowl*

3. Drying

Drying is done in the open air, they are exposed to the sun to accelerate the evaporation of water for 24 hours to ensure that the bags are dry before moving on to the next step.

Figure 3. *Drying of Samples After Washing*

4. Addition of Sand

The French standard XP P 18-540 defines the aggregate as a set of mineral grains, with dimensions between 0 and 80 mm. It is intended for the preparation of mortars and concretes as well as for wearing courses, base courses and foundation courses of roadways and railroads.

For this experiment, the sand is classified into two granulometries. The sand of higher granulometry than 0.5 mm, is noted GS and the sand of lower granulometry than 0.5 mm, is noted Gi.

5. Dosing and Weighing

After the sand and plastics are prepared, it is the stage of dosage of these raw materials.

Table 1. Proportion by Mass of Plastics and Sand of each Test

% mass	**Sand**	40	50	60	70
	Plastic	60	50	40	30

6. Cooking and Mixing

To avoid negative impacts on the environment, it is imperative not to burn waste. Before any manipulation, it is necessary to protect oneself and put on Personal Protective Equipment (PPE) to ensure safety throughout the process.

First, the fire is lit, then the metal drum is heated for 10 minutes, then the plastic waste compacted manually (to avoid too much space) and already weighed is introduced into the drum. Good control of the fire guarantees that the properties of the polymers do not degrade or are not completely carbonized. The temperature (120°C) is well monitored with a thermocouple.

At the same time, the sand is preheated to a temperature of 120°C so that no solidification can take place during the mixing process.

As soon as the plastics start to wilt, mixing is required to melt everything. When a homogeneous fluid of this compound from the plastic waste is obtained, preheated sand is added (Tafitason, 2017). The mixing of the mixture [sand + plastic waste] guarantees the homogenization of this paste. When the appearance of white smoke (120°C-124°C) is observed after about 30 minutes of cooking, this indicates that the mixture is well homogenized and ready to be poured into the mold.

7. Molding and Compaction

Molding is the process of shaping. The resulting homogeneous paste is removed from the metal barrel and poured into the mold with a trowel. This operation must be done as quickly as possible so that the paste does not solidify prematurely before compaction. To eliminate voids and pores that could store water, compaction is the way to go, which is where a press comes in. The paste takes the shape of the mold and solidifies.

8. Demolding and Cooling

To facilitate the work of demolding, the paving stone and the case of the mold are soaked in a bowl of cold water for 3 minutes, the cooling water must be changed when its temperature is near 60 ° C.

9. Pause Time

In order to test the mechanical properties and obtain a good accuracy of value, the pavers are soaked in cold water for 72 hours in a basin and then dried for 24 hours in the open air on a table.

2.3 Mechanical and Physical-Chemical Tests

a. Absorption Test

The principle of this test is to compare the mass of the paving stone after being immersed in water and its initial dry mass. For the determination of the porosity of the material thus prepared (Rafanomezantsoa, 2015) a dry weighing is made. Then, the material is immersed in a bowl filled with water for a period of 72 hours. When the material comes out, it is weighed again.

The porosity is expressed by the formula:

$$P = \frac{M_f - M_i}{M_i} \times 100$$

with:
P : the absorption rate in %

M_f : the final weight in (g)
M_i : the initial mass in (g)

b. Compression Test

The mechanical tests were carried out at the technical block of the University of Antananarivo in Ambohitsaina with a universal testing apparatus composed of a plate on which a press connected to the control system is fixed (Andriamamonjisoa, 2016). The machine is equipped with a dial showing the possible values of the modulus of the resistance force (in daN).

First, the mold containing the specimens is proportional to the aggregate used. The sample to be tested is installed above this support. The material is subjected to two opposing forces which tend to shorten it, then it is progressively subjected to a load until it breaks by compression under axial load.

IV. Discussion

4.1 Granulometric Analysis

The following table shows the results of the granulometric analysis of the sand.

Table 2. Results of the Granulometric Analysis of the Sand

Screen		Partial refusal	Cumulative refusals		Sieve
N°	Opening in mm	(g)	(g)	(%)	(%)
1	1,600	32	32	6,4	93,6
2	0,500	287	319	63,8	36,2
3	0,400	49	368	73,6	26,4
4	0,200	97	465	93,0	7,0
5	0,100	23	488	97,6	2,4
6	0,063	6	494	98,8	1,2
7	0,040	2	496	99,2	0,8
8	PAN	4	500	100,0	0,0

Here is the plot in a semi-logarithmic diagram:

On the abscissa the number of each sieve, the size of the sieve openings in decreasing values as mentioned in the table. And in ordinate, the percentage, in mass of the total material of the fraction of sand whose grains have an average diameter lower than that of the corresponding abscissa.

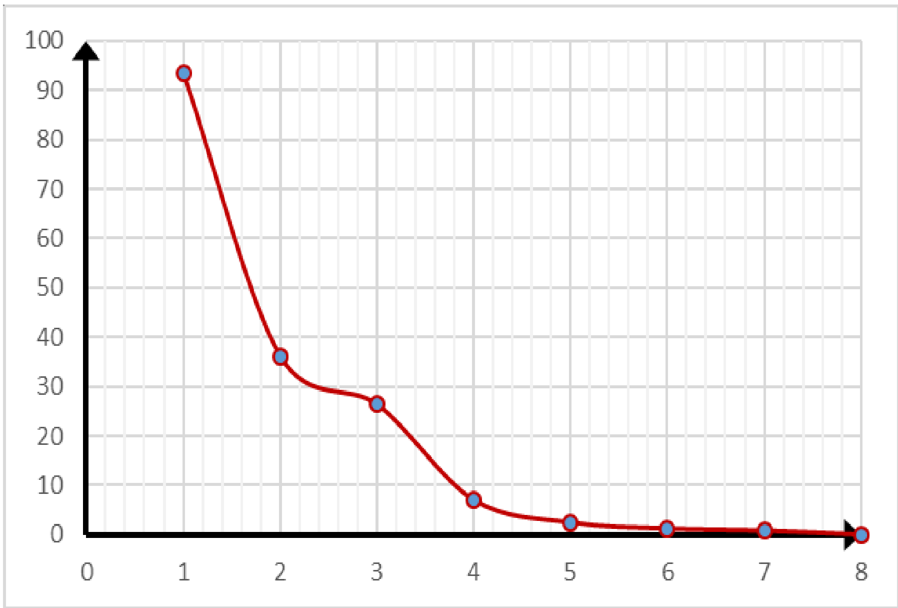

Figure 4. *The Grading Curve of the Sand*

The granulometric curve expresses the granularity and gives the distribution of the average dimension of the grains, as a percentage of the total mass of the material. Following a deduction of these results, the sand used represents more than 63% of sand in granulometry higher than 0.5 mm.

4.2 Manufacturing of the Pavers

After manufacturing, the integration of sand in the molten thermoplastic improves the heat resistance and the hardness of the paver. It also plays the role of plasticizer to improve the hot fluidity of the mixture.

For granulometry smaller than 0.5mm, the products obtained show cracks. On the other hand, for those which are higher than 0.5mm, the obtained pavers are in good condition.

For the continuation of this work, the study on the pavers manufactured with sand of granulometry higher than 0.5mm is adopted. After weighing each paver, the density of these products with their respective dosages is shown in the table below.

Table 3. Mass Results of the Products Obtained

	Plastic bag waste				**Plastic packaging films**			
Test N°	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mass in gramme	282	280	281	281	286	283	285	284
Density in g/cm3	1,51	1,50	1,50	1,50	1,53	1,51	1,52	1,52
Average in g/cm3	1,50				1,5 2			

Behaviors of the tests performed:

The experiment consists in manufacturing interlocking paving stones and studying the mechanical behaviors of the products obtained according to the dosages of the mixture and the granulometry of the sand. The various weighings carried out give the masses consigned on the table below for the composition of the mixture and allow to know their states.

The masses of raw materials used for each test are reported in the following tables.

a. Mass Proportioning of Paving Stones with Sand of Grain Size Greater than 0.5 mm

In order to carry out the different tests, it is necessary to specify the mass percentages of the materials to be introduced for the composition of these mixtures.

Table 4. Mass Proportioning of Paving Stones with Sand of Grain Size Greater than 0.5 Mm and Waste Plastic Bags

Test n°		1	2	3	4
Percentage of sand/plastic		40/60	50/50	60/40	70/30
Mass in kg	Sand	2	2	3	0,7
	Plastic	3	2	2	0,3

Table 5. Mass Proportioning of Paving Stones with Sand of Size Greater than 0.5 mm and Waste Plastic Film from JB

Test n°		5	6	7	8
Percentage of sand/plastic		40/60	50/50	60/40	70/30
Mass in kg	Sand	2	2	3	0,7
	Plastic	3	2	2	0,3

Table 6. Mass Proportioning of Paving Stones with Sand of Grain Size Less than 0.5 mm and Waste Plastic Bags

Test n°		9	10	11	12
Percentage of sand/plastic		40/60	50/50	60/40	70/30
Mass in kg	Sand	2	2	3	0,7
	Plastic	3	2	2	0,3

Table 7 : Mass Proportioning of Paving Stones with Sand of Grain Size Less than 0.5 mm and Waste Plastic Film from JB

Test n°		13	14	15	16
Percentage of sand/plastic		40/60	50/50	60/40	70/30
Mass in kg	Sand	2	2	3	0,7
	Plastic	3	2	2	0,3

1: Pavement with waste plastic bags
2: Pavement with plastic film waste
A: Pavement with sand of grain size greater than 0.5 mm
B: Paving stone with sand of granulometry lower than 0,5 mm
Figure 4. *Samples of Paving Stones Obtained*

4.3 Mechanical characterization and absorption test

a. Porosity Test

Table 8: Results of Pavement Absorption Tests [Sand+Plastic Bag Waste]

test	1	2	3	4
Mi (g)	282	280	281	281
Mf (g)	288	288	290	291
Rate of absoption (%)	2,2	2,7	3,1	3,6

M_i : the initial mass in (g)
M_f : the final mass in (g)

Table 9. Results of Pavement Absorption Tests [Sand + JB Plastic Film Waste]

.Test	5	6	7	8
Mi (g)	286	283	285	284
Mf (g)	288	286	290	290
Rate of absoption (%)	0,7	1,2	1,6	2,1

M_i : the initial mass in (g)
M_f : the final mass in (g)

According to these two tables 8 and 9, the absorption rate increases with the proportion of sand added. This would be explained by the fact that plastic acts as a binder, the less plastic there is, the more interstice there is, and the more absorption increases. This observation is valid for both types of plastic waste, plastic bag waste and JB packaging waste. Only this rate of absorption is increased for the paving stones having as binder waste of plastic bags. For the latter, the lowest rate of 2.2 is close to the highest rate of 2.1 for paving stones with JB plastic packaging waste as binders.

b. Mechanical Tests

The compressive strength is expressed in daN.mm-2. It is calculated by applying the following formula:

$$R_c = \frac{F}{S}$$

with :
Rc : Compressive strength [daN.mm-2]
F : Maximum pressure force supported by the material [daN]
S : Section [mm2].
The molds used in our production are hexagonal, with side a = 60 mm and height h=20 mm.
The section and volume are calculated using the following formulas:

$$S = \frac{3\sqrt{3}}{2}a^2 \quad \text{et} \quad V = \frac{3\sqrt{3}}{2}a^2H$$

The section of the paving stone is: S = 9353 mm^2

When testing the pavers obtained from each type of test, the accuracy of the limit compression forces is not obtained, due to the fact that the measuring device is limited to a value of 12,000daN. And in the end, these pavers resisted this compression force. It was the same for the traction.

Following these different tests, the paving stones obtained from the superior granulometry in the sand have strong mechanical resistances superior to 12.000 daN, therefore they can be used in road construction if those with granulometry inferior to 0,5 mm can be used to cover low walls as a decoration.

The sand thus plays the role of plasticizer (Rasoatahinjanahary, 2014) and the sand of granulometry higher than 0,5mm represents more than half of the used sand which are originating from the edges of the river of Imerintsiatosika. The sand of granulometry superior to 0,5mm is the most suitable due to its facility of compaction and that the obtained products do not present cracks.

According to the results obtained for the absorption tests, the higher the percentage of sand, the higher the value of the absorption rate. This parameter must be taken into account to have products with a lower absorption rate.

Regarding the difference between the plastic films of JB and the waste in plastic bags of Vontovorona, the average value in density is 1.52 and 1.50 g/cm3 (Rakotondramanana, 2016). There is a slight difference between the two.

IV. Conclusion

The objective of the work was to valorize plastic waste in the self-locking pavement, and try to optimize some parameters that could improve the aspects or characteristics of the products obtained. These studies confirm that an important point of this manufacturing process is the preheating of the sand. A risk of solidification of the plastic already in fusion can take place if the sand was not brought to the temperature of 120°C. The paving stones obtained from plastic packaging and plastic bags do not have much difference, sand with a grain size of more than 0.5 mm is the most suitable for manufacturing. The quantity of sand-plastic influences the absorption rate of the obtained paving stones.

Thus, the formulation and the operating conditions were important factors in the improvement of the mechanical performance of these self-locking pavers.

The obtained pavers have good mechanical resistance to compression. The materials thus obtained can however compete with the traditional materials currently encountered on the market.

Plastic waste is indeed a real resource of sustainable development for a country. Its valorization leads to ecological development, and to the protection of the environment. The treatment of this waste also allows for to reduction of the emission of greenhouse gases, but also a socio-economic development: the creation of work for the local population.

However, the exploitation of plastic waste as a source of energy is possible due to the fact that its calorific value is as high as that of oil.

But doesn't this mean that plastic waste could be one of the unimaginable sources of progress and sustainable development for a better future?

Acknowledgements

This study represents the completion of part of a laborious but rewarding work that would not have been possible without the advice, help, and presence of many people.

We would like to thank the Be MIRAY team of the ED GPSIAA and the Technical Unit of Ambohitsaina team, for having offered excellent working conditions.

References

Andriamamonjisoa, J. L. (2016). Proposition de valorisation de déchets solides industriels : cas de la biomasse papier, carton et plastique de la Socolait. (Master's thesis). Université d'Antananarivo. Madagascar

Dairou, S., Alain, L. P., Arafat, G. & Jacques D. H. (2020). Valorisation des déchets plastiques dans la production des matériaux de construction : cas des paves dans la ville de Garou. Cameroun du Nord. Retried from http://creativecommons.org/licenses/ by-nc/4.0/

Ndepete C.P., Zaguy-Guerembo R., Deganai Gbongo A.M., Regakouzou L.M-P., Ngaissona Namndouta V.O. & Kpeou-Kolengue J. (2022). Valorisation des déchets plastiques en matériaux de construction. European Scientific Journal, ESJ, 18 (21), 317. Retrieved from https://doi.org/10.19044/esj.2022.v18n21p317

Rafanomezantsoa, S. S. (2015). Contribution à la valorisation des dechets plastiques en matériaux de construction. (Master's thesis). Université d'Antananarivo. Madagascar

Rakotosaona, R., Ramaroson, J., Mandimbisoa, M., Andrianaivoravelona, J. O., Andrianary, P., Randrianarivelo, F. & Andrianaivo, L. (2014). Valorisation à l'échelle pilote des déchets plastiques pour la fabrication de matériaux de construction. Mada hary, vol 2. Retrieved from http://madarevues.recherches.gov.mg/IMG/pdf/hary2_6_-2.pdf

Ranarivelo, R. A. (2019). Valorisation des déchets plastiques - étude de l'influence de l'ajout de plastique dans le béton bitumineux routier. (Master's thesis). Université d'Antananarivo. Madagascar.

Rasoatahinjanahary, H. (2014). Contribution à l'optimisation de la production de matériaux de construction à base de plastique recycle-sable. (Master's thesis). Université d'Antananarivo. Madagascar. Retrieved from http://biblio.univ-antananarivo.mg/pdfs/rasoatahinjanaharyHarivola_ESPA_ING_14.pdf

Rasolonjatovo, T. M. S. (2012). Contribution à la valorisation des déchets plastiques par la fabrication des tuiles. (Master's thesis). Université d'Antananarivo. Madagascar.

Rakotondramanana, H M. (2016). Contribution à la valorisation des déchets emballages films plastiques de la société JB. (Master's thesis). Université d'Antananarivo. Madagascar.

Tafitason, M. S. (2017). Contribution à la valorisation des déchets emballages films plastiques de la société JB - essai de fabrication de pavé en plastique. (Master's thesis). Université d'Antananarivo. Madagascar. Retrieved from http://biblio.univ-antananarivo.mg/pdfs/TafitasoaMahefanjakaS_ESPA_MAST_2017.pdf