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Design and Physico-mechanical and Thermal Characterization of a Composite Eco-material based on Sand and Plastic Waste Melted by a Scheffler Solar Concentrator

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Abstract–In Burkina Faso, population growth, lifestyles and consumption patterns have led to a significant production of plastic waste (PW). A tiny proportion of this PW is recycled, in particular by material recovery, which is the most common method. However, for melting the PW, this method uses not clean energy sources (wood, butane gas), making the produced materials less environmentally friendly. The present study aimed to develop a composite eco-material based on sand and plastic waste melted using a Scheffler solar concentrator. It involved manufacturing and installing the solar concentrator, the accessories for solar irradiation and temperature measuring, and the device for melting and mixing the new composite materials. Then, two types of mix were formulated: a sand/PW mix with ratios of 75/25, 70/30, 65/35 and 60/40, and a sand/PW/laterite mix with a ratio of 60/30/10. The concentrator enabled an internal melting temperature of 172.42°C to be reached for the new environmentally friendly composite production. Specimens measuring 4×4×16 cm3 were made and tested using 3-point bending, compression, capillary absorption and thermal tests. The best mechanical resistance was obtained with the 65/35 ratio of the sand/PW mix, with average values of 12.15 MPa in 3-point bending and 23.96 MPa in compression. This composite eco-material had a water absorption rate of 0.4% and a thermal diffusivity of 0.36 mm²/s. On the other hand, the sand/PW/laterite mix had a mechanical strength of 10.1 MPa in 3-point bending and 22.83 MPa in compression, with a water absorption rate of 2.3% and a thermal diffusivity of 0.44 mm²/s. In addition to these initial results, we plan to analyse the effect of thermal shock or wetting-drying cycles on the durability of this composite eco-material. However, it can be used to produce paving blocks as well as hollow and solid masonry bricks.

Keywords: Eco-material, composite, recycling of Plastic waste, Scheffler solar concentrator.

I. INTRODUCTION

For several decades now, plastic waste (PW) has been gradually transforming planet Earth and aquatic system, into an open-air rubbish tip, causing unprecedented environmental pollution that threatens ecosystems and biodiversity, as well as human health [1]. In 2016, global plastic waste production amounted to 53 kg of waste per capita and approximately two billion tonnes of carbon dioxide emissions [2].

With this proliferation of waste, various effort has been down in plastic waste recycling and several studies have been undertaken on the possibilities of recycling it into construction materials. Investigations into the possibility of combining it with other raw materials to obtain composites have been reported, notably with sand, gravel and laterite [3]. and the effect the incorporation of PW on concrete behavior [4]. In this regard, composite materials based on a granular matrix (sand) and PD as a binder have been developed for road surfacing and indoor and outdoor flooring [5]. In addition, sand/plastic mixtures can be used as materials for the production of paving stones and bricks [6] [7]. These products resulting from plastic waste based

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composite are light weight and economically low and present benefits [8] [9]. So, these studies revealed that the developed composites exhibit commendable mechanical properties, especially flexural and compression resistance, and minimal water absorption [10]. From multi-criteria analysis Malbila et al., (2024) concluded that the mains components of eco-friendly paving stones are plastic waste, glass waste and aggregates [11] and these findings emphasize the importance of optimizing material formulation and processing parameters to enhance overall performance [8].

The novelty of the present study is the use of a clean energy source, namely solar energy, for melting plastic waste and the mechanical mixing device. Among the renewable sources of energy, solar energy offers a practical solution for the energy problem which is clouding the prospects of mankind [12]. This study therefore aims to develop an eco-composite based on sand and plastic waste melted by a Scheffler solar concentrator.

II. MATERIALS and METHODS

A. *Raw Materials*

The raw material used in this study were sand, laterite soil and plastic waste. The sand and laterite soil were obtained from a site in Fada N'Gourma area with respectively a Global Positioning System (GPS) coordinates of 12.05600 N; 0.34610 E andv12.10020 N 0.34710 E. The PW was the high-density polyethylene type and collected from the BARAJI Society. Physicals properties of the sand and the lateritic soil are respectively a coefficient of uniformity of 0.42 and 26.66, finesse modulus of 2.15 and 1.24 and are suitable according to standard NF EN 933-1 [13], NF EN 13043 [14], EN 12620 [15].

B. *Methods*

1) Solar Power Source Device Installation and Operation: The experimental fusion unit used in this study is located in Saaba in Ouagadougou area and comprises a pair of 16 m² mobile Scheffler primary reflectors sharing a fixed receiver and equipped with glass mirror (m.e.v) and aluminum mirror (m.e.a) (Fig. 1). The receiver is positioned between the two dishes, 1.10 m above the ground and inclined at 12.38° latitude in the north-south direction. The focal length is chosen to be 2.69m and the calculated focal point is approximately 1.43m from the ground on the vertical axis.

Fig.1: Layout of solar fusion device at Saaba (latitude 12.38°, longitude -1.43°)

In the operation of the device, no-load (no lift testing) and load experiments of PW melting were carried out as part of this study. Type J and K thermocouples linked to a data logger, in particular the GRAPHTEC midi LOGGER GL220, were used to measure the temperatures evolution during the operation (Fig. 2).

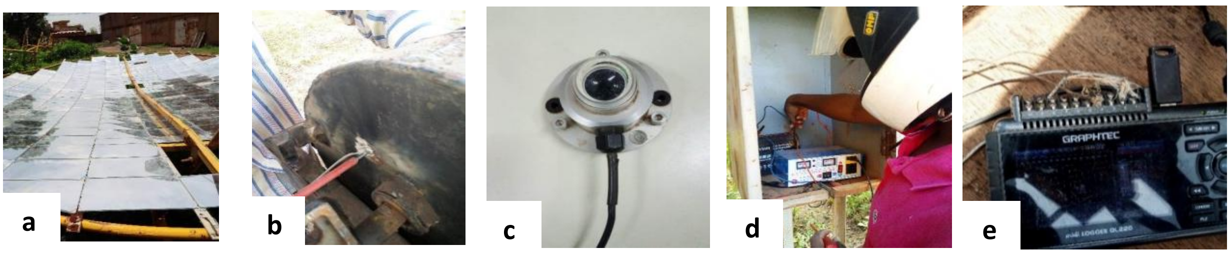

Fig. 2 : Main components of the energy source device a) Reflectors mirrors b) Thermocouples c) Scanning Pyranometer d) Battery connection with converter and e) Datalogger

For the experiment, it was decided to automatically measure temperatures at a time step of five (05) minutes.

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2) *Composite preparation and experimental design:* The graphical design of the composite formulation is presented in Fig. 5. The ratios of the raw materials are summarized respectively in Table 1. The raw materials are mixed in mass ratio which are obtained by applying equation 1 below.

$$\boldsymbol{M_p} = \boldsymbol{n} \times \boldsymbol{P}(\%) \times \boldsymbol{M_t} \quad \textbf{(1)}$$

*With M_p, the mass of PW in the mix, **n**, the number of samples, $P(\%)$ the ratio of PW in the mix and M_t, the theorical mass of the sample.*

TABLE I
RATIO OF THE COMPONENTS OF EACH FORMULATION TYPE

Formulation type	F1(75%/25%)	F2 (70%/30%)	F3 (65%/35%)	F4 (60%/40%)	F5 (60%/30%/10%)
Plastic waste (PW)	25 %	30%	35%	40%	30%
Sand	75%	70%	65%	60%	60%
Laterite	0%	0%	0%	0%	10%
Number of sample	15	15	15	15	15

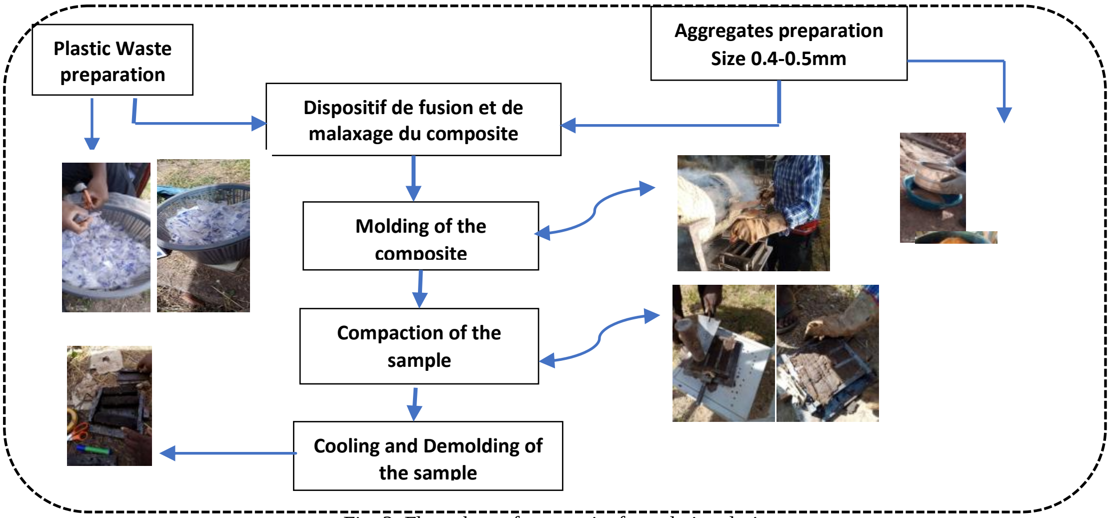


Fig. 3: Flow chart of composite formulation design

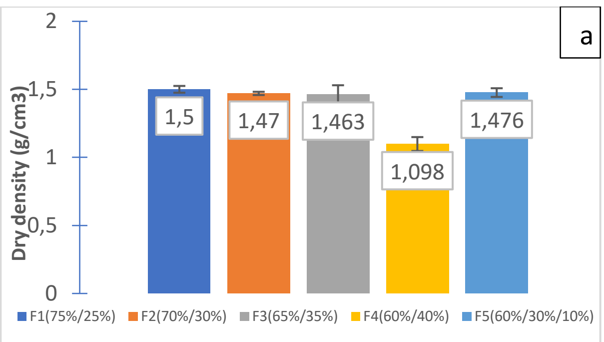
3) *Physical behavior of the Composite:* The characterization of the composite sample consisted in the determination of the density, the withdrawal, the linear shrinkage (α in %), the water absorption and porosity, following the standard DIN 18947 *[16]*, AFPC - AFREM *[17] [18]* , NF P18-459 and NF EN 14617-1 *[19]*.

4) *Mechanical and Thermal behaviour of the composite:* The mechanical characterization of the composite is consisted in the Abrasion, the compressive and flexural strength tests. The thermal characterization was conducted by using the thermal conductivity meter KD2 Pro Decagon©, to have at same time the value of thermal conductivity (λ) from 0.1 to 2 W/m.K, volumetric thermal capacity (C) from 0,5 to 4 MJ/m3.K and thermal diffusivity (α) from 0,1 to 1 mm²/s.

III. RESULTS and DISCUSSION

A. Physical characteristics of the composite

Fig. 4 and 5 show the physicals properties of the samples.



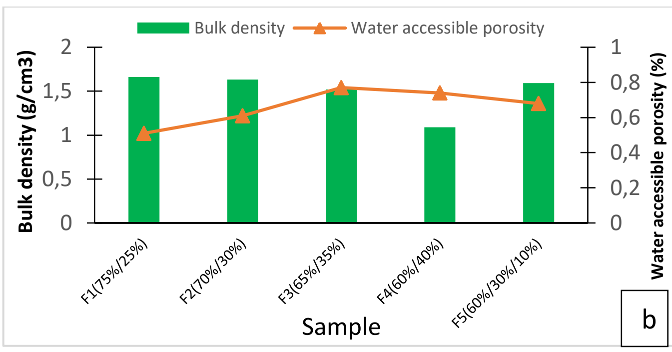


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Fig. 4 **:** Value of a) dry density and b) Link between Dry density and Water Accessible Porosity

Fig. 4 shows a decrease in density as the plastic content increases. This decrease is due to the material's plastic-like properties, which have a lower density (0.96 g/cm³) than sand's (1.5 g/cm³).The denser the composite (1.66 kg/m³), the fewer pores it has (0.51%) and conversely, the less dense it is (1.09 kg/m³), the more porous it is (0.74%). This observation can be explained by the good adhesion between the filler (sand) and the matrix (HDPE) in (excellent mixture stability), and the porosity coefficient values are ranging from 0.51 to 0.77%. Fig. 5 present the composite behavior in contact with water, by capillary and its sorptivity and the absorption by total immersion are summarized in Table 2.

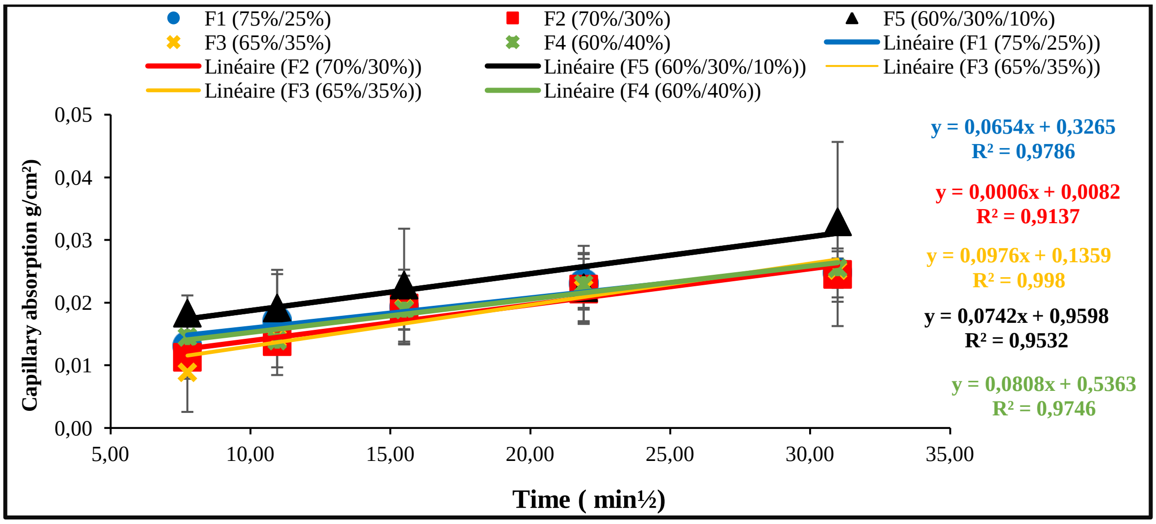

Fig. 5**:** Evolution of the coefficient of Capillary absorption of the composite

Tableau 1: Evolution of the sorptivity and the water absorption by total immersion of the composite

Samples	Sorptivity [kg.m² /h$^{1/2}$]	Water absorption by total immersion (%)
F1 (75%/25%)	0,0654	1,60%
F2 (70%/30%)	0,0006	0,60%
F3 (65%/35%)	0,0976	0,40%
F4 (60%/40%)	0,0808	0,30%
F5 (60%/30%/10%)	0,0742	2,30%

The analysis of results presented in Table 4 show the decreasing of water absorption by total immersion from **1.6% to 0.3 %** when the ratio of PW in the mix increase from 25wt% to 40wt% this is due to the hydrophobic nature of plastic which prevents water entering in the composite. F5 (60%/30%/10%) composite has high water absorption with the addition of laterite soil, which is a material that is highly sensitive to water.

B. Mechanicals and Thermal characteristics of the composite

Fig. 6 show the evolution of abrasion coefficient (Ca) which is ranges from 0.026 g/cm² – 0.002 g/cm² depending on the addition rate of PW and the thermal conductivity of the composite.

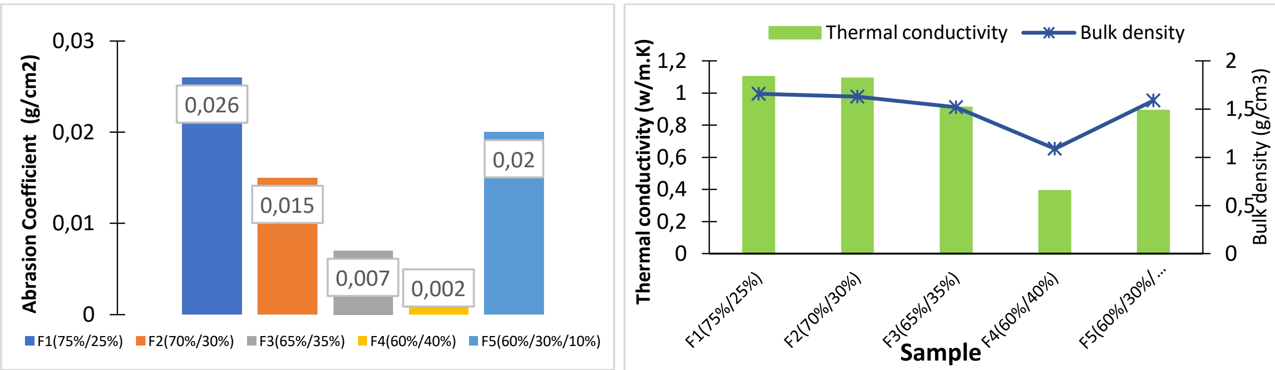

Fig. 6**:** Results of abrasion test and Thermal conductivity

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The abrasion coefficient (Ca) decrease while the PW rate increase from 25wt%-40wt% in the mix, with the grains consolidation in contact with the melted plastic. The supplementary load of 10wt% of laterite soil in mix F5 (60%/30%/10%) the abrasion coefficient increase (**50,66 cm^2**/g) in comparison to F2(**70%/30%**), F3(**65%/35%**) and F4(**60%/40%**). This low consolidation of the composite F5 is due to the presence in the mixture of laterite soil which is less resistant to impact compared to sand.
We note that the increase of PW in the mix result by the decrease of thermal conductivity of the composite. This behavior is probably due to the change in the compactness of the composite. These results corroborate those obtained by [20]. We observed that the thermal capacity and thermal diffusivity changes with the rate of PW in the mix. The decreasing tendency of the thermal capacity with the increasing of PW in the mixture were observed respectively with polyurethane foam and high-density polyethylene by [21].

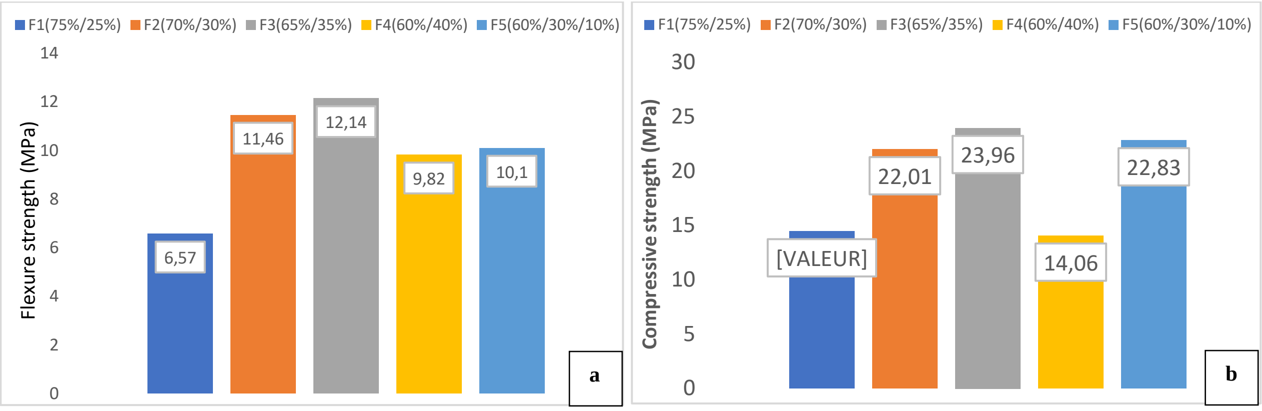

Fig. 7**:** Mechanical properties a) Flexure strength and b) Compressive strength

Fig. 7 presents mechanicals strength and the maximum value is obtained with the composite of 35wt% PW and 65wt% of sand. Furthermore, we noted that the mechanicals properties of the composite increase with the loading of 10wt% of laterite soil in the mixture in partial replacement of sand.

IV. IMPLICATION on PRACTICE and RESEARCH of the NEW COMPOSITE

Base on the mechanicals strengths and water absorption coefficient obtained, we can then propose the various materials from Formulations with (30wt%, 35wt%) plastic and those with 10% laterite, such as F2 (70%/30%), F3 (65%/35%) and F5 (60%/30%/10%) for use as class **T5 traffic pavers** in accordance with standards NF EN 12390-3 [22], NF EN 1339 [23].
According to standards NF DTU 52.1 P1-2 [24], NF DTU 54.1 P1-1 [25] and NF EN 13451-1 [26], flooring materials are classified according to stress. According to the standards, the minimum compressive and flexural strengths are set at 16 and 4 MPa respectively. By comparing them with the results obtained, we can propose formulations F2 (70%/30%), F3 (65%/35%) and F5 (60%/30%/10%) as P3-type coatings for **soil pavement.**
All the composite samples show satisfactory mechanical strengths in relation to the standard for the use of **hollow and solid block breeze-blocks**. The minimum compressive strength of our materials is 14.06 MPa, well above the minimum tolerances of 4 MPa for hollow blocks and 8 MPa for solid blocks.

V. CONCLUSION

The main conclusions that can be drawn from this research work are:

- The average indoor temperature of 172.45°C melted the plastic waste (HDPE) and the plastic must be heated for around 3 hours to obtain liquid;
- The composite Sand/PW is suitable and presents an interesting characteristic, by:
  - Increasing the flexural and compressive strength up to rate of 35wt% of PW in the mix;
  - Reducing Water absorption with increasing plastic content;
  - Increasing thermal insulation performance of the samples.
- The addition of 10% laterite to replace sand in the mixture, improves mechanical properties and increases water absorption compared to other formulations.

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RÉFÉRENCES

[1] Y. S. El-Metwally, K. M. Dewidar, M. R. Ismail and I. S. El-Mahallawi, "A Review on Sustainable Disposal of Plastic Waste by Integration in Construction Materials," *Civil Engineering and Architecture,* vol. 11, no. 2, pp. 714-725, 2023.

[2] D. Dabilgou, "Optimisation énergétique du processus de fusion des déchets plastiques par concentration solaire Scheffler," Ouagadougou, 2022.

[3] M. Gouasmi, A. Benosman, H. Taïbi, M. Belbachir and Y. Senhadji, "The physico- thermal properties of mortars made of composite aggregates "PET- siliceous sand"," *Journal of Materials and Environmental Sciences,* vol. 7, no. 2, pp. 409-415, 2016.

[4] O. Safer, O. Chaib, A. H. Mostefa, M. Dahmane, A. A. M. Amer, M. Salhi, M. Benadouda, N. Latroch and A. Safa, "Effect of the incorporation of plastic waste on the mechanical properties of composite materials," *Studies in Engineering and Exact Sciences,* vol. 5, no. 1, pp. 2529-2564, 2024.

[5] C. Ndepete, R. Zaguy-Guerembo, A. Deganai Gbongo, L.-P. Regakouzou, V. Ngaissona-Namndouta and J. Kpeou-Kolengue, "Valorisation des déchets plastiques en matériaux de construction," *ESJ Natural/Life/Medical Sciences,* vol. 18, no. 21, pp. 317-329, 2022.

[6] A. Singh, A. K. Srivastava, G. Singh, A. D. Singh, H. K. Singh, A. Kumar and G. K. Singh, "Utilization of Plastic Waste for Developing Composite Bricks and Enhancing Mechanical Properties: A Review on Challenges and Opportunities," *Advances in Polymer Technology,* vol. Article ID 6867755, p. 24, 2023.

[7] F. J. Khan and S. N. Gurav, "Design and Fabrication of Plastic Recycling Machine and Testing of Its Products," vol. 47, no. 1, pp. 300-304, 2024.

[8] S. Mekideche, M. Rokbi, Z. E. A. Rahmouni, R. Phiri, S. M. Rangappa and S. Siengchin, "Manufacture and characterization of lightweight sand-plastic composites made of plastic waste and sand: Effect of sand types," *International Journal of Lightweight Materials and Manufacture,* vol. 8, pp. 53-65, 2025.

[9] R. Roobankumar and M. SenthilPandian, "A review of utilization of waste polyurethane foam as lightweight aggregate in concrete," *Heliyon,* vol. 10, no. e40479, pp. 1-19, 2024.

[10] M. Hassan, A. Ahmed, R. Ahmed, A. Siddiqui, M. Tanoli and R. Ali, "Mechanical and microstructural characterization of recycled plastic waste in sustainable building applications," *Construction of Unique Buildings and Structures,* vol. 115, no. 11506, pp. 1-12, 2025.

[11] E. Malbila, A. G. L. Koungwe and D. Y. Toguyeni, "Multicriteria analysis of the components of ecological paving stones made from plastic and glass waste, and granular reinforcements," *Open Ceramics,* vol. 18, no. 100604, pp. 1-8, 2024.

[12] S. Dawange Sahebrao, "Renewable Energy Technology: A Case Study of Solar Steam Cooking System at Shri Saibaba Sansthan Trust, Shirdi, MS, India," *Int. Res. J. of Science & Engineering,* vol. Special Issue A4, pp. 1-6, 2018.

[13] *NF EN 933-1: Essais pour déterminer les caractéristiques géométriques des granulats - Partie 1 : détermination de la granularité - Analyse granulométrique par tamisage,* 2012.

[14] *NF EN 13043-Granulats pour mélanges hydrocarbonés et pour enduits superficiels utilisés dans la construction des chaussées, aérodromes et d'autres zones de circulation,* 2003.

[15] *EN 12620-2002_Aggregagtes concretes.*

[16] *DIN 18947: Mortier de terre pour enduit - Exigences, essai et étiquetage,* 2024.

[17] *AFPC-AFREM (1997) Essai de carbonatation accélérée, Mesure de l'épaisseur de béton carbonaté, Mode opératoire recommandé par l'AFREM. Compte rendu des journées techniques AFPC-AFREM Durabilité des bétons, Toulouse, 11-12 Décembre 1997, 153-158..*

[18] F. Ntimugura, S. Sore, L. Bello and A. Messan, "The Influence of Metakaolin from Saaba (Burkina Faso) over Physico-Mechanical and Durability Properties of Mortars," *Open Journal of Civil Engineering,* vol. 7, pp. 389-408, 2024.

[19] *NF EN 14617-1: Pierre agglomérée - Méthodes d'essai - Partie 1 : détermination de la masse volumique apparente et du coefficient d'absorption d'eau,* 2013.

[20] M. Boumhaout, L. Boukhattem, H. Hamdi, B. Benhamou and F. A. Nouh, "Thermomechanical characterization of a bio-composite building material: Mortar reinforced with date palm fibers mesh," *Construction and Building Materials,* vol. 135, pp. 241-250, 15 March 2017.

[21] A. Badache, A. S. Benosman, Y. Senhadji and M. Mouli, "Thermo-physical and mechanical characteristics of sand-based lightweight composite mortars with recycled high-density polyethylene (HDPE)," *Construction and Building Materials,* vol. 163, pp. 40-52, February 2018.

[22] *NF EN 12390-3_Essais pour béton durci - Partie 3 : résistance à la compression des éprouvettes,* 2019.

[23] *NF EN 1339 : Dalles en béton - Prescriptions et méthodes d'essai,* 2004.

[24] *NF DTU 52.1 P1-2-DTU 52.1 - Travaux de bâtiment - Revêtements de sol scellés - Partie 1-2 : critères généraux de choix des matériaux,* 2020.

[25] *NF DTU 54.1 P1-1_Building works - Cast in situ synthetic resin flooring - Part 1-1 : contract bill of technical model clauses,* 2018.

[26] *NF EN 13451-1+A1_Équipement de piscine - Partie 1 : exigences générales de sécurité et méthodes d'essai pour les équipements installés dans des piscines à usage public,* 2024.

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