World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Thermomechanical characterization of a cement mortar based on tyre granules

Abelim PASSOLI [1, 2, *], Tiambo Abbas DATCHOSSA [1] and Emmanuel OLODO [1]

[1] *Laboratory of Applied Energetics and Mechanics (LAEM), Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Benin.*
[2] *National Institute for Scientific Research of the University of Lomé (NISR-UL), University of Lomé, Togo.*

World Journal of Advanced Research and Reviews, 2026, 29(01), 1440-1446

Publication history: Received 08 November 2025; revised on 12 December 2025; accepted on 16 December 2025

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.4155

Abstract

Industrial waste management is a topical issue for both the present and the future. Current policies around the world encourage waste recovery as a means of managing waste. This study aims to recover tyre granules in construction materials. The goal is to determine the thermomechanical characteristics of cementitious mortars made from tyre granules. To achieve this, we formulated mortars in accordance with standard EN 196-1 for the control mortar. Tyre granules were then added to the control mortar at rates of 5%, 10%, 15% and 20% to produce formulations MT5, MT10, MT15 and MT20, with MR as the reference mortar. These formulations were tested using thermal probe, compression strength and three-point bending strength tests. The test results show that the addition of tyre granules leads to a reduction in thermal conductivity. Compressive and flexural strengths decrease with increasing tyre granule content. Flexural strength decreases from 5.95MPa for the reference mortar to 1.31MPa for the MT20 mortar. Compressive strength decreases from 29.36MPa for MR mortar to 7.95MPa for MT20 mortar. Compressive and flexural strengths indicate that 10% is the optimal rate for incorporating tyre granules into cement mortar.

Keywords: Cementitious Mortars; Tyre Granules; Thermal Conductivity; Compression Strength; Flexural Strength.

1. Introduction

Changes in attitudes and technology, along with increasingly stringent environmental protection requirements and the revision of economic benchmarks inspired by sustainable development, mean that the recycling and recovery of industrial by-products is now a growing concern for mankind [1]. Composed of mixtures of rubber, steel and various textiles, used tyres are not hazardous waste, but they do pose a danger to the environment and health in the event of a fire at the storage site. Global users generate an estimated one billion tyres each year. They are bulky solid waste that is harmful to the environment and takes centuries to biodegrade [2]. Currently, the problems of handling and disposing of this waste are major concerns. Thermal treatment of used tyres is preferred over other methods of management. It promotes their conversion into valuable energy and chemicals [3]. Several studies have been carried out by researchers on different types of cementitious composite materials.

For example, the work of [4] showed that incorporating tyres into mortar reduces heat propagation through the material. Alongside this work, other studies have been conducted to demonstrate the importance of waste recovery and its usefulness in construction materials.

For example, Arnaud L. and Boyeux B. [5] carried out work on hemp mortar samples to study their thermal performance. This enabled them to estimate the thermal conductivity of this material. The thermal conductivity of hemp concrete is 0.1 W/m.K., which makes it a good thermal insulator. Similarly, Ashraf Fadiel and his colleagues [6] studied the use of tyre granules in mortar, varying the amount of tyre granules added from 10%, 20%, 30% and 40% and the size of the

* Corresponding author: Abelim PASSOLI

rubber particles. Thermal conductivity decreases by 28% when switching to aggregate diameters of 10-20 mm compared to 30 mm aggregates. The thermal conductivity of the mortar decreases as the amount of rubber increases, regardless of the size of the tyre granules. He found that the conductivity of tyre granule-based mortars varies between 0.492 and 0.682 W.m-1.K-1 when the diameter of the aggregates is varied.

Although this work is very interesting, few people are interested in the mechanical characteristics of cementitious materials containing tyre granules. The present work aims to determine the thermomechanical characteristics of cementitious mortars made from tyre granules for construction.

2. Experimental design

2.1. Composite formulation

The formulation of the tyre granulate mortar composite was carried out in accordance with standard EN 196-1, this time with aggregates composed of sand and tyre granulates. The tyre granulates were fixed at a mass ratio of 10% of the total weight of the aggregates for the thermal tests. For the mechanical tests, the mass fraction of tyre granules varied between 0%, 5%, 10%, 15% and 20%, giving the formulations MR, MT5, MT10, MT15 and MT20 respectively.

2.1.1. Preparation of tyre granulate test specimens for thermal testing

The test specimens used to measure the thermal conductivity of tyre granulate mortar were obtained by compacting the granulate into PVC cylinders with volumes identical to those of the test specimens of materials compacted in CBR or modified Proctor moulds using a vibrating table. A total of three test specimens were prepared, one per sample.

2.1.2. Preparation of tyre granulate mortars for mechanical testing

The test specimens for mechanical testing were prepared in accordance with EN 196-1. Mechanical testing was carried out in accordance with EN 196-1.

2.2. Thermal characterization

2.2.1. Material

The method used to measure thermophysical parameters is the thermal probe method. The device used to measure these parameters is designed for conductivity and diffusivity.

- A thermal needle probe: a device that creates a heat source and incorporates a temperature measuring element (thermocouple or thermistor) to measure the temperature variation at a point along the line;
- Constant current source: A device for producing a constant current (power regulator);
- Thermal reading unit: A computer for reading the temperature in degrees Celsius;
- A multimeter: Device capable of measuring voltage and current intensity;
- A stopwatch;
- An instrument capable of drilling a straight vertical hole with a diameter as close as possible to that of the probe and to a depth at least equal to the length of the needle;
- PVC cylinders with the characteristics of a Modified Proctor mould;
- A 30 kg capacity balance;
- An oven with adjustable temperature up to 300±2°C;
- Containers;
- A trowel.

The water temperature is 20°C.

2.2.2. Methodology

Thermal conductivity

The test we will use to determine the thermal properties of our mortar is the quasi-steady-state thermal probe test.

Standard: ASTM International, 2014

Principle: This method consists of creating a linear thermal disturbance in the medium and measuring the temperature variation over time.

Sample preparation

- Weigh the required volume of each ingredient and place them in a container to mix them.
- Pour in the calculated volume of water.
- Mix everything together.
- Compact the sample in a modified Proctor mould or in a PVC cylinder with the same geometric characteristics as a modified Proctor mould using a vibrating table.
- Weigh the sample.
- Immerse the test specimens in water for 28 days after the mortar has set.
- Weigh the sample.

Measurement and acquisition

Measurement

- Insert the thermal needle probe into the sample either by pushing it into a pre-drilled hole (dense sample) to a depth equal to the length of the probe or by pushing it into the sample. Care should be taken to ensure that the thermal probe shaft is fully integrated into the sample and not left partially exposed.
- Leave the sample for a moment to allow its temperature to stabilize.
- Connect the heating wire of the thermal probe to the constant current source (power regulator).
- Connect the acquisition system wires to the computer to enable temperature readings to be taken.
- Apply a constant current of known intensity to the heating wire.
- Record the temperature readings at 0 s, 5 s, 10 s, 15 s, 30 s, 45 s, and 60 s, then take measurements at 30 s intervals for a minimum of 1000 s.
- Turn off the constant current source once the measurement time has elapsed and record the temperature readings until the temperature stabilizes.
- Plot the temperature data against the logarithm of time on a semi-logarithmic graph.
- Select the linear portion of the curve (quasi-steady state phase) and plot a straight line through the points (linear regression).
- select times t_1 and t_2 at the appropriate points on the line and read the corresponding temperatures T_1 and T_2.
- At the end of the test, weigh the sample to determine its dry density and take a representative sample of the sample to determine its water content at the end of the test.

Acquisition

The power variator connected to the thermal probe powers the heating element (heating wire) inside the probe. The acquisition system connected to the thermal probe is responsible for collecting temperature values over time. It communicates with the thermal probe by means of a control program that contains the test parameters, which are:

- Intensity of the current supplied by the variable speed drive: I = 0, 15 A.
- Probe resistance: $\boldsymbol{Rsonde}$ = **54 Ω**.
- Probe length: l = 0, 1 m.
- Heating element length L = 0.216 m
- Curent voltage $\boldsymbol{U}$ = 8.1 W ;

The program is written in Python. Once the connection between the probe and the acquisition system is established, the control program is sent to the acquisition system, which collects the temperature values every second. Once all the necessary measurements have been taken, the temperatures are recorded in an output file that will be used to calculate the thermal conductivity.

Presentation of results

Before taking any measurements, the temperature probe must be calibrated. Calibrating the device involves standardizing it to assess its efficiency and accuracy on the one hand, and to define a correction factor used to correct measurements on the other. The correction factor $C\lambda$ is defined by the ASTM D5334 standard as the ratio between the thermal conductivity $\lambda matériau$ of the known material and that measured using using the probe denoted $\lambda mesurée$, as follows:

$$C_\lambda = \frac{\lambda_{matériau}}{\lambda_{mesurée}} \quad (2\text{-}1)$$

The calibration material must have a thermal conductivity within the following range: ($0.2 < \lambda < 5$ W/m. K). There are several materials used for calibrating this tool, including dry trench sand and fine coal dust. Both materials have well-documented thermal conductivities; Table 11 gives their value.

Table 1 Thermal conductivities of materials used during the calibration phase

Material	**▯ (W/m.°C)**	**Condition**
Dry channel sand	0,400	ρ = 1600 $kg/m3$
Fine coal dust	0,12	30 ≤ °C ≤ 150

2.2.3. Data analysis

The table shows data which corresponds to the ideal result of a thermal conductivity test. The λ coefficient is determined by considering the temperature values during the quasi-steady state portion.

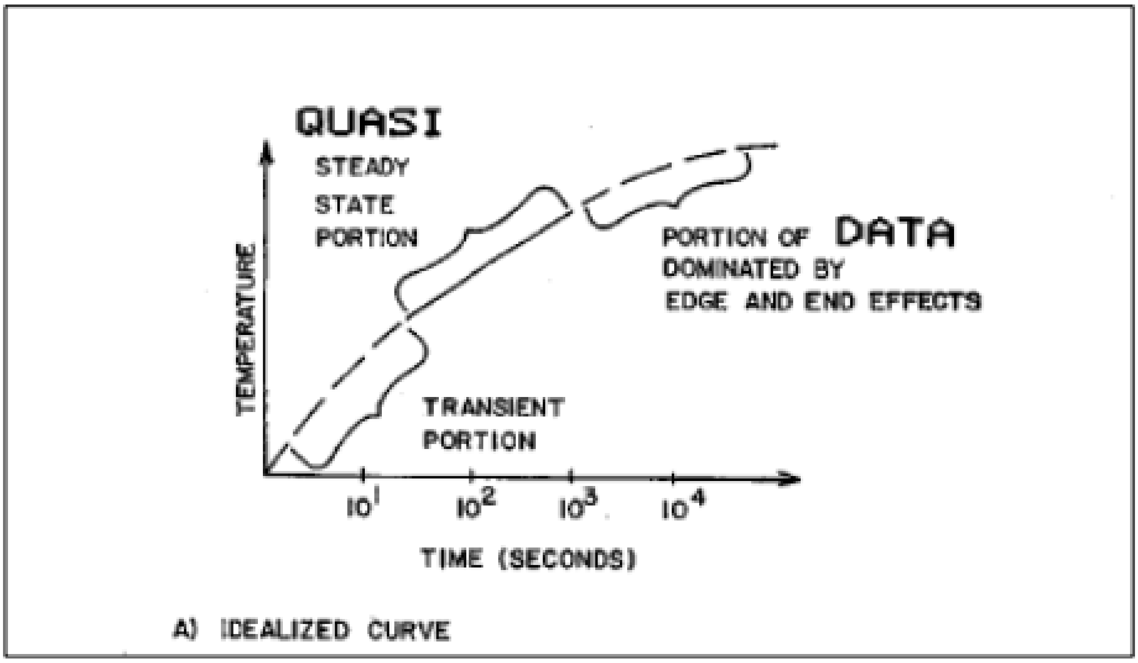

Figure 1 Typical temperature evolution over time [7]

According to ASTM D5334, the transient phase of the test should not be considered when processing the results. This is because when the heat source is generated along the probe, it must pass through the material that makes up the probe before reaching the test material [8]. The non-linear part at the beginning therefore corresponds to the heating of the probe and must be removed from the analysis.

For the heating phase, we then obtain a series of points in the plane (ln(t), T) that can be interpolated by a straight line whose slope will be denoted S_h.

The thermal conductivity of the medium is then given by relation 2.3. The probe required a calibration phase, which must also be considered in the calculation of thermal conductivity. To do this, relation 2.2 also incorporates the calibration coefficient C_λ.

$$\lambda = C_\lambda \frac{Q}{4\pi(T_2 - T_1)} \ln\left(\frac{t_2}{t_1}\right) \quad (2\text{-}2)$$

Where :

$$Q = \frac{RI^2}{L} = \frac{UI}{L} \quad (2\text{-}3)$$

By setting :

$$S_h = \frac{(T_2 - T_1)}{\ln(t_2) - \ln(t_2)} = \frac{(T_2 - T_1)}{\ln\left(\frac{t_2}{t_1}\right)} \quad (2\text{-}4)$$

λ then becomes :

$$\lambda = C_\lambda \frac{Q}{4\pi S_h} \quad (2\text{-}5)$$

Where:
Q: Linear power supplied to the center (W/m).
R: resistance of the thermal probe (Ω).

I: constant current flowing through the heating resistance (A).
L: length of the heating element (m).
: thermal conductivity (W/(m·K).
C : correction factor.
t_1 and t_2 : measurement times (s).
T_1 *et* T_2 : temperatures corresponding to times t_1 and t_2, respectively.
S_h : slope of the linear regression.
The thermal conductivity value used for a given formulation is the arithmetic mean of conductivity determined on three test specimens of the same formulation.

2.3. Mechanical characterisation

The mechanical characterisation of the test specimens mainly concerned compressive strength and three-point bending strength. The half-specimens from the three-point bending test are used to determine compressive strength, in accordance with standard EN 196-1. The test specimens are produced and stored for 28 days, then crushed on a mechanical press. They were stored in the laboratory at a controlled temperature of 25°C and a relative humidity of 30%.

3. Results and discussion

3.1. Thermal characteristics

Table 2 Thermal conductivity of tyre granulate mortar

Mortar based on tyre granules	λ (W/m.K)
Test piece No. 1	0,43
Test piece No. 2	0,27
Test piece No. 3	0,5
Average	0,4
Standard deviation	0,009

Table 2 shows the thermal conductivity of tyre granulate mortar with the dispersion associated with its production on the different test specimens. The thermal conductivity obtained for tyre granulate-based mortar is 0.40± 0.04 **W/m**.K. This value is in the same order of magnitude as that obtained by [9]. This result suggests that tyre granule mortar has good thermal insulation properties. Tyre granule mortar could therefore provide very good performance in terms of thermal insulation in buildings. The thermal conductivity obtained in this study are like those obtained by Ashraf Fadiel and his colleagues [10], who obtained a thermal conductivity ranging from 0.49 to 0.68 W.m.K for a mortar based on tyre granules in different proportions.

3.2. Mechanical characteristics

3.2.1. Flexural strength

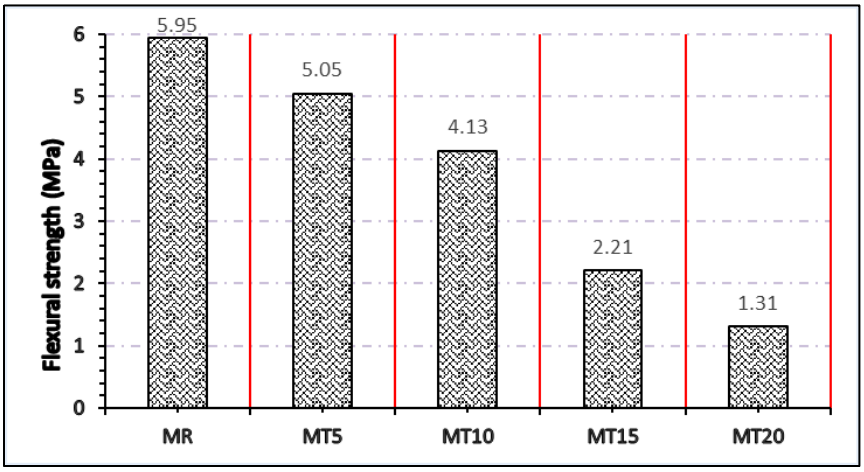

Figure 2 Variation of flexural strength as function of tire granules' rate

Figure 2 shows the evolution of the flexural strength of tyre granule mortars as a function of the mass fraction of tyre granules. In this figure, we observe a reduction in flexural strength as the proportion of tyre granules increases. This observation has been made by other authors, such as [11] and [12]. The reduction in flexural strength varies from 5.95 for the control mortar to 1.31 MPa for the mortar containing 20% tyre granules. Despite this drop in flexural strength with the mass fraction of tyre granules, the 10% fraction appears to be optimal because above this fraction there is a sharp drop in flexural strength. This decrease in compressive strength could be linked to a lack of adhesion between the mortar and the tyre granules [4]. Nevertheless, the presence of tyre granules prevents any sudden breakage of the mortar.

3.2.2. Compressive strength

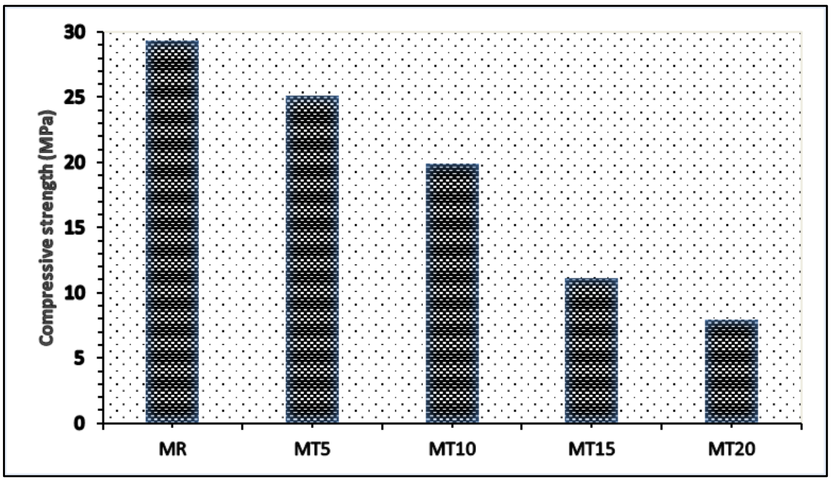

Figure 3 Variation of compressive strength as function of tire granules' rate

Figure 3 shows the evolution of compressive strength as a function of the mass fraction of tyre granules in the cement mortar.

This figure shows a decrease in compressive strength as the proportion of tyre granules increases. This was to be expected, given the decrease in flexural strength. There is a close correlation between compressive strength and flexural strength for cementitious materials. The decrease ranges from 29.95MPa for the control mortar to 7.95MPa for the mortar containing 20% tyre granules. The decrease in compressive strength could be explained by the drop in mortar density as the granule content increases.

Furthermore, the lack of adhesion between the mortar and the tyre granules could be the reason for the decrease in compressive strength, as mentioned in [4].

4. Conclusion

This article aims to study the thermal and mechanical behaviour of cement mortars containing tyre granules. The results of this research show that incorporating tyre granules into cement mortar leads to a decrease in thermal conductivity. Similarly, it is noted that increasing the proportion of tyre granules leads to a decrease in both flexural and compressive strength. It is noted that even though flexural strength decreases with the proportion of tyre granules, the presence of these granules in the mortar prevents the appearance of cracks.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] M. Faroudja, 'Reducing environmental pollution through recycling and recovery of used tyres,' COST, vol. 10, no. 1, pp. 13–18, Jan. 2012.

[2] H. Aouled Mhemed, 'Energy and environmental recovery of used tyre waste: improvement of liquid pyrolysis products through catalysis', Theses, Ecole nationale supérieure Mines-Télécom Atlantique; École nationale d'ingénieurs de Gabès (Tunisia), 2021. Accessed: 8 December 2025. [Online]. Available at: https://theses.hal.science/tel-03336153

[3] M. Ourak, 'Energy and chemical recovery from pyrolysis oils from used tyres', PhD thesis, Ecole nationale supérieure Mines-Télécom Atlantique; École nationale d'ingénieurs de Gabès (Tunisia), 2021. Accessed: 8 December 2025. [Online]. Available at: https://theses.hal.science/tel-03299354

[4] F. Bouakline, G. Bouakline, and D. Nehari, 'Contribution to the recovery of plastics from tyre waste,' 2023, Accessed: 8 December 2025. [Online]. Available at: http://dspace.univ-temouchent.edu.dz/handle/123456789/5755

[5] L. Arnaud and B. Boyeux, 'Hemp shives as a new ecological and high-performance aggregate for use in construction,' French Academy of Agriculture–Session of, vol. 12, 2011.

[6] Fadiel, 'use of crumb rubber to improve thermal efficiency of cement-based materials,' American Journal of Engineering and Applied Sciences, vol. 7, no. 1, pp. 1-11, Jan. 2014, doi: 10.3844/ajeassp.2014.1.11.

[7] A. I. S. D. 12 on R. Mechanics, Standard test method for determination of thermal conductivity of soil and soft rock by thermal needle probe procedure. ASTM International, 2008.

[8] N. I. Kömle, W. Macher, G. Kargl, and M. S. Bentley, 'Calibration of non-ideal thermal conductivity sensors,' Geoscientific Instrumentation, Methods and Data Systems, vol. 2, no. 1, pp. 151–156, Apr. 2013, doi: 10.5194/gi-2-151-2013.

[9] L. Arnaud and B. Boyeux, 'Hemp shives as a new ecological and high-performance aggregate for use in construction,' Académie d'Agriculture de France, 12 January 2011. [Online]. Available at: https://www.academie-agriculture.fr/system/files_force/seances-colloques/20110112communication3.pdf?download=1

[10] A. Fadiel, F. Rifaie, T. Abu-Lebdeh, and E. Fini, 'Use of crumb rubber to improve thermal efficiency of cement-based materials,' vol. 7, pp. 1-11, March 2014, doi: 10.3844/ajeass.2014.1.11.

[11] Y. Yu and H. Zhu, 'Influence of Rubber Size on Properties of Crumb Rubber Mortars,' Materials, vol. 9, no. 7, p. 527, July 2016, doi: 10.3390/ma9070527.

[12] E. Khalil, M. Abd-Elmohsen, and A. M. Anwar, 'Impact Resistance of Rubberised Self-Compacting Concrete,' Water Science, vol. 29, no. 1, pp. 45-53, Apr. 2015, doi: 10.1016/j.wsj.2014.12.002.