Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN


J. Mater. Environ. Sci., 2024, Volume 15, Issue 4, Page 552-563

http://www.jmaterenvironsci.com

# Physico-Mechanical Characterisation of Micro-Concrete Roofing Tiles Produced from Bambui (North West Cameroon) and Garoua I (North Cameroon) River Sands

**Zoum F. A.[1]*, Aye A. B.[1], Ndimungiang B. L.[1], Loweh S. S.[2], Kemmeugni D.[2]**

[1]*Department of Mining and Mineral Engineering, National Higher Polytechnic Institute, University of Bamenda, Bambili, P.O. Box 39, Cameroon*

[2]*Local Materials Promotion Authority (MIPROMALO), P. O. Box 2396, Yaounde, Cameroon*

**Corresponding author, Email address: alainfon4@gmail.com;zoumfon@uniba.cm*

***Received*** *28 Feb 2024,*
***Revised*** *07 Apr 2024,*
***Accepted*** *13 Apr 2024*

**Keywords:**
- ✓ *River Sands;*
- ✓ *MCR Tiles;*
- ✓ *Flexural Strength;*
- ✓ *Permeability;*
- ✓ *Water Absorption;*
- ✓ *Impact Resistance*

***Citation****: Zoum F. A., Aye A. B., Ndimungiang B. L., Loweh S. S., Kemmeugni D.(2024) Physico-Mechanical Characterisation of Micro-Concrete Roofing Tiles Produced from Bambui (North West Cameroon) and Garoua I (North Cameroon) River Sands , J. Mater. Environ. Sci., 15(4), 552-563.*

**Abstract:** In Cameroon, many Micro-Concrete Roofing (MCR) tiles on houses have been replaced with traditional aluminium roofing sheets due to leakages caused by the use of raw materials like river sands with high organic and clay content, and sea sands with alkaline salt issues. To address this, quarry sands have been considered as a substitute for river sands in MCR tile production. However, quarry sands are more expensive and require mixing with other sands of different particle sizes to meet production standards. Previous investigations showed that river sands from Bambui and Garoua I had representative of different grain sizes (Coarse, medium and fine grains), and acceptable sand equivalent value (>80%). While the mechanical properties of MCR tiles made from the river sands have not been extensively studied, this study seeks to promote the adoption of sustainable roofing solutions that balance economic viability with environmental responsibility. The production of MCR tiles from each river sands followed the recommended standard procedures. The resulting MCR tiles displayed favorable Physico-mechanical properties across various tests such as flexural strength, permeability, water absorption, and impact resistance. Upon comparative analysis, it was observed that MCR tiles made from Garoua I river sands exhibited superior characteristics compared to those made from Bambui river sands, particularly in terms of flexural strength, water absorption and impact resistance. The flexural strength, average water absorption, impact resistance (ball drop height) values were measured at 12.08 MPa, 10.31%, 110mm for Garoua I river sands and 10.68 MPa, 10.70%, 900mm for Bambui river sands respectively.

## 1. Introduction

The construction industry is a vital sector that significantly impacts the global economy, playing a crucial role in infrastructure development and societal progress (Mane *et al*. (2017). However, the industry's conventional practices have been associated with substantial environmental degradation, resource depletion, and waste generation (Bogas *et al*., 2015; Angel *et al*., 2017). In response to these challenges, there has been a growing emphasis on sustainable construction practices that prioritize eco-friendly materials and technologies to reduce the industry's carbon footprint and promote environmental conservation (Shen *et al*., 2016; Oludolapo and Charles, 2017). One area of sustainable construction that has gained increasing attention is the production of Micro-Concrete Roofing (MCR) tiles. These tiles offer a durable and cost-effective alternative to traditional roofing materials, such as clay or metal, while also providing thermal insulation and aesthetic appeal (Agbede *et al*. (2016). The production of MCR tiles involves the use of locally sourced materials, which can help reduce transportation costs and support local economies (Kagongbe *et al*. (2020).

MCR tiles, a form of concrete tiles, comprise cement, aggregates, water, and sometimes admixtures. Among these components, aggregates are pivotal in shaping the material's characteristics. Sand, a crucial aggregate in concrete, provides stability and volume to the mix (Chowdhury (2022), which is more than 30 percent of the total volume of concrete (Akinboboye *et al*., 2015; Sabih *et al*., 2016). Sand is a naturally occurring granular material composed of finely divided rock and mineral particles (Sabih *et al*., 2016; Magudeaswaran and Eswaramoorthi, 2016). The composition of sand is highly variable, depending on the local rock sources and conditions. In composition, silica ($SiO_2$) is the predominant oxide. Mineralogically, they consist of quartz resulting from the disintegration of granites, sandstone and similar rocks by natural processes of weathering and erosion (Mhedhebi *et al*. (2015). Generally, sand is obtained from river beds or from sand dunes originally formed by the action of winds. The usual particle size of sand grains is between 0.075 and 4.75 mm with further subdivision of coarse sand in range of 2 mm to 4.75 mm, medium sand in range of 0.42 mm to 2 mm and fine sand between 0.075 mm to 0.42 mm (Terzaghi *et al*. (1996). The characteristics of sand significantly affect the performance of fresh and hardened concrete and have an impact on the cost effectiveness of concrete (Tebbal and Rahmouni (2016). Gradation or particle size distribution and cleanliness of sand affects the properties of concrete like packing density, voids content, workability and strength (Sabih *et al*. (2016).

The use of river sand in concrete production varies widely depending on the availability of resources and local construction practices. In some regions, such as Southeast Asia and parts of the Middle East, river sand accounts for over 90% of the total sand used in concrete production (Abdias *et al*. (2023). In contrast, in some developed countries, such as the United States and Australia, the use of river sand in concrete production is relatively low, and alternative sources of sand, such as crushed rock and manufactured sand i.e. quarry sand, are more commonly used (Alisha (2021).

The high demand for river sand has led to unsustainable mining practices, causing environmental degradation, and social conflicts in some areas. As a result, there has been a growing interest in using alternative sources of sand, such as recycled construction waste and manufactured sand (quarry sand), to reduce the reliance on river sand in concrete production (Liu *et al*. (2018). Several studies have investigated various aspects of micro-concrete roofing tile production, including material properties, mix design optimization, curing methods, and the incorporation of waste materials. Choi and Choi (2013) and Nkengue *et al*. (2019) investigated the effect of using river sand, sea sand, and quarry sand on the properties of concrete, it follows that the properties of concrete change when the origin or quality of the sand is modified (Haitham (2018). Ogunbiyi and Olugbenga (2016) explored the mechanical properties of micro-concrete roofing tiles using different curing methods, highlighting the importance of proper curing techniques in ensuring the durability and performance of the tiles. Oyekan and Olubanwo (2018) evaluated the performance of micro-concrete roofing tiles incorporating waste materials as partial replacements for sand, demonstrating the potential for sustainable production practices. Moreover, Adekunle and Adegoke (2019) investigated the influence of curing duration on the durability properties of micro-concrete roofing tiles, emphasizing the need for adequate curing periods to enhance the longevity of the tiles. Ezeokonkwo and Uzoma (2017) utilized response surface methodology to optimize mix proportions for micro-concrete roofing tiles, aiming to achieve superior mechanical properties and cost-efficiency in production. Additionally, Ogunleye and Oyedepo (2020) conducted an environmental impact assessment of micro-concrete roofing tile production in Nigeria using a life cycle assessment approach, highlighting the environmental benefits of using locally sourced materials.

In Cameroon, the replacement of MCR tiles with aluminum roofing sheets (a traditional metal roofing sheet) is often due to leakages from poor raw materials like river sands with high organic and clay content, and sea sands with alkaline salt issues. As a solution, quarry sands are considered, being free from these impurities but costly due to energy-intensive production processes (e.g., crushing plant operations). Furthermore, the sands used for MCR tile production must have well-graded particle sizes, including fine, medium, and coarse grains, and should be free from organic materials, silt, and clay, with a sand equivalent value exceeding 80% (Ndigui and Uphie (1999). Previous studies by Zoum (2023) on the physical characteristics of Bambui and Garoua I river sands revealed that these sands were well-graded, showing a good mix of coarse, medium, and fine grains based on particle size analysis. The sand equivalent tests indicated that the sands were clean, with values exceeding 80%.

While the mechanical properties of MCR tiles made from Bambui and Garoua I river sands have not been extensively studied, this research seeks to address this gap by comparing the suitability of sands from these two localities for producing sustainable micro-concrete roofing tiles. These regions are known for their abundant natural resources, including river sands that can be utilized in the production of sustainable building materials. The choice of Bambui and Garoua I River sands as raw materials for micro-concrete roofing tile production is significant due to their availability, affordability, and potential for enhancing the sustainability of construction projects in the region. By utilizing these locally sourced sands, the production process can be streamlined, transportation costs reduced, and environmental impacts minimized. Additionally, by characterizing the physico-mechanical properties of the resulting roofing tiles, this study seeks to promote the adoption of sustainable roofing solutions that balance economic viability with environmental responsibility.

## 2. Materials and Method

### *2.1 MCR Tile Production*

Portland cement (CPJ CEM II 42.5R) from the Cameroon Cement Corporation (CIMENCAM) was used in this study as the binding material, fulfiling the European cement standard (EN 197–1/2011 (2011). A study carried out by Biyindi *et al*. (2019), reveals CEM II 42.5R cements can be used for reinforced and stressed concrete standard structures requiring high resistance.

The river sands from Bambui and Garoua I were each mixed with Portland cement in the ratio 2:1 as prescribed by (SKAT, 1992; Ramakrishna *et al*., 2011) forming two compositions (see **Figure 1**). Each compositions were used to produce 8 mm thickness double II MCR tiles. Water was added to the compositions and mixed thoroughly with a trowel to form a viscous slurry paste otherwise known as concrete. The concrete was placed on a tile vibrator for vibration, this was to reduce the pore spaces in the concrete. After vibration, it was placed in a mold, covered with a cloth and place on a hydraulic compressor machine, where it was compressed to take the shape of the mold.

Two 8mm thickness double roman II MCR tiles were produced from each composition (see **Figure 2**). The MCR tiles were covered for about 48 hours, then were removed from their mold and wet cure for 7 days. After curing for seven days, they were cure (dry curing) for 14 days making a total of 21 days curing period, before taken to the quality control laboratory in MIPROMALO (Local Material Promotion Authority). The purpose for curing was to ensure hardening of the concrete (Adekunle and Adegoke (2019).

**Figure 1.** The two Compositions formed by mixing each river sand and cement in the ratio 2:1

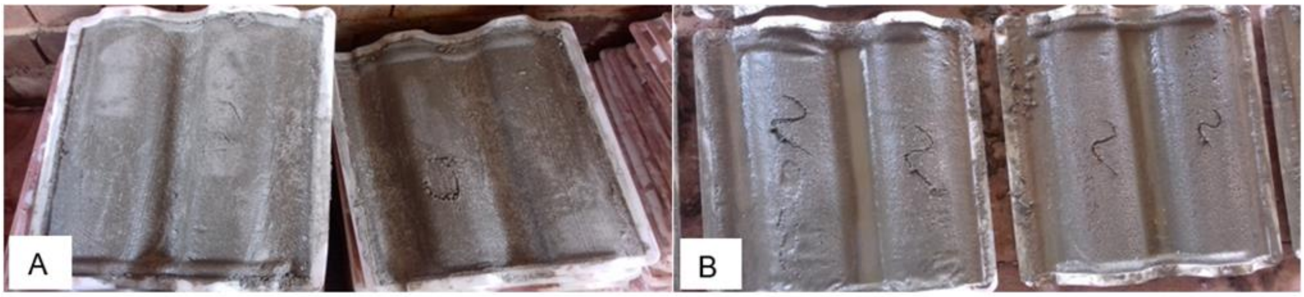


**Figure 2.** MCR tile produced from each composition: (A) Composition 1(from Garoua I river sand), (B) Compositon 2 (from Bambui river sand)

### *2.2 Physico-Mechanical Characterisation of the MCR tiles produced*

In the Quality control laboratory, the following test were carried out on the 8mm thickness double roman II MCR tiles: Flexural Strength test, Permeability test, Water absorption test and Impact test.

***Flexural Strength test***: Flexural strength indicates the load that a material can withstand without breaking or rupture. This test was conducted in accordance by American Society for Testing and Materials (ASTM) standard method (ASTM C 67-13, 2013; ASTM C 1492-03, 2009; WSDOT 802, 2009). One MCR tile twenty-eight (21) days old, was selected for testing from each composition. The tile was immersed in water for 24 hours and tested soon after removal from water. The tile to be tested was supported on two bearings or supports. The distance between the supports was two thirds of the length of the tile. The load was applied centrally through a third bearer using a rod of 38 mm diameter attach with a bucket of water whose mass (Kg) can be measured and converted to Newton (N) to get the maximum bending load capacity for the tile under testing.

The flexural stress was calculated using the formula in **Eqn. 1**;

$$\text{Flexural strength (MPa)} = (3 \times P \times L) / (2 \times W \times d^2) \qquad \textbf{Eqn. 1}$$

Where;

P =Loading force in Newton (N)

L = Span Length of the tile in millimeters (mm)

W = Width of the tile in millimeters (mm)

d = Thickness of the tile in millimeters (mm)

***Permeability Test***: Permeability test was carried out according to ASTM standard method (ASTM C 67-13, 2013; ASTM C 1167-03, 2012; ASTM C 1492-03, 2009). One tile from each composition was selected for the test. The selected sample was placed on a stand in such a way that its undersides were visible. Water up to approximately 10 mm height was allowed to sit on the top of the sample for 24 hours. The area between the sample and setup was properly sealed with a sealant to prevent leakage. Water drops were inspected after 24 hours and if more than two of them found on the underside of the sample, then the sample would be consider as significantly permeable. A tile is considered to have failed the test if after the 24 hours, it was found that water was dripping from, or there was free water on the underside.

***Water Absorption Test***: Water absorption test was carried out according to ASTM standard method (ASTM C 67-13, 2013; ASTM C 1492-03, 2009). Four (4) pieces of MCR tiles samples from each compositions were dried in an oven at 110° C for 24 hours, weighed (Dry Mass) and then immersed in a 500 ml test tube containing 200 ml of water for 24 hours. The volume of water displaced by each sample were observed. Then the samples were carefully wiped with a cloth and weighed again (Wet mass). Water absorption value four each sample was calculated using the formula in **Eqn. 2**;

$$WA = [(M2 - M1)/ (M1)] \times 100 \qquad \textbf{Eqn. 2}$$

Where;

WA = Water Absorption (%)

M1 = Dry mass (g)

M2 = Wet mass (g)

***Impact Test***: This test makes it possible to predict whether the MCR tiles will be able to withstand the shock of a fruit falling from a fruit tree, hailstorms, etc., once placed on the roof. The method adopted for this study was a Drop-ball test drawn from Johannson (1995).

One MCR tile produced from each composition was placed horizontally on a 100 mm thick layer of sand. The tile was press to heel in the sand, so as to take a flat orientation. A steel ball weighing 225g was drop from a height of 500 mm onto the center of the MCR tile. The position of the ball with respect to the tile was carefully determined by a plumb line. After each drop, the height was raised by 100 mm and the procedure repeated. After each drop, the MCR tile was observed for any cracks. A minimum requirement should be that the tile with stands the first drop without any visible crack.

## 3. Results and Discussion

### *3.1 Flexural Strength*

Flexural strength test was conducted after the 8mm double II MCR tiles were cured for a period of 21 days. The flexural strength for the MCR tiles produced from each compositions were calculated according to standard method and the results shown in **Table 1**.

**Table 1**. Flexural strength of MCR tiles produced from each composition cured for 21 days (Span Length=420mm, Width of tiles=330mm, thickness of tiles=8mm)

| Composition | Loading Force, P (N) | Flexural Strength (MPa) |
|---|---|---|
| Composition 1 (Garoua I) | 405 | **12.08** |
| Composition 2 (Bambui) | 358 | **10.68** |

From **Table 3**, the tile produced from composition 1(Garoua I river sand) had a value of 12.08 MPa, and that produced from composition 2 (Bambui river sand) had a value of 10.68 MPa. It can been seen from **Figure 3** that the flexural strength for the MCR tiles were approximately twice in contrast to the minimum standard requirements of 6 MPa (CIP-16 (2000). Nonetheless, the values of flexural strength obtained were much higher as compared to BS 6073 (1981), this is due to an excellent binding ability between the Portland cement and the river sands. This results are similarly to the findings of Nadeem *et al*. (2017), where the flexural strength values for the roofing tiles were reported to be in a range of 11.4 MPa to 12.2 MPa far above the minimum standards, the results obtained was due to the fact that the sands were clean constituting less than 20% of organic materials and silt that could potentially hinder the reaction between sands and the binder. Varela *et al.* (2015), investigated the average flexural strength of concrete tiles with different levels of partial substitution of pulverized solid waste materials for sands. The average flexural strength of the concrete tiles with pulverized clear plastic wrappers was reduced by 0.388 MPa (43.45%) while the average flexural strength of those with pulverized aluminized plastic wrappers was reduced by 0.495 MPa (55.43%). The findings show that the level of partial substitution of pulverized solid waste material for sand strongly reduced the flexural strength of concrete tiles.

The flexural strength results for the Garoua I and Bambui river sands can be attributed to the cleanliness of the sands, as indicated by (Zoum (2023), with less than 20% organic materials, clay, and silt content. This cleanliness factor plays a significant role in ensuring the structural integrity of the concrete, thus leading to the satisfactory flexural strength values observed in the produced MCR tiles. The results indicates that both compositions are sustainable in terms of flexural strength.

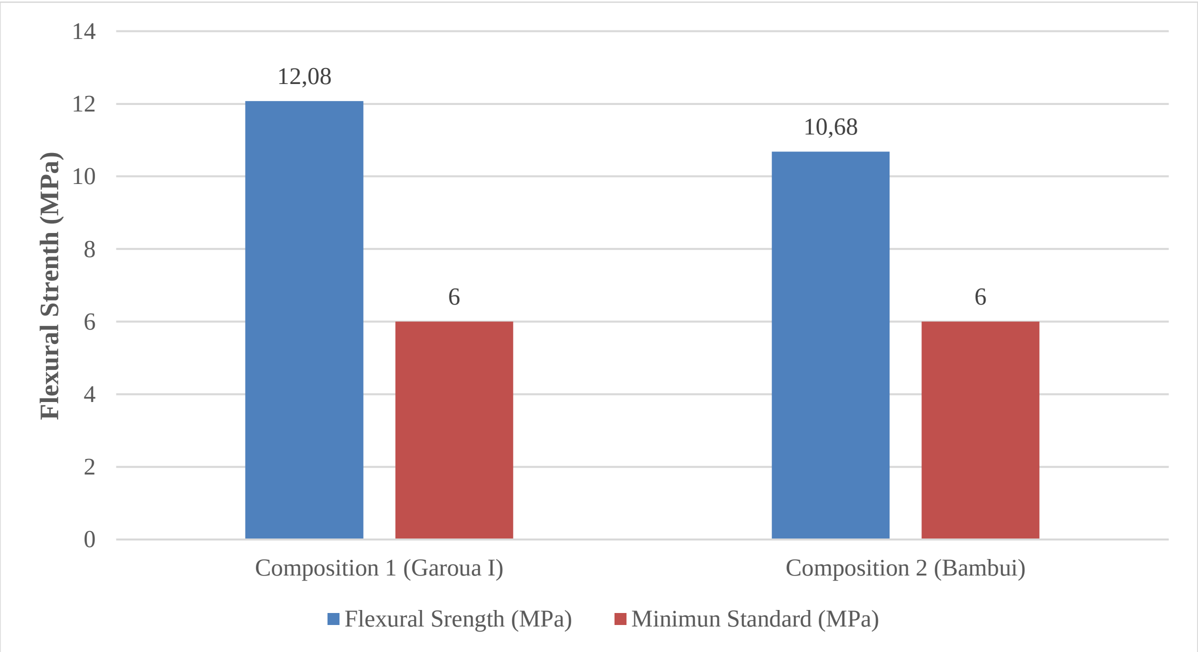


**Figure 3.** Flexural Strength Values for the MCR tiles produced from Garoua I and Bambui river sands with reference to the Minimum standard of 6 MPa

### *3.2 Permeability test*

The permeability test conducted on the Micro-concrete roofing (MCR) tiles produced from both Garoua I and Bambui river sands revealed positive results, indicating that no water droplets were found on the opposite side of the tiles after the 24 hours testing period. This absence of water droplets indicates that the tiles did not allow water to pass through, signifying a successful test outcome for both compositions, as shown in **Table 2**.

**Table 2.** Permeability test results for composition 1 and 2

| Composition | Permeability test |
|---|---|
| Composition 1 (Garoua I) | **PASS** |
| Composition 2 (Bambui) | **PASS** |

The permeability test is essential for assessing the presence of micro voids within the MCR tiles, which might result from factors such as insufficiently graded sands or inadequate vibration of the mortar during production, leading to increased pore spaces. The positive results in this test for both compositions suggest the absence of micro voids within the tiles. This outcome can be attributed to the well-graded nature of the sands used in the production process, including a mix of coarse, medium, and fine grains as identified through Particle size analysis, as mentioned in the study by Zoum (2023). Similar findings were reported by Ndigui and Uphie (1999) in their research on natural river sands from Monatele, where positive results in the permeability test indicated the absence of micro voids. The reason for this absence of micro voids was attributed to the well-graded nature of the sands from Monatele, underscoring the importance of proper grading in preventing the formation of micro voids within the MCR tiles. The comparison between the current study and the work of Ndigui and Uphie (1999) suggests that the positive results obtained in the permeability test for the MCR tiles made from Garoua I and Bambui river sands can be attributed to the well-graded composition of the sands used in the production process.

### *3.3 Water Absorption Test*

Water absorption test is crucial for determining the moisture content that roofing tiles can absorb, as excessive absorption can lead to undesirable cracking and structural integrity issues in MCR tiles.

The more pores are contained in a material, water absorption is greater and so the resistance of the material reduces. Cavities (pores) contained in a material happened because of poor quality and the composition of the constituent materials (Martínez-Lage *et al*. (2016). In this study, the water absorption test was conducted to quantify the moisture uptake of the MCR tiles.

**Table 3.** Percentage of water absorption for the four samples from each composition

| Composition | Sample | M1(dry mass in g) | M2 (wet mass in g) | Water absorption value (%) |
|---|---|---|---|---|
| Composition 1 (Garoua I) | 1 | 248 | 273 | 10.08 |
| | 2 | 232 | 255 | 9.91 |
| | 3 | 240 | 267 | 11.25 |
| | 4 | 230 | 253 | 10.00 |
| Average | | | | **10.31** |
| Composition 2 (Bambui) | 1 | 221.5 | 244 | 10.16 |
| | 2 | 226 | 249 | 10.18 |
| | 3 | 227 | 252 | 11.01 |
| | 4 | 222.5 | 248 | 11.46 |
| Average | | | | **10.70** |

Percentage of water absorption for the samples were calculated according to standard method and the results are shown in **Table 3.** The results in **Table 3** and **Figure 4** indicates that, the water absorption for composition 1 (Garoua I) range from 9.91% to 11.25%, with an average value of 10.31%, while for composition 2 (Bambui), the water absorption range from 10.16% to 11.46% with an average value of 10.70%. The water absorption values attained were below the standard limit of 12% (ASTM C 1492-03, 2009). The low percentage of water absorption was thought to be due to low porosity of the MCR tiles (Hung *et al*., 2015; Zhang and Zong, 2014).

In a study conducted by Ndigui and Uphie (1999) on natural river sands from Monatele, the water absorption test yielded an average value of 7.03%, indicating high-quality roofing tiles with regards to water absorption. Similarly, Jayasinghe *et al*. (2006) examined the engineering properties of micro-concrete roofing tiles from Sri Lanka, with the water absorption test revealing an average water absorption of 8.63%.

A low water absorption is an indication that the MCR tiles are less absorptive and more durable, while MCR tiles with high water absorption are susceptible to damage (Abdullah *et al*. (2015). Furthermore, the MCR tiles tested for permeability passed the test. Less porous materials are denser and denser materials have fewer chances to leak and vice versa. The higher the density, thus the lower will be the porosity and permeability (Zhang and Zong (2014). Low porosity, low percentage of water absorption and impermeability increases the durability of Concrete tiles (Farhana *et al*. (2015)

Comparing the results of this study to those of other researchers, it can be noted that the Garoua I and Bambui river sands utilized in the production of MCR tiles demonstrated water absorption values well within the acceptable range for good performance tiles. These findings suggest that the sands from Garoua I and Bambui are suitable for producing high-quality and sustainable MCR tiles that can be effectively used in regions prone to frequent rainfall, ensuring durability and structural integrity in varying environmental conditions.

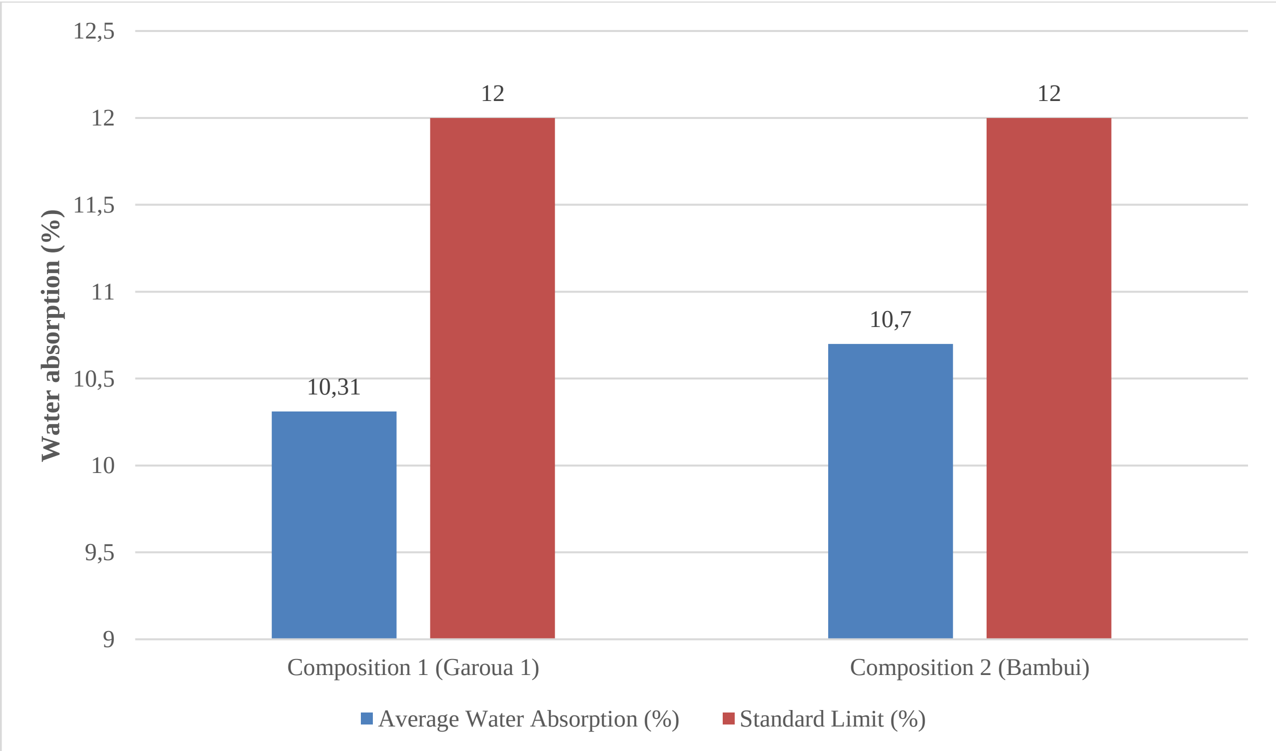


**Figure 4.** Average water absorption for both compositions with reference to the standard limit of 12%

### *3.4 Impact Test*

The impact test is vital as it helps in assessing whether the roofing tiles can withstand various impacts such as fruits falling from trees or hailstorms, simulating real-life scenarios once the tiles are installed on a roof.

**Table 4. Impact test (Drop-ball) result for MCR tiles produced from Garoua I and Bambui river sands**

| | | **Composition 1 (Garoua I)** | **Composition 2 (Bambui)** |
|---|---|---|---|
| **Drop Height (mm)** | **Weight of Ball (g)** | **Tile After Impact** | **Tile After Impact** |
| 500 | 225 | ok | ok |
| 600 | 225 | ok | ok |
| 700 | 225 | ok | ok |
| 800 | 225 | ok | ok |
| 900 | 225 | ok | **crack** |
| 1000 | 225 | ok | ------ |
| 1100 | 225 | **crack** | ------ |

The Drop-ball impact test results presented in **Table 4** showed that the MCR tile produced from composition 1 (Garoua I river sand) exhibited no cracks from 500mm to 1000mm ball drop height, while the MCR tile produced from composition 2 (Bambui river sand) exhibited no cracks from 500mm to 800mm ball drop height. The first visible crack for the tested MCR tiles from composition 1 was observed at the 1100mm drop ball height while that of composition 2 was observed at the 900mm drop ball height. This test was drawn from Johannson (1995), who highlighted that the minimum requirement for impact resistance should be that the MCR tiles with stands the first drop height of 500mm without any visible crack. From the impact resistance results presented in **Figure 5**, the first visible cracks for both compositions were observed far above the minimum requirement which is an indication that the MCR tiles have a satisfactory impact resistance. However, MCR tiles produced from Garoua I river sands will exhibit more impact resistance to Bambui river sands.

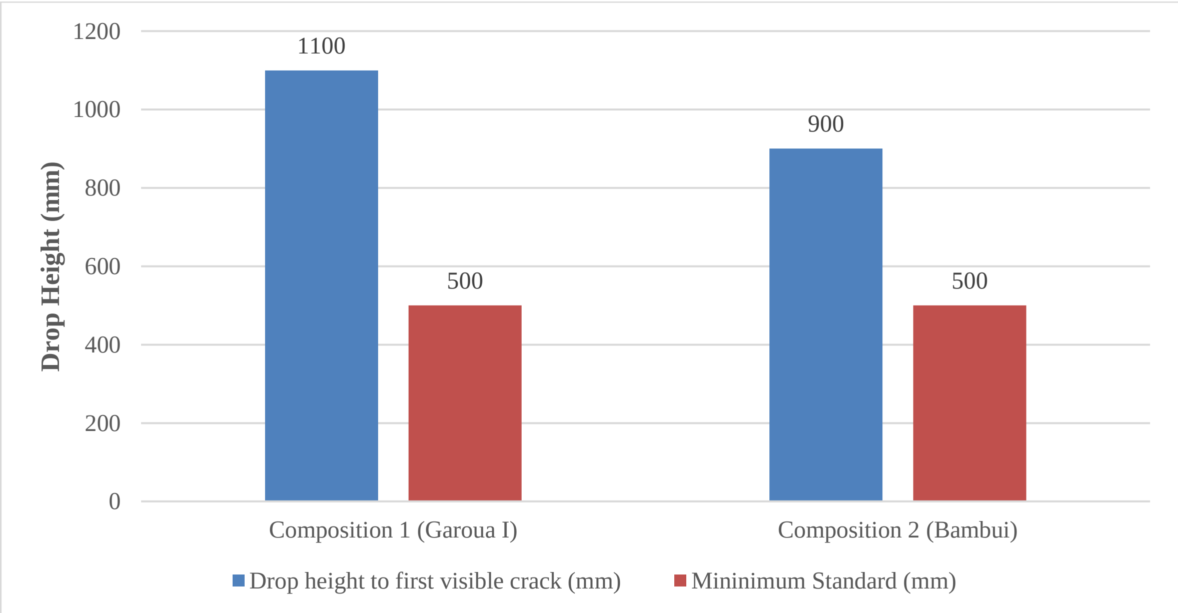


**Figure 5.** Drop height to first visible crack for MCR tiles produced from river sands (Garoua I and Bambui)

MCR tiles produced using Garoua I and Bambui river sands are resilient and able to withstand impacts from falling fruits, hailstorms, and other potential sources of shock. This indicates that the sands from Garoua I and Bambui are suitable for manufacturing MCR tiles that exhibit high durability and resistance to impact, ensuring their reliability in varying environmental conditions once installed on roofs.

## Conclusion

The production of Micro-concrete roofing (MCR) tiles using river sands from Garoua I and Bambui sites followed the recommended standard procedures. The resulting MCR tiles displayed favorable Physico-mechanical properties across various tests such as flexural strength, permeability, water absorption, and impact resistance. Upon comparative analysis, it was observed that MCR tiles made from Garoua I river sands exhibited superior characteristics compared to those made from Bambui river sands, particularly in terms of flexural strength, water absorption and impact resistance. The flexural strength, average water absorption, impact resistance (ball drop height) values were measured at 12.08 MPa, 10.31%, 110mm for Garoua I river sands and 10.68 MPa, 10.70%, 900mm for Bambui river sands respectively. This indicates that the MCR tiles manufactured using Garoua I river sands demonstrated higher resistance to loads in comparison to those produced from Bambui river sands. The findings suggest that Garoua I river sands are more suitable for the production of sustainable micro-concrete roofing tiles, as they offer enhanced structural integrity and durability, especially in scenarios where resistance to bending forces is crucial for long-term performance and reliability of the roofing tiles.

**Acknowledgement,** Special thanks to Dr Likibi Boubakar, the General Manager of MIPROMALO for granting the authors access into the tiles production unit and quality control laboratory where the analysis were carried out. Also we appreciate the contributions of Dr Ndigui Bilong for making this work a success.

**Disclosure statement:** *Conflict of Interest:* The authors declare that there are no conflicts of interest.
*Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

## References

Abdias, M.W.M., Blanche, M.M., Nana, U.J.P., Abanda, H.F., François, N. and Chrispin, P. (2023) River Sand Characterization for Its Use in Concrete: A Revue. *Open Journal of Civil E ngineering* , 13, 353-366. https://doi.org/10.4236/ojce.2023.132027

Abdullah, M. J., Zakiah, A., Atikah, F. D. and Nur, K. M. (2015). Compressive Strength and water absorption characteristics of brick using quarry dust, *InCIEC*, 51-64.

Adekunle, K. F. and Adegoke, A. A. (2019). Influence of curing duration on the durability properties of micro-concrete roofing tiles produced from locally sourced materials. *Journal of Sustainable Construction Materials and Technologies*, 10(1), 25-33.

Agbede, O., Tersoo, A., Tiza, M. and Terry, U. (2016). Production of concrete roofing tiles using rice husk ash (rha) in partial replacement of cement. *International Research Journal of Engineering and Technology (IRJET)*, pp. 2678-2689.

Akinboboye, F.A.O., Adegbesan, O.O., Ayegbusi, O.A. and Oderinde, S.A.(2015). Comparison of the compressive strength of concrete produced using sand from different sources. *International Journal of Academic Research in Environment and Geography*, 2(1), pp 6-16.

Alisha, A. (2021) Global trends in river sand usage in concrete production. *Sustainable Construction Journal*, 4(3), 189-201.

Angel, S., Jose, A. P.B., David, C. A., Pedro, L. L. J., Luis, M. E., Luis, J.S., Jose, L. S., Juan, R. and Daniel O. (2017). Physico-mechanical properties of multi-recycled concrete from precast concrete industry. J. Clean. Prod. 141. 248-255.

ASTM C 1167-03. (2012). Standard specification for Clay Roof Tile, ASTM International, West Conshohocken, PA.

ASTM C 1492-03 (2009). Standard Specification for Concrete Roof Tile, ASTM International, West Conshohocken, PA.

ASTM C 1492-03. (2009). Standard Specification for Concrete Roof Tile, ASTM International,West Conshohocken, PA.

ASTM C 67-13. (2013). Standard test methods for sampling and testing Brick and Structural Clay Tile, ASTM International, West Conshohocken, PA.

Biyindi, T.A., Mbakop, F.K., Toumi, E., Etonleu, B.W. and Pondi, J. (2019) Comparative Physico Mechanical Study of Cements CEM II 42.5R in Cameroon: Case of DANGOTE and CIMENCAM. *Open Journal of Civil Eng ineering* , 9, 18-34. https://doi.org/10.4236/ojce.2019.91002

Bogas, J.A., de Brito, J. and Figueiredo, J.M. (2015). Mechanical characterization of concrete produced with recycled lightweight expanded clay aggregate concrete. *J. Clean. Prod*. 89, 187-195.

BS 6073. (1981). Precast concrete masonry units, Specification for precast concrete masonry units, British Standards Institution.

BS EN 197–1/2011. (2011). Cement, Part (1): Composition, Specifications and Conformity Criteria for Common Cements. British Standards Institution (BSI).

Choi, Y. and Choi, J.H. (2013) A Comparative Study of Concretes Containing Crushed Limestone Sand and Natural Sand. *Open Journal of Civil Engineering* , 3, 13-18. https://doi.org/10.4236/ojce.2013.31003

Chowdhury, S. (2022) Role of sand in Micro-concrete roofing tile production. *Concrete Technology Review*, 15(1), 45-56.

CIP-16. (2000). Flexural strength concrete. Concrete in Practice, National Ready Mixed Concrete 578 Association (NRMCA).

Ezeokonkwo, J. E. and Uzoma, C. C. (2017). Optimization of mix proportions for micro-concrete roofing tiles using response surface methodology. *Journal of Materials Research and Technology*, 6(4), 387-396.

Farhana, Z. F., Kamarudin, H., Rahmat, A. and Al Bakri, M. (2015). The Relationship between Water Absorption and Porosity for Geopolymer Paste. *Mater. Sci. Forum*, 803, 166-172. 594.

Haitham, A.T. (2018) Effect of Using River Sand on the Strength of Normal and High Strength Concrete. *International Journal of Engineering and Technology* , 7, 222-228. https://doi.org/10.14419/ijet.v7i4.20.25930

Hung, V., Forth, J.P. and Tropov, V. (2015). The use of glycerol and cooking oil in masonry unit production, Proc. *ICE- Construction Materials*, 1-14.

Jayasinghe, C., Silva, M., Dissanayake, D. and Fernando, C. (2006). Engineering properties of Micro-Concrete roofing tiles, 35-41

Johansson B. (1995). Concrete roofing tiles. Building Isues, Lund University Centre for Habitat Studies, Vol 4, No 2, 1995, pp.4-15.

Kagonbe, B.P., Tsozue, D., Djepaze, Y., Nzeugang, A.N., Balo, A.M., Basga, S.D. and Ngoss, S. (2020). Physical Characterization and Optimization of Fineness Moduli of Natural Sand from The North Region of Cameroon Used in Construction. *J Sustain. Construct. Mater. Technol*, 5(1); 407-419. https://doi.org/10.29187/jscmt.2019.45

Koirala, M.P. and Joshi, E. B. (2017). Construction sand, Quality and supply management in infrastructure project. *International Journal of Advances in Engineering & Scientific Research*, ISSN: 2349-3607, 4:1-15.

Liu, K.-B., Lam, N.S.N. and Xu, Y.J. (2018) Resilience and Sustainability of the Mississippi River Delta as a Coupled Natural-Human System. *MDPI*, Basel.

Magudeaswaran, P. and Eswaramoorthi, P.(2016). High Performance Concrete Using M Sand. *Asian Journal of Research in Social Sciences and Humanities*, Vol. 6, pp. 372-386.

Mane, K.M., Kulkarni, D.K. and Joshi A. A., (2017). Strength and workability of concrete with manufactured sand. *International Journal of Engineering Research and Technology*, Vol. 10(1), pp. 331-335.

Martínez-Lage, I., Velay-Lizancos, M., Vázquez-Burgo, P., Rivas-Fernández, M., VázquezHerrero, C. and Ramírez-Rodríguez, A. (2016). Concretes and mortars with waste paper industry: biomass ash and dregs. *J Environ Manage*, 181(1):863–73.

Mhedhebi, M., Gallala, W. and Gaied, M.E. (2015). Caractérisation et essais de traitement des sables de la formation de Boumar de la région de Sned. *VSSS, Harmmamet,* 20-22.

Mhedhebi, M., Gallala, W. and Gaied, M.E.(2015). Caractérisation et essais de traitement des sables de la formation de Boumar de la région de Sned, *VSSS*, Harmmamet, pp. 20-22.

Nadeem, H., Habib, N.Z., Ng, C.A., Zoorob, S.E., Mustaffa, Z., Chee, S.Y. and Younas, M. (2017). Utilization of catalyzed waste vegetable oil as a binder for the production of environmentally friendly roofing tiles. *Journal of Cleaner Production*, vol. 145, pp. 250-261. https://doi.org/10.1016/j.jclepro.2017.01.028

Ndigui, B. and Uphie, C.M. (1999). Contribution to the Production of Micro-Concrete Tiles from Natural Sand: Case of sand De Monatele, Cameroon. Materials and quality Control laboratory, MIPROMALO, 1-9.

Nkengue, C.B., Malanda, N., Ganga, G., Louzolo-Kimbembe, P. and Mouengue, G.R. (2019) Influence of Aggregate Grain Size on the Formulation of Sand Concrete in the Construction Industry in Congo. Geomaterials , 9, 81-96. https://doi.org/10.4236/gm.2019.94007

Ogunbiyi, O. F. and Olugbenga, O. A. (2016). Investigation of the mechanical properties of micro-concrete roofing tiles using different curing methods. *Journal of Building Engineering*, 5, 342-350.

Ogunleye, G. and Oyedepo, O. S. (2020). Environmental impact assessment of micro-concrete roofing tiles production in Nigeria: A life cycle assessment approach. *Sustainable Cities and Society*, 54, 101987.

Oludolapo, A. O. and Charles, M., 2017. Assessing potential reduction in greenhouse gas: An integrated. J. *Clean. Prod*. 141, 891-899.

Oyekan, G. L. and Olubanwo, A. O. (2018). Performance evaluation of micro-concrete roofing tiles incorporating waste materials as partial replacements for sand. *Construction and Building Materials*, 172, 124-133.

Ramakrishna, G., Sundararajan, T. and Kothandaraman, S. (2011). Strength of corrugations of a roofing sheets reinforced with sisal fibres. *ARPN Journal of Engineering and Applied Sciences*, vol. 6, no. 12, December, ISSN 18196608.

Sabih, G., Tarefder, R.A. and Jamil, S.M. (2016). Optimization of gradation and fineness modulus of naturally fine sands for improved performance as fine aggregate in concrete. *Procedia Engineering* 145, 66-73.

Shen, W., Cao, L., Qiu, L., Zhaijun, W., Jing, W., Yun, L., Rui, D., Tan, Y. and Rufa, C. (2016). Is magnesia cement low carbon? Life cycle carbon footprint comparing with Portland cement. *J. of Clean. Prod*. 131, 20-27

Swiss Center for Appropriate Technology (SKAT). (1992). Production Guide For Fibre Concrete Roofing Tiles And Micro Concrete Roofing Tiles.

Tebbal, N. and Rahmouni, Z.E. (2016). Influence of Local Sand on the Physicomechanical Comportment and Durability of High Performance Concrete. *Advances in Civil Engineering*, 10 p.

Terzaghi, K., Peck, R.B. and Mesri, G.(1996). Soil mechanics in engineering practice, third edition, 592p.

Varela, B.D., Quito, J.L.S. and Piaza, N. C. (2015). Flexural and compressive strength of concrete tiles with different levels of partial substitution of pulverised solid waste for gravel. *Open Access Library Journal*, 2:e1187. https://dx.doi.org/10.4236/oalib.1101187

WSDOT Test Method T 802. (2009). Method of Test for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading), Materials Manual, Washington.

Zhang, S. P. and Zong, L. (2014). Evaluation of Relationship between Water Absorption and Durability of Concrete Materials, *Adv. Mater. Sci. Eng*, 8p. http://dx.doi.org/10.1155/2014/650373

Zoum, F.A. (2023). Suitability of the Garoua I and Bambui river sands for the production of Micro-concrete roofing tiles. Thesis submitted to the Department of Mining and Mineral Engineering, National Higher Polytechnic Institute, University of Bamenda, Cameroon.

(2024); http://www.jmaterenvironsci.com