MANUFACTURING PROCESS AND MECHANICAL TESTING OF HOLLOW CONCRETE BLOCKS MADE FROM A CEMENT-GLASS POWDER MIXTURE

Abstract

Against a backdrop of the search for sustainable building materials and the recovery of industrial waste, this study focuses on the production process for hollow concrete blocks made from a cement–glass powder mixture. The aim is to assess the influence of glass powder on the mechanical and physical properties of the hollow blocks produced. The experimental work involved the manufacture and mechanical testing of hollow cement blocks measuring 15 cm × 20 cm × 40 cm incorporating glass powder. The samples were produced at an industrial site in order to replicate real-world manufacturing conditions. Glass powder was incorporated at different levels (0%, 10%, 15% and 20%) into the material formulation. The samples underwent a curing phase before being tested in the laboratory. The mechanical results show that a glass powder incorporation rate of 20% achieves a compressive strength of 6.40 MPa. This value exceeds the minimum requirement of 3.2 MPa set by standard NFP 14-301 of September 1983. The flexural strength measured for this same formulation is 1.96 MPa. Furthermore, the water absorption test revealed a coefficient of 4.48% after 1,440 minutes of immersion, in line with the specifications of the AFPC-AFREM standard (1997), which set this range between 4% and 8%.Looking ahead, future research will focus on investigating the thermal performance of hollow cement blocks containing glass powder.

Key words:-
Process, hollow concrete block, cement, glass powder, mechanical testing

Introduction:-

The building sector, alongside the transport and industrial sectors, ranks among the world's three largest energy consumers[1].

Globally, the building sector alone accounts for of total energy consumption [2], approximately of greenhouse gas emissions [3], and 50% of this annual consumption is generally caused by heating, ventilation and air conditioning systems [4]. Like other African countries, Burkina Faso is a nation where the building sector is one of the major contributors to energy consumption. Until now, buildings have been designed without energy efficiency considerations, resulting in high costs for operators who have not been made aware of the need for rational energy use. Furthermore, the building sector leads to increased consumption of natural resources and significant production of solid waste. Among this waste, glass represents a major environmental challenge due to its low biodegradability and low recycling rate [5].In this context, the use of glass powder in cementitious materials represents a promising alternative for improving the physical, mechanical and thermal properties of building walls. Several studies have shown that glass powder can act as a pozzolanic material, enhancing the mechanical performance and durability of materials [6] [7]. However, few studies have examined its use in hollow concrete blocks produced under industrial conditions, particularly in the context of Burkina Faso. This study therefore aims to analyse the effect of glass powder on the mechanical and physical performance of hollow cement blocks, with a view to a follow-up study on the thermal performance of this material. These materials could thus represent an interesting alternative for more sustainable buildings that are better suited to the country's climatic conditions.

I. Materials and methods

I.1. The process of manufacturing concrete blocks

a. Materials

The materials used in the manufacture of concrete blocks are shown in **Figure 1**:

- The cement used (Figure 1.a) is of the CEM II-42.5R type, produced by a company in Burkina Faso;
- The sand is crushed granite sand of 0/8 mm grain size and a fineness modulus of 4.12 (Figure 1.b). It was collected from the quarry site at Koubri (Ouagadougou). The particle size distribution curve (Figure 2) for the crushed granite sand shows a slightly discontinuous gradation (due to breakage caused by crushing) but is low in fines (only 4% ≤ 0.08 mm);
- The sand equivalent value (SEV) test on our crushed sand yielded an SEV of 91%, compared with an SEV of 89% as per standard NF EN 933-6 [8]. The particle size class is 0/8, with a fines content of 4%;
- Glass powder derived from 16.10 kg of end-of-life BR-M250V polycrystalline solar modules. The glass cover of the module is removed and crushed in a mill to produce glass powder (with a particle size of < 75 µm) (Figure 1.c);

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Figure 1.a: Cement used

Figure 1.b: Crushedsand

a) Glass beads **b)Glass powder** **c) Crushing of glass beads**

Figure 1.c: Glass beads and glass powder

Figure 1: Materials used in the manufacture of concrete blocks

Figure 2 shows the particle size distribution curve for crushed granite sand.

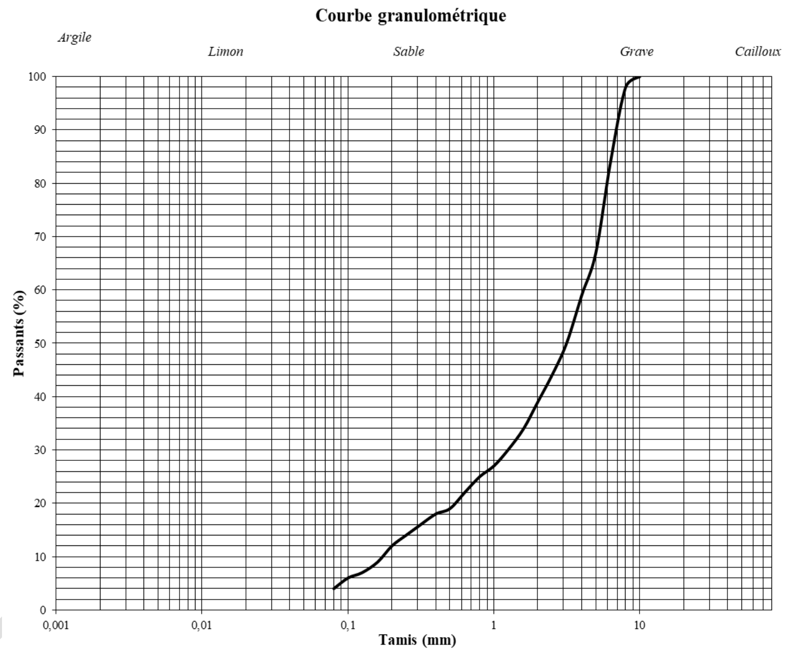

Figure 2: Particle size distribution curve for crushed granite sand

In **Figure 2**, the particle size distribution curve for crushed granite sand shows a slightly discontinuous profile (due to breaks caused by crushing) but is low in fines (only 4% ≤ 0.08 mm). The sand is angular, with the largest particle having a diameter of 8 mm. It is therefore suitable for achieving good mechanical strength, but less so for the workability of the mortar.

b. Equipment

The equipment used for geotechnical characterisation, material quantification and the manufacture of concrete blocks is as follows (see **Figure 3**):

- Mesh sieves: used to carry out a particle size analysis, which involves determining the size distribution of the particles making up an aggregate with dimensions ranging from 0.063 to 125 mm;

- Electronic scales: these are used to weigh each concrete block using the electronic scales in order to determine its mass before carrying out the test;
- The mixer: used to mix the mortar once the required quantities of materials for making the concrete blocks have been measured;
- The hydraulic press: The mortar produced after mixing is placed into the mould of the hydraulic press to form the bricks.

Figure 3 shows how measurements are taken for the different mortar formulations

Figure 3.a: Mesh sieve

Figure 3.b: Weighing crushed sand, glass powder and cement using an electronic balance

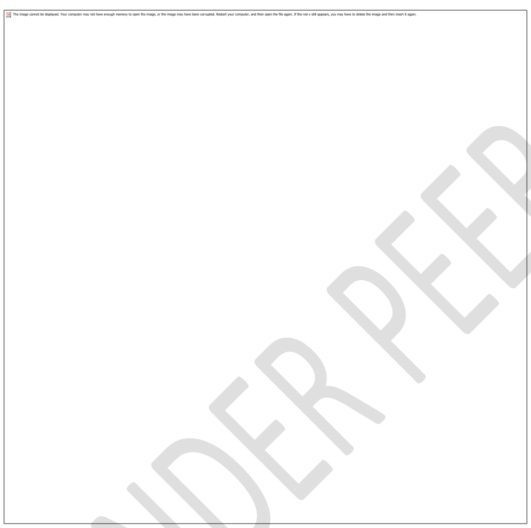

Figure 3.c: The mixer

Figure 3.d: The hydraulic press

Figure 3: Equipment used for the characterisation and production of concrete blocks

c. Principles of mortar formulation

For the mortar mix design, we are working on the basis of producing 31 concrete blocks, requiring 449.5 kg of sand (at a rate of 14.5 kg of sand per block), a 50 kg bag of cement, and 54.25 litres of water, depending on the sand's moisture content.

The calculation of the proportions involves determining the ratios of each component used in the mortar mix. For this study, these are cement, sand, glass powder and water. For the mortar mix,

the calculation is based on the mass of the materials. Measurements are taken using a precision balance and the various proportions obtained are converted into the appropriate units.
To determine the quantities of the constituent elements in the composition of a brick, we assume that the concrete block is mixed with 11% cement:

- Mass of sand required for one concrete block: Ms = 14.5 kg;
- Corresponding mass of cement: Mc = (11/100) × 14.5 = 1.595 kg;
- Volume of water for one concrete block: Vp = 1.75 litres, or 1.75 kg;
- Total mass of one concrete block: Mp = 17.845 kg;
- Number of bricks per bag of cement is: (50 kg / 1.595 kg) = 31 bricks;
- Mass of sand per bag of cement is: 31 x 14.5 = 449.5 kg;
- Mass of water per bag of cement is: 31 x 1.75 kg = 54.25 kg

The proportion of glass powder added is determined based on the mass of cement contained in a concrete block. Thus, for one concrete block, the mass of glass powder used for the additions is 159.5 g; 239.25 g; 319 g and 398.75 g for a ratio of 10%, 15%, 20% and 25% glass powder. This choice is justified by the fact that the higher the percentage of powder, the less cohesion there is between the sand and the cement.

d. Manufacture of concrete blocks

The concrete blocks were produced at the METABA-Groupe site in Ouagadougou. The hydraulic press mould allows four (4) blocks to be produced simultaneously. Each hollow block measures 40 cm x 20 cm x 15 cm. It consists of two parallelepiped-shaped cavities with the following geometric characteristics: the depth, width and length of the cavities are 17.5 cm, 10 cm and 16.25 cm respectively.
Figures 4 show the various stages of production through to the storage of the blocks.

Figure 4.a: Pouring the mortar into the mould

Figure 4.b: Compaction of mortar

Figure 4.c: Removing the blocks from the moulds and moving them

Figure 4.d: Storage of concrete blocks

Figure 4: The various stages of production through to the storage of concrete blocks

e. Treatment conditions

The conditions under which bricks are stored over time play a very important role in the development of their strength. Care taken during manufacture and storage can prevent significant reductions and variations in strength. For cement blocks, the presence of water inside the bricks is essential for the stabiliser to reach its maximum strength; a high temperature will also aid setting. In this case, the blocks produced are then subjected to a curing process under a shed in order to retain the water content and prevent rapid setting, which is unnecessary and detrimental to the use of the cement blocks.

I-2. Tests carried out

I-2-1. Compressive strength

a. Method

The crushing test is used to measure the compressive strength of concrete blocks. Compressive strength tests are carried out on the concrete blocks produced by the press. These blocks are crushed flat, in the same position as they occupy in the structure. The press used for this crushing test is the electric press at the National Laboratory for Buildings and Public Works (LNBTP) in Ouagadougou.

The principle involves loading the block until failure in a compression testing machine, in accordance with the required standard NFP 14-301-September 1983 [9] (**Figure 5**). The maximum load F reached is recorded and the compressive strength Rc is calculated using the following equation:

$$R_c = \frac{F}{A} \quad (1)$$

A: cross-section of the brick

Figure 5 shows the LNBTP electric press crushing a brick made with 10% glass fibrereinforcement.

Figure 5: Electric press

Once the concrete blocks have cured, we water them for twenty-six (26) days before carrying out the compression test on the twenty-eighth (28th) day.

b. Procedure for compressive strength tests

- Before carrying out the test, we first weigh each concrete block using the electronic scales to determine its mass.

Figure 6 shows the weights of the concrete block samples alongside the test results.

Figure 6: Weighing the samples

- Place the entire cement block sample into the press (electric in our case);
- Position the assembly (the block and the anti-shrinkage system) between the press plates;
- Apply the load continuously at a constant rate of 0.05 mm/s until the specimen breaks completely;

- Record the breaking load withstood by the specimen during the test, as well as the breaking stress.

Figure 7 shows the crushing of the concrete block specimens in the electric press.

Figure 7: Crushing of concrete block samples in the hydraulic press

Once the concrete block has been crushed, the breaking load is displayed on the hydraulic press's dial.

Figure 8 shows the loads and breaking stresses of the concrete blocks for samples with 0%, 10%, 15% and 20% cement content.

Figure 8: Stresses and fracture loads of the specimens

c. **Calculation of compressive strength at 28 days**

The compressive strength of concrete blocks is given by the following formula:

$$R_c = \frac{10F}{S} \quad \textbf{(2)}$$

Where: Rc: is the compressive strength of the blocks in megapascals (MPa),

F: is the maximum load borne by the block in newtons (N)

S: is the average area of the test faces in square centimetres (mm²)

The compressive strength of the bricks is the arithmetic mean of the strengths obtained from at least three tests carried out on samples from the same batch.

I-2-2. Bending test

Bricks are subjected to a bending moment until failure by applying a load F at the centre using an upper roller (standard EN 12390-5 [10]).

a. Equipment

The equipment required for the flexural strength test on hollow concrete blocks is as follows:

- Universal testing machine or hydraulic press capable of applying a progressive and continuous load;
- Two-point bending apparatus in accordance with standard EN 12390-5;
- Cylindrical metal supports to hold the test specimen;
- Load cell to measure the applied load;
- Caliper or metal ruler to measure the dimensions of the test specimens;
- Electronic balance to determine the mass of the samples;
- Drying oven or curing tank for conditioning the concrete blocks;
- Hollow concrete blocks to be tested.

b. Test procedure

The test involves subjecting the concrete block to an increasing load until failure using a two-point bending apparatus.

- The test specimen is placed horizontally on two supports;
- The load is applied at two symmetrically positioned points;
- The load is gradually increased until the concrete block fails;
- The maximum load F is recorded.

c. Calculation of bending strength

The flexural strength R_f is calculated using the formula:

$$R_f = \frac{F.L}{l.H^2} \quad \textbf{(3)}$$

Where: L represents the length, l the width and H the height of the brick

In reality, a flexural test cannot be carried out on bricks for the simple reason that they are not specifically subjected to bending stresses.

I-2-3. Water absorption

a. Materials and methods

The equipment used to carry out the above tests is as follows:

- Precision balance, with an accuracy of ± 0.005 kg;
- Drying oven;
- Water bath.

The test involves drying the samples until a constant weight is achieved, then immersing them completely in water at 25°C for 24 hours.

b. Calculation of the absorption coefficient

The water absorption coefficient Ab is defined by the following equation:

$$Ab = \frac{M_a - M_s}{M_s} X100 \quad \textbf{(4)}$$

M_a : Mass of the wetted sample

M_s : Mass of the dry sample

Figure 10 illustrates the weighing and soaking of the concrete block samples.

Figure 10: Weighing the concrete block before submerging it in the water-filled tank

II. Results

The results of the 28-day compressive strength tests are summarised in **Table 1**.

Table 1: Results of stresses and breaking loads at 28 days

Dosage (%)	Section (cm^2)			Mass (kg)		Breaking load		Compressive strength (MPa)	
	Raw (sb)	Net (sn)	Support (sa)	Raw	Average	Load (daN)	Average (kN)	Resistance (MPa)	Average(MPa)
0%	600	330	330	16.7	**17,13**	14 520	**15,040**	4.4	**4.60**
	600	330	330	17.6		15 740		4.8	
	600	330	330	17.1		14 860		4.6	
10%	600	330	330	18.2	**18,17**	14 820	**14,986**	4.6	**4.60**
	600	330	330	18.4		15 510		4.7	
	600	330	330	17.9		14 630		4.5	
15%	600	330	330	18.5	**18,22**	18 810	**16,370**	5.7	**5.03**
	600	330	330	18.1		14 850		4.5	

	600	330	330	18.1		15 450		4.9	
	600	330	330	18.3		22 110		6.7	
20%	600	330	330	18.4	**18,33**	21 120	**22,130**	6.4	**6.40**
	600	330	330	18.3		23 160		6.1	

Table 1 shows that the compressive strength of the concrete blocks increases with the proportion of glass powder.

Thus, the concrete blocks made with 20% glass powder exhibit a higher compressive strength of 6.40 MPa. These values comply with the certification standard of NFP 14-301 (September 1983), which specifies a minimum of 3.2 MPa [9]

However, when the glass powder content exceeds 20%, cracks appear in the concrete blocks as soon as they are removed from the moulds.

Figure 9 shows the variation in compressive strength as a function of the percentage of glass

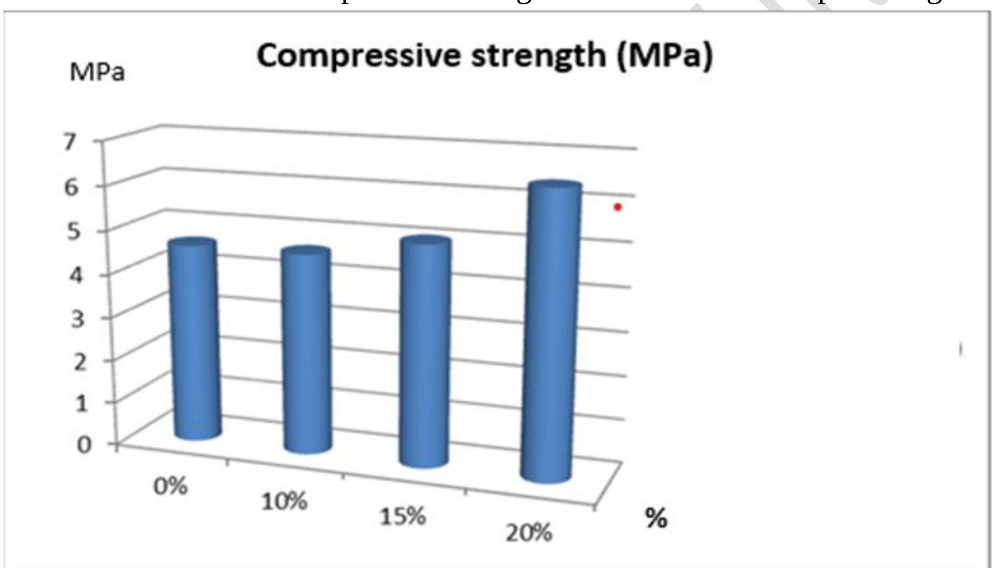

Figure 9: Variation in compressive strength as a function of glass content

Concrete blocks containing 20% glass offer an average maximum compressive strength of 6.4 MPa at 17 days, whereas those containing 10% and 0% glass have virtually the same compressive strength.

Table 2 shows the flexural strengths of the samples.

Table 2: Flexural strengths of the samples after 28 days

Glass content	Length L (mm)	Width l (mm)	Height (mm)	Load (N)	Resistance (MPa)
0%(witness)	400	200	150	15040	1.336
10%	400	200	150	14986	1.332
15%	400	200	150	16370	1.455
20%	400	200	150	22130	1.967

We observe that concrete blocks containing 20% glass powder have better flexural strength. The other mixtures have virtually the same value. It should be noted that concrete blocks are not specifically subjected to bending stresses in building walls.

Figure 10 shows the variation in breaking load (**Figure 10.a**) and strength (**Figure 10.b**) as a function of the percentage of glass powder.

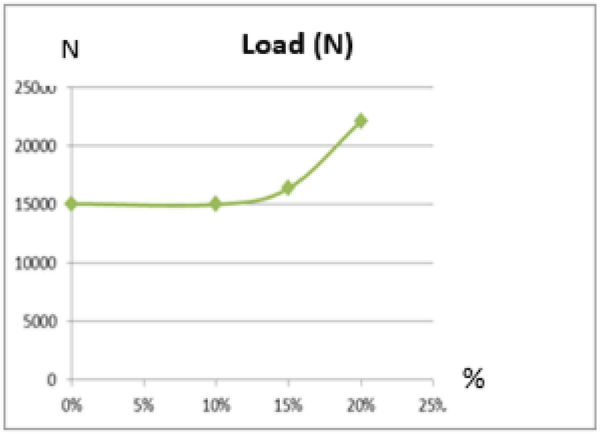

Figure 10.a: Variation in breaking load as a function of the percentage of glass powder

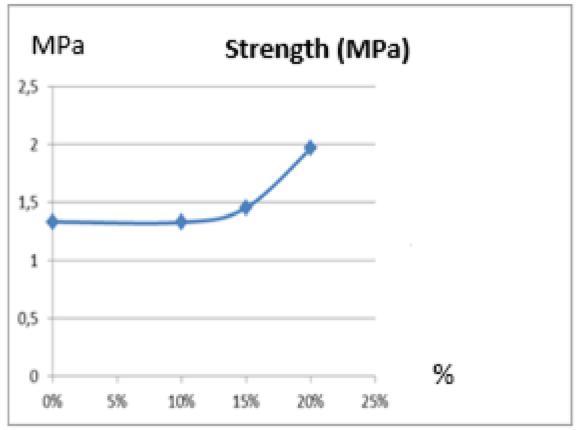

Figure 10.b: Variation in flexural strength as a function of the percentage of glass powder

Figure 10: Variation in breaking load (Figure .a) and strength (Figure .b) as a function of the percentage of glass powder

The addition of glass powder during the manufacture of hollow cement blocks improves their flexural strength. These low values reflect the excellent plasticity of the blocks. Although these results are low, there is no cause for concern; indeed, given the stresses to which bricks are subjected in masonry, bending and tensile forces have little effect. Even high-strength concrete has low resistance to bending and tensile stress (BAEL 91 mod. 99) [11].

Table 3 shows the absorption coefficient of the block samples

Table 3.a: Absorption coefficient of the control concrete block (0%)

Percentage of glass powder	Immersion time (mm)	Mass of the dry sample (g)	Mass of the sample after immersion (g)	Absorption coefficient (%)
Witness (0%)	15	16 590	17 415	4.97%
	30	16 590	17 440	5 .12%
	60	16 590	17 025	2.62%
	120	16 590	17 455	5.21%
	240	16 590	17 775	7.14%
	480	16 590	17 875	7.75%
	1440	16 590	17 790	7.23%

Table 3.b: Absorption coefficient of concrete blocks containing 10% glass

Percentage of glass powder	Immersion time (mm)	Mass of the dry sample (g)	Mass of the sample after immersion (g)	Absorption coefficient (%)
(10%)	15	16 995	17 765	4.53%
	30	16 995	17 800	4.74%
	60	16 995	17 420	2.50%
	120	16 995	17 865	5.12%
	240	16 995	17 875	5.18%
	480	16 995	17 875	5.18%
	1440	16 995	17 875	5.18%

Table 3.c: Absorption coefficient of concrete blocks containing 15% glass

Percentage of glass powder	Immersion time (mm)	Mass of the dry sample (g)	Mass of the sample after immersion (g)	Absorption coefficient (%)
(15%)	15	17 100	17 765	3.89%
	30	17 100	17 785	4.01%
	60	17 100	17 305	1.20%
	120	17 100	17 835	4.30%
	240	17 100	17 880	4.56%
	480	17 100	17 880	4.56%
	1440	17 100	17 880	4.56%

Table 3.d: Absorption coefficient of concrete blocks containing 20% glass

Percentage of glass powder	Immersion time (mm)	Mass of the dry sample (g)	Mass of the sample after immersion (g)	Absorption coefficient (%)
(20%)	15	17 395	18 115	4.13%
	30	17 395	18 140	4.28%
	60	17 395	17 505	0.63%
	120	17 395	18 165	4.42%
	240	17 395	18 175	4.48%
	480	17 395	18 175	4.48%
	1440	17 395	18 175	4.48%

The concrete block made with 20% glass powder has a low absorption coefficient of 0.63% over the 60-minute period, compared with the others, particularly the control block. This finding remains valid over a 24-hour period, as the absorption coefficient is 4.48% for the blocks containing 20% glass powder and 7.23% for the control blocks containing 0%. The samples of blocks containing 20% glass powder are less permeable to water than the other samples.

The results obtained during the various tests show an improvement in the mechanical performance of the hollow concrete block incorporating glass powder. These results confirm the trends reported in the literature [12] [13]. The improvement in performance at 20% can be attributed to:

- The filler effect of the glass powder,
- The densification of the cementitious matrix,
- Secondary pozzolanic reactions [14] [7].

Beyond 20%, the decrease in performance is linked to:

- A reduction in internal cohesion,
- Saturation of the chemical reactions [15].

These results are consistent with those observed in concrete and bricks incorporating glass waste.

Conclusion

This study shows that the incorporation of glass powder significantly improves the mechanical and physical properties of hollow cement blocks. The optimal proportion identified is 20%, resulting in a compressive strength of 6.40 MPa, low water absorption (4.48%), and compliance with the NF P 14-301 and AFPC-AFREM standards. Glass powder therefore represents a viable solution for the recovery of glass waste in the construction sector in Burkina Faso. Further research, including characterisation of thermal properties and numerical simulations, is nevertheless required to develop more sustainable constructions better suited to the country's climatic conditions.

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