Research Article

Mineralogical, geochemical, and physico-mechanical features of Bidzar (North Cameroon) termite mound materials and its suitability in producing fired bricks with marble powder additive

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RÉSUMÉ

Les matériaux de termitières de Bidzar (Nord Cameroun) ont été caractérisés pour une potentielle utilisation comme matériau de construction. Pour atténuer le problème environnemental causé par l'exploitation du marbre de Bidzar, ce dernier a été utilisée comme additif (0, 5, 10, 15 et 20%) avant cuisson à 900, 1000, 1100 et 1200°C. Les matériaux de termitières sont composés de quartz, illite-smectite, vermiculite, chlorite, muscovite, calcite, hématite, et anatase avec pour principaux oxydes SiO_2, Al_2O_3, et Fe_2O_3. Ce sont des argiles sableuses et des argiles très sableuses dont la granulométrie est indiquée pour les produits creux, les tuiles et les briques. Certaines briques montrent des gonflements après cuisson jusqu'à 1100°C pendant que les autres présentent des retraits à la cuisson. Les autres caractéristiques des briques cuites sont : densité apparente (1,60–1,96 g/cm³), porosité (19,39–34,41%), absorption d'eau (10,41–21,44%), résistance à la flexion (1,25–5,64 MPa) et résistance à la compression (2,89–18,76 MPa). L'ajout de marbre couplé à la présence de matière organique (4,04–5,35%) augmente l'absorption d'eau tout en réduisant le retrait linéaire et la résistance mécanique à cause de la transformation de $CaCO_3$ durant la cuisson qui entraîne la création d'une porosité secondaire. Ces caractéristiques physico-mécaniques répondent néanmoins aux standards des matériaux de construction.

Mots-clés : Matériaux de termitières, poudre de marbre, caractérisation, briques cuites, Bidzar

ABSTRACT

Termite mound materials (TMM) from Bidzar (North Cameroon) were characterized for their potential use as raw materials for the fired brick industry. To alleviate the environmental problem caused by the exploitation of the Bidzar marble, marble powder (0, 5, 10, 15, and 20 wt%) has been used as an additive in the formulation of bricks before firing at 900, 1000, 1100, and 1200°C. The TMM are made up of quartz, illite-smectite vermiculite, chlorite, muscovite, calcite, hematite, and anatase, with SiO_2, Al_2O_3, and Fe_2O_3 being the main oxides. These materials are sandy clays or strongly sandy clays, which can be used for the manufacture of hollow products, roofing tiles, and masonry bricks. Some studied materials exhibit expansion up to 1100°C, while others show shrinkage at all studied temperatures. The varied characteristics of fired bricks are bulk density (1.60–1.96 g/cm³), apparent porosity (19.39–34.41%), water absorption (10.41–21.44%), flexural strength (1.25–5.64 MPa), and compressive strength (2.89–18.76 MPa). The addition of marble powder coupled with the presence of organic matter (4.04–5.35%) increases the water absorption while decreasing the linear shrinkage, flexural strength, and compressive strength of bricks due to the transformation of $CaCO_3$ during firing, which leads to the creation of secondary porosity. Nevertheless, these physico-mechanical characteristics meet the standards of construction materials.

Keywords: termite mound materials, marble powder, characterization, fired bricks, Bidzar

1. Introduction

The creation of non-decaying waste materials, combined with a growing consumer population, has resulted in a world waste disposal crisis. Governmental agencies, contractors, and environmentalists are very concerned (Saboya Jr. et al., 2007). A solution to this crisis lies in recycling waste into useful products (De Rezende and de Carvalho, 2003). A wide variety of waste materials have been studied to produce sustainable bricks, including waste marble, fly ash, mine tailings, slags, construction and demolition waste, wood sawdust, cotton waste, pulp and paper production residues, boron waste, cigarette butts, waste tea, rice husk, ash, and crumb rubber (e.g., Shih et al., 2004; Zhang, 2013; Sutcu et al., 2015; Arslan et al., 2021). Among them, Saboya Jr. et al. (2007), Montero et al. (2009), Bilgin et al. (2012), Eliche-Quesada (2012), Sutcu et al. (2015) were particularly interested in the use of waste marble. Saboya Jr. et al. (2007) fired their brick products from 750 to 950°C because most of the ceramic industries in their studied region of Brazil use Hoffman kiln type, where temperatures above 900°C are difficult to obtain; Montero et al. (2009) have used marble residues as well as sewage sludge in the manufacture of ceramic tile bodies; Bilgin et al. (2012) added 0–80 wt.% of waste marble powder in brick mortar; Eliche-Quesada (2012) added spent earth from oil filtration, compost, sawdust, and marble to the clay in different amounts to manufacture bricks; Sutcu et al. (2015) added up to 35 wt.% waste marble powder fired at 950 and 1050°C for 2 h. In the North Region of Cameroon, the soil profiles are poorly developed and consist of vertisols (Gouban Hamadjida et al., 2022). Termite mounds are found in abundance in this Region. On the other hand, the Bidzar marble is exploited industrially to produce cement and tiles, resulting in waste material that may cause serious environmental problems. Thus, this study tried to match society's need for safe and economic disposal of waste materials with industry's needs for better and cheaper building materials, using termite mound materials as the predominant raw material, made from clay whose plasticity and water resistance properties have been further enhanced by termite secretion (Odumodu, 1999; Minjinyawa et al., 2007). These termite mound materials also possess the ability to support a permanent structure after molding due to their

resilience and tendency to crack less than conventional clay (Minjinyawa et al., 2007). The aim of this research is to study the behavior of fired bricks made from termite mound materials and marble waste in order to assess the effect of marble addition on their physical and mechanical properties.

2. Geological Setting

The studied area is located in Bidzar. It is found in Mayo Louti, North Region of Cameroon (Fig. 1). The area has a soudano-sahelian climate with two main seasons: dry (November to May) and rainy (June to October) (Lyonga et al., 2022). This area is part of the north segment of the Pan-African range of Central Africa in Cameroon. The geological formations in the study area are mainly metamorphic rocks (gneisses and micashists), plutonic rocks (syenite and granite), and volcano-metasedimentary rocks (Montes-Lauar et al., 1997; Sababa et al., 2021).

3. Materials and methods

Three termite mound materials (TMM) and waste marble were collected from the Bidzar locality for this study. TMM are indexed as BZR-T1, BZR-T2, and BZR-T3. Geochemical, mineralogical, and geotechnical studies were initially conducted on the termite mound materials. The chemical composition of the raw materials was determined by X-ray fluorescence (XRF) spectrometry. The crystalline phase of the termite materials was analyzed by X-ray powder diffraction (XRD). Geotechnical properties were analyzed in accordance with French AFNOR (Association française de normalisation) standards. The properties include Atterberg limits NF P 94-051 (AFNOR, 1993), particle size analysis through sieving NF P 94-056 (AFNOR, 1996) and sedimentometry NF P 94-057 (AFNOR, 1992), absorbing methylene blue NF P 94-068 (AFNOR, 1998), and determination of organic matter XP P 94-047 (AFNOR, 1998).

Fired samples were produced by mixing termite mound materials and marble additives, as shown in Fig. 2. The raw materials underwent pre-treatments, including drying, grinding, and sieving to achieve a particle size of 1 mm or smaller, for brick production. The termite mound and marble powder were mixed in an electric grinder. Specimens were created for each BZR-T termite
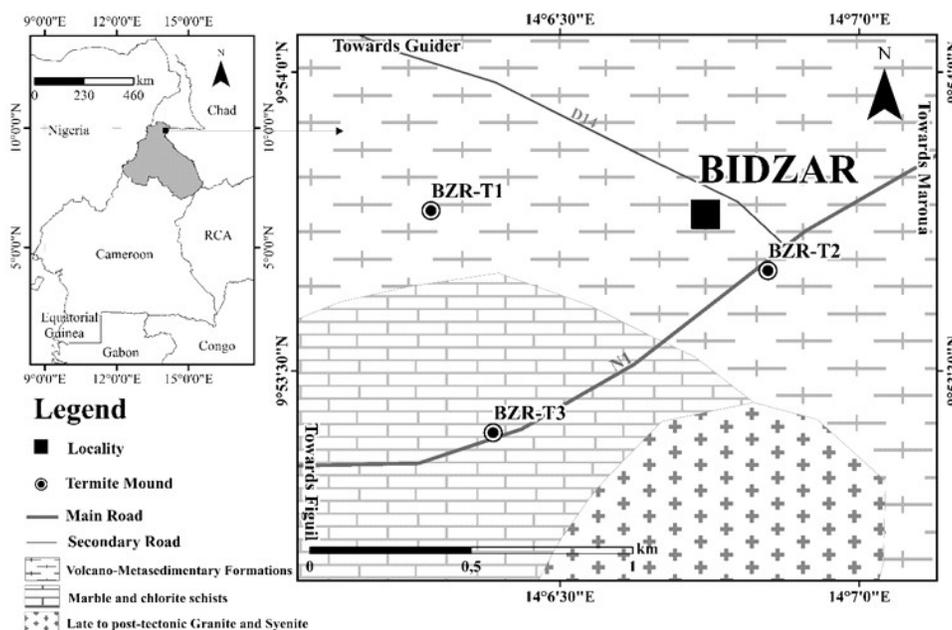

Fig. 1. Location of the study area and sampling points in the geological map (modified from Sababa et al., 2021)
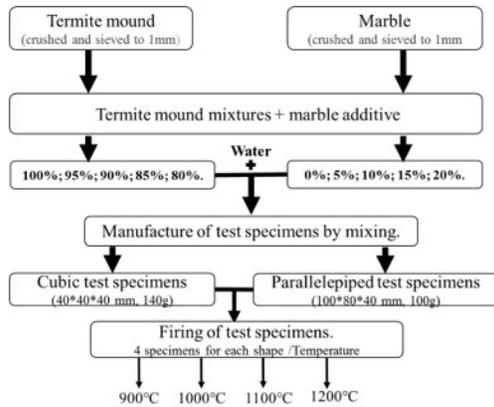
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Fig. 2. Methodology for brick mixtures production and testing

mound using five different proportions of marble by weight (0, 5, 10, 15, and 20 wt%). The raw materials were mechanically mixed for 30 minutes to get a uniform consistency. After dry mixing, about 10 wt% water of total weight was sprayed on the powder mixtures for the production of semi-dry molded brick samples. Cubic (40 × 40 × 40 mm) and parallelepiped (80 × 40 × 10 mm) shaped specimens were produced using a hydraulic press. The specimens were then air-dried for a week after shaping and later dried in an oven at 105°C for 24 hours before firing to remove moisture. Four firing temperatures (900, 1000, 1100, and 1200°C) were studied in this work. The physico-mechanical properties of the samples after firing were determined: color using the Munsell Soil Colors Charts, linear shrinkage (ASTM C531, 2000), apparent density, apparent

porosity, and water absorption values (ASTM C20, 2000); mechanical strength by compression test (ASTM F417, 1996), as well as a bending test (NF P 18-406, AFNOR, 1981).

4. Results and discussion
4.1. Properties of the raw materials

X-ray diffraction analysis of termite mound materials reveals peaks of primary minerals (quartz, muscovite, calcite, and dolomite), secondary minerals (illite-smectite, vermiculite, chlorite, and hematite), and accessory anatase (Fig. 3). This mineralogical composition reveals that the local environmental conditions are not favorable for hydrolysis processes, and the studied weathering materials are outside of the lateritization field (Sababa et al., 2021). The presence of chlorite in weathering materials is due to its presence in the parent rock (chlorite schist) and to termites, which can take elements from deep within the rock and bring them to the surface. Termite mounds are built from clay soils mixed with saliva and some secretion of the termite colony (Kessoum Adamou et al., 2023). The chemical composition of the raw materials is given in Table 1. The TMM from Bidzar contains a large fraction of SiO_2 (49.69–61.57%) as well as Al_2O_3 (14.04–16.22%) and Fe_2O_3 (6.9–11.52%). The Al_2O_3 contents will act as a binder for the brick production (Toure et al. 2017). The proportion
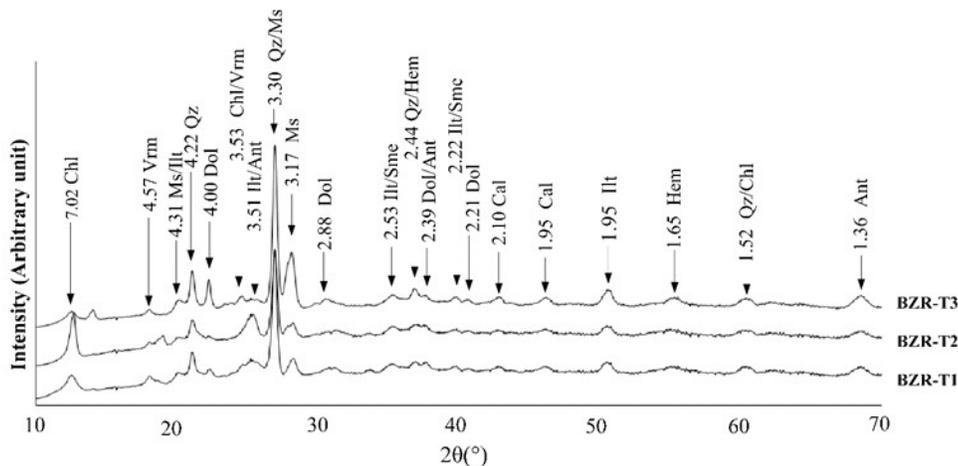

Fig. 3. XRD patterns of Bidzar termite mound materials

of fluxing oxides (Na_2O, K_2O, CaO, and MgO) in the materials is greater than 2.50 wt% and varies between 4.03 and 7.02%, which could allow for good sintering (Onana et al., 2016; Tchounang et al., 2016). The marble admixture includes large amounts of CaO (51.77%). It should be emphasized that the calcium oxide content is greater than 49% and the magnesium oxide content is about 2.6 wt%, indicating that this powder comes from calcite-type marble.

The physical properties of the three termite mound materials are shown in Table 2. The particle size distribution (PSD) curves (Fig. 4)

reveal that the studied TMM have a spread granulometry that encourages compaction of the final products (Reeves et al., 2006). This spreading grain size consists of clays (29.90–44.86 wt%), silts (19.68–37.38 wt%), sands (27.00 – 42.02wt%), and very low to almost no proportions of gravels (0.10–6,79 wt%). The Belgian ternary diagram shows that these termite mounds are sandy clays or strongly sandy clays (Fig. 5). The projection of these data in the Winkler diagram (Fig. 6) shows that BZR-T1 and BZR-T2 particle sizes are indicated for the manufacture of hollow products, while BZR-T3 can be used in roofing tiles and masonry bricks production.

Table 1. Chemical composition of the Bidzar raw materials

	SiO_2	Al_2O_3	MgO	MnO	CaO	Na_2O	K_2O	Fe_2O_3	TiO_2	P_2O_5	LOI	Total
BZR-T1	53.63	16.22	1.34	0.11	2.08	0.77	1.24	9.83	2.17	0.08	14.37	99.84
BZR-T2	49.69	15.23	2.56	0.1	1.81	0.63	1.11	11.52	1.58	0.11	15.72	100.06
BZR-T3	61.57	14.04	0.76	0.12	0.92	1.65	2.27	6.99	0.6	0.06	10.78	99.76
Marble	2.45	0.50	1.63	0.03	51.77	0.08	0.08	0.69	0.05	0.07	42.70	100.05

Table 2. Physical properties of Bidzar termite mound materials

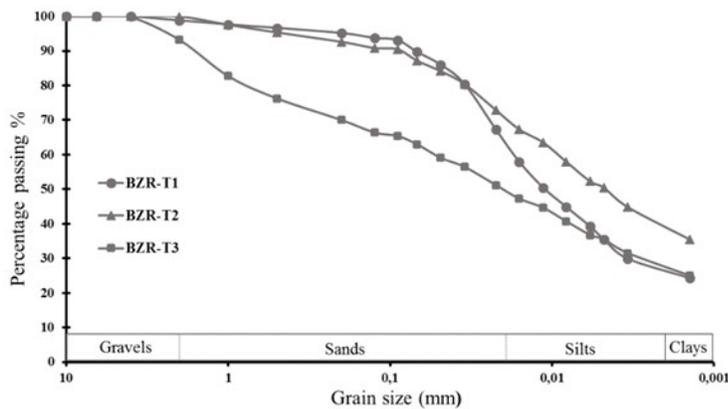| Ref. code		BZR-T1	BZR-T2	BZR-T3
Plasticity (%)	LL	45.78	45.36	42.93
	PL	34.41	28.94	22.64
	PI	11.36	16.42	20.29
PSD (wt%)	Gravels	1.21	0.10	6.79
	Sands	31.50	27.00	42.02
	Silt	37.38	28.03	19.68
	Clays	29.90	44.86	31.50
OM (wt%)		5.18	5.35	4.04

Fig. 4. Particle size distribution of Bidzar termite mound materials

Regarding the plasticity of the Bidzar TMM, the liquid limits (LL) are respectively 45.78, 45.36, and 42.93% for BZR-T1, BZR-T2, and BZR-T3. The plasticity index (PI) recorded are 11.36, 16.42, and, 20.29% respectively, for the same samples. These values higher than 10% might be adequate for designing structural clay products by the extrusion process (Vieira et al., 2008). These materials are classified as inorganic silt of medium compressibility and organic silt (BZR-T1 and BZR-T2) and as inorganic clay of medium plasticity (BZR-T3) in the Casagrande plasticity chart (Fig. 7).

The organic matter (OM) contents of the studied materials range from 4.04 to 5.35 wt%. The presence of organic matter may significantly increase the clay plasticity (Husein Malkawi et al., 1999). The organic matter content should be less than 2 wt%
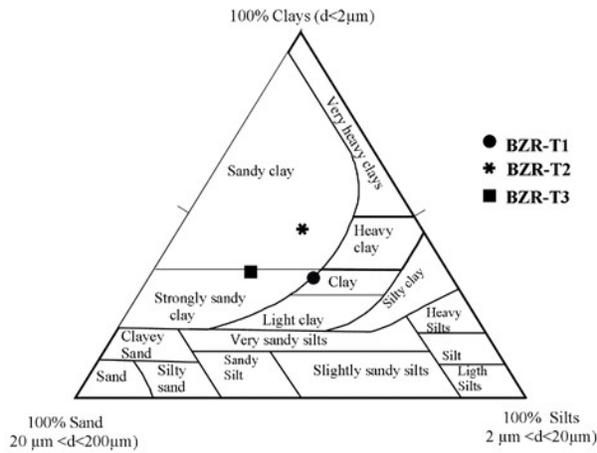
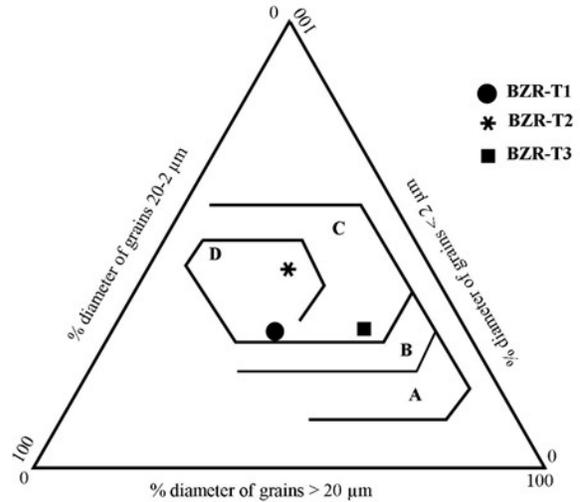**Fig. 5. Belgian ternary diagram showing the textural classification of Bidzar TMM**

Fig. 6. Winkler diagram.
A: Common bricks; B: Vertically perforated bricks; C: Roofing tiles and masonry bricks; D: Hollow products
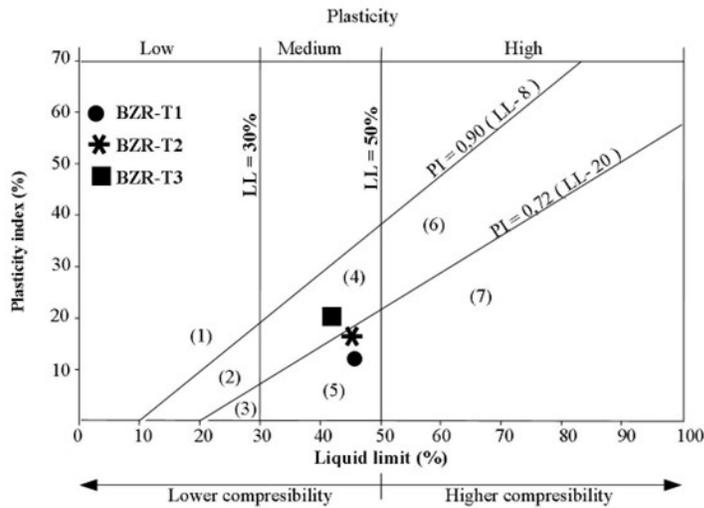

Fig. 7. Plasticity chart of Bidzar TMM

(1) Cohesionless soils, (2) Inorganic clays of low plasticity, (3) Inorganic silts of low compressibility, (4) Inorganic clays of medium plasticity, (5) Inorganic silts of medium compressibility and organic silts, (6) Inorganic clays of high plasticity, (7) Inorganic silts of high compressibility and organic clays

for brick manufacturing (Mango-Itulamya et al., 2019). During the sintering process, the organic matter could be completely burned off, increasing the secondary porosity (Maritan et al., 2006; Xu et al., 2014).

4.2. Physico-chemical properties of fired bricks

Color

The color of the bricks varies slightly with the mixture composition and firing temperature (Fig. 8). They are light brown (7.5YR 6/4), brown (7.5YR 5/4), or strong brown (7.5YR 5/6, 7.5YR 5/8). Iron in the form of Fe_2O_3 is responsible for the red color in the material, while anatase (TiO_2) is responsible for the yellow color (Souza et al., 2002; Andreola et al., 2009). The brown color of the ceramic blocks comes from the presence of Fe_2O_3 and MnO (Arib et al., 2008). The persistence of this brown color after firing with different marble proportions and temperatures is due to the burning of $CaCO_3$ during firing to form CaO and the release of CO_2.

Linear shrinkage

Globally, there is a continuous expansion of BZR-T1 up to 1100°C (Fig. 9-a), followed by low shrinkage at 1200°C and a gradual decrease in BZR-T2 and BZR-T3 shrinkage as marble is added (Fig. 9-b-c). This expansion behavior can
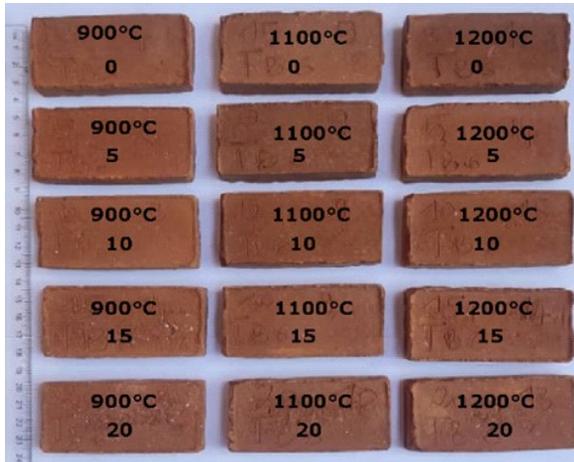
Fig. 8. Color of bricks with BZR-T1 and marble mixtures after firing at 900, 1100 and 1200°C

be attributed to the presence of secondary porosity created during firing (Eliche-Quesada et al., 2012; Xu et al., 2014). It could be due to the presence of organic matter, which is completely calcined during the sintering process, resulting in porous materials that are lighter and less resistant if the sintering temperature does not

allow the elimination of these pores (Maritan et al., 2006). On the other hand, the low shrinkage behavior of BZR-T1 at 1200°C is attributed to the disappearance and/or reduction of porosity during sintering. The high shrinkage mainly observed on reference materials BZR-T2_0 and BZR-T3_0 is attributed to the presence of a considerable percentage of clay (illite) in these two materials (Fig. 9-b-c). It improves plasticity and favors the appearance of vitreous phases during sintering, which increases densification and strength (Andreola et al., 2009; Arsenovic et al., 2013). The CaO formed is an expandable material (Sutcu et al., 2015). The increase in decomposed carbonates in mixtures (5 wt%, 10 wt%, 15 wt%, and 20 wt% marble) causes a considerable expansion or reduction of shrinkage. Normally, the clay mineral shrinks after the sintering process. Organic matter burns and causes the material to shrink, but waste marble powder mixtures exhibit
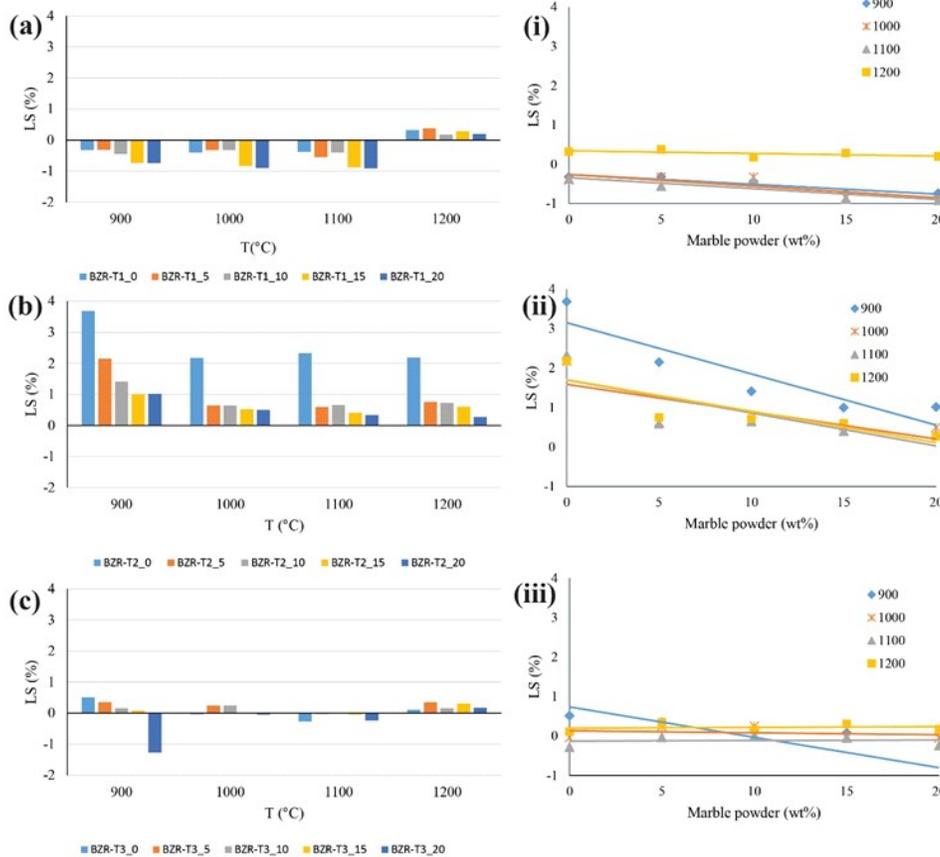

Fig. 9. Linear shrinkage of Bidzar TMM base-bricks a: BZR-T1, b: BZR-T2, c: BZR-T3, and linear fits of linear shrinkage to marble powder proportion i: BZR-T1, ii: BZR-T2, iii: BZR-T3

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the opposite behavior, especially when they contain a high proportion of waste marble powder. Despite the reduction in weight, the size increased. The main reason for the increase in size is the appearance of pores in the structure, which is due to the release of CO_2 during calcinations of $CaCO_3$. This is a property requested in the manufacture of bricks by increasing the porosity and, on the other hand, by reducing the weight of the material. Therefore, it could be used in industrial brick mortar (Bilgin et al., 2012). The linear shrinkage values of the studied bricks remain lower than 5%, which is the minimum requirement for traditional ceramic raw materials (Millogo et al., 2011).

Water absorption

The water absorption values of the experimental bricks are shown in Fig. 10. They range from 10.41 (BZR-T2_0) to 21.44% (BZR-T3_20), 13.00 (BZR-T3_0) to 18.35% (BZR-T1_20), 13.84 (BZR-T2_0) to 17.80% (BZR-T1_20), and 12.39 (BZR-T2_0) to 18.08% (BZR-T1_10), respectively, at 900, 1000, 1100, and 1200°C. As shown in the figure, the overall difference between the water absorption values of the three reference bricks (BZR-T1_0, BZR-T2_0, and BZR-T3_0) at all temperatures is less important than bricks with a high marble powder content. The lowest water absorption value was obtained in BZR-T2_0 (0% marble content) after firing at 900°C (Fig. 10-b). Normally, WA should decrease with increases in temperature (Onana et al., 2019; Kessoum Adamou et al., 2023). Linear fits between absorption and marble content reveal that water absorption is directly proportional to the percentage of marble powder added to the bricks (Fig. 10i-ii-iii). This was expected since calcium carbonate in the residue was transformed during the thermal process and leads to an increased amount of the open pores of the ceramic bodies (Montero et al. 2009). According to Bilgin et al. (2012), it is due to the CaO mineral in the

marble powder, which is very reactive and reacts with water, releasing heat and forming $Ca(OH)_2$. According to the Iranian standard specification for the construction of thermally insulated bricks, the water absorption of bricks must not exceed 20% by weight (Ahmadia et al., 2018). This specification is exhibited by Bidzar experimental TMM-based bricks, except for BZR-T3_20 at 900°C. According to Brazilian Standards (NBR 6480), the maximum allowed value of water absorption is 22% for commercial use of the bricks (Saboya Jr. et al., 2007), and all the studied bricks can be used for bricks production.

Bulk density

The bulk density values of the bricks produced are presented in Fig. 11. The bulk density values of the samples varied between 1.60 (BZR-T3_20 at 900°C) and 1.96 g/cm³ (BZR-T2_20 at 1100°C) depending on the waste content and firing temperatures. The bulk density of bricks without marble waste is higher than that of those containing marble. The addition of marble waste decreases the density of fired bricks. As explained above, this would be due to the increase in decomposed carbonates in the brick mixes. When looking at each group containing the same ratio of marble waste at all studied temperatures, it appears that the effect of the temperature indicated on the bars is negligible. The proportions of linear fits to the percentage of marble waste for bulk density are shown in fig. 11i-ii-iii. The linear fit shows that bulk density is directly proportional to the percentage of marble waste added to the bricks at 1100 and 1200°C. At 900°C for BZR-T1 and 1000°C for BZR-T2, BD slightly increases with marble powder proportion. According to Eliche-Quesada et al. (2012), increasing the temperature to 1050°C produces an increase in the liquid phase amount, which tends to approach the fine pores contained in the ceramic body. This mechanism is less effective when adding larger amounts of waste,
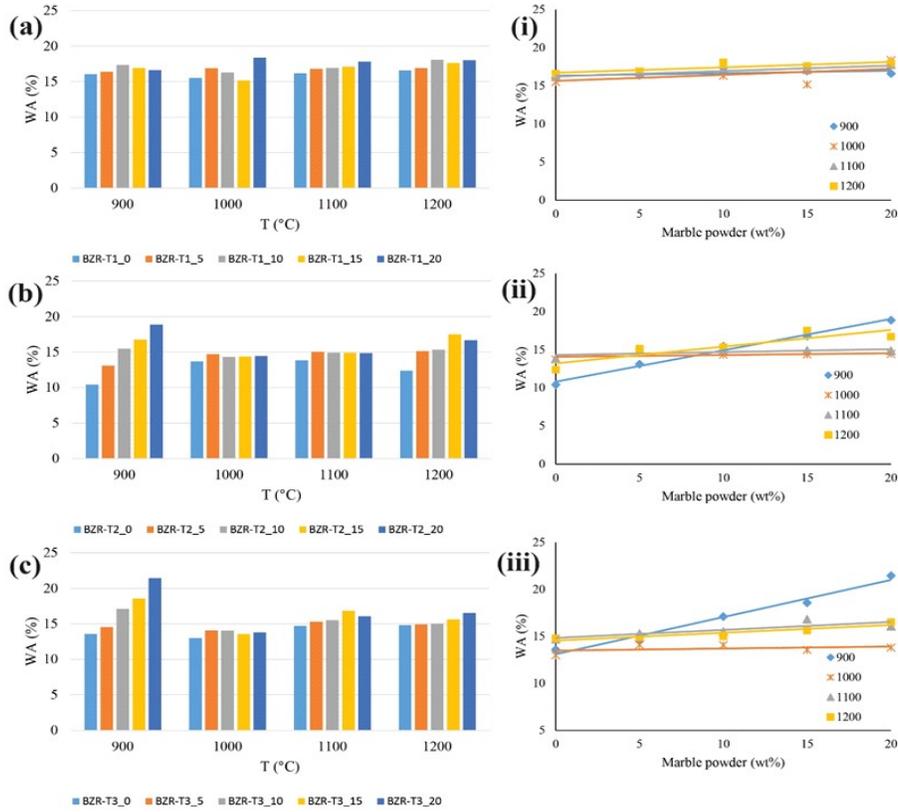
Fig. 10. Water absorption of Bidzar TMM base-bricks a: BZR-T1, b: BZR-T2, c: BZR-T3, and linear fits of water absorption to marble powder proportion i: BZR-T1, ii: BZR-T2, iii: BZR-T3
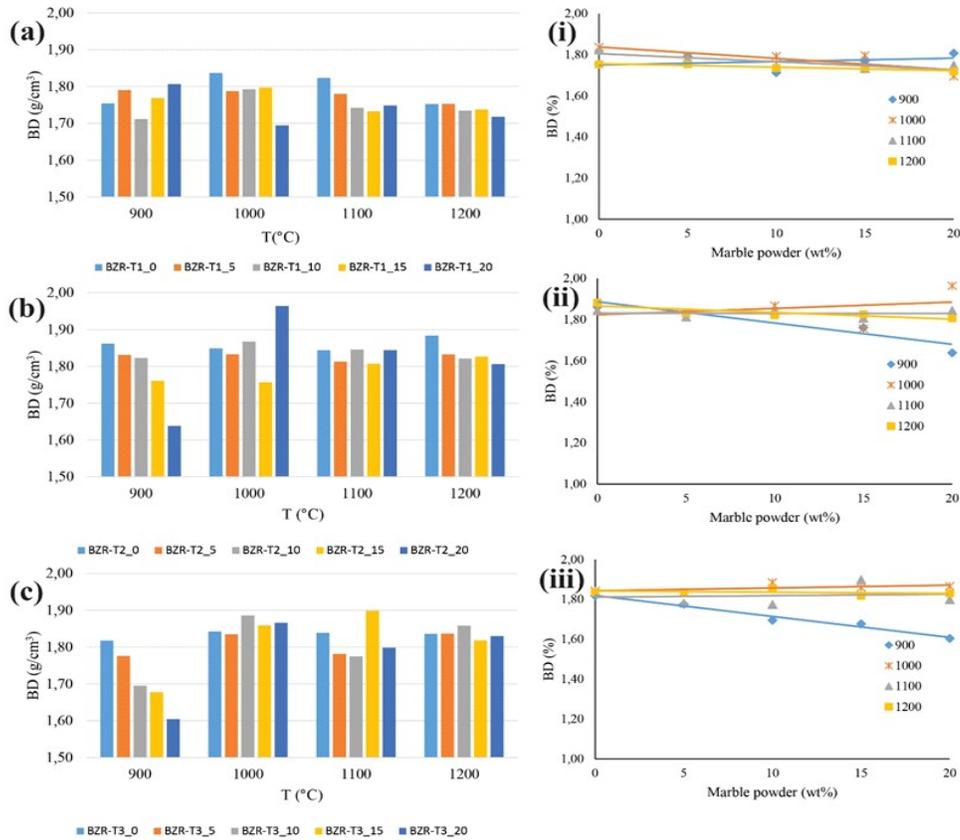

Fig. 11. Bulk density of Bidzar TMM base-bricks a: BZR-T1, b: BZR-T2, c: BZR-T3, and linear fits of bulk density to marble

resulting in lower bulk density and higher porosity. The minor BD variations may be due to the similar mineralogical composition of the samples (Ndjigui et al., 2021).

Apparent porosity

The apparent porosity (AP) values of the bricks produced are shown in Fig. 12. AP varies between 19.39% (BZR-T2_0 at 900°C) and 34.41% (BZR-T3_20 at 900°C). The apparent porosity increases with marble powder content (Fig. 12i-ii-iii). There is a relationship between water absorption, porosity, and the bulk density of bricks. Porosity should decrease because of the increasing sintering process with the increasing temperature, but marble powder shows opposite behavior under the effect of the sintering

temperature due to the release of CO_2, which leads to porousness in the structure (Bilgin et al. 2012). Increasing the porosity of the bricks helps to improve their thermal insulating properties (Sutcu et al., 2015). Thermal insulation maintains temperatures in appropriate conditions by creating a barrier between the warm air inside the house and the cold air outside, and vice versa. The more effective this barrier is, the less energy the house needs to cool and heat itself (Aldawi and Firoz Alam, 2016). There is no fixed maximal porosity for the fired clay bricks, but a very high value could be problematic (Bories et al., 2014).

Flexural strength

The flexural strength (FS) of the fired bricks as a function of waste content and firing temperature
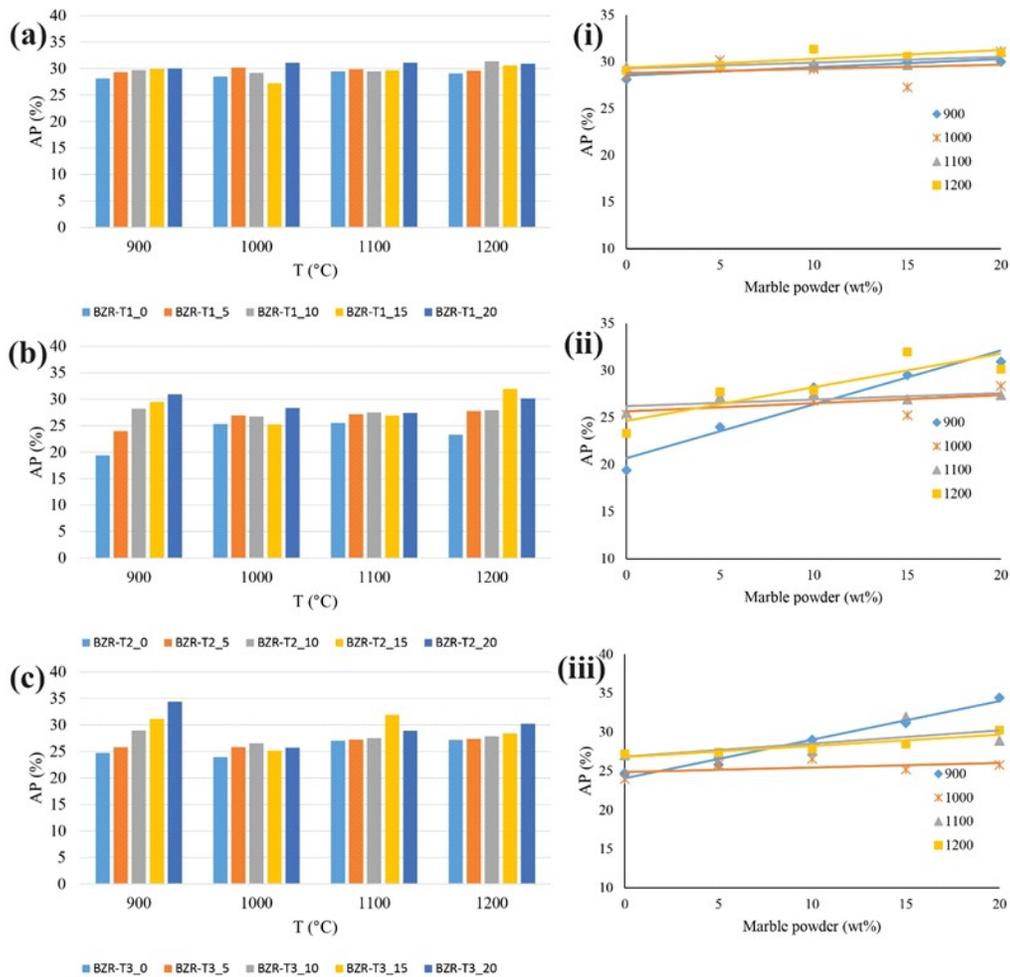

Fig. 12. Apparent porosity of Bidzar TMM base-bricks a: BZR-T1, b: BZR-T2, c: BZR-T3, and linear fits of apparent porosity to marble powder proportion i: BZR-T1, ii: BZR-T2, iii: BZR-T3

is illustrated in Fig. 13. FS values range between 1.25 (BZR-T3_20) and 8.13 MPa (BZR-T2_10), 2.40 (BZR-T3_20) and 5.64 MPa (BZR-T2_15), 2.52 (BZR-T1_20) and 5.48 MPa (BZR-T2_20), and 2.56 (BZR-T3_20) and 5.00 MPa (BZR-T2_15), respectively, at 900, 1000, 1100, and 1200°C. Flexural strength decreases with waste marble content for BZR-T1 and BZR-T3 (except for BZR-T1 at 1200°C), while it increases for BZR-T2 at 1000, 1100, and 1200°C (Fig. 13i-ii-iii). Decreases in the flexural strength (FS) of marble-added bricks are expected since the addition of marble powders to the mortar reduced densities and increased porosities (Bilgin et al., 2012). The flexural strength values do not depend on either firing temperature or mix composition. This behavior can be due to mineral re-crystallization at high temperatures, which probably makes the effects of waste content secondary (Saboya Jr. et al. 2007) or to the spatial variation in microcracking on some samples. The Bidzar experimental bricks having flexural strengths greater than 2 MPa (except for BZR-T3_20 at 900°C) are suitable to produce dense bricks (Souza et al., 2002; 2011).

Compressive strength

The compressive strengths (CS) of the Bidzar TMM base bricks are shown in Fig. 14. Globally, the compressive strength of the produced bricks decreased as a function of the concentration of marble waste in the brick body at the tested temperatures. The highest compressive strengths were obtained for bricks: BZR-T2_0 at 900 (18.76 MPa) and 1000°C (12.08 MPa) and BZR-
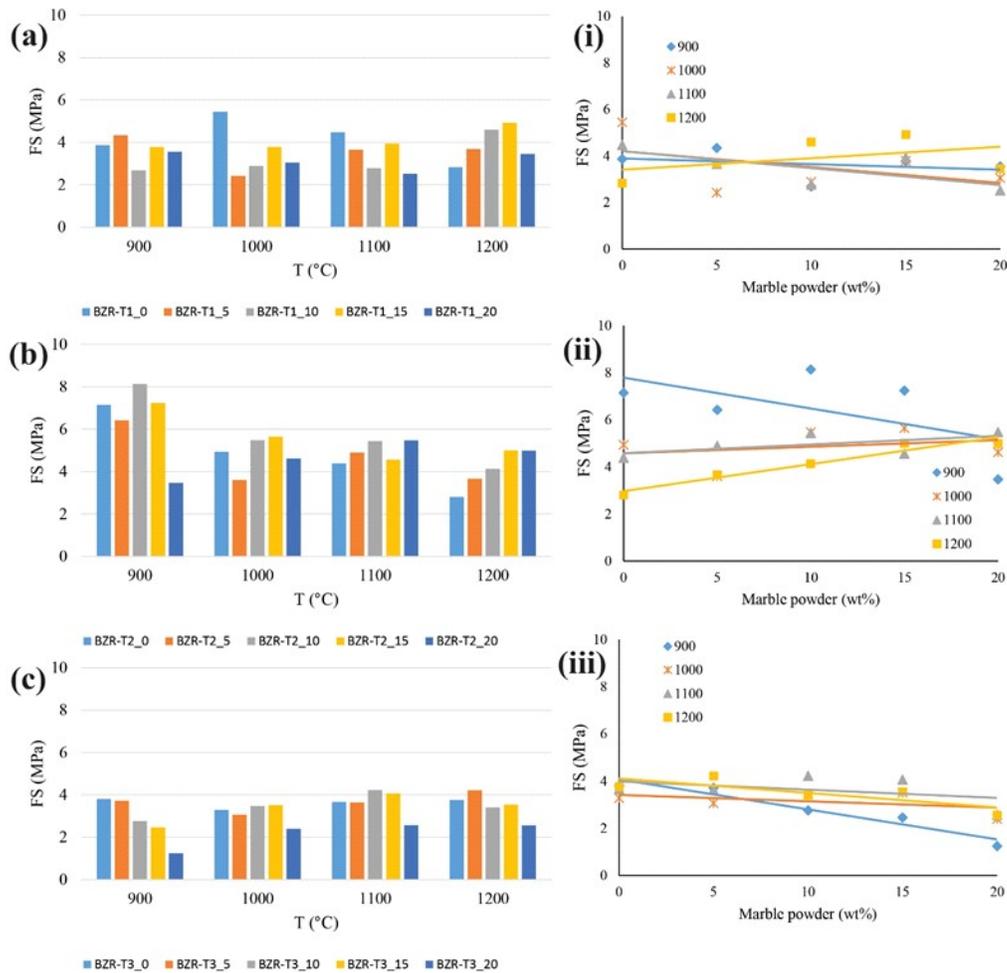

Figure 13. Flexural strength of Bidzar TMM base-bricks a: BZR-T1, b: BZR-T2, c: BZR-T3, and linear fits of flexural strength to marble powder proportion i: BZR-T1, ii: BZR-T2, iii: BZR-T3

T2_5 at 1100 (13.24 MPa) and 1200°C (16.87 MPa). The lowest value belongs to BZR-T3 at 900°C (3.29 MPa), to BZR-T1 at 1100 (2.89 MPa), and 1200°C (3.12 MPa) when 15 wt% of marble powder is added, and to BZR-T1 at 1000°C (3.12 MPa) with 10 wt% in the body. It appears that marble waste has a more significant effect on the compressive strength of the studied bricks than temperature. The linear fits (Fig. 14i-ii-iii) show that for any BZR-T sample, the CS is directly proportional to the percentage of marble waste added to the bricks. There was a clear increase in the compressive strength of concrete with the increasing amount of marble dust (Binici et al., 2007; Gacu and Sim, 2022). The decreases observed for the studied bricks are due to the sintering process, as explained above. Regarding

the various applications of bricks according to the Iranian standard specification (INSO 7, 2016) for thermally insulated buildings, all bricks (except BZR-T1_15 fired at 1100°C) meet the standard for embedded bricks (> 3 MPa).

5. Conclusion

The effect of marble powder addition on the physical and mechanical characteristics of termite mound materials was investigated. By reusing and recycling marble waste as an additive in the manufacture of bricks, we can help solve the environmental problem posed by their production. The TMM are made up of quartz, illite-smectite, vermiculite, chlorite, muscovite, calcite, hematite, and anatase, with SiO_2, Al_2O_3, and Fe_2O_3 being the main oxides. These materials
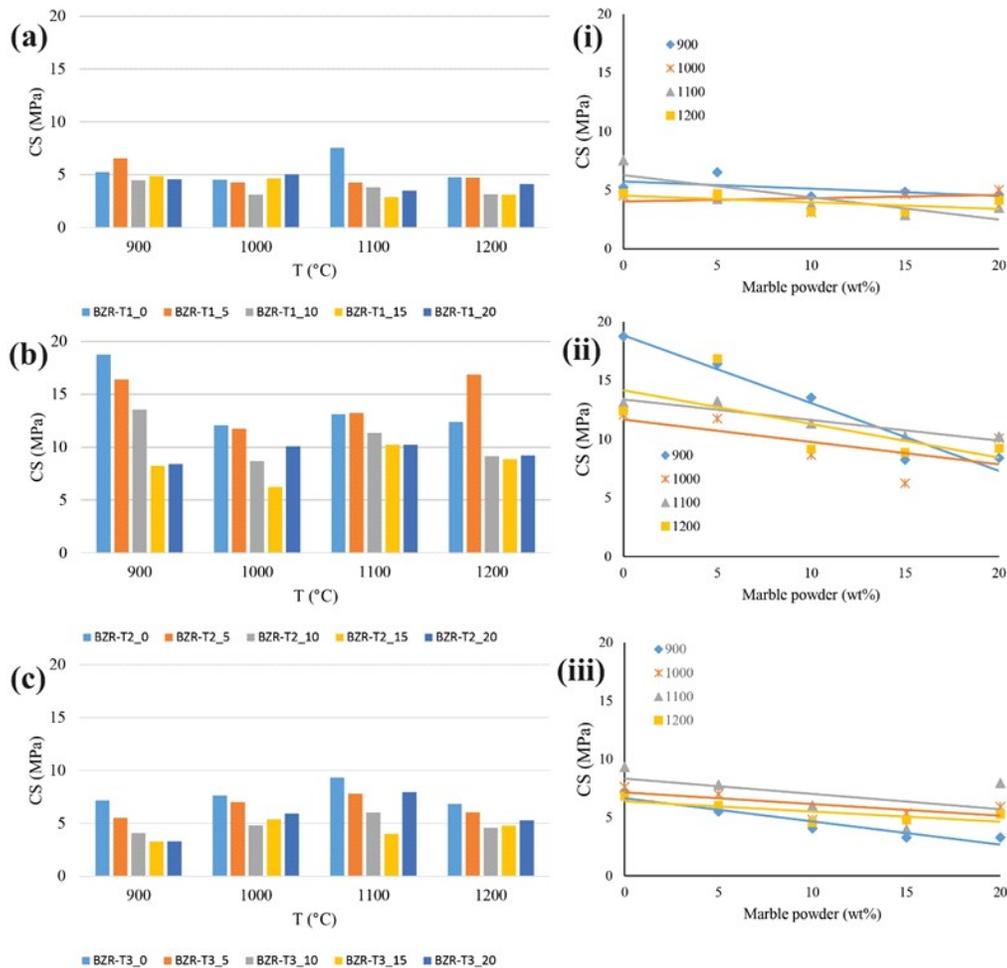

Figure 14. Compressive strength of Bidzar TMM base-bricks a: BZR-T1, b: BZR-T2, c: BZR-T3, and linear fits of compressive strength to marble powder proportion i: BZR-T1, ii: BZR-T2, iii: BZR-T3

are sandy clays or strongly sandy clays, which can be used for the manufacture of hollow products, roofing tiles, and masonry bricks. Linear shrinkage (LS) decreases with increasing marble powder content in the specimen body and remains below 5% for all studied materials, while water absorption (WA) values increase with the addition of marble and remain below 20%, which is good for the production of thermally insulating bricks. The percentage of marble has a significant influence on the flexural and compressive strength and adding to organic matter leads to the creation of secondary porosity that decreased with increased marble content. The addition of 5 to 20% marble powder reduces the overall characteristics of bricks made from Bidzar termite mounds. However, for thermally insulated buildings, the percentage of marble waste in this study enables embedded brick standards to be met.

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Author contribution statement

Roger Firmin Donald Ntouala Conceived the project, carried out the field campaigns and drafted the manuscript.
Brondon Ebeedom Ndjankoum performed the experiments; analyzed and interpreted the data; conceived the figures and tables; carried out the field campaigns.
Estelle Ndome-Priso analyzed and interpreted the data and wrote the paper.
Marie Thérèse Nanga Bineli analyzed and interpreted the mineralogical and geochemical data.
Vincent Laurent Onana contributed reagents and reviewed the manuscript.
Georges Emmanuel Ekodeck supervised the work.

Declarations

The authors declare that they have no competing interests.

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