

1 **EFFECTS OF THICKNESS OF A MINERAL LAYER OF**
2 **GRANITE AND MARBLE ON THE MECHANICAL PROPERTIES**
3 **OF A BILAYER MATERIAL: CASE OF GRANITES**

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8 **ABSTRACT**

9 The present work is dedicated to the study of the mechanical properties of a bilayer material. This material consists of a substrate in mortar and a mineral layer in granite and marble. The mixture of these two constituents of different characteristics gives a material whose properties will vary depending on the density of each constituent. The standardized testing on the sand and the bend tests three points and compression are among other methods used for the evaluation of the mechanical characteristics of the specimens of $4 \times 4 \times 16$ cm dimensions. The results of these tests show that samples of the mineral layer in granite with a thickness of 1.7 and that of 1.4 cm in marble get good bending resistance three points respectively equal to 10.63 and 10.3 MPa. As for the compression tests, it appears that the compressive resistance increases with the thickness of the mineral layer but evolves in reverse with the rate of water absorption of these materials. The best resistance in compression obtained with the samples having the thickness of 2 cm of the granite and marble mineral layers are respectively 24.47 and 24.07 MPa. In addition, for this same thickness, the Bilayers offer a better rate of water absorption.

10
11 *Keywords: Granite, marble, bilayer material, mechanical resistance, water absorption.*
12 *water absorption.*

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14 **NOMENCLATURE**

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16 LERGC : Test and Research Laboratory in Civil Engineering
17 UAC : Université of Abomey Calavi
18 SONEB : National Water Company of Benin
19 NOCIBE : New Cement Factory of Benin

20 M_S : Mass of sand (g)

21 M_C : Mass of cement (g)

22 M_E : Mass of water (g)

23 R_f : Maximum resistance to flexion (MPa)

24 b : Side of prism square section (mm)

25 F_f : Load applied in the middle of the prism at break (N)

26 l : Distance between supports (mm)

27 R_c : Compressive maximum resistance at 28 days (MPa)

28 F_c : Maximum load at break (N)

29 W : Absorption rate of water in (%)

30 m_1 : The dry sample weight

31 m_2 : The mass of saturated the sample water

32 N : Number of test tubes

33 \bar{X} : Resistance average to flexion or compressive in (MPa) or absorption rate of water in (%)

34 X_i : Resistance in flexion or compression in (MPa) or the water absorption rate in (%) of
35 each test tube.
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38 **1. INTRODUCTION**

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40 Composite materials have seen a very significant advance in recent decades. The basic idea
41 is to combine two or more compatible materials in order to achieve remarkable compromises
42 between the properties of materials while taking advantage of the qualities of the
43 components. These materials have excellent characteristics and have important advantages
44 over traditional materials.

45 Among the most commonly used composite materials are two-layer materials. Cement /
46 Granites bilayers are inexpensive and environmentally friendly materials that can be
47 produced using relatively simple technology. They are mainly used in the building for non-
48 structural applications, as interior and exterior coatings, light partitions, tiles, square tiles,
49 pavers, screeds, noise and fire barriers (Moslemi, 1999). These materials offer a good
50 lightness, a good behavior with humidity, good resistance to fire and shocks with interesting
51 mechanical and thermal performances

52 Many parameters affect the mechanical behavior of these bilayer structures:

- 53 - The relative thicknesses of the different layers;
- 54 - Stacking sequences;
- 55 - The nature of the constituent materials (density, physical and mechanical
56 properties).

57 The bibliographical reference relating to granitic bilayer materials suffers a lot of
58 insufficiencies. Meanwhile, for some years, some work has been done on composite
59 materials. Thus, the work of (Pouteau, Chabot and De Larrard, 2002) and (Pouteau, 2004)
60 focused on a 4-point flexural bending test of bilayer structures. The efforts at the interface
61 between the layers of the composite materials have been analyzed by (Chabot A, 1997).
62 (Romain BRAULT, 2013) studied the mechanical behavior of composite materials by volume
63 correlation. The work of (Taoukil, Albouardi, Ajzoui and Ezbakhe, 2011) and (Aouadja,
64 Mimoune, and Laquerbe, 1995) relate respectively to mechanical and water characterization
65 and experimental study of concrete with wood residues. In addition, the characterization of a
66 mineral bilayer material produced by (Toukourou, Fagla, Prodjintono and Bello, 2015) has
67 shown that at 20% of coarse sand, granitic bilayers offer good resistance in three points and
68 in compression with a normal water absorption rate. Moreover, these results obtained by
69 these authors are practically the same as those obtained with 30% coarse sand content.

70
71 However, knowledge in the field of bilayer materials including granites is still limited and
72 studies must be conducted to better know and improve the properties of these materials.
73 The present study is therefore part of this logic and aims to study the influence of the
74 thickness of the granite and marble mineral layer on the mechanical characteristics of such
75 materials.
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77 **2. MATERIAL AND METHODS**

78 **2.1. Equipment**

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80 The materials used in the manufacture of bilayers are: sand, cement, water and granites.
81 The following paragraphs describe the characteristics of each of these constituents.

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83 **2.1.1. Sand**

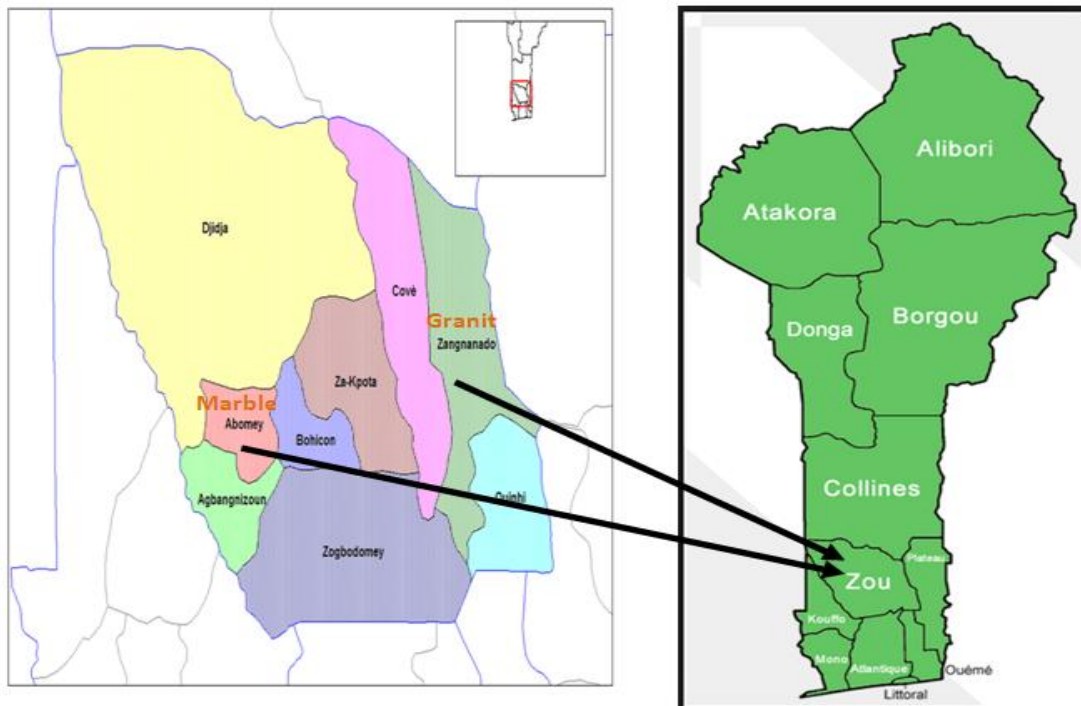
84 The sand used in this work comes from the region of Agamè, commune of Bonou; region
85 located in the south of Benin, in the department of Ouémé. This sand, washed with tap
86 water, is dried in an oven at 105 ° C until stabilization of the mass and then sieved in two
87 different granular classes: Medium sand and coarse sand composed of grains, respectively
88 with the dimensions ranging from 0.4 mm to 2 mm and from 2 mm to 6.3 mm. The sand
89 used for the preparation of the substrate is composed of 30% of coarse sand and 70% of
90 medium sand (Toukourou, Fagla, Prodjinonto and Bello, 2015).

91 2.1.2. Cement

93 **Portland cement** CPJ 35 of type CEM II/B-LL.42,5R of the NOCIBE is used because of its
94 relatively fast setting.

95 2.1.3. Granites

97 **Granites** used are crushed granite and marble respectively from the town of **Zangnanado**
98 and **Abomey**, two regions of the southern **Benin** located in the department of **Zou** (fig. 1).
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102 **FIG. 1 Geographical locations of rock sampling sites**

103 2.1.4. Water

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105 The water used is that of SONEB collected at UAC. It is supposed to be drinkable
106 and contains no impurities harmful to the mechanical characteristics of bilayer
107 materials.

108 2.2. Methods

109 In order to carry out the mechanical tests, the parallelepiped shaped samples were
110 made after having characterized the sand.
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112 **2.2.1 Sand Physical tests**

113 Before the preparation of the substrate on which the **granite** must rest, the sand was
114 initially characterized by LERGC. These physical tests are:

115 - Particle size analysis

116 - Equivalent of sand

117 - Actual pre-dried density (specific weight)

118 - Bulk density

119 - Water content

120 **2.2.2. Samples making**

121 The preparation of the specimens began with the preparation of the substrate while
122 varying its thickness and respecting the ratios of the dosage:

123
$$\frac{M_C}{M_S} = \frac{1}{3} \quad (1)$$

124
$$\frac{M_E}{M_C} = \frac{1}{2} \quad (2)$$

125 After this step, the granite coating is placed so as to have a final bilayer sample
126 of 4 cm thick (fig. 2). Once the bilayer was obtained, we immersed it in water for 28
127 days. The 28 days reached, the surface of the sample out of the water is sanded
128 (fig. 3). The bilayers then obtained, the step of the tests of three-point bending and
129 compression at 28 days on the test tubes is carried out.



130 **FIG. 2 Coatings laying**



131 **FIG. 3 Sanding operation**

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134 **2.2.3 The bending tests**

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136 The press used for our tests is a hydraulic press with digital display (Fig. 4). The test piece
137 is centered along its length while presenting the face of the mineral layer to the effort. Then,
138 a normal force is applied to this face and the value of the maximum load at break is noted
139 after each test. The flexural strength of the specimens was determined by the relationship
140 established by BAILON and DORLOT (2000):

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$$R_f = \frac{1,5 \times F_f \times l}{b^3} \quad (3)$$

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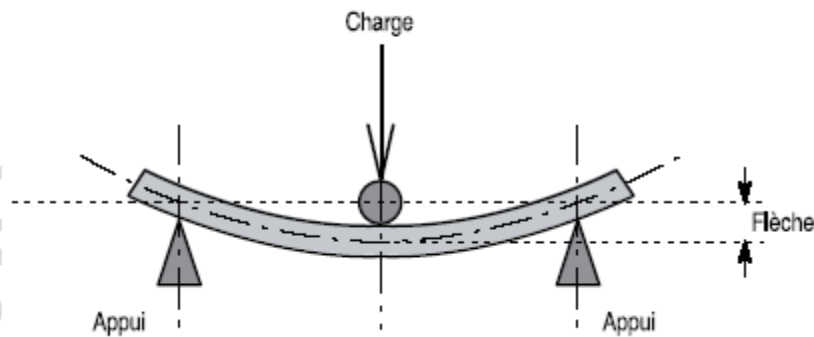


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FIG. 4 The bending and compression testing equipment



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FIG. 5 The three-point bend test setup on the test specimens

149 **2.2.4 Compression test**

150 The procedure adopted is the compression on each half-test piece resulting from the three-
151 point bending test with the same apparatus, the two halves not being always of regular
152 shape. The compressive strength is obtained by the formula:

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$$R_c = \frac{F_c}{1600} \quad (4)$$

154 **2.2.5 The bilayer water absorption test**

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156 The samples, initially dried and weighed with a precision scale of 0.1 g, were immersed in
157 water and then left after 24 hours of total immersion. Wiped with a damp cloth, these
158 samples were weighed again. The rate of water absorption is determined by the following
159 formula:

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$$W (\%) = \frac{m_2 - m_1}{m_1} \times 100 \quad (5)$$

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163 **2.2.6 The assessment of uncertainties**

164 The standard deviation is determined from the following formula:

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$$E = \sqrt{\frac{1}{N} \sum (\bar{x} - x_i)^2} \quad (6)$$

166 The uncertainty is deduced from the following relation:

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$$I(\%) = \frac{E}{E_{moyenne}} \times 100 \quad (7)$$

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169 **3. RESULTS AND DISCUSSION**

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171 **3.1. The influence of the thickness of the granite layer and marble on the 3**
172 **point flexural strength**

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174 Tables 1 and 2 summarize the results of the three-point bending resistances obtained on the
175 different samples. These are the average values found on the different test pieces. These
176 values made it possible to draw curves representing the variation of the bending strength as
177 a function of the thickness of the granite layer and the marble
178 (Figures 6). It can be seen that there are no significant differences between the 28 day
179 flexural rupture strength values of granite bilayers and those of marble bilayers of the same
180 thickness.

181 In addition, we note that these curves first decrease with the thicknesses (0.8 cm and 1.1
182 cm) of the marble and granite layer and then oscillate as the thickness of the mineral layer
183 increases. The decrease followed by growth could be explained respectively by an excess
184 of binder in the coating causing the effective nonparticipation of the granites and a deficiency
185 of binder to coat these granites which represent one of the factors of the resistance of the
186 bilayer material. Such behavior of the samples is similar to that of bilayer materials
187 (TOUKOUROU et al, 2015), fragile materials (BAILON and DORLOT, 2000).

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189 **TABLE 1 The summary of the bending test results of granite bilayers**

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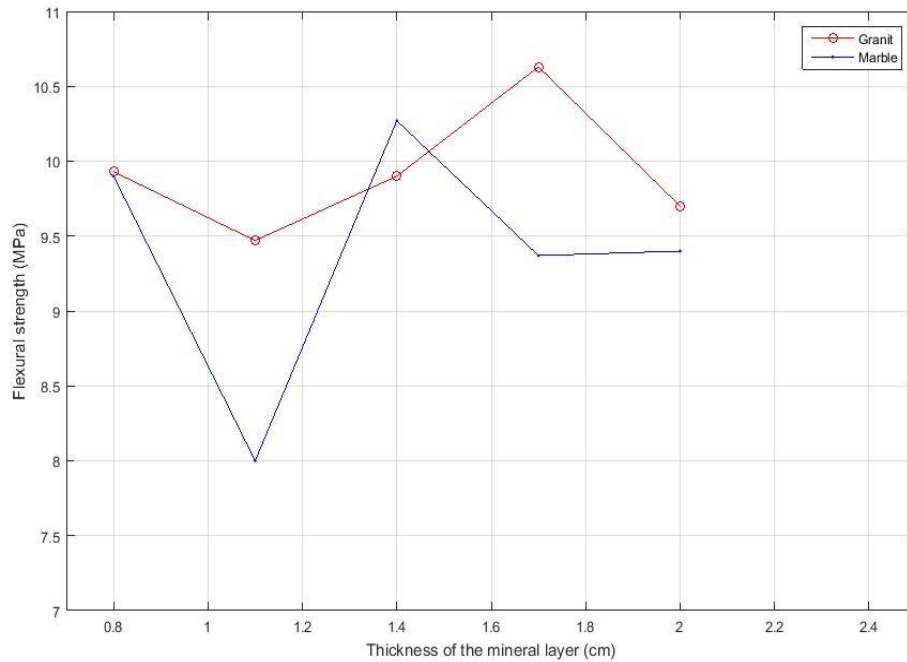
Thickness of the mineral layer (cm)	Flexural strength (MPa)	Spread type (MPa)	Uncertainty (%)	Average uncertainty (%)
0.8	9.93	0.83	8.36	
1.1	9.47	0.37	3.91	
1.4	9.9	0.67	6.77	5.44
1.7	10.63	0.31	2.92	
2	9.7	0.51	5.26	

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TABLE 2 The summary of the bending test results of marble bilayers

Thickness of the mineral layer (cm)	Flexural strength (MPa)	Spread type (MPa)	Uncertainty (%)	Average uncertainty (%)
0.8	9.9	0.22	2.22	5.66
1.1	8	0.43	5.38	
1.4	10.27	0.45	4.38	
1.7	9.37	0.74	7.90	
2	9.4	0.79	8.40	

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FIG. 6 The influence of granite layer and marble thickness on the bending strength at 28 days

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3.2 Effects of granite layer and marble thickness on the compressive strength at 28 days

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The results of the 28-day compressive strengths of the different samples are given in Tables 3 and 4. Figure 7 shows the 28-day compressive strength variation curves of the two categories of bilayers as a function of the thickness of the mineral layer of granite and marble.

It can be seen in this figure that the compressive strength increases in the same direction as the thickness of the granite and marble mineral layer. As a result, an increase in the thickness of the mineral layer is synonymous with an increase in the volume of rock aggregates, whose compressive strength would drive that of the composite material. Moreover, it is important to note that these bilayers exhibit for this variation in the thickness of the mineral layer a different behavior in flexion than in compression. In addition, these materials are rigid in compression than in flexion.

212 **TABLE 3 Summary of the 28-day compression test results for granite bilayers**

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Thickness of the mineral layer (cm)	Compressive strength (MPa)	Spread type (MPa)	Uncertainty (%)	Average uncertainty (%)
0.8	13.93	0.29	2.08	4.81
1.1	15.67	0.58	3.70	
1.4	16.87	0.93	5.51	
1.7	22.70	1.27	5.59	
2	24.47	1.76	7.19	

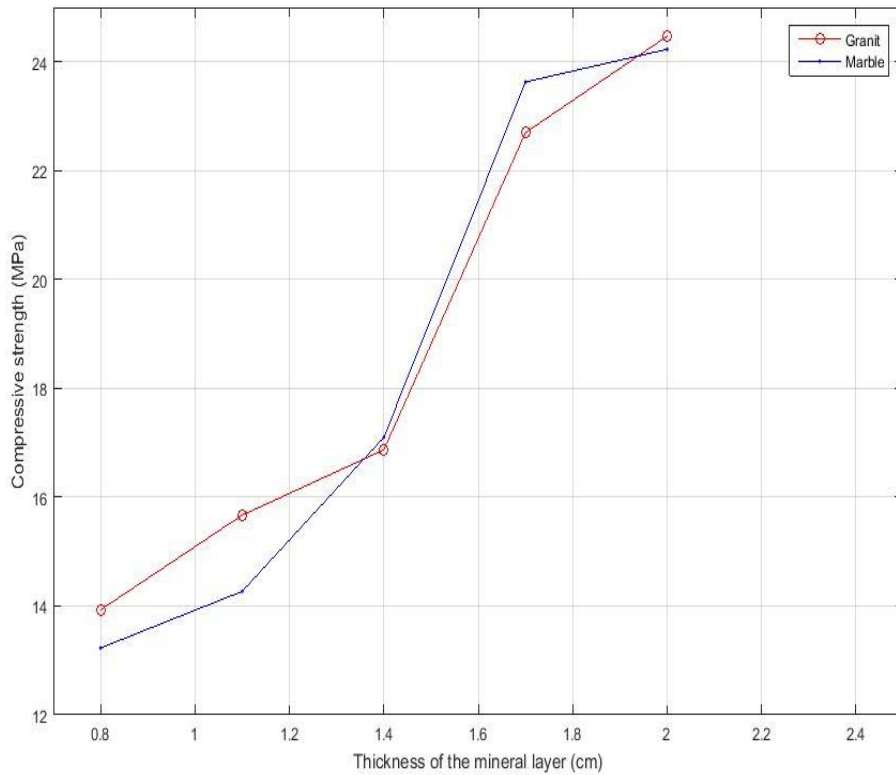
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215 **TABLE 4 Summary of the 28-day compression test results for marble bilayers**

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Thickness of the mineral layer (cm)	Compressive strength (MPa)	Spread type (MPa)	Uncertainty (%)	Average uncertainty (%)
0.8	13.23	0.53	4.01	4.60
1.1	14.27	0.59	4.13	
1.4	17.1	1	5.85	
1.7	23.63	1.11	4.70	
2	24.23	1.05	4.33	

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FIG. 7 The influence of granite and marble layer thickness on the 28-day compressive strength

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3.3 The influence of the of the granite and marble layer thickness on the water absorption rate of bilayers

Fig 8 gives an overview of the variation in the rate of water absorption by total immersion of the specimens as a function of the thickness of the layer of granite and marble. These curves are obtained from the results synthesized in Tables 5 and 6. It can be seen that the water absorption rate of the various samples decreases as the thickness of the mineral layer increases and varies between 3.09% and 5, 25%. This decrease is all the stronger as the thickness of the mineral layer is important. This observation can be justified by a low porosity of aggregates including rocks used on the one hand or by a high level of binder in the mixture of the mineral layer, thus making the bilayer material tight on the other hand.

TABLE 5 Summary of water Absorption results for granite bilayers

Thickness of the mineral layer (cm)	Absorption rate of water (%)	Spread type (MPa)	Uncertainty (%)	Average uncertainty (%)
0.8	4.15	0.26	6.27	
1.1	3.50	0.11	3.14	
1.4	3.35	0.18	5.37	4.60
1.7	3.25	0.13	4.00	
2	3.09	0.13	4.21	

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TABLE 6 Summary of water absorption results of marble bilayers

Thickness of the mineral layer (cm)	Absorption rate of water (%)	Spread type (MPa)	Uncertainty (%)	Average uncertainty (%)
0.8	5.25	0.3	5.71	
1.1	4.54	0.15	3.30	
1.4	4.34	0.13	3.00	4.23
1.7	4.22	0.18	4.27	
2	3.96	0.19	4.80	

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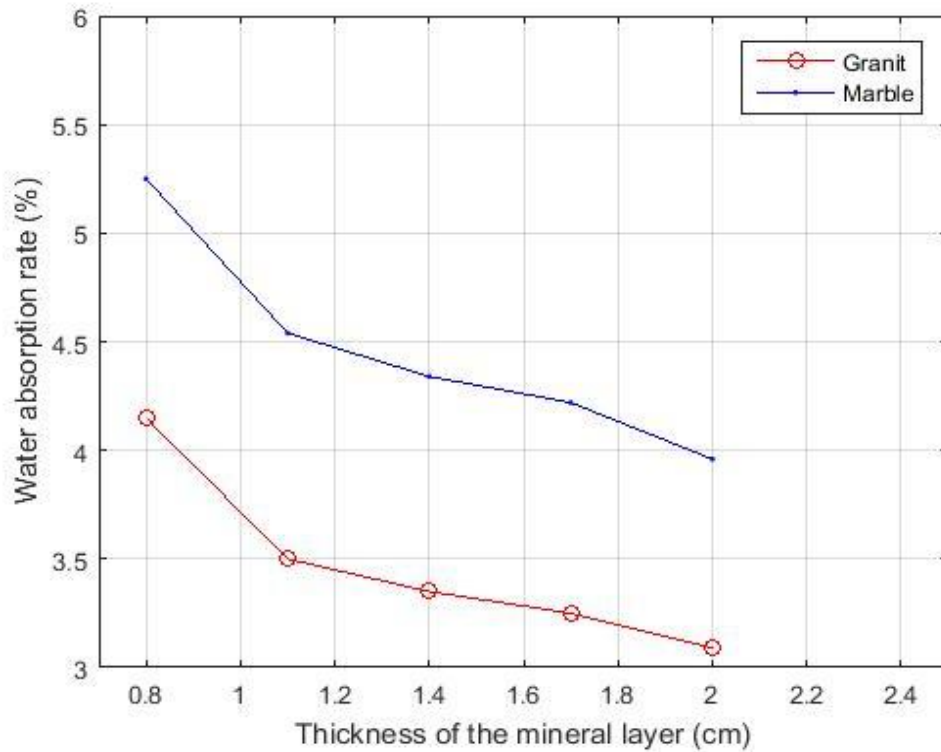


FIG. 8 The influence of granite and marble layer thickness on the water rate

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3.4 The evolution of the compressive strength in terms of the water absorption rate of the bilayers.

Fig. 9 gives the evolution of the compressive strength in terms of the water absorption rate of the bilayers. A decrease in the compressive strength is noted for an increase in the water absorption rate, and therefore in the open porosity of the bilayers. Since these bilayer materials consist of the substrate and a mineral granite and marble coating, this reduction could be justified by an increase in the amount of pores in the substrate whose thickness increases when that of the mineral layer decreases.

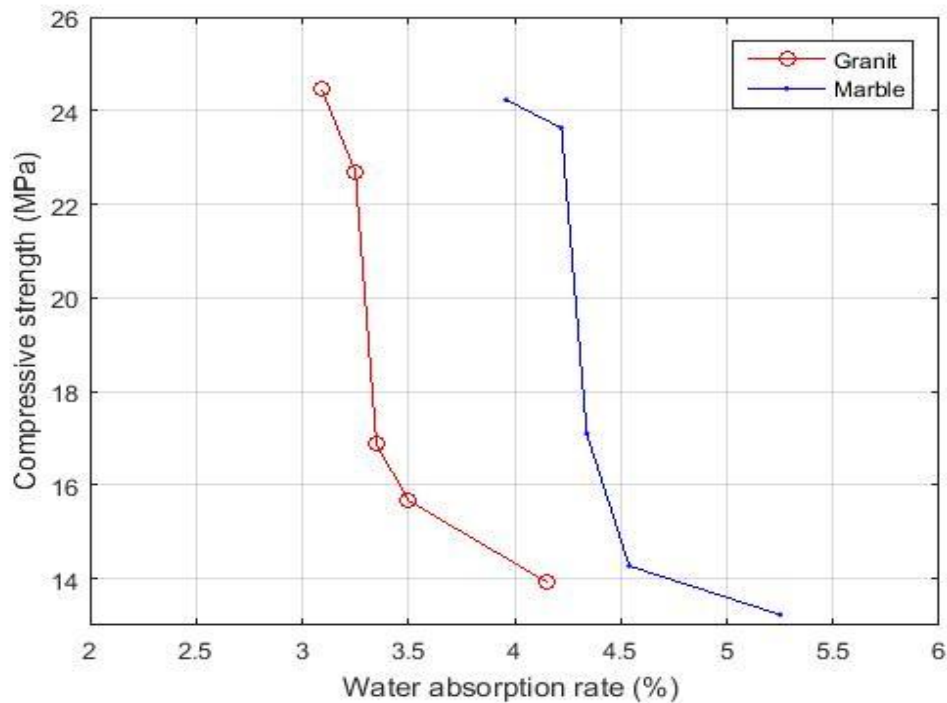


FIG. 9 Effects of compressive strength on the open porosity of granite bilayers

4. CONCLUSIONS

Materials used in the building industry must have, among other things, certain mechanical properties to ensure the structural durability of the building. The studies carried out as part of this work whose objective is the valorization of local building materials in Benin with a view of improving their performance in terms of thermomechanical characteristics, have focused on bilayer materials, especially tiles coated with granites. The results obtained showed that:

- Granite-clad tiles are suitable for both interior and exterior cladding in our premises;
- For a thickness of 2 cm of the granite and marble mineral layer, the two-ply materials offer good compression strength at 28 days respectively equal to 24.47 MPa and 24.23 MPa with a normal water absorption rate;
- For a mineral layer of 1.7 cm of granite and 1.4 cm of marble, these two-layer materials have good three-point bending strengths respectively equal to 10.63 and 10.27 MPa, respectively.

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