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Effects of Thickness of a Mineral Layer of Granite and Marble on the Mechanical Properties of a Bilayer Material: Case of Granites

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present work is dedicated to the study of the mechanical properties of a bilayer material. This material consists of a mortar substrate and a mineral layer of granite or 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 sand and the three point bending and compression tests are among other methods used for the evaluation of the mechanical characteristics of the specimens of 4 cm × 4 cm × 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 in three point 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

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materials. The best resistance in compression obtained with the samples having the thickness of 2 cm of the granite or 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.

Keywords: Granite; marble; bilayer material; mechanical resistance; water absorption.

NOMENCLATURES

LERGC	:	*Test and Research Laboratory in Civil Engineering*
UAC	:	*University of Abomey Calavi*
SONEB	:	*National Water Company of Benin*
NOCIBE	:	*New Cement Factory of Benin*
M_S	:	*Mass of sand (g)*
M_C	:	*Mass of cement (g)*
M_E	:	*Mass of water (g)*
R_f	:	*Maximum resistance to flexion* (MPa)
b	:	*Side of prism square section* (mm)
F_f	:	*Load applied in the middle of the prism at break (N)*
l	:	*Distance between supports (mm)*
Rc	:	*Compressive maximum resistance at 28 days* (MPa)
Fc	:	*Maximum load at break (N)*
W	:	*Absorption rate of water in (%)*
m_1	:	*The dry sample weight*
m_2	:	*The mass of saturated water sample*
N	:	*Number of test tubes*
$\overline{X}$	:	*Resistance average to flexion or compression in* (MPa) *or absorption rate of water in (%)*
X_i	:	*Resistance in flexion or compression in* (MPa) *or the water absorption rate in (%) of each test tube.*

1. INTRODUCTION

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

Among the most commonly used composite materials are two-layer materials. Cement / Granites bilayers are inexpensive and environmentally friendly materials that can be produced using relatively simple technology. They are mainly used in building for non-structural applications, as interior and exterior coatings, light partitions, tiles, square tiles, pavers, screeds, noise and fire barriers [1]. These materials offer good lightness, humidity, resistance to fire and shocks with interesting mechanical and thermal performances.

Many parameters affect the mechanical behavior of these bilayer structures:

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

The bibliographical reference relating to granitic bilayer materials suffers a lot of insufficiencies. Meanwhile, for some years, some work has been done on composite materials. Thus, the work of [2,3] focused on a 4-point flexural bending test of bilayer structures. The efforts at the interface between the layers of the composite materials have been analyzed by [4]. Romain Brault [5] studied the mechanical behavior of composite materials by volume correlation. The work of [6,7] relate respectively to mechanical and water characterization and experimental study of concrete with wood residues. In addition, the characterization of a mineral bilayer material produced by Toukourou et al. [8] has shown that at 20% of coarse sand, granitic bilayers offer good resistance in three points and in compression with a normal water absorption rate. Moreover, these results obtained by these authors are practically the same as those obtained with 30% coarse sand content. Furthermore, [9,10,11] have carried out works on the valorization of the wastes issued from granite and marble for the reformulation of bricks and tiles.

However, knowledge in the field of bilayer materials including granites is still limited and studies must be conducted to better know and improve the properties of these materials. The present study is therefore part of this logic and aims to study the influence of the thickness of the granite and marble mineral layer on the mechanical characteristics of such materials.

2. MATERIALS AND METHODS

2.1 Equipment

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

2.1.1 Sand

The sand used in this work comes from the region of Agamè, commune of Bonou; region located in the south of Benin, in the department of Ouémé. This sand, washed with tap water, was dried in an oven at 105°C until stabilization of the mass and then sieved in two different granular classes: Medium sand and coarse sand composed of grains, respectively with the dimensions ranging from 0.4 mm to 2 mm and from 2 mm to 6.3 mm. The sand used for the preparation of the substrate is composed of 30% of coarse sand and 70% of medium sand [8].

2.1.2 Cement

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

2.1.3 Granites

Granites used are crushed granite and marble respectively from the town of Zangnanado and Abomey, two regions of the southern Benin located in the department of Zou (Fig. 1).

2.1.4 Water

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

2.2 Methods

In order to carry out the mechanical tests, the parallelepiped shaped samples were made after having characterized the sand.

2.2.1 Sand physical tests

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

- Particle size analysis
- Equivalent of sand
- Actual pre-dried density (specific weight)
- Bulk density
- Water content

2.2.2 Samples preparation

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

$$\frac{\mathrm{M_C}}{\mathrm{M_S}} = \frac{1}{3} \tag{1}$$

$$\frac{\mathrm{M_E}}{\mathrm{M_C}} = \frac{1}{2} \tag{2}$$

After this step, the granite coating was placed so as to have a final bilayer sample of 4 cm thick (Fig. 2). Once the bilayer was obtained, it was immersed in water for 28 days. After 28 days, the sample was taken out of water and was sanded (Fig. 3). The 3 point bending and compression tests were carried out after 28 days.

2.2.3 The bending tests

The press used for our tests is a hydraulic press with digital display (Fig. 4). The test piece is centered along its length while presenting the face of the mineral layer to the effort. Then, a normal force is applied to this face and the value of the maximum load at break is noted after each test. The flexural strength of the specimens was determined by the relationship established by Bailon and Dorlot [12]:

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

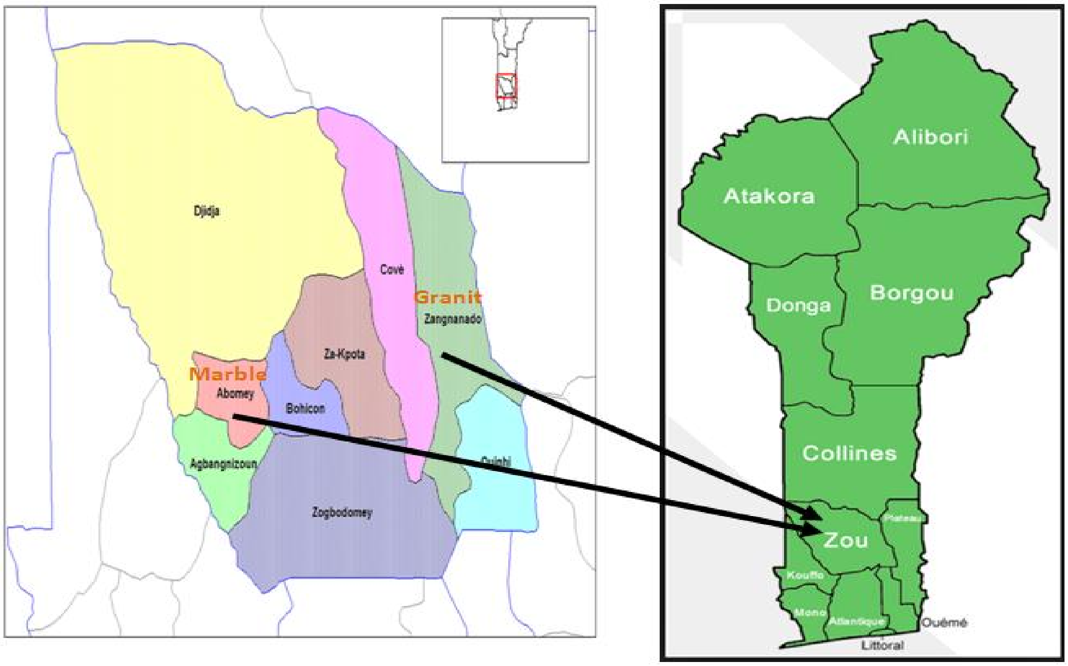

Fig. 1. Geographical locations of rock sampling sites

Fig. 2. Coatings laying

Fig. 3. Sanding operation

2.2.4 Compression test

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

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

2.2.5 The bilayer water absorption test

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

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

Fig. 4. The bending and compression testing equipment

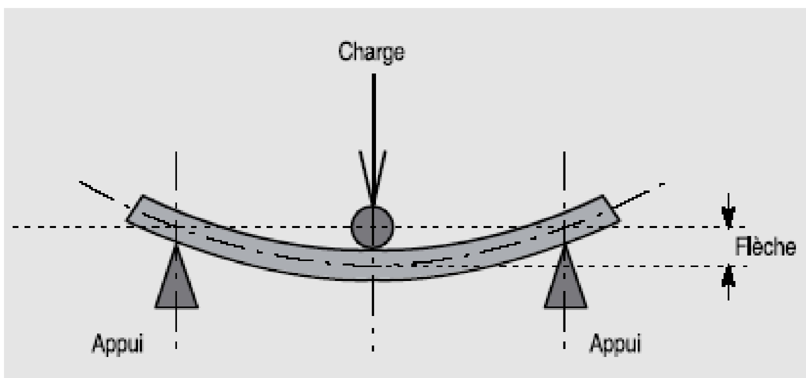

Fig. 5. The three-point bend test setup on the test specimens

2.2.6 The assessment of uncertainties

The standard deviation was determined from the following formula:

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

The uncertainty was deduced from the following relation:

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

3. RESULTS AND DISCUSSION

3.1 The Influence of the Thickness of the Granite Layer and Marble on the 3 Point Flexural Strength

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

In addition, we note that these curves first decrease with the thicknesses (0.8 cm and 1.1 cm) of the marble and granite layer and then oscillate as the thickness of the mineral layer increases. The decrease followed by growth could be explained respectively by an excess of binder in the coating causing the effective nonparticipation of the granites and a deficiency of binder to coat these granites which represent one of the factors of the resistance of the bilayer material. Such behavior of the samples is similar to that of bilayer materials [8], fragile materials [12].

3.2 Effects of Granite Layer and Marble Thickness on the Compressive Strength at 28 Days

The results of the 28-day compressive strengths of the different samples are given in Tables 3 and 4. Fig. 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.

Table 1. The summary of the bending test results of granite bilayers

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	

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	
1.1	8	0.43	5.38	
1.4	10.27	0.45	4.38	5.66
1.7	9.37	0.74	7.90	
2	9.4	0.79	8.40	

Table 3. Summary of the 28-day compression test results for granite bilayers

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

Table 4. Summary of the 28-day compression test results for marble bilayers

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

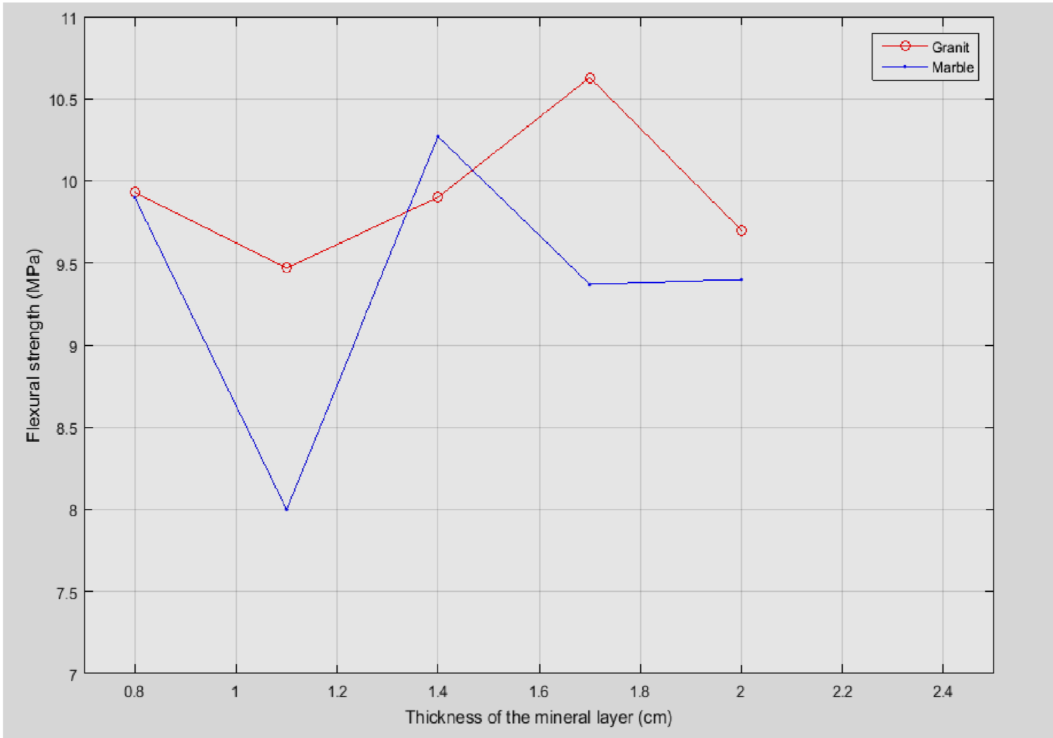

Fig. 6. The influence of granite layer and marble thickness on the bending strength after 28 days

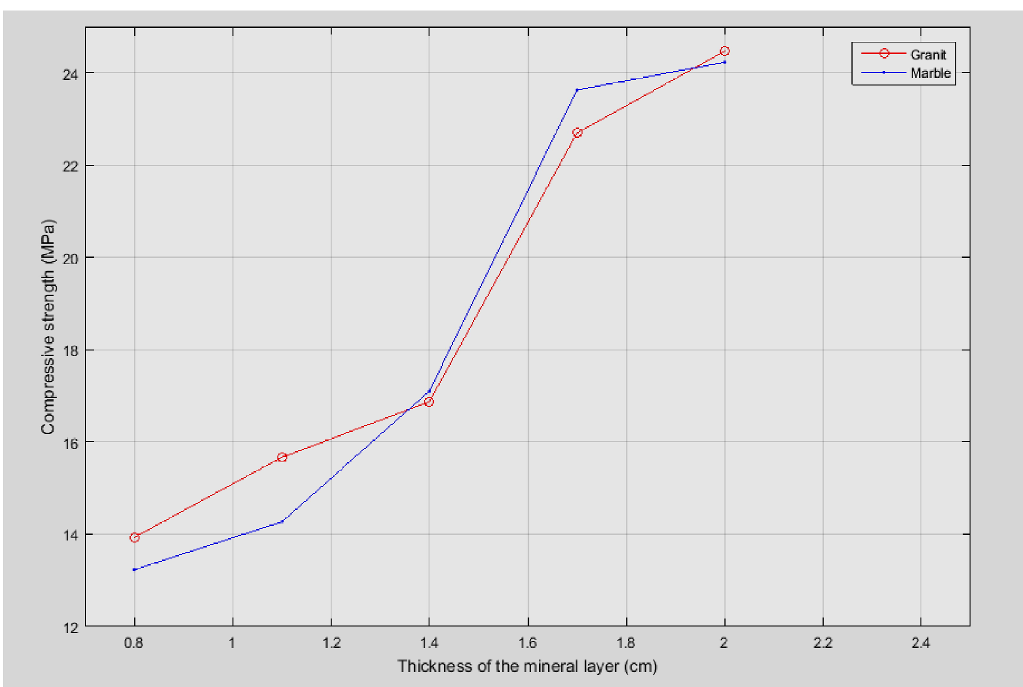

Fig. 7. The influence of granite and marble layer thickness on the 28-day compressive strength

3.3 The Influence 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 were obtained from the results 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%. Those obtained figures are weak according to the british norm BS 5628 part 1. Such behavior of the samples is similar to that of micro concrete tiles [13].

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 (%)	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	

Table 6. Summary of water absorption results of marble bilayers

Thickness of the mineral layer (cm)	Absorption rate of water (%)	Spread type (%)	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	

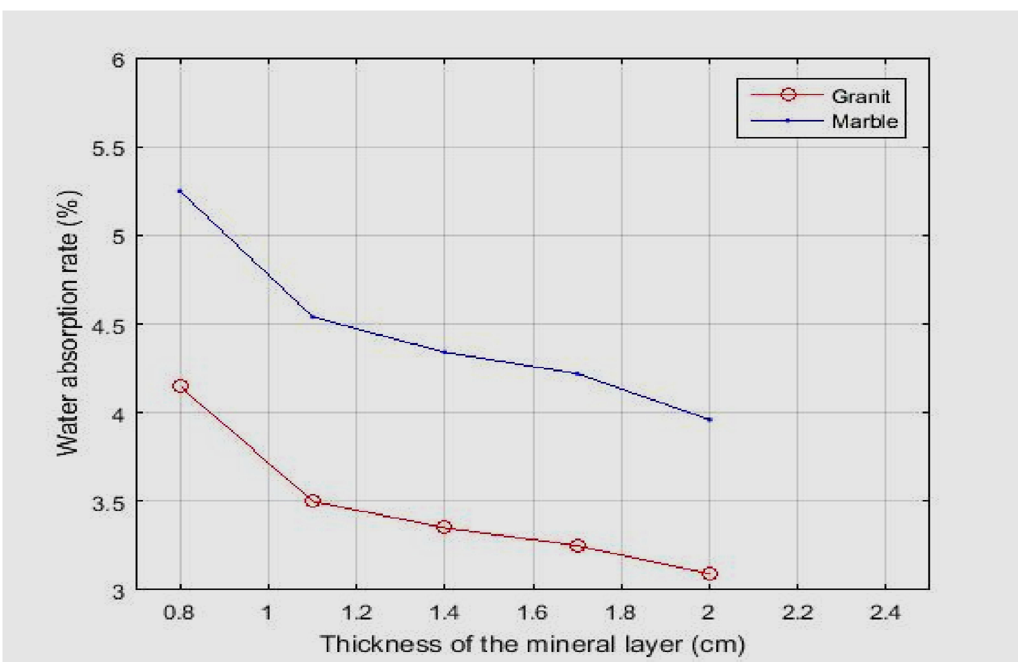

Fig. 8. The influence of granite and marble layer thickness on the water rate

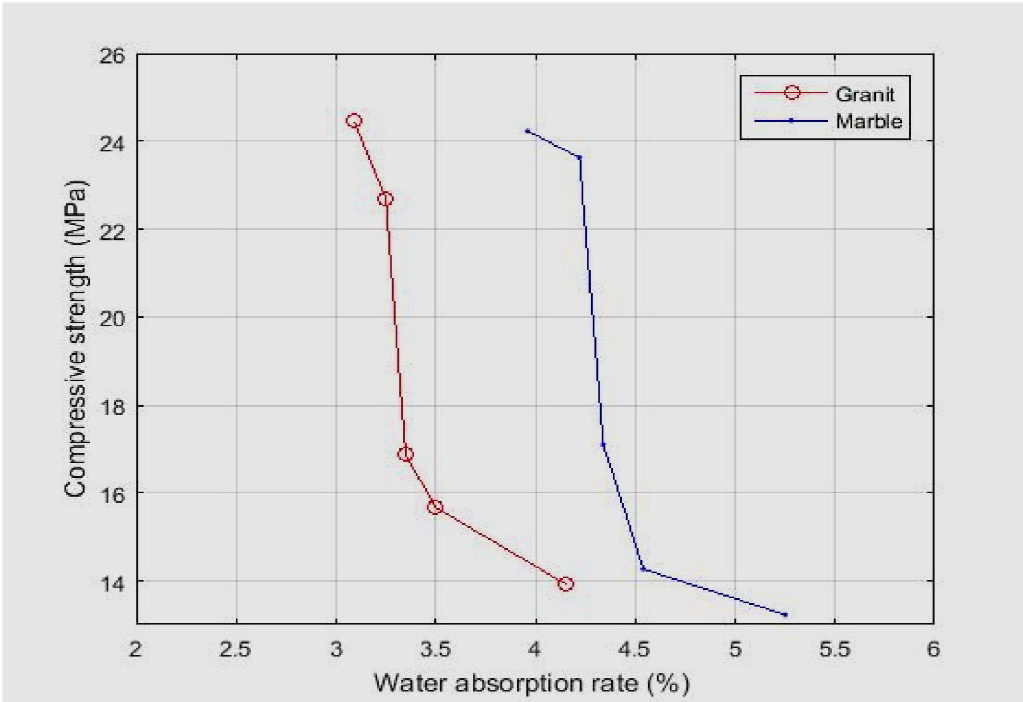

Fig. 9. Effects of compressive strength on the open porosity of granite bilayers

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 or 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.

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 was the valorization of local building materials in Benin with a view of improving their performance in terms of thermo-mechanical characteristics and then to facilitate their choice as efficient flooring materials, 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 bilayer materials have good three-point bending strengths equal to 10.63 and 10.27 MPa, respectively.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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