

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**

4
5 **Original Research Articles**
6
7

8 **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 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.

9
10 *Keywords: Granite, marble, bilayer material, mechanical resistance, water absorption.*

11
12 **NOMENCLATURE**

13
14 LERGC : Test and Research Laboratory in Civil Engineering

15 UAC : University of Abomey Calavi

16 SONEB : National Water Company of Benin

17 NOCIBE: New Cement Factory of Benin

18 M_S : Mass of sand (g)

19 M_C : Mass of cement (g)

20 M_E : Mass of water (g)

21 R_f : Maximum resistance to flexion (MPa)

22 b : Side of prism square section (mm)

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

24 l : Distance between supports (mm)

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

26 F_c : Maximum load at break (N)

27 W : Absorption rate of water in (%)

28 m_1 : The dry sample weight

29 m_2 : The mass of **saturated water sample**

30 N : Number of test tubes

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

32 X_i : Resistance in flexion or compression in (MPa) or the water absorption rate in (%) of each
33 test tube.

34

35 1. INTRODUCTION

36

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

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

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

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

54 The bibliographical reference relating to granitic bilayer materials suffers a lot of
55 insufficiencies. Meanwhile, for some years, some work has been done on composite
56 materials. Thus, the work of (Pouteau, Chabot and De Larrard, 2002) and (Pouteau, 2004)
57 focused on a 4-point flexural bending test of bilayer structures. The efforts at the interface
58 between the layers of the composite materials have been analyzed by (Chabot A, 1997).
59 (Romain Brault, 2013) studied the mechanical behavior of composite materials by volume
60 correlation. The work of (Taoukil, Albouardi, Ajzoui and Ezbakhe, 2011) and (Aouadja,
61 Mimoune, and Laquerbe, 1995) relate respectively to mechanical and water characterization
62 and experimental study of concrete with wood residues. In addition, the characterization of a
63 mineral bilayer material produced by (Toukourou, Fagla, Prodjintono and Bello, 2015) has
64 shown that at 20% of coarse sand, granitic bilayers offer good resistance in three points and
65 in compression with a normal water absorption rate. Moreover, these results obtained by
66 these authors are practically the same as those obtained with 30% coarse sand content.
67 Furthermore, (Dhanapandian, Manoharan and Gnanavel, 2008); (Torres, Fernandes,
68 Agathopoulos, Tulyaganov and Ferreira, 2004) and (Torres, Manjate, Quaresma, Fernandes
69 and Ferreira, 2007) have carried out works on the valorization of the wastes issued from
70 granite and marble for the reformulation of bricks and tiles.

71

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

77

78 2. MATERIAL AND METHODS

79

80 2.1. Equipment

81

82 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.

83

84 **2.1.1 Sand**

85 The sand used in this work comes from the region of Agamè, commune of Bonou;
86 region located in the south of Benin, in the department of Ouémé. This sand, washed with
87 tap water, was dried in an oven at 105 ° C until stabilization of the mass and then sieved in
88 two different granular classes: Medium sand and coarse sand composed of grains,
89 respectively with the dimensions ranging from 0.4 mm to 2 mm and from 2 mm to 6.3 mm.
90 The sand used for the preparation of the substrate is composed of 30% of coarse sand and
91 70% of medium sand (Toukourou, Fagla, Prodjinonto and Bello, 2015).

92

93 **2.1.2 Cement**

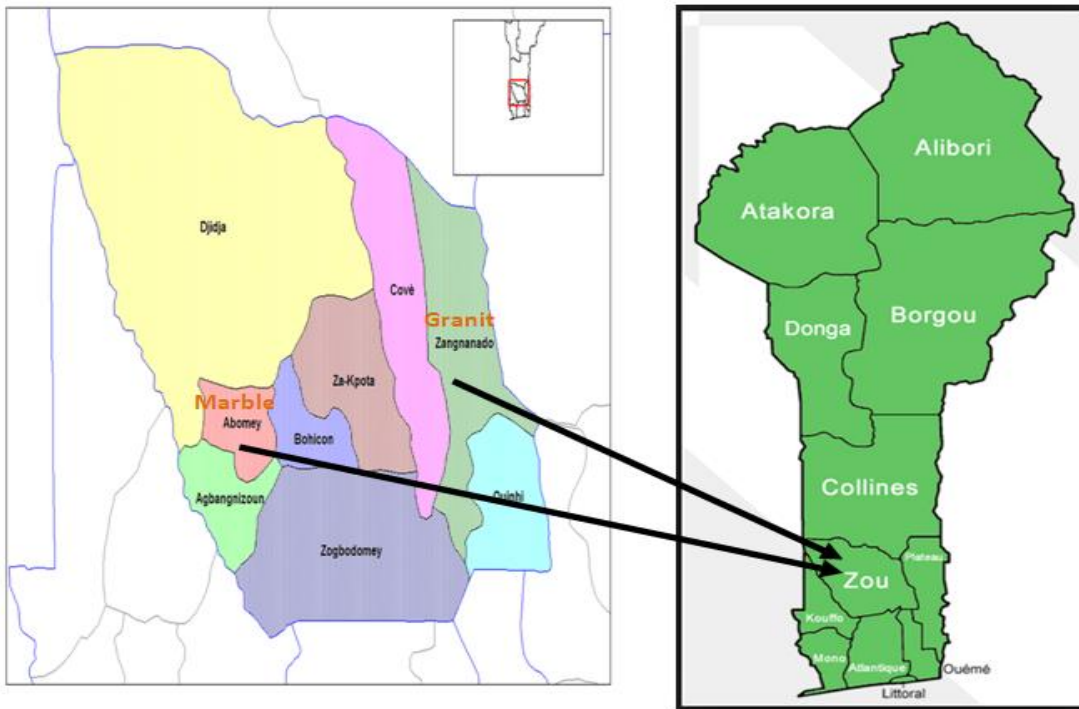
94 **Portland cement** CPJ 35 of type CEM II/B-LL.42,5R of the NOCIBE is used because
95 of its relatively fast setting.

96

97 **2.1.3 Granites**

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

101



102

103

104

105

106

107

108

109

110

111

FIG. 1 Geographical locations of rock sampling sites

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

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

114

115 **2.2.1 Sand Physical tests**

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

118 - Particle size analysis

119 - Equivalent of sand

120 - Actual pre-dried density (specific weight)

121 - Bulk density

122 - Water content

123 **2.2.2 Samples preparation**

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

126
$$\frac{M_C}{M_S} = \frac{1}{3} \quad (1)$$

127
$$\frac{M_E}{M_C} = \frac{1}{2} \quad (2)$$

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



132 **FIG. 2: Coatings laying**



133 **FIG. 3: Sanding operation**

134

135

135 **2.2.3 The bending tests**

136

137

138

139

140

141

142

143

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 (2000):

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



FIG. 4 The bending and compression testing equipment

144

145

146

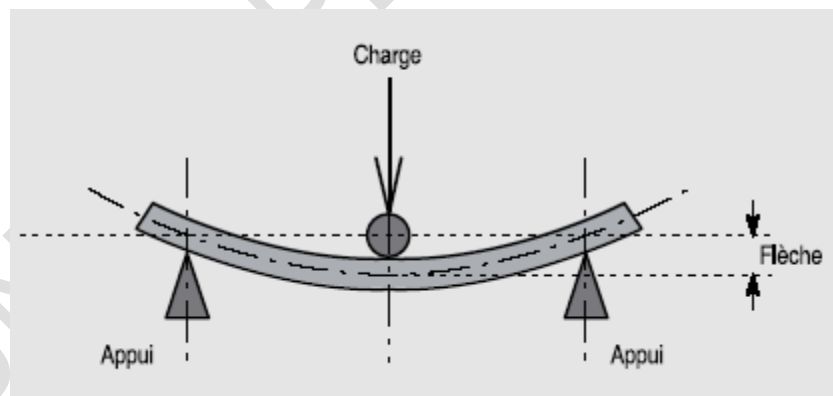


FIG. 5 The three-point bend test setup on the test specimens

147

148

149

150

2.2.4 Compression test

151

152

153

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:

154

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

155 **2.2.5 The bilayer water absorption test**

156

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

161

162
$$W (\%) = \frac{m_2 - m_1}{m_1} \times 100 \quad (5)$$

163

164 **2.2.6 The assessment of uncertainties**

165 The standard deviation was determined from the following formula:

166
$$E = \sqrt{\frac{1}{N} \sum (\bar{x} - x_i)^2} \quad (6)$$

167 The uncertainty was deduced from the following relation:

168
$$I(\%) = \frac{E}{E_{\text{moyenne}}} \times 100 \quad (7)$$

169

170 **3. RESULTS AND DISCUSSION**

171

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

174

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

182

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

189

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

191

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	

192

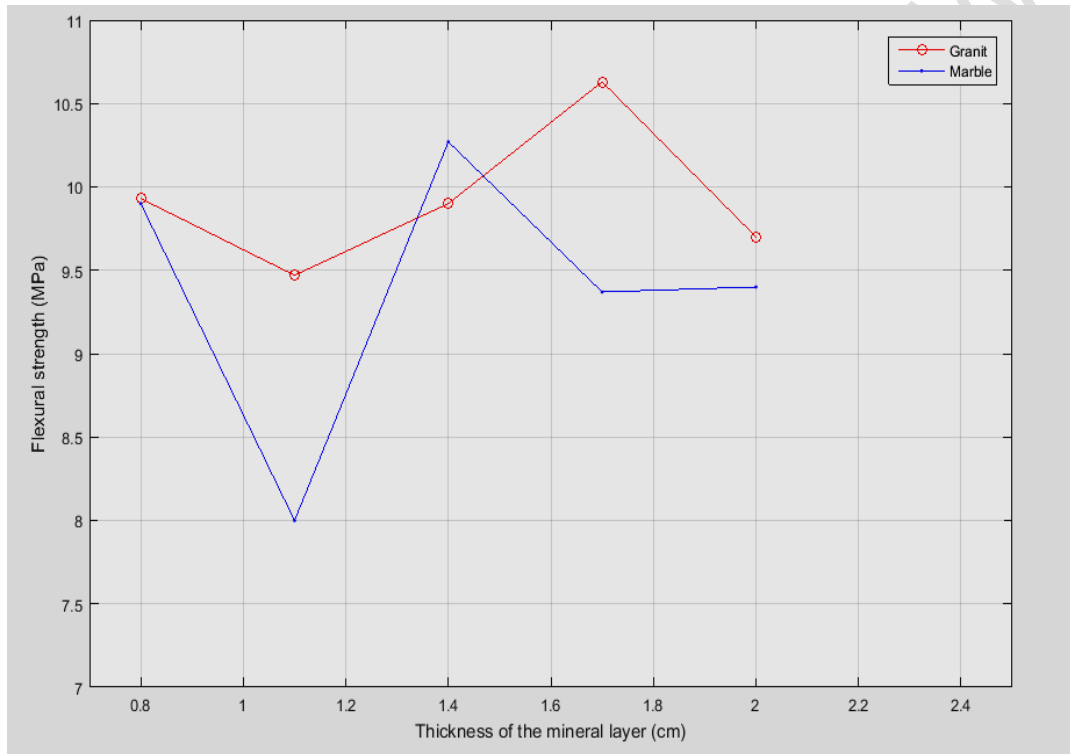
193

194
195
196

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	

197



198
199
200
201
202

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

203
204

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

205
206
207
208
209

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.

210
211
212
213
214

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

215 of the mineral layer a different behavior in flexion than in compression. In addition, these
 216 materials are rigid in compression than in flexion.

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

218

Thickness of the mineral layer (cm)	Compressive strength (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	

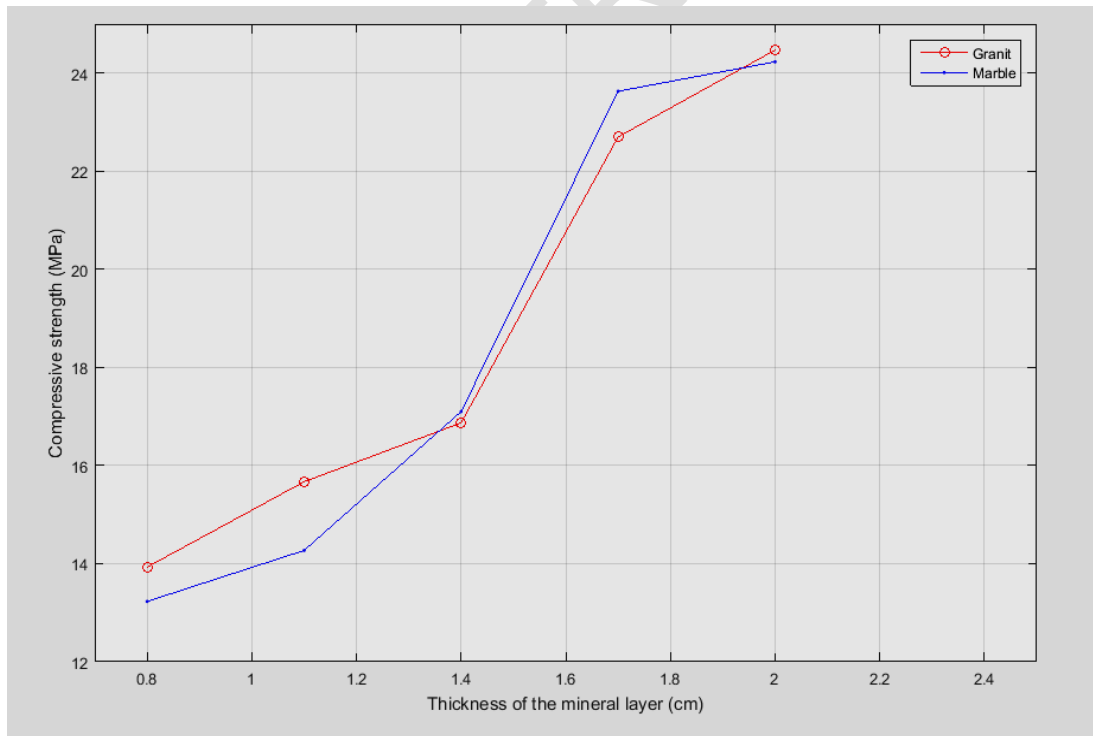
219 **TABLE 4 Summary of the 28-day compression test results for marble bilayers**

220

Thickness of the mineral layer (cm)	Compressive strength (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	

221

222



223

224

225

226

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

227 **3.3 The influence of the granite and marble layer thickness on the water**
 228 **absorption rate of bilayers**

229
 230 Fig 8 gives an overview of the variation in the rate of water absorption by total
 231 immersion of the specimens as a function of the thickness of the layer of granite and marble.
 232 These curves were obtained from the results in Tables 5 and 6. It can be seen that the water
 233 absorption rate of the various samples decreases as the thickness of the mineral layer
 234 increases and varies between 3.09% and 5.25%. Those obtained figures are weak
 235 according to the british norm BS 5628 part 1. Such behavior of the samples is similar to that
 236 of micro concrete tiles (BAGAN GC, 2002).

237
 238 This decrease is all the stronger as the thickness of the mineral layer is important.
 239 This observation can be justified by a low porosity of aggregates including rocks used on the
 240 one hand or by a high level of binder in the mixture of the mineral layer, thus making the
 241 bilayer material tight on the other hand.

242 **TABLE 5 Summary of water Absorption results for granite bilayers**
 243
 244

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	

245 **TABLE 6 Summary of water absorption results of marble bilayers**
 246
 247

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	

248

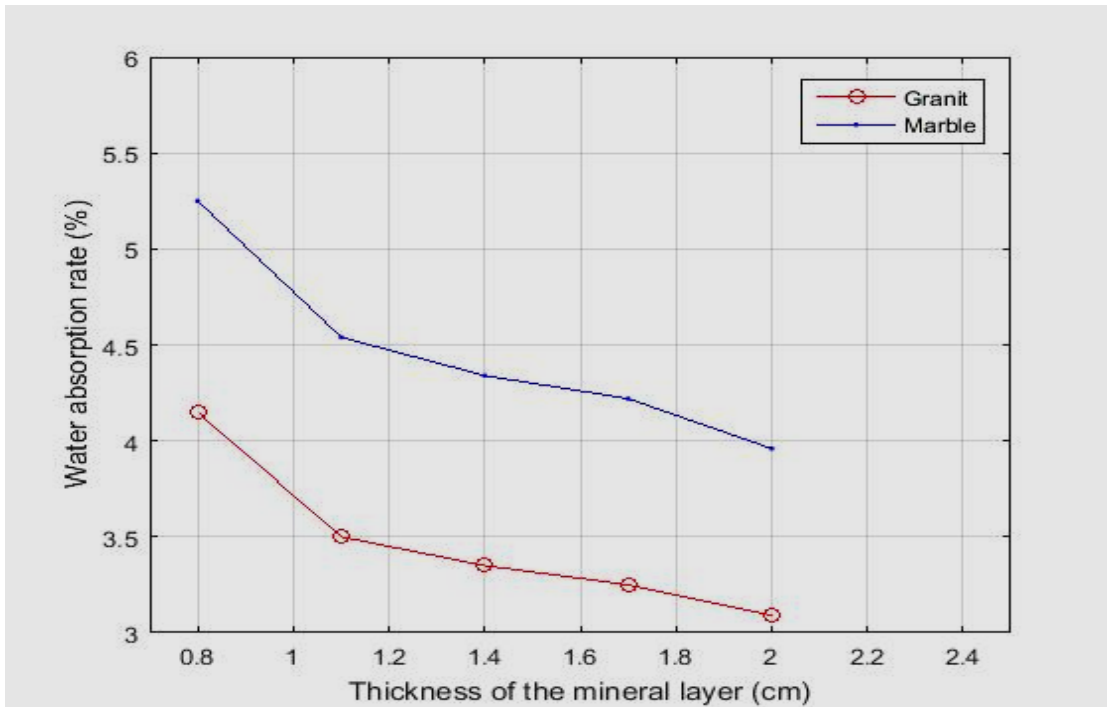


FIG. 8 The influence of granite and marble layer thickness on the water rate

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.

249
250
251
252
253
254
255
256
257
258
259
260
261
262

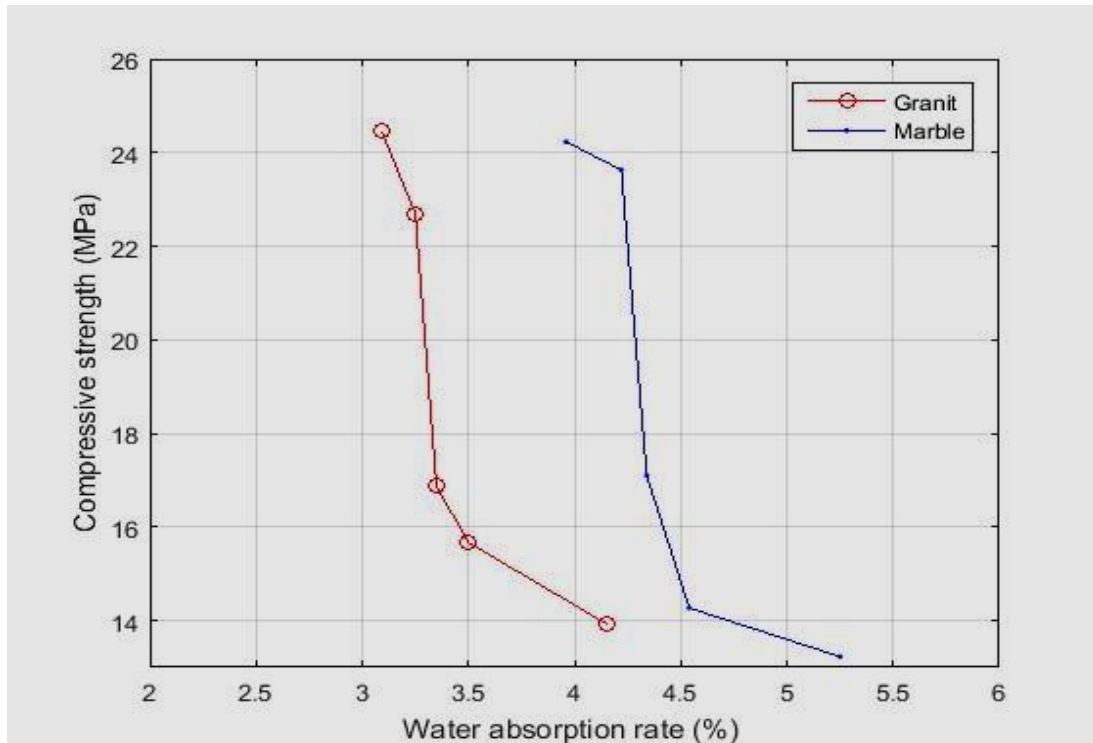


FIG. 9 Effects of compressive strength on the open porosity of granite bilayers

263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287

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.

REFERENCES

Moslemi AA. Emerging Technologies in Mineral Bonded Wood and Fiber Composites. Advanced Performance Materials. 1999; 6: 161-179.

- 288 Pouteau B, Chabot A, De Larrard F. Laboratory study of concrete / bituminous material
289 bonding, *Materials*, Towers. 2002; 21-25.
- 290 Pouteau B. Mechanical durability of white-on-black bonding in pavements, Thesis of Ecole
291 Centrale de Nantes; 2004.
- 292 Chabot A. Analysis of the forces at the interface between the layers of composite materials
293 using Multi-particulate Multilayer Materials Modeling (M4). Thesis of the National School
294 of Bridges and Roads; June 1997.
- 295 Toukourou C, Fagla ZB, Prodjinonto V, Bello S. Study and Characterization of a Mineral
296 Belayed Material: Case Tiles Coated Granites. *International Journal of Applied Science
297 and Technology*. 2015; 5-6.
- 298 Romain Brault. Study of the mechanical behavior of composite materials by volume
299 correlation: Application to the analysis of transverse shear effects. Thesis of the doctoral
300 school Mechanical engineering, mechanics of materials of the University of Toulous;
301 October 2013.,.
- 302 Taoukil DA, Albouardi T, Ajzoul H, Ezbakhe. Mechanical and hydric characterization of
303 lightweight concrete with wood residues, *International Review of Heliotechnics*. . 2011;
304 43: 1-7.
- 305 Aouadja FZ, Mimoune M, Laquerbe M. Experimental study on wood-based concretes,
306 *Algeria-Equipment Review*. 1995; 24-27.
- 307 Bailon JP. Dorlot JM. *Materials-International Polytechnic Presses, Ecole Nationale
308 Polytechnique -Montreal*; 2000.
- 309 Brazier JF. Characterization of the tolerance to damage and durability of glass-cement
310 composites by flexural tests with loading-unloading cycles - PhD thesis from Claude
311 Bernard University of Lyon; 1991.
- 312 Amey KB, Neglo V, Samah OD, Kouto AY, P'kla A. Experimental study of the formulation of
313 mortar based on silty sand from Togo and binder of plastic bags type "voltic". *Africa
314 Science*. 2014; 10 (3): 48-58.
- 315 Alawar A, Hamed M, Al-Kaabi k. Characterization of treated date palm tree fiber as
316 composite reinforcement, *Composites Part B: Engineering*. 2009;40: 601-606.
- 317 Bagan G, Toukourou C. Study of the porosity of mortar or micro concrete tiles vibrated by
318 water absorption. *J. Rech . Sci . Univ. Benin (Togo)*, 2001.
- 319 British Standards Institution. *Code of practice for use of masonry. Part 3. Materials
320 and components, design and workmanship (formerly CP 121: Part 1). BS 5628: Part 3:
321 1985. BSI. London, England, 1985.*
- 322 Dhanapandian S, Manoharan C, Gnanavel B. Reformulation of bricks with addition of granite
323 and marble wastes from sawing operations mechanical analysis. *Annamalai University
324 Science Journal*. 2008; 44: 51-54.

- 325 Torres P, Fernandes HR, Agathopoulos S, Tulyaganov DV, Ferreira JMF. Incorporation of
326 granite cutting sludge in industrial porcelain tile formulations. *Journal of the European*
327 *Ceramic Society*. 2004; 24: 3177-3185.
- 328 Torres P, Manjate R, Quaresma S, Fernandes H, Ferreira J. Development of ceramic floor
329 tile compositions based on quartzite and granite sludges. *Journal of the European Ceramic*
330 *Society*. 2007; 27: 4649–4655.

UNDER PEER REVIEW