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Research article

Physico-Mechanical Characteristics of Dawala Bidzar Marbles (North Region Cameroon) and Their Experimentation in Epoxy Terrazzo Tiles Production

Collins Achille Mballa[a], Nguo Sylvestre Kanouo[a,*]

[a]*Department of Mining Engineering and Mineral Processing, National Advanced School of Mines and Petroleum Industries, University of Maroua, Cameroon.*

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* Corresponding author:

Nguo Sylvestre Kanouo
E-mail: sylvestrekanouo@yahoo.fr

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A B S T R A C T

This study determines the physical and mechanical properties of marbles (pink, white, greyish, pinkish white or greyish white) from Bidzar Dawala village, used these values for their characterization as raw materials for epoxy terrazzo tiles processing, processes epoxy terrazzo tiles, and evaluate their quality. Within the physical properties: porosity varies from 0.78 to 0.96 %; water absorption varies from 0.18 to 0.25 %; durability ranges from 0.38 to 0.50 %; specific gravity ranges from 2.68 to 2.73 g/cm³; and hardness is 3. The studied marbles are compact and less porous type; with an excellent to satisfactory SG, and a low to very low water absorption. The physical properties fall within the standard values of marbles used to process terrazzo tiles. The compression and flexural strengths vary from 75.0 to 78.5 MPa, and from 16.5 to 18.1 MPa, respectively. These strength values are compatible with that of strong stone and standard values of rocks used in terrazzo tiles processing. The water absorption for processed epoxy terrazzo tiles is up to 0.409 %; and the compressive strength varying from 30.3 to 32.81 MPa; classify them as moderate compressive strength tiles; used in both interior and exterior surface.

1. INTRODUCTION

Marbles are mainly non-foliated regional and contact metamorphic rocks formed from recrystallisation of some sedimentary rocks; such as limestones and dolostones [1]. Theses rocks are used as a raw material in cement and lime production; in road construction and bricks processing, as aggregates in concretes, as ornamental stone, in paper, ceramic, tile, and paint industries [2-9]. In tiles industries, marbles are used to produce ceramic tiles (marble waste partially replacing clay), terrazzo tiles (cement or epoxy-based) or polished for flooring, wall coverings, countertops, building facades, and decorative elements [4, 7, 10]. In terrazzo tiles in particular, marble forms embedding of smaller to coarse-grained size aggregates bind with epoxy resin or cement, and polished to produce a smooth, uniformly textured surface [10, 11]. Factors governing the production of terrazzo tiles include: (1) the nature and characteristics of the used aggregates (rock fragments or other material: quartz, sand, mother-of-pearl, recycled tile particles, porcelain or mirror chips); (2) the nature and properties of binder, and (3) tile's processing equipment, steps, production cost and marketing [10]. Two types of rock fragments "rock-aggregates" (granite or marble) with different characteristics are frequently used to process terrazzo tiles [10]. As the nature and characteristics of the used rock-aggregates also play important role during the processing of terrazzo tiles, It is therefore necessary to characterize these aggregates in other to see if they are suitable for terrazzo tiles production. This question can therefore be asked "Which are the main properties that make a rock to be used in terrazzo tiles production?" Marble for example, is white in color (when pure), or colored (when impure); It is generally not structured; but, rarely banded, zoned, or encloses folded veins or veinlets, which might be syn or post metamorphism [1]. The color and the structure of a marble might be interesting for its use in terrazzo tiles production. Other characteristics interesting for marble used in terrazzo tiles production include the durability, the hardness, the density, porosity, water absorption, specific gravity, the abrasion resistance, and compressive and flexural strength [10]. Determine these characteristics for an uncharacterized marble helps to verify and confirm if it is a suitable raw material in terrazzo tiles production.

Cameroon marble deposits found in the North Region, are partially mined and used as raw materials in cement production, polished stone tiles, and also to produce industrial lime and pharmaceutic $CaCO_3$. These deposits crop out in Biou, Bidzar (Bidzar Tela and Bidzar Dawala), and Batao, three villages found in the north of Figuil Sub-Division in the Mayo-Louti Division. These marble deposits are estimated at about 2.5 million tons; with just a limited portion industrially mined by CIMENCAM and ROCCAR. CIMENCAM mines and uses the Bidzar-Tela marbles for clinker and blended cement production [6, 8]. ROCCAR mines those in Biou for the production of industrial lime, pharmaceutic $CaCO_3$ and polished stone tiles. The Batao marble occurrences and those of Bidzar-Dawala are mined, manually worked and sold by the locale population. Wastes from the mines are partly used by local council in the opening and maintenance of secondary roads [5]. Some research works have been published on part of the North Cameroon marble deposits; notably, that of Bidzar-Tela [3, 5, 6, 8, 9], since the geologic mapping of Garoua-East [12], figuring the north of the Figuil Sub-Division (were the marbles deposits are found). Wouatong et al., [3] studied the geology and determined the physico-mechanical properties of marbles mined in the Bidzar-Tale CIMENCAM quarry. Lyonga et al., [5] characterized marble tailings from the same Bidzar-Tale CIMENCAM quarry for their potential use in civil engineering. Hamadou et al., [6] characterized siliceous marbles from the Bidzar-Tale CIMENCAM quarry and cement kiln dust in CIMENCAM Figuil, and used these two raw materials for an experimental processing of blended cements. Djifack et al., [8] characterized marbles and meta-schists from the Bidzar-Tale CIMENCAM quarry and used these two rocks types for an experimental processing of the blended cements. Ntouala et al., [9] determined the mineralogical, geochemical, and physico-mechanical features of termite mound materials found in Bidzar and combined them with Bidzar marble powder additive to experimentally produce fired bricks. Sababa et al., [13] studied the petrology of weathering materials developed on granites cutting across marble deposits in Biou area. Up to date research work has not yet been carried out and published on the characteristics North Cameroon marbles as raw materials for the processing terrazzo tiles. They have not yet been used to process terrazzo tiles; considered as easy-maintenance, high strength, water and heat resistant, excellent chemical resistance, slip resistance, fast curing durable and environmentally friendly (cf. [10]). The physical and mechanical properties of Bidzar-Dawala marbles leading to their use to process epoxy-based terrazzo tiles are not known. These rocks have not yet been used to process epoxy-based terrazzo tiles.

In this paper, we: (1) determine the physical and mechanical properties of the Bidzar-Dawala marbles (North Region Cameroon) as a raw material for the processing of epoxy-based terrazzo tiles; (2) process epoxy-based terrazzo tiles with the characterized marbles; and (3) determined the properties of the processed epoxy-based terrazzo tiles in comparison with standard values and values published for other terrazzo tiles in other to verify the suitability.

2. MATERIALS AND METHODS

This part presents materials and methods used for sampling and experimental work. Experimental work includes the determination of the physical and mechanical properties of marble samples, processing of the terrazzo tiles, and the determination of the physical and mechanical properties of processed tiles.

2.1. Sampling

Each located marble outcrop in Bidzar Dawala (Figure 1) was macroscopically described, the geographic coordinates recorded, before the collection of large fresh boulder size fragments with the aid of a sledgehammer, an iron rode, a spade, and a pickaxe.

Fig. 1. Part of the Bidzar Dawala marble outcrops.

Each collected fragment was acid tested, size reduced (Figure 2), numbered, and packaged before transportation to the laboratory for sample preparation. A total of nine packaged samples were collected for a ratio of one package /sampling point (100 kg/package) with the recorded geographic coordinates. Collected samples were sent to the Energy Laboratory of Nigeria for the determination of the physical and mechanical properties as a raw material for terrazzo tile processing.

Fig. 2. White marble samples.

2.2. Experimental works

The experimental works carried out include the determination of the physical properties (the porosity, water absorption, durability, hardness, specific gravity, and bull density) and mechanical properties (compression and flexural strength) of the sampled Bidzar Dawala marble. These also include the processing of terrazzo tiles and quality tests (water absorption and compression strength) on processed tiles.

Marble samples were prepared and the porosity determined according to the ISRM [14] standard. The volume (V) of each prepared sample was determined via Archimedes principal. This sample was immersed in water for 48 hours on till saturation, removed and weighed (for a corresponding weight: Ww). The weighed sample was oven-dried at 105 ºC for 24 hours, removed and put to cool for 30 minutes in a desiccator. The cooled sample was weighed and the corresponding weight (Wd) recorded. The porosity (P) was calculated via formula (1):

$$P = \frac{Ww - Wd}{V} \times 100 \quad (1)$$

With Ww: The weight (g) of the removed water-immersed sample, Wd: The weight (g) of the oven-dried sample, V: The volume (cm^3) of the sample before water immersion, and P: The porosity of the sample (%).

The procedure used to carry out water absorption test on prepared 50 x50x50 mm size marble sample is that of ASTMC97M [15] standard. Each prepared sample was immersed in water for 24 hours, removed, wiped, weighed and the weight (W_{2w}) recorded. This sample was oven-dried at 212 ^{o}C for 24 hours, removed, cooled, weighed, and the corresponding weight (W_{2d}) recorded. The value of water absorption (Wab) was determined with this formula (2):

$$W_{ab} = \left(\frac{W_{2w}-W_{2d}}{W_{2d}}\right) \times 100 \qquad (2)$$

With W_{2w}: The weight (g) of marble sample after water immersion, W_{2d}: The weight(g) of the same marble sample removed from water immersed and oven-dried, and Wab: Water absorption (%). Excepting the different in sample types, the procedure used to carry out water absorption test on processed tiles is similar the one used for marble sample. The used samples are processed terrazzo tile's specimens with measured dimensions.

The determination of marble hardness was done according to the ASTMC241 [16] standard. Each prepared marble sample was weighed (with the corresponding weight W_2 recorded) and its dimension measured and recorded. Abrasive test was performed of the weighed sample with the aid of a rotative wheel; with the weight loss of each sample recorded. The abrasion resistance was calculated based on the weight loss or change in diameter.

Marble samples durability (freeze- thaw loss$^{0}/_{0}$) was determined according to the ASTMC666 [17] standard. Each marble sample with a volume of 7.5 cm^3, undergone a repeated cycle of freezing and thawing in water, and in the air. Freezing and thawing effects (presence of cracks, spalling or other damage) on the sample were visualized with the aid of a binocular magnifying glass.

The determination of the specific gravity of the marble samples was done according to the ASTMC97M [15] standard. Prepared 50 mm size marble fragments were oven-dried at 105 ^{o}C for 24 hours, allowed to cool, and weighed (the corresponding weight: W1d recorded). The oven-dried samples were immersed in water on till saturation for 48 hours and weighed (W1w). The rock sample still in a soaked condition was weighed (Ws) while suspended in water. The obtained weights were used to calculate the specific gravity (SG) with formula (3):

$$SG = \frac{W1d}{W1w-Ws} \qquad (3)$$

With, W1d: The weight of the oven-dried marble sample (g), W1w: The weight of the immersed marble sample, Ws: The weight of the suspended sample (g), and SG: The specific gravity (g/cm^3).

The value of each marble sample density (Dm) was obtained by multiplying the obtained value of the specific gravity for the same sample with water density (Dw). The density of the sample was calculated with formula (4):

$$Dm = SG\ X Dw \qquad (4)$$

With, SG: The specific gravity of the marble sample, Dw: The water density, and Dm: The density of marble sample with the corresponding SG.

The compression test carried out on the marble samples was done according to the ASTMC170 [18] standard. 5 cm size marble samples were loaded gradually, one at a time, on the base of a Universal Testing Machine (UTM). Loading continued until first crack appeared in the marble's sample indicating beginning of failure. The same procedure was used to carry out compression strength test on processed tiles. The applied force until failure (F) was used to calculate the compression, strength with this formula (5):

$$Cs = \frac{F}{S} \qquad (5)$$

With F: The force applied (KN) by the compression test machine on the marble sample until a crack appear, S: The surface area (cm^2) on the marble sample on which the loading force was applied, and Cs: The compression strength (MPa).

Excepting the different in sample types, the procedure used to carry out the compression strength test on processed tiles is similar the one used for marble sample. The used samples are processed terrazzo tile's specimens with measured dimensions.

Flexural strength carried out on the marble samples was conducted according to the ASTMC880-25 [19]. Marble samples with 100x100x400 mm dimension were loaded and supported at ends by steel rollers of about 38 mm. The pressure at which the sample breaks is taken as the fracturing modulus. The flexural was calculated with formula (6):

$$Fs = \frac{3xPxa}{bxd^{2}} \quad (6)$$

With, P: Load applied at rupture (KN), a: The distance between the line of fractures and nearest support (mm), b: The width of the sample (mm), d: The failure point depth of the sample in (mm), and Fs: The flexural strength (MPa).

The procedure used to process the epoxy-based terrazzo tiles specimens is similar to the one presented in Karam and Tabbara [20]. This includes sample preparation and the formulation of the tile's specimens. After selection and cleaning of the mold, epoxy resin was mixed with hardener to obtain a uniform mixture (Figure 3). Pigment was added to the mixture to obtain a desired color, before the introduction of the marble aggregates and mixed, ensuring they were evenly distributed throughout the epoxy mixture (Figure 4). Filler powder was added to the mixture to enhance its stability and reduced shrinkage. The epoxy-resin-marble aggregate mixture was poured into a prepared mold, allowed to cure, and harden. The harden epoxy terrazzo tile specimen was demolded.

Fig. 3. Preparation of epoxy resin mixture during the processing of the tile.

Fig. 4. Placing and arrangement of marble's aggregates in a mold for tile processing.

3. RESULTS AND DISCUSSIONS

This part presents and discuses physical and mechanical tests results characterizing the studied Bidzar Dawala marble samples to be used as raw materials to process terrazzo tiles. It also presents and discusses water absorption and compression tests results for processed terrazzo tiles formulated with the characterized Bidzar Dawala marble samples.

3.1. Characteristics of Bidzar Dawala marbles

The porosity of the Bidzar Dawala marble samples (Table 1) varies from 0.78 to 0.96 %. The highest values are that of sample MB-04 (pinkish white marble: 0.96 %) and that of MB-02 (greyish white marble: 0.92 %). The lowest values are that of MB-01 (pink marble: 0.85 %), MB-05 (greyish marble: 0.81 %), and MB-03 (white marble: 0.78 %), respectively (Figure 5).

Table 1. Porosity, water absorption, specific gravity for the marbles.

Sample Number	Rock type (Color)	Porosity (%)	Water absorption (%)	Specific gravity (g/cm³)
MB-01	Pink marble	0.85	0.21	2.69
MB-02	Greyish white marble	0.92	0.24	2.70
MB-03	White marble	0.78	0.18	2.71
MB-04	Pinkish white marble	0.96	0.25	2.68
MB-05	Greyish marble	0.81	0.20	2.73

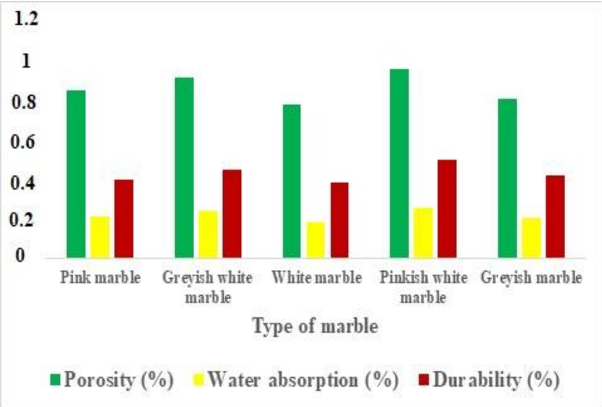

Fig. 5. Line graph showing the proportion porosity, water absorption, and durability in the Bidzar Dawala marbles.

This shows that some of the marble are relatively much porous than others. In a general point of view, the lowest porosity was obtained in white marble, which is considered as pure marble (c.f. [8]); whereas, the relatively high porosities were found in colored marble samples (considered as impure marbles: [21]). It is not easy at this point to relate the relatively high porosities in the impure marble to the present of impurities. According to Von Moos and de Quervain [22] rock porosity classification scheme, the porosity of the studied marbles (< 1.0 %) falls within that of compact type rock. These marbles can be considered as compact rock, probably suitable to be used to process terrazzo tiles or polished stone tiles. Marble deposits in Biou few kilometers to the studied marble deposits and belonging the same regional metamorphic marble context, are currently mined by ROCCAR, processed and sold as polished stone tiles. Data on the porosity of the Biou ROCCAR marbles are not available, which makes a local comparison, difficult. Never the less, the obtained porosities for Bidzar Dawala marble samples are less than that of Dawi marble (1.98 %), and that of Telmet marble (1.81 %) found in Eastern Desert (Egypt) industrially mined and processed for construction and decoration [23]; and those of marbles (≥ 0.91 to ≥ 0. 96 %) cropping in Wadi Allaqi (Southern Eastern desert, Egypt) studied by Shalaby et al. [24]; but greater than those of marbles (0.14 to 0.44 %) cropping Northwestern Pakistan [25]. The Bidzar Dawala marbles are therefore much compact and less porous than the Egyptian marbles; which make them suitable as raw material for stone and terrazzo tiles processing.

The obtained values of water absorption for the marble specimens vary from 0.18 to 0.25 % (Table 1). The highest values 0.25 and 0.24 % are that of MB-04 5 (pinkish white marble) and that of MB-02 (greyish white marble), respectively (Figure 5). The lowest value is that of white marble (MB-03). Intermediate values 0.20 % and 0.21 % are found in pinkish marble and greyish marble, respectively. The value of greyish marble is much closer that of white marble; which also shows a low water absorption. The water absorption for marble found in the Southern Eastern desert (Egypt), varies from 0.34 to 0.41 % [24]; It ranges from 0.05 to 0.16 % for marble from northwestern Pakistan [25]; and from 0.1 to 1.07 %, for marble from Eastern Desert (Egypt) [23]. Comparing the values of water absorption for Bidzar Dawala marble with those for marble from Southern Eastern desert (Egypt), Eastern Desert (Egypt), and Northwestern Pakistan; those of Bidzar Dawala marble specimens are lower than those of marbles from Southern Eastern and Eastern Desert (Egypt); but, higher than those for marble from Northwestern Pakistan. According to the ASTMC503 [26] standard on the value of water absorption recommended for marble used as dimension stone, the maximum value of water absorption is 0.2 %. If base on the ASTMC503 [26] standard, MB-03 (white marble) and MB-05 (greyish marble) with their water absorption ≤ 0.2 % are more lightly to be used to process stone tile. The other specimens with the water absorption ≥ 0.21 %; but, less than those in Southern Eastern desert, already mined and sold as building decoration [24]; they can also be used to process tiles. Their possible use is supported by the low porosity.

The specific gravity for the Bidzar Dawala marble samples ranges from 2.68 to 2.73 g/cm^3 (Table 1) with an average value of 2.70 g/cm^3. The highest values 2.73 g/cm^3, 2.71 g/cm^3, and 2.70 g/cm^3 are that of MB-05 (greyish marble), MB-03 (white marble) and that of MB-02 (greyish white marble), respectively; whereas, the lowest values 2.69 g/cm^3, and 2.68 g/cm^3 are that of MB-01 (pink marble), and MB-04 (pinkish white marble), respectively. The obtained specific gravities (2.68 - 2.72 g/cm^3) are more than that of Dawi marble (2.627 g/cm^3) and Telmet marble (2.629 g/cm^3) mined in Eastern Desert (Egypt) [23]. This difference shows that the studied marble samples are denser than those in Eastern Desert (Egypt). For

Wahab et al., [23] the specific gravity (≤ 2.629 g/cm³) for their studied marbles makes them suitable to be used in buildings decoration. The specific gravity for marble tailings in CIMENCAM Bidzar quarry determined by Lyonga et al., [5] ranges from 2.70 to 2.73 g/cm³; that of white marble sample in this same quarry is 2.75 g/cm³ [3]. Most SG values obtained for marble samples in this study (notably, the value of MB-02: 2.70 g/cm³, MB-03: 2.71 g/cm³, and MB-05: 2.73 g/cm³) are similar or close to those presented in Lyonga et al., [5], but, below that of white marble presented in Wouatong et al., [3]. According to EN13383 [27] standard classification scheme, a SG for marble is excellent (when the SG is greater than 2.7); satisfactory (when the SG ranges from 2.5 to 2.7); limited (when the SG ranges from 2.3 to 2.5); and mediocre (when the SG is less than 2.3). If base of the EN13383 [27] standard classification scheme, two groups of marbles can be distinguished: (1) marbles with an excellent SG (MB-03: white marble; and MB-05: greyish marble); and (2) marbles with a satisfactory SG (MB-01: pink marble, and MB-04: pinkish white marble). The SG values for all the two groups are compatible with those of marbles used to process terrazzo tiles.

The studied marble samples have the same hardness (3) which is probable that of calcite mineral which in Moh's scale is 3 (Table 2). For Wahab et al., [23] marble hardness of 3 is due to the fact that this rock is mainly composed of calcite. Petrographic studies of marbles mined in CIMENCAN quarry, close to the Bidzar Dawala marble deposits, show that they are white, yellow, light-grey, dark-grey, and dull-yellowish dolomitic type; The non-dolomitic type marbles are dominantly composed of calcite [8]. Djifack et al., [8] never studied the hardness of their marbles, but their marbles show a color similarity with those found to the Bidzar Dawala marble. The hardness of 3 could be due the dominant presence of calcite in the studied marbles. According to ASTMC503 [26], marble ranks on 3-4 on the Moh's hardness scale indicating that it is relatively soft strong stone, prone to scratching and etching composed primarily of calcite, making it easy to carve and ideal for sculptures and ornamental work.

Durability refers to a material's ability to resist deterioration while maintaining its original properties over time [23]. Marble is generally durable, and with proper sealing and maintenance, it can last decades or even centuries. The durability of the Bidzar Dawala marble samples varies from 0.38 to 0.50 % (Table 2), with a mean value of 0.43 %. The highest value is that of MB-04 (Pinkish white marble) which has the highest porosity (0.96 %) (Figure 5). The lowest value, is that of MB-03 (White marble), which has the lowest porosity (0.78 %). This therefore shows that the higher the durability of the studied samples, the higher the porosity. Pinkish white marble is presented as relatively most porous, is the most durable.

Table 2. Density, hardness, durability for the marbles.

Sample Number	Rock type (Color)	Density (Kg/m³)	Hardness (Mohs)	Durability (Freez-Thaw loss: %)
MB-01	Pink marble	2690	3.0	0.40
MB-02	Greyish white marble	2700	3.0	0.45
MB-03	White marble	2710	3.0	0.38
MB-04	Pinkish white marble	2680	3.0	0.50
MB-05	Greyish marble	2730	3.0	0.42

The compression strength (CS) for the studied marble specimens ranges from 75.0 to 78.5 MPa (Table 3); with a mean value of 76.03 MPa. The highest value is that of MB-03 (white marble). The lowest value is that of MB-02 (greyish white marble) (Figure 6). MB-01, MB-04, and MB-05, have their compression strength values close to the lowest value. This difference in compression strength values distinguishes the white marble, with CS (78.5 MPa: relatively higher) from the others marble specimens (colored marbles), whose CS (≤ 75.3 MPa) are relatively low. Relating the low CS of the colored marble specimens to their impure nature is not easy at this stage, as other studies are still needed. The obtained CS values compared with those of marbles specimens from Northwestern Pakistan, show a clear difference. The compression strength for the studied marble are higher than those in Pakistan. This shows the studied marbles are stronger than those in Pakistan. According to the ISRM [28] of rock's compression strength classification scheme, the CS for the studied marble specimens all fall withing the strong class; with the white marble being much stronger than colored marbles. This important parameter supports the use of the Bidzar Dawala marbles as raw materials to process terrazzo tiles.

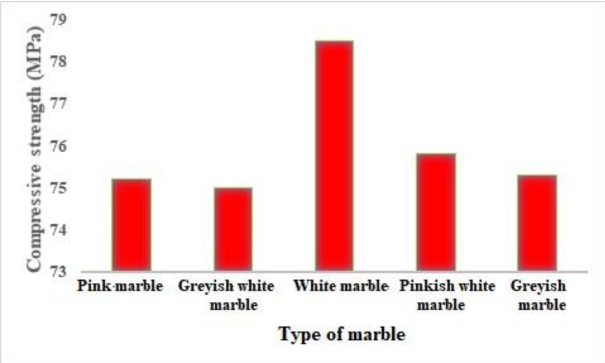

Fig. 6. Line graph showing the compressive strength for the Bidzar Dawala marbles.

The flexural strength values for Bidzar Dawala marble specimens ranging from 16.5 to 18.1 MPa with a mean of 17.22 MPa, show some variation (Table 3). The highest value is that of white marble, followed by that of grey marble, greyish white marble, pink marble and pinkish white marble, respectively (Figure 7). This shows that the white marble is stronger than the other marble (colored and impure marbles). It can be suggested that the impure nature of the colored marbles reduces their strength. According to the ASTMC503 [26] standard, the flexural strength for rocks used as stone tiles ranges from 6.9 to 8.3 MPa. The obtained flexural strength values (> 16.0 MPa) for the studied marble specimens are greater than the maximum ASTMC503 [26] standard value (8.3 MPa). This makes the studied marble specimens good to be used as raw material for stone tiles processing.

Table 3. Compressive and flexural strength for the Bidzar Dawala marbles.

Sample number	MB-01	MB-02	MB-03	MB-04	MB-05
Compression Strength (MPa)	75.2	75.0	78.5	75.8	75.3
Flexural Strength (MPa)	16.8	17.2	18.1	16.5	17.5

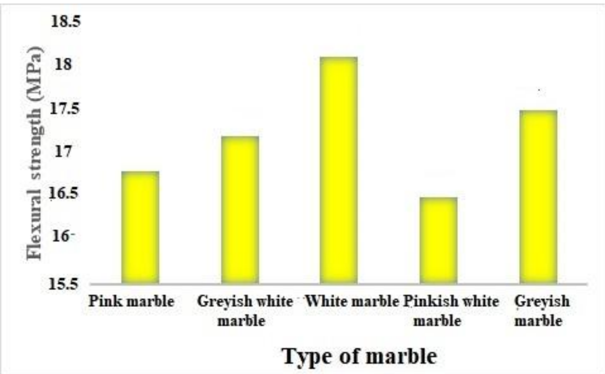

Fig. 7. Line graph showing the flexural strength for the Bidzar Dawala marbles.

3.2. Characteristics of processed epoxy-based terrazzo tiles

Water absorption (Wab) test result for two processed epoxy terrazzo tiles is 0.407 % and 0.409 % (Table 4). According the ASTMC97M [15] standard, the maximum value of water absorption in terrazzo tile is 0.7 % (with 0.2 % for exterior use; and, 0.7 % interior use). According the ASTM C140 [29] standard, the average value of water absorption in terrazzo tiles is less than 5 %. The obtained values of water absorption for the processed epoxy terrazzo tiles are within the rang required by the ASTMC97M [15] standard. They can be classified as relatively low-water absorption tiles, as water absorption in terrazzo tiles is less than 5 % (c.f. [28]). If base on ASTMC97M [15] standard on the use of terrazzo tiles in relation with the value of their water absorption (0.2 % for exterior use and 0.7 % for interior use), with the value of Wab close to 0.41 %, the processed tiles are suitable both for interior and exterior use.

Table 4. Proportion of water absorption in two processed epoxy terrazzo tiles specimens.

Tile number	W1 (g)	W2 (g)	L (mm)	Wth (mm)	Th (mm)	Wab (%)
ETE-01	269.98	271.08	274	75	12	0.407
ETE-02	301.07	302.3	274	82	12	0.409

The compression strength (CS) for the studied marble specimens ranges from 75.0 to 78.5 MPa (Table 5); with a mean value of 76.03 MPa. The highest value is that of MB-03 (white marble). The lowest value is that of MB-02 (greyish white marble) (Figure 6). MB-01, MB-04, and MB-05, have their compression strength values close to the lowest value. This difference in compression strength values distinguishes the white marble, with CS (78.5 MPa: relatively higher) from the others marble specimens (colored marbles), whose CS (≤ 75.3 MPa) are relatively low. Relating the low CS of the colored marble specimens to their impure nature is not easy at this stage, as other studies are still needed. The obtained CS values compared with those of marbles specimens from Northwestern Pakistan, show a clear difference (see Table 4). The compression strength for the studied marble are higher than those in Pakistan. This shows the studied marbles are stronger than those in Pakistan. According to the ISRM [29] of rock's compression strength classification scheme, the CS for the studied marble specimens all fall withing the strong class; with the white marble being much stronger than colored marbles. This important parameter supports the use of the Bidzar Dawala marbles as raw materials to process terrazzo tiles.

Table 5. Compressive strength for four processed epoxy terrazzo tiles specimens.

Tile number	W (g)	L (mm)	Wth (mm)	th (mm)	F (KN)	CS (MPa)
ETE-01	8.84	25.65	18.24	11.86	14.4	30.78
ETE-02	7.79	25.42	17.11	11.8	14.2	32.65
ETE-03	7.54	25.91	15.51	11.92	12.2	30.37
ETE-04	8.57	27.58	17.24	11.67	15.6	32.81

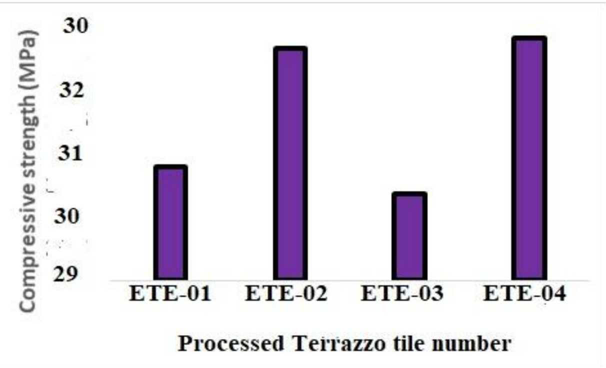

Fig. 8. Line graph showing the compressive strength in the processed epoxy terrazzo tiles specimens.

Fig. 9. Prototypes of processed epoxy terrazzo tiles.

4. CONCLUSION

Based on the experimental works and results obtained in this study the following conclusions were made:

1. Physical properties of the Dawala Bidzar marbles: the porosity of the studied white, greyish, greyish-white, pink and pinkish-white marbles classify them as compact type; the specific gravity classifies them as marbles with an excellent SG (greyish white marble, white marble, and greyish marble), and marbles with a satisfactory SG (pink marble and pinkish white marble). The hardness places the studied marbles withing the relatively soft strong stone type. The durability and water absorption, dominantly within the standard requirement, coupled with the interesting values of the other parameters make the studied rocks suitable for terrazzo tiles processing.
2. The compressive and flexural strength shows that the white marble is much stronger than the colored marble. The strength values for all the studied marbles are compatible with standard requirements for rocks used in terrazzo tiles processing.

3. The water absorption of processed terrazzo tiles found within the ASTMC97M standard, classify theme as relatively low-water absorption tiles suitable both for interior and exterior use. The compressive strength distinguishes relatively high CS tiles and relatively low CS tiles, with both of them classify as moderate compressive strength tiles to be used in area with low to medium foot traffic, like residential spaces, office or light commercial areas.

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