British Journal of Applied Science & Technology
19(5): 1-11, 2017; Article no.BJAST.30421
ISSN: 2231-0843, NLM ID: 101664541

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A Geological and Physico - Mechanical Characterization of Marble of the Bidzar Quarry North-Cameroon

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Authors' contributions

This work was carried out in collaboration of all authors. Authors ASLW, ORMK and FN designed the study, performed the characterization of raw material, wrote the protocol, and wrote the first draft of the manuscript. Authors ASLW and FN managed the analyses of the study (Chemical, Physical and Mechanical analysis). Authors VK and VBKK corrected the first draft and last version. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2017/30421
Editor(s):
(1) Ahmed Fawzy Yousef, Geology Department, Desert Research Center, Egypt.
Reviewers:
(1) Dolores Pereira, University of Salamanca, Spain.
(2) Ivana Miličević, University of Osijek, Croatia.
(3) Natt Makul, Phranakhon Rajabhat University, Bangkhen Bangkok, Thailand.
(4) Shyam Prakash Koganti, Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/18395

Original Research Article

Received 8th November 2016
Accepted 2nd February 2017
Published 29th March 2017

ABSTRACT

This study of the geological and physico-mechanical characteristics of the Bidzar quarry white marble exploited for cement manufacture has given rise to an exploitation model. This model has enabled the reduction in the size of the blast products through site reconnaissance and laboratory testing. The outcrops of white marble, dolomitic marble, quartzite and shales which were revealed

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on the ground surface and were foliated and fractured. The foliation plans however, showed two main directions of orientation on white marble: [NNE - SSW and NNW - SSE]. Likewise, the two main directions of fractures [NNW - SSE (N160°E) in N - S and NNE - SSW (N10°E)] and two secondary directions [W - E and NNW - SSE (N140°E)] were present on white marble which is richer in CaO (52.65 to 55.45%) than the dolomitic one (30.15 to 31.78%). It came out that the quartzite was richer in SiO_2 (95.43 to 98.86%) than shale (45.67 to 79.12%). The physical and mechanical characteristics of the white marble were: absolute density (2.77g/cm^3) and bulk density (2.75 g/cm^3). The mechanical fragmentation strength on the 6/10 mm and 10/14 mm fractions was 32% and 31%. The wear resistance on the same fractions was 33% and 25% respectively.

Keywords: White marble; dolomitic marble; raw blasting; foliation; fracture; quarry.

1. INTRODUCTION

Man has always shad to resort to natural materials to build houses since the beginning of History. These materials are generally either widespread on the earth's surface or buried underground. However, the materials found on the earth's surface are exploited mechanically either with hand implements or with the help of mechanical motorized equipment meanwhile the buried ones are exploited by using explosives. In Cameroon, massive varieties of rocks are found, among which some are potential materials that can be used to produce aggregates. These aggregates are used in constructing the base layers and as well as the rolling surfaces of pavements, and in concrete work. The Bidzar white marble layer is used for several purposes such as a soil amender in agriculture and in the provision of calcium mineral for nutritional purposes. In cement manufacture, it is valued as the main raw material for the production of clinker. Clinker constitutes one of the basic elements required in the confectioning of Portland cement. Clinker is obtained by kilning the primary materials constituted of 80% of limestone and 20% of clay at a temperature of about 1500°C. Thereafter it is milled together with gypsum to produce cement. Other cement varieties are manufactured thanks to the addition of the secondary constituents such as volcanic ashes, blast furnace slag and pozzolans.

2. GENERALITIES ON THE STUDY AREA

The study area is situated in the Bidzar quarry, of the North region of Cameroon. It covers a surface area of 70 ha and is located between latitudes 9°55' and 9°56' and longitudes 14°07'13 " and 14°07'68 " as shown in Figure1.Bidzar is situated along the N°1 national road at 22 kilometers to the NE of Figuil between Figuil and Maroua. The soudano-sahelian climate prevails here, and it is characterized by two seasons: a long dry season and a short rainy one. Maximal temperatures reach 48.8°C in March and 47.8°C in April. The dendritic hydrographic network of this zone is nourished by temporary and seasonal rivers.

The study area is part of the North segment of the Pan-African range of Central Africa in Cameroon. Current studies of this area distinguish between Precambrian formations represented by cristallophyllian rocks and igneous formations more or less dominated by deformed granitic intrusions [1,2,3,4,5,6,7,8,9]. These formations are grouped in five main geological units: the neo-proterozoïc shale unit of volcanic and volcano-sedimentary origin [10,9], the neo-proterozoïc gneiss unit is in agreement with shale. However, the degree of metamorphism of the shales is one of the facies domain of the green shales to amphibolites while that of gneiss is characterized by high temperature amphibolites [2,3,6,11]. The Pan-African granitoïdes, syn in tardi-tectonic D_1 (620-630 Ma) (Fig. 2) of calco-alkali composition, the syn granitoïdes to post D_2 tectonics (600-580 Ma) constitute the biggest proportion of the Pan-African plutonic rocks of the North region of Cameroon of the Pan-African Belt of central Africa, the tardi-tectonic D_2 (560-540 Ma) granitoïdes corresponded to granites and to the leucocratic syenites with variable textures (aplitic, porphyroïd, pegmatitic), which shows as domes or inselbergs on the surface cutting up the regional structure D_2 and dominates the plain relief. To these different units, are weakly added numerous but varying volcano-sedimentary formations said to be a deposit of Pan-African molasse [12] of which white marbles of the Bidzar quarry in the North of Cameroon is made of.

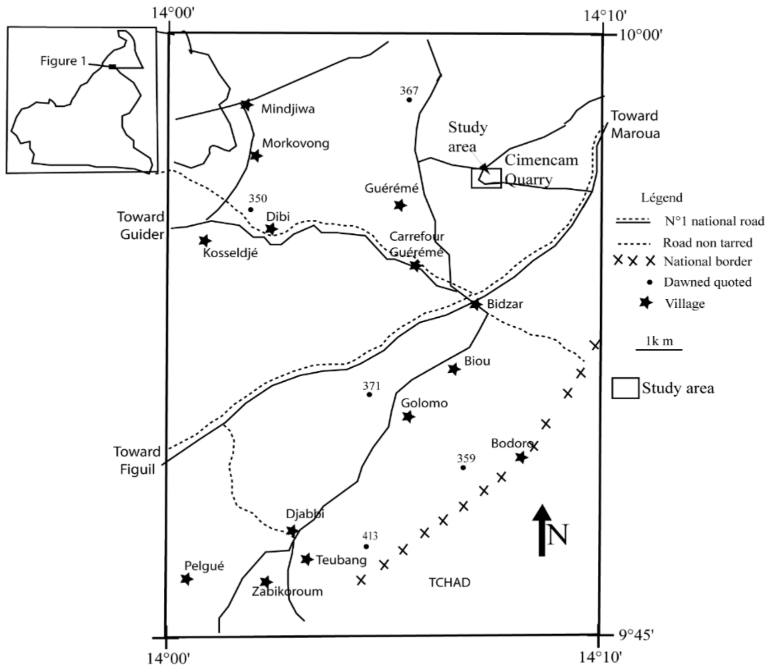

Fig. 1. Location map of the study area

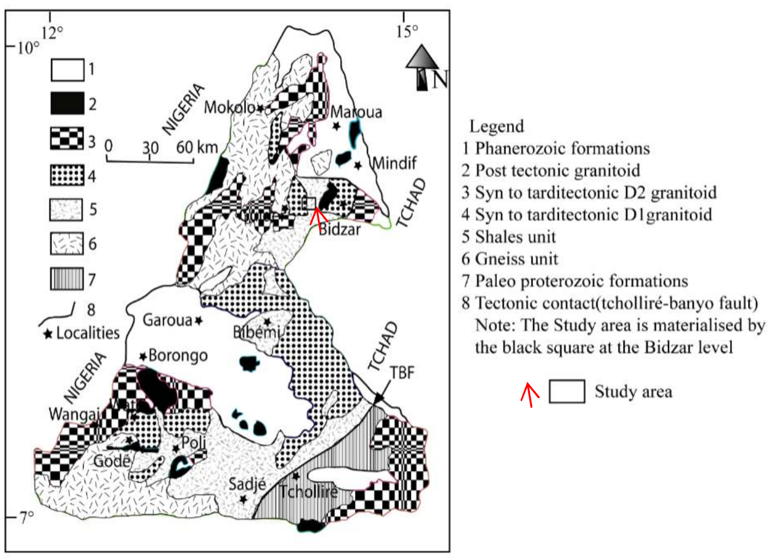

Fig. 2. Lithostructural units on geologic maps of the North domain of the Pan-African Belt of Central Africa in Cameroon according to [5]

3. MATERIALS AND METHODS

3.1 Sampling

In the Bidzar quarry, rocks exploitation presents itself in steps of 10 m and 12m of height and more (Fig. 3).

This disposition is conditioned by the presence of the calcium carbonate ($CaCO_3$) in the exploited materials. Successions of white marble and shale face to face along the exploitation front are noted. Otherwise, the blocks got after shot blasting with the use of large quantities of explosives are coarse in the order of 2 to 20 m

(Figs. 4a and 4b). They require supplementary operations of treatment so as to further fragment them into medium size blocks or the use of the pneumatic drill to break them up into 20 and 35 cm diameter blocks (Fig. 4c), then followed by the crushing phase (Fig. 4d).

The petrographic characteristics [means of outcrop, grain size, color, structure, and numbers] and structural elements [foliation and fractures] were recorded and described. Thus the samples of exploited rocks were collected and wrapped carefully in polystyrene paper. They were labeled as follows: (WM) to designate white marble, (DM) for the dolomitic marble, (QTZ) for quartzite and finally (GS) for the green shale and thereafter these were transported to the laboratory.

Fig. 3. Panoramic view of the Bidzar quarry rocks exploited (size front: 10 to 12 m of height, 70 ha of surface)

Fig. 4. Exploited materials, 4a and 4b: Blasted blocks in the order of 2 to 20 m, 4c: Treated blocks in the order of 20 to 35 cm, 4d: Crushed blocks

3.2 Experimentation

Various studies were carried out in different laboratories. Microscopic observations were made with the help of a polarizing microscope. The structural description was made thanks to the foliation stereograms and the rose fracturation windows. The chemical analysis were carried out in the chemistry laboratory of CIMENCAM, the physical and mechanical tests [absolute and bulk density, Microdeval, Los Angeles, simple compression and the indirect tensile strength test] were carried out at the Cameroon National Civil Engineering Laboratory of Yaounde.

3.3 Chemical Analysis

The bulk chemical composition of materials was studied with an X-ray fluorescence spectrometer. To achieve this, specimens were quarted and were ground. After grinding, 2.000 g powder of specimen was brought to a temperature of ≤ 1150℃ to determine the loss on ignition(LOI); LOI = (P_1 - P_0) 100. Then another 2.000 g of powder was mixed with distilled water and 5 ml of hydrochloric acid in a 250 ml Erlenmeyer, to determine the lime percentage of the specimen. Furthermore, a mixture of 7.200 g lithium tetraborate ($Li_2B_2O_4$) and 0.800 g of powder were brought to a temperature of ≤ 1150℃ to manufacture the pearl. This product was directly placed in an X-ray fluorescence spectrometer connected to a computer which detected and gave the total percentage of oxides present in the specimen.

3.4 Physical and Mechanical Analysis

The Physical and mechanical analysis were studied. The absolute density also termed the true, real, apparent or skeletal density was obtained when the volume measured excluded the pores as well as the void spaces between particles within the bulk sample. It was determined using the pycnometer method according to norms NFP 18 - 554 and NFP 18 – 55 respectively. Otherwise, true density sometimes called the bulk density was determined for porous materials when pore spaces within the material particles are included in the volume measurement. It was determined by the use of paraffin and hydrostatic balance method on the rocks samples. However, microdeval test was carried out according to norm NFP 18-572 which measures the wear strength by rubbing 500 g of granular class placed with a load constituted of steel balls. Furthermore, the Los Angeles test was carried out according to norm NFP 18 - 573 which determines the combined strength and fragmentation by shocks and reciprocal rubbing of aggregates. Thereafter the quantity of elements smaller than 1.6 mm produced as a result of these shocks and rubbings by the Los Angeles machine was determined. The simple compression strength test was carried out according to norm NFP 18 – 406 which permits to measure the crushing material strength. This was carried out by placing a cylindrical specimen between two platens of a compressive press and was subjected to increasing loads until failure occurred. Finally, the indirect tensile strength test was carried out according to norm NFP 18 – 408 which permit to subject a cylindrical shape specimen to an increasing compression along the side till rupture occurred.

4. RESULTS AND ANALYSIS

4.1 Petrographical Results

The macroscopic and microscopic petrographical characteristics of the Bidzar quarry rocks have been studied and are shown in Table 1.

4.2 Structural Analysis Results

The structural analyses were carried out consisting of mainly of foliation and fractural studies. The foliation had clearly demarcated stripes. It was essentially marked by an alternation of calcitic to quartzo-feldspathic clear stripes and dark ferromagnesian minerals stripes (Fig. 5b). The orientation of the foliation plans showed two main directions: the [NNE - SSW and the NNW – SSE]. The study area was also strongly affected by dry fractures without the relative displacement of the separated compartments (diaclase) on the outcrop (Fig. 5a). While in Fig. 5b the fractures are open and the two compartments are separated by some centimeters.

4.3 Chemical Analysis Results

The bulk chemical composition of Bidzar white marble and dolomitic marble were studied and are represented in Table 2 and Table 3 respectively.

Table 1. Macroscopic and microscopic petrographic characteristics of the Bidzar quarry rocks

Rocks	Ref	Structure	Aspect / Color	Grain size	Texture	Outcrop style	Microscopic composition
White marble	WM	Massive	Milky white	Average to fine	Granoblastichetero-Granular	Tiles and balls	Cal+Q+Mus+Op
Dolomitic Marble	DM	Massive	Brown / grey	Average to fine	Granoblastichetero-Granular	Blocks	Dol+Q+Cal+Op
Quartzite	QTZ	Massive	Vitreous white	Average to coarse	Protoclastic	Blocks	Q+Op
Green shale	GS	Massive	Greenish / greyish	Coarse	Grano-lepido-blastic	Stretched blocks	Ser+Bt+Chl+Op+Q+Py

Legend: Cal: calcite; Dol: dolomite; Q: quartz; Mus: muscovite; Py: pyrite ; Ser: sericite; Bt: biotite; Chl: chlorite; Op: opaque

Table 2. Bulk chemical composition of Bidzar white marble

Samples	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	Mn_2O_3	LOI	Total
WM_1	0.27	0.06	0.03	54.36	1.13	0.07	0.03	0	0	0.07	0.01	42.39	98.42
WM_2	0.73	0.19	0.25	53.77	0.76	0.07	0.02	0.02	0.06	0.06	0.02	42.92	98.85
WM_3	0.64	0.21	0.21	53.06	1.29	0.06	0.01	0.04	0.01	0.06	0.01	42.41	96.71
WM_4	0.9	0.1	0.15	52.65	1.45	0.06	0.03	0.02	0	0.03	0.01	42.30	97.67
WM_5	0.14	0.06	0.05	55.45	0.69	0.07	0.02	0	0	0.09	0	42.30	98.87
WM_6	1.50	0.13	0.12	52.96	1.07	0.06	0.03	0.01	0	0.02	0.01	42.66	98.57
WM_7	0.76	0.11	0.16	54.89	0.65	0.06	0.02	0	0	0.08	0.01	41.64	98.38
WM_8	0	0.13	0.13	53.71	0.76	0.06	0.02	0.01	0.01	0.11	0.02	42.62	97.58
WM_9	0.16	0.11	0.13	53.36	0.74	0.06	0.02	0.01	0.01	0.09	0.02	42.38	97.09

Table 3. Bulk chemical composition of Bidzar dolomitic marble

Samples	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	Mn_2O_3	LOI	Total
DM_1	8.46	0.15	0.28	30.59	16.60	0.07	0.03	0.02	0.01	0.19	0.03	41.9	98.33
DM_2	2.15	0.09	0.32	31.78	19.69	0.06	0.08	0	0	0.13	0.13	44.78	99.21
DM_3	2.11	0.11	0.65	31.66	18.94	0.05	0.08	0.01	0	0.01	004	44.99	98.65
DM_4	4.19	0.27	0.25	30.15	15.76	0.06	0.01	0.01	0.01	0.01	0.02	46.35	97.05

Fig. 5. Foliation and fractures on white marble
5a: Dry fracture, 5b: foliated bands with separated compartments

As seen in Table 2, the white marble of the study area was characterized by a high percentage of CaO (52.65 - 55.45%).

The study reveals low percentage contents in MgO (0.65 - 1.45%) and SiO_2 (0 - 1.50%), very low percentage contents of Al_2O_3 (0.1 - 0.21%), Fe_2O_3 (0.03 - 0.25%), SO_3 (0.06 - 0.07%), Na_2O (0.01-0.03%), K_2O (0 - 0.04%), TiO_2 (0 - 0.06%), P_2O_5 (0.02 - 0.11%) and Mn_2O_3 (0 - 0.02%). The losses on ignition were relatively high (41.64 - 42.92%).

The bulk chemical composition of Bidzar dolomitic marble were studied and represented in the Table 3.

As seen in Table 3, the dolomitic marble of the study area was less rich in CaO (30.15-31.78%), and had relatively high contents in MgO (15.76-19.69%).

The dolomitic marble had average percentage contents of SiO_2 (2.11 - 8.46%) and very low percentage contents of Al_2O_3 (0.09 - 0.27%), Fe_2O_3 (0.28 - 0.65%), SO_3 (0.05 - 0.07%), Na_2O (0.01 - 0.08%), K_2O (0 - 0.02%), P_2O_5 (0.01-0.19%), Mn_2O_3 (0.02 - 0.13%). The losses on ignition were relatively high (41.9 - 46.35%).

4.4 Physical and Mechanical Characteristics of Bidzar White Marble

The physical and mechanical characteristics of Bidzar white marble are presented in Table 4.

As seen in Table 4 that the Bidzar white marble had an absolute density of 2.77 g/cm^3, a bulk density of 2.75 g/cm^3, a mechanical fragmentation strength of between 32 and 31%, a wear strength of between 33 and 25% respectively for the granular classes 6/10 and 10/14 mm, a simple compression strength of 75 MPa and an indirect tensile strength of 8.9 MPa.

Table 4. White marble physical and mechanical characteristics

Characteristics	Values
Absolute density (g / m^3)	2.77
Bulk density (g / m^3)	2.75
Mechanical fragmentation strength (%)	32 - 31
Wear strength (%)	33 - 25
Simple compression strength (MPa)	75
Indirect tensile strength (MPa)	8.9

5. DISCUSSION

The geological as well as the physical and mechanical characterization of the white marble has led to the propositioning of an adequate solution to reduce the size of raw blast obtained from the Bidzar quarry.

The mineralogical composition and the size of the grains of the whole petrographical study area play an important role on the fragmentation of the materials. Besides, the rocks are composed of carbonate minerals (calcite; dolomite) and of white minerals (quartz) of millimetric sizes, with better crystals that are welded and require a strong explosive load to dislocate them. Otherwise, the explosive load used to produce the leucocratic rocks is far superior to the one used to produce the mesocratic rocks. Thus, the

Bidzar quarry presents a heterogeneous lithology. This disposition rather encourages their detachment in blocks. The two main directions and two secondary directions of orientation of fractures are recorded as: [NNW - SSE (N160°E) to N-S and NNE - SSW (N10°E)] relative to the main directions, while [W - E and NNW - SSE (N140°E)] for the secondary directions (Fig. 6). These fractures constitute zones of weakness on the rocky massif likely to facilitate their fragmentation into blocks. Therefore, the miner can orientate the shooting plans following these different zones of weaknesses. Thus, when the propagation of the explosive load, meets a discontinuity in a favorable direction, it augments the performance of the explosive load whereas when it meets an un-oriented discontinuity, it rather causes a lower performance.

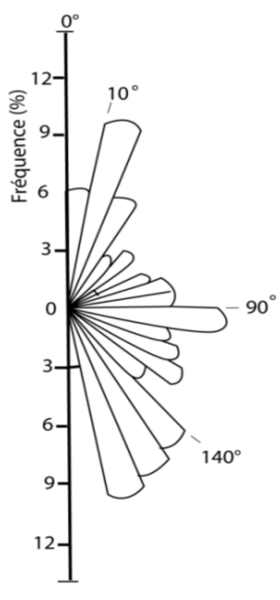

Fig. 6. Rose window of main and secondary direction of fracturation in the formations of the study area. n = number of measure

The standards values of the chemical composition of the ingredients used for clinker manufacture are shown in the Table 5.

The proportions of the various oxides as found above gives the following clinker compositional parameters:

LSF = $\frac{CaO}{2.8SiO2+1.18Al2O3+0.65Fe2O3} = 98\,\% \pm 1.0\%$;

$$AR = \frac{Al2O3}{Fe2O3} = 1.5 \pm 0.1$$

SR = $\frac{SiO2}{Al2O3+Fe2O3} \leq 2.65 \pm 0.5$; MgO ≤ 1.60.

Where LSF is the lime saturation ratio, SR is the silica ratio and AR is the alumina ratio.

The white marble of the study area is very rich in CaO; its average percentage content is 53.80%. It has low percentage content of MgO with its average being 0.95%. So, there is a high proportion of CaO (52.65% - 55.45%) and the low proportion of MgO (0.65% - 1.45%). Therefore with MgO ≤ 1.60 and the LSF being (29.40 ± 1.0) in the white marble justifies its use as main raw material of the CPJ 35 and CPJ 45 cement production. The dolomitic marble is less rich in CaO (30.15% - 31.78%) and the average of the percentages is 31.04%. It is rich in MgO (15.76%-19.69%); the average of the percentages rises to 16.99%. This value is a far superior to the limits value (1.60) tolerated in the mix. The magnesia not being part of the main necessary oxides for the manufacture of the clinker thus constitutes an impurity. Its presence beyond the considered threshold would entail the expansion of the cement in the mortar or the concrete while at the same time forming of magnesium hydroxide (Mg (OH) $_2$ in accordance with the equation below :

MgO+ H_2O——>2Mg (OH) + $\frac{1}{2}O_2$

This is responsible for the expansion and contraction phenomenon at the origin of numerous cracks observed on construction works.

The high value LOI (41.64 – 42.92%) in the white marble and (41.9 – 44.99%) in the dolomitic marble is attributable to decarbonatation of the calcium carbonates according to the equations:

$CaCO_3$ (s) —>CaO (s) + CO_2 (g) and
$CaMg(CO_3)_2$ (s) —>CaO (s) + MgO (s) + 2 CO_2 (g)

On the one hand and of the high presence of organic matter in the original materials on the other. Otherwise, the Table 6 gives the guide line on the assessment of the quality and the durability of the materials.

As shown in Table 6 the Bidzar white marble of absolute density 2.77 g/cm^3 belongs to the domain of the rocks of absolute density> 2.7 g/cm^3, therefore it is classified as having an excellent absolute density. This high value obtained could be due to the low porosity of this

Table 5. Percentage composition of the ingredients used in clinker manufacture

Elements	SiO_2	Al_2O_3	Fe_2O_3	Mn_2O_3	TiO_2	CaO	MgO	$Na_2O.K_2O$	SO_3	P_2O_5
%	16-26	4-8	2-5	0-3	0-3,5	58-67	1-5	0-1	0.1-0.5	0-1.5

Table 6. Guideline on assessment of the quality and the durability of the materials

Criteria	References methods	Excellent	Satisfactory	Limited	Mediocre
Absolute density (g/cm^3)	EN 13383-2	>2.7	2.5 — 2.7	2.3 — 2.5	< 2.3
Los Angeles test	EN 1097-2	< 15	15 — 25	25 — 35	>35
Microdeval test	EN 1097-1	< 10	10 — 20	20 — 30	>30
Indirect tensile strength test (MPa)	ASTM D-3967-95a (2004) ; ISRM(1978)	>10	5 — 10	2 — 5	< 2
Simple compression test (MPa)	EN 1926	>120	120 — 80	80 — 60	< 60

rock. Besides, this marble also has high bulk density (2.75 g/cm^3). This high value may be related to the calcite density (2.71 g/cm^3), its principal constituting material and also of quartz 2.65 g/cm^3. The absolute and the bulk density are in most cases comparable. Compared to with other, limestone and marble have fairly stable densities, widely distributed between 2.67 and 2.78 g/cm^3 [13].The white marble of the study area is said to be less resistant. According to [14] the value of its compressive resistance is lower by 100MPa. These same authors portray that rock resistance are often in the range of 1 - 200 MPa. Values lower than 5 MPa are classified as very tender and values above 100 MPa are very resistant. The white marble of the study area has an indirect tensile strength of 8.9 MPa. This was evaluated according to ASTM-ISRM standards which therefore classify the white marble in the class 5 - 10 characteristic of rocks which are said to be satisfactory.

6. CONCLUSION AND RECOMMENDATION

The following conclusions and recommendations can be drawn from the study of the geological and the physical and mechanical characterization of the Bidzar quarry white marble.

- In the Bidzar quarry, white and dolomitic marble, quartzite and the green shale outcrop on the surface.
- The white marble is affected by the type of stripes and fractures.
- The white marble is richer in CaO (52.65% - 55.45%) than the dolomitic one (30.15% - 31.78%) and less rich in MgO (0.65% - 1.45%) than the dolomitic marble (15.76% - 19.69%). This justifies its preference for use in clinker production.
- The Bidzar white marble presents features of a less resistant, satisfactory but limited rock.

For blasting purposes, shootings should be orientated according to the main directions of fracturation of the rocks. Since blasting operation is not a precise science, the rock formation itself must be considered in order to produce desirable results [15]. The results of blasting operation is dependent on some factors such as the type, features loading procedures and quantity of the explosives, critical diameter, the hydrostatic pressure, temperature, minimum primer weight, gap sensitivity, water resistance, reliability for bulk operations and overall drilling and blasting economics. Likewise, some essential elements of the shooting plan must be brought into perspective, notably: the bench (B), spacing (E), loading of the drilled hole (LF) consistency report (CR), powder factor / specific load (PF), stemming (S) [16]. Also, it is necessary to add: stuffing (Sg), volume of material to cut down (VM) and the beginning (Bg). When, B = 3.3 m; E = 4 m; LF = 69.4 kg; CR = 3.6; PF = 0.44 kg/m^3; S = 1 m; Sg = 2.31 m; VM = 158.4 m^3.

Since the disposition of the materials in the quarry is stratified, a bi-stacked loading of the mine holes could also be considered while taking care to avoid energy losses by the use of the remnants of drilling or gravels (of angular shapes and diameter d = 5, 5 mm because they resist compression better in relation to the remnants of flattened shape) in relation to the level of striation of shales.

ACKNOWLEDGEMENTS

The authors thank the Director of CIMENCAM of Figuil, for his field assistance as well as the head of the laboratory for the physical and mechanical tests. Thanks also to the head of the Cameroon National Civil Engineering Laboratory in Yaounde.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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FN P 18-408: Indirect tensile strength test

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