

Geological study, physical and mechanical characterization of the Bidzar quarry white marble (North-Cameroon) incoming in the CPJ 35 and CPJ 45 cement manufacturing

ABSTRACT

A geological study, physical and mechanical characterization of the Bidzar quarry white marble exploited by CIMENCAM incoming in the CPJ 35 and CPJ 45 cement manufacturing has permitted to propose a model for exploitation aiming to reduce the size of the blasting raw. This may be achieved through consistent gait leaned on land and laboratory works. The outcrops of white marble, dolomitic marble, quartzite and shales were revealed on the land. The compositional litage foliation and dry fractures were mentioned. However, the foliation plans showed two main directions of orientation on white marble: [NNE - SSW and NNW - SSE]. Otherwise, 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 proved was 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 SiO₂ (95.43 to 98.86%) than shale (45.67 to 79.12%). The physical and mechanical characteristics of the white marble exploited were: absolute density (2.77g/cm³) and bulk density (2.75g/cm³). 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, blasting raw, compositional litage, quarry

1. INTRODUCTION

Man always had resort to natural materials to build houses since the beginning of History. These materials are generally either widespread on the earth surface or buried in under soil. However, the materials spilled in earth surface are exploited mechanically either with hand or with the help of contraption mean while the buried ones are exploited by the use of explosives. In Cameroon, a big variety of rocks are reported, among which some potentially materials that can be used to produce granulates. These granulates are useful to consolidate soils in the base layer and rolling, and the concrete granulates in the public works. Furthermore, the Bidzar white marble layer is used for several purposes. In the agriculture, it serves for soils amend. In the nutrition, it is solicited since it brings calcium as nutritious element. In the cement factory, it's valued for is useful like main raw material of the clinker process manufacturing. So the clinker constitute basis element of the composed Portland cement. Thus, the clinker is got by grinding the vintage constituted of 80% of limestone and 20% of clay. Some more cement varieties are manufactured thanks to the addition of the secondary constituents as volcanic ashes, blast furnace slag and pouzzolanes.

2. Generalities on the study area

The study area is situated in the Bidzar quarry, in the North region of Cameroon. It covers a surface of 70 ha and is located between 9°55' and 9°56' parallels of North latitude, 14°07'13 " and 14°07'68 " meridians of East longitude (Figure1). Bidzar is situated on the N°1 national road at 22 kilometers to the NE of Figuil between Figuil and Maroua. A soudano-sahelian climate prevails there. 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.

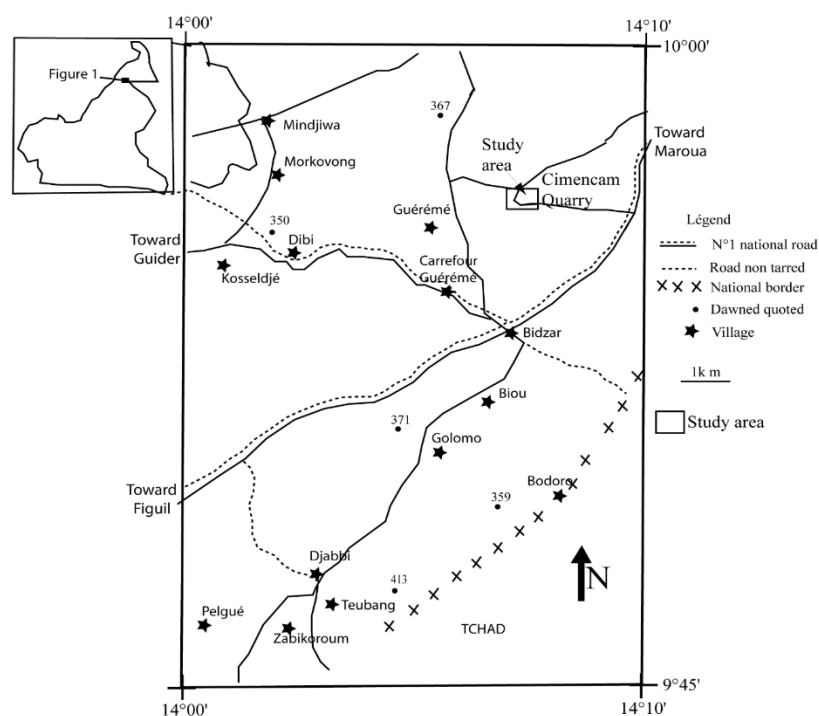


Figure 1: location map of the study area

The study area is a part of the North region of the Pan-African range of Central Africa in Cameroon. The recent studies on this area permit to distinguish between Precambrian formations represented by cristallophyllian rocks and igneous formations more or less dominated by deformed granitic intrusions (Dumont and al, 1985; Ngako 1986, 1999; Nzenti and al, 1992; Toteu, 1990,; Toteu and al., 1987, 2001, 2004, 2006). These formations are grouped in five main geological units: the neo-proterozoïc shale unit of volcanic and volcano-sedimentary origin (Njel, 1988,; Toteu and al, 2006), the neo-proterozoïc gneiss unit is in agreement with shale. However, the metamorphism degree of shales is one of the facies domain of the green shales to amphibolites while that of gneiss is characterized by high amphibolites temperature (Ngako 1986, 1999,; Toteu and al., 1987; Penaye 1988, 1989). The Pan-African granitoïdes, syn in tardi-tectonic D_1 (620-630 Ma) (Figure2) 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 CPAC, the tardi-tectonic D_2 (560-540 Ma) granitoïdes corresponded to granites and to the leucocratic syenites with variable textures (aplitic, porphyroïd, pegmatitic), that 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 volcano-sedimentary metamorphose formations interpreted like a deposit of Pan-African molasse (Montes-Lauar and al., 1997) of which white marbles of the Bidzar quarry in the North of Cameroon

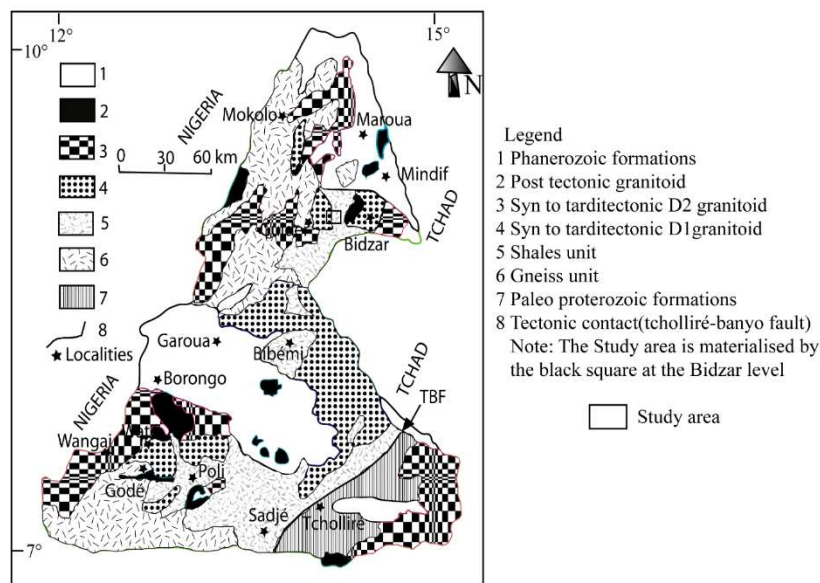


Figure 2: Lithostructural units on geologic maps of the North domain of the CPAC in Cameroon according to Toteu 1990.

3. MATERIALS AND METHODS

3.1. Sampling

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



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

This disposition is conditioned by the presence of the calcium carbonate (CaCO_3) in the exploited materials. Successions of white marble and shale in part along the front of size in exploitation are noted. Otherwise, the blocks got after the blasting shooting with the use of big quantities of explosives are coarse in the order of 2 to 20 m (Figure 4a and 4b). They require supplementary operations of treatment

(petardage) or the use of the pneumatic drill to break them up into 20 and 35 cm diameters (Figure 4c), then follows the crushing phase (Figure 4d).



Figure 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.

The petrographic parameters [means of outcrop, granulometrie, color, structure, and numbers] and structural elements [foliation and fractures] are recorded and described. Thus the samples of appropriated rocks have been wrapped carefully in polystyrene papers. On these papers, the samples are and numbered as follows: (WM) to designate white marble, (DM) for the dolomitic marble, (QTZ) for quartzite and finally (GS) for the green shale in order to take them to the laboratory.

3.2. Experimentation

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

3.3. Chemical analysis

The bulk chemical composition of materials has been studied through X fluorescence spectrometer. To achieve this, specimens were grinded and were quartered. After grinding, 2.000g powder of specimens were brought to a temperature of $\leq 1150^{\circ}\text{C}$ to determine the loss of ignition (LOI); $\text{LOI} = \frac{(P_1 - P_0)}{100}$. Then other 2.000g of powder were taken and mixed with distilled water and 5 ml of hydrochloric acid in a 250 ml Erlenmeyer, to determine the lime percentage of it. Furthermore, the mixture of 7.200g lithium

tetraborate ($\text{Li}_2\text{B}_2\text{O}_4$) and 0.800g of powder were brought to a temperature of $\leq 1150^\circ\text{C}$ to manufacture the pearl. This product was directly placed in an X fluorescence spectrometer connected to a computer which detected and gave the total percentage of oxides present in the sample.

3.4. Physical and mechanical analysis

The Physical and mechanical analysis has been studied. Absolute density also termed the true, real, apparent or skeletal density is obtained when the volume measured excluded the pores as well as the void spaced between particles within the bulk sample. It was determined using the pycnometer method according to norms NF P 18 - 554 and NF P 18 – 55 respectively. Otherwise, Enveloppe 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 used of paraffin and hydrostatic balance method on the rocks samples. However, microdeval test achieved according to norm NF P 18 - 572 enables to measure the wear strength by rubbing 500g of granular class placed with a load constituted of steel balls. Furthermore, Los Angeles test achieved according to norm NF P 18 - 573 enables to measure the strength combined fragmentation by shocks and reciprocal rubbings of granulate. It was determined through the quantity of elements lower to 1.6 mm produced while submitting the material to a set of shocks and rubbings in the Los Angeles machine. Hence, the simple compression strength test achieved according to norm NF P 18 – 406 permits to measure the breaking materials strength. So, the cylindrical material of twinge $H = E D$ are placed between two trays of a press and are submitted to increasing loads has the breaking.

Finally, the indirect tensile strength test achieved according to norm NF P 18 - 408 permits to split a cylindrical shape test-tube applied to an effort of compression along two opposite generating.

4. RESULTS AND ANALYSIS

4.1. Petrography analysis results

The Macroscopic and Microscopic Petrography characteristics of the Bidzar quarry rocks has been studied through table 1 below.

Table 1: Macroscopic and Microscopic Petrographic characteristics of the Bidzar quarry rocks

Rocks	Ref	Structure	Aspect / Color	Granulometry	Texture	Outcrop fashion	Microscopic composition
White marble	WM	Massive	Milky white	Average to fine	Granoblastic hetero-Granular	Tiles and balls	Cal+Q+Mus+Op
Dolomitic	DM	Massive	Brune / gray	Average to fine	Granoblastic hetero-Granular	Blocks	Dol+Q+Cal+Op

Marble							
Quartzite	QTZ	Massive	Vitreous white	Average to coarse	Protoclastic	Blocks	Q+Op
Green shale	GS	Massive	Greenish / grayish	Coarse	Grano-lepido-blastic	Stretched blocks	Ser+Bt+Chl+Op+Q+Py

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

4.2. Structural analysis results

The structural analysis has been studied. Then foliation and fractures were recorded. The foliation was compositional type litage. It was essentially marked by an alternation of calcitic to quartzo-feldspathic clear stripes and dark ferromagnesian minerals stripes (Figure 5b). Orientation measurement 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 relative displacement of the separated compartments (diacase) to the outcrop (Figure 5a). These fractures are open and the two compartments were separated of some centimeters.



Figure 5: Foliation and fractures on white marble, 5a: Dry fracture, 5b: Compositional litage

4.3. Chemical analysis results

The bulk chemical composition of Bidzar white marble and dolomitic marble has been studied and are represented in table 2 and table 3 below respectively.

Table 2: Bulk chemical composition of Bidzar white marble

Samples	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Mn ₂ O ₃	LOI	Total
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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

As seen in this table 2, the white marble of the study area was characterized by a strong percentage in CaO (52.65 - 55.45%) (Figure 6),

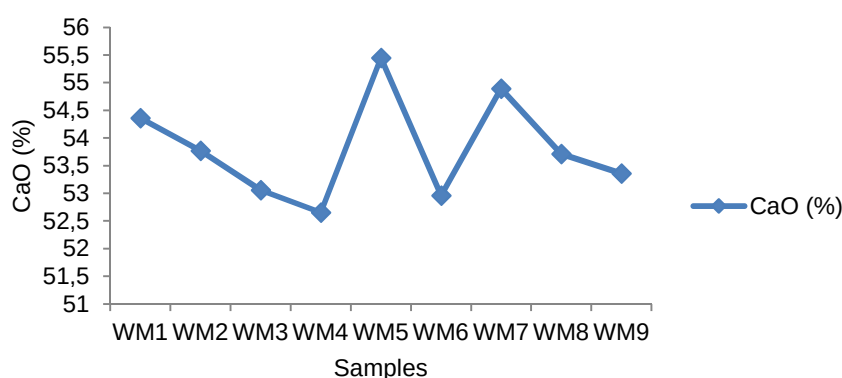


Figure 6: Evolution curve of the CaO percentages

The weak contents in MgO (0.65 - 1.45%) and SiO₂ (0 - 1.50%), the very weak contents in Al₂O₃ (0.1 - 0.21%), Fe₂O₃ (0.03 - 0.25%), SO₃ (0.06 - 0.07%), Na₂O (0.01 - 0.03%), K₂O (0 - 0.04%), TiO₂ (0 - 0.06%), P₂O₅ (0.02 - 0.11%) and Mn₂O₃ (0 - 0.02%). The losses of ignition were relatively high (41.64 - 42.92%). (Table 2).

The bulk chemical composition of Bidzar dolomitic marble has been studied and represented in the table 3 below.

Table 3: Bulk chemical composition of Bidzar dolomitic marble

Samples	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Mn ₂ O 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	0.04	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

As seen in the table 3 above, the dolomitic marble of the study area was less rich in CaO (30.15 - 31.78%), the relatively high contents in MgO (15.76 - 19.69%), (Figure 7)

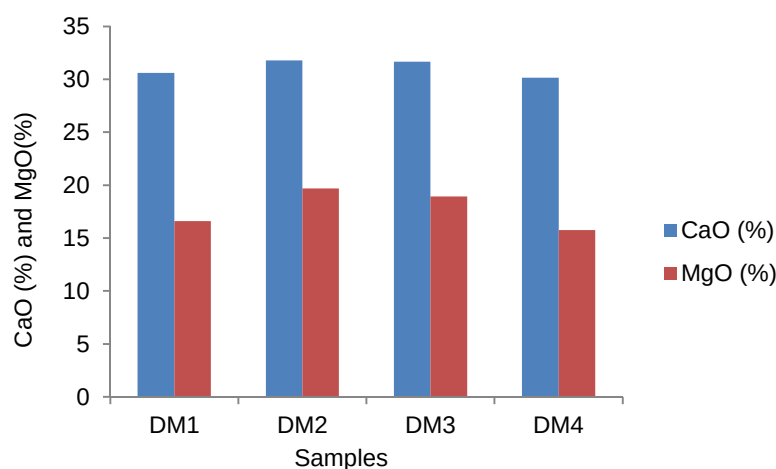


Figure 7: Histogram of variation of the percentages of CaO and MgO

The middle contents in SiO₂ (2.11 - 8.46%) and the very weak contents in Al₂O₃ (0.09 - 0.27%), Fe₂O₃ (0.28 - 0.65%), SO₃ (0.05 - 0.07%), Na₂O (0.01 - 0.08%), K₂O (0-0.02%), P₂O₅ (0.01 - 0.19%), Mn₂O₃ (0.02 - 0.13%). The losses of ignition were relatively high (41.9 – 46.35%) (Table 3).

4.4. Physical and mechanical Characteristics of Bidzar white marble

The physical and mechanical characteristics of Bidzar white marble as shown to the table 4 below.

Table 4: white marble physical and mechanical Characteristics

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

As seen in the table 4 above that the Bidzar white marble had an absolute density of 2.77 g/cm³, an bulk density of 2.75 g/cm³, a mechanical fragmentation strength of 32 and 31%, a wear strength of 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.

5. DISCUSSION

The geological study, the physical and mechanical characterization of the white marble have been led to propose an adequate solution to reduce the size of the blasting raw got from the Bidzar quarry.

The mineralogical composition and the size of the grains of the whole petrography 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, better crystals are welded and require a strong exploding load, therefore to dislocate them. Otherwise, the exploding load used to produce the leucocratic rocks is from afar 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. Two main directions and two secondary directions orientation of fractures are recorded: [NNW-SSE (N160°E) to N-S and NNE-SSW (N10°E)] relative to the main directions; [W-E and NNW-SSE (N140°E)] for the secondary directions (Figure 8). These fractures constitute weaknesses zones on the rocky massif likely to facilitate the fragmentation of the blocks. Then, the miner could orient the shootings plans following these different zones of weaknesses. Therefore, when the propagation of the exploding load, meets a discontinuity in a favorable direction, it deludes the performance of the exploding load whereas when this one meets an oriented discontinuity differently, it rather causes the deterioration of the results discounted.

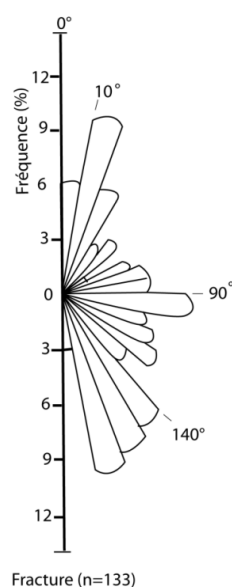


Figure 8: Rose window of main and secondary direction of fracturation in the formations of the study area. n = number of measure.

The standards values of the chemical composition of the vintage wished for the clinker manufacturing is shown in the table 5 below.

Table 5: Chemical composition of the vintage

Elements	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Mn ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O.K ₂ O	SO ₃	P ₂ O 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

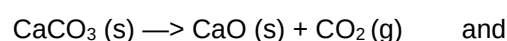
The proportions of the various oxides are bound above closely below the modules.

$$LSF = \frac{CaO}{2.8SiO_2 + 1.18Al_2O_3 + 0.65Fe_2O_3} = 98 \pm 1.0 \quad ; \quad \frac{SiO_2}{Na_2O + K_2O} = 1.5 \pm 0.1$$

$MS = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} \leq 2.65 \pm 0.5 \quad ; \quad MgO \leq 1.60$. The white marble of the study area is very rich in CaO; its average is 53.80%. It has less MgO and its average is 0.95%. So, the strong proportion of CaO (52.65% - 55.45%), the weak proportion of MgO (0.65% - 1.45%). Therefore $MgO \leq 1.60$ and the LSF (29.40 ± 1.0) in the white marble justifies its use as main raw material of the CPJ 35 and CPJ 45 cement. 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 vintage. 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 doorstep would entail the expansion of the cement in the mortar or the concrete while forming the hydroxide of magnesium ($Mg(OH)_2$) with reference to the equation below :

$MgO + H_2O \longrightarrow 2Mg(OH) + \frac{1}{2}O_2$ responsible of the inflation and withdrawal phenomenon at the origin of numerous cracks observed on the constructed works.

The LOI raised (41.64 – 42.92%) in the white marble and (41.9 – 44.99%) in the dolomitic marble could be bound to decarbonation of the calcium carbonates according to the equations:



$CaMg(CO_3)_2(s) \longrightarrow CaO(s) + MgO(s) + 2CO_2(g)$ on the one hand and of the strong presence of organic matters in the original materials on the other.

Otherwise, the table 6 below give the guide of assessment of the quality and the durability of the materials.

Table 6: guide of 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

As seen in the table 6 above that 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 having an excellent absolute density. This strong gotten value would be due to the weak porosity of this rock. Besides, this marble also has enough elevated bulk density ($2.75 g/cm^3$). This strong value would be related to the calcite density

(2.71 g/cm³), its principal constituting material and one of quartz of 2.65 g/cm³. The absolute and the bulk density are in most cases comparable. The chalky rocks and marbles present some densities related steady enough, extensively included between 2.67 and 2.78 g/cm³ (Hassani and al, 2009). The white marble of the study area is said to be less resistant. According to Duffaut and al, (2000); its value is lower to 100 MPa. For these authors, the values of the resistance are consisted rudely between 1 and 200 MPa; the values lower to 5 MPa correspond to rocks qualified of "very tender"; the values superior to 100 MPa characterizing some rocks are seen "Resistant". The white marble of the study area has an indirect tensile strength of 8.9MPa. This parameter determined from the method of ASTM - ISRM reference so classifies the white marble in the domain 5 - 10 characteristic of the rocks said satisfactory.

6. CONCLUSION AND RECOMMENDATION

The geological study, physical and mechanical characterization of the Bidzar quarry white marble incoming in the CPJ 35 and CPJ 45 cement manufacturing permits to bear out the following points:

- ❖ In the Bidzar quarry, white and dolomitic marble, quartzite and the green shale show on the surface.
- ❖ The white marble is affected by the foliation of compositional litage type 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 justified its strong use in the clinker manufacturing.
- ❖ The Bidzar white marble presents the features of a less resistant, satisfactory and limited rock.

On the structural plan, the products drifted of the exploitations would have the wished measurements if the plans of shootings are oriented according to the main directions of fracturation. Then, blasting operation is not a precise science but while considering the rocky formation itself, it is possible to produce the desirable results (Assakaf, 2003). Also, the production of the results discounted pass by the knowledge of some factors: the types of explosives, the quantities of explosives, the types of beginning, the sequence of beginning, the structure of the formation, the features of the explosives used, the mechanical features of the materials. Otherwise, some essential elements of the shooting plan must be thrown into relief. It is about notably of: bench (B), spacing (E), loading of the hole of foration (LF), report of consistence report (CR), powder factor / specific load (PF), surforation (S) (US. Department Transportation of Federal Highway Administration, 1991). After, it is necessary to add: stuffing (Sg), volume of material to cut down (VM) and the beginning (Bg). Then, B = 3.3 m; E = 4 m; LF = 69.4 kg; CR = 3.6; PF = 0.44 kg/m³; S = 1 m; Sg = 2.31 m; VM = 158.4 m³

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 the losses of energies by the use of the remnants of foration or gravels (of angular shapes and diameter d = 5,5mm because they resist the compression better in relation to the remnants of shapes flattened) to the level of the strata or layers of shales.

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