



Physico-chemical characterization of marble from Assiyo (Dassa-Zoumè) in Benin

Igor, B.A., AKODEDJROHOUN^{1*}, Etienne, V., SAGBO¹, David, DODOO-ARHIN²

¹Laboratoire de Chimie Physique, Matériaux et Modélisation Moléculaire (LCP3M), Faculté des Sciences et Techniques (FAST), Université d'Abomey-Calavi (UAC), Bénin

²BANGA Africa Energy & Hybrid Materials Lab, Department of Materials Science and Engineering, University of Ghana, Legon, Ghana

*Corresponding author: lediscipledelavoisier@gmail.com

Abstract The valorization of the natural resources located in Benin Republic, in particular, marble obtained from Assiyo (Dassa-Zoumè) was the purpose of this study. It was characterized to elucidate its properties for industrial applications. The results of the analysis by X-ray diffraction, infrared spectroscopy, X-ray fluorescence and thermal analysis showed that Assiyo marble is dolomitic limestone. This marble sample is basic with $\text{pH} \approx 8.6$. The particle size analysis of the powder particles of these marbles showed two major size fractions: 35 % of the particles have a size between 250 μm and 500 μm and 23 % of the particles have a size between 125 μm and 250 μm . These characteristics make this marble very good additives that can be used in the production of fertilizer, glass, cement, mortar, concrete and functional construction material. Assiyo marble can be used in metallurgy and as dolomite-based sorbent to remove pollutants from water.

Keywords marble; characterization; calcite; dolomite

1. Introduction

Marble is a naturally occurring stone mainly used in the construction industry [1][2][3][4][5] or as a raw material for artwork [6]. Since antiquity, it is one of the most frequently used materials for architecture and sculpture and therefore has been given an exceptional importance, particularly under the Romans [5][6]. The major phases constituting marble are either calcite (CaCO_3), or dolomite [$\text{CaMg}(\text{CO}_3)_2$] or both when they coexist in chemical equilibrium [2][3].

Some recent studies carried out by Topcu et al [7], Alyamac and Ince [8] showed that four different marble dusts produced in Turkey could be successfully and economically utilized as fillers in self-compacting concrete. Corinaldesi et al. [9], reported that marble powder proved to be very effective in assuring very good cohesiveness of mortar and concrete [9][10][11], even in the presence of a superplasticizing admixture [12], provided that water to cement ratio was adequately low.

Powdered marble can also be used as calcium and magnesium-based adsorbents for pollutants removal from drinking water, such as lead (II) ions [13][14][15][16][17], fluoride ions [18][19][20][21], copper (II) ions [22], cadmium (II) ions [16][17][23], zinc (II) ions [17], arsenic (III) [24], arsenate [25], strontium (II) [26], barium (II) [26], nickel (II) [23], catechol [27] and methylene blue [28][29].



According to OBRGM (Office Béninois des Recherches Géologiques et Minières) [30], the Assiyo marble deposit is currently being assessed in order to know the quantity. From available literature, studies have mainly been concentrated on the thermophysical properties of granite, marble and basalt deposits in Benin. They reported that granite is more insulating whiles marble has better ability to store heat [31]; however, no physicochemical characterization of the marbles were undertaken. The physical and chemical properties of natural stones play an important role in choosing their field of application especially as building stone.

This study carefully presents the results of the physicochemical characterization of eight marble samples taken from different regions of the Republic of Benin in order to demonstrate their different potential applications. X-ray diffraction analysis, granulometric study, thermal analysis, chemical analysis by X-ray fluorescence and infrared spectroscopy have been used to characterize this sample for its physical, thermal, chemical and microstructural properties.

2. Materials and Methods

2.1 The Study Area and Sample Collection

The marble sample was collected from deposit site of Assiyo (Dassa-Zoumè) in Benin. Information on the sample collected and the sampling areas are presented in Table 1 and Fig 1 respectively.

Table 1: The names of the village, municipality, department, and code of the sample studied

Department	Municipality	Village	Sample code
COLLINES	Dassa-Zoumè	Assiyo	ASS

After the sample collection in marble deposit site, the primary marble blocks were coarsely crushed into secondary marble blocks and taken to the laboratory for further evaluations.

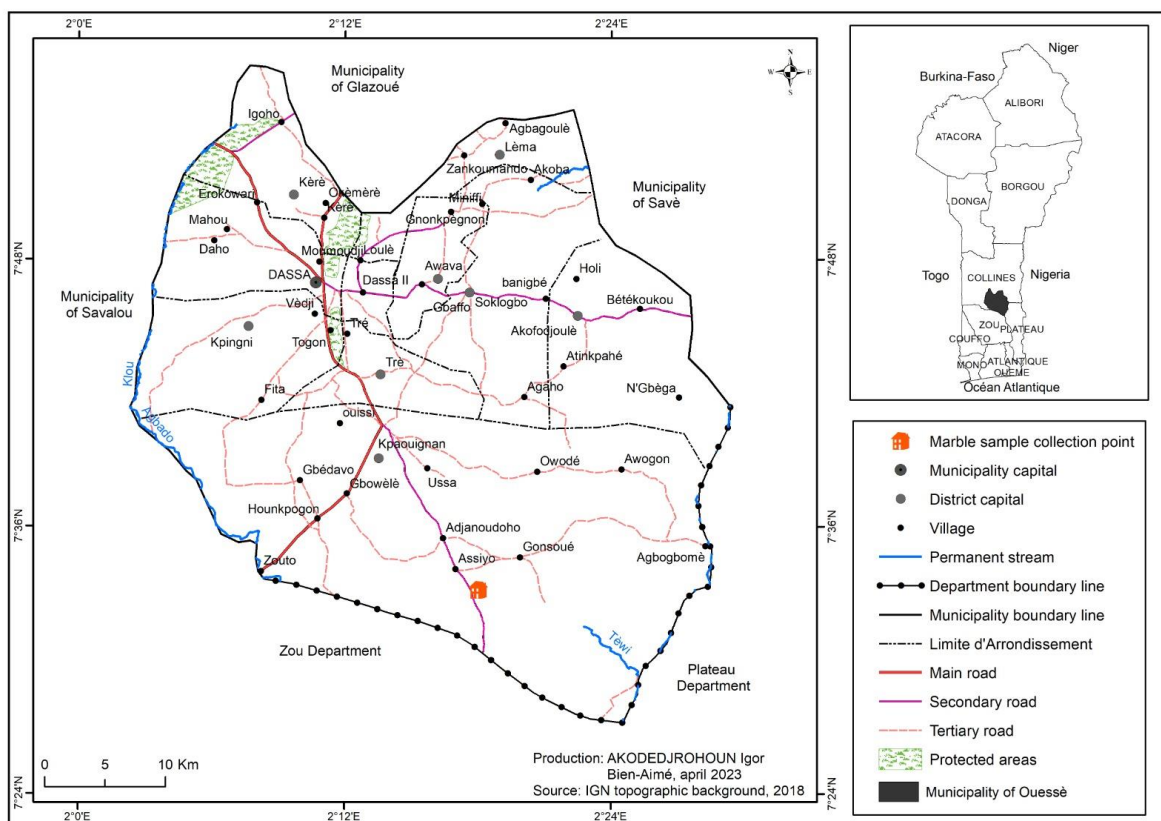


Figure 1: Map of Benin showing sample location



These secondary marble blocks were further crushed into coarse marble particles (aggregates) using a mass hammer mill to facilitate crushing: this is known as secondary crushing. These obtained marble particles were plundered in an aluminum mortar and then finely ground in a ceramic mortar. The marble powder obtained was sifted through a 500 micrometers mesh sieve. The sifted marble powder (*see Fig 2*) was stored at room temperature in clean plastic bottles.

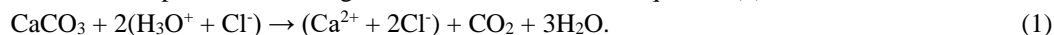


Figure 2: Pictures of marble and powder obtained after crushing

2.2 Methods

For the granulometric analysis, about 200 g of marble powder sample was sieved and separated into six different fractions by using Haver & Boecker sieves with mesh sizes ranging from 500 μm to 50 μm . With the aid of a Mettler-Toledo pH-meter, the pH of sample was determined according to the method used by Emofurieta *et al* [32]. Typically, 5 g each of crude marble powder was placed in two s 50 mL bottle of distilled water and magnetically stirred for 24 h and 48 h respectively. After this time, the colloidal solution was left standing for 12 hours to allow the settling of the marble suspensions; after which the pH measurement was performed on water supernatants [33]. Five separate tests were carried out and the average values taken.

The percentage mass of calcium carbonate in the powdered marble sample were measured using the back titration methodology. 1 g of each powdered marble sample was weighed and placed in labelled 250 mL conical flasks. Few drops of ethanol were added to the flasks to act as a wetting agent and catalyst for acid reactions. 50 mL of HCl solution (1.0 M) was then added to each of the labeled conical flasks, and swirled well to completely wet all the solids. The solutions in the flasks were magnetically stirred for 5 hours to allow the total dissolution of the carbonate (CaCO_3) contained in the powder according to the reaction showed in equation (1).



3-4 drops of phenolphthalein indicator were added to the flasks, while excess of unreacted acid was titrated against standardized NaOH solution (2 M), until barely pink color appears, persists for 30 s and fades slowly. The titration experiments were repeated 5 times to obtain concordant values. The mass percent of calcium carbonate in the powdered marble samples was determined using equation (2)

$$\%(\text{CaCO}_3) = \frac{m(\text{CaCO}_3)}{m(\text{marble powder})} \times 100 \quad (2)$$

X-ray powder diffraction (p-XRD) measurements were performed using a Philips diffractometer (PANalytical, X'pert Pro MPD model) with a Bragg-Brentano configuration equipped with a $\text{Cu-K}\alpha$ radiation (1.54059 \AA) tube operated at a voltage of 45 kV and current of 40 mA. The data of the randomly arranged powder sample were



collected in the $5^\circ - 80^\circ 2\theta$ value range with scan speed of $0.042^\circ/\text{sec}$, step size of 0.01° and a count time of 10.0 s per step. The diffraction patterns were matched against the ICDD's PDF database and qualitative phase analysis conducted using the X'Pert Highscore plus search match software (Panalytical, Netherlands).

The chemical composition of the marble sample was determined using a THERMOFISHER ARL PERFORM'X 2.5KW X-ray fluorescence spectrometer. The sample studied was analyzed in the form of pellets. Thus, 2 g of very fine powder are shaped into a uniform pellet with a diameter of 25 mm using a mold under a pressure of 8 to 15 tons.

Chemical bonding was analyzed by transmission infrared spectroscopy, using a Perkin Elmer 100 Series Fourier Transform Infrared (FTIR) spectrometer. Powdered marble sample was finely ground in a mortar and then mixed with potassium bromide (KBr) powder (1/100 by weight). The powder mixture was put in a 13 mm diameter mould and pressed at high pressure using a hydraulic press to form thin pellets. In order to minimize the amount of water adsorbed, the pellets were heated in a furnace overnight at 100°C . Spectra data were recorded and analysed using the Spectrum 10™ software within the $4000 - 450\text{ cm}^{-1}$ spectral range in transmission mode.

Thermal analysis, i.e. thermogravimetry (TG) and differential thermal analysis (DTA), were performed by using a SETARAM LABSYS system, from ambient temperature to 1000°C , using a $20^\circ\text{C}/\text{min}$ heating rate and a 100 ml/min nitrogen flow. The measurement was made using about 8 mg of powdered marble in a $100\ \mu\text{L}$ alumina crucible.

3. Results and Discussion

3.1 Measurements of pH and carbonate content

The pH of the suspensions indicates the level of alkaline or acidic species contained in the marble powder. The average pH values of the ASS marble sample (Fig.3) are approximately equal to 8.6 for suspensions stirred for 24 h and 48 h. These measured pH values are therefore higher than the neutral pH value (7.00), showing that suspensions are basic: an indicator of the presence of alkaline species in the ASS marble powder. These results are close to those reported by Ahmed *et al* [11], on the potential use of marble and granite solid wastes as environmentally friendly coarse particulate in civil construction.

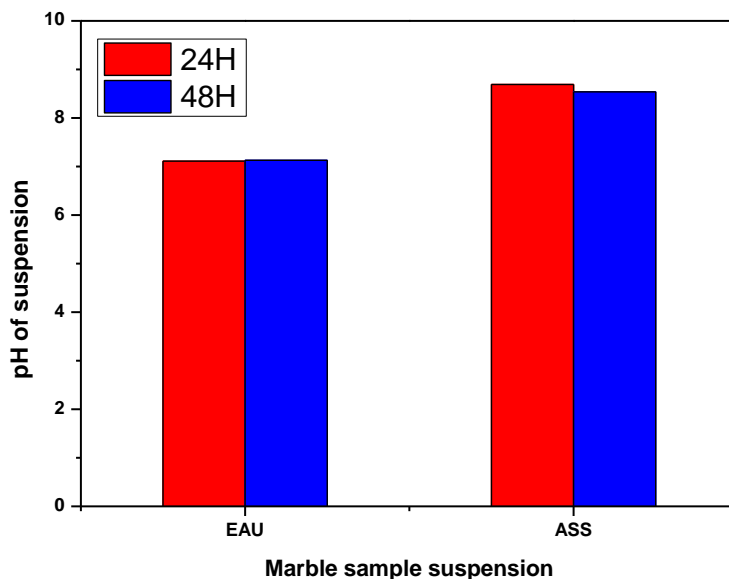


Figure 3: The average pH of the ASS marble sample

The percentage carbonate content in the ASS marble sample is presented in Fig 4. This result revealed high carbonate content (72.4 wt.%) for ASS sample. This suggests that ASS sample is carbonated.



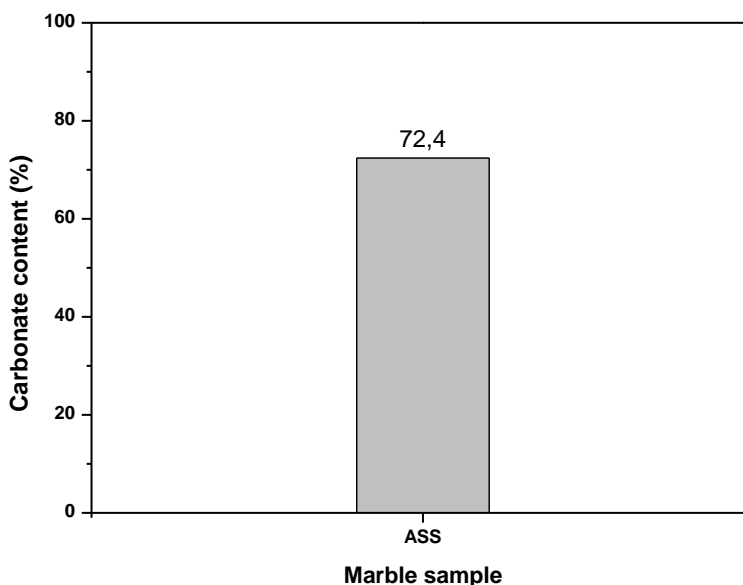


Figure 4: Carbonate content of the ASS marble sample

3.2 Particle Size Distribution

From the particle size distribution results presented in Fig. 5, the ASS sample could be categorized into three size fractions. The first size fraction is in the range of 250 μm and 500 μm , the second size fraction is between 125 μm and 250 μm ; and the third size fraction is between 63 μm and 125 μm . These results showed that for the marble powder sample, only about 19 wt.% of the grains have a size < 63 μm and therefore, can be used to reinforce concrete.

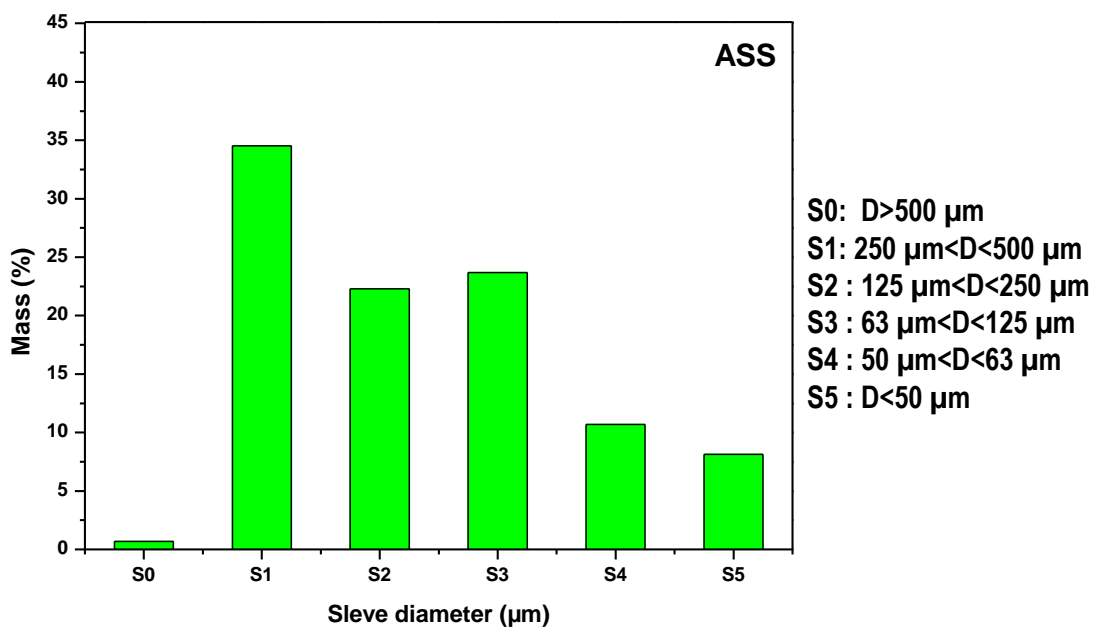


Figure 5: Histogram of the granulometric repartition of the ASS marble powder

3.3 X-ray Diffraction (p-XRD)

Fig. 6 shows the p-XRD patterns of the ASS marble sample. The diffraction peaks of ASS sample were matched with ICDD PDF-no. 01-085-1108 and 98-008-7088 which indicated the presence of Calcite (CaCO_3) and Dolomite

[CaMg(CO₃)₂], respectively. The main reflections of calcite and dolomite have almost the same intensity for ASS marble. Attributions of calcite and dolomite reflections are in good agreement with those reported on marbles characterization [2][3][9][34][35][36][37].

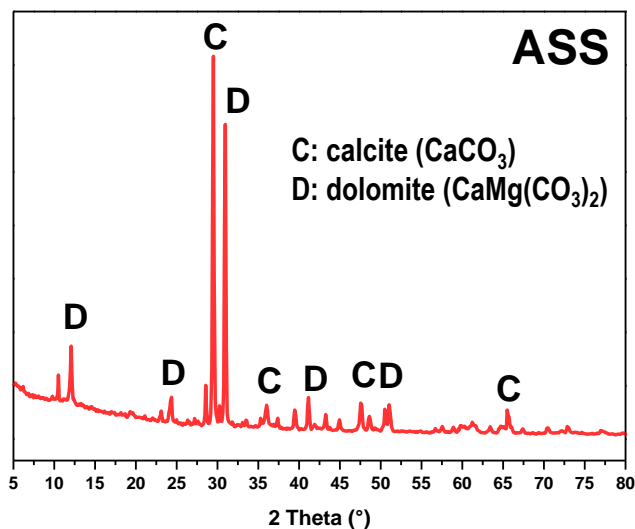


Figure 6: XRD pattern of ASS marble sample

3.4 XRF chemical analysis

The chemical composition of the IDA marble sample was determined by an X-ray fluorescence spectrometer. The analysis revealed the results grouped in Table 2 below.

Table 2. Chemical composition of the studied marble powder sample (% by weight).

Sample	Composition in %								
	CaO	MgO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	Na ₂ O	LOI	TOTAL
ASS	30,65	19,18	13,86	00,36	00,55	00,01	00,07	34,93	99,61

According to Table 2, high amounts 30.65% and 19.18% of calcium (CaO) and magnesium (MgO) oxides respectively were observed, showing that ASS essentially contain dolomite or calcite (CaCO₃) and dolomite [CaMg(CO₃)₂] [24][27][38]. The loss on ignition, symbolized by L.O.I., essentially represents carbon dioxide (CO₂) from the calcite and dolomite contained in this sample and revealed by X-ray diffraction. The percentage of other oxides (SiO₂, Al₂O₃, K₂O, Na₂O and Fe₂O₃) is negligible (almost zero) except for the silica (SiO₂) contents which reached 13.86%.

3.5 Fourier Transformed Infrared Spectroscopy

Fig. 7 shows the FT-IR analysis spectra of the ASS marble sample. The main bands of absorption obtained from Fig. 6, are regrouped in Table 3.

Table 3 Main bands of FT-IR absorption and associated bond vibration of ASS marble sample

Fundamental frequencies (cm ⁻¹)		Modes of vibration
713	v ₄	In-plane bending mode of CO ₃ ²⁻
877	v ₂	Out of plane bending mode of CO ₃ ²⁻
1414	v ₃	Asymmetric stretching mode of CO ₃ ²⁻
1810	v ₁ + v ₄	Combination of vibrations of v ₁ and v ₄
3470	v	Symmetric OH stretch in H-O-H

The spectra of ASS marble sample shows the bands observed at 713 cm⁻¹, 877 cm⁻¹, the broad band at 1414 cm⁻¹ and 1810 cm⁻¹ representing vibration bands of carbonate radicals which is due to the presence of dolomite and calcite mineral [39][40] in the ASS marble sample. This result corroborated with those obtained by carbonate content



(section 3.1), XRD (section 3.3) and XRF (section 3.4) in this study, revealed the presence of mixture of calcite-dolomite in the ASS marble.

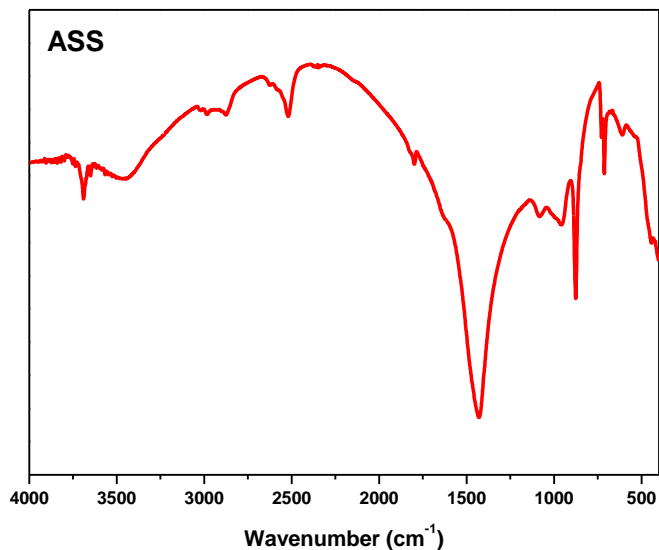
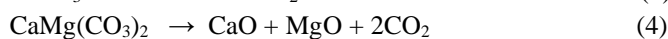
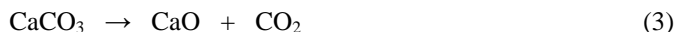


Figure 7: FT-IR spectra of ASS sample

3.6 Thermogravimetric/Differential Thermal Analyses

The TGA/DTA curves show the thermal decomposition under nitrogen flow for the ASS sample.

The curve of the ASS sample (in Fig. 8) shows a loss of mass. This mass loss begins slowly at 350 °C. It goes from 350°C up to 650°C (loss of 4.2 %) and increases between 650°C and 825°C with a loss of 29.1 %, i.e. a total of 33.3 %. The mass loss observed at the level of ASS is low compared to the others because it contains silicon oxide (SiO₂) up to 13.86 %. As for the DTA curves, an endothermic peak is observed at 800 °C with a splitting at 710 °C which shows in addition to the presence of calcite, the presence of dolomite which decomposes in two stages [27][41][42][43][44][45][46][47][48]. The resolution at 710 °C indicates the decomposition of the magnesium carbonate contained in the dolomite into magnesium oxide (MgO) and carbon dioxide (CO₂). The endothermic peak at 800 °C indicates the decomposition of calcium carbonate from calcite and dolomite. These different reactions give the following equations:



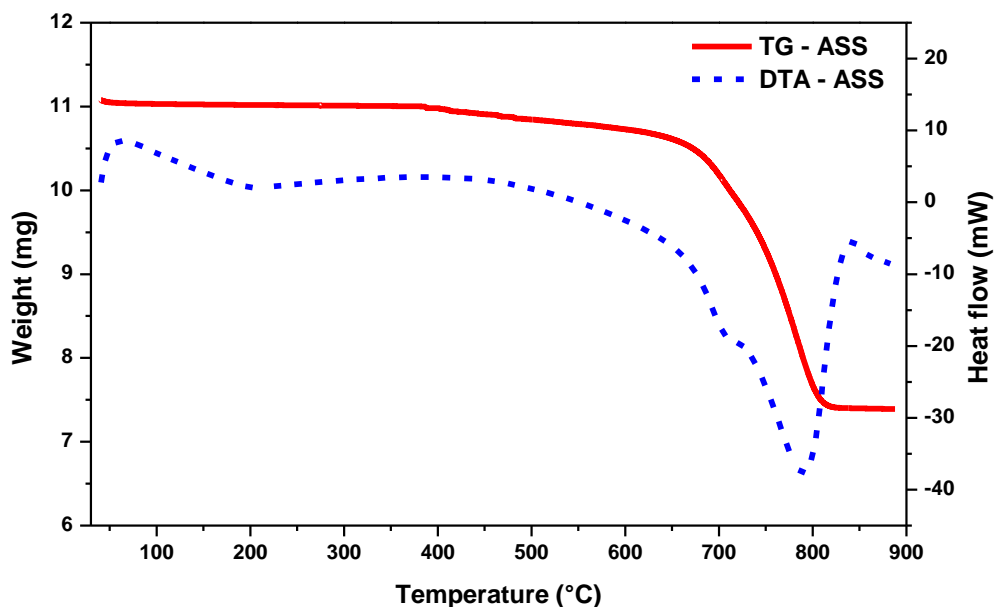


Figure 8: TG-DTA curves of ASS marble sample

4. Conclusion

The following conclusions have been drawn from this study: ASS marble is dolomitic limestone. This sample is basic ($\text{pH} \approx 8.6$). The particle size study of the powder of this sample shows two major size fractions: 23 % of the particles have a size between 125 μm and 250 μm and 35 % of the particles have a size between 250 μm and 500 μm .

The characteristics obtained make this marble very good additives that can be used in the production of fertilizer, glass, cement, mortar, concrete and functional construction material. ASS marble can be used in metallurgy and as dolomite-based sorbent to remove pollutants from water.

References

- [1] E. Gokul, P. Sharma, and D. K. Singhal, "A New Technology of Marble Slurry Waste Utilization in Buildings .," pp. 2289–2291, 2017.
- [2] S. Khrissi, M. Haddad, and L. Bejjit, "Caractérisation spectrométrique de marbres du Maroc : étude de provenance," no. December, 2019.
- [3] M. E. A. and C. F. S Khrissi, M Haddad, L Bejjit, S Ait Lyazidi, "Raman and XRD characterization of Moroccan Marbles," *Mater. Sci. Eng.*, 2017.
- [4] D. B. MANPREET SINGH, ANSHUMAN SRIVASTAVA, "Potential applications of marble dust in industrial use by characterization techniques – a review," *Int. J. Adv. Struct. Geotech. Eng.*, vol. Vol. 05, doi: ISSN 2319-5347.
- [5] K. C. G. Vagenas N. V., "A methodology for quantitative determination of minor components in minerals based on FT-Raman spectroscopy: The case of calcite in dolomitic marble," *Vib. Spectrosc.*, vol. 32(2), p. pp.261-264, 2003.
- [6] S. D. E, "Thermal deterioration of marbles: Gloss, color changes," *Constr. Build. Mater.*, pp. 102 416–21, 2016.
- [7] U. T. Topcu IB, Bilir T, "Effect of waste marble dust content as filler on properties of self-compacting concrete," *Constr Build Mater*, vol. 23, pp. 1947–53., 2009.
- [8] I. R. Alyamac KE, "A preliminary concrete mix design for SCC with marble powders," vol. 23, pp. 1201–10, 2009.
- [9] V. Corinaldesi, G. Moriconi, and T. R. Naik, "Characterization of marble powder for its use in mortar and



- concrete,” *Constr. Build. Mater.*, vol. 24, no. 1, pp. 113–117, 2010, doi: 10.1016/j.conbuildmat.2009.08.013.
- [10] S. A. Khedr, S. El-haggar, and R. Hamza, “Utilization of Marble and Granite Waste in Concrete Brick Marble and Granite Waste : Characterization and Utilization in Concrete Bricks,” no. January, 2011, doi: 10.7763/IJBBB.2011.V1.54.
- [11] H. M. A. G. S. A. A. Ahmed, “Potential use of marble and granite solid wastes as environmentally friendly coarse particulate in civil constructions,” *Int. J. Environ. Sci. Technol.*, no. 0123456789, 2020, doi: 10.1007/s13762-020-03014-2.
- [12] G. Civil, “VALORISATION DE LA POUDRE DE MARBRE COMME ADDITIF DANS LA FORMULATION DE BETONS AUTOPLAÇANTS CHAÏD Rabah 1 , HADDADOU Naïma 2 , HAMZA Malika Sabria 1 , MESBAH Habib Abdelhak 3,” pp. 11–19, 2021.
- [13] S. Kocaoba, “Comparison of Amberlite IR 120 and dolomite ’ s performances for removal of heavy metals,” vol. 147, pp. 488–496, 2007, doi: 10.1016/j.jhazmat.2007.01.037.
- [14] Z. Campus, Z. Campus, and Z. Campus, “on Limestone and Dolomite Tailings,” pp. 199–204, 2014.
- [15] M. Irani, M. Amjadi, and M. Ali, “Comparative study of lead sorption onto natural perlite , dolomite and diatomite,” *Chem. Eng. J.*, vol. 178, pp. 317–323, 2011, doi: 10.1016/j.cej.2011.10.011.
- [16] A. Sdiri, “Physicochemical Characterization of Natural Dolomite for Efficient Removal of Lead and Cadmium in Aqueous Systems,” vol. 00, no. 00, pp. 1–8, 2018, doi: 10.1002/ep.12893.
- [17] N. Yamkate, S. Chotpantararat, and C. Sutthirat, “Removal of Cd , Pb and Zn from contaminated water using dolomite powder,” vol. 7039, no. April, pp. 0–39, 2017, doi: 10.1080/10807039.2017.1309264.
- [18] S. K. Nath and R. K. Dutta, “Fluoride removal from water using crushed limestone,” vol. 17, no. March, pp. 120–125, 2010.
- [19] S. K. Nath and R. K. Dutta, “Fluoride removal from water using crushed limestone,” no. March 2010, 2016.
- [20] M. Poonam, G. Suja, and M. Dhiraj, “Use of Calcite for Defluoridation of Drinking Water in Acidic medium,” vol. 4, no. 6, pp. 62–65, 2014.
- [21] R. Mohan and R. K. Dutta, “Journal of Environmental Chemical Engineering A study of suitability of limestone for fluoride removal by phosphoric acid-crushed limestone treatment,” *J. Environ. Chem. Eng.*, vol. 8, no. 6, p. 104410, 2020, doi: 10.1016/j.jece.2020.104410.
- [22] G. Qiu, Q. Xie, H. Liu, T. Chen, J. Xie, and H. Li, “Applied Clay Science Removal of Cu (II) from aqueous solutions using dolomite – palygorskite clay : Performance and mechanisms,” *Appl. Clay Sci.*, vol. 118, pp. 107–115, 2015, doi: 10.1016/j.clay.2015.09.008.
- [23] P. Taylor, M. Mohammadi, A. Ghaemi, M. Torab-mostaedi, and M. Asadollahzadeh, “Desalination and Water Treatment Adsorption of cadmium (II) and nickel (II) on dolomite powder,” no. July 2014, pp. 37–41, 2013, doi: 10.1080/19443994.2013.836990.
- [24] K. H. Shah, M. Ayub, M. Fahad, and M. Bilal, “Natural dolomite as a low-cost adsorbent for efficient removal of As (III) from aqueous solutions Natural dolomite as a low-cost adsorbent for efficient removal of As (III) from aqueous solutions,” no. Iii.
- [25] G. M. Ayoub and M. Mehawej, “Adsorption of arsenate on untreated dolomite powder,” vol. 148, no. February, pp. 259–266, 2007, doi: 10.1016/j.jhazmat.2007.02.011.
- [26] A. Ghaemi, M. Torab-mostaedi, and M. Ghannadi-maragheh, “Characterizations of strontium (II) and barium (II) adsorption from aqueous solutions using dolomite powder,” *J. Hazard. Mater.*, vol. 190, no. 1–3, pp. 916–921, 2011, doi: 10.1016/j.jhazmat.2011.04.006.
- [27] I. W. A. Publishing and W. Science, “Removal of catechol from water by modified dolomite : performance , spectroscopy , and mechanism Aouda Khalfa , Senia Mellouk , Kheira Marouf-Khelifa and Amine Khelifa,” pp. 1920–1930, 2018, doi: 10.2166/wst.2018.071.
- [28] S. M. MM Hamed, IM Ahmed, “Adsorptive removal of methylene blue as organic pollutant by marble dust as eco-friendly sorbent,” *J. Ind. Eng. Chem.*, vol. 20 (4), pp. 2370–2377, 2014.
- [29] C. R. K. Haddad, S. Jellali, S. Jaouadi, M. Benlifa, A. Mlayahb, A. H. Hamzaoui, “No Title,” *Chime*, 2014, doi: <http://dx.doi.org/10.1016/j.crci.2014.07.006>.



- [30] L. ministre de l'Eau et des M. du Bénin, *Les potentialités minières du Bénin*. [Online]. Available: <https://eau-mines.gouv.bj/potentialites-minieres/#ii.2.2-marbre>
- [31] M. Ambelohoun, B. K., Toukourou, C., Fannou, J.-L., Semassou, C., & Anjorin, "Thermophysical Characterization of Granite, Basalt and Marble Ornamental Stones in Benin," *Curr. J. Appl. Sci. Technol.*, vol. 1–6, p. 37(1), 2019, doi: <https://doi.org/10.9734/cjast/2019/v37i130267>.
- [32] C. S. Emofurieta WO, Kayode AA, "Mineralogy, geochemistry and economic evaluation of Kaolin Deposit near Ubulu – Uku, Awo- Omana and Buan in Southern Nigeria," *J Min Geol*, vol. 28, pp. 210–281, 1992.
- [33] I. B. Edem CA, Malu SP, "Characterization and beneficiation of the glass making potentials of silica sand deposit from River Benue North Central Nigeria," *J Nat Sci Res*, vol. 4(19), pp. 49–58, 2014.
- [34] S. Gunasekaran, G. Anbalagan, and S. Pandi, "Raman and infrared spectra of carbonates of calcite structure," no. March, pp. 892–899, 2006, doi: 10.1002/jrs.1518.
- [35] H. Ouali and R. Ajakane, "Caractérisation et valorisation du calcaire métamorphique de Bou-Acila (Maroc central) [Characterization and valuation of metamorphic limestone of Bou-Acila (central Morocco)]," vol. 11, no. 3, pp. 778–784, 2015.
- [36] L. Lindawati, I. Irwansyah, N. Fitriadi, and M. Silviana, "Physical-Chemical Characteristics of South Aceh Marble and Its Suitability for Tiles Application," vol. 5, no. 1, pp. 1–5, 2020, doi: 10.31572/inotera.Vol5.Iss1.2020.ID93.
- [37] G. S. and A. G., "Optical absorption and EPR studies on some natural carbonate minerals," *Spectrochim. Acta, Part A*, vol. 69, pp. 383–90, 2008.
- [38] B. K. Shahraki, B. Mehrabi, R. Dabiri, and K. Blv, "THERMAL BEHAVIOR OF ZEFREH DOLOMITE MINE (CENTERAL IRAN)," no. 1, pp. 35–44, 2009, doi: 10.2298/JMMB0901035S.
- [39] S. Gunasekaran and G. Anbalagan, "Spectroscopic characterization of natural calcite minerals," vol. 68, pp. 656–664, 2007, doi: 10.1016/j.saa.2006.12.043.
- [40] Y. Kim, M. Caumon, O. Barres, A. Sall, and J. Cauzid, "Identification and composition of carbonate minerals of the calcite structure by Raman and infrared spectroscopies using portable devices Spectrochimica Acta Part A : Molecular and Biomolecular Spectroscopy Identification and composition of carbonate minerals of the calcite structure by Raman and infrared spectroscopies using portable devices," *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.*, vol. 261, no. June, p. 119980, 2021, doi: 10.1016/j.saa.2021.119980.
- [41] M. O. M. Jablonski, "Thermal behavior of natural dolomite," no. March 2014, pp. 2239–2248, 2015, doi: 10.1007/s10973-014-4301-6.
- [42] W. Wulandari, P. M. Adinata, and A. Fajrin, "Thermal decomposition of dolomite under CO₂ -air atmosphere Thermal Decomposition of Dolomite under CO₂ -Air Atmosphere," vol. 040006, no. January 2017, 2019, doi: 10.1063/1.4974427.
- [43] H. Qian, W. Kai, and X. Hongde, "Thermochimica Acta A novel perspective of dolomite decomposition : Elementary reactions analysis by thermogravimetric mass spectrometry," *Thermochim. Acta*, vol. 676, no. December 2018, pp. 47–51, 2019, doi: 10.1016/j.tca.2019.03.042.
- [44] D. Decompositionx, "t Communication No. 3 on the thermal decomposition of dolomite. 166," no. 3, 1951.
- [45] E. S. P. B. V, R. M. Mcintosh, J. H. Sharp, and F. W. Wilburn, "The thermal decomposition of dolomite," vol. 165, pp. 281–296, 1990.
- [46] P. G. Caceres and E. K. Attiogbe, "THERMAL DECOMPOSITION OF DOLOMITE A N D THE EXTRACTION OF ITS CONSTITUENTS," vol. 10, no. 10, pp. 1165–1176, 1997.
- [47] C. R, K. K, and E. R, "The mechanism of thermal decomposition of dolomite : New insights from 2D-XRD and TEM analyses," vol. 97, p. 18071, 2012.
- [48] S. Gunasekaran and G. Anbalagan, "Thermal decomposition of natural dolomite," no. August, 2007, doi: 10.1007/s12034-007-0056-z.

