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Effect of waste marble powder on the properties of white mortar made from tuff

H. Sellaf [a]* and B. Balegh[b]

[a] Department of civil engineering and hydraulic, Faculty of Technology, Saida University, BP 138, DZ-20000, Saida, Algeria.

[b]Department of technology science, Faculty of Technology , Adrar University, DZ-01000, Adrar, Algeria.

[1]LGCE, Environmental and Civil Engineering Laboratory. Faculty of Technology, SidiBel Abbes University, BP 89, DZ-22000, SidiBel Abbes, Algeria.

*Corresponding author, email:hamid.sellaf@univ-saida.dz

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Abstract

The preservation of ancient archaeological structures calls for generic and analogous basic materials. The production and use of marble generates a significant amount of waste, which creates environmental problems. This study investigates the impacts of using waste marble powder and tuff as a replacement for conventional natural aggregate mortar with a low cement content of 5%. Compressive strength and dry density tests were conducted on all mortar specimens. Additionally, the ultrasonic pulse speed and tensile strength of mortar samples and their blends with various marble powders (5, 10, 15%, and 20%) were examined. Results show that mass, pulse speed of ultrasonic, tensile strength, and compressive tensile strengths increased as the quantity of marble powder increased. Large quantities of marble powder are needed to make restoration mortar, and this contributes to the recycling of waste marble.

Keywords: Mortar; Tuff; Waste marble powder; Physical performances; Mechanical performances

1. Introduction

Due to heavy loads, soil collapse, earthquakes, and wind influences, old buildings are vulnerable to a number of fissures and collapses. To guarantee stability and resistance, these challenges must be addressed. Mortar serves as a binding agent for the stones and aids in the distribution and transfer of loads inside the construction. Prior to the invention of cement in 1850 [1], there were four different varieties of old mortar that were utilized, including plaster mortar, hydraulic stable, geo-lime mortar, and air-lime mortar [2]. Additionally, foundling mortar, a cement and lime mixture now employed in the restoration of masonry, is applied. Cement mortars are used more frequently in monument restoration because they have higher mechanical resilience than ordinary mortars [3]. Contrarily, using cement mortar for rehabilitation is not advised because it can decrease the permeability of the wall [4].

Tuff is a locally accessible building material that has been used since the pre-Roman era in the Pannonian-Carpathian region. They can be found in forts, castles, thrush, and other buildings [5]. Many researchers have recently demonstrated that tuff's qualities have been demonstrated by several analyses [6], and its potential application as an additive in mortar or concrete composition [7–8] or as lightweight concrete blocks [9] has also been raised, as has the use of mortars based on lime and polypropylene fibers to restore stone constructions [10]. In the current experimental research, the tuff slurry was mechanically assessed to enhance its fresh and solid properties, with particular emphasis on the chemical influence of low cement (5%), since the penetration of cement through the matrix of the tuff slurry can speed up the breakdown of the mixtures.

Metamorphic rocks include marble, which is defined. Rocks that have undergone metamorphism are created from other substances that are already present on the earth's surface. In terms of geology, marble is produced from limestone and is a crystallized kind of dolomite or limestone. Marble waste powders are produced in the construction industries. When marble rocks are cut and polished into suitable floor slabs for buildings, as well as during quarry activities. However, the disposal of marble particles has created a number of environmental problems that can lead to pollution, environmental damage, and health risks due to extraction activities and airborne particles. Thus, the use of marble powder has been considered a sustainable and beneficial raw material substitute in the manufacture of concrete [11] and mortar, which also helps to preserve the environment [12–15].

This study was to investigate the effect of waste marble powder in different percentages (5–20% by weight) and tuff with low cement content on the mechanical and physical characteristics of mortar in terms of composite adhesion. The physical, mineralogical, and mechanical tests, which include the sum of the tests dry-mixed, packing density, hardened density, and water absorption properties of the mortar block, were conducted. Their use would convert a chemical industry waste into a benefit for the construction and restoration industries.

2. Material and methods

2.1. Materials

2.1.1 Tuff

The investigation was mainly concerned with the utilization of calcareous tuff which is available in abundant quantities in the state of Mascara. The calcareous tuff material was brought from the quarries of Tizi (Mascara, West Algerian).This sample was put through several laboratory identification tests utilizing the AFNOR and ISO standards' established protocols [16–18]. The findings are reported in Table 1. Specific gravity of 1.97 for the Tuff. The distribution of tuff particle sizes is shown in Figure 1. The chemical analysis of the species was carried out in accordance with NF EN 1744 [19], and the findings are shown in table 2.

The main components of tuff, according to Figure 2(a, and b) of XRD patterns, are calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and quartz (SiO_2).

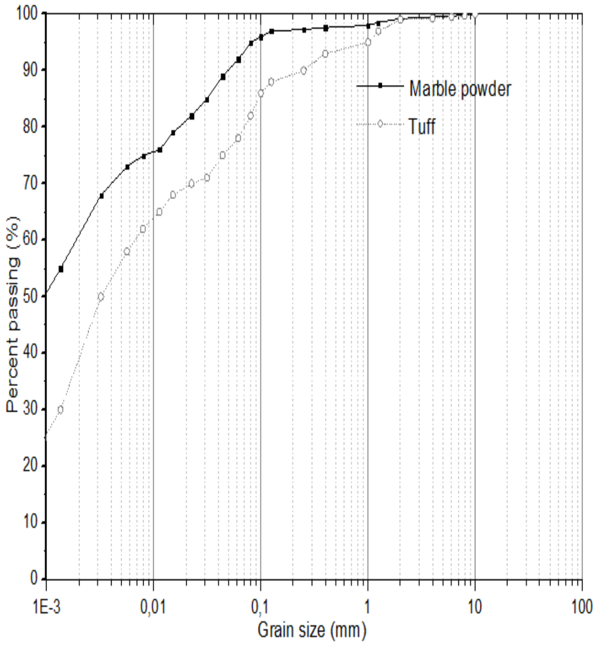

Figure 1. Grain size distribution of studied materials

2.1.2. Marble powder

In this study, samples of marble powder were collected after breaking and grinding marble waste, and this powder was then put through multiple laboratory identification tests in accordance with standard practices approved by the Standards

As shown in Table 1. The specific gravity of marble powder is 2.68,

Table 2 shows the chemical analysis of marble powder following the NF EN 1744 standard. The main components of marble powder are calcite ($CaCO_3$), albite (Al_2O_3), and quartz (SiO_2).

2.1.3. Cement (C)

The cement utilized in this study is regular Portland cement (CPJ), which is prepared from 76% clinker, 18% calcareous, and 6% gypsum. An analytical chemical analysis of the cement is presented in Table 2.

Table 1: Some properties of the investigated tuff and marble powder.

	Properties	Marble powder	Tuff
Consistency limits : NF: 94051	Liquid limit (%)	32	39
	Plastic limit (%)	-	23
	Plasticity index (%)	-	16
Specific weight NF: P 94-054	Specific weight	2.68	1.97
Grains sizes analysis NF: P 94-057	Sand (%)	5	22
	Silt (%)	39.60	50
	Clay (%)	55.40	28
	γopm	1.76	1.96
Compaction NF P 94-093	VB (cm3)	0.12	0.85
	SST (m²/g)	2.52	17.85

Table 2: Chemical compositions of Tuff, Marble powder, and cement.

Property	Marble powder	Tuff	Cement
SiO_2 (%)	23.56	9.56	20.19
Al_2O_3 (%)	4.64	2.65	5.23
Fe_2O_3 (%)	2.89	0.58	4.56
CaO (%)	62.32	70.25	56.90
MgO (%)	1.36	2.61	2.01
NaOH (%)	0.08	4.90	0.15
Cl (%)	0.15	0.25	0.21
SiO_3 (%)	0.02	1.2	3.2
$P.F_2$ (%)	4.98	8	7.55

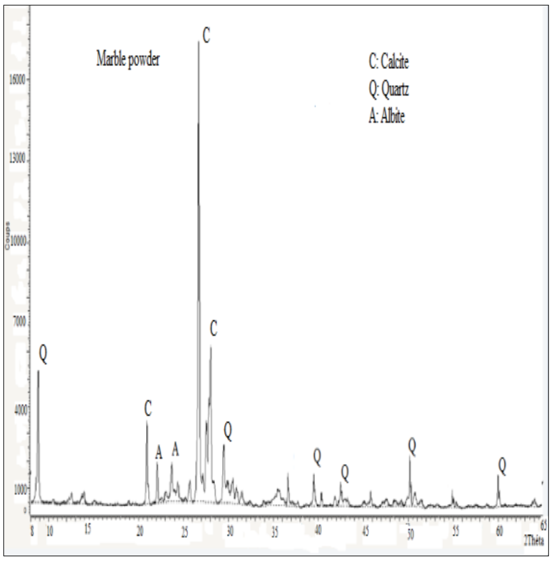

Figure 2 a. XRD patterns and identified phases of Marble powder

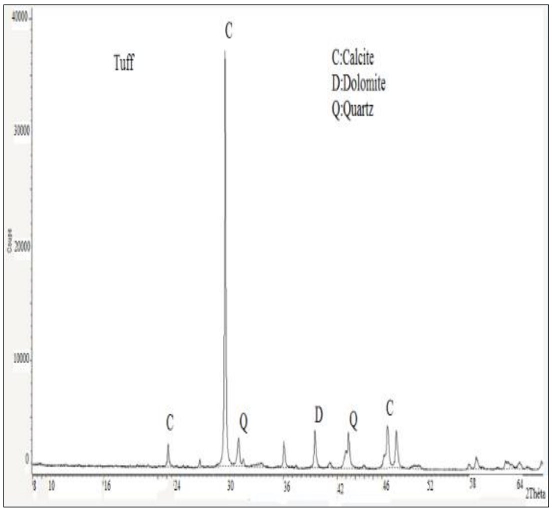

Figure 2 b. XRD patterns and identified phases of Tuff

2.2. Mortar mix proportion

The contents of marble powder were chosen as 5, 10, 15.0%, and 20% of the total weight of reinforced samples, according to previous work experience [20–22].

According to EN 196-1 [23] standards, mixing procedure was followed to prepare the specimens. Cube specimens (40 mm) were produced to tests compressive strength, Bulk density, Ultrasonic pulse velocity, and Water absorption coefficient. Mortar prisms of 40 to 40 to 160 mm^3 were used for test tensile strength.

A fixed cement-tuff ratio of 5% was utilized for all mixes. The compressive strength, tensile strength, and Ultrasonic pulse velocity were tested at 14, 28, 56, 72, and 96 days according to the standards mentioned later. The same mixtures were used to determine the Bulk density of dry mortar at 28 days according to standards.

The mortar samples were cured in the laboratory for 24 hours at 20 C° and about 50% relative humidity.

A Partial composition of mortars is given in Table 4.

The mixture code consists of a letter that indicates the type of marble powder contents.

Table 3: Compositions of mortar (kg/m3).

Mixture code	MT	MTM 5	MTM 10	MTM 15	MTM 20
Tuff	1862	1764	1666	1568	1470
Water	225	225	225	225	225
Marble powder	-	98	196	294	392
Cement	98	98	98	98	98

3. Results and Discussion

3.1. Consistency limits

According to the AFNOR NF P 94-051[24] standard, Atterberg limit tests were performed to establish the upper and lower bounds for the consistency of the values of the tuffs and their mixtures.

Figure 3 illustrates how marble powder affects the maximum consistency standards for combinations. The liquid limits are expected to drop steadily as the marble powder content of the mixes increases.

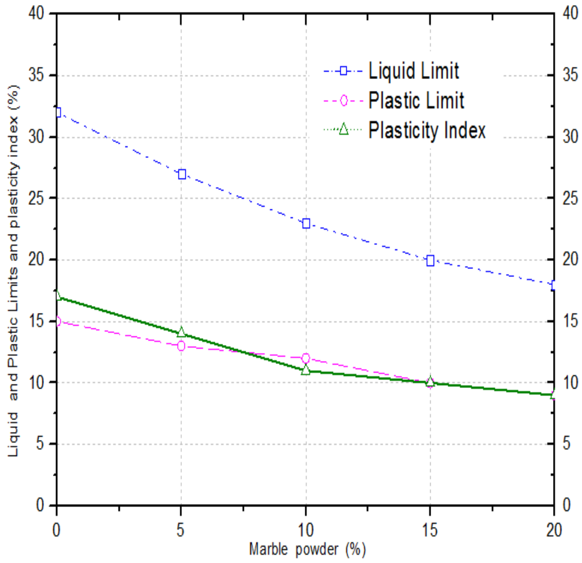

Figure 3 Effect of marble powder on the consistency limits of tuff

The plastic limit decreases for the sample with 5% of marble powder, then decreases gradually and is equal to half the plastic limit of the mixture for the samples with 0% of marble powder. Changes in the consistency limits of mixtures may be due to the type of combination, the capacity for cation exchange, and the relative amount of clay minerals in the mixtures [25–27]. These outcomes are comparable to those of soil types with fine-grained particles that are consistent with mild plasticity.

3.2. Bulk density of fresh mortar

According to European Norm EN 1015-6 (1998) [28], this test was conducted. Figure 4 shows the values of the bulk density variation of the mortars made with different ratios of marble powder. The bulk density values of the mortars prepared with 0%, 5%, 10%, 15%, and 20% marble powder were 2090, 2040, 2020, 2010, and 1990 kg/m3, respectively. Evidently, as the marble powder content increased, the bulk density decreased. The bulk density of the original mortar decreased by 5.02% upon the partial replacement of tuff with marble powder. The finding is consistent with those of [16], who reported that as the rate of powders (granite, ceramic, or marble) increased [29–31], substitution with soil increased. It has been determined that the bulk density of new mortar considerably decreases in direct proportion to the amount of powder added to the mixture.

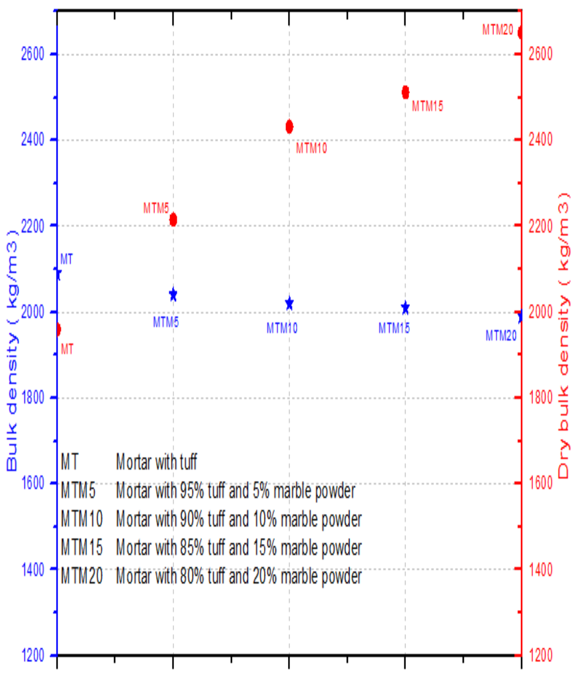

Figure 4. Effect of the marble powder content on bulk density and dry bulk density of mortars

3.3. *Bulk density of dry mortar*

After 28 days of drying and curing in water at 20 °C, apparent density is determined on cylindrical samples. Three samples of each mixture are utilized for each test, and the average value is taken into account. Apparent density is measured and computed in accordance with NBN EN 1015-10 recommendations [32].

Figure 4 displays the apparent density findings. The maximum value discovered is 2650 kg/m3 for the mortar MTM-20. In contrast, the minimum value is roughly 1960 kg/m3 for the reference mortars made entirely of treated tuff. As a result, the perceived density is slightly reduced.

This trend might be brought on by the properties of treated materials themselves. Contrasted with Portland cement, treated tuffs have a larger Blaine surface area (Table 1), but require more water to attain a similar consistency. Consequently, mortars made of more processed tuffs have a harder time being cast in the mold, which leads to the creation of more air bubbles. The apparent density increases with increasing amounts of marble powder in the blended mortar. Contrary to what happened with fresh mortar, the mortar MTM20 showed a higher dry bulk density than the reference mortar MT. As this confirms the findings of Silva et al. [33], this seems to be due to the decrease of air voids within the mortars due to the addition of the marble powder. Therefore, some of the voids that are not filled with marble powder in the mortar without tuff incorporation are filled with the latter.

3.4. Compressive strength and tensile strength

From Figures 5 and 6, the results of the tensile strength tests follow the same trend as the compressive strength tests. The strongest mortar was discovered to be MTM20, followed by MTM15 in terms of mechanical strength after MTM10 and MTM5 mortar, and finally MT mortar. The figures for the MTM5 mortar are higher than those for the reference mortar (MT).

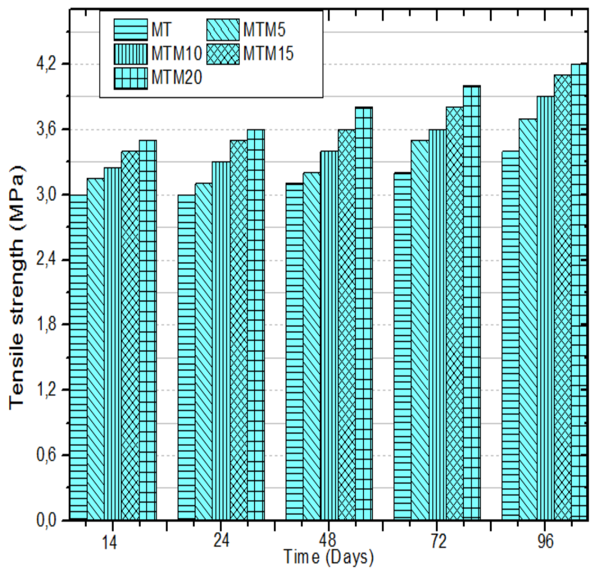

Figure 5. Effect of the marble powder content on tensile strength of mortars.

The proportionate water absorption in mortars is frequently discovered to be a key factor in how the grained components change the characteristics of a hardened mortar. Strength rises as aggregate water absorption capacity rises [34]. When marble powder is added to substitute for some of the tuff, the compressive strength increases as the quantity of marble powder used increases [35]. Beam specimens of sizes 40 to 40 to 160 mm are cast in accordance with EN 196-1 to determine the specimen's flexural strength, which is then determined by applying three point loads (pure bending) to the specimens [36, 37].

Figure 6 shows the variance in flexural strength in relation to the percentage increase in marble powder. As the quantity of marble powder rises, the flexural strength increases.

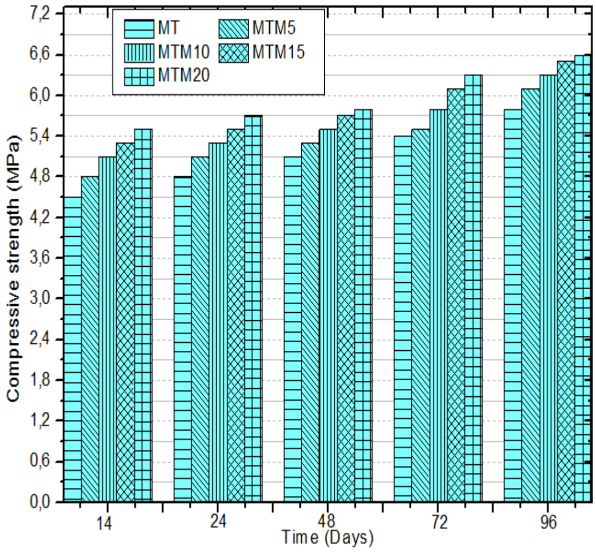

Figure 6. Effect of the marble powder content on compressive strength of mortars

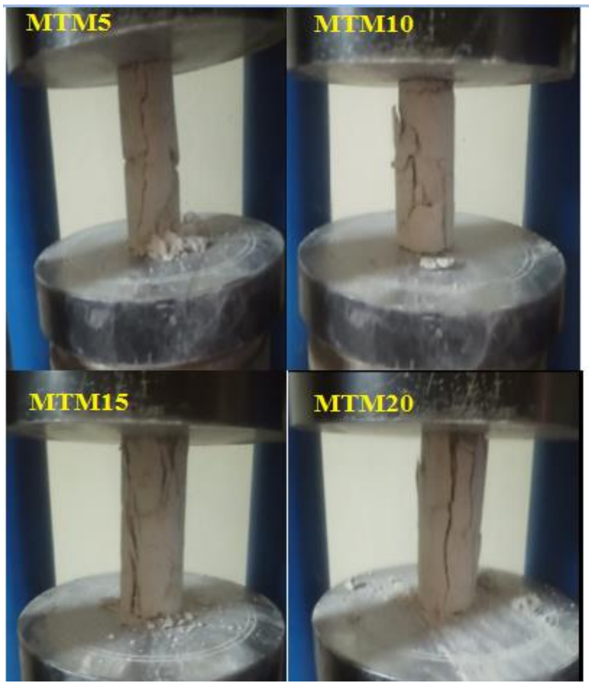

Figure 7: The photograph shows the samples' fracture

Figure 7 displays each crack on the specimen. The quantity of cracks multiplies with the amount of marble powder present, indicating the homogeneity of the combination.

3.5. Ultrasonic pulse velocity

The pulse velocity of MT was generally less than the pulse velocities of MTM5, MTM10, and MTM15, which in turn were less than the pulse velocities of MTM20. Because of this, the pulse velocity increased as the amount of marble powder per unit volume increased. This proves the relationship between porosity and pulse velocity in mortar samples [38, 39].

As shown in Figure 8, the ultrasonic pulse velocities for the 28 days were 3355 m/s, 3468 m/s, 3542 m/s, 3589 m/s, and 3611 m/s, all of which were lower than the 4010 m/s[40],value for the ordinary mortar. The control group's ultrasonic pulse velocity over 56 days was 3625 m/s, which was higher than the previous values 7.4 %,4.3%,2.2%,0.9%,and 0.3% .

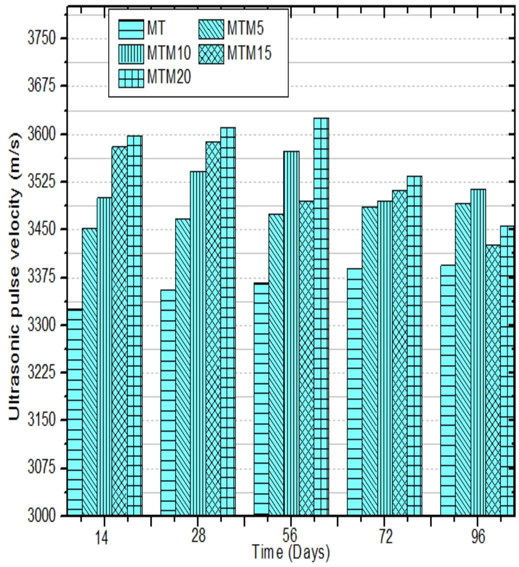

Figure 8. Effect of the marble powder content on Ultrasonic pulse velocity of the mortars.

3.6. *XRD analysis*

The X-ray diffraction measurements were performed on samples of mortars MT, MTM 5, MTM 10, MTM 15, and MTM 20 and their starting materials, i.e., Tuff (T) and Marble (M).

Based on the XRD results of the untreated tuff mixtures, it is found that kaolinite, illite, and chlorite are the main minerals in the tuff, as illustrated in Figure 2. Other non-clay minerals were also detected in the samples, including quartz and feldspar. According to the chemical analysis as shown in Table 4, the major component of marble powder is calcium oxide, and the minor contents.

are SiO_2, MgO, Al_2O_3, and Fe_2O_3, indicating its carbonate nature; calcite is the main crystalline mineral, and quartz is also identified in very low concentration (Figure 2).

As can be seen in Figure 9, the peak intensities of kaolinite, illite, and chlorite were relatively reduced with increasing lime percent, according to X-ray diffraction (XRD) studies of the marble powder-treated tuff. This is explained by how lime reacts with these minerals, destroying their structure. Meanwhile, compared to illite. and cholorite, kaolinite demonstrated a lower rate of reduced relative peak intensity with increasing lime content, which can be attributed to the relative stab.

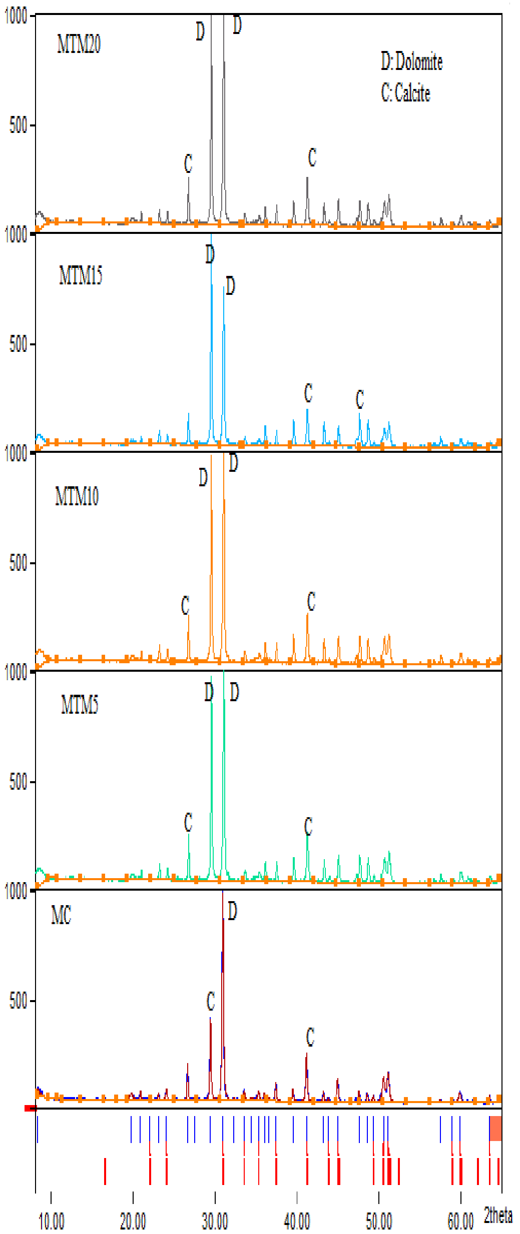

Figure 9. XRD patterns and identified phases of the mortars

3.7. *Water absorption coefficient*

In this work, water absorption tests were carried out to determine how quickly the dry mortar samples absorbed water. The produced samples were submerged in water for time of one hour before being dried in an oven at 1105 °C for two days. Using Equation (1), the samples' water absorption coefficient was calculated.

$$K_a = \left(\frac{Q}{A}\right)^2 \frac{1}{t} \qquad (1)$$

Where Ka is the coefficient of water absorption (cm2/s). Q is the volume of water the oven-dry sample absorbed during time t (cm^3); t is the duration of sample immersion, the time the sample was submerged is t=1h (3600 S) ,and A represents the sample's whole surface area that water can access (cm^2).

The water absorption coefficients of MT, MTM5, MTM10,MTM15, and MTM20 mortar at 28 days were 12.53×10^{-10}, 10.15×10^{-10}, 8.56×10^{-10},$6.78\times10^{-10}$and 4.46×10–10 m2/s, respectively, and the corresponding values decreased to 7.23×10^{-10}, 5.15×10^{-10}, 3.56×10^{-10},4.28×10^{-10} and 3.36×10^{-10} m^2/s, respectively, at 90 days, as graphically demonstrated in table 6. It is possible that continual curing caused the drop in water absorption coefficient; the hydration products created (marble powder) by the moisture filled the pores once more, increasing the microstructure's density and reducing pore size [41-43].

Table 5. The values of the Water absorption coefficient (m^2/s).

Mixture code	MT	MTM 5	MTM 10	MTM 15	MTM 20
At 28 days $x10^{-10}$	12.53	10.15	8.56	6.78	4.46
at 96 days $x10^{-10}$	7.23	5.1	3.56	4.28	3.36

4. Conclusions

From this study, the following could be concluded:

1. The Bulk density of fresh mortar and Dry bulk density of hardened mortar for the different mortar had a significantly approximate march.
2. The ultrasonic pulse velocity would decrease with an increase in the amount of waste marble powder.
3. The compressive strength of the hardened mortar improved with the utilization of up to 5 % to 20% marble powder as tuff replacement with a maximum compressive strength achieved at 20% marble powder.
4. XRD patterns indicate that the large variation in chemical composition of marble powder paste does not affect the hydration process of the mix.
5. The Water absorbing capacity of the mortars was affected by the type of adopted materials. In particular, the

mortar made with tuff aggregate and low cement 5% (MT) was characterized by greater water absorption than the one made with marble powder mortar (MTM). Conversely, the MT samples was more prone to capillary rise than the samples made with the Marble powder mortar (MTM), which showed moisture increase only in the lowermost layer of samples.

6. MTM20 mortar seems the most effective to prevent capillary rise of water when compared to the other mortars types tested.

References

[1] T. Gharib, Renforcement des structures historiques en maçonnerie par matériaux composites : Application aux murs en pierres calcaires. Thèse de doctorat, l'université claude bernard – lyon 1, 2015.

[2] N. Domede, Méthode de requalification des ponts en maçonnerie. Thèse de doctorat, L

[3] l'Institut National des Sciences Appliquées de Toulouse, 2006.

[4] T. Zimmermann, A. Strauss, K. Bergmeister, Structural behavior of low- and normal strength interface mortar of masonry, Materials and Structures ,45 (2012) 829–839.

[5] P.R. Rossi-Doria, Mortars for restauration, basic requirements and quality control, Materials and Structures, 19 (1986) 19 : 445–448.

[6] A. Szakacs, Z. Pécskay, L. Silye, K. Balogh, D. Vlad, A. Fulop, On the age of the Dej Tuff, Transylvanian Basin (Romania), Geologica Carpathica, 63 (2012) 139–148.

[7] N. Cobirzan, A. Balog, E. Mo Sonyi, Investigation of the Natural Pozzolans for Usage in Cement Industry, Procedia technology, 19 (2015) 506–511.

[8] D. Barnat-Hunek, R. Siddique, B. Klimek, M. Franus, The use of zeolite, lightweight aggregate and boiler slag in restoration renders, construction building materials, 142 (2017) 162–174.

[9] [8] M. Askrabic, M. Vysvaril, D. Zakic, A. Savic, B. Stevanovic, Effects of natural zeolite addition on the properties of lime putty-based rendering mortars, construction building materials ,270 (2021) 121363.

[10] K. Yamanel, U. Durak, S. İlkentapar, İİ. Atabey, O. Karahan, C. Duran, Influence of waste marble powder as a replacement of cement on the properties of mortar, Rev. Constr. 18 (2) (2019) 290-300.

[11] D. Benchiheub, C. Amouri, H. Houari, M. Belachia, Effect of natural pozzolana and polypropylene fibers on the performance of lime mortar for old buildings restoration, Journal of Adhesion Science and Technology,32 (2018) 12.

[12] S.D. Kore, A.K. Vyas, Impact of marble waste as coarse aggregate on properties of lean cement concrete, Case Studies in Construction Materials ,4 (2016) 85-92.

[13] O. Benjeddou, R. Alyousef, H. Mohammad hosseini, C. Soussi, M.A. Khadimallah, H. Alabduljabbar, M.M. Tahir, Utilisation of waste marble powder as low-cost cementing materials in the production of mortar, Journal of Building Engineering, 32 (2020) 101642.

[14] P. Kechagia, D. Koutroumpi, G. Bartzas, A. Peppas, M. Samouhos, S. Deligiannis, PE. Tsakiridis, Waste marble dust and recycled glass valorization in the production of ternary blended cements, Science of The Total Environment, 761 (2021) 143224.

[15] N. Toubal Seghir, M. Mellas, L. Sadowski, A. Krolicka, A. Zak, K. Ostrowski, The utilization of waste marble dust as a cement replacement in air-cured mortar, Sustainability, 11 (2019) 2215.

[16] NF P 94-054, Sols: reconnaissances et essais, Détermination de la masse volumique des particules solides des sols, Méthode du pycnomètre à eau, Association Française de Normalisation, France. (in French).

[17] NF P 94-056, Sols: reconnaissances et essais, Analyse granulométrique, Méthode de tamisage à sec après lavage. Association Française de Normalisation, France. (in French).

[18] NF P 94-057, Sols: reconnaissances et essais, Analyse granulométrique des sols, Méthode par sédimentation. Association Française de Normalisation, France. (in French).

[19] NF EN 1744, Essais visant à déterminer les propriétés chimiques des granulats. Association Française de Normalisation, France. (in French).

[20] W. Acchar, F.A. Vieira, D. Hotza, Effect of marble and granite sludge in clay materials, Materials Science and Engineering ,419 (1-2) (2006) 306-309.

[21] K.S.A. Kabeer, A.K. Vyas, Utilization of marble powder as fine aggregate in mortar mixes, construction building materials. 165 (2018) 321-332.

[22] R.K. Khyaliya, K.S.A. Kabeer, A.K. Vyas, Evaluation of strength and durability of lean mortar mixes containing marble waste, construction building materials. 147 (2017) 598-607.

[23] EN 196-1 Norme européenne, « méthodes d'essais des ciments, partie 3 » Août 1995 (in French).

[24] NF P 94-051, Sols: Reconnaissance et Essais – Détermination des limites d'Atterberg – Limite de liquidité à la coupelle – limite de plasticité au rouleau. Association Française de Normalisation, France. (in French)

[25] C.O. Okagbue, T.U.S. Onyeobi, Potential of marble dust to stabilize red tropical soils for road construction, Engineering Geology, 53 (1999) 371-380.

[26] P.V. Sivapullaiah, A. Sridharan, R.K.V. Bhaskar, Role of amount and type of clay in the lime stabilization of soils, Ground Improvement. 4 (2000) 37–45.

[27] R.M. Schmitz, C. Schreoder, R. Charlier, Chemo-mechanical interactions in clay a correlation between clay mineralogy and Atterberg limits, applied clay science. 26 (2004) 351–358.

[28] EN 1015-6, Methods of test for mortar for masonry - Part 6: Determination of bulk density of fresh mortar, 1998.

[29] A. Ababneh, F. Matalkah, Potential use of Jordanian volcanic tuffs as supplementary cementitious materials, case study construction materials. 8 (2018) 193-202.

[30] N. Sarkar, A. Faris, V. Martin, and Flexural strength of weathered granites: Influence of freeze and thaw cycles, construction building materials. 156 (2017) 891-901.

[31] S.V. Silva, J.B.L. Liborio, C.R. Silva, Rendering mortars using burnt clay pozzolan. (in Portuguese), III Brazilian Symposium of Mortars Technology (SBTA), April, 1999.

[32] EN 1015-10, Methods of test for mortar for masonry - Part 10: Determination of dry bulk density of hardened mortar (includes Amendment A1:2006).

[33] J .Silva, J. De Brito, R. Veiga, Incorporation of fine ceramics in mortars, construction building materials 23 (2013) 556–564.

[34] N. Parsompech, R. Rianyoi, A. Chaipanich, Compressive strength, water absorption and pulse velocity tests of calcined clay- limestone cement mortars, Materials today, Proceeding. 65(4) (2022) 2394-2398.

[35] V. Horsakulthai, Effect of recycled concrete powder on strength, electrical resistivity, and water absorption of self-compacting mortars, case study construction materials. 15 (2021) e00725.

[36] D. Hatungimana, C. Taşköprü, M. Müslim, M. Saç, Ş Yazıc, Compressive strength, water absorption, water sorptivity and surface radon exhalation rate of silica fume and fly ash based mortar, Journal of Building Engineering, 23 (2019) 369-376.

[37] Y. Li, C. Zou , Z. Liu, C. Wang, Effect of sintering additives on the densification, crystallization and flexural strength of sintered glass-ceramics from waste granite powder, Materials Chemistry and Physics ,216 (2018) 1-7.

[38] P. Wiciak, G. Cascante, M.A. Polak, Sensor and Dimensions Effects in Ultrasonic Pulse Velocity Measurements in Mortar Specimens, Procedia Engineering. 193 (2017) 409-416.

[39] X. Zhang, J. Zuo, Z. Wang, Y. Cai, Y. Zhou, The evolution of the microstructure and mechanical properties of coral aggregate mortar under uniaxial compression using ultrasonic analysis, Construction and Building Materials, 300 (2021) 124000.

[40] F.Belabdelouahab ,H. Trouzine ,H. Hellal , B.Rahali,SO.Kaci,M.Medine ,Comparative analysis of estimated young's modulus of rubberized mortar and concrete. International Journal of Civil Engineering 16(2)(2016)243–253.

[41] E. Yedra, D. Ferrández, C. Morón, P. Saiz, New test methods to determine water absorption by capillarity. Experimental study in masonry mortars, Construction and Building Materials ,319 (2022) 125988.

[42] S. Wenhao, W. Qing, W. Lei, L. Xiaodong, X. Shuangshuang, Study of water absorption and corrosion resistance of the mortar with waste marble powder, Construction and Building Materials ,345 (2022) 128235.

[43] F.Z. Ren, C.S. Zhou, Q. Zeng, Z.D. Zhang, A. Ueli, W. Wang, Quantifying the anomalous water absorption behavior of cement mortar in view of its physical sensitivity to water, Cement and Concrete Research ,143 (2021) 1.