

Cuban marble slabs exposed on a building facade for 40 years: Mineralogical and geological characteristics, re-use and recycling challenge

Tatiana DURMEKOVÁ¹, Peter RUŽIČKA^{2*} and Renáta ADAMCOVÁ¹

Authors' affiliations and addresses:

¹ Department of Engineering Geology, Hydrogeology and Applied Geophysics, Faculty of Natural Sciences, Comenius University, Ilkovičova 6, 842 15 Bratislava, Slovakia
e-mail: tatiana.durmekova@uniba.sk, renata.adamcova@uniba.sk

² Department of Mineralogy, Petrology and Economic Geology, Faculty of Natural Sciences, Comenius University, Ilkovičova 6, 842 15 Bratislava, Slovakia
e-mail: peter.ruzicka@uniba.sk

*Correspondence:

Peter Ružička, Department of Mineralogy, Petrology and Economic Geology, Faculty of Natural Sciences, Comenius University, Ilkovičova 6, 842 15 Bratislava, Slovakia
tel.: +421 2 9014 9356
e-mail: peter.ruzicka@uniba.sk

Funding information:

This research was funded by APVV VV-MVP-24-0197.

Acknowledgement:

Authors acknowledge the company Immocap a. s. for providing marble panels necessary for the research.

How to cite this article:

Durmeková, T., Ružička, P. and Adamcová, R. (2026) Cuban Marble Slabs Exposed on a Building Facade for 40 Years: Mineralogical and Geological Characteristics, Re-use and Recycling Challenge, *Acta Montanistica Slovaca*, Volume 31 (2), 449-464

DOI:

<https://doi.org/10.46544/AMS.v31i2.10>

Abstract

Marble slabs obtained from Cuba covered the facade of a cultural center in Bratislava, Slovakia, for 40 years. The recent demolition of the building enabled laboratory testing of slabs, separately from the southern and northern facades. Regarding the environment, re-use/recycling options were analyzed to minimize waste and save construction materials. This applied research started with visual evaluation and mineral analysis, and continued with laboratory determination of selected physical properties. Different thermal conditions (direct sunlight only on the south) resulted in different properties and a higher-quality marble on the northern facade. The marble slabs from the northern facade are suitable for decorative cladding and flooring, but with a thickness of 30 mm, they can only be used for pedestrian areas. Crushing them to waste marble aggregate looks more promising. Susceptibility tests, micro-Deval, and Slake Durability tests indicate the effective substitution of natural aggregates in the production of different concrete products and agglomerated stones. Based on the mineralogical investigation, the marble quarry could be related to Isla de la Juventud, Cuba. Identified properties of the dismantled marble could be compared with internet data on the Gris Siboney marble, the commercial name for that quarry product. Data published online were also used to evaluate marble ageing, as reflected, for instance, in the lower flexural strength. A geological description of the quarry based on archival research was compiled.

Keywords

marble, re-use and recycling of cladding, quality parameters, Gris Siboney, waste-marble aggregates



© 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Introduction

Marble is a natural stone often used in construction and architecture. From a geological point of view, it is a metamorphic rock composed of recrystallized carbonate minerals. Marble is prized for its unique aesthetic, durability, and ability to attain a high shine. For these reasons, it is often considered a high-end building material that can enhance a building's value.

In the 1980s, marble slabs imported from Cuba were used as facade cladding on a public building situated in the central part of Bratislava, the capital city of Slovakia. It was a present from Cuban president Fidel Castro to Czechoslovakia, as both countries co-operated within Comecon (Dulla and Moravčíková, 2002; https://sk.wikipedia.org/wiki/Dom_odborov_Istropolis). The construction was completed in 1981. The marble cladding should enhance the monumentality of the building. Called “Istropolis”, it served as a congress and cultural center for many years, with a big hall for 1280 visitors and three smaller ones (Figure 1).

A number of marble facades worldwide exhibited serious deterioration due to the stone's material. Bowing of marble slabs was reported as the main failure mode, increasing with cladding age and requiring further research, but it is not the only one (Grelk et al., 2007; Siegesmund et al., 2008). In Bratislava, after ca. 40 years, the appearance of marble exposed to climatic effects has not changed significantly. No serious damage was found, and the stone's interesting textural pattern was not disturbed. No significant decay or bowing (bending) of the facing slabs was observed. The 40-year-old building with the marble facade was in very good condition when it was demolished to free up the space for more modern construction.

The demolition of “Istropolis” provided an opportunity to study in detail the impact of the last 40 years on the marble facade. Although no documents are available on the original technical parameters of the marble, it must have fulfilled the strict criteria for cladding. Technical parameters from standards, together with data on recently quarried Cuban marbles found on the internet, were used to compare the “aged” cladding. Bulk density, porosity, water absorption, and frost resistance are the most important parameters of physical properties. To evaluate the current physical condition based on those parameters, rock samples were collected from marble slabs separated from demolition waste. For any waste management, the “3R-rule” (refuse, re-use, recycle) should be followed, with consideration given to the re-use or recycling of those cladding slabs. This required further tests to evaluate technical parameters crucial for their re-use as “second-hand” cladding on facades and floors, or as recycled material for aggregates. Solving this problem would not only minimize waste volume but could also reduce CO₂ emissions in the construction industry.

The production of waste marble aggregate and its use mainly in concrete products is evaluated in the literature by many authors (Akbulut and Güner, 2007; Binici et al., 2008; Hebhoub et al., 2011; Rodrigues et al., 2015; Khyaliya et al., 2017; Singh et al., 2017). All research results indicate the promising prospects for using waste marble in the production of concrete products and in road construction, both as fine and coarse aggregates. However, these experiments have been targeted at fresh marble waste from production, not at one that has been exposed to climatic agents for decades.

Besides this re-use/recycle challenge, the detailed mineralogical and petrological study allowed the identification of the probable Cuban marble quarry, the commercial name of the stone, and its declared qualitative parameters.



Fig. 1. The conference and cultural center Istropolis in Bratislava, Slovakia (Hamšíková, 2020)

Materials and Methods

Sampling and preparation of specimens

In the second half of January 2022, demolition of the Istropolis building began, starting with the removal of the exterior marble cladding (Figure 2).

Several dismantled marble panels with dimensions of approximately 650 mm x 440 mm were taken to the rock-mechanics laboratory. The panels were approximately 30 mm thick. Test specimens were prepared from the panels by cutting and drilling into plates, prisms, cubes, or cylinders according to the requirements of the standard test methods (Figure 3). Specimens were prepared and tested separately, depending on whether they came from the south or northern facade of the building.

To specify the mineral content, thin sections of the marble were prepared. For mineralogical analysis, a polarizing microscope and an electron probe microanalyzer were used.

Finally, waste marble from specimen preparation, marble broken during strength tests, and some damaged, dismantled slabs were crushed to grain sizes of 4-14 mm to test the recycled aggregate quality.



Fig. 2. Removal of the marble cladding from the Istropolis building (photo: Ružička, February 2022)

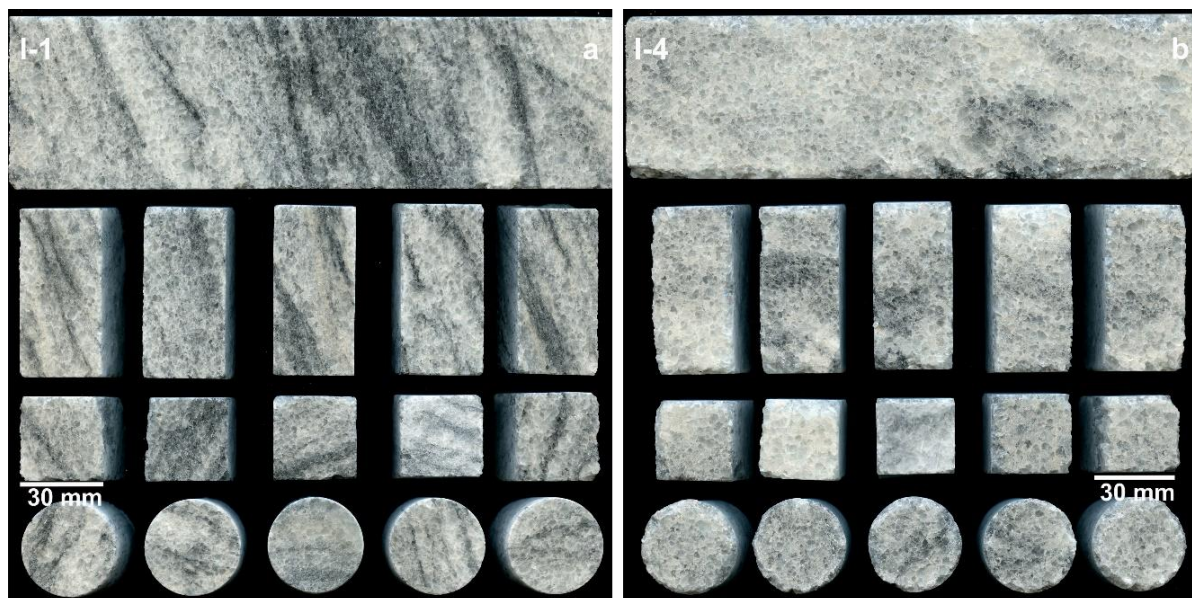


Fig. 3. Different types of specimens prepared for tests on the physical and mechanical properties. a) from the southern facade; b) from the northern facade

Testing

The mineralogical analysis of the marble was performed. Polished thin sections were microscopically observed in transmitted light using a Leica DM2500P polarizing microscope. Vacuum-evaporated polished sections with a thin carbon layer were analyzed on an electron probe micro-analyzer (EPMA) JEOL JXA-8530FE at the Slovak Academy of Sciences (Earth Science Institute of SAS in Banská Bystrica). Quantitative chemical analyses (WDS) of minerals were done at an accelerating voltage of 15 kV and a measuring current of 20 nA. The

diameter of the electron beam ranged from 5 to 10 μm . “ZAF correction” (i.e., correction of atomic number, absorption, and fluorescence) was used. In the carbonates, the following standards and X-ray lines were used: hematite ($\text{FeK}\alpha$), rhodonite ($\text{MnK}\alpha$), diopside ($\text{MgK}\alpha$, $\text{CaK}\alpha$). The detection limit of every element ranged from 0.002 to 0.03 wt. %. The resulting tables do not contain any elements that do not reach the detection limits. Photographic documentation of relationships among minerals was performed in BSE (backscattered electron) mode.

To characterize the pore-size distribution of the marble, the mercury intrusion porosimetry (MIP or Hg porosimetry) was used at the Slovak Academy of Sciences in Bratislava. MIP can be used to characterize pores with diameters from 4 nm to 200,000 nm.

Basic physical and mechanical properties of the marble were determined in the rock mechanics laboratory at the Faculty of Natural Sciences, Comenius University in Bratislava, following standard test methods as follows:

- ultrasonic P-waves' propagation velocity (UPV) through prismatic samples in 3 directions (EN 14579),
- bulk density, particle density, open and effective porosity (EN 1936),
- water absorption – by total immersion (EN 13755) and by capillarity (EN 1925),
- frost resistance by freeze-thaw (F-T) testing (EN 12371),
- uniaxial compressive strength (UCS) (EN 1926) and flexural strength (EN 12372) before and after freeze-thaw testing.

In F-T tests, 25 cycles were applied, as required by the Slovak Technical Standard STN 72 1800, in order to calculate the frost resistance coefficient K_{fr} . This is a technical parameter used for the evaluation of natural stones as construction materials. It can be calculated as the following ratio:

$$K_{fr} = \frac{\sigma_2}{\sigma_1} \quad (1)$$

where σ_1 is the strength (either UCS or flexural strength) determined before the F-T testing, and σ_2 is the strength (either UCS or flexural strength) determined after 25 cycles of F-T testing.

The suitability of the slabs for paving was assessed based on the minimum force P required to break them (i.e., the maximum force measured before the slab breaks). This was used to calculate the necessary thickness of the slab according to EN 1341 as follows:

$$h = \sqrt{\frac{1500 \cdot P \cdot L \cdot F_s}{W \cdot R_f}} \quad (2)$$

where h [mm] is the necessary thickness of the slab, P [kN] is the breaking force for the expected use of the paving (given in EN 1341), L [mm] is the length of the slab, W [mm] is the width of the slab, R_f [MPa] is the minimum value of the flexural strength determined following EN 12372 and F_s is a safety factor as given in Table A.1 in EN 1341.

To evaluate waste-marble aggregates, the following tests were carried out by standard methods:

- F-T tests to measure the mass loss after 10 cycles (EN 1367-1),
- tests for mechanical and physical properties of aggregates and calculation of the micro-Deval coefficient M_{DE} that indicates the resistance to wear (STN EN 1097-1),
- Slake durability tests for the calculation of the durability index I_{SDT} (Ulusay and Hudson eds., 2007).

Based on those test results, the suitability of such recycling in road construction was evaluated. Unbound base layers, concrete surface courses on roads less heavily trafficked, and the application in concrete products were considered, in accordance with relevant technical standards and regulations.

Results

Petrography and mineral composition

The studied marble is a crystalline carbonate metamorphic rock, composed of medium- to coarse-grained calcite crystals. Generally, the size of the calcite crystals depends on the graphite content; the crystals are larger (from 3 to 5 mm, sporadically more than 7 mm) in white parts, and the calcite crystals are much smaller (from 1 to 2 mm) in the dark bands. According to the Rock Color Chart (2011), the rock colour is generally light white (N9) or very light gray (N8). Marble is characterized by the presence of non-continuous bands formed by dark gray to black spots of graphitic pigment. Black graphite bands are arranged in parallel form, generally with a

thickness of 0.5 to 1.0 cm (Figure 4). The marble texture is granoblastic, with crystals having a polygonal morphology. For the marble, a granular disintegration is typical.

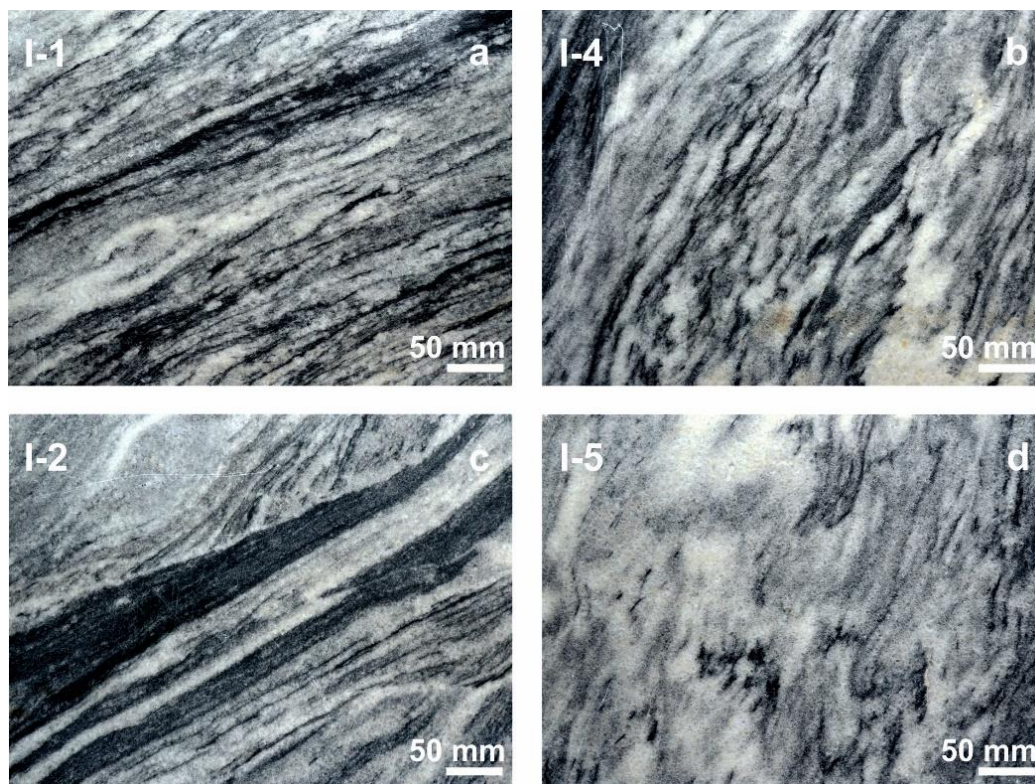


Fig. 4. Textural characteristics of the tested marble: I-1 and I-2 southern facade (a-c); I-4 and I-5 northern facade (b-d). The black stripes in the rock are formed by graphite

Calcite was identified in the polarizing microscope (plane-polarized light – PPL) and on the electron probe micro-analyzer (backscattered electron – BSE). Both microscopic images of the marble are presented in Figure 5. Results of mineral analyses and the calculated cations for calcite are given in Table 1.

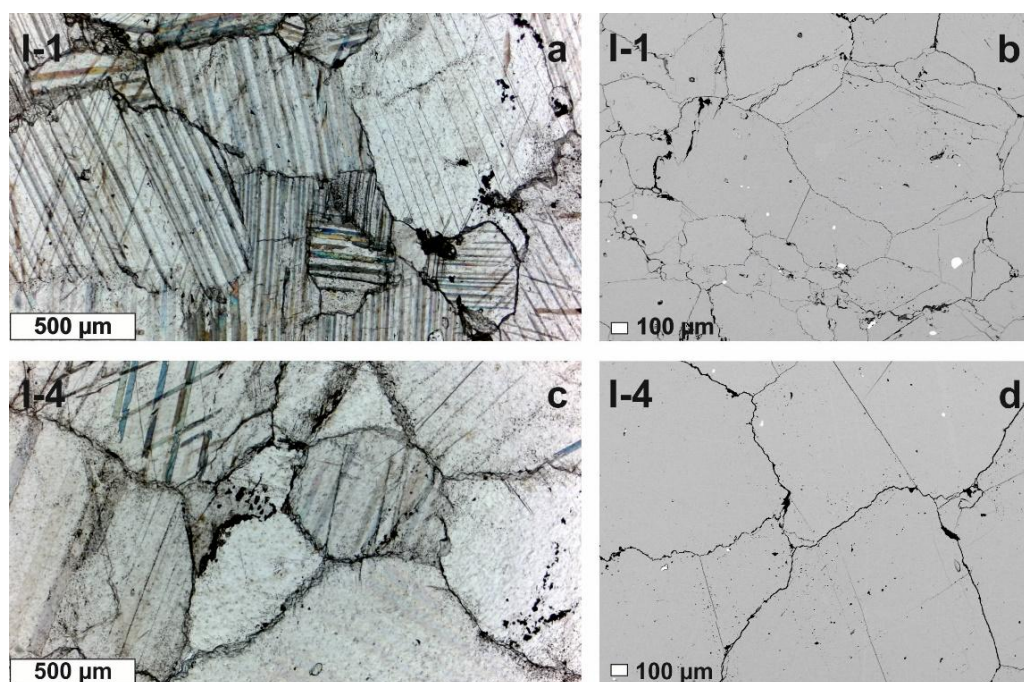


Fig. 5. Microstructures of the calcite marble from the Istropolis building: I-1 southern facade (a-b) and I-4 northern facade (c-d) in PPL images (a-c) and BSE images (b-d)

Tab. 1. Representative electron microanalyses of calcite in the tested marble calculated on 1 cation (*apfu*).
The *symbol indicates the calculation of CO₂ based on the ideal stoichiometry of calcite

Sampling site	Southern facade					Northern facade				
Sample	I-1					I-4				
Analysis	1	2	3	4	5	1	2	3	4	5
FeO	0.00	0.00	0.04	0.00	0.00	0.00	0.01	0.04	0.00	0.00
MnO	0.02	0.00	0.00	0.00	0.02	0.02	0.04	0.00	0.04	0.01
MgO	0.32	0.25	0.30	0.22	0.21	0.40	0.52	0.42	0.40	0.38
CaO	54.64	54.67	55.06	54.67	54.59	54.47	54.77	54.76	54.81	54.64
CO ₂ *	43.37	43.33	43.65	43.16	43.29	43.24	43.76	43.52	43.56	43.38
Total [wt. %]	98.34	98.24	99.05	98.05	98.11	98.12	99.11	98.73	98.80	98.41
atomic proportions (calculated on the basis of 1 cation)										
Fe	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
Mg	0.008	0.006	0.008	0.006	0.005	0.010	0.013	0.011	0.010	0.010
Ca	0.992	0.994	0.992	0.994	0.994	0.990	0.986	0.989	0.990	0.990
Total [<i>apfu</i>]	1.000	1.000	1.001	1.000	0.999	1.000	1.000	1.001	1.001	1.000
end-member compositions										
FeCO ₃	0.00	0.00	0.05	0.00	0.00	0.00	0.02	0.05	0.00	0.00
MnCO ₃	0.02	0.00	0.00	0.00	0.03	0.02	0.05	0.00	0.06	0.01
MgCO ₃	0.80	0.63	0.75	0.55	0.52	1.01	1.31	1.05	0.99	0.96
CaCO ₃	99.18	99.37	99.20	99.45	99.45	98.96	98.62	98.91	98.95	99.03
Total [mol. %]	100.00	100.00	100.00	100.00	100.00	99.99	100.00	100.01	100.00	100.00

The chemical composition of the calcite in the marble is homogeneous. The presence of dolomite was not confirmed. The analyzed calcites are chemically pure. The contents of Fe and Mn reach almost zero values *apfu* (atoms per formula unit). Mg contents reach a maximum of 0.01 *apfu*, which is up to 1.31 mol. % MgCO₃ in sample I-4 from the northern facade (Table 1).

Pore-size distribution

Results of the Hg porosimetry are shown in Figure 6. There are mainly micropores with a radius from 3 nm to 100,000 nm in the marble. The typical pore-size distribution is bimodal and uniform, the same for samples taken from the southern and northern facades. Quantitative parameters are summarized in Table 2. The MIP characterized the first group of pore sizes, ranging from 4 to 50 nm, with a major peak within a pore diameter range of 4 to 20 nm. A second group of pore sizes, from 2,000 to 20,000 nm, has a major peak located within a pore diameter range of 5,000 to 10,000 nm. Pores with a diameter > 10 nm are sometimes referred to as capillary pores (Dong et al., 2017). In the studied marble, the vast majority of pores are of such character.

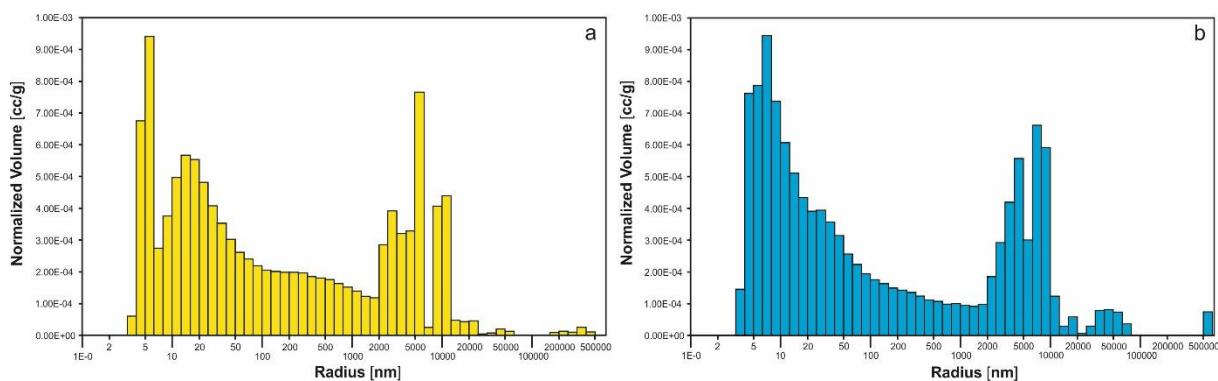


Fig. 6. Pore-size distribution in the marble samples determined by the mercury intrusion porosimetry; a) southern facade, b) northern facade

The MIP analysis showed that intraparticle pores (i.e., pores within individual grains, minerals, or particles) are prevalent (Table 2). Those pores are accessible by mercury under high pressure, as the mercury diameter is only 1.33 to 1.42 Å (depending on the bond type) (www.webelements.com), but mostly not available for the twice-as-big water molecules (2.75 Å) (<https://bionumbers.hms.harvard.edu>). This explains the lower porosity resulting from standard methods using water, as well as the low water absorption and high frost resistance, as mentioned in the next section.

Tab. 2. Summary of mercury intrusion porosimetry results

Parameter	Southern facade	Northern facade
Total intruded volume [$\text{cm}^3 \cdot \text{g}^{-1}$]	0.0117	0.0122
Total Surface Area [$\text{m}^2 \cdot \text{g}^{-1}$]	1.2074	1.4925
Bulk density ρ_{dHg} [$\text{g} \cdot \text{cm}^{-3}$]	2.6731	2.7263
Particle density ρ_{sHg} [$\text{g} \cdot \text{cm}^{-3}$]	2.6808	2.7389
Total interparticle porosity [%] (Pores between individual particles)	0.0543	0.1030
Total intraparticle porosity [%] (Pores within individual particles or grains)	3.0672	3.2326
Total porosity n_{Hg} [%]	3.1215	3.3356

Basic physical, mechanical, and technical properties

Physical and technical properties of the marble slabs determined by standard laboratory tests are listed in Table 3. Due to the inhomogeneity of the mineral composition and random presence of the dark graphite bands, very variable values of the P-waves velocity were measured. The velocity depends on the distribution of light and dark components in the marble. The higher values were measured in dark parts of the rock, especially if the wave direction was parallel. P-waves perpendicular to the dark spots propagated with a lower velocity. Table 3 presents only the highest measured values; details on the velocities in the 3 directions are provided later, related to the F-T tests.

Tab. 3. Basic physical properties of weathered marble slabs – mean values

Facade	Southern			Northern
Slab	I-1	I-2	I-3	I-4
Bulk density ρ_d [$\text{g} \cdot \text{cm}^{-3}$]	2.669	2.673	2.681	2.701
Particle density ρ_s [$\text{g} \cdot \text{cm}^{-3}$]	2.700	2.700	2.705	2.720
Total porosity n [%]	1.1	1.0	0.89	0.70
Open porosity n_o [%]	0.68	0.74	0.69	0.52
Water absorption by total immersion WAI [%]	0.25	0.28	0.26	0.19
Water absorption by capillarity WAC [$\text{g} \cdot \text{m}^{-2}$]	187	221	183	145
Water absorption coefficient by capillarity C , after 24 hours [$\text{g} \cdot \text{m}^{-2} \cdot \text{s}^{-0.5}$]	0.635	0.753	0.624	0.492
Uniaxial compressive strength UCS [MPa] (determined on non-standard specimen size)	51.6	46.5	44.0	55.2
Flexural strength R_f [MPa]	4.6	5.0	4.1	6.8
P-waves propagation velocity v [$\text{m} \cdot \text{s}^{-1}$]	4020	3817	3080	3356

The water absorption by capillarity WAC is also presented in Figure 7, where "SQRT time" means the value of the square root of time, if given in seconds. Tests on WAC proved very sensitive; even when WAI is low, these tests reflect the rock's physical conditions very well.

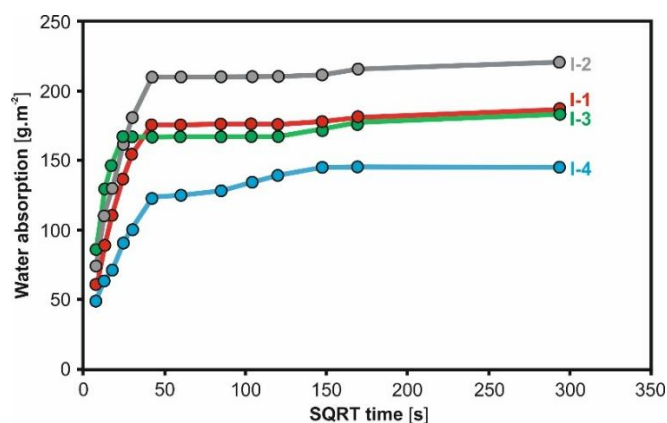


Fig. 7. Capillary water absorption of the marble samples over time

Frost resistance testing

For all specimens that resisted the 25 F-T cycles and maintained their coherence, UPV measurements and technological strength tests could be followed. Despite the high variability of the measured UPV values resulting from mineral heterogeneity, it is, on average, clear that the F-T testing has weakened the structural integrity of all samples. All measured UPV values were lower after F-T cycles (Table 4 and Figure 8).

Tab. 4. Comparison of ultrasonic P-waves propagation velocity in three directions before and after F-T tests

Facade	Slab	Specimen	UPV [m.s ⁻¹]					
			before F-T			after F-T		
			x	y	z	x	y	z
Southern	I-1	1.2	4785	3812	4295	4127	3272	3494
		1.5	4367	3344	3515	3764	2979	3320
	I-2	2.3	4566	4071	3688	4016	3382	2184
		2.5	4566	3382	2658	3672	2893	2015
		2.6	3672	4637	3114	3135	4071	3066
		3.2	3584	3421	3197	3382	3135	2946
	I-3	3.3	3717	2735	2482	3272	2465	1925
		3.4	3685	2893	2727	3424	2593	2626
		3.5	3699	2760	2061	2926	2295	1838
	I-4	4.1	2826	3584	3412	2506	3421	3105
		4.3	3273	4127	3489	2775	3308	2434
		4.4	2775	3717	3268	2372	2950	2943
		4.5	2703	3542	3549	2372	3272	3184

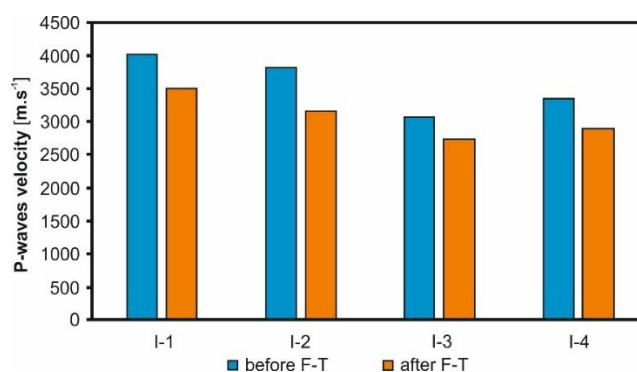


Fig. 8. Impact of F-T tests upon the mean values of UPV

The results of the strength tests are presented in Figure 9. The flexural strength of all samples decreased after F-T cycles, similarly to the UPV values. UCS values are not so clear. In some samples (sample groups I-2 and I-3), light was measured at higher values compared to measurements before F-T cycles.

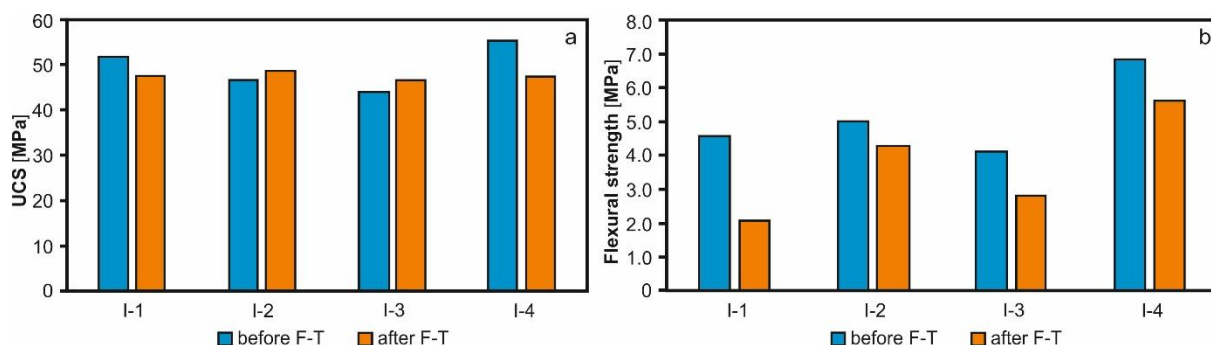


Fig. 9. Impact of F-T tests upon the strength parameters: a – uniaxial compressive strength, b – flexural strength

The reduction in flexural strength R_{ft} after F-T tests was quantified in Table 5, along with the frost resistance coefficient K_{fr} calculated according to Eq. 1.

Tab. 5. Input data for the calculation of the parameter K_{fr} .

Facade	Slab	Flexural strength [MPa]		Strength decrement after F-T [%]	K_{fr}
		before F-T	after F-T		
Southern	I-1	4.58	2.1	54	0.46
	I-2	5.03	4.32	14	0.86
	I-3	4.11	2.82	31	0.69
Northern	I-4	6.84	5.62	18	0.82

Waste marble aggregates properties

The use of crushed marble in construction works provides many benefits. One of them is improving the appearance of decorative projects. Fine- and coarse-grained aggregates, or marble powder, can be used. Results of laboratory tests on coarse crushed marble aggregates (marble chips) are presented in Table 6. The waste marble aggregate was tested together, without separation, to determine whether the material used for crushing was taken from the south or the northern facade. Slake durability test is a non-standard test; it can serve as a comparison test.

Tab. 6. Physical and mechanical properties of the waste-marble aggregates

Sample	Water absorption	Freeze-thaw testing 25 cycles	Micro-Deval test	Slake durability test
	10 – 14 mm	4 – 8 mm	10 – 14 mm	40 – 60 g
	WA [%]	Mass loss F [%]	M_{DE}	I_{SDT} [%]
No. 1	0.26	1.09	79	97.2
No. 2	0.23	1.11	82	96.6
Mean value	0.25	1.10	80	96.9

Discussion

Material identification

The visual appearance and mineral composition of the marble best match one type of Cuban marble, known as “Gris Siboney Marble” (alternative names include Gris Claro Marble, Siboney Gris Marble, Gray Siboney Marble, Siboney Grey Marble, depending on translation).

Though Siboney is both the name of a coastal village in Eastern Cuba and of a neighborhood in the Playa borough of Havana (<https://en.wikipedia.org/wiki/Siboney>), i.e., far from the marble quarry, the term “Siboney”

refers also to one of the indigenous tribes of the Taíno people that inhabited Cuba before the arrival of Spanish colonists. This might be the reason for taking such a name for the very typical Cuban marble.

Gris Siboney Marble is a silver-grey, pale grey to white, medium-grained stone, excellent for countertops, monuments, mosaics, exterior/interior wall and floor applications, fountains, pool and wall capping, stairs, window sills, and other design projects (www.stonecontact.com). It can be processed into polished, saw-cut, sanded, rock-faced, sandblasted, or tumbled products. It is quarried in the largest and oldest marble quarry in Cuba, on Isla de la Juventud (Isle of Youth), near Nueva Gerona town. There is a marble quarry in the small hill between the beaches Punta de Piedro and Paraiso, about 4 km East of Nueva Gerona. The GPS coordinates of the marble quarry are 21°52'31.3"N 82°48'45.7"W. This type of marble can be seen on Cuban buildings, private houses, and monuments, including the giant memorial monument with a José Martí statue in Havana's Plaza de la Revolución (Figure 10).



Fig. 10. José Martí monument, Havana, Cuba (photo Adamcová, 2024)

The physical and mechanical properties of the fresh Gris Siboney Marble reported online are compared with those from this study in Table 7. The already mentioned non-standard dimensions of the test specimens may have influenced the strength results; the comparison is not simple. The 40 years of exposition at the facade must be reflected in certain weathering/weakening of the marble, too. However, the compared parameters are still very similar to the published properties of the Gris Siboney Marble. There is no obvious reason to doubt the correctness of the marble identification. There are 11 other commercial marbles in Cuba, but their colours are different (www.stonecontact.com).

Tab. 7. Published physical and mechanical properties of the Gris Siboney Marble vs. the own results of testing the dismantled marble cladding

Source	Colour	Bulk density ρ_d [g.cm ⁻³]	Water absorption W_{AI} [%]	Flexural strength R_{ff} [MPa]	Compressive strength UCS [MPa]
www.stonecontact.com	silver grey	2.788	1.0	5.8	49
www.interstonemarble.com	grey with black bands	2.700	0.06	11.1	67.4
www.ecured.cu	grey with black bands	2.600 (avg.)	max. 1.5	min. 6.0	min. 50
Petrov et al. (1974)	grey with notable stratification	2.690 – 2.700	0.12 – 0.30	8.0	-
This study	grey with black bands	2.690 – 2.702	0.19 – 0.28	4.1 – 6.8	44 – 55

Geological setting of the quarry

Cuba is the largest island in the Greater Antilles Arc in the Caribbean Sea. The geologic evolution of Cuba records three important episodes (Iturralde-Vinent et al., 2016): 1) the Jurassic breakup of North and South America (Pangea) with associated passive margin and oceanic sedimentary and magmatic evolution; 2) the sedimentary, magmatic and metamorphic evolution of an intra-oceanic Cretaceous-Paleogene ophiolite-arc

complex; and 3) the Paleogene “soft collision” and transfer of the NW Caribbean plate (and Cuba) to the North American Plate. Thick sequences of Jurassic-Cretaceous strata (conglomerates, sandstones, limestones, dolostones, shales) and interlayered basaltic rocks characterize passive margin sequences of Cuba (Figure 11a).

Isla de la Juventud (Isle of Youth), located to the southwest of Cuba, was called Isla de Pinos until 1978; herein, the Pinos terrane. The Pinos metamorphic terrane forms most of the island's crystalline core, except for the NW, where it is tectonically overlain by the Sabana Grande volcanics. The major lithological features of the Pinos terrane include graphite-bearing siliciclastic and carbonate metasediments with occasional metabasite intercalations (Daguilla amphibolites) (Somin and Millán-Trujillo, 1981; Millán-Trujillo, 1997). Some sections (Cañada and Agua Santa Fms.) are dominated by siliciclastic rocks (Figure 11b). The Pinos metamorphic terrane has a continental foundation made of terrigenous and carbonatic stratigraphic sequences (Figure 11c) that span Lower-Middle Jurassic to Upper Cretaceous age (Millán-Trujillo, 1997; Iturralde-Vinent, 1994; García-Casco et al., 2001, 2008).

K-Ar ages of the metamorphic rocks of the Pinos terrane range from 78 ± 4 (mica schist) to 49.3 ± 3.8 Ma (amphibolite; Iturralde-Vinent et al., 1996). Mica schists of the Pinos terrane are $78-73 \pm 4$ Ma old, dated by K-Ar from muscovite (Meyerhoff et al., 1969). Late to post-metamorphic acid subvolcanic dikes show K-Ar ages of 68–60 Ma (Buguelski et al., 1985). The $^{40}\text{Ar}/^{39}\text{Ar}$ dating of phengite from low-grade phyllites gives ca. 72 Ma, suggesting high-pressure metamorphism during the latest Cretaceous. The $^{40}\text{Ar}/^{39}\text{Ar}$ ages of biotite and muscovite from medium- and high-grade metapelites yield a consistent age of 68 ± 2 Ma for the uppermost Cretaceous (García-Casco et al., 2001).

In the Pinos terrane, metamorphism reached high-grade conditions (Somin and Millán-Trujillo, 1981; Millán-Trujillo, 1997). In the medium and high-grade metapelites, garnet+kyanite-bearing assemblage developed at pressures of >1200 MPa at 600–650 °C and 700–750 °C, respectively (García-Casco et al., 2001, 2003).

Marble cladding ageing

In general, marbles are very compact rocks, with both low porosity and related low water absorption (Karaca, 2010; Bellopede et al., 2016; Kuchařová and Příkrýl, 2017). Ružička and Durmeková (2012) studied 20 types of marble from Slovakia, with *WAI* from 0.1% to 0.31%. They did not notice any significant increase in *WAI* after 168 cycles of freeze-thaw. Though the number of cycles was very high, *WAI* changed only to 0.12–0.38%. After 40 years of exposition on the facade in the urban environment, the Gris Siboney Marble yielded similar low *WAI* values (Table 3). While calcitic marbles are more susceptible to weathering and disintegration than dolomitic marbles (Siegesmund et al., 2000, in Bellopede et al., 2016; Luque et al., 2010), this marble still looked very fresh. However, a certain weakening of the material after F-T cycling is evident already when looking at the lower UPV values after F-T tests. The results of the *UCS* are not as clear (higher values for slabs 2 and 3 after the F-T test); the non-standard dimensions of the test specimens may be the reason. The slab thickness allowed cutting cubes with edges up to 30 mm, which is a relatively small dimension compared to the grain size; the specimens were not representative enough.

Bowing phenomenon and rapid strength reduction are known to occur in some marbles when used as exterior cladding on buildings across Europe (Grelk et al., 2007; Marini and Bellopede, 2009; Sousa and Sousa, 2019). Several inspected buildings showed that bowing and deterioration may occur in slabs shortly after exposure, even after 5–10 years (Grelk et al., 2007). With the increasing effort to reduce construction costs and the development of modern cutting technologies in the rock industry, slabs for cladding have become thinner nowadays, from former thicknesses of more than 10 cm to present thicknesses of 4 to 8 cm only. Although most thin marble claddings perform satisfactorily, durability problems and a tendency to bow have become increasingly common after ca. 50 years of use. Currently, to avoid bowing, laboratory testing according to EN 16306 is recommended for rock-clad facades; their resistance to thermal and moisture cycles should also be evaluated. While the thickness of the cladding appears to be the most important factor in bowing, some authors disagree, as they did not find any correlation (Yates et al., 2004, in Grelk et al., 2007). The facade's orientation might be more important. Grelk et al. (2007) state that the bowing phenomenon is less significant on facades exposed to minor daily temperature differences. The smallest bowing amplitudes are usually found on the northern facades (in the Northern Hemisphere), because these are not exposed to large temperature cycles from the sun. Zimmermann (2001 in Grelk et al., 2007) reported a 20-year-old building in Köln, Germany, with marble cladding from Greece. On the western and southern facades, the marble lost 65% of its original flexural strength, whereas on the northern facade, the loss was “only” 10%. Lekso (2002, in Grelk et al., 2007) reported another case in which the flexural strength decreased by 45% after 35 years. Based on macroscopic observation, the marble cladding removed from Istropolis showed no bending. During dismantling, only mechanical damage occurred by accident. However, when compared to the Gris Siboney Marble data on the internet, a slight reduction in flexural strength is evident (Table 7). Marble slabs from the northern facade showed better quality parameters (Table 3, Figure 9) than those reported by Grelk et al. (2007). Hatir et al. (2024) use the term microclimatic environments, as they found that the intensity of solar radiation and wind velocity to which building stones are exposed are the factors that directly determine the type and degree of deterioration.

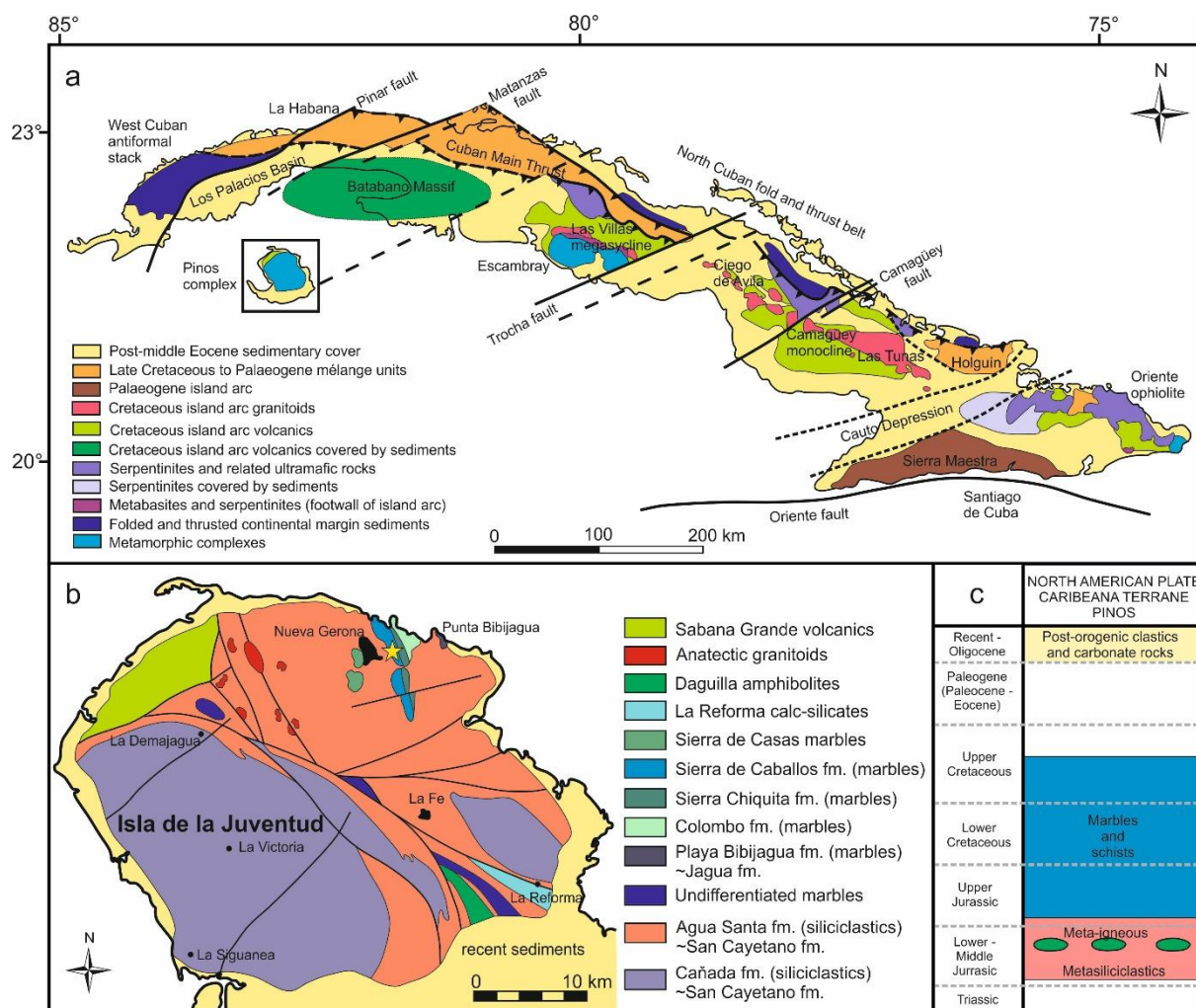


Fig. 11. a) Generalized geological map of Cuba compiled from the Geological Map of Cuba 1: 500 000 (Perez Othon and Yarmoliuk, 1985); b) Geological map of the Isla de la Juventud with indications of formations and reconstructed stratigraphy (modified after Millán-Trujillo, 1997 in: García-Casco et al., 2008). The place of marble mining is marked with the yellow star; c) Generalized tectonic-stratigraphic chart of Cuba modified from Iturralde-Vinent et al. (2016)

Re-use/recycling potential of dismantled cladding

The re-use of the marble slabs as second-hand cladding is a very rational first plan idea. In addition to meeting legislative requirements, repeated use of materials depends predominantly on their quality, documented by selected technical parameters. Data on bulk density, open porosity, and water absorption are required for each construction rock product. Bulk density is also used to calculate the thermal conductivity required for energy audits, which is a very current topic. The European Technical Standard EN 1469 contains suggestions on which properties of stone slabs for cladding must be declared by the producer, if relevant: geometric characteristics, flexural strength under concentrated load, breaking load at dowel hole, water absorption by capillarity, bulk density, open porosity, freeze-thaw resistance, resistance to thermal shock, reaction to the fire, dangerous substances and others. These data serve architects for design and civil engineers for the calculation of building statics. But, in contrast to previous national standards, it contains no suitability limits. The responsibility for the suitability assessment was fully transferred to the civil engineers. It makes this technical standard useless for the intended suitability assessment of the dismantled slabs. The older edition of this standard allowed at least a 20% decrease in R_{fT} after 12 F-T cycles, but even this single quantitative “limit” was removed from the last edition (by the way, instead of 12 cycles, data on R_{fT} after 14 F-T cycles are now required). To determine any quantitative suitability limits, other technical standards for rock used in construction were also studied.

For each natural stone product and its application, European standards contain lists of obligatory parameters that must be declared. These can include slip and skid resistance, abrasion resistance, durability of slip and skid resistance, resistance to ageing from thermal shock, resistance to dangerous substances, etc. But again, no limits are stated there, which complicates the suitability assessment of the natural rocks. The Slovak Technical Standard STN 72 1800 is much more useful and user-friendly. It gives explicit technical requirements for the so-called “dimension stone” (stone blocks, massive elements, rough-cut slabs, regularly shaped building stone, etc.).

Because of the 30 mm thickness of the slabs, the dismantled cladding could be compared only to “roughly cut slabs” in terms of this standard. Limits for marbles are listed in Table 8. Their comparison with average test values shows that the low frost resistance of the dismantled Gris Siboney Marble from Istropolis makes it unsuitable for re-use as dimension stone. Only the slightly better slabs from the northern facade could be used for this purpose.

Tab. 8. Suitability assessment of the dismantled marble for re-use as dimension stone

	Bulk density ρ_d [g.cm ⁻³]	Water absorption WAI [%]	Compressive strength UCS [MPa]	Flexural strength R_{ff} [MPa]	Frost resistance coefficient K_{fr}
Southern facade	2.674	0.26	47.4	4.6	0.67
Northern facade	2.701	0.20	55.2	6.8	0.82
STN 72 1800 (limits for marble)	> 2.60	< 0.8	> 40	> 4	> 0.75

In the European norms for exterior paving (EN 1341) or for interior floors and stairs (EN 12058), this is similar. Some requirements for reported data were added (abrasion resistance, slip and skid resistance, and durability of slip and skid resistance); only frost resistance is limited. The R_{ff} value decrement must be less than 20% after F-T tests, but 56 F-T cycles are normative here. As the tested samples underwent only 25 cycles, neither of these technical standards is applicable for the frost resistance assessment here. However, the minimum slab thickness for a given application can be calculated from the flexural strength results according to EN 1341 (Table 9). The 30 mm-thick marble slabs with $R_{ff} = 4.6$ MPa (average value from the southern facade) or $R_{ff} = 6.8$ MPa (northern facade) were suitable only for pedestrian areas when bedded in mortar. They are too thin for other applications.

Marble slabs recycled as aggregates

Crushing the dismantled marble slabs seems to be a feasible recycling in the form of aggregates of the required grain size for less demanding applications. While the tests showed that the water absorption of such aggregates is suitable for all applications (WA is less than 1 %), other tested properties are less favourable (Table 6).

Considering road construction, these recycled-marble aggregates are not suitable for the surface course, flexible bituminous pavements, or rigid cement-concrete pavements. The parameter M_{DE} exceeds the required limit for wear, which must be less than 30% even at the lowest traffic load (category M_{DE30}). Therefore, they can only be used in sub-base and base courses of sidewalks and roads with low traffic load, with or without binders.

Tab. 9. Required minimum thickness of slabs depending on their usage according to EN 1341

Class	Typical use	Minimum breaking force P [kN]	Safety factor F_s for slabs of length $L > 600$ mm	Required min. thickness of a slab h [mm]	
				if $R_{ff} = 4.6$ MPa	if $R_{ff} = 6.8$ MPa
0	Decoration	No requirement	-	-	-
1	Slabs bedded in mortar, pedestrian area only.	0.75	1.8: bound construction	25.5	21.0
			2.4: unbound construction	29.4	24.2
2	Pedestrian and cycles areas and paths.	3.5	1.8: bound construction	55.1	45.3
			2.4: unbound construction	63.6	52.3
3	Occasional car, light vehicle, and motorcycle access, garage entrances.	6.0	1.8: bound construction	72.1	59.3
			2.4: unbound construction	83.3	68.5

For concrete production, this crushed marble can be used only in less demanding applications where concrete category F2 is sufficient (mass loss less than 2%). The low frost resistance prevents its application in concretes of higher categories.

But the waste marble aggregates might be successfully used to produce various concrete products with added aesthetic value, such as terrazzo flooring, mosaic composite surfaces, and artificial stone. There, recycled

aggregates can substitute for the high-quality natural stone. The ideal substitution ratio must be found by experimental testing. This idea is not new; such applied research has already been reported by different authors (Hebhoub et al., 2011; Uygunoğlu et al., 2014; Benjeddou and Mashaan, 2022; Puttaganti, 2024). The waste marble aggregates studied by Hebhoud et al. (2011) could replace up to 75% of the natural aggregates without affecting concrete quality. In self-consolidating concretes, workability was even better with recycled marble aggregates than with natural limestone, without a significant reduction in strength (Uygunoğlu et al., 2014).

Conclusions

Laboratory research on marble cladding slabs, which were exposed to natural weathering processes in an urban environment for 40 years, yielded findings on their current physical condition and potential for further use, i.e., recycling. Separate sampling of slabs from the northern and southern facades of the building proved to be the correct sampling procedure. Laboratory determination of their basic physical and mechanical properties showed that marble slabs from the northern facade are better preserved and exhibit better (more favourable) technical parameters, such as lower porosity and water absorption, higher frost resistance, and higher compressive and tensile strength. This is probably due to the less pronounced temperature fluctuations on the northern facade, but the analysis of the environmental processes underlying that difference was not a subject of this research.

Comparison of the determined properties with the parameters specified in the national technical standard showed that marble slabs from the northern sides of the building are usable as decorative stone even after such a long exposure to external weathering. But the re-use as cladding, especially in outdoor conditions, requires further, larger-scale experimental testing to enable responsible evaluation of the entire volume of material dismantled from the building.

Tests showed that these dismantled marble slabs are unsuitable for re-use as paving slabs due to both their insufficient thickness (30 mm) and their low flexural strength. With such a thin thickness, their re-use is very limited, for instance, for pedestrian walkways/sidewalks.

The re-use of these old marble slabs as recycled aggregate for various concrete products, with added aesthetic value, has proven to be the ideal, most reliable option.

In addition to the laboratory research on the physical and mechanical properties, the identification of the marble source in Cuba was successful; its commercial name, Gris Siboney, was confirmed based on detailed mineralogical and petrological analysis, and the quarry of origin was geologically described through archival research.

References

- Akbulut, H., & Güner, C. (2007). Use of aggregates produced from marble quarry waste in asphalt pavements. *Building and Environment*, 42, 1921–1930. <https://doi.org/10.1016/j.buildenv.2006.03.012>
- Bellopede, R., Castelletto, E., Marini, P. (2016). Ten years of natural ageing of calcareous stones. *Engineering Geology* 211, 19–26. <https://doi.org/10.1016/j.enggeo.2016.06.015>
- Benjeddou, O., & Mashaan, N. (2022). Experimental Study of the Usability of Recycling Marble Waste as Aggregate for Road Construction. *Sustainability* 14(6), 3195. <https://doi.org/10.3390/su14063195>
- Binici, H., Shah, T., Aksogan, O., Kaplan, H. (2008). Durability of concrete made with granite and marble as recycle aggregates. *Journal of Materials Processing Technology* 208(1–3), 299–308. <https://doi.org/10.1016/j.jmatprotec.2007.12.120>
- Buguelski, Y., Vázquez, O., Grigorieva, I. (1985). Ore Deposits of Cuba. *Nauka*, Moscow, 246 p (in Russian)
- Dong, H., Gao, P., Ye, G. (2017). Characterization and comparison of capillary pore structures of digital cement pastes. *Materials and Structures* 50, 154. <https://doi.org/10.1617/s11527-017-1023-9>
- Dulla, M., Moravčíková, H. (2002). Architecture of Slovakia in the 20th century. *Slovart*, Bratislava, 512 p (in Slovak with English summary)
- García-Casco, A., Torres Roldán, R.L., Millán-Trujillo, G., Monié, P., Haissen, F. (2001). High-grade metamorphism and hydrous melting of metapelites in the Pinos Terrane (W Cuba): Evidence for crustal thickening and extension in the northern Caribbean collisional belt. *Journal of Metamorphic Geology* 19, 699–715. <https://doi.org/10.1046/j.0263-4929.2001.00343.x>
- García-Casco, A., Haissen, F., Castro, A., El-Hmidi, H., Torres Roldán, R.L., Millán-Trujillo, G. (2003). Synthesis of staurolite in melting experiments of a natural metapelite: Consequences for the phase relations in low temperature pelitic migmatites. *Journal of Petrology* 44(10), 1727–1757. <https://doi.org/10.1093/petrology/egg056>
- García-Casco, A., Iturralde-Vinent, M.A., Pindell, J. (2008). Latest Cretaceous collision/accretion between the Caribbean Plate and Caribbeana: Origin of metamorphic terranes in the Greater Antilles. *International Geology Review*, 50(9), 781–809. <https://doi.org/10.2747/0020-6814.50.9.781>

- Grelk, B., Christiansen, C., Schouenborg, B., Malaga, K. (2007). Durability of Marble Cladding – A Comprehensive Literature Review. *Journal of ASTM International* 4(4), 1-19. <https://doi.org/10.1520/JAI100857>
- Hamšíková, J. (2020). ISTROPOLIS – Dom odborov. <https://muop.bratislava.sk/istropolis-dom-odborov/d-5665>, accessed 2025-04-10 (in Slovak)
- Hatır, M.E., İnce, İ., Korkanç, M. (2024). The effect of wind and solar radiation on deterioration developments in historic buildings: Şeyh Osman Rumi Tomb, Central Turkey. *Environmental Earth Sciences* 83, 617. <https://doi.org/10.1007/s12665-024-11941-3>
- Hebhoub, H., Aoun, H., Belachia, M., Houari, H., Ghorbel, E. (2011). Use of waste marble aggregates in concrete. *Construction and Building Materials*, 25, 1167–1171. <https://doi.org/10.1016/j.conbuildmat.2010.09.037>
- Iturralde-Vinent, M.A. (1994). Cuban Geology: A new plate tectonic synthesis. *Journal of Petroleum Geology* 17(1), 39–69. <https://doi.org/10.1111/j.1747-5457.1994.tb00113.x>
- Iturralde-Vinent, M.A., Millán-Trujillo, G., Korkas, L., Nagy, E., Pajón, J. (1996). Geological interpretation of the Cuban K-Ar Database. In: Iturralde-Vinent, M. (ed.). Cuban ophiolites and volcanic arcs: Special Contribution no. 1 to IGCP Project 364, Miami, Florida, 48–69
- Iturralde-Vinent, M.A., García-Casco, A., Rojas-Agramonte, Y., Proenza, J.A., Murphy, J.B., Stern, R.J. (2016). The geology of Cuba: A brief overview and synthesis. *GSA Today* 26(10), 4–10. doi: 10.1130/GSATG296A.1
- Karaca, Z. (2010). Water absorption and dehydration of natural stones versus time. *Construction and Building Materials*, 24(5), 786–790. <https://doi.org/10.1016/j.conbuildmat.2009.10.029>
- Khyaliya, R.K., Kabeer, K.I.S.A., Vyas, A.K. (2017). Evaluation of strength and durability of lean mortar mixes containing marble waste. *Construction and Building Materials* 147, 598–607. <https://doi.org/10.1016/j.conbuildmat.2017.04.199>
- Kuchařová, A., Příkryl, R. (2017). Mineralogical and geochemical (stable C and O isotopes) variability of marbles from the Moldanubian Zone (Bohemian Massif, Czech Republic): implications for provenance studies. *Environmental Earth Sciences* 76, 48. <https://doi.org/10.1007/s12665-016-6348-0>
- Luque, A., Cultrone, G., Mosch, S., Siegesmund, S., Sebastian, E., Leiss, B. (2010). Anisotropic behaviour of White Macael marble used in the Alhambra of Granada (Spain). The role of thermohydric expansion in stone durability. *Engineering Geology* 115, 209–216. <https://doi.org/10.1016/j.enggeo.2009.06.015>
- Marini, P., & Bellopede, R. (2009). Bowing of marble slabs: Evolution and correlation with mechanical decay. *Construction and Building Materials* 23(7) 2599–2605. <https://doi.org/10.1016/j.conbuildmat.2009.02.010>
- Meyerhoff, A.A., Khudoley, K.M., Hatten, C.W. (1969). Geologic significance of radiometric dates from Cuba. *American Association of Petroleum Geologists Bulletin*, 53(12), 2494–2500
- Millán-Trujillo, G. (1997). Geología del macizo metamórfico de la Isla de la Juventud. In: Furrázola Bermúdez, G.F., Núñez Cambra, K.E. (eds.). Estudios sobre Geología de Cuba: Centro Nacional de Información Geológica, La Habana, Cuba, 259–270
- Perez-Othon, J., Yarmoliuk, V.A. (1985). Mapa Geologica de Cuba. MINBAS: CIG, La Habana.
- Petrov, V.P., Finko, V.I., Belikov, B.P., Coutín-Correa, D.P., Garcia, C. (1974). Los mármoles de Cuba. En: Geología de los yacimientos minerales útiles de Cuba. Publicación Especial Número 3, Instituto de Geología y Paleontología, Academia de Ciencias de Cuba, La Habana, 125–143
- Puttaganti, V.N. (2024). Replacement of Coarse Aggregate with Waste Marble. *International Journal of Science and Research*, 13(5), 497–514. <http://dx.doi.org/10.21275/sr24506110055>
- Rock-Color Chart (2011). Geological Rock-Color Chart with Genuine Munsell Color Chips. Produced by Munsell Color, Geological Society of America, USA.
- Rodrigues, R., de Brito, J., Sardinha, M. (2015). Mechanical properties of structural concrete containing very fine aggregates from marble cutting sludge. *Construction and Building Materials*, 77, 349–356. <https://doi.org/10.1016/j.conbuildmat.2014.12.104>
- Ružička, P., Durmeková, T. (2012): Long-term cyclic testing of frost resistance of the Slovak marbles. *Geotechnika*, 1-2, 31–37 (in Slovak)
- Siegesmund, S., Ruedrich, J., Koch, A. (2008). Marble bowing: Comparative studies of three different public building facade. *Environmental Geology*, 56, 473–494. <https://doi.org/10.1007/s00254-008-1307-z>
- Singh, M., Choudhary, K., Srivastava, A., Sangwan, K.S., Bhunia, D. (2017). A study on environmental and economic impacts of using waste marble powder in concrete. *Journal of Building Engineering*, 13, 87–95. <https://doi.org/10.1016/j.job.2017.07.009>
- Somin, M.L., Millán-Trujillo, G. (1981). Geology of the Metamorphic Complexes of Cuba. *Nauka*, Moscow. 218 pp (in Russian)
- Sousa, H., & Sousa, R. (2019). Durability of Stone Cladding in Buildings: A Case Study of Marble Slabs Affected by Bowing. *Buildings* 9(11), 229. <https://doi.org/10.3390/buildings9110229>
- Ulusay, R., Hudson, J.A. (eds.) (2007). The complete ISRM suggested methods for rock characterization, testing and monitoring: 1974-2006. Kozan Ofset Matbaacılık San. ve Tic. Şti. Ankara, Turkey, 628 p.

- Uygunoğlu, T., Topçu, İ.B., Çelik, A.G. (2014). Use of waste marble and recycled aggregates in self-compacting concrete for environmental sustainability. *Journal of Cleaner Production*, 84, 691–700. <https://doi.org/10.1016/j.jclepro.2014.06.019>
- EN 1097-1 (2023) Tests for mechanical and physical properties of aggregates. Part 1: Determination of the resistance to wear (micro-Deval)
- EN 1341 (2012) Slabs of natural stone for external paving. Requirements and test methods
- EN 1367-1 (2007) Tests for thermal and weathering properties of aggregates. Part 1: Determination of resistance to freezing and thawing
- EN 1469 (2015) Natural stone products. Slabs for cladding. Requirements
- EN 1925 (1999) Natural stone test methods. Determination of water absorption coefficient by capillarity
- EN 1926 (2006) Natural stone test methods. Determination of uniaxial compressive strength
- EN 1936 (2006) Natural stone test methods. Determination of real density and apparent density, and of total and open porosity
- EN 12058 (2015) Natural stone products. Slabs for floors and stairs. Requirements
- EN 12371 (2010) Natural stone test methods. Determination of frost resistance
- EN 12372 (2022) Natural stone test methods. Determination of flexural strength under concentrated load
- EN 13242 (2007) Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
- EN 13755 (2008) Natural stone test methods. Determination of water absorption at atmospheric pressure
- EN 14066 (2013) Natural stone test methods. Determination of resistance to ageing by thermal shock
- EN 14579 (2004) Natural stone test methods – Determination of sound speed propagation
- EN 16306 (2022) Natural stone test methods – Determination of resistance of marble to thermal and moisture cycles
- STN 72 1800 (1987) Natural building stone for stonecutting purposes. Technical requirements (in Slovak)
- https://www.ecured.cu/M%E1rmol_Gris_Siboney, accessed 2025-01-13
- <https://www.interstonemarble.com/marmi-pietre/gris-siboney/>, accessed 2024-11-20
- <https://www.stonecontact.com/gris-siboney-marble/s2817>, accessed 2024-11-15
- https://sk.wikipedia.org/wiki/Dom_odborov_Istropolis, accessed 2024-11-12
- <https://bionumbers.hms.harvard.edu/search.aspx>, accessed 2025-03-04
- https://www.webelements.com/mercury/atom_sizes.html, accessed 2025-03-04
- <https://en.wikipedia.org/wiki/Ciboney>, accessed 2025-04-01