

1	 Tarbiat Modares University	Technical Properties of Aligudarz Crystalline White Marble	
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Technical Properties of Aligudarz crystalline White Marble

Company that required the test: Kohestanstone Company

Prepared by:

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1. Summary of the Results

The summary of the laboratory results for Aligudarz crystalline white marble is presented In Table

1.

Parameters	Value	Description	Quality
Mineralogy	Calcite	Not undesirable mineral	Very good
Dry Density (gr/cm3)	2.69	Medium	-
Saturated Density (gr/cm3)	2.69	Medium	-
Specific gravity	2.69	Medium	-
Porosity (%)	0.21	Very Low	Very good
Forced Water absorption (%)	0.10	Very Low	Very good
Thermal expansion coefficient (10⁻⁶ C⁻¹)	12.97	High	Sensitive to temperature
Compressive strength (MPa)	69.56	Medium	Very good
Flexural strength (MPa)	6.03	Medium	Very good
Hardness (Cerchar abrasivity indes)	1.62	Medium	Medium
Slip Resistance in dry condition	52	High	Good as paving
Slip Resistance in wet condition	20.3	Very Low	Not recommended as paving
Weight loss after 30 cycles of Freeze-thaw (%)	0.16	Medium	Medium resistance against freeze-thaw
P-wave reduction after 30 cycles of Freeze-thaw (%)	42.99	Medium	Medium resistance against freeze-thaw
Weight loss after after 30 cycles of Wetting-drying (%)	0.00	Very low	Very resistant against wetting-drying
P-wave reductio after 30 cycles of Wetting-drying (%)	0.85	Very low	Very resistant against wetting-drying

2. Materials and Methods

This report includes the methods and results of technical laboratory tests which has been conducted on Aligudarz crystalline white marble.

2.1 Chemical composition

XRD and XRF tests were performed in order to determine the mineralogical and elemental content of the stone. Samples were crushed into a fine powder. Oven-dried powder samples were examined under a Philips X'PERT MPD XRD tester and a Philips PW2404 XRF apparatus.

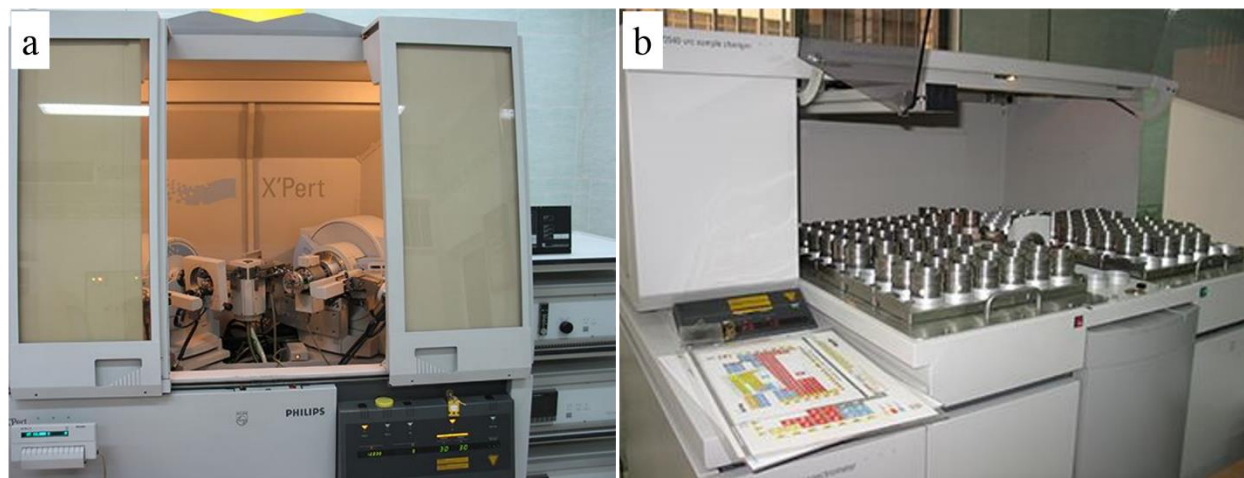


Figure 1 Chemical composition testers. a: XRD tester and b: XRF tester

2.2 Thermal expansion

Thermal expansion test was conducted on 3 dry samples with an original length of nearly 20 cm, a width of 6 cm and a thickness of 2 cm according to EN 14581:2004. Samples were subjected to a temperature ranging from -20 °C to +80 °C. The variation in the length of samples due to thermal expansion was measured with an accuracy of 1 μ m. Thermal expansion (millimeter/meter or mm/m) expresses the relative length change of the stone with changing temperature. Thermal expansion coefficient, which describes the specific length change per unit temperature depends on the considered temperature interval. The thermal dilatation coefficient (α) is calculated as the ratio

between the length change of the samples (ΔL) and the initial sample length (L) multiplied by the temperature interval T (100 °C here) in centigrade as following:

$$\alpha = \frac{\Delta L}{L \times T}$$

2.3 Physical Properties

5 specimens having the dimension of $7 \times 7 \times 7$ cm were analyzed using saturation-buoyancy technique according to EN 1936 (2006). Samples were washed with the tap water, and dried at an oven with the temperature of 80 ± 2 °C till reaching a constant mass. Dry samples were weighed within an accuracy of 0.01 g. Samples were totally submerged in the water under vacuum pressure of 0.8 bar for 24 hours. Specimens were removed from the water, and wiped with a damp cloth and recorded the saturated and submerged masses. Dry and saturated densities, effective porosity, and water absorption under vacuum pressure were obtained for the specimens. Finally, the mean values of each parameter were obtained for the studied samples.

2.4 Mechanical properties

Uniaxial compressive strength (UCS) and Flexural strength (FS) tests were used to measure strength properties of samples.

UCS tests were carried out in accordance with EN 1926:2007 on samples with dimension of $7 \times 7 \times 7$ cm. Four oven-dried samples were loaded vertically with a constant loading rate of 0.50–1.00 MPa/s to measure UCS of samples.

Flexural strength test was performed according to EN 13161(2008) using 3-point bending methods. For this test, plate-shaped samples having a length and wide of 20 cm $\times$ 6 cm and thickness of 2 cm were used (**Figure 2**).



Figure 2 Measurement of flexural strength of Aligudarz crystalline white marble.

2.5 Hardness

Cerchar abrasivity index (CAI) was carried out using the original Cerchar apparatus to measure hardness of the stone. The original layout features a vice holding the rock specimen and a testing lever that is directly connected to a steel stylus. The steel stylus has a 90° conical tip and Rockwell hardness of HRC 54–56. The steel stylus is applied to the surface of a rock specimen under a static force of 70 N and scratched over the rock surface by moving the lever at a velocity of 10 mm/s. After the test, the wear surface of the steel stylus is measured under a microscope to an accuracy of 0.01 mm. The Cerchar test was applied to sawn specimens. The Cerchar abrasivity index (CAI) was calculated as following:

$$CAI = 10d$$

Where, d is diameter of wear flat measured in mm to an accuracy of 0.01 mm.

2.6 Slip resistance

The slip resistance angles of the samples were determined by means of the pendulum slipmeter referred in EN 14231. The pendulum slipmeter is a dynamic friction tester. The device comprises of four main components, being a base, scales, a pendulum arm and a rubber slider. The rubber

slider scuffs on the surface of the sample as the pendulum makes a free fall. A pendulum device of model Vessex was used in the experiment. The test was done on both wet and dry samples in polished surfaces of the stone. The risk of slipping based on slip resistance value (SRV) is presented in Table 1.

Table 1 Slip resistance rating based on SRV

SRV	Description
0-24	Very Dangerous
24-34	Dangerous
35-64	Good
>65	Very Good

2.7 P-wave velocity

P-waves velocity (ISRM 1981) was conducted on 5 samples with the dimension of 7 cm × 7 cm × 7 cm using Pundit Lab apparatus. Ultrasonic gel was rubbed at contact area of the transducers and samples surface to achieve a good contact between the transducers and the sample. P-wave transducers were 20 mm in diameter and 54 kHz in frequency.

2.8 Freeze-Thaw test

The samples were imposed to freeze–thaw test up to 30 cycles according to the guidelines outlined in ASTM (2013). Initially, the samples were saturated by immersion in water under atmospheric pressure. The saturated samples were placed into a freezer and frozen at – 18 °C for 12 h. After removal from the freezer, samples were placed into a water bath at 12 °C for 12 h.

2.9 Wetting-drying

In order to measure the resistance of the stone to the wetting and drying cycles, samples were immersed in water 12 h. Samples were taken from water and then placed an oven at 75 °C for 12h. The test were conducted for 30 cycles.

3. Results

3.1 XRD Results

The results of XRD test showed that Aligudarz crystalline white marble is composed of calcite (CaCO_3).

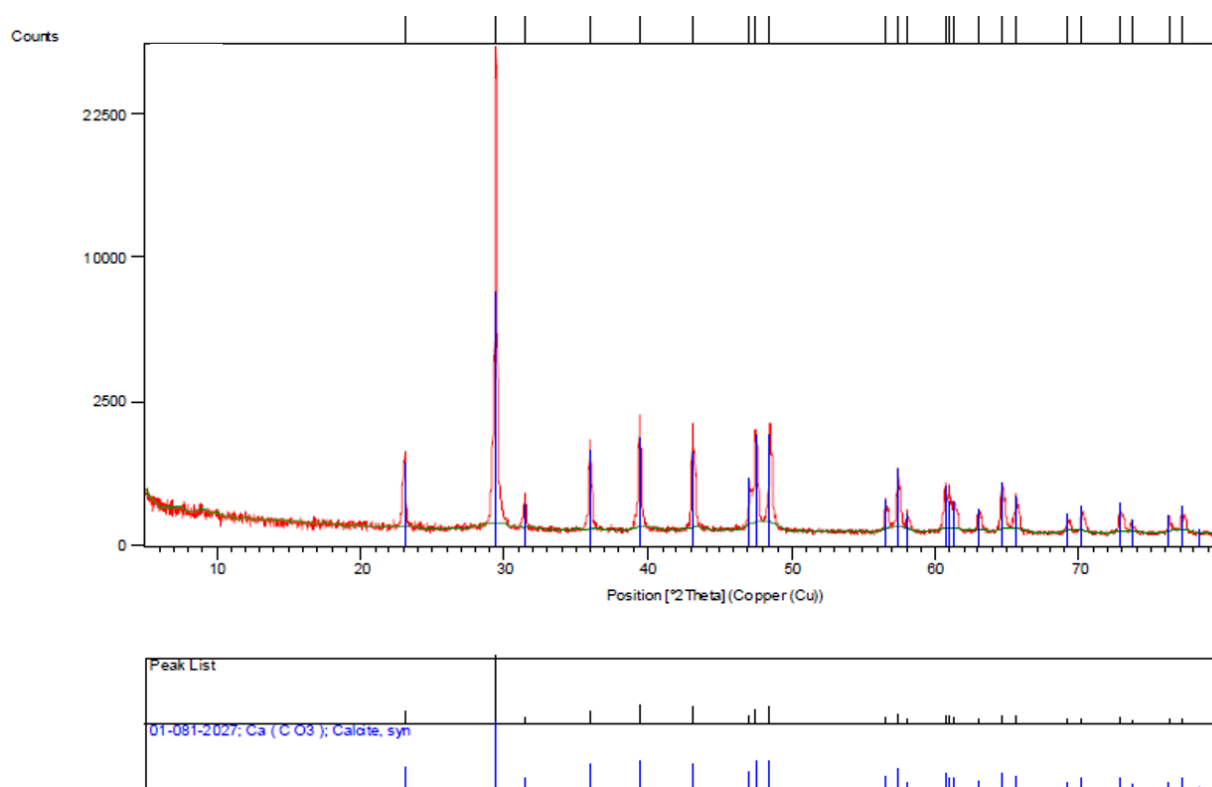


Figure 3 XRD results of Aligudarz crystalline white marble

3.2 XRF Results

The results of XRF test showed Aligudarz crystalline white marble has a high loss on ignition (L.O.I) value and CaO value. This is because calcite (CaCO_3) decomposes on heating to give carbon dioxide (CO_2) and calcium oxide CaO. The high LOI content is due to the CO_2 gas emission.

Table 2 The results of XRF test for Aligudarz crystalline white marble

L.O.I (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	CaO (%)	Na ₂ O (%)	Fe ₂ O ₃ (%)	MgO (%)	P ₂ O ₅ (%)	SO ₃ (%)	Cl (%)	Sr+Zn Rb
43.48	0.12	0.03	55.72	0.05	0.12	0.49	0.003	0.016	0.008	0.029

3.3 Thermal expansion properties

The results of thermal expansion of the stone with a changing temperature of -20 °C to 80 °C are listed in Table 3. As can be seen, the thermal expansion of the stone changes from 1.04 mm/m to 1.46 mm/m with an average value of 1.30. The average thermal expansion coefficient of the stone is $12.97 \times 10^{-6} \text{ C}^{-1}$. This stone has a high thermal expansion coefficient.

Table 3 Thermal expansion of the stone with a changing temperature of -20 °C to 80 °C

Sample	Length (cm)	Temperature (centigrade degree)	Linear expansion (mm/m)	Thermal expansion coefficient (10^{-6} C^{-1})
1	20	-20–80	1.39	13.9
2	20	-20–80	1.46	14.6
3	20	-20–80	1.04	10.4
Average			1.30	12.97

3.3 Physical properties

The physical properties of Aligudarz crystalline white marble are shown in **Table 4**. The average dry and saturated density is 2.69 g/cm^3 . The specific gravity of the stone is 2.69. In terms of density, it is classified as medium density rock (density ranges between 2.25 to 2.75 gr/cm^3). Based

on porosity and water absorption values, Aligudarz crystalline white marble is classified as very low porous rock (less than 0.5%) and very water absorption (less than 0.3%).

Table 4 Physical properties of Aligudarz crystalline white marble

Sample number	Dry density (gr/cm ³)	Saturated density (gr/cm ³)	Specific gravity	Effective porosity (%)	Forced Water absorption (%)
1	2.68	2.68	2.69	0.31	0.11
2	2.71	2.71	2.71	0.22	0.08
3	2.68	2.68	2.68	0.24	0.09
4	2.66	2.67	2.67	0.27	0.10
5	2.70	2.71	2.71	0.26	0.10
Average	2.69	2.69	2.69	0.26	0.10

3.4 Strength properties

The results of the uniaxial compressive strength test showed that the average compressive strength of Aligudarz crystalline white marble is about 69.56 MPa (Table 5). In terms of compressive strength, Aligudarz crystalline white marble is classified as a medium strength stone (50-100 MPa). In terms of flexural strength, Aligudarz crystalline white marble has an average flexural strength of 6.03 MPa.

Table 5 Mechanical properties of Aligudarz crystalline white marble

Sample	Uniaxial compressive strength (MPa)	Flexural strength (MPa)
1	74.06	4.97
2	68.58	5.68
3	73.12	6.39
4	62.47	7.10
Average	69.56	6.03

3.5 Strength Hardness (Cerchar abrasivity Index)

The results of Cerchar abrasivity tests showed that the Cerchar abrasivity index of the stone changes from 1.31 to 1.82 with an average value of 1.62. In terms of Cerchar abrasivity, Aligudarz

crystalline white marble is classified as a medium resistant to the abrasion by foot traffic (Table 6).

Table 6 Stone classification based on Cerchar abrasivity index

Classification	Cerchar abrasivity index
Soft rock	0.2-0.5
relatively Soft rock	0.5-1
Medium	1-2
Hard	2-4
Very hard	4-6

1.1 Slip resistance test

The results from the slip resistance test are presented in Table 7. According to the findings, when the polished stone is dry, it falls into the category of samples with a low slip risk (35-64). However, when the polished stone is wet, it falls into the category of samples with a high slip risk (0-24). Therefore, it is not recommended to use the polished stone as a flooring material in areas where the stone is likely to become wet.

Table 7 slip resistance values (SRV) for polished stone

Sample	SRV in dry condition	SRV in wet condition
1	56	24
2	48	20
3	52	17
Average	52	20.3

1.2 Freeze-Thaw test

The investigation of weight loss variation showed that the amount of dry weight loss is about 0.13% after the 30 cycles (Table 8). The reduction in P-wave velocity was around 42.99% of its initial value after 30 cycles. The stone has a medium resistance to frost action.

Table 8 Average variation in dry weight and P-wave velocity of stone during Freeze-Thaw test

Cycle	Weight variation (%)	P-wave velocity (m/s)	P-wave velocity variation (%)
0	0.00	5385	0.00
30	-0.13	3070	-42.99

1.3 Wetting-drying test

The stone showed no tangible dry weight loss after the wetting-drying in water (**Table 9**). The reduction in P-wave velocity was measured to be 0.85 % after the test. The stone has a high resistance against wetting-drying.

Table 9 Average variation in dry weight and P-wave velocity during wetting-drying test

Cycle	Weight variation (%)	P-wave velocity (m/s)	P-wave velocity variation (%)
0	0.00	5306	0.00
30	0.00	5261	-0.85

Conclusion

Table 14 shows the application of this stone based on laboratory results.

Table 10 Application of polished Aligudarz crystalline white marble based on laboratory tests

Application	Recommendation
External façade	It is not recommended for wet areas (lower part of building or floor) with possible frost action and where stone experiences thermal shocks It is recommended for places with high moisture content
External paving	It is recommended in dry areas
Interior decoration	It is recommended
Stair	It is recommended in dry areas
Internal paving	It is recommended in dry areas
Grave stone	It is recommended

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