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MECHANICAL BEHAVIOUR OF MARBLES FROM THE RHODOPE MASSIF: EXAMPLES FROM PANGAIO MOUNTAIN AND THASSOS ISLAND

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ABSTRACT

The studied areas are of the most famous and most important marble producing areas in Greece. The mineralogical composition of the studied marbles can be characterised as white, coarse grained, dolomitic marble, in Thassos and as white medium grained, dolomitic marble, together with white-gray coarse grained calcite marble in Pangaio mountain.

The present study conserns the description of the existed relationship, between physicomechanical properties, such as the bulk specific gravity, water absorption, ultra-sonic velocity and compressive strength. This relationship was expressed by mathematic models and diagrams.

INTRODUCTION

In Greece, marble has been considered, from the antiquity, as a privileged construction material, used to create monuments such as Parthenon etc.

The considerable increase of the construction causes the increase of the demand for more building materials. The suitability of new building stones, before being used, must be studied carefully, especially for construction of important buildings, in order to resist in time. Furthermore, the effective conservation of the existing historic monuments is related to the study of the change of the physico-mechanical behaviour of the construction materials. Rock weathering, depended of the mineralogical and physical data of the material, is a factor which contributes to the gradual destruction of hard laboured monuments of historical significance. The location of the weathered zones on marble walls of monuments is imperative before restoration planning; For this purpose the ultra-sonic method can be used.

This study attemps to correlate the changes of some physico-mechanical properties of each investigated marble, to the ultra sonic velocity, being characterised as an indicator of the material's quality.

DESCRIPTION OF THE ROCK MATERIAL

The studied areas are situated in the eastern part of the northern Greece and belong geologically to the Rhodope Massif (Voreadis, 1954, Kromberg et al., 1970, Papanikolaou, 1981, fig. 1d).

The collected samples derive from the following areas:

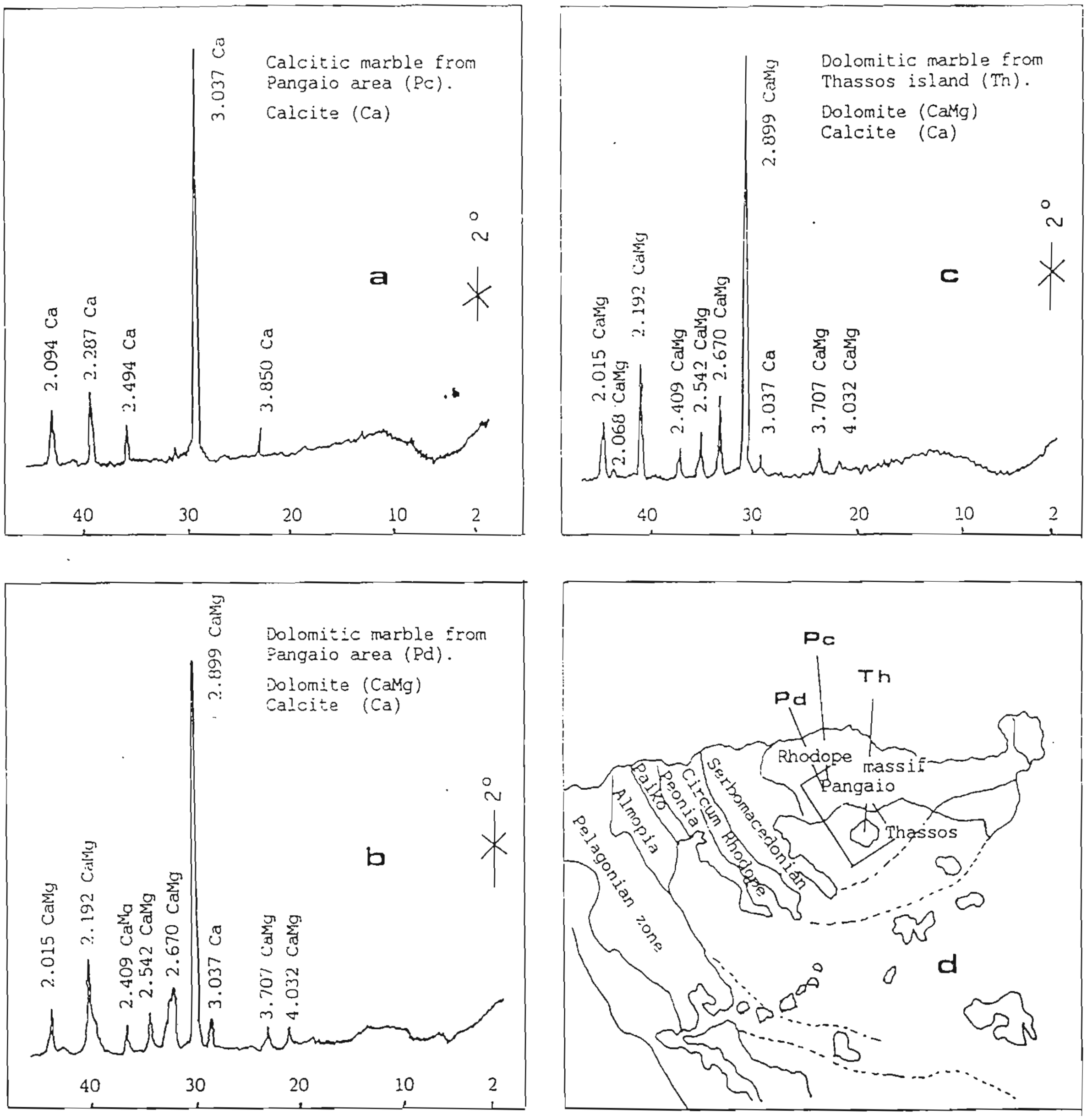

Fig. 1. XRD mineralogical data (a, b, c) and location (d) of the studied marble areas.

i) Thassos island (near Panagia village). It is composed of dolomitic marble (Th).

ii) Pangaio mountain (near Nikissiani village). It is composed of calcite marble (Pc).

iii) Pangaio mountain (Drama province). It is composed of dolomitic marble (Pd, commercial name: Ajax).

Samples collected from the above areas are studied as follows.

i) Mineralogically, by thin section examination, under the polarized microscope and by XRD method with the use of Philips RWD 1010 diffractometer

TABLE I. Experimental data for description of the rock material of the studied marbles.

Description	Pangaio-Pc	Pangaio-Pd	Thassos-Th
1) Mineralogical Characterisation	Calcitic	Dolomitic	Dolomitic
2) Texture			
a) grain size	coarse grained	medium grained	coarse grained
b) relative grain size	almost uniform	almost uniform	almost uniform
c) grain shape			
i) angularity	angular (to subangular?)	angular (to subangular?)	angular (to subangular?)
ii) form	equidimensional	equidimensional	equidimensional
iii) surface texture	rough	rough	rough
3) Color	grayish-white	white with rare small brown veins	light white
4) Miner.Composition			
$CaCO_3$	98.64%	8.75%	5.00%
$CaMg(CO_3)_2$	1.19%	88.45%	94.50%
5) Chemical Composition			
CaO	55.60%	31.82%	31.68%
MgO	0.26%	19.23%	20.63%
Al	< 0.01%	< 0.01%	< 0.01%
Fe	< 0.01%	0.79%	< 0.01%
Si	< 0.01%	< 0.01%	< 0.01%

(Cuka radiation, $\lambda = 1.54$ Å with Ni-filter) of the Thessaloniki Faculty of Earth Sciences and Technology (fig. 1).

ii) Chemically, by atomic absorption method (IGME, Athens) shaving not only quantitative but also qualitative difference to their chemical composition.

The rock material was described according to the requirement of IAEG (1981), for engineering geological purposes (Table I). Some of the data used in this study were taken from Christaras (1988).

PHYSICAL AND MECHANICAL PROPERTIES

Ten cubic test specimens, from each studied marble, were used; their lateral dimension was 4 cm (instead of 5 cm, according ASTM, because of technical difficulties - however DIN specifications accept 4 cm as a minimum lateral dimension, Hummel and Charisius, 1957). Each specimen was studied for:

i) The bulk specific gravity (d_{110}, ASTM C 97-47) which is obtained by dividing the dry weight (after drying for 24h at 110^{o} C) of the specimens, by the total volume (solids and voids).

TABLE II. Experimental data of the studied physical and mechanical properties.

Specimens		d_{110} (gr/cm^3)	Ab (‰)	V (mm/μs)	σc (Kg/cm^2)
Pangaio	Pc1	2.78	0.04	5.27	872
	Pc2	2.75	0.07	4.98	740
	Pc3	2.72	0.09	4.95	732
	Pc4	2.78	0.04	5.30	882
	Pc5	2.75	0.05	5.20	780
	Pc6	2.82	0.03	5.35	902
	Pc7	2.70	0.12	4.72	705
	Pc8	2.79	0.04	5.34	890
	Pc9	2.79	0.03	5.31	898
	Pc10	2.77	0.06	5.13	787
Pangaio	Pd1	2.98	0.17	6.34	1348
	Pd2	2.77	0.26	5.76	1094
	Pd3	3.00	0.18	6.39	1357
	Pd4	2.90	0.22	6.35	1340
	Pd5	2.90	0.19	6.30	1344
	Pd6	2.83	0.20	6.24	1295
	Pd7	2.83	0.21	6.19	1302
	Pd8	2.85	0.21	6.26	1335
	Pd9	2.84	0.22	6.22	1328
	Pd10	2.76	0.27	5.73	1058
Thassos	Th1	2.65	0.27	5.32	890
	Th2	2.89	0.19	6.18	1182
	Th3	2.64	0.28	5.29	905
	Th4	2.90	0.17	6.19	1204
	Th5	2.92	0.15	6.21	1210
	Th6	2.78	0.22	5.85	1017
	Th7	2.77	0.23	5.62	910
	Th8	2.79	0.22	5.72	1024
	Th9	2.80	0.21	5.62	1020
	Th10	2.84	0.20	5.87	1044

ii) The water absorption, in vacuum (Ab, ASTM C 97-47) expressed as the ratio of the absorbed water weight (after a period of 24 h) to the dry weight of the specimens.

iii) The compressive strength (σ_c, ASTM C 170-50) by dividing the compressive effort by the surface of the base of the cube. For this purpose the 40th loading system of the Thessaloniki Faculty of Technology was used.

iv) The ultra-sonic velocity (v, ASTM 597), as a good index characteristic of the physico-mechanical behaviour of the hard and soft rocks. For this purpose the PUNDIT portable ultra-sonic non destructive digital tester of the Thessaloniki Faculty of Technology was used.

The results of the above tests for the studied marbles, are given in Tables II, III.

TABLE III. Mean values of the calculated physicomechanical features.

	Ab	d	σ_c	V
Pc				
$\bar{x}$	0.057	2.765	819	5.115
σ_{n-1}	0.027	0.034	74	0.199
Pd				
$\bar{x}$	0.21	2.866	1280	6.178
σ_{n-1}	0.030	0.075	104	0.224
Th				
$\bar{x}$	0.22	2.798	1041	5.787
σ_{n-1}	0.039	0.091	116	0.321

The measured physico-mechanical data conform to ASTM physical requirements, given in Table IV. It must be mentioned that they are marbles of high quality with high strength and low absorption.

TABLE IV. ASTM Physical requirements (ASTM C 503).

Physical Property	Requirement
1) Absorption, max	0.75%
2) Specific gravity, min,	
calcite	2.60 gr/cm^3
dolomite	2.80 gr/cm^3
serpentine	2.70 gr/cm^3
travertine	2.30 gr/cm^3
3) Compressive strength, min	7500 psi (52 MPa)
4) Modulus of rupture, min	1000 psi (7 MPa)
5) Abrasion resistance, min (Pertains to foot traffic only)	10

STATISTICAL INTERPRETATION

The study showed a distinct influence of the change of the physical properties and the mechanical resistance on the change of the observed ultra - sonic velocity (fig. 2). This influence is expressed, in the range of the measured values, by linear regressions with a significant correlation coefficient, given in Table V.

In order to verify the significance of the studied correlation with a probability of 99% the coefficient $t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$ was calculated with the aid of the Student Tables according to which the correlation coefficients must be higher than 0.7646 (n-2 = 8, n: number of specimens).

According to the calculated relationship, the increase of the water absorption, is related to the decrease of the compressive strength and ultra sonic velocity. According Winkler (1988), the relationship of the water absorption to the strength, as the modulus of rupture, shows a negative curvi-

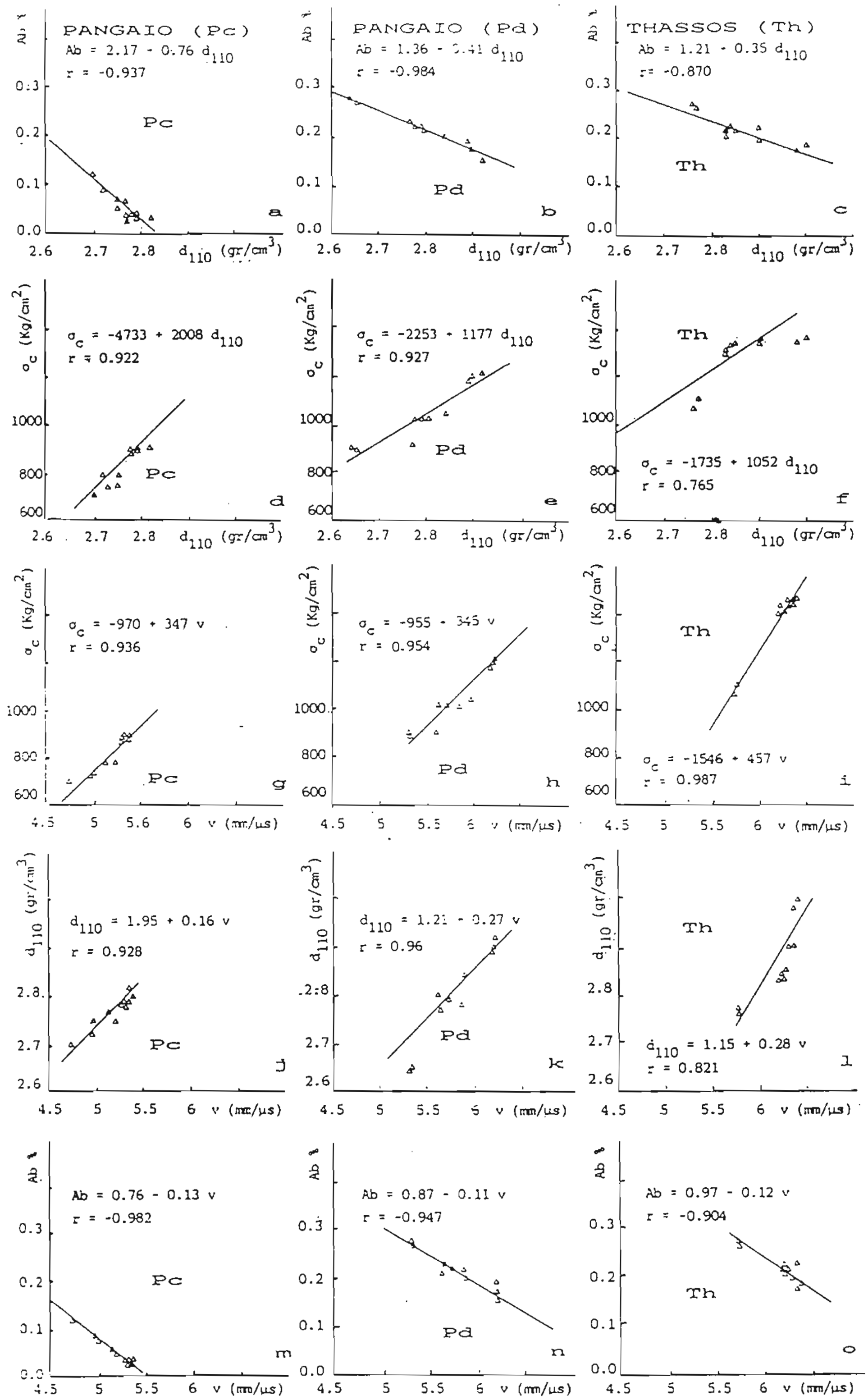

Fig. 2. Statistic diagrams between the studied properties, for each marble (Pangaio, Pc: a,d,g,j,m; Pangaio, Pd: b,e,h,k,n; Thassos, Th: c,f, i,l,o).

TABLE V. Mathematic expression of the relationship which is observed between the studied properties.

Area	Regression	Correlation Coefficien
Pangaio (Pc)	$Ab = 2.17 - 0.76\ d_{110}$	$r = -0.937$
	$\sigma_c = -4733 + 2008\ d_{110}$	$r = 0.922$
	$\sigma_c = -970 + 347\ v$	$r = 0.936$
	$d_{110} = 1.95 + 0.16\ v$	$r = 0.928$
	$Ab = 0.76 - 0.13\ v$	$r = -0.982$
Pangaio (Pd)	$Ab = 1.21 - 0.35\ d_{110}$	$r = -0.870$
	$\sigma_c = -1735 + 1052\ d_{110}$	$r = 0.765$
	$\sigma_c = -1546 + 457\ d_{110}$	$r = 0.987$
	$d_{110} = 1.15 + 0.28\ v$	$r = 0.821$
	$Ab = 0.97 - 0.12\ v$	$r = -0.904$
Thassos (Th)	$Ab = 1.36 - 0.41\ d_{110}$	$r = -0.984$
	$\sigma_c = -2253 + 1177\ d_{110}$	$r = 0.927$
	$\sigma_c = -955 + 345\ v$	$r = 0.954$
	$d_{110} = 1.21 + 0.27\ v$	$r = 0.966$
	$Ab = 0.87 - 0.11\ v$	$r = -0.947$

linear relationship for Carrara marble.

It must be mentioned that increasing water absorption can be related directly to the increase of weathering. (Irfan and Dearman, 1978, Zatler and Lengar, 1984, Christaras et al, 1989). Marble in contrast to limestones, tends to crack inward around the grain boundaries, caused to dilation phenomena. Many marble building stones develop fine cracks starting at the surface continuing inward thus loosening the tight stone fabric; percolating acid rain water and salt spray coming from sea side areas, strengthens this process (Auger, 1988). The degree of dilation can be masured by ultra sonic method because of the observed relationship with the water absorption and strength.

CONCLUSION

In the present study three different marbles, two from Pangaio mountain and one from Thassos island, have been examined in terms of physicomechanical behaviour. The results of this study are summarized as follows.

i) The mineralogical composition of the studied marbles differs in these two areas. The material can be characterised as white, coarse grained, dolomitic marble, in Thassos and as white, medium grained, dolomitic marble together with whitegray coarse grained, calcite marble in Pangaio.

ii) Properties, such as bulk specific gravity, water absorption, ultra sonic velocity and compressive strength, were measured and the calculated relationships are given in Table V.

iii)The increase of the water absorption causes a decrease of the compressive strength and ultra sonic velocity. This relationship is expressed by linear regression. Hence, for building stone protection, the water absorption increasing as weathering expression can be measured with ultrasonic instruments.

Finally, it must be mentioned that a carefull examination of the physico-mechanical behavior of the construction materials, must be considered imperative. So, the constructed buildings would resist in time

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