"Schist" from "Trás-os-Montes e Alto Douro" (NE of Portugal) — Potential use as Natural Stone

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Abstract. The main purpose of this work was to increase the knowledge about the geological resources of "Trás-os-Montes e Alto Douro" (TMAD), particularly about its "Schist", due to the economic and social effects that their mining and manufacturing can have, not only on the local economy, but also on a national level. This work presents the results of the study conducted on "Schist" (slate, phyllite and schist) from TMAD, aiming for its use as natural stone. Special emphasis is given on the results obtained in the following physical and mechanical tests: compressive strength, flexural strength, apparent density, open porosity, water absorption, abrasion resistance and resistance to ageing by thermal shock. These tests were determinant to define the suitable applications for each schistose stone that was studied, taking into account the existing groups of natural stone products.

For settling the recommended applications for each "Schist", European Standards for natural stone products were considered. It was also taken into account technical specifications existing in some European countries, which were the basis for the establishment of a proposal of technical specifications for our country, already published by one of the authors of this work [1].

Introduction

The assessment of the potential use of "Schist" from TMAD as natural stone was a project financed by the Portuguese Foundation for Science and Technology (FCT). It was coordinated by the Geology Centre of Oporto University and developed between 2007/10/01 and 2011/03/30. The first task of this project was the selection of the target areas [2]. Afterwards the lithologies to be studied were set up. Sampling was also set up and carried out. Samples were characterized from a petrographic, chemical and physical-mechanical point of view, through testing. The results were analysed in order to establish, for each rock, the recommended applications. This work relates only to the last stages of this project: the physical-mechanical characterization of the samples and the evaluation of the obtained results that led to the "Schist" assortment, regarding the applications' type.

Testing

Many properties should be determined on natural stones, whose test methods are laid down in European standards. The properties selected for this project were those considered as the most important to characterize a natural stone: compressive strength, flexural strength under concentrated load, apparent density, open porosity and water absorption at atmospheric pressure. In addition, two more properties were selected: abrasion resistance and resistance to ageing by thermal shock. Abrasion resistance was used to evaluate the stone suitability for paving. Resistance to ageing by thermal shock was used to assess the suitability for external applications of places with climates

such as the Portuguese. Each property was determined according to the appropriate European standard (Table 1).

Table 1

Property	European Standard	Principle	Specimens
Compressive strength	[3]	Each specimen is laid and centred on the plate of a testing machine. A uniformly distributed load is applied and increased continuously until failure occurs. The breaking load is measured and the compressive strength calculated.	10, at least Cubes or cylinders (50±5)mm or (70±5)mm
Flexural strength under concentrated load	[4]	Each specimen is placed on two supporting rollers (l is the distance between them); a load is progressively applied in the middle of the upper face of the specimen by a third roller until failure occurs. The breaking load is measured and the flexural strength calculated.	10, at least Prisms (50×50×300)mm - preferred 25mm ≤ height (h) ≤ 100mm l = 5×h; length (L) = 6×h 50mm ≤ width (b) ≤ 3×h
Apparent density and open porosity	[5]	In both standards, after drying to constant mass, the specimens are weighed. In EN 1936 specimens are then submitted to a specific vacuum immediately before and during water absorption; the two properties are determined by submerged and saturated weighing of the specimens. In EN 13755, specimens are then placed in contact with water at atmospheric pressure until constant mass; water absorption is determined by saturated weighing of the specimens.	6, at least Cubes, cylinders or prisms AV ≥ 60cc $0{,}08\text{mm}^{-1} \leq \text{SA/AV} \leq 20\text{mm}^{-1}$ Legend: AV – Apparent Volume SA – Surface Area
Water absorption at atmospheric pressure	[6]		
Abrasion resistance (Method A)	[7]	The face of a specimen which will be exposed in use is abraded by means of a rotating wide wheel made of steel and an abrasive material, under standard conditions.	6, at least cut piece measuring at least (100×70)mm, incorporating the upper face of the unit
Resistance to ageing by thermal shock	[8]	After drying to constant mass, the specimens are subjected to 20 successive cycles, each formed by (18±1)h in a ventilated oven at (105±5)ºC followed by immediate immersion in distilled water at (20±5)ºC during (6±0.5)h. Results are evaluated by specimens' changes in: their dried mass and their visual appearance.	7, at least (1 specimen to be used as reference specimen) (200×200×20)±2mm – – preferred dimensions. At least one of the square faces of the specimens shall be polished or, at least, honed.

Test Results

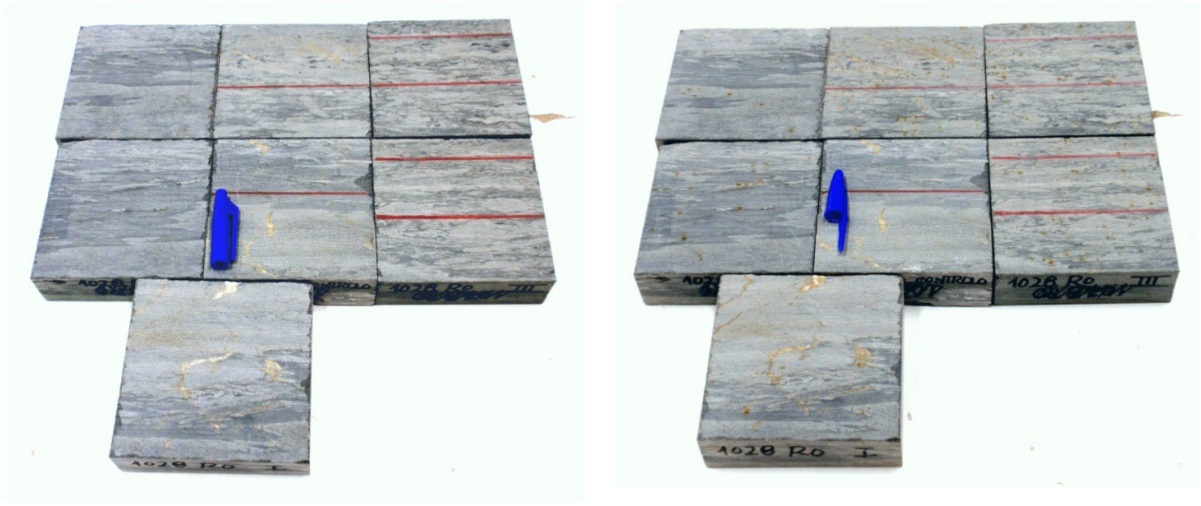
Results obtained on testing are summarized in Table 2.

Table 2

Schists	Mean values						R.T.S.
	C.S. (MPa)	F.S. (MPa)	A.D. (kg/m^3)	O.P. (%)	W.A. (%)	A.R. (mm)	
Eucísia 1	53	16.3	2520	9.3	1.2	26.0	R.
Eucísia 2	51	9.8	2670	3.9	1.6	24.5	1)
Nozelos	78	40.1	2740	1.3	0.6	24.5	R.
Tanha	110	42.9	2760	1.3	0.5	26.5	2)
Poio Amarelado	136	45.5	2700	1.1	0.5	20.0	R.
Poio Azulado	114	61.0	2760	0.4	0.2	22.0	2)
Garraia 1 [9]	150	35.6	2630	1.6	0.7	19.0	R.
Zebras 1 [9]	89	29.6	2630	0.8	0.3	18.5	R.
Zebras 2 [9]	87	37.7	2650	0.8	0.3	16.5	R.
Nogueira	76	26.7	2570	3.6	1.4	21.0	R.
Palheiros	213	35.2	2670	1.2	0.5	18.5	R.
Gimonde	39	10.5	2510	5.6	2.3	31.5	R.
Aveleda	221	33.3	2670	1.4	0.5	17.5	R.
Deilão A.P.	60	27.4	2560	5.6	2.2	25.5	R.
Cruzinha (A. F.)	51	18.2	2880	1.5	0.6	21.5	2)

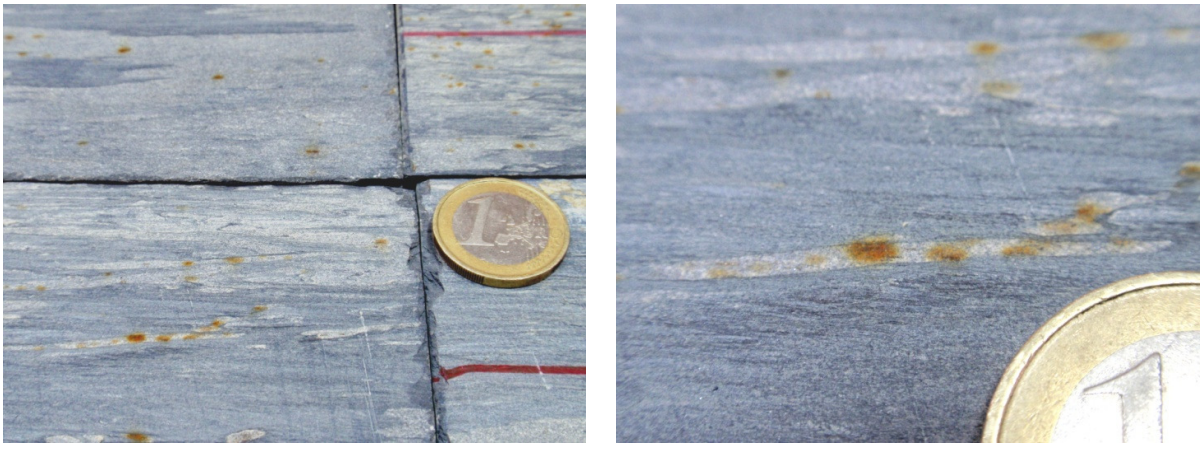
Legend:

C.S. – Compressive strength.
F.R. – Flexural strength.
A.D. – Apparent density.
O.P. – Open porosity.
W.A. – Water absorption at atmospheric pressure.
A.R. – Abrasion resistance (Method A — Wide Wheel Abrasion Test).
R.T.S. – Resistance to ageing by thermal shock.
R. – Resistant.
1) Occurrence of cracking in one of the tested specimens.
2) Occurrence of spots and/or stains of iron oxide in one or more of the tested specimens (see Fig. 1 and Fig. 2).



a) b)

Fig. 1 — Resistance to ageing by thermal shock of Poio Azulado schist: a) before cycling; b) after 20 cycles of thermal shock. The specimen with the pen cover in his top face is the reference specimen, which was not submitted to testing. During cycling, the iron oxide spots and stains that existed in all specimens before cycling became larger and more intense; also new iron oxide spots developed on the surface of all tested specimens.



a) b)

Fig. 2 — Details of the resistance to ageing by thermal shock of Poio Azulado schist after 20 cycles of thermal shock. a) Note that the spots of iron oxide appeared mainly on the lighter colour layers; b) Detail from a).

Technical Specifications Used for Settling the Recommended Applications

Compressive Strength

It is an important property, particularly for specific structural units (walls, columns, etc.). For compressive strength obtained with the load applied perpendicular to the schistosity planes, the requirements shown in Table 3 should be taken into account.

Table 3

Application type	Tested specimens	Compressive strength
Bearing units (walls, columns, etc.)	Honed or sawn	≥ 60Mpa
	Cleft	≥ 40Mpa
Non-bearing units (fence walls and other non-bearing walls, etc.)	Honed or sawn	< 60Mpa
	Cleft	< 40Mpa

Flexural Strength

It is also a very important property to establish which stones are suiTable for the production of bearing units. For flexural strength obtained with the load applied perpendicular to the foliation planes, the requirements shown in Table 4 should be considered.

Table 4

Application type	Flexural strength	
	Average	Difference between average and minimum value
Bearing units (lintels, etc.)	≥ 30MPa	≤ 15%
Slabs for paving and other applications	≥ 10MPa	—

Water Absorption and Open Porosity

Water absorption at atmospheric pressure is the fundamental property to establish which stones are suiTable for external applications. Water absorption is related with another property: open porosity. Regarding the application type, the water established absorption and open porosity requirements are shown in Table 5.

Table 5

Application type	Water absorption at atmospheric pressure (W.A.)	Open porosity (O.P.)
External paving and cladding of wet areas	≤ 0.6%	≤ 3.0%
Exposed masonry	≤ 3.0%	≤ 6.0%
Masonry, depending upon the circumstances of use	3.0% < W.A. ≤ 6.0%	6.0% < O.P. ≤ 10.0%
Only suiTable for external paving, steps and cladding if used under very favourable circumstances	> 6.0%	> 10.0%

Abrasion Resistance

It is a specific property to evaluate de stone suitability for application as paving. Considering the expected traffic of the application place, the requirements shown in Table 6 were established.

Table 6

Traffic type		Method C Amsler Abrasion Test (200m travel)	Method A Wide Wheel Abrasion Test (Capon machine)
Very high[(1)]	Public use	≤ 0.8mm	≤ 18.0mm
High[(2)] and high to moderate	Public use Collective use	≤ 2.0mm ≤ 3.5mm	≤ 19.5mm ≤ 21.5mm
Moderate	Collective use	≤ 5.5mm	≤ 24.5mm
Low	Private use	≤ 9.5mm	≤ 30.0mm

[(1)] Includes traffic of heavy vehicles and other cargo transport vehicles.
[(2)] Includes occasional traffic of emergency vehicles and cargo transport vehicles.

Resistance to Ageing by Thermal Shock

Like water absorption and open porosity, it is an important property to establish which stones are suiTable for external applications, but of areas which exhibit a specific climate: Mediterranean or a climate similar to this one. After testing, schists mustn't show exfoliation, cracking or other structural changes, neither change in their original colour (colour intensification/fading, or appearance of spots or stains).

Recommended Applications

Based upon the previous technical specifications and in others specified on the proposal of technical specifications for our country [1] were established the recommended applications for each schist (Table 7).

Table 7

Schist	Recommended application					
	Rustic masonry units	Bearing masonry units/Columns	Lintels	Paving	Cladding	Roofing[1)]
Eucísia 1	X	X ?		X (B)	X [2)]	
Eucísia 2	X	X ?			X [2)]	
Nozelos	X	X	X	X (C)	X	X
Tanha	X	X	X[2)]	X (A)		
Poio Amarelado	X	X	X	X (D)	X	X
Poio Azulado	X	X	X[2)]	X (C)	X	
Garraia 1 [9]	X	X	X [2)]	X (G)	X [2)]	
Zebras 1 [9]	X	X		X (F)	X	X
Zebras 2 [9]	X	X	X	X (H)	X	X
Nogueira	X	X		X (E)		
Palheiros	X	X	X	X (F)	X	X
Gimonde	X				X [2)]	
Aveleda	X	X	X	X (H)		X
Deilão A.P.	X	X		X (B)	X [2)]	
Cruzinha (A. F.)	X	X ?		X (D)	X	

Legend:

[1)] As slabs of different thicknesses, not as discontinuous roofing.
[2)] Mainly indoors.
X ? – Application is possible, but conditioned.
(A) – Low traffic.
(B) – Low traffic, mainly indoors.
(C) – Moderate traffic.
(D) – High to moderate traffic.
(E) – High to moderate traffic, mainly indoors.
(F) – High traffic.
(G) – High traffic with conditioned use outdoors.
(H) – Very high traffic.

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[4] EN 12372: Natural stone test methods. Determination of flexural strength under concentrated load.

[5] EN 1936: Natural stone test methods. Determination of real density and apparent density, and of total and open porosity.

[6] EN 13755: Natural stone test methods. Determination of water absorption at atmospheric pressure.

[7] EN 14157: Natural stone test methods. Determination of the abrasion resistance.

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