Stone roofing in the Aosta Valley, Italy: Technical properties and durability of traditional Lithotypes

Stone Roofing In The Aosta Valley, Italy: Technical Properties And Durability Of Traditional Lithotypes

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Abstract: The Aosta Valley Region has promulgated in 1990 a law to partially finance stone roofs to the owners of houses in the historic centers of the valley, provided that the stone material chosen was suitable for this use. This suitability was certified by physical, mechanical and durability tests. More than twenty years ago, roofing slabs were extracted in north-western Alps mainly from schistose rocks. In recent time instead roofing slabs, according to global market, have an international origin. All the traditional stones tested showed excellent technical features according to the local legislation on roof slates. One of these traditional stones is a phyllite whose trade name is "Porfiroide" having the best physical and mechanical properties compared to the other kinds of traditional stones, but with a high standard deviation in the results of flexural strength performed after the freeze and thaw cycles. In the roofing installed 40 years ago, despite their best technical features, the "Porfiroide" roof slabs show a poor state of conservation with widespread detachments, fractures, growth of mosses and lichens, variations in colours. Otherwise, stones with a lower value of flexural strength and higher water absorption instead show good behaviour in the roofing in situ and also in terms of colour change.

Evidently the only characterisation of the stone materials is not sufficient but it must be associated to a on-site verification, comparing each slab to be installed with a reference sample, part of the sample submitted to the tests, and to a control on site of the resistance of the stones to degradation.

Keywords: stone slab; aesthetical variation; mechanical strenght; legal requirements; stone roofing; stone durability;

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1. Introduction

The choice of stone as a covering and roofing material depends on the colour and appearance in general, as well as its durability and mechanical strength. Stone roofing has to last for centuries, to be reused several times and to hold to the loading of snow. In addition, the supply of stone slabs coming from nearby areas brings economic and environmental advantages, due to a lower cost, as well as the decreasing of transportations emissions and providing work to local companies and people. Dobszay [1] compared historical and contemporary stone cladded roofs, showing examples of ancient roofing and demonstrating that, traditionally, only natural and durable stone were used in comparison with the requirement of visual appearance in the contemporary architecture.

Roofs, made with stone slabs, are one of the specific characteristics of the Aosta Valley architecture. The slabs for roofing have an irregular shape and larger dimensions and thickness than in the roofs of other mountain sites. The choice of a stone should be based on its strength, its easy splitting and its durability in aspect and properties [2]. Several studies have been carried out on this typical Aosta stone roofing by different authors [3;4;5;6] dealing with traditional use of local stone in roofing (named traditionally "lose").

In some locations of the Aosta Valley, such as Ayas, a Prasinite (type of metabasite) has been employed since ancient times (1700's) for roofing. However, in more recent time Prasinite has been substituted by other stones due mainly to its scarcity. A very fine-grained stone with the trade name "Porfiroide", coming from Lombardy and belonging to the petrographic family of phyllites, was therefore used for the roofing in the valley.

The regional law n. 10 of 1990 concerning roof cladding [7], has been in force in the Aosta Valley with the aim of enhancing the use of stones for roofing, funding part of the cost if the chosen stone met specific requirements. The law n. 13 of 2007 [8], replacing the one of 1990, updated the test methodologies, previously established according to the Italian test method UNI, to the harmonised European standard UNI EN (specified in the Annex 1 of the law). In the Table 1 a comparison between the threshold limits of 1990 and 2007 law, for different technical determinations, required by legislation, is shown.

Table 1. Comparison between the threshold limits for physical and mechanical requirements of Aosta Valley Region law n. 10 of 1990 and law n. 13 of 2007*. Significant absence of pyrite is defined when, to a macroscopic evaluation, no surface inclusion of pyrite is visible in the covering elements.

Technical determinati	**Threshold limits of Aosta Valley Region law n. 10 of 1990**	**Threshold limits of Aosta Valley Region law n. 13 of 2007**	***EN reference standard, according to Law n.13 of 2007 - Annex 1**
Water absorption	0.30% for gneiss 0.25% for all the other stones	<0.5%	EN 13755
Flexural strength	≥15 MPa	>15 MPa	EN 12372
Variation in flexural strength after freeze thaw cycles	≤ 20%	<20%	EN 12371
Resistance to HSO_4 (1%)	Thickness of the weathered layer ≤ 0.05mm	/	
Resistance to decay caused by atmospheric agents	/	To be performed only when calcium carbonate content >5%	EN 12407
Presence of pyrite	Absent	Absent	
Material uniformity	Homogeneity	Homogeneity (no stain or veins)	

The goal of this research is to verify if the tests required by Aosta Valley laws (table 1) are sufficiently representative to define the durability of roofing stone slabs analysed. This has been made comparing the results obtained in the laboratory with the in situ observation.

2. Materials and Methods

2.1. Stones

This research is based on the analysis of 146 technical reports on different samples tested according to the 2 laws of the Aosta Valley Region. All the tests performed for this study were carried out in Marble Laboratory of Politecnico di Torino between the years 1998 and 2014. Before carrying out the tests, each stone was studied from a mineralogical point of view. In Table 2 the stones tested, as well as information on their origin the number of quarries and the number of tests performed were given.

Gneiss PL from Piedmont, and BS from Switzerland, Calcschist from Aosta Valley, Serpentinite and Phyllite named Porfiroide from Lombardy, Quartzites from Greece, Norway and China are the stones considered.

The oldest roofs of the valley are covered with Calcschist slabs found, during the in situ survey, in the villages of Ayas (Challant Saint Anselme, Lignod, Antagnod and Magneaz). This stone is known as "Morgex stone" and is quarried in Morgex near Aosta [9]. Porfiroide, used since the 1950, is characterised by a high resistance and it is easy to split, but, in site, its alteration is connected with oxidation or detachment. The other varieties of stones were installed in the roofs from about 30-40 years ago.

Table 2. Different kinds of roofing stone employed in the Aosta Valley.

Petrographic name	Acronym	Country of origin	Number of quarries	Samples tested *
Gneiss	PL	Piedmont (Italy)	22	85
	BS	Switzerland	1	3
Morgex Calcschist	CM	Aosta Valley (Italy)	3	6
Serpentine	SE	Lombardy (Italy)	5	11
Phyllite "Porfiroide"	PO	Lombardy (Italy))	2	11
Quartzite	QC	China	2	7
Quartzite	QG	Greece	2	17
Quartzite	QN	Norway	2	8

*Each sample is constituted from 7 to 10 specimens.

Different Quartzite samples, coming from Norway (QN), Greece (QG), China (QC) are shown in Fig. 1.

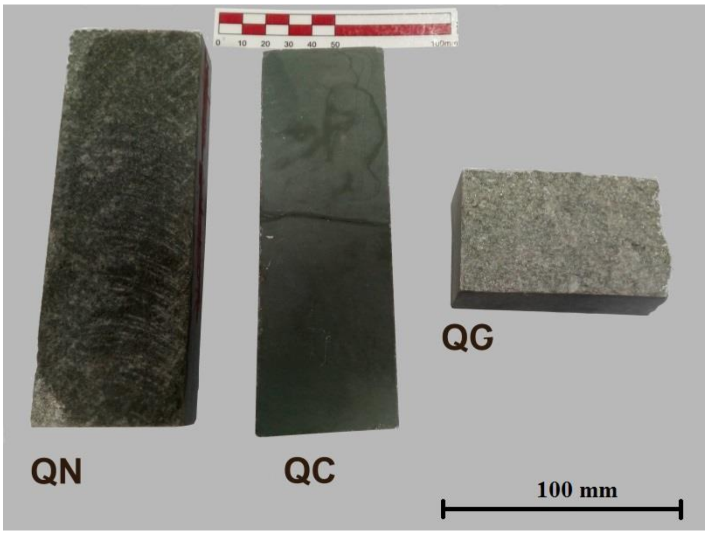


Figure 1. Different kinds of quartzite tested for Aosta Valley roofing. QN from Norway, QG from Greece, QC from China.

2.2. Laboratory tests

Physical and mechanical test executed for stone roofing qualification follow the requirements indicated by Law n. 13 of 2007 according to EN standard. In the Law n. 10 of 1990 the same tests were referred to UNI standard according to Annex A of the same law. As specified from the laws (Table 1), the main physical tests to be executed for the qualification of roofing stone are: water absorption according to EN 13755 [10], flexural strength under concentrated load according to EN 12372 [11], freeze and thaw resistance after 48 cycles according to EN 12371 [12], resistance to decay caused by atmospheric agents according to EN 13919 [13], evaluation of the presence of pyrite.

The determinations required from Aosta Valley regulation of 1990 were described in Annex A of the same law and referred to the UNI standards in force at that time and there were only few differences between the two group of tests are mainly in the specimen dimensions and not in the test method. The resistance to decay was the only parameter whose methodology changed: when the resistance to H_2SO_4 attack was required, the methodology of EN 13919 (a standard now deleted) was provided, but only for the stones with a calcium carbonate content > 5 %.

The presence of pyrite and of calcium carbonate is determined through petrographic analysis on the hand sample and microscopically on thin sections. Concerning calcium carbonate content, an attack with HCl (33% dilution in water) in three different parts of the specimens was performed to confirm the petrographic observation: if no effervescence was noted, the calcium carbonate content was considered minor than 5%.

Water absorption and flexural strength before and after 48 freeze and thaw cycles were measured on 14 specimens (7 in natural conditions and 7 subjected to weathering cycles) with dimensions of 20*30*120 mm according to the regulation of 1990 and on 20 specimens (10+10) 25*50*150 mm for each sample according to 2007 law. The effect of thickness on flexural strength value is negligible considering the measurements uncertainty: in other terms varying the thickness specimens there is no considerable variation in the flexural strength measured.[14].

For water absorption both methodologies require the ratio between the surface area and volume between 0.08 mm^{-1} and 0.20 mm^{-1}. On the base of these considerations, the results obtained on specimens of different dimensions have been comparatively evaluated.

2.3. Stone roofing (in situ monitoring)

The site investigated in order to identify the state of conservation of the different stones used is in Val d'Ayas (Aosta Valley). In particular, the sites where monitoring campaigns have been carried out are shown in Fig. 2.

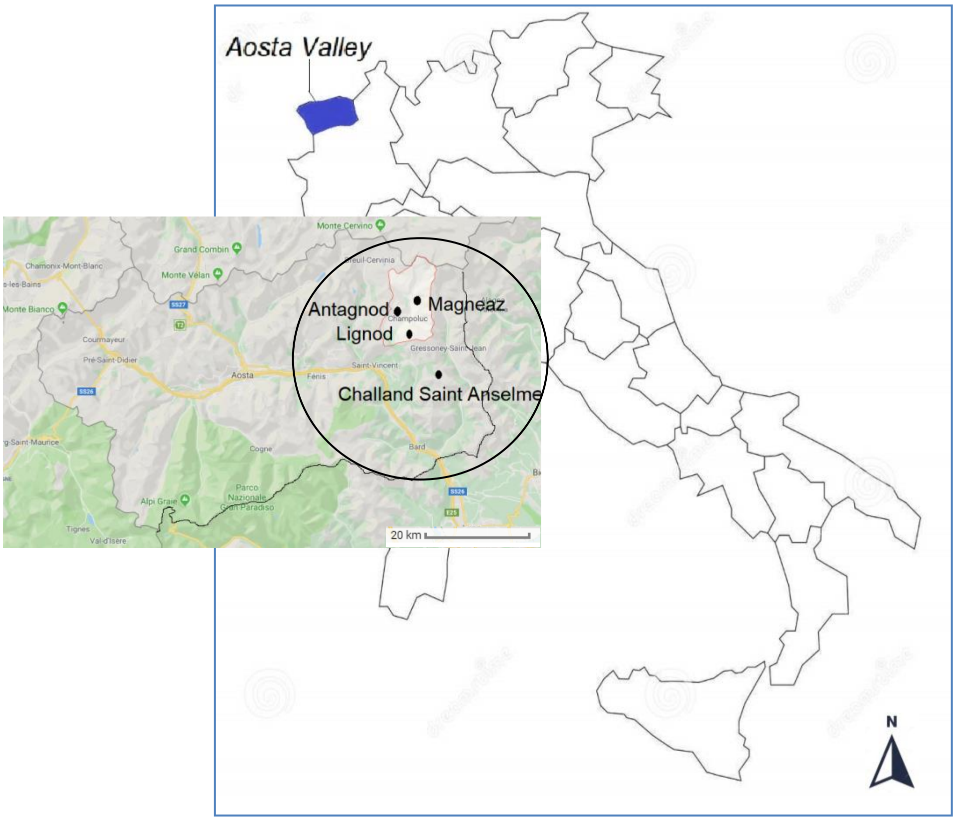


Figure 2. Aosta Valley in Italy and the site of the stone roofing monitoring (Source: Google maps).

In figure 3 the photos of the details of the historical centres of the 4 investigated municipalities are shown, with their altitude.

Figure 3. From above: Antagnod, Challant Saint Anselme, Lignod and Magneaz old town maps, with altitude. Source: Google Earth.

As can be seen from figure 3, in Valle D'Aosta, all the buildings present in the historic center have stone roofs. This is what is defined by the Regional law 1 June 2007, n. 13 [8].

In Aosta Valley, the climate is warm and temperate. There is significant rainfall throughout the year, even during the driest month. The average temperature is 9.7 ° C. The average annual rainfall is 805 mm. The driest month is January with 51 mm. The month of August is the one with the greatest rainfall, having an average of 82 mm.

Roofing of Antagnod, Magneaz and Lignod (Ayas hamlets) were monitored together with the nearby Challant Saint Anselme comparing the in situ slabs with stone specimens kept after the tests for Aosta Valley. During this surveys only 4 of 8 stones of table 2 (Porfiroide, Morgex Calcschist, gneiss PL and Norwegian quartzite) have been identified.

3. Results

3.1. Stones desciption

In Tables 3 and 4, a microphoto of a representative thin section for each stone tested is shown together with a brief description. The petrographic analysis has been made in addition to test report elaboration in order to better understand the behaviour of different kind of stone. The compositions as a percentage, were the mean values obtained from the different samples tested of the same stone, sometimes coming from different quarries as in the case of PL (Table 2.)

Table 3. Stones from China, Greece and Norway used for Aosta Valley roofing. Reference size: 100 µm.

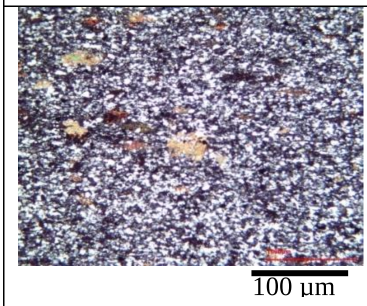
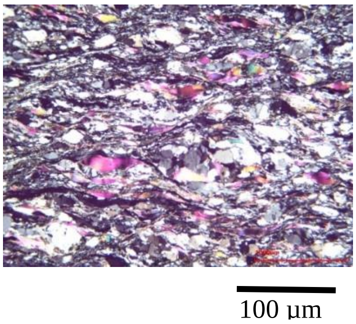
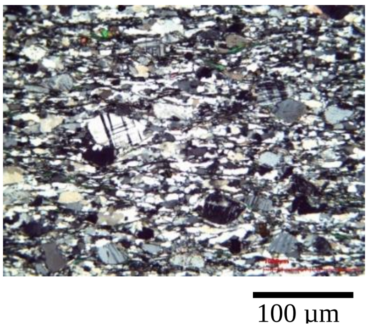
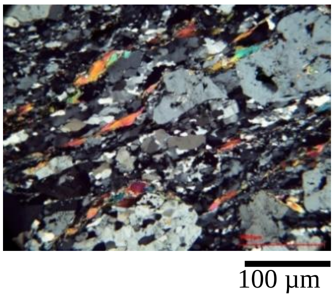
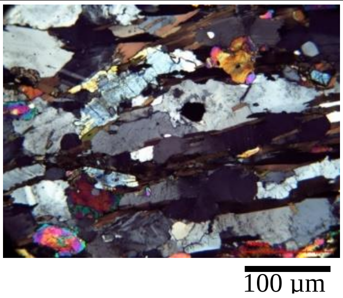
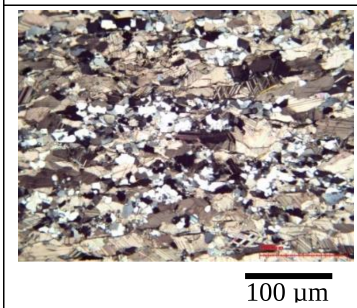
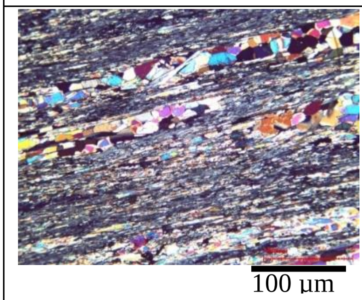
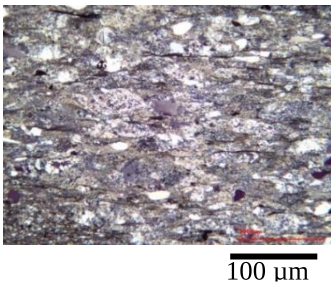
Thin section	Stone and main mineralogical composition
	**QUARTZITE (China) QC:** Greenish, very fine-grained with schistose texture. Main minerals: - 50% quartz; - 40% white mica; - 10% biotite, opaque and chlorite.
	**QUARTZITE (Greece) QG:** Grey-green, fine grained and schistose texture. Main minerals: - 45% quartz; - 20% chlorite; - 25% feldspars; - 10% epidote; zircon and rutile.
	**QUARTZITE (Norway) QN:** Dark grey, medium-fine grained and schistose texture. Main minerals: - 70% quartz; - 20% feldspar; - 10% white mica; carbonates, opaque and pyroxene.

Table 4. Stone from neighbouring quarries used for Aosta Valley roofing Reference size: 100 µm.

Thin section	**Stone and main mineralogical composition**
	**GNEISS PL**: Grey rock with a fine grained and schistose texture. Main minerals: - 40% quartz; - 30% plagioclase; - 15% K-feldspar; - 10% white mica; - 5% epidote biotite and chlorite, apatite, zircon and rutile.
	**GNEISS BS**: Grey in colour with white lentiform levels alternating with wavy black, medium-fine grained and schistose texture. Main minerals: - 35% quartz; - 35% feldspars; -20% biotite; - 10% pyroxene.
	**CALCSCHIST CM**: Light grey rock with small white eyes, medium grained and schistose texture. Main minerals: -65% carbonate; - 25% quartz; - 10% white mica and opaques.
	**SERPENTINITE SE**: Dark green, fine-grained rock with a schistose texture. Main minerals: - 60% serpentine antigorite; - 30% olivine; - 10% pyroxenes, chlorite and opaque.
	**PORFIROIDE (PHYLLITE) PO:** Dark grey, very fine grained and schistose texture. Main minerals: - 35% chlorite; - 30% white mica; - 20% quartz; - 10% opaque minerals: pyrite and other opaque ; - 5% feldspar.

In Fig. 4, the different stones tested from 1998 to 2014 in the Marble Laboratory of Politecnico di Torino supplied by different companies are reported. After 2014 the test requests for Aosta Valley roofing slate decreased, due to a new regional law (l.r. 17/2012 [15] art. 38) the tests became compulsory only for the stones employed in the historical centre buildings.

In Fig. 5, where there are reported the percentages of different stones tested in 2004, the year with the higher number of tests for Aosta Valley, (Fig. 4), it is evident that more than 20% of roofing stones come from outside Italy (Chinese, Norwegian and Greek Quartzites).

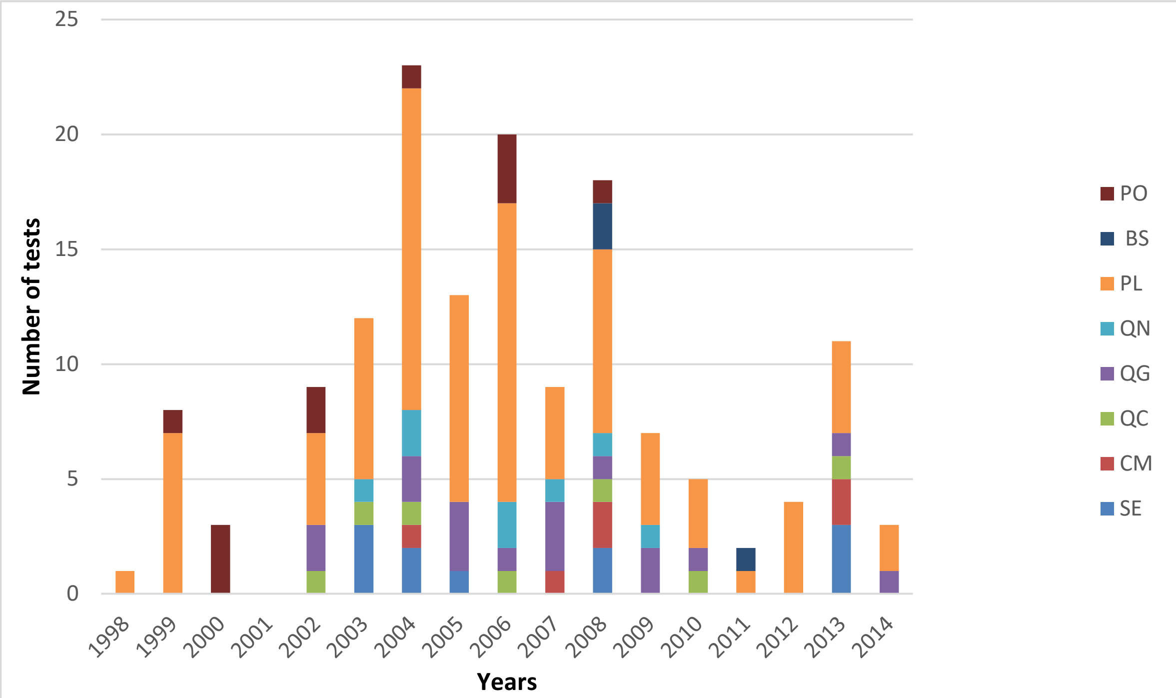


Figure 4. Number of tests for different stones tested in the years for roofing.

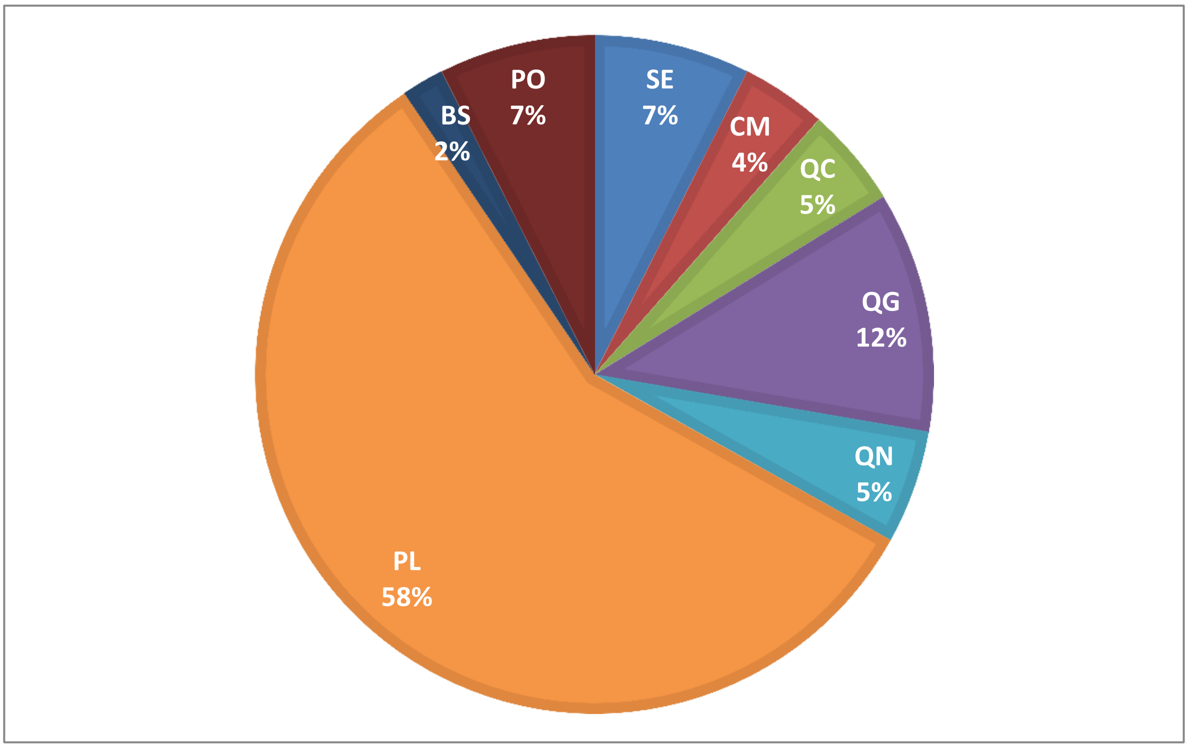


Figure 5. Tests performed in 2004 on different roofing stones.

3.2. Laboratory tests

In Table 5, the results of flexural tests carried out according to the Aosta Valley region laws are reported for the 8 types of stone analysed. In addition, in table 6, the main petrographic as mean grain size, carbonate content and water absorption data are shown. The mean grain size is the weighted average of the dimension of the crystals of the different minerals constituents the stones.

All the specimens tested are characterised by a very low or any presence of pyrite content and only CM has a carbonate content more than 5%. PO and CM are those with the higher variation in flexural strength after the freeze and thaw cycles.

Table 5. Mechanical properties of stones tested.

Stone tested	Flexural strength (MPa)				
	FS in natural condition		FS after freeze-thaw cycles		Variation in FS (%)
	Mean value	Stand. Dev.	Mean value	Stand. Dev.	
PL	24.7	3.0	24.3	2.8	-1.9
BS	22.6	1.4	22.1	3.3	-2.2
PO	**45.0**	**6.7**	**40.7**	**8.7**	**-9.6**
SE	83.0	15.8	83.8	17.1	0.9
CM	**24.5**	**3.2**	**22.3**	**3.2**	**-9.2**
QC	33.9	5.6	33.1	6.4	-2.4
QG	34.3	4.7	33.3	4.9	-2.9
QN	47.4	6.4	46.6	4.4	-1.6

Table 6. Physical and petrographic characteristics of stones tested.

Stone tested	Water absorption (%)		Carbonate content (%)	Mean grain size (mm)
	Mean value	Stand. Dev		
PL	0.3	0.0	<5	1.2
BS	0.3	0.0	<5	1.5
PO	**0.2**	**0.0**	**<5**	**0.2**
SE	0.1	0.0	<5	0.3
CM	**0.2**	**0.0**	**>5**	**0.3**
QC	0.3	0.1	<5	0.5
QG	0.3	0.1	<5	0.4
QN	0.1	0.0	<5	1.2

3.3. Conservation of Stone roofing (in situ observation)

The in situ survey was carried out comparing specimens of the tested samples with roofs slabs easily accessible.

In Challant Saint Anselme, from a roof slab with lichens (Fig. 6 on the right) installed in 2002 (communication of the owner) the sample 1 of Fig.10 was taken. From a quick comparison with the sample brought from the laboratory it was assumed that the stone used was the Norway Quartzite QN . The preservation state of quartzite slabs of this roof can be compared with the older one slabs probably by Calcschist CM covering a nearby house (Fig.6 on the left)

Figure 6. An ancient roofing in Challant Saint Anselme on the left and Norway quartzite roofing on the right.

In Ayas municipality, Lignod hamlet, the slabs of the roof in Fig. 7 have been recognized as Calcschist according to the comparison with the specimens brought by the laboratory. These slabs were similar but less weathered then those of Fig 6 on the left: the whole house was restructured in the early 2000s.

Figure 7. Calcschist CM roofing in Lignod after renovation.

In Antagnod, it was possible to detect other varieties of ornamental stones: Prasinite in the cemetery, Quartzite and Porfiroide. In Fig. 8, the roofing in Porfiroide near new kinds of stones is shown. The Porfiroide slabs were broken therefore a sample of Porfiroide was taken (sample 2 of Fig. 10).

In Magneaz, a sample from an old roofing dated to 1980 (Fig. 9) where detachment and oxidation traces were present was taken (sample 3 of Fig.10).

Figure 8. Porfiroide roofing near the new roofs of gneiss on the left and Quartzite on the right in Antagnod.

Figure 9. Old stone roofing in Porfiroide in Magneaz hamlet.

In laboratory, the macroscopic comparison of the samples taken in situ with specimens tested, confirmed that sample 1 is a Norway quartzite QN, and samples 2 and 3 are Porfiroide PO (Fig. 10).

The climatic condition of the municipalities considered is the same, as they are not very distant from each other, as can be seen from figure 2. The weather conditions therefore do not influence the diversity of deterioration in the stone types analyzed, unlike stone properties that is the main aspect affecting different stone decay .

Figure 10. Comparison of sample from in situ and the laboratory specimens tested. On the left the sample 1 compared with Norway quartzite specimen; on the right samples 2 and 3 compared to Porfiroide specimen.

4. Discussion and conclusions

All the stones tested respect the threshold limits of physical and mechanical properties requested by the Aosta Valley Region (Table 1) apart from the carbonate content of CM. However, from table 5 and 6, Porfiroide (PO) and Calcschist (CM) show high decreasing in flexural strength after freeze and thaw cycles (respectively -9,6% and 9,2%) despite the mechanical resistance after artificial decay still maintain good performances (PO > 40 MPa, CM > 22 MPa). These behaviours, for Morgex Calcschist CM, can be due surely to the high carbonate content (>5%) and mica (10%) and for Porfiroide PO to the very high mica content (30%). From the in situ monitoring, the low durability of PO and CM is enhanced. These are the stone roofing slabs with highest percentage of detachment and weathering (Fig. 7, 8 and 9). The relation between mica content and resistance to decay is well known [16,17]. Consequently, the mica content could be a further petrographic feature to take into account in the evaluation of stone roofing durability: the increasing in mica content (more than 10%) is strictly connected to the increasing in the decay under the action of climatic agents as thermal shock and presence of water that causes the mica swelling and therefore stone deterioration and detachments.

The in situ survey suggest that the uniformity of stone slab samples is an important factor to be taken into account together with physical and mechanical characteristics. The difference between the technical performance and the behaviour in situ can be related also to the high variability of some rocks when supplied in high quantity. The samples sent to laboratory for technical characterisation do not always reflect this variability, specimens probably were chosen among the first-class choice while for big supplying all the produced slabs have to be used.

Concerning the "new" stones as the Norway quartzite, further research in addition to those developed on other quartzite in the past [18,19,20] could be a future research, in order to study the growing of the lichens on the stone slabs and the methods to prevent this kind of biological attack in site also after a few years in new constructions.

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