Structural Analysis of Historical Constructions – Jerzy Jasieńko (ed)
© 2012 DWE, Wrocław, Poland, ISSN 0860-2395, ISBN 978-83-7125-216-7

SANDSTONE DECAY: FROM HISTORICAL BUILDINGS TO LABORATORY TESTS

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ABSTRACT

Sandstone is a sedimentary rock whose composition is determined by the depositional environment. The large family of sandstone covers, therefore, stones showing a great variability in grains, porosity, cement or matrix, compactness, chemical composition etc., some times this variability can be found in the same quarry too: in historical buildings often can be observed stones coming from the same quarry showing a different decay behaviour.
This study is focused on some Italian sandstones with the goal of assessing the main intrinsic factors connecting with their durability and of optimizing the test methodologies for the decay evaluation.
The results of durability tests on sandstones with different petrographic and mineralogical properties have been analysed.
Moreover all the durability tests have been performed following the EN standards methodology. From the results some indication have been obtaining concerning:

- the effectiveness of the durability tests to reproduce the sandstone decay;
- the effectiveness of the evaluation methodology to assess the induced decay.

Keywords: *Sandstones, Durability, Test methods*

1. INTRODUCTION

The weathering of a sandstone is a phenomenon correlated with its chemical-mineralogical composition as well as with its physical-mechanical characteristics.
The large family of sandstone covers stones with different grains, porosity, cement or matrix, compactness, chemical composition etc.
The variability of the rock characteristics in the quarry should be taken into account when evaluating the durability of the sandstones used in the monuments or historical constructions: it can happens that from the same quarry (that is to say, a stone named in the same way) a sandstone shows different conservation state even if is exposed from the same lapse of time and under similar climatic conditions.
Many studies have been conducted on the decay of sandstones, focusing mainly on the effects of salt crystallization and SO_2 action, as they are considered to be the most harmful decay mechanism for this kind of stone [1-5]. As for the damage mechanism due to the action of salts, Shrerer and Flatt [3, 4] developed a one-dimensional model of confined crystal growth to understand the transfer of stress from the growing salt crystal to the matrix. The repulsive force growing in the rock depends on the solid materials, on the solution composition and also on the distance of separation of the surfaces (dimensions o pores and/or microcracks). The action of SO_2, instead, dissolves the calcite cement that binds the mineral matrix together [6].
The aim of this work was to assess the main intrinsic factors connecting with sandstone durability and to optimize the test methodologies for the decay evaluation.

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2. MATERIAL AND METHODS

The laboratory tests were carried out on twelve sandstones from Central Apennine-Italy (Table 1) being mainly fine grained, grey, feldspar litharenites. The cement is carbonatic (from 8 to 45%). The grains are quartz, feldspar, micas, and silicatic and carbonatic lithoclasts. The grains appear from medium to well sorted with a rounded or subangular shape and average dimensions of 0.06-0.5 mm.

Table 1 Main petrographic properties of Apennine central sandstones

Apennine central sandstones	mean size (mm)	carbonate content (%)	apparent density (kg/m^3)	open porosity (%)
Apc1	0.125	8.29	2630	2.9
Apc2	0.25	36.67	2560	5.4
Apc3	0.125	32.42	2610	3.7
Apc4	0.25	28.09	2550	5.7
Apc5	0.25	30.35	2570	4.8
Apc6	0.25	14.59	2500	7.6
Apc7	0.25	18.8	2550	5.9
Apc8	0.25	17.72	2490	7.7
Apc9	0.1	44.06	2610	4.1
Apc10	0.2	20.05	2550	5.5
Apc11	0.25	35.41	2600	4.2
Apc12	0.25	19.87	2560	5.7

Durability tests carried out are are:
- salt crystallization (SC);
- SO_2 action (SO_2);
- frost resistance (FR).

The SC test was conducted according to EN 12370 (1999). The test reproduces the action of a water solution of sodium sulphate inside the stone. 15 cycles were carried out. Each cycle consists of 2 hours of immersion of the specimens in a 14% sodium sulphate decahydrate solution and of 10 hours of drying in an oven at a temperature of (105 ±5)°C. The standard foresees that the test results are given as the relative mass difference, percentage of the initial dry mass. However, taking into account that this kind of test causes a disintegration not always connected with a change in mass (mainly for sandstone, see par. 2.1 and Table 2), the water absorption coefficient (WA, according to EN 13755: 2001) was determined and the results were expressed as the relative variation of WA, as a percentage (see Equation 1).

$$\Delta WA = \frac{WAf - WAi}{WAi} x100 \qquad (1)$$

where WAf is the water absorption coefficient after the artificial ageing cycles and WAi is the WA coefficient in natural conditions.
The water absorption test is calculated as the ratio of the mass of water absorbed by each specimen and its dry mass. After the durability tests, in order to measure the WA coefficient, the specimen is washed accurately with water and then dried (to measure the mass of the dry specimen) and saturated till constant mass (to measure the mass of the saturated specimen).
The SO_2 test was carried out according to EN 13919 (2002, but now deleted). The resistance of natural stone subjected to a combination of temperature, humidity and sulphurous acid (H_2SO_3 – SO_2 in water at 5/6%) is determined by placing test specimens in two containers for 21 days with two different sulphur dioxide concentrations. Solution A is composed of 500 ml of sulphurous acid in 150 ml of water and solution B of 150ml of sulphurous acid in 500 ml of water. After the 21 days, the Standard requires the evaluation of change in mass, but, as for the SC test, the WA variation was determined as a percentage (equation 1) too.
As far as the FR tests are concerned, EN 12371 (2001) was followed: decay was evaluated by means of mechanical tests, such as flexural and compressive strength tests, performed on specimens in natural conditions and on specimens subjected to artificial ageing. The test foresees the execution of 48 freeze and thaw cycles, in air and in water, respectively.

2.1. The decay assessment

Very often the change in mass, required for the Standards to assess the decay after the execution of artificial ageing tests, results a not satisfactory method for some kinds of stones. An example is reported in the Figure 2 where a set of calcarenitc specimens weathered by means of SC are shown: the decay is visible but the mass weight loss is nearly of 1%.

Fig. 2 Calcarenitc specimens (6) after salt crystallization test and the not altered (KO7). The weight loss of the specimens was of 1% but the alteration is evident

Previous researches on the sandstones weathered by means of salt crystallization [7,8,9] gave weight loss very small and unrepresentative for the durability estimation on cubic specimens (the example of Figure 2). Benavente [7] tried to solve this changing shape and dimensions of the specimens and obtaining finally a good correlation between decay (visible macroscopically) and weight loss. In this research instead, specimens shape and dimensions are still those required by the Standards but a new determination has been introduced.

The sandstones tested in this research, with open porosity from 3% to 8%, show visible weathering effects both for SC (15 cycles) and SO_2 (21 days) that are not always revealed by the weight loss values (see Table 1). The sandstones weathered, showing a small values of weight loss are reported in the Figures from 3 to 7.

Fig. 3 Apc8 specimen after 15 SC cycles (40 mm edge)

Fig. 4 Apc12 specimens after the salt crystallisation cycles (cubes of 40 mm edge)

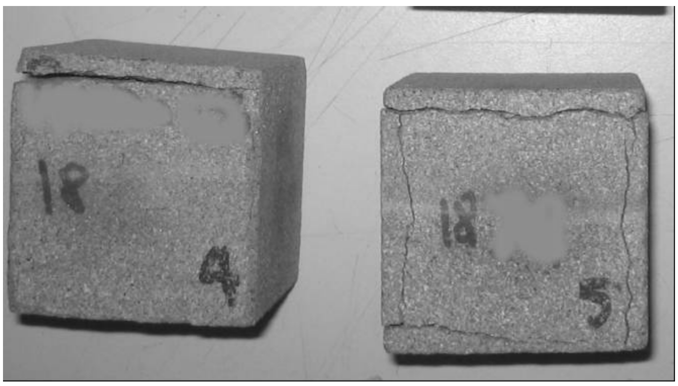

Fig. 5 Apc4 specimens after the salt crystallisation cycles. (cubes of 40 mm edge)

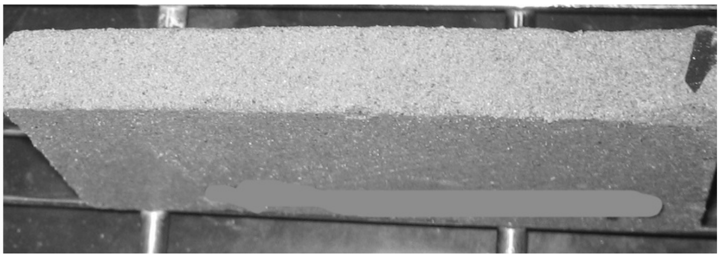

Fig. 6 Apc2 specimens after the SO_2 cycles with solution A (120 × 60 × 10 mm dimensions)

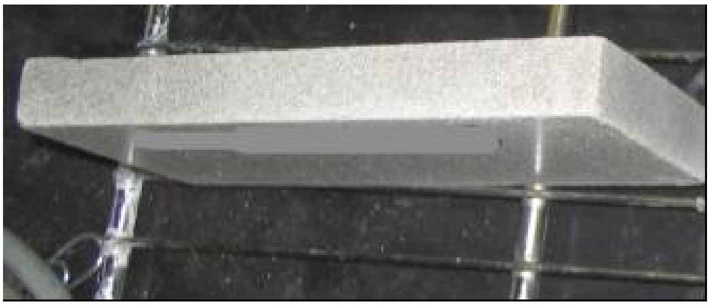

Fig. 7 Apc2 specimens after SO_2 cycles with solution B (120 × 60 × 10 mm dimensions)

To assess the decay, the WA measurements have been taken as reference, instead of the weight loss, to evaluate the resistance to ageing of the sandstones tested. In previous researches WA was defined a good indicator of the decay of a stone. The results of water absorption test can be correlated with in situ non destructive tests and laboratory destructive tests [10, 11]. The water absorption, beside, is strictly connected, by means of the stone density, to its open porosity.

3. RESULTS AND DISCUSSION

The durability tests performed on each tested sandstone are reported in Table 1. On the base of the results of visual inspection and mechanical strength (ΔMs) correlated to the corresponding ΔWA of the specimens decayed, the following limit in water absorption change (ΔWa) have been established to define the sandstone tested not resistant to the three different ageing tests.
Salt crystallization: ΔWa> 20%.
SO_2 action: ΔWa > 50%.
Freeze and thaw ageing: ΔMs > 20%
The sandstones that decayed after the durability tests (exceeding the limit values determined) are indicated in Table 2 and are the same clearly weathered at a visual inspection.

Table 2 Sandstones and durability tests. The X indicate the decayed sandstone

Sandstones	SC	SO_2 (sol A)	SO_2 (sol B)	FR
Apc1	-	-	-	-
Apc2	X	X	-	-
Apc3	-	-	-	-
Apc4	X	X	-	-
Apc5	X	X	-	-
Apc6	-	-	-	-
Apc7	-	-	-	-
Apc8	X	-	-	-
Apc9	-	-	-	-
Apc10	-	-	-	-
Apc11	-	-	-	-
Apc12	X	-	-	-

In Table 3 the variation in water absorption and in mass of the 12 kinds of Apennine central sandstones are reported. It is possible to note that only for the sandstone Apc7 both an appreciable decreasing in mass and an increase in WA is recorded, while for Apc2, Apc4, Apc5, Apc8 and Apc12 sandstones, strongly decayed (Figs. 3-7) only Wa changes (reaching even the +48%). evidences the weathering.

Table 3 Variation in water absorption (ΔWa) and in mass (Δm) after SC and SO_2 tests

Apennine central sandstone	SC		SO_2 sol.A	
	ΔWa (%)	Δm (%)	ΔWa (%)	Δm (%)
Apc1	-2,1*	0,1	23,2	-0,02
Apc 2	23,7	0,2	177,1	-0,03
Apc 3	5,3	0,11	44,3	-0,56
Apc 4	48,1	0,04	161,5	-0,76
Apc 5	26,3	-0,2	53,72	-0,02
Apc 6	6,7	-1,5	5,1	0,5
Apc 7	15,2	-4,7	15,2	0,09
Apc 8	46,6	-1,4	-1,1*	0,09
Apc 9	2,5	0,3	0,6	0,05
Apc 10	3,7	0	-1*	-1,43
Apc 11	2,9	0,1	-2,6*	0,06
Apc 12	22,2	0,1	-1*	0,06

*this variation is less or of the same order than the st.dev.: it can be considered negligible.

The Apc8 and Apc12 sandstones showed an increased in WA only after the SC cycles (Table 2), with visible fractures along the sides of the specimens and a superficial roughness caused by grain decohesion (Figs. 3 and 4).
The Apc2, Apc4 and Apc5 specimens, that showed remarkable increase in WA after both SC and SO_2 cycles (TABLE 1), also showed fractures along the sides of the specimens (Fig. 5, after SC) and grain decohesion (Figs 6 and 7, after SO_2).
Solution B of the SO_2 ageing test did not produce any alteration due to the low percentage of sulphur dioxide. In the next graphs, reference is only made to the decay induced by solution A.
The carbonate content of the sandstones, with the same medium grain dimension of 0.25 mm, was correlated to the WA variations measured after both the SC and SO_2 tests. (Fig. 8). The circled value refers to Apc8 (highest value of open porosity: 7,7%).

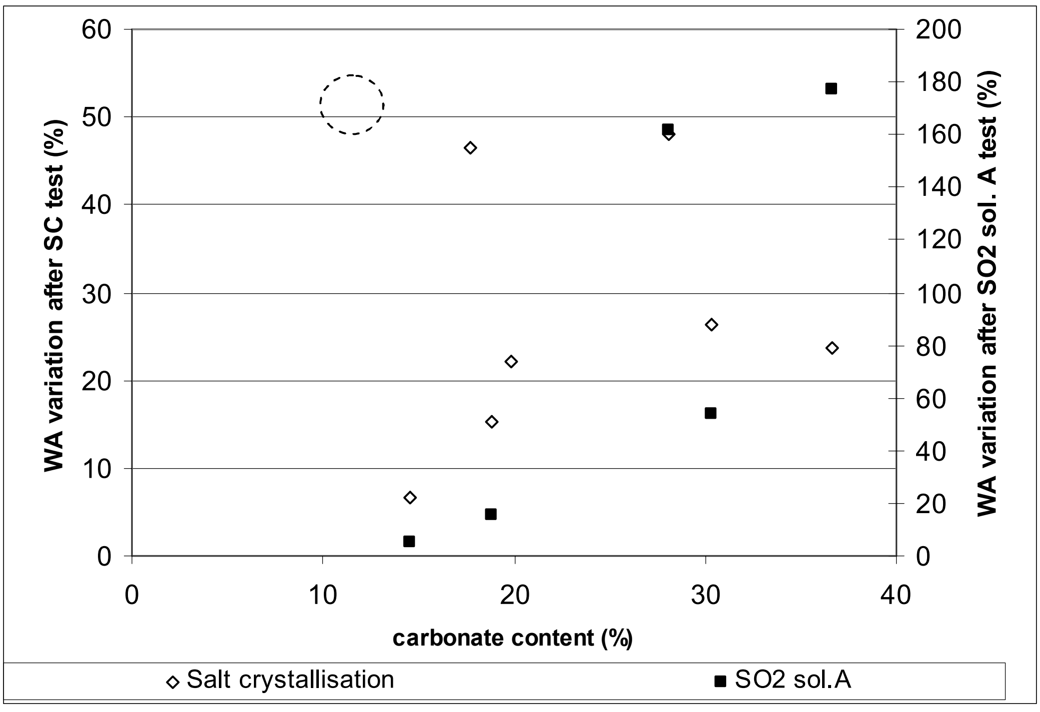

Fig. 8 SC and SO_2 tests: WA variation vs carbonate content

The response to the decay, mainly due to salt crystallisation and SO_2, is connected to the open porosity and carbonate content respectively, but also to the grainsize.
Sandstone with a very low carbonate content shows a high resistance to weathering, while those containing carbonates do not always show low durability: an example of this is sample Apc9 which has over 44% of carbonate content but results to be resistant to weathering probably because of its fine grain together to its high tensile strength and the grains interlocking (see Tables 1, 2 and 3).

4. CONCLUSIONS

In order to foresee the durability of a sandstone, its intrinsic factors have to be taken into account: mineralogical properties, fabric and texture.
The grainsize, together with its porosity and carbonate content are the main intrinsic causes of the decay of sandstone and the salt crystallization with solution A (see par. 2) is, among the durability tests performed, the most aggressive and its effectiveness to reproduce the sandstone decay has been demonstrated.
The evaluation methodology foreseen from the Standards to assess the induced decay isn't efficacious. The Standards in fact provide the mass weight variation as an indicator of decay, but in all the tests performed within this research this indicator never gave information on durability for the tested stones. The execution of a WA test before and after artificial ageing could be a reliable methodology to assess the induced decay of the stone.

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