Construction and Building Materials 75 (2015) 385–394

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Decay of calcareous building stone under the combined action of thermoclastism and cryoclastism: A laboratory simulation

Luigi Germinario [a,*], Gioacchino Francesco Andriani [b], Rocco Laviano [b,c]

[a] Dipartimento di Geoscienze, Università degli Studi di Padova, via Gradenigo 6, 35131 Padova, Italy
[b] Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari Aldo Moro, via Orabona 4, 70125 Bari, Italy
[c] Centro Interdipartimentale "Laboratorio di Ricerca per la Diagnostica dei Beni Culturali", Università degli Studi di Bari Aldo Moro, via Orabona 4, 70125 Bari, Italy

HIGHLIGHTS

- The response of calcareous building stone to thermo-hygrometric stresses was studied.
- A calcarenite historically used in Apulia (Italy) was subjected to artificial ageing.
- The changes in fabric and technical properties of the stone were examined.
- The dynamics of the decay by thermoclastism and cryoclastism were reconstructed.
- Clues were provided for indirectly assessing stone durability to climatic pressure.

ARTICLE INFO

Article history:
Received 9 July 2014
Received in revised form 1 October 2014
Accepted 12 November 2014
Available online 5 December 2014

Keywords:
Weathering
Artificial accelerated ageing
Durability
Calcarenite
Soft stone
Freezing–thawing
Heating–cooling
Thermo-hygrometric stress
Fabric
Technical properties

ABSTRACT

This paper aims at illustrating the driving forces of thermoclastism and cryoclastism in calcareous building stone and their effects on fabric and technical properties.

An artificial accelerated ageing test was carried out on a soft and porous calcarenite, which is exploited in Apulia (southern Italy) and historically used in the local architecture and manufacture as building and carving stone. The ageing was calibrated over the typical climatic characteristics of the region, attempting to simulate seasonal climatic changes. In details, quarry samples were subjected to temperature cycles from 60 to −5 °C, in a climatic chamber with a maximum relative humidity of 60%. During the test, the modifications in fabric were observed via SEM, whereas the changes in technical properties were analyzed through the direct or indirect measurement of: density, porosity, residual strains, p-wave velocity, compressive strength and Young's modulus.

The results give clues about the durability of soft calcareous stone opposed to thermo-hygrometric stresses and, indirectly, to natural weathering driven by climate variables. Moreover, a method is suggested for evaluating the resistance of stone to freezing–thawing decay, combining its porosimetric distribution with the environmental conditions of weathering. Finally, this paper globally adds new information about a material of significant cultural interest, which has been studied only recently in archaeometry.

1. Introduction

1.1. Goals

The aim of this research is to investigate the thermoclastic and cryoclastic processes in calcareous building stone, giving an insight into the driving forces of decay due to thermo-hygrometric stresses and its effects on fabric and technical properties. The topic was investigated through a laboratory simulation: a soft calcareous stone, exploited in Apulia (southern Italy) and historically used in the local architecture and manufacture, was selected and subjected to an artificial accelerated ageing. This was programmed according to the typical climatic characteristics of the region where the material is mainly quarried and used, in order to simulate seasonal climatic changes through thermal cycling within realistic temperature ranges. The goal is to provide clues about the durability of soft calcareous stone, giving indirect indications about its resistance to natural weathering driven by climate variables.

* Corresponding author.
E-mail addresses: luigi.germinario@gmail.com (L. Germinario), gioacchinofrancesco.andriani@uniba.it (G.F. Andriani), rocco.laviano@uniba.it (R. Laviano).

http://dx.doi.org/10.1016/j.conbuildmat.2014.11.035
0950-0618/

1.2. Background

The weathering of outdoor-exposed stone works is closely linked to the environmental, climatic and microclimatic conditions affecting the constituent materials and, in particular, is often related to the combined action of temperature and humidity fluctuations and water.

Temperature ranges detected both in the air and inside the materials equally influence the conservation of stone works. Short and long-term changes in environmental temperature depend on daily and seasonal variations connected to the regional climate characteristics. Temperature gradients inside stones, instead, are due to their thermal conductivity, which is generally very low [1]: they especially develop during summer months, when the surface temperature of sun-exposed stone can easily reach and exceed 50 °C [2,3], while the inner parts keep cooler. Temperature ranges are particularly wide in the areas characterized by arid-desert or cold-continental climates [4,5], but have a certain importance even in temperate Mediterranean regions. The continuous temperature cycles lead to shape changes of the rock-forming minerals and to a subsequent general disintegration of stone. If calcareous stones are considered, during heating calcite expands along the crystallographic *c*-axis and contracts along the *a*-axis, whereas during cooling it shows an opposite behavior. In this way, shear, compression and tensile stresses are produced, which mainly occur at triple junctions and along grain boundaries [6]. Their intensity and distribution is influenced by texture characteristics, i.e. orientation, size and shape of crystals and grains [7–12]. These internal stresses are released with thermoclastism, by intra- and intercrystalline fracturing [13]. The resulting increase of porosity due to decementation and granular disintegration makes the stone more prone to physical, chemical and microbiological deterioration [14].

Another effect of thermoclastism and porosity increase is residual strain, which is far enhanced if stone is wet [11]. From this point of view, in addition to temperature fluctuations, it is necessary to consider the incidence of hygrometric variations and the decay associated with hygric expansion and contraction, especially for clay-rich lithotypes [15]. Moreover, when temperature drops below 0 °C and stone is wet, cryoclastism can take place: water inside pores crystallizes with a volume increase of about 9% and produces tensile stresses, which can then cause the formation of fractures or the dilation of pre-existing discontinuities; during thawing, water flows through the new voids, accelerating the damage [16]. Two factors are extremely influential: the degree of saturation and the size of pores. In fact, every lithotype, depending on the characteristics of its pore network, has a critical degree of saturation, below which cryoclastism is not actually significant [17]. Furthermore, due to supercooling, inside the smallest pores (<0.1 μm), water can keep liquid for temperatures far below 0 °C [3].

The modifications of fabric and physico-mechanical properties of stone materials due to thermal and/or hygrometric stresses are investigated in numerous researches. They often deal with the problem through an indirect methodology, studying the gradual deterioration of specimens subjected to laboratory tests of artificial accelerated ageing; in order to assess the degree and rate of decay, the progressive changes of some critical properties (density, effective porosity, water absorption, p-wave velocity, mechanical strength and deformability) are measured and the microstructural modifications are observed through microscopic techniques. Many of the experimentations carried out in the last years focus on the effects of repeated cycles of freezing–thawing and/or heating–cooling: these usually range between −20 and 100 °C, if the high-temperature tests of thermal shock are excluded [17–28]. Nevertheless, an unrealistic approach is often noted: not only due to the temperature and humidity ranges adopted, but also because there is no attempt to relate the conditions of artificial ageing to the climatic conditions recorded in a given place for a given geomaterial. However, Warke and Smith [29] warn about the representativeness of these tests: as they always produce an indirect thermal action – excluding the direct action that, as an instance, can naturally occur with insolation – it is not possible to recreate the natural microclimatic variety at the stone–air interface.

2. Materials

The studied material is a soft and porous calcareous stone exploited in Apulia and known as ‘‘Pietra gentile’’, a traditional denomination standing for ‘‘gentle stone’’, which describes its characteristics of good workability and carvability. It has a great importance in the local cultural heritage, as it has been widely used in construction, sculpture and artisan manufacture, even in rural architecture, such as in the famous *trulli* [30]. This stone can be observed in important Apulian churches, fortification works, historical residences and archaeological monuments of different age, as well as in decorative particulars in common buildings. ‘‘Pietra gentile’’ is still exploited nowadays for the building industry, although for minor applications. For this reason, its qualities as building and decorative material can be especially admired in the monumental architecture of historical significance, particularly in the area of Valle d’Itria [65]: in this regard, a notable example is the sacred and civil architecture from Middle Ages and Baroque of Ostuni, one of the most renowned tourist centers in Apulia, known as ‘‘the White Town’’ [31–33] (Fig. 1).

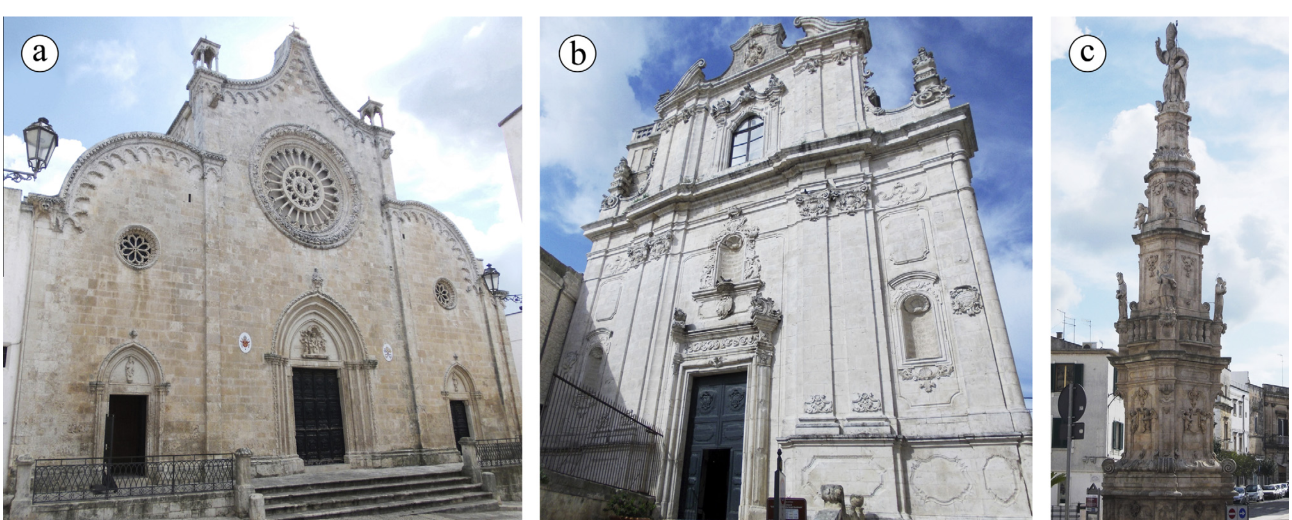

Fig. 1. Some examples of the use of ‘‘Pietra gentile’’ in the historical monumental heritage of Ostuni (Apulia, southern Italy): (a) the Cathedral, 15th century. (b) St. Vito Martire’s Church, 18th century. (c) St. Oronzo’s *Guglia*, 18th century.