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Effects of thermal changes on Macael marble: Experimental study

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Abstract

The continuous action of frequent thermal changes in conditions of extremes temperature is the main cause of the alteration of marble in monumental and artistic buildings. This is the case of the deterioration observed in the Court of the Lions in the Alhambra (Granada, Spain), the white marble of which columns are from Macael (Almería, Spain). In order to understand the effects of thermal stress on this type of material, samples of marble from the Macael quarry have been subjected to cycles of heating and cooling and determined their influence on the physical–mechanical characteristics of the material (ultrasonic transmission velocity, hydric behaviour, mechanical resistance and granular cohesion).

Keywords: Marble; Macael; Restoration–conservation; Thermal deterioration

1. Introduction

Marble is a material that is constantly found in building, either for structural (columns, floors, etc.) or decorative purposes (frieses, reliefs, statues, etc.). It is a noble material of particular beauty and easy manipulation, but it is susceptible to alteration by natural atmospheric agents or others resulting from urban and industrial activity. Given its abundant presence in buildings of historic and artistic value, this had led to special interest in understanding the alteration processes of marble and how to restore and preserve it. One of the most commonly described phenomena of deterioration is that resulting from its exposure to continuous, extreme changes of temperature, to which the anisotropic nature of calcite crystals also contributes. It is known [25] that under unirome heating such crystals dilate to different degrees according to the direction (maximum dilation along the crystallographic axis and even contractions along the directions perpendicular to this axis). It is therefore natural to suppose that continuous dilations and contractions of the calcite grains in different directions eventually weaken the interangular and intrangular cohesion forces, resulting in different, mainly superficial alteration phenomena in the form of microfractures, microfissures, pitting and loss of material through scaling or flaking or detachment.

The many studies of the anisotropic behaviour of calcite in marbles through tension caused by temperature variation (e.g. [3,4,7–9,21,25–27]) make direct reference to the formation of microfractures or microcracks as a result of expansion or residual deformation caused by even moderate, but continuous temperature variations in marble.

In Spain, Macael marble has been used since ancient times in works of art and monuments. Specifically, it is the material used in the famous Courtyard of the Lions in the Alhambra (Granada), that jewel of Nasrid Islamic art. The columns in this courtyard are affected by differing degrees of alteration, particularly in the form of superficial scaling and microcracks. The studies by Galán et al. [10,11] and Sáez [20] examine the intimate

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relation between the type and degree of deterioration presented by each column and the thermal gradient to which it is continuously exposed, as determined by the length of its exposure (approx. 500 years) to the sun. In order to confirm experimentally the previous hypotheses, and also to gain better understanding of the processes and mechanisms occurring in Macael marble in conditions of continuous, important temperature change, sample specimens of the material has been subjected to a different number of cycles of heating–cooling and determined the effects of these cycles on the physical and structural characteristics of the marble (ultrasonic transmission velocity, hydric behaviour, mechanical resistance) and examined the effects of the cycles on the granular cohesion of the material using an electron microscope.

2. Materials and methods

The marbles at Macael belong to the Nevado–Filabride Complex in the so-called Betic Internal Zone [12], where different units are developed that have undergone, in general, low thermal gradient, high pressure metamorphic processes, followed by other processes with higher thermal gradients. Both the metamorphism and the posterior deformations undergone by these units are Alpine in age. The geological units in which the marble quarries are located are the Nevado–Lubrin and Bedar–Macael, which in turn contain two different types of formations – the Huertecica Formation and the Las Casas Formation, the latter being where the quarries of Macael marble are located.

The characteristic materials of this formation are Late Triassic carbonated rocks, although these sometimes alternate with micaschists, calcareous micaschists, quartzite micaschists with garnet and quartzite micaschists with amphibole.

Generally speaking, two lithological sequences can be distinguished in this formation, one consisting mainly of carbonate rocks and the other of quartzite schists. From a stratigraphic point of view, the carbonate rocks are predominantly found in the uppermost and lowermost parts of the formations, with frequent pellitic layers in the central part.

The carbonate rocks, including the marble outcrops described above, are coloured white, blue, yellow and dark brown. Rocks can be found ranging from very white marble with high crystallisation to yellowish terrigenous limestone similar to calcarenite and between these two extremes a range of carbonate rocks (marbles with millimetric mica intercalations, ferruginous limestones, well crystallised, intense yellow limestones, etc.).

The material for testing was taken from the La Umbria quarry approximately 1500 m from Macael at the place known as Umbría de las Canteras (Fig. 1). It is white marble with some greyish banding. At first $50 \times 50 \times 15$ cm blocks were cut, from which specimens measuring $5 \times 5 \times 15$ cm were later cut. These dimensions were chosen in order to fit the highest possible number of normalisations into the tests. The sample blocks were cut so that the direction of the greyish banding followed the largest dimension and lay parallel to one of the lateral faces. We decided to denominate the direction of the longitudinal axis H. The direction perpendicular to H and parallel to the greyish bands as F and the direction perpendicular to the bands as L.

Fig. 1. View of "La Umbría" quarry from which the material tested in this paper was extracted.