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Ultrasonic evaluation of the physical and mechanical properties of granites

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Abstract

Masonry is the oldest building material that survived until today, being used all over the world and being present in the most impressive historical structures as an evidence of spirit of enterprise of ancient cultures. Conservation, rehabilitation and strengthening of the built heritage and protection of human lives are clear demands of modern societies. In this process, the use of nondestructive methods has become much common in the diagnosis of structural integrity of masonry elements.

With respect to the evaluation of the stone condition, the ultrasonic pulse velocity is a simple and economical tool. Thus, the central issue of the present paper concerns the evaluation of the suitability of the ultrasonic pulse velocity method for describing the mechanical and physical properties of granites (range size between 0.1–4.0 mm and 0.3–16.5 mm) and for the assessment of its weathering state. The mechanical properties encompass the compressive and tensile strength and modulus of elasticity, and the physical properties include the density and porosity. For this purpose, measurements of the longitudinal ultrasonic pulse velocity with distinct natural frequency of the transducers were carried out on specimens with different size and shape. A discussion of the factors that induce variations on the ultrasonic velocity is also provided.

Additionally, statistical correlations between ultrasonic pulse velocity and mechanical and physical properties of granites are presented and discussed. The major output of the work is the confirmation that ultrasonic pulse velocity can be effectively used as a simple and economical nondestructive method for a preliminary prediction of mechanical and physical properties, as well as a tool for the assessment of the weathering changes of granites that occur during the serviceable life. This is of much interest due to the usual difficulties in removing specimens for mechanical characterization.

Keywords: Granite; Ultrasonic pulse velocity; Testing; Tensile behaviour; Fracture parameters; Weathering; Planar anisotropy

1. Introduction

One of the major challenges in rehabilitation and repair of existing structures is inspection, which includes the detection of damaged zones, cracks and defects, and mechanical characterization of materials. This task is generally carried out not only based on experimental investigation on the laboratory but also by means of in situ nondestructive testing. Sophisticated non destructive techniques have been developed and improved throughout the years and are applied to various types of structures in distinct fields, namely masonry structures. One example of such techniques is the ground probe radar, which appears to be a powerful tool in the detection of voids and structural irregularities such as inclusions, moisture content and in the identification of the cross section of ancient multiple leaf masonry walls [1,2]. Another example is given by sonic tests, which allow e.g., the evaluation of the morphology of the masonry walls, detection of voids or crack damage patterns [3]. In both cases, by using appropriate tomography techniques, it is possible to recon-

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struct the internal characteristics of structural element. These tests are mainly used in structural identification, whereas other types of tests are normally used for material characterization. An example of such techniques is given by the controlled micro-drilling, which can be correlated with the elastic and strength properties of brick [4]. The ultrasonic pulse velocity method falls in the last category as an expedite and economical nondestructive technique.

Ultrasonic pulse velocity (UPV) testing has been reported by several authors [5,6] as an useful and reliable non destructive tool of assessing the mechanical characteristics of concrete from existing structures, such as the modulus of elasticity and the compressive strength. These parameters can be subsequently used in the safety evaluation of the structure. In the field of timber structures the results are far less appealing due to the anisotropy and variability of mechanical properties [7,8]. But in the field of rock structures, the ultrasonic pulse velocity has also been suggested as a useful method for an estimation of elastic and strength properties. This aim has been accomplished by means of empirical correlations between the ultrasonic pulse velocity and the compressive strength and modulus of elasticity [9–11].

UPV can be also of use to evaluate closed cracks in a material [12] or to study concrete behavior at early stage, namely in the analysis of the concrete microstructure development and strength [13–17]. When associated to tomography, UPV can give good qualitative information on the changes on material properties as well as on its microcracking state [18–20]. Kahraman [21] also studied the influence of the fracture roughness of granites on UPV and provided a correlation between both parameters. Although acoustic emission seems to be more appropriate in the evaluation of the crack damage in concrete and especially in rocks under uniaxial compression [22–24], UPV appears also to provide some indication about the damage in concrete [25–27].

The main goal of the present study is to provide correlations for a wide variety of granites between UPV and mechanical properties in tension and compression (compressive and tensile strength, modulus of elasticity) and between UPV and physical properties (porosity and density). Correlations between UPV and the fracture parameters characterizing the fracture compressive behavior (stress markers like the crack initiation stress and crack damage stress) and tensile behavior (normalized mode I fracture energy) are provided. A discussion about the factors that influence variations on the velocity measurements is also carried out, namely with respect to moisture content, weathering state and material anisotropy. It should be stressed that only propagation of longitudinal waves were considered in the experimental analysis.

The relevance of the proposed statistical correlations is based on the possibility of estimating the mechanical properties of granitic lithotypes from ancient masonry structures, which are very common in the Northern region of Portugal and several other countries. This is also of relevance in diagnosis and inspection of the structural and material condition, reducing the need of sampling material cores and making stone conservation treatments more cost-efficient.

2. Brief description of the material

Granite is the most used stone in the construction of ancient buildings, ornamental elements and movable stone heritage artifacts (e.g., statues, altar pieces, benches, etc.) in the North of Portugal, either in monumental or vernacular architecture. A wide range of granitic rocks is present in masonry buildings and artifacts, depending on their petrographic features, such as grain size and internal texture. Therefore, the mechanical characterization of only one type of granite would be rather limitative. In addition, the weathering processes, to which granites are subjected through years, lead to changes on the mechanical properties that require characterization.

The granitic types considered in the present study were mostly collected from the Northern region of Portugal. The selection of the granite types was based on mineralogical, textural and structural characteristics. Thus, fine to medium, medium to coarse, and coarse-grained granites were selected (some with porphyritic textures), see Table 1.

Table 1
Brief petrologic description of granites

Granite designation	Description	Mean length (mm)	Grain size range (mm)	Loading directions
BA	Fine to medium-grained porphyritic biotite granite	0.5–0.6	0.2–6.5	Parallel to the rift plane
GA, GA*	Fine to medium-grained, with porphyritic trend, two mica granite	0.5–0.6	0.3–7.5	Parallel to the rift plane
RM	Medium-grained biotite granite	1.3–2.3	0.4–13.5	Parallel to the rift plane
MC	Coarse-grained porphyritic biotite granite	1.6–2.4	0.3–16.5	Parallel to the rift plane
AF	Fine to medium-grained two-mica granite	0.5–0.6	0.1–4.0	Parallel and perpendicular to the foliation plane
MDB, MDB*	Medium-grained two- mica granite	0.7–0.9	0.3–14.5	Parallel and perpendicular to the foliation plane
PTA, PTA*	Fine to medium-grained two-mica granite	0.7–0.8	0.3–12.0	Parallel and perpendicular to the foliation and rift plane
PLA, PLA*	Medium to coarse-grained porphyritic biotite granite	0.5–1.1	0.2–14.0	Parallel and perpendicular to the rift plane