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Correlative relations between three-body abrasion wear resistance and petrographic properties of selected granites used as floor coverings

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ABSTRACT

Stone tiles used as flooring materials in buildings are subject to three-body abrasion wear due to pedestrian traffic. Hence, wear resistance characterization of stone materials is an important issue in civil engineering projects for appropriate selection and design of floor coverings. The objective of the present work was to identify the most influential quantitative petrographic properties of granites affecting their wear resistance values determined by the Wide Wheel Abrasion (WWA) test. For this purpose, petrographic analyzes and abrasion wear tests were performed on selected granites showing variations in their mineral modal composition, grain size distribution, hardness, porosity and density values. Results of the statistical analyzes indicate that the abrasion resistance of the tested granites is more influenced by modal mineral composition than the grain size. The overall Rosiwal hardness (HR) and the presently proposed petrographic index 'quartz to all cleavable minerals ratio' (Q/CLV), both have the potential to be employed as effective tools for obtaining preliminary estimations of abrasion resistance in similar granite types. Micro-hardness determined by the Knoop indenter did not prove to be a reliable indicator of granite wear resistance, which is in disagreement with the Archard's classical wear law formulated for relatively homogeneous and isotropic materials.

1. Introduction

Use of natural stone in the building and construction industry is continually increasing. Based on 2014 data, the global stone production has been estimated as 1.5 billion square meters of processed products, equivalent to conventional 20 mm tile thickness [1]. A large majority of this production is consumed for flooring and decorative purposes. When used for floor covering purposes, selection and installation of stone tiles are based not only on their aesthetic appearances but also on their abrasion wear resistance characteristics. The most common form of wear on floors is that caused by pedestrians, which is mainly due to the friction generated by contact between the shoe and the floor under the presence of sand or similar material between the surfaces [2]. The wear resistance of stone materials is particularly important at locations subject to heavy foot traffic (i.e. shopping centers, airports, metro and railway stations, etc.). In such cases improperly selected stone tiles with respect to wear resistance may result with high replacement costs. Besides volume loss of material, surface abrasion causes variations in aesthetic features such as color and brightness [3]. On the other hand, wear resistance becomes an important issue also when combining two or more stone materials in a project for color and design effects [4].

Estimations of wear in real-life applications are often based on experimental testing in the laboratory, under accelerated test conditions and idealized test geometries [5]. The wear resistance of a material can be measured by a wide range of laboratory tests and the value obtained depends on the intrinsic properties of the material and on the test method employed [6]. Regarding stone materials, the most commonly used abrasion resistance testing methods are the European Standard [7] and the American Standard [8]. The European Standard involves selection of one of the three different test methods: Wide Wheel Abrasion test (the reference test method), Böhme test and the Amsler test. On the other hand, the American Standard specifies the use of Taber abrasion test. The results obtained from these tests are used as a measure of the relative ability of a stone to withstand wear caused by the pedestrian traffic. Correlations between some of these test methods have been examined by previous authors [9,10]. Despite differences in the employed equipment and procedures followed, all of the preceding laboratory-scale test methods are basically

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three-body abrasion tests. In three-body abrasion wear the abrasive grits are loose, free to move and roll when sliding across the surfaces, which is similar to the prevailing wear mechanism resulting from pedestrian traffic. In the case of sliding, the predominant action is shearing in the form of scratching, scraping and cutting of the asperities. In the case of rolling, sharp points generate high compressive stresses leading to microscopic crushing in localized areas [11].

A thorough knowledge of the factors that influence wear behavior of stone materials can allow predictions to be made about their relative performance in real life applications. The following brief review of the previously conducted laboratory studies reveals that the abrasion resistance of stone materials can be affected mainly by *material properties*, *environmental conditions*, and *operating parameters*.

The relations between abrasion resistance and material properties of building stones have been investigated by a great number of researchers under standardized experimental conditions. Perhaps due to their potentially high susceptibility to wear, the majority of these investigations seem to have been focused on softer rocks such as marble, limestone, and travertine. The general conclusion from these studies [12–15] is that abrasion resistance increases with increasing mechanical strength, hardness, and density, while an opposite effect is observed for porosity. Also, abrasion resistance can be adversely affected due to the weakening effect of weathering process on stone materials [16]. For this reason, in civil engineering projects, stone floor coverings are normally selected from 'fresh' and 'sound' samples to resist better to the pedestrian environment. Concerning the climatic and environmental conditions, the influence of freeze-thaw process on the abrasion resistance of different stone materials was studied by Karaca et al. [17]. They reported that the abrasion resistance of the samples generally reduced after being subjected to freeze-thaw processes. However, the degree of reduction was more pronounced in the case of marble, limestone and travertine samples compared to those observed in samples of granite and onyx. The influence of operating parameters on abrasive wear is often represented by Archard's classical wear equation [18], which is based on the theory of asperity contact:

$$V = \frac{k.\,S.\,F}{H} \tag{1}$$

where V is the volumetric loss of the wearing material (m^3), k is the wear coefficient, S is the sliding distance (m), F is the applied normal load (N), and H is the hardness of the wearing material in terms of pressure (Pa). It is well-known that this model has been applied to abrasive wear conditions of a wide range of materials, such as engineering ceramics, metals and polymers. However, there are very limited studies in the literature on its applicability to stone materials. Yavuz et al. [13] observed that the abrasion rate of carbonate rocks increased linearly with sliding distance, as predicted by Eq. 1. The influence of contact load on abrasion wear rate was studied by Karaca et al. [19]. In the case of carbonate stones, abrasion wear rates of the test specimens were found to be linearly proportional to the applied load. In contrast, however, the stone materials in the granite group exhibited non-linear abrasion wear behaviors, where wear rates tended to revert to lower values at relatively high contact loads, not conforming to Archard's law which implies a linear increase.

In this study, the Wide Wheel Abrasion (WWA) test was employed with the aim of investigating the relations between quantitative petrographic properties and abrasion resistance characteristics of selected granites used as flooring materials. The topic is important for scientific purposes as well as for practice, since this group of stone materials is widely used as construction materials for flooring applications due to their high abrasion resistance, excellent environmental performance, and attractive aesthetic properties. The main reason for focusing on petrographic properties is that, being a '*surface*' phenomenon, any changes that affect the wear resistance of a stone material will primarily be influenced by its surface/near surface properties in the wear zone. From this point of view, in the present contribution the petrographic properties of main concern were modal mineral composition, grain size distribution and mineral hardness. For the completeness of the study, however, two intrinsic rock properties, namely porosity and density were also included in the analyses. By employing correlation and regression analyzes to the experimentally obtained data, the most significant petrographic properties influencing the wear behavior of the studied samples were determined. Accordingly, some wear prediction models were established. Detailed analytical interpretations and discussions of the main findings were made. The information provided in this study may be used in practice as a guide to quantify or differentiate wear resistance of granites in the same category.

2. Materials and methods

In the present work, eight different granite varieties were obtained from a stone processing company and used as the test samples. Selection of the granite samples focused on variations in their mineralogical composition and texture, as well as availability. All samples were 'sound' and free from visible indications of weathering. It is important to note that the term "granite" as used throughout this study is from scientific standpoint, which represents hard and crystalline igneous rocks primarily composed of quartz, feldspar and lesser amounts of accessory minerals. From the commercial standpoint, however, regardless of their mineral composition, all hard crystalline igneous rocks capable of taking a good polish are termed as "granite" [20].

2.1. Mineral composition and grain size

The studied samples belonged to families of alkali granite, monzonite, granodiorite, porphiroidal granite, calc-alkali granite and monzo-granite (Table 1). Quantitative petrographic characterization of the samples included mineralogy - and texture - related properties such as modal composition and grain size distribution. For this purpose, thin sections of the samples as well as factory-polished hand specimens were examined. Micro-structural characteristics, such as the presence of micro-cracks and their potentially existing preferred orientations, were not considered in the petrographic analyses.

Mineral constituents of the studied granites were quartz, potassium feldspar (K-feldspar), plagioclase feldspar, and minor amounts of accessory minerals such as biotite, hornblende and epidote. Modal compositions and mean grain sizes of these mineral constituents were determined to study their relations with respect to abrasion wear resistance (Tables 2 and 3, respectively). The equivalent grain size of each granite sample, which will be referred to hereafter as 'Granite grain size' (G_s), was calculated according to the equation provided by Sousa[21]:

$$G_s = S_q \times P_q + S_{k-f} \times P_{k-f} + S_{pl} \times P_{pl} \tag{2}$$

where S_q, $S_{k\text{-}f}$, and $S_{pl}$are the mean grain size of quartz, K-feldspar and plagioclase minerals, respectively, and P_q, $P_{k\text{-}f}$and $P_{pl}$are the respective percentage contents. Due to their relatively low percentage contents and small grain sizes, the accessory minerals (biotite, hornblende and epidote) were not included in the granite grain size calculations.