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Flexural strength of weathered granites: Influence of freeze and thaw cycles

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HIGHLIGHTS

- Non-destructive testing of Australian Granite's.
- Effect of freeze-thaw cycles on the flexural strength of granite.
- Ultrasonic pulse velocity of unweathered and weathered granite.
- Correlation between flexural strength and UPV.

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ABSTRACT

The effect of freeze-thaw cycles (FTC) on the flexural strength of granite panels is investigated in this paper. Specimens from three different types of Australian granite were sampled. Fifteen specimens were used as control (unweathered) specimens while another 36 specimens were subjected to accelerated weathering consisting of 100 FTC over a period of 34 days. A controlled freeze-thaw chamber and a temperature range between −10 °C and +70 °C was used for this purpose. Ultrasonic pulse velocity (UPV) of the specimens was measured before and after FTC testing. Flexural strength tests were conducted after the FTC were completed. Results showed that thin granite veneers suffered physical degradation accompanied by a noticeable reduction in UPV, density and flexural strength following FTC. Correlation between flexural strength and UPV and between unweathered and weathered UPV is proposed for the three types of Australian granite used in this paper.

1. Introduction

Failure of cladding panels can lead to expensive restoration works as well as serious risks from falling debris. Numerous incidents of stone cladding failures have been reported around the world [1]. A notable example is the Amoco building in Chigaco that cost around US $75 million to replace the façade stone work. In Australia, stone cladding failure was reported in the Melbourne Metropolitan Board building, 210 George St building in Sydney and 344 Queen St building in Brisbane, among others. There is a notable increase in the number of new high-rise buildings around Australia. With the recent safety concerns regarding aluminium panels cladding, it is expected that the use of thin granite veneers as a façade solution on high-rise buildings will increase.

Over the past few decades, an increasing demand for aesthetically pleasing, structurally adequate thin structural stone veneer as cladding panels on buildings, particularly high-rise, has been observed. Among thin structural cladding veneers, Granite is the most commonly used (Pires et al. [2]). Being superior to other thin structural stone veneers in terms of strength and durability, granite has received less research attention. In particular, a limited research is available on the effect of long-term freeze-thaw cycles (FTC) on the flexural strength of thin granite veneer [3]. It is generally accepted that weathering has the propensity to degrade the strength of building stones and thin cladding panels over time and reduce their capacity to perform under seismic and cyclonic loadings during their service life [3,4].

Although destructive testing methods (such as four point bending test) are still preferred in conventional engineering practice, recent developments in non-destructive testing (NDT) methods such as acoustic emission, rebound hammer, laser scanning and ultrasonic pulse velocity (UPV) have facilitated detailed structural

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investigation and retrofitting of modern structures [5]. Several researchers adopted NDT techniques in micro level material characterisation and damage detection [5,6]. The UPV method has been successfully employed for assessing the mechanical behaviour of concrete [7], masonry [6] and various thin structural stone veneers [8,9]. High frequency sound waves above 20 kHz are referred to as ultrasound. These waves are transmitted through the material under test and the velocity of the wave passing through is termed as the ultrasonic pulse velocity. The measured UPV is a function of the inherited mineral composition, material properties and defects. Vasconcelos et al. [10] used UPV to assess the strength, stiffness and fracture energy of granite. Furthermore, Chen et al. [11] successfully estimated crack depth and direction and determined the thickness of damaged surface layers using UPV. This paper refers to work conducted on the structural properties evaluation of various granite specimens [9–11] using the ultrasonic NDT method.

It is well known that thin structural stone veneers possess low tensile strength, usually <10% of its compressive counterpart. While more research is focused on the compressive strength of thin structural stone veneers [3,11], the flexural tensile behaviour has received fewer attention. The direct tensile and compressive strength of granite specimens were reported in [10] from series of destructive/non-destructive tests. A correlation between the strength and UPV was established [10] which showed that the direct tensile strength increased exponentially while the compressive strength increased linearly with UPV. A number of studies have reported on the influence of weathering due to salt crystallisation [8], wetting/flooding [6,12] and heating [13] on the mechanical properties of thin structural stone veneers. Franzoni et al. [13] tested several stones including limestone and sandstone under cycling heating between $100 \sim 400$ °C, showed that the mechanical properties of limestone degraded with temperature, while the sandstone specimens showed the opposite characteristics, which triggered the need to investigate the influence of FTC on the material characteristics of granite. While FTC testing procedure has been standardized, the guidelines provided in ASTM D5312/D5312M-12 [14] and EN 12371 [15] reflect different climates and practices and hence vary in-terms of the number of applied cycles, heating/cooling duration and the required temperature range. Infact FTC for different rocks has been simulated using 50, 200 and 1400 FTC cycles in [16,3,17], respectively. Furthermore, various temperature ranges were adopted; for example [3,18,19,20] used temperatures range of (−40 °C to 40 °C), (−40 °C to 180 °C), (−20 °C to 20 °C) and (−7 °C to 14 °C), respectively. Most of the Australian cities experience a wide range of temperature from above +50 °C in summer to −10 °C in winter. Furthermore, a sharp temperature difference between daytime and nighttime temperatures is common within the 24hrs cycle. For these reasons, a temperature range of −10 °C to +70 °C is selected for the accelerated FTC used in this work.

The effects of freeze-thaw cycling on the flexural strength of a series of granite cladding panels using UPV and four point bending tests are investigated in this paper. Specimens from three different types of Australian granite, namely; Calca, Imperial Black and Grandee were considered in this study. The specimens were partially immersed in water and placed in a controlled freeze-thaw chamber to simulate accelerated weathering through FTC. Based on test results, correlations between UPV of weathered and unweathered specimens and between UPV and flexural strength are established.

2. Experimental program

Ultrasonic NDT, freeze-thaw cycling and flexural testing of the granite cladding specimens were conducted at the Civil Engineering laboratory of the University of Queensland. Details of the experimental program are discussed in this section.

2.1. Material and test specimens' description

Three common Australian granite types were considered in this study. These are; Calca, Imperial Black (or Adelaide Black) and Grandee. Calca and Imperial Black stones are quarried in the Eyre Peninsula and Black Hill regions of South Australia while Grandee in the Mulliandry district of central New South Wales. These three stone types are characterised by high compressive strength, hardness, durability and visible crystalline structure with interlocking crystals of medium to coarse grain. The three stones are distinguishable by their appearances as shown in Fig. 1; with Calca having pink/red clusters on black appearance, Imperial Black with dark black appearance and Grandee with dark grey appearance. The specimens were prepared from 32 mm granite slabs using laser guided saw.

Sample dimensions were selected based on ASTM C880/C880M specifications [21] and were approximately L400 × W100 × t 32 mm, with the exact dimension of each sample being specified in Table 2. A total of 36 specimens (12 specimens of each stone type, S1–S12, Table 2) were subjected to freeze-thaw cycling before conducting flexural test. Another 15 control specimens (5

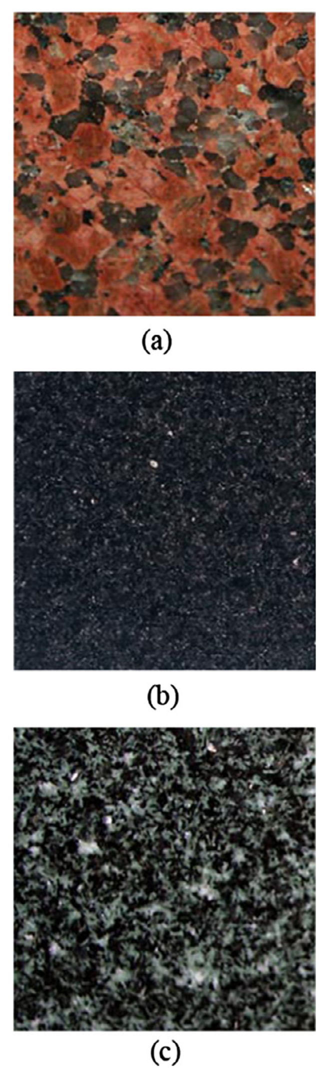

Fig. 1. Granite types (a) Calca; (b) Imperial Black; (c) Granadee.