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Mixed-Mode Fracture Behavior of a Marble Exposed to Acidic Environments

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Abstract

The effect of different acidic conditions on the fracture parameters of marble including fracture toughness of the modes I, II, and I–II, load–displacement curves, and crack propagation angle, was investigated. The specimens were treated based on the different acidic conditions in seen cycles of 2, 4, 6, 8, 10, 12, and 24 h. Sulfuric acid chemical solution at various pH levels of 2, 4, and 5 was used to simulate the different acidic environments. To examine the marble specimens more closely, microscopic studies including thin section and scanning electron microscope images, were performed before and after the treatment of specimens. Finally, 90 rock fracture toughness tests were conducted to investigate the rock fracture behavior. The results showed that the principal factor in the structure variation of marble specimens is the formation of the intergranular and to some extent intragranular microcracks due to the effect of different acidity levels. Rock fracture toughness under the influence of acid exhibited a decreasing trend, particularly at the lowest pH level (i.e., pH 2). Modes I, II, and I–II fracture toughness values and the corresponding crack propagation angles under all different acidic conditions were compared to the predictions by various mixed-mode I–II fracture criteria. It was found that the extended maximum tangential strain criterion better predicts the experimental data.

Highlights

- Marble fracture toughness drops in acidic pH (2, 4, 5) in modes I, II, and I–II.
- Chemical solution had no effect on marble's fracture angles during sample processing steps under acidic conditions.
- The accuracy of different fracture criteria predictions depends on the pH levels.
- EMTSN criterion outperforms other criteria in predicting experimental data.

Keywords Acidic conditions · Marble · Fracture toughness · Crack propagation angle · Intergranular and intragranular microcracks

1 Introduction

Sulfates and nitrates, along with their other derivatives, are indices of air pollution, causing acid rain when combined with moisture in the air (Moreiras et al. 2008; Giavarini et al. 2008; Christoforou et al. 1994; Salmon et al. 1995). The most important acidic solutions that have been used as acid rain in several studies are sulfuric acid (Yu et al. 2020; Li et al. 2018; Taghipour et al. 2016), nitric acid (Deng et al. 2014), ammonium sulfate (Zhou et al. 2018), hydrochloric acid (Wang et al. 2018), and acetic acid (Moutsompegka et al. 2019). The pH level of acid rain can be as low as 3 (or even less in some cases) as reported in the literature (Li et al. 2016). Solutions with different acidities are likely to result in

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