Abstract

Fractures (herein also cracks) influence the deformability, strength, and permeability of rock masses. At various scales, faults, joints, and micro/micro-cracks can govern failure mechanisms, particularly in hard rock slopes when the density of such features is high. Rock bridges play a fundamental role in slope stability. When rock bridges exist between the tips of non-persistent fractures, failure may result from stress concentrations at the crack tips, often accompanied by microcracking and subsequent propagation. This failure can ultimately lead to the detachment of rock volumes and the occurrence of rockfalls. In this work, propagation and coalescence of pre-existing fractures are investigated, with a specific focus on periglacial high mountain environments, where the hazard related to rockfalls is increasing due to global warming. The influence of crack geometry, loading conditions, boundary constraints, and neighboring defects on propagation can be investigated by resorting to Linear Elastic Fracture Mechanics (LEFM), through the definition of stress intensity factors to be compared to a given threshold depending on the fracture toughnesses. Crack propagation is initiated when the threshold is reached. Under certain conditions, the propagation can extend to the coalescence of nearby cracks. In the context of rockfall hazard assessment, understanding this failure mechanism is necessary for the estimation of event volume, magnitude, and temporal probability, which are key components for hazard evaluation and the design of mitigation strategies. Among the predisposing factors, Freeze-Thaw (FT) cycles are particularly relevant in periglacial high mountain environments. Therefore, the progressive degradation of rock bridges subjected to FT cycles is explored. Field data collected at the Sommeiller Pass (Italian Western Alps), including 13 years of air temperature records and FT cycle estimates, constitute the basis for a contextualized laboratory campaign. Two lithologies were selected for testing: a fine-grained, low porosity metamorphic quartzite from the Sommeiller Pass, and, for comparison, a medium-coarse, medium-low porosity sandstone from Tuscany (Italy). Semi-Circular Bending (SCB) specimens of both rocks were subjected to 60 FT cycles with a temperature excursion from -12°C to room temperature, and subsequently tested in Mode I failure. The results highlight the dependence of the FT-induced damage on porosity and grain structure. The sandstone showed a more pronounced reduction in fracture toughness after 60 FT cycles, indicating a greater degradation compared to the quartzite. A simple linear empirical damage law is proposed to relate the reduction of Mode I fracture toughness K_{Ic} with the number of FT cycles. Using parameters obtained from the SCB and companion tests, a few LEFM-based numerical simulations were conducted to explore how geometry influences crack propagation and rock bridge coalescence under compressive stress fields. Finally, a preliminary investigation into the cyclic loading response of quartzite is presented, aimed at evaluating some parameters involved in the degradation of K_{Ic} under cyclic mechanical conditions. Overall, this work provides new insights into time-dependent damage and crack propagation in rock bridges resulting from thermal and mechanical stresses. These findings are particularly relevant for the analysis of rock slope stability in periglacial settings and can contribute to the development of predictive models integrating laboratory and field data, in the broader context of climate change adaptation.