



A new laboratory method for true Mode II fracture toughness determination under sustained in-plane shear loading

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ABSTRACT

The measurement of true Mode II fracture toughness (K_{IIc}) of rocks remains a challenging task due to complex specimen preparation and the undesired influence of Mode I loading in conventional methods. This paper develops a new testing method for accurately determining the true Mode II fracture toughness of rocks using the Staggered Double Notched Specimen (SDNS). To obtain a very low K_I/K_{II} ratio, the optimal geometric parameters were determined using the Finite Element Method (FEM), and the normalized stress intensity factors (K_I/K_{II} ratio) were calculated. To validate the proposed method, experimental tests were performed on three rock types (tuff, limestone, and granite), coupled with Digital Image Correlation (DIC) analysis to monitor the fracture process. The SDNS results were compared with existing Mode I (SCB) and Mode II (SCC and DNBD) testing methods. Microstructural analysis of the fracture surfaces showed that the SDNS method induces a true shear-driven, transgranular fracture mechanism rather than the intergranular fracture typically observed in Mode I. The results demonstrate that the SDNS method provides highly consistent K_{IIc} values, with significant advantages including simple specimen preparation from standard cylindrical or cubic cores, applicability to anisotropic materials, and reliable execution of true Mode II loading.

1. Introduction

Rock fracturing is fundamental to numerous industrial applications, including hydraulic fracturing [1–5], tunneling [6–9], mining [10–14], underground excavations [15,16], geothermal energy extraction [17–19], wastewater disposal [20–22], and CO₂ sequestration [23,24]. In these applications, rock experiences complex mechanical, thermal, and hydraulic loading conditions that can trigger either the propagation of pre-existing fractures or the nucleation of new ones [25]. When these fracture processes occur rapidly and uncontrollably on a large scale, they can result in catastrophic failures that pose severe safety hazards, cause substantial material damage and operational disruption, and potentially lead to broader social impacts. Rock fracture mechanics concerns the initiation and propagation of cracks in rock materials [26–28].

As one of the fracture parameters, fracture toughness, measured by the critical stress intensity factors (SIFs), quantifies the material's resistance to crack growth. Fracture toughness represents a critical mechanical property of materials, with distinct values corresponding to each fracture mode. Rock often behaves in a quasi-brittle manner, allowing the use of linear elastic fracture mechanics (LEFM) to predict fracture growth [27,29]. Within the framework of LEFM, Mode I, Mode II, and Mode III fracture toughness quantify a material's resistance to brittle crack propagation under tensile (opening), in-plane shear, and out-of-plane shear (tearing)

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