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Rebuttal: Shallow wide groove scratch tests do not give fracture toughness

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ABSTRACT

Lin and Zhou (2013) recently showed that by using the depth of cut as a size measure, cutting forces from scratch tests on a quasibrittle material, such as rocks, followed Bažant's simple size effect law (SEL). It was clear that LEFM applied only at deep cutting which might not be attainable. Akono et al. (2014) disagreed and contended that wide shallow groove cuts gave K_{IC} based on an SEL that was scaled by width. We show herein that their conclusions were not supported by data and that the presence of sidewall friction on groove cuts further complicates efforts to obtain K_{IC}.

1. Introduction

Scratch tests are known to induce two modes of failure on a quasibrittle material. When the depth of cut is shallow, the ductile mode of failure dominates and the material failure is strength govern; when the depth of cut is deep, the brittle mode of failure dominates and the material failure is fracture govern [3–6]. By taking the depth of cut as a size measure, Lin and Zhou [1] have shown that strength from scratch tests with different depths of cuts follows Bažant size effect law (SEL) [7]. It was clear from the SEL that fracture failure was only reached at deep cutting, and thus it might not be possible to determine fracture toughness within the range of cutting depths commonly used, let alone those from shallow cuts. Slab cuts, in which the width of cutter is equal or greater than the width of a sample, were the data base used. Groove cuts, which are the focus of the present discussion, have cutter widths narrower than the sample widths, and create grooves during cuts.

The claim that shallow scratch tests could provide fracture properties was first made in [8]. In a revised version, Akono et al. [2] argued that considering the three dimensional effects of the groove scratch tests, a width scaling could merge the results from different widths of shallow cuts into one single SEL plot, and that the widest shallow cut of the data points would lie on the fracture region of a revised SEL and thereby provide fracture toughness, K_{IC}.

We would show herein that their revised claim is not supported by their data, and that they have violated a fundamental similarity requirement in applying SEL for they have grouped data that were not geometrically similar in their width scaling attempt. We would argue instead that shallow groove cuts are strength driven and could not provide fracture properties. To facilitate the discussion, a brief review of how SEL is derived is reviewed first. Even though the material is well established, it is essential for the present discussion and is included. This is followed by an examination of Akono et al.'s data interpretation

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Nomenclature

a_0	initial crack length
a	extended crack length
b	sample width
B	a scale factor
c_f	characteristic size of a fracture process zone
d	depth of cutting
E	specific energy
ε	intrinsic specific energy
d_o	failure mode transition depth
g, k^2	dimensionless energy release function of a specimen
k	dimensionless shape factor for the stress intensity factor
k', g'	derivative of k and g, respectively
F_T	average scratch horizontal force
$\overline{(F_T)_{peak}}$	average of the peak scratch horizontal force
F_V	average scratch vertical force
f_t	tensile strength
α_0	relative initial crack length
α_E	relative equivalent crack length
θ	rake angle of the cutter
ψ	friction angle between the cutter and material
ϕ	friction angle of the wear flat contact
S	drilling strength
σ_N	nominal stress
σ_{Nu}	nominal strength
w	width of cutter

and counter arguments. The current understanding of scratch tests and implications from the presence frictions [9] are further discussed at the end.

A scratch test is characterized by the slant of a cutter, namely the rake angle, θ, the depth of cut, d, the width of the cutter, w, and the width of a sample, b. In the present discussion, only the rectangular cutter is considered. A cutter may be sharp, or blunt in that the latter has a wear flat area. A general geometry as posed by a groove cut is depicted in Fig. 1. A slab cut refers to a scratch test in which $w \geqslant b$; whereas a groove cut refers to a cutter with $w < b$ .The former poses a two dimensional problem, while the latter a three dimensional one. The forces exerted by a cutter are often decomposed into a vertical and a horizontal component denoted as F_V and F_T, respectively. Unless otherwise noted, hereafter the notations F_T and F_V both refer to average forces obtained from a test.

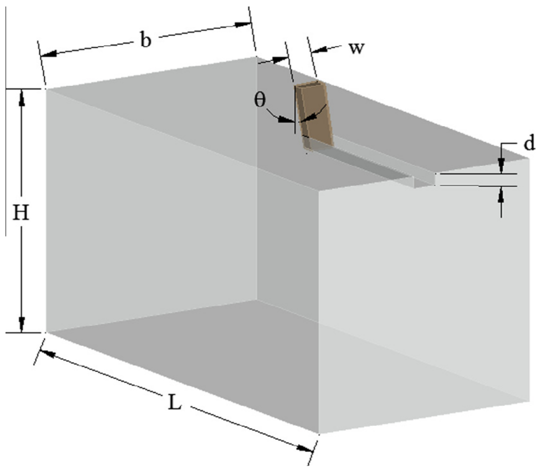

Fig. 1. An schematic drawing of a groove scratch test.