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Assessment of Crack Stability in a Quasi-brittle Particle Composite

Lucie Malíková[a,b,]*, Jan Klusák[b], Zbyněk Keršner[a]

[a]Brno University of Technology, Faculty of Civil Engineering, Institute of Structural Mechanics, Veveří 331/95, 602 00 Brno, Czech Republic
[b]Academy of Sciences of the Czech Republic, Institute of Physics of Materials, Žižkova 22, 616 62 Brno, Czech Republic

Abstract

Fracture behaviour of a crack in a particle (silicate based) composite is studied. The crack propagation depends not only on mutual elastic mismatch of matrix and aggregate but also the influence of the interfacial transition zone (ITZ) between the matrix and the aggregate is discussed. Various combinations of materials and geometry of matrix, aggregate and ITZ can improve or degrade fracture properties of the composite. Extensive numerical simulations on a basic 3-point-bending cracked specimen via the finite element method are performed in order to analyze the stress field near the crack tip. Linear elastic fracture mechanics approach is utilized in order to assess the crack stability and summarize several conclusions.

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Keywords: Stress intensity factor; Particle composite; Interfacial transition zone; Finite elements; Crack stability

1. Introduction

Silicate based (particularly cement-based) composites are definitely the most often used building materials with a specific fracture behaviour. Their mechanical fracture properties are strongly influenced (and can be partially controlled) by the presence of aggregates (AGG) in a matrix (MTX). The aggregates as well as the interfacial transition zone (ITZ) between AGG and MTX affect the crack propagation through the matrix and cause a non-linear response of the complex material. In this paper, the particular effect of the aggregate size, thickness and elastic properties of the ITZ on the crack stability is investigated via a parametric study. Classical linear elastic fracture mechanics (LEFM) approach [1,2] is considered and application of its generalized form is discussed with respect to both higher-order terms of the Williams expansion [3] and change of the singularity level [4,5] when the crack

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* Corresponding author. Tel.: +420 541 147 381.
E-mail address: malikova.l@fce.vutbr.cz

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reaches some of the interfaces (MTX/ITZ or ITZ/AGG). The importance of the non-singular and higher-order terms of the Williams expansion has been described for instance in [6,7].

Nomenclature

3PB	3-point-bending test
AGG	aggregate
ITZ	interfacial transition zone
MTX	matrix
a	crack length
B_1	dimensionless parameter related to the stress intensity factor
d_{AGG}	diameter of the AGG
E_{AGG}	Young's modulus of the AGG
E_{ITZ}	Young's modulus of the ITZ layer
E_{MTX}	Young's modulus of the MTX
F	applied force in the 3PB test
K_{I}	stress intensity factor (mode I)
L	half specimen length
S	half span between the supports in the 3PB test
t	thickness of the specimen
t_{ITZ}	thickness of the ITZ layer
v	depth of the aggregate centre from the free surface of the specimen
W	specimen width
ν	Poisson's ratio (used for all the materials considered)
σ	nominal normal stress in the 3PB test

2. Parametrical study

It is stated in the previous section that both the AGG and the ITZ can influence the crack behaviour. In order to investigate the effect of various properties of AGG and ITZ on the crack propagation, a parametrical study has been performed. A simplified model of a 3-point-bending specimen with a crack propagating to the ITZ and AGG was prepared and following parameters were varied:

- Thickness of the ITZ layer, t_{ITZ}: 10, 50 and 100 μm;
- Elastic properties of the ITZ layer (Young's modulus), E_{ITZ}: 10, 30 and 60 GPa;
- Diameter of the AGG, d_{AGG}: 4, 8 and 12 mm.

Moreover, the AGG was considered to be placed at various depths v from the free surface. The other material and geometrical properties were kept constant; schema of the specimen can be found in Fig. 1 (due to the symmetry, only a half of the specimen could be modelled).

The particular values of the individual parameters were considered as follows: half specimen length $L = 80$ mm, half span between the supports $S = 60$ mm, specimen width $W = 40$ mm, crack length $a = 12$ mm, applied force $F = 1$ kN, Young's modulus of the matrix $E_{\mathrm{MTX}} = 30$ GPa (corresponds to cement paste properties), Young's modulus of the aggregate $E_{\mathrm{AGG}} = 60$ GPa (corresponds to basalt properties), dimensionless Poisson's ratio for all materials $\nu = 0.2$.