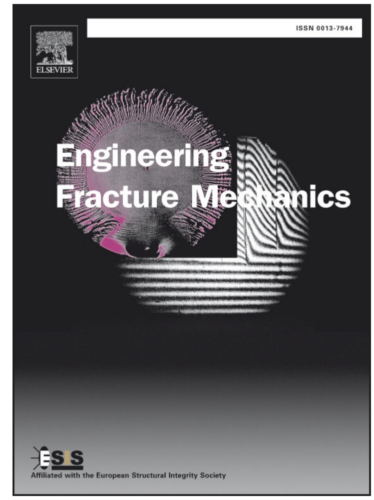
Accepted Manuscript



Particle arrangement effects on the stress intensity in composite material

Shahlaa Al Wakeel, Farshad Ghanbari, Mija Hubler

PII: S0013-7944(18)30512-5
DOI: https://doi.org/10.1016/j.engfracmech.2018.09.014
Reference: EFM 6149

To appear in: *Engineering Fracture Mechanics*

Received Date: 17 May 2018
Accepted Date: 6 September 2018

Please cite this article as: Wakeel, S.A., Ghanbari, F., Hubler, M., Particle arrangement effects on the stress intensity in composite material, *Engineering Fracture Mechanics* (2018), doi: https://doi.org/10.1016/j.engfracmech.2018.09.014

Particle arrangement effects on the stress intensity in composite material

Shahlaa Al Wakeel, Farshad Ghanbari, Mija Hubler*

University of Colorado Boulder, Boulder, CO 80309, USA

Abstract

Motivated by recent advances in material design methods that allow for the controlled engineering of microstructure, we study how the degree of spatial ordering of the inclusions within a particle composite will affect the stress intensity factor associated with an existing crack. By exploring statistically representative sets of random inclusions using linear elastic fracture mechanics expressions, trends of the particle arrangement effect on the stress intensity factor are observed. We find that ordered, random, and clumped inclusion arrangements show an increasing effect on toughness, in that order. These results are verified using finite element analysis. To quantify the observed trend in material behavior with the spatial order of inclusions we consider two metrics of order: the bond-orientational order parameter, Q, and the translational order parameter, T. Finite element models of particle composites with increasing degrees of order reveal that the increasing effect on toughness can be captured and that T is more closely correlated to the effect on the stress intensity factor. We also find that the correlation between the stress intensity factor and particle arrangement is sensitive to the nearest-neighbor distance in Q, revealing that a quantifier approaching a global measure of order is more representative depending on the inclusion volume fraction. The results of this work can improve our understanding of how the stress intensity factor in particle composites explicitly varies with inclusion arrangement. It also provides key insights to develop formulations to engineer random composite microstructures for improved material fracture integrity and to identify issues in quality control of manufacturing methods involving particle distribution.

Keywords:
Stress intensity factor, Composites

1. Introduction

Recent developments in micro- and nano-scale fracture testing methods have revealed a greater sensitivity to the presence of inclusions as seen in random heterogenous materials such as rock and ceramics [1; 2]. Existing studies of fracture toughness focus on effects of inclusion size, density, and representative volume elements (RVE) of inclusion features [3; 4]. Studies of fracture resistance have avoided closed-form solutions which introduce spatial information into crack growth formulations due to their expected complexity [3], in favor of Monte Carlo approaches. However, spatial correlations between the stress concentration point caused by a crack within a material and the surrounding inclusions clearly have an effect in the random sense, as numerous studies of RVE characteristics on mechanical behavior have revealed [5; 6]. The closed-form solution of fracture toughness as a function of inclusion arrangement may be feasible if a single statistical measure of the random inclusion arrangement is able to capture the effect on the selected mechanical response. In this work we pose the question: Is an order parameter a good metric to capture the effect of spatial order of inclusions on the fracture toughness of random particle composites?

Concepts in soft matter physics state that, the degree of order, or jamming, of a particle system is directly related to the stiffness and yield stress of the materials [7; 8]. Based on these theories, we may regard a typical random particle composite as a system of ordered or disordered particles moving within a less dense matrix media. Since the fracture toughness of a material is governed by how stress concentrations around a crack tip interact with local material, spatial statistical measures which relate to the stiffness and yield stress of the random local inclusion arrangement are a logical metric to consider. We do not propose to suggest an independent correlation between the stress concentration factor and the degree of inclusion order. Other material parameters such as elastic/inelastic behavior, loading rate, interface properties, and so forth [9], all affect the stress concentration of random particle composites. Thus, a statistical measure of the inclusion arrangement will provide a correlation to the stress concentration of the material with cross-correlations introduced by other material parameters. However, by introducing the effect of inclusion arrangement, we will be able to describe the sensitivity of stress intensity in materials where inclusion arrangement plays a role [10; 11].

*Corresponding author.
Email address: mija.hubler@colorado.edu (Mija Hubler)