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PHASE FIELD MODELLING OF BRITTLE FRACTURE: AN EXTENSION TO FRACTURE SURFACE TOPOLOGY

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Abstract

In order to model inter-granular brittle fracture, a two-dimensional staggered phase field method has been implemented in the commercial finite element code ABAQUS/Standard. Rate independent variational principle has been used for the above diffused fracture modelling. Besides, an attempt to study fracture surface topology to gain an insight to fracture profiles and processes, has been made through calculation of a universal Hurst Exponent. Consequently, its universality has also been verified.

1. Introduction

Fracture, being the most commonly encountered failure mode in design, needs to be prevented. Computational modelling of fracture is an indispensable tool not only to predict the failure of cracked structures; but also, to gain an insight to fracture processes. Linear Elastic Fracture Mechanics (LEFM) has been explained by the pioneer works of Griffith et al [1] and Irwin et al [2]. Still, predictive modelling of fracture patterns in materials and structures pose a significant challenge. Fracture of solids can be numerically modelled using either a discontinuous approach (LEFM, CZM) or a continuous approach (Phase Field Modelling (PFM), Peri-Dynamics). LEFM and CZM are not self-contained since they need additional criteria to explain cracking processes; whereas in methods like PFM, the displacement fields and set of cracks are obtained automatically as part of the solution with no realtime tracking of the crack tip. The observation of universal scaling behavior on real fracture surfaces has raised hope for a unified theoretical framework to capture fracture processes in disordered solids. However, such a quantitative understanding of the scaling properties is still missing. Most experimental fracture surfaces report persistent fracture profiles with large roughness (Hurst) exponent $H \geq 0.5$ characterised as ductile fracture processes, whereas anti-persistence $H \leq 0.5$ is predicted by LEFM and characterized as brittle fracture processes, with a claim of universality in H irrespective of loading and crack pattern. H is defined as the fractal dimension of the fracture surface with H=0 signifying mean reverting crack pattern and H=1 signifying trending crack pattern.

2. General Specifications

An attempt to study 2D static inter-granular brittle fracture was made using PFM, followed by a computational verification of universality of the Hurst Exponent. Subroutines UEL and UMAT were used in accordance with Miehe et al [3] and Molnár et al [4]. A Single Edge Notched Tension (SENT) Steel specimen with an initial notch length half of the specimen width was considered, subjected to linearly increasing displacements at the top and bottom edges. A honeycomb grain structure succeeding the notch was considered with grain size small enough to accumulate 10^2 orders of magnitude of data. The grain boundaries were made weaker to force inter-granular fracture. The fracture pattern from PFM was obtained as shown in Figure 1. A height-height correlation (Δh) between two points (δx) on the failure profile was sought followed by an exponential fit $(\Delta h) \sim (\delta x)^H$ in a logarithmic scale. The slope of the linear fit determines H, which was then verified for universality.

3. Simulation Specifications

The finite element formulation involves decoupling the governing equations and solving them using a Staggered Algorithm involving a history field. Weaker grain boundaries were ensured by incorporating a sufficiently small constant fracture toughness (g_c) value compared to the material fracture toughness (G_c), which in-turn predicted a value of the length scale parameter for PFM. Time period of simulation was selected such that the crack propagates throughout the entire material. Further, an attempt to randomize grain boundary fracture toughness was carried out using values from a Normal Distribution and assigning to random areas in the grain boundaries keeping the grain properties constant. Crack pattern was obtained as shown in Figure 2. For all the cases, crack extraction, generation of unique fracture surface and calculation of the Hurst Exponent was carried out.

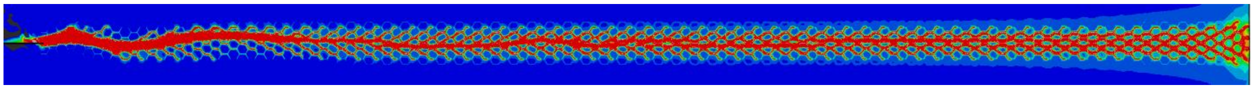

Fig.1 – Crack pattern obtained through PFM (constant g_c)

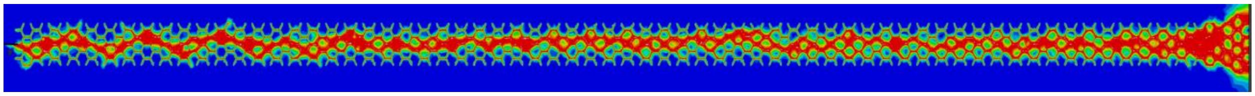

Fig.2 – Crack pattern obtained through PFM (random g_c)

4. Conclusions

H values of 0.5160 and 0.5181 were calculated and its universality was thus verified with the range reported for brittle anti-persistent fracture by Ponson et al [5]. Further studies show two distinct regimes (small scale & large scale) depending on the window size considered for the height-height correlation. For larger window sizes, a self-affine character of the crack surface is seen with roughness exponent H.

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