

# A Unified Model Capturing Increasing or Non-Monotonic Fracture Energy vs. Crack Speed Relationships in Polymers

Giulio Alfano\*<sup>†</sup> and Marco Musto<sup>†</sup>

<sup>†</sup> Department of Mechanical, Aerospace and Civil Engineering  
Brunel University  
UB8 3PH Uxbridge, UK

\*e-mail: giulio.alfano@brunel.ac.uk, web page: <http://www.brunel.ac.uk>

<sup>†</sup>e-mail: marco.musto@brunel.ac.uk, web page: <http://www.brunel.ac.uk>

## ABSTRACT

The relationship between fracture energy,  $G_c$ , and crack speed,  $\dot{a}$ , in rate-dependent polymers may assume different forms. While often the  $G_c$ - $\dot{a}$  relationship is increasing, opposite experimental findings have been reported even for materials of great engineering interest [1, 2]. The possibility of a non-monotonic  $G_c$ - $\dot{a}$  law exists as well [3]. This can have important implications, as decreasing branches of the  $G_c$ - $\dot{a}$  curve can induce fracture instabilities, e.g. stick-slip crack growth [4] or catastrophic failure.

Motivated by a recently formulated thermodynamic derivation [5] for the fractional cohesive-zone model developed in Ref. [6], we present an improved cohesive-modelling scheme based on micromechanics-based physical arguments, which can result in either monotonic or non-monotonic  $G_c$ - $\dot{a}$  curves within a unified conceptual and modelling framework. Although alternative modelling approaches predicting non-monotonic curves exist, to the authors' knowledge they all resort to structural arguments, such as crack blunting/branching [7] or test specimen finiteness [8]: on the other hand our model is fully local and can exhibit non-monotonicity even for a single material point. Postulating the existence of a rate-independent rupture energy, associated with the rupture of bonds, a damage variable is introduced, which is assumed to evolve as a rate-independent function of part of the elastic energy. The overall rate-dependent response is retrieved by introducing additional internal variables associated with viscous dissipation. With our proposed approach, the choice of different evolution laws for the damage variable results either in a sigmoidal shape of the  $G_c$ - $\dot{a}$  curve, typical of certain elastomeric interfaces (as in Ref. [6]), or in a non-monotonic bell shape of the  $G_c$ - $\dot{a}$  curve, which can be associated with the behaviour of some polymers below their glass-transition temperature, as it was experimentally found for the mode-I cohesive-failure of aluminium adhesive joints bonded with the epoxy adhesive Betamate XD4600 [3]. The model can thus capture the significant differences found in the rate dependence of fracture in elastomers and glassy polymers, supported by a physical explanation of these differences.

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