# Mechanism-based hydrogen embrittlement assessment

**Covadonga Betegón[‡]*, Susana del Busto[‡] and Emilio Martínez-Pañeda [†]**

[‡] Department of Construction and Manufacturing Engineering, University of Oviedo
Gijón, 33203, Spain

[†] Department of Mechanical Engineering, Technical University of Denmark
Kgs. Lyngby, DK-2800, Denmark

*e-mail: cova@uniovi.es, web page: http://www.simumecamat.com

## ABSTRACT

Strain gradient plasticity (SGP) formulations have proven to capture the dislocation interactions that give rise to strengthening effects with diminishing size. Thus, by relating the plastic work or the yield strength with both strain and strain gradients, SGP models naturally introduce a length scale into the constitutive equations, rationalizing the *smaller is stronger* response. Not surprisingly, the use of gradient plasticity models has been extended to a number of large scale engineering applications where large variations of plastic strain take place within a relevant micron-size domain. This is the case of crack tip mechanics, hydrogen embrittlement, friction and contact, void growth or strengthening in fiber-reinforced materials, among many other examples.

In this work, focus is placed on the role of strain gradients in the prediction of damage in corrosive environments. A gradient plasticity formulation build upon Taylor's dislocation model is adopted and its richer crack tip characterization is employed to investigate the influence of geometrically necessary dislocations on hydrogen diffusion and subsequent cracking. Results show that large dislocation densities associated with gradients of plastic strain elevate crack tip stresses [1], significantly impacting the diffusion of hydrogen towards the fracture process zone [2]. A novel dislocation-based trapping scheme is proposed and its implications thoroughly discussed. Crack propagation is subsequently investigated by means of a hydrogen-dependent cohesive zone formulation. A significant reduction in the steady state fracture toughness is observed when the role of plastic strain gradients is accounted for [3]. Moreover, environmentally assisted fatigue is also addressed by means of a cycle-dependent traction separation law [4]. Again, important differences with conventional continuum theories can be observed for relevant values of the length parameter. The results highlight the need to incorporate the role of geometrically necessary dislocations in a number of structural integrity problems.

## REFERENCES

[1] E. Martínez-Pañeda and C. Betegón, "Modeling damage and fracture within strain-gradient plasticity", *Int. J. Solids Struct.*, **59**, 208-215 (2015).

[2] E. Martínez-Pañeda, S. del Busto, C.F. Niordson and C. Betegón, "Strain gradient plasticity modeling of hydrogen diffusion to the crack tip", *Int. J. Hydrogen Energy*, **41**, 10265-10274 (2016).

[3] E. Martínez-Pañeda, S. del Busto and C. Betegón, "A mechanism-based framework for hydrogen assisted cracking" (submitted)

[4] S. del Busto, C. Betegón and E. Martínez-Pañeda, "A cohesive zone framework for environmentally assisted fatigue", *Eng. Fract. Mech.* (2017).