

# Numerical Modeling of Material Deformation Responses Using Gradient Continuum Theory

Jurica Sorić\*, Boris Jalušić, Tomislav Lesičar, Filip Putar, Zdenko Tonković

Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Ivana Lučića 5, 10000 Zagreb, Croatia.

\*Corresponding Author: Jurica Sorić. Email: jurica.soric@fsb.hr.

**Abstract:** In modeling of material deformation responses, the physical phenomena such as stress singularity problems, strain localization and modeling of size effects cannot be properly captured by means of classical continuum mechanics. Therefore, various regularization techniques have been developed to overcome these problems. In the case of gradient approach the implicit gradient formulations are usually used when dealing with softening. Although the structural responses are mesh objective, they suffer from spurious damage growth. Therefore, a new formulation based on the strain gradient continuum theory, which includes both strain gradients and their stress conjugates, has been proposed. In this way, a physically correct structural response can be captured. The  $C^1$  continuity displacement based finite element formulation employing that theory has been derived. The element consists of three nodes and 36 degrees of freedom, and displacement field is approximated by a condensed fifth order polynomial. By employing an appropriate softening law, the damage evolution may be modeled [1]. This element formulation may be also used in the multiscale computational approach as shown in [2]. As an alternative to finite element method (FEM), a relatively new meshless approach is used for the discretization of higher-order continuum. In comparison to FEM, it possesses real advantages in a simpler construction of shape functions of arbitrarily high-order continuity as well as in formulation with fewer nodal unknowns at the global level. In this contribution, the mixed meshless Local Petrov- Galerkin method will be presented. The governing equations of gradient elasticity are solved using two different operator-split approaches, and the problem is considered as an uncoupled sequence of two sets of second-order differential equations [3]. The performance of the presented methods is demonstrated using appropriate numerical examples.

**Keywords:** Strain gradient theory; finite element method; meshless method

## References

1. Putar, F., Sorić, J., Lesičar, T., Tonković, Z. (2017). Damage modeling employing strain gradient continuum theory. *International Journal of Solids and Structures*, 120, 171-185.
2. Lesičar, T., Tonković, Z., Sorić, J. (2014). A second-order two-scale homogenization procedure using  $C^1$  macrolevel discretization. *Computational Mechanics*, 54, 425-441.
3. Askes, H., Morata, I., Aifantis, E.C. (2008). Finite element analysis with staggered gradient elasticity. *Computers & Structures*, 86, 1266-1279.



This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.