Fracture assessment of DED manufactured FGM system using phase-field ductile fracture approach

E. Azinpour[1*], S. Rzepa[2], D. Melzer[2], A. Reis[1], J. Dzugan[2], J. Cesar de Sa[1]

[1]Institute of Science and Innovation in Mechanical and Industrial Engineering, R. Dr. Roberto Frias, 400, 4200-465, Porto, Portugal, eazinpour@inegi.up.pt

[2] COMTES FHT, Dobřany, Czech Republic

Functionally graded materials (FGMs) are among the advanced materials that can be suitably produced using additive manufacturing (AM) technologies. In particular, stainless steel/Inconel FGM systems are well-suited for underwater and aerospace applications, as they possess a combination of excellent properties including high corrosion resistance and good weldability. Directed energy deposition (DED) is AM-based procedure which can be effectively used to manufacture FGMs. Due to the gradient changes of material properties, FGMs are not susceptible to issues like premature failure caused by stress concentration, which is a common difficulty in laminated composites. However, the failure analysis in FGMs can be significantly challenging due to the fact that the energy required for crack propagation in these materials is non-uniform, leading to intricate and potentially unpredictable crack paths.

The inherent capability of the phase-field method (PFM) in dealing with wide range of fracture scenarios including crack initiation, propagation, merging, and branching, without the need for any additional criteria, has attracted scientists in many engineering fields. In recent studies, for instance in [1,2], the fracture analysis and problem of crack tip mode mixity in FGMs was approached by combining PFM with homogenization techniques to account for the spatial variability of properties.

In the present work, the failure in FGMs and multi-materials are systematically investigated using phase-field approach in ductile fracture. Following the author's previous study in [3], the PFM is integrated with the $J2$ plasticity model to account for the plastic deformations, and a plastic threshold value is incorporated to regularize the material post-critical softening behavior. To consider the spatial variations of the properties, the effective values for fracture and elastoplastic properties are calculated using the rule of mixtures. The mathematical description of the model is thermodynamically-consistent and is implemented using finite element method. The validation of the model is conducted through a combination of the numerical and experimental procedures. The influence of the gradation profile on the crack trajectory and quantitative force diagrams is highlighted. The workability of the numerical model is then evaluated against the experimental test data from miniaturized tensile test specimens excised from FGM block consisting of 316L and IN718 powders.

References

[1] Hirshikesh, S. Natarajan, R. K. Annabattula, E. Martínez-Pañeda, Phase field modelling of crack propagation in functionally graded materials, Compos Part B Eng 169 (2019) 239–48.

[2] P. K. Asur Vijaya Kumar, A. Dean, J. Reinoso, P. Lenarda, M. Paggi, Phase field modeling of fracture in Functionally Graded Materials: Γ-convergence and mechanical insight on the effect of grading, Thin-Walled Struct 159 (2021).

[3] E. Azinpour, D. J. Cruz, J. Cesar de Sa, A. Santos, Phase-field approach in elastoplastic solids: application of an iterative staggered scheme and its experimental validation, 68 Comput Mech 2021.