Thermomechanical failure of 3D CGI microstructures for engine applications

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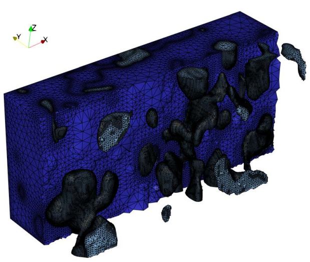
ABSTRACT

Modern engines are subjected to severe operational conditions due to combined mechanical and thermal loads. Engine materials are often exposed to cyclic thermal-mechanical loads, which directly affect the lifetime of the components made thereof. The low-cycle start-up and shutdown load of an engine may induce progressive localized cracking due to the thermal gradients and resulting stresses. Many engine or cylinder blocks are made of a Compacted Graphite Iron (CGI) which is an optimal compromise between the ductility and creep resistance of the pearlitic phase and the thermal conductivity of the embedded graphite. This thermo-mechanical compromise is established through the multi-phase nature of the microstructure, which entails rather complex failure and damage mechanisms. Using a multi-scale 3D approach, the critical conditions triggering micro-cracks are here assessed.

A 3D representative volume element of CGI is constructed, exploiting 3D EBSD data of the microstructure. The inclusion surface contours are defined by level-set functions [1]. Signed distance functions (relative to the inclusion boundaries) are exploited for adaptively optimizing the mesh close to the graphite particles [2].



The pearlite matrix material is modeled with a thermo-visco-plastic model, which includes all mechanisms relevant for thermo-mechanical loading conditions. Model parameters have been identified on the basis of experiments on pearlitic steel. The graphite inclusions are highly anisotropic. Using physical arguments, a graphite model is proposed in which the anisotropy axes are determined from the geometry of the particles. The interface between the graphite and the matrix is described by an anisotropic cohesive zone model. The interfacial parameters for the cohesive model are determined on the basis of established theoretical and experimental results. The resulting 3D RVE model is subjected to representative cyclic thermal loads, whereby the material is mechanically constrained. The development of damage and the crack initiation at the graphite-pearlite interfaces are qualitively and quantitatively assessed. The simulations results are shown to be in adequate agreement with experimental data obtained on these engine materials.

REFERENCES

[1] Sonon B., Francois B., Massart T.J., A unified level set based methodology for fast generation of complex microstructural multi-phase RVEs, *Comput. Methods Appl. Mech. Eng.*, (2012) **223–224**:103–122.

[2] Ehab Moustafa Kamel K., Sonon B., Massart T.J., An integrated approach for the generation and conformal discretization of complex inclusion-based microstructures, Article in preparation.