Void growth and damage evolution in metals and alloys of low lattice symmetry - multiscale modelling and experimental analysis

Nucleation, growth and coalescence of intra/intergranular micro-voids is a usual scenario by which polycrystalline ductile metallic materials fail. Most often micro-voids are nucleated as a result of decohesion or fracture process of second phase precipitates. Growth of those micro-defects takes place due to diffuse plastic deformation up to the onset of coalescence when strain localizes in the ligament connecting closely spaced voids. After that moment the voids continue expansion, mostly towards each other up to final ligament failure or full impingement.

The aim of the project is to understand and describe *how the voids grow and coalesce leading to failure in metallic materials of high specific strength and stiffness*, like titanium or magnesium alloys. Contrary to traditional steels or aluminum alloys with a high lattice symmetry, materials of interest usually have hexagonal close packed (hcp) crystal structure, which is characterized as *a lattice of low symmetry*. Low lattice symmetry results in strongly anisotropic material response at the local level, so that important dependence of mechanical properties on the loading orientation is observed. At some directions plastic deformation of the material is restricted which invokes local stress concentration in the component. This leads to low ductility and fracture toughness. Contrary to the well-grounded theories of ductile-failure-related phenomena available for traditional alloys, the respective proposals and analyses addressing the same issue for low symmetry metallic materials are in its infancy. Better understanding of the relation between material microstructure and void growth failure mechanism may thus reduce limitations hindering application of hcp alloys as structural elements. They are increasingly used in transport and aerospace industry searching for fuel-consumption-reduction solutions. An access to the reliable, physically-based description of the mechanical behaviour reduces risk connected with an unexpected failure of the designs employing new material solutions.

In order to formulate the mathematical model of ductile damage of the metallic material of low lattice symmetry we will use *micromechanical (multiscale) modelling technique*. Within this methodology we estimate the macroscopic averaged (effective) properties of heterogeneous material, i.e. we homogenize such medium, knowing the mechanical properties of the phases at the micro-level and geometrical features of microstructure within the material representative volume - in our case orientation of crystallographic axes, void geometry and their space distribution. In the frame of this technique we will use both numerical and analytical solutions when searching for local response. The key component of the individual micromechanical models is *a micro-macro transition scheme* which constitutes a bridge between the input local mechanical behaviour and gives as a result *homogenized macroscopic response, preferably in the form of the effective material model*. Microstructure features are represented in this model by a set of few parameters, instead of its full reconstruction, which makes the model to be computationally efficient and applicable in engineering tools used in commercial computer codes dedicated to large scale component designs. We will also verify our model by experimental analysis performed, in particular, at the local level by *measuring mechanical response, the void growth and related microstructural changes in single crystals*.

Research undertaken in the project are useful in the application-driven design process of advanced metallic materials in the following aspects:

- Better control of how the local material properties, such as crystallographic texture and the initial precipitates distribution, influence on the void growth failure mechanisms in strongly anisotropic metallic materials.

- Optimization of the material microstructure in view of their future applications by recognizing the impact of loading conditions on failure phenomena.

- Making the step forward towards the verified tool for large scale component design made of metals and alloys of low symmetry.