Details concerning the PhD program

Title: Impact of Forming Processes on the Residual Fatigue Life of Metal Aeronautical Structures

Research period: 3-4 years

Advisors:

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1. State of the art and context

It is well established that during the manufacture of mechanical components by large plastic strains (stamping, forging, machining, etc.), residual fields (stresses, deformations, damage, etc.) are generated in the final component. These residual fields have a significant impact on the service life of these components, particularly when they are subjected to more or less complex cyclic loading paths (fatigue). Predicting the service life of these structures and establishing the link between forming processes and fatigue service life has become a vital issue for mechanical component manufacturers.

In addition, many models have been performed in the literature to predict the life of solids and structures under cyclic loading with a low cycles number (low cycle plastic fatigue $N<10^6$ cycles) or a high cycles number (polycyclic fatigue $N>10^6$ cycles). In addition to the large number of papers published about this subject for various types of materials, an exhaustive synthesis concerning the modelling of the failure of metallic materials under cyclic loading can be found in the books dedicated to the mechanics of damage[1] to [7]. In LASMIS, our work about low cycle fatigue damage modeling concerns both micro-macro approaches ([11] to[14]) and numerical issues for efficient simulations for structures under cyclic loading with macroscopic models[15].
To our knowledge, very little work has been done on modelling and numerical simulation of the induced effect of forming processes on the service life of components in service under complex multi-axial stresses.

The main objective of this project is to develop a numerical methodology for enhanced and efficient prediction of the residual service life under cyclic and non-proportional loading paths of complex industrial parts obtained with forming processes by large plastic strains taking into account the residual fields and without calculating the entire charge cycles. This numerical methodology for calculating service life will be implemented to the commercial FEM software ABAQUS®.

2. Main objectives of the project

The numerical methodology for predicting service life under cyclic loads is based on different aspects:

- *Theoretical aspects*: Use of "advanced" behaviour and damage fatigue models with isotropic and kinematic mixed hardening and strong behaviour/damage coupling with various types of initial and induced anisotropies in a non-associated theory. Quadratic (Hill type) and non-quadratic (Barlat type) plasticity criteria will be coupled with multi-axis fatigue damage criteria covering both in-phase (or proportional) and non-phase (or non-proportional) multi-axis loading paths. A two-surface behaviour model formulated in the context of micromorphic theory will be proposed to determine plastic flow and the evolution of fatigue damage. Some phenomena that are initially described at microscopic scales (intrusion/extrusion for example) will be introduced into the model from micromorphic variables.

Numerical aspects: The formulated models will be implemented in the ABAQUS/Standard code using the user routines: (i) UMAT to implement the fatigue behaviour and damage model, (ii) UELE to implement a new finite element with micromorphic nodal unknowns, and (iii) ULOAD to impose the most complex cyclic loads with a cycle jump algorithm to avoid calculating all stress cycles without neglecting the two important transient phases: the hardening phase and the phase due to the softening induced by the damage. A global program in C++ will allow to call ABAQUS/Standard as solver as well as other routines that allow the operation of the cycle skip algorithm with adaptation of jumps according to the transient periods of each element. For some very complex examples, we can use the sub-model structuring capabilities offered in the abaqus software to focus only on the localization areas.
Such a tool will optimize the manufacturing processes of mechanical components while guaranteeing them a fixed service life.

Experimental aspects: All the parameters of the behavior model must be identified from characterization tests and fatigue tests. Different characterization tests with different loading paths (single-axis traction, shear and torsion) will be used. Fatigue tests from special tensile/torsion specimen will be used to identify the parameters of the fatigue damage criteria. Some experimental tests may be done in collaboration with the laboratory (GML) of Shandong University

applications aspects: This numerical methodology will be tested in the case of calculating the service life of different aeronautical components (aerofoils blades or turbine disc)

References

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