COUPLED MECHANICAL-CHEMICAL SIMULATION OF AN OXIDIZED CFRP COMPOSITE.

L. Olivier 1, J.C. Grandidi
ter 1, M.C. Lafarie-Frenot 1

1 Laboratoire de Mécanique et de Physique des Matériaux, UMR CNRS 6617, ENSMA, BP 40109, 86961 Futuroscope-Chasseneuil Cedex, FRANCE
Email: grandidier@lmpm.ensma.fr

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In the field of aeronautic structures, it is now assessed that oxidation at high temperature accelerates damage kinetics of composite materials. In our laboratory, for a few years, the influence of oxidation on damage initiation has been studied, both under thermal cycling and isothermal ageing conditions. It was shown that, in both cases, the presence of an oxidative environment accelerates the onset and accumulation of damages, mainly constituted of matrix shrinkage, fiber debonding, and matrix cracking. Experimental characterizations of the oxidized material were made thanks to microscopic observations (optical microscope, Scanning Electronic Microscope, X Rays) and mechanical properties measurements (Dynamic Mechanical Analysis and Resonance method, instrumented Ultra-Micro Indentation). For the polymer matrix, confrontation of these observations and measurements with some typical chemical values predicted by a kinetic model of oxidation developed by Verdu and coll. [1, 2] led to a phenomenological correlation between some mechanical properties of the material and its level of oxidation [3]. Moreover, the use of a specific octagonal composite laminate sample showed that, in thermal cycling in an oxidative atmosphere, the local stress field influences significantly the kinetics of development of the induced matrix cracks [4].

The study presented here is part of a research program named ‘COMEDI’, that was initiated at LMPM-ENSMA in collaboration with CCR-EADS, LIM ENSAM-Paris and which is supported by the French Research National Agency (ANR). It concerns the durability of aeronautical CFRP composite laminates subjected to long-term ageing and especially aims to better understand the magnitude of intricate interactions which can appear between local mechanical stresses and thermo-oxidative kinetics. In that context, a new specific finite element is developed to take into account the involved interactions, with the aim to evaluate precisely the mechanical state of the matrix when thermo-oxidation occurs, and, with pertinent criteria, to predict the onset of damage.

This new finite element is constructed so as to calculate the local stress-strain fields inside an oxidized layer of a composite, around fibers, where it was observed that damage initiates. In that situation, matrix shrinkage induced by oxidation generates very important deformations, which lead to the failure of the matrix (matrix cracking and/or fiber debonding). All couplings detailed above are modeled [5], implemented inside a ‘User Element’ of the commercial finite element code ABAQUS, and tested on composite models. Actually, the case of a composite with fibers equally distributed according to an equidistant square pattern is already studied and the local stress and strain fields around fibers are obtained. In figure 1, an example of the calculated matrix shrinkage is given, that corresponds to 48h of oxidation at 150°C under atmospheric air (Fig. 1).
In order to calibrate and validate the model, an extensive experimental campaign of thermal ageing of CFRP laminates is in progress. The calculation of the stress and strain fields generated by oxidation at any time and any position inside a composite laminate makes it possible to quantify the effect of oxidation in terms of local mechanical singularities, and to better understand the conditions of damage initiation. These results will be extremely helpful for predicting durability of composite laminates used in aeronautical components submitted to ‘high’ temperature in oxidative environments.

REFERENCES


