Onset of Fibre/Matrix Debonding on the Surface of Organic Matrix Composites Due to Thermo-Oxidation

M. MINERVINO, M. GIGLIOTTI, M. C. LAFARIE-FRENOT and J. C. GRANDIDIER

1 INTRODUCTION

In modern aircrafts about 50% of the whole structure is composed by organic matrix composites (OMCs). For instance, OMCs can be found in the body and the wings of Boeing 787 and Airbus A380, where temperatures are usually lower or close to the ambient temperature. Currently, aircraft manufacturers are planning to replace some metal parts near the engine by organic matrix composites. The temperature range covered is between 150 °C and 250 °C, wherein many polymer matrices with high glass transition temperatures are now available. In order to integrate such materials in these structures, deep understanding of the degradation phenomena occurring at these temperatures, like thermo-oxidation, is needed.

It has been previously shown that, at medium temperatures, carbon fibres - epoxy matrix composites can be affected by thermo-oxidation, that is a coupled phenomenon of oxygen diffusion and chemical reaction taking place in the oxidation sites present in the molecular structure of the organic matrix. Thermo-oxidation can lead to damage the composite surface, without any applied external load [1].

At a very local scale, matrix shrinkage and fibre/matrix debonding phenomenon have been observed by [2] on the surfaces of aged epoxy matrix composite specimens. Mechanisms leading to the rupture of the fibre matrix interface have been identified and linked firstly to the matrix shrinkage induced by oxidation. It has been shown that the shrinkage strain is proportional to the distance between fibres and it increases also with the ageing duration [3]. Consequently, on the surface of the composite, the local stress level changes with the fibres distance and with the oxidation level: the longest distances match the highest stresses that increase with the ageing time. Moreover, thermo-oxidation induces embrittlement of the polymer matrix. All these effects lead to the occurrence of the debonding phenomenon at the fibre/matrix interfaces.

This work focuses on the onset of the fibre/matrix debonding phenomenon that has been investigated through observations and measurements of the composite surface, by Confocal Interferometric Microscopy (CIM), and numerical Finite Element simulations.

Figure 1 shows what occurs at the surface of a composite sample when kept in an oxidizing environment at high temperature (e.g. 150°C). In the initial state, low matrix shrinkage is observable on the composite surface, possibly due to residual thermal strains and polishing. After thermo-oxidation, polymer shrinkage increases, leading to an increase of the internal strain/stress state. In addition, depending on the fibres distance and on the ageing duration, the onset of the fibre/matrix debonding may occur.

Département de Physique et Mécanique des Matériaux, Institut Pprime – CNRS – ENSMA – Université de Poitiers, 1, Avenue Clément Ader, F86961, Futuroscope Chasseneuil Cedex, France
e-mail: matteo.minervino@ensma.fr ; web page: http://www.pprime.fr/

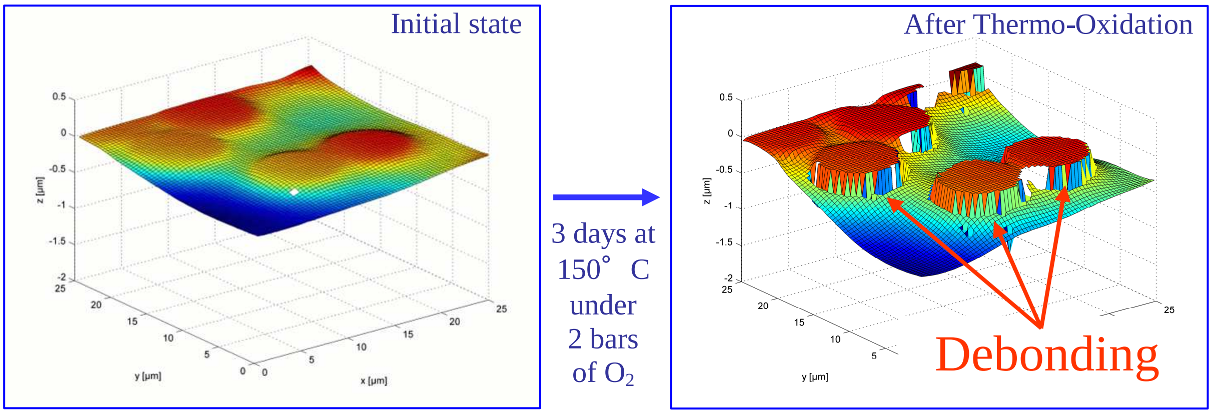

Fig. 1 Confocal Interferometric Microscopy observations of a composite surface before thermo-oxidation (on the left) and after 3 days at 150°C under 2 bars of oxygen (on the right)

In order to have a proper interpretation of this phenomenon, a numerical model has been developed in ABAQUS [4]. The local polymer mechanical behaviour, and its evolution with oxidation, has been introduced in the model thanks to the constitutive law proposed in [5].

The experimental/numerical approach allows identifying the thermo-oxidative induced shrinkage strain distribution into the composite, and its changes over time, by inverse analysis of the CIM measurements at different ageing durations. Finally, we propose a way to evaluate the value of a critical energy release rate for the fibre/matrix debonding, affected by thermo-oxidation.

REFERENCES

[1] Lafarie-Frenot, M. C., Grandidier, J. C., Gigliotti, M., Olivier, L., Colin, X., Verdu, J., Cinquin, J., 2010. Thermo-Oxidation Behaviour of Composite Materials at High Temperatures: A Review of Research Activities Carried out Within the COMEDI Program. Polymer Degradation and Stability, 95, pp. 965-974.

[2] Vu, D. Q., Gigliotti, M., Lafarie-Frenot, M. C., 2012. Experimental characterization of thermo-oxidation-induced shrinkage and damage in polymer–matrix composites. Composites Part A: Applied Science and Manufacturing, 43, pp. 577-586.

[3] Gigliotti, M., Olivier, L., Dinh, Q., Grandidier, J. C., Lafarie-Frenot, M. C., 2011. Local shrinkage and stress induced by thermo-oxidation in composite materials at high temperatures. Journal of the Mechanics and Physics of Solids, 59, pp. 696-712.

[4] Abaqus Ver. 6.9. Dassault Systèmes Simulia Corp. Providence (RI, USA), 2009.

[5] Minervino, M., Gigliotti, M., Lafarie-Frenot, M. C., Grandidier, J. C. Identification of the thermo-oxidative affected material properties of polymers for high temperature applications by a coupled experimental/numerical approach. ECCM15 - 15TH EUROPEAN CONFERENCE ON COMPOSITE MATERIALS, Venice, Italy, 24-28 June 2012.