Composites Science and Technology 70 (2010) 1926–1933

Contents lists available at ScienceDirect

Composites Science and Technology

journal homepage: www.elsevier.com/locate/compscitech

Local damage in a 5-harness satin weave composite under static tension: Part I – Experimental analysis

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ARTICLE INFO

Article history:
Received 5 October 2009
Received in revised form 7 April 2010
Accepted 4 July 2010
Available online 2 August 2010

Keywords:
A. Textile composite
C. Transverse cracking
D. Acoustic emission
C. Multiscale modelling
B. Weft yarn damage

ABSTRACT

This paper presents an experimental damage analysis of a 5-harness satin weave carbon–PPS (polyphenylene sulphide) composite under uni-axial static tensile load. In order to understand the local damage behaviour, tensile tests were performed and accompanied by acoustic emission (AE) and microscopic analysis of the composite specimen. These tests enable us to detect the damage initiation stress as well as the damage initiation location in the composite. Microscopic observation of the tested composite laminates allowed the characterization of the sequence of intra-yarn transverse damage (perpendicular to the load direction) occurrence at different locations in the laminate, starting from crack initiation to the final failure of the composite.

The earliest crack events occurred inside the laminate middle layers, followed by the damage on the traction free surface. It is observed that the initiation of the transverse crack, the location of the crack in the weft yarn cross-section (centre/near the edges) is affected by the relative position of the ply in the laminate (local nesting configuration). The first part of this paper deals with the experimental characterization of sequential damage in a 5-harness satin weave composite. Part II deals with the meso-FE modeling of damage using a satin weave unit cell, and the correlation between experimental and numerical results.

1. Introduction

Damage accumulation in textile composites is a complicated process, and development begins on the micro-scale with the fibre matrix debonding, the matrix cracking and the fibre failure (the micro-scale defines the arrangement of fibres in an impregnated yarn or fibrous ply). On the meso-scale, damage develops by intra-yarn cracking and delaminations (the meso-scale defines the internal structure of the reinforcement, variation of the fibre direction and the fibre volume fraction inside the yarns and the fibrous plies). Finally, the macro failure of the composite is characterized by dense cracking, intersection of several small cracks (crack conjunction) and fibre rupture [1] (the macro scale defines the three-dimensional geometry of the composite part and the distribution of local reinforcement properties).

Starting from the micro-scale, Fig. 1 schematically depicts the weft yarn damage that is affected by the restriction of local ply deformation caused by the surrounding layers. The influence of local constraints is manifested by a change in the weft yarn crack location (edge/centre) based on the location of the chosen ply in the laminate (inner/surface).

In order to obtain comprehensive knowledge of the damage phenomena occurring in textile composites, it is necessary to understand the factors that contribute to the damage at different length scales. Apart from the natural variability in yarn spacing and its dimensions, the unit cells of textile reinforcement are theoretically the same. However, parameters such as the fibre orientation, localized fibre spacing and packing often exhibit a wide statistical variation when evaluated on the micro-scale in a processed composite. Therefore, some localized micro-volumes are stressed more than others. The stress inhomogeneity is further enhanced by the inhomogeneity of the elastic properties of the composite constituents. The inhomogeneity of the stress field, coupled with the inhomogeneity of the strength properties of the reinforcing elements, the matrix and the interface, lead to the gradual damage development in composites [2]. Moreover, the micro-scale stress–strain state defines the number of transverse cracks in a particular yarn and how they are placed over its entire cross-section [3].

In addition to the micro-scale parameters mentioned above, at the ply level (meso-scale), geometrical parameters such as the yarn crimp and the variations in intra-yarn volume fraction can contribute to the stochastic nature of the stress concentration in the micro-volumes [4,5]. Finally on the scale of laminate, in the textile composite, different layers have different yarn nesting pat-

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doi:10.1016/j.compscitech.2010.07.003

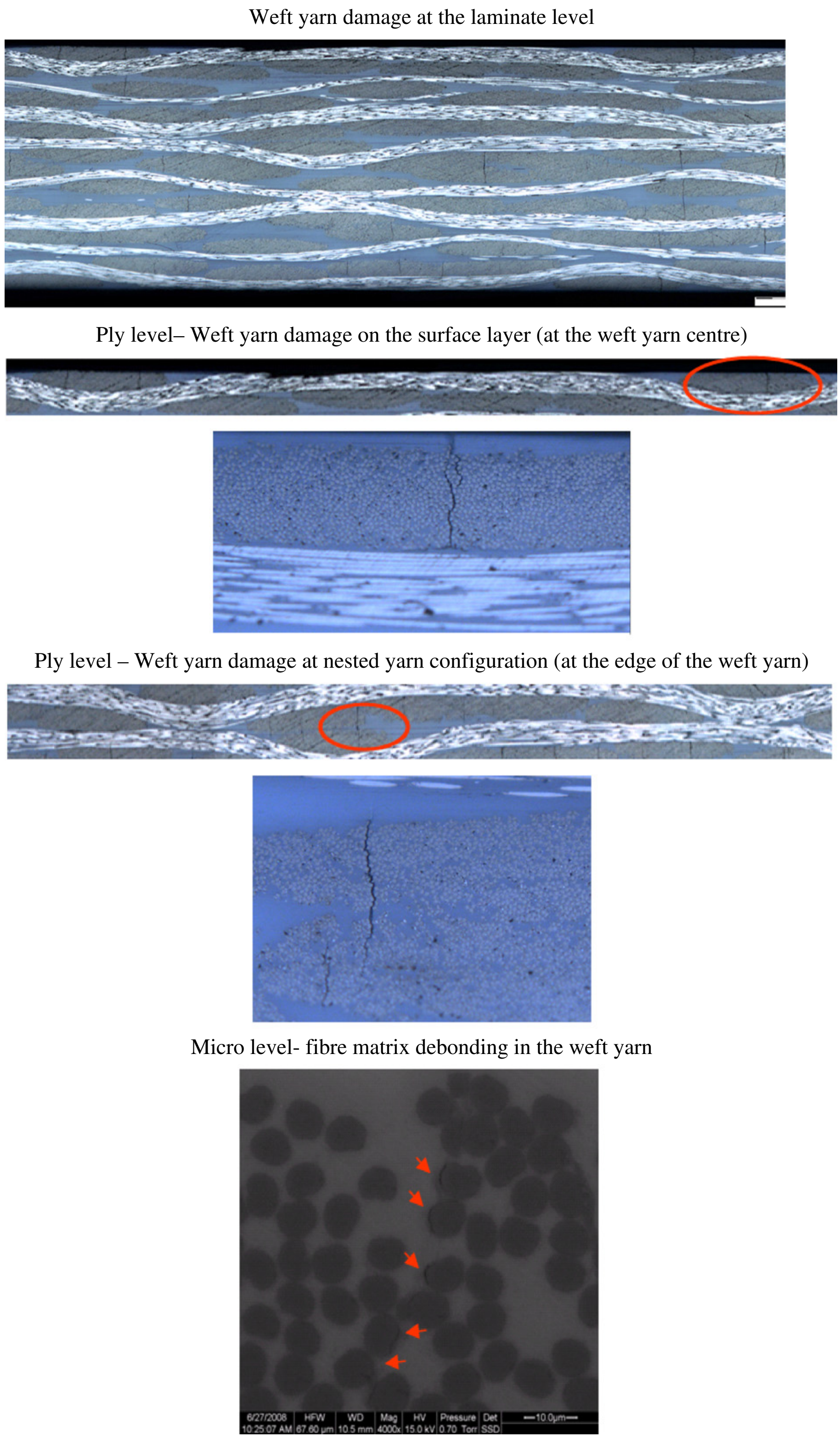

Fig. 1. Schematic representation of the damage at various levels in a satin weave carbon–PPS thermoplastic composite: (a) weft yarn damage at the laminate level; (b) ply level – weft yarn damage on the surface layer (at the weft yarn centre); (c) ply level – weft yarn damage at nested yarn configuration (at the edge of the weft yarn); (d) micro-level – fibre matrix debonding in the weft yarn.

terns. The nesting conditions of the particular laminate are defined by the (random) shifting of its layers during the manufacturing process. Hence, the stress–strain state inside the ply (as in the micro-volumes) depends on the placement of ply inside the laminate [6–8]. The above mentioned parameters of the textile composites at various hierarchical levels can lead to different damage initiation conditions, different patterns of progressive damage in the chosen ply of a laminate. In general, micro-scale damage initi-