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Mechanical behaviour of composite material in presence of wrinkles

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Abstract

In this work the mechanical behaviour of CFRP laminates having an artificial wrinkle introduced in the critical section has been studied in the Open Hole Tension and Open Hole Compression configuration. The experimental test allowed determining the failure mechanism and the knockdown of the ultimate strength in five different configurations.

Keywords: Composite material; CFRP; Wrinkles; Mechanical behaviour

1. Introduction

In the last years the diffusion of composite laminates for structural applications is continuously growing and the experience highlighted advantages and critical point of this kind of material. An aware use of these materials requires a critical evaluation of the effects that the presence of imperfections or defects introduced during manufacturing could provoke on the mechanical behavior and structural performance.

Several geometrical irregularities are originated by the difficulty that an operator encounter during placement of fiber or laminate during manufacturing, as reported in Cantwell and Morton (1992). They consist in lack of planarity of plies, introduction of undulations, partial superposition or wrinkles. In all cases, the real orientation of fibers may differ highly from the one defined in design phase, leading to unexpected stress concentration. In particular, a recurrent and diffused imperfection is represented by wrinkles. A large number of mechanisms are involved in the

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wrinkle formation and the research is active to individuate causes and possible solutions as suggested by Pandey and Sun (1999) and Lightfoot et al. (2013).

Wrinkles are defects particularly relevant since fiber are not aligned in the correct way but show a curvature and the formation of an orientation angle out of the plane of the laminate. Wrinkles can be assimilated to the introduction of a curvature on the fiber of a texture Due to this geometrical configuration, the application of a uniaxial load on curved fiber, which have a bending stiffness practically absent, produces relevant stress perpendicular to the plane. As a consequence the probability of delamination, even at low load level with respect to ultimate strength, is highly increased.

Several authors studied the effect of wrinkles on the mechanical strength of composite material: starting from the work of Van Dreumel and Kamp (1977), which showed that the mechanical performance of tensile strength will suffer about 20% decrease due to the existence of out-of-plane wrinkles, more recently Bloom et al. (2013) measured a knockdown of 40% of the tensile strength in presence of 30° maximum-angle misalignment wrinkles. In compression reduction ranging from 33% to 36% have been determined in two different works by Adams and Hyer (1993) and Mukhopadhyay et al (2015). Finally, an accurate description of the failure mechanism both in traction and compression is reported by Hallett et al. (2013).

In this experimental work, the mechanical behaviour of several configurations of carbon fiber composite specimen that presents in the critical section a hole and an artificial wrinkle has been studied using both a tensile and compressive load. Mechanical tests allowed determining the failure mechanism and the mechanical strength considering the contemporary presence of a stress concentration and a wrinkle.

Nomenclature

W	width of the artificial wrinkle
D	depth of the artificial wrinkle
t	nominal thickness of laminate
s	reduced thickness in the critical section
α	out of plane angle of fibres
F_{OHT}	ultimate Open Hole Tensile strength
E_{OHT}	Modulus of elasticity in OHT configuration
ε_{max}	maximum strain to failure
F_{OHC}	ultimate Open Hole Compression strength

2. Geometry and methods

2.1. Specimen geometry

The specimen geometry that has been selected to study the effects of wrinkles on the mechanical behavior of CFRP is constituted by Open Hole. This standard configuration consists of a flat rectangular specimen having in the middle section a hole. The presence of hole determines exactly the position of the failure section. Moreover this configuration has important application in practice, due to the large use of riveted joints in the field of composite material. Nominal width of specimen is 38 mm, while thickness depends by the number of plies in the selected lay-up. The hole has a nominal diameter of 6.35 mm. Specimen geometry is coherent with the indications of the standard ASTM D5766 and ASTM D6484 that have been used to carry out the tensile and compressive test, respectively.

Each ply is constituted by a unidirectional laminate IMS 977-2 and has a nominal thickness of 0.186 mm.

Five different series of specimens have been tested both in tension and compression using at least five specimens. The detail of laminate lay-up is reported in Table 1. In particular three series have the same lay-up but a different geometry of the artificial wrinkles introduced in correspondence of the reduced section.

The artificial wrinkle introduced in the reduced section is obtained adding several calibrated thickness during cure process. As a consequence local sections of the specimen around the hole appear like in Figure 1. However, the