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Experimental investigation of the influence of substrates' fibers orientations on the impact response of composite double-lap joints

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ABSTRACT

The main concern of this work is the mechanical characterization of the double-lap composite bonded assemblies under impact shear loads. The assemblies were made of unidirectional PEEK/Carbon composites and a brittle epoxy adhesive. The impact shear strength and failure strain were measured experimentally by the Split Hopkinson Pressure Bar apparatus, taking into account the set-up accuracy correction by finite element methods. The composite joints shear strength and strain at failure are sensitive to the loading rate and the substrates' fibers orientation. The highest shear strength is recorded when the substrates fibers are oriented in the same direction as the impact loading. Moreover, the lowest shear strength is observed when the substrates fibers are oriented perpendicular to the impact loading. However, the loading rate and the substrates fibers orientation have opposite effects on the shear strain at failure.

1. Introduction

The industrial application of composite materials is growing in a remarkable rate due to many advantages over metals and ceramics. The mechanical investigation of composite materials, as bulk materials, has been attracting the interest of engineers and researchers for several decades. Such materials are widely used in structures and susceptible to be assembled together with other parts, especially in transportation field. Adhesive bonding technique has several advantages such as low cost, weight and, simplicity of joining. Besides, it does not alter assembled parts, it can be used to join dissimilar materials and it induces the least stress concentration. Thus, it is preferred to others joining techniques such as bolting or riveting.

The adhesively bonded composite joints combine two complex structures: the composite material and the adhesive joint. Consequently, a lot of work is needed to understand the mechanical behavior of these highly complex structures. In terms of dynamic loads, most of works have dealt with adhesively bonded joints of metallic substrates (e.g. [1–5]). Only few works concentrated on the impact behavior of adhesively bonded composite joints.

Pang et al. [6] applied the drop weight tower to test single lap composite joint at low impact velocities; an analytical model was also established. Using the same technique, Vaidya et al. [7] measured the transverse normal stress in a carbon–epoxy single lap joint under impact load which they compared to a 3D FEM analysis carried using LS-DYNA. Kim et al. [8] analyzed the damage in glass/epoxy composite joint under transverse impact. In the same context, Aga and Woldesenbet [9] used the drop-weight technique to investigate the effect of thickness on the damage and impact response of adhesively-bonded graphite/epoxy composite panels. Ghasemnejad et al. [10] used the Charpy impact test to measure the response of CFRP and GFRP single-lap joints to transverse impact loads.

In terms of out-of-plane loads, Park and Kim [11] examined also the plies delamination at highest peel and shear stresses under transverse ice impact. Besides, Grujicic et al. [12] used finite element analysis to assess the role of adhesive layer in the ballistic response of ceramic/polymer composite armors. In the same context, Prakash et al. [13] investigated the effects of the adhesive layer thickness on the ballistic response of ceramic/metal composite armors.

Former references have dealt with the transverse impact loads. In terms of axial loads, Zubaidy et al. [14–16] characterized the impact tensile response of steel-CFRP composite double strap joints using a customer-made drop-weight impact tensile testing

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machine. They showed that the dynamic strength is 1.1 to 2.8 times as high as the static strength depending on the bond length and the number of layers of the CFRP sheets. The maximum increase is obtained for an impact velocity of ~3.35 m/s. Later, the same authors [17] carried out 3D finite element simulations on ABAQUS and good agreement was obtained with the experimental observations. In the same context, Zubaidy et al. [18] carried out pull-off experiments to characterize CFRP-steel joints. These works are briefly reviewed in Ref. [19].

Ashcroft et al. [20] and Casas-Rodriguez et al. [21] characterized damage evolution in CFRP single-lap joints under impact-fatigue loading. Essersi et al. [22] used a servo-hydraulic machine to measure the dynamic stiffness and strength of double-lap composite joints. Raykhere et al. [23] measured the shear strength of dissimilar aluminum-GFRP composite butt joints using the torsional Hopkinson bar technique. They reported a dynamic strength 1.7 to 3.5 times as high as the static strength. Galliot et al. [24] used a drop weight technique to characterize the shear strength of carbon/epoxy laminate single-lap joints. The influence of stacking sequence has been also considered. Recently, Hazimeh et al. [25,26] carried out finite element 3D simulation to understand stress distribution and heterogeneity in double-lap glass/PEEK composite joint tested with split Hopkinson bar experiments. In line with these works, Saleh et al. [27] were interested in double-lap carbon/epoxy braided composites.

Few works have been dealing with the characterization and modeling of the impact behavior of adhesively bonded composite joints. Besides, most of these works were dealing with thermoset composite substrates. This paper aims at characterizing the impact response of double-lap Carbon/PEEK unidirectional laminate composite joint. Mainly, the effect, of carbon fibers' orientations on the shear strength and the failure strain of the joint will be investigated.

2. Method

2.1. Specimen preparation

We are dealing here with the double lap joint used in [28]. The outer substrates are 2 mm thick, while the inner is 4 mm (Fig. 1). This helps wave transfer from the inner to the outer adherents by matching the mechanical impedance of the inner adherent from one side and the two outer adherents from the other side [29]. All substrates are 12 mm in width and 16 mm in length, which gives an overlap length of 14 mm.

The substrates are made of APC2/AS4 unidirectional composite laminates built up from pre-pregs, which are a combination of Cytec PEEK (APC2) and Hexcel carbon fibers (AS4) under code APC2/AS4. The pre-pregs are furnished by Cytec (France). The static mechanical properties of the APC2/AS4 as per the manufacturer datasheet are shown in Table 1. These data are given for room temperature conditions. Two plates were fabricated. The first is of dimensions $300 \times 300 \times 4\ mm^3$ and the second is of $300 \times 300 \times 2\ mm^3$. The plates are made from unidirectional tape of APC2/AS4 using a press molding technique under a curing temperature of 382 °C. Laminates were typically of 60% fiber volume. The lay-up of the first plate was realized out from 28 plies of parallel orientation and a total thickness of 4 mm. The second plate was also made from parallel orientated 14 plies, which yields a 2-mm thick plate. The molding was made by HACOMA (France). Abrasive water-jet cutting was used to cut specimens from the plates. Substrates of dimensions $16 \times 12\ mm^2$ were cut from both plates in order to be assembled as double-lap joints.

The laminate APC2/AS4 substrates are bonded using epoxy Araldite 2031. This structural adhesive is a 1:1 by volume mixture ratio of resin and hardener. It has a brittle behavior. Its static mechanical properties at room temperature are summarized in Table 2.

Four different double-lap joints were prepared depending on the fiber orientation of the substrates (Table 3). The 0° means that the fibers are orientated parallel to the loading direction. The [0-0-0] double-lap joints are similar joints where all substrates are oriented in the axial (loading) direction. Likewise, [90-90-90] double-lap joints are similar joints where all substrates are oriented in the transverse (perpendicular to the loading) direc-

Table 1
Static and room temperature APC2/AS4 mechanical properties [30].

Loading	Strength (MPa)	Modulus (GPa)
0° Tension	2070	138
0° Compression	1360	124
0° Flexural	2000	124
90° Tension	86	10.2
In-plane shear	186	5.7

Table 2
Static and room temperature (23 °C) Araldite 2031 mechanical properties.

Young's modulus (GPa)	1
Poisson's ratio	0.4
Elongation at break (%)	5
Tensile strength (MPa)	20

Table 3
Tested double-lap joints.

Double-lap joint	Inner adherent orientation	Outer adherents orientation
[0-0-0]	$[0]_{28}$	$[0]_{14}$
[90-90-90]	$[90]_{28}$	$[90]_{14}$
[0-90-0]	$[90]_{28}$	$[0]_{14}$
[90-0-90]	$[0]_{28}$	$[90]_{14}$

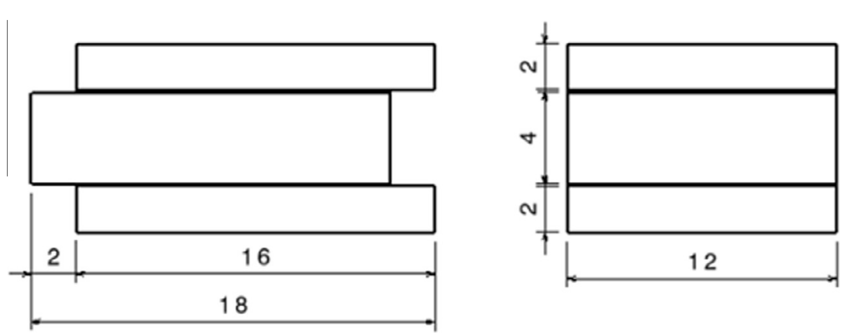

Fig. 1. Geometry of the double-lap joint.