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Ultrasonic damage investigation on woven jute/poly (lactic acid) composites subjected to low velocity impact

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A B S T R A C T

In the present contribution, particular attention is devoted to the fabrication and characterization of fully bio laminated structures based on a commercial poly (lactic acid) (PLA) including a jute fabric as reinforcements, even because of the limited availability of the reference literature.

An ultrasonic technique is used to investigate the delamination caused by low velocity impact tests, on plates obtained by typical film stacking and compression molding techniques. The square specimens, 100*100 mm, were impacted by a falling dart machine at five increasing impact energy values of 2 J, 5 J, 10 J, 12 J, and 15 J. The delamination is investigated by the very commonly used Ultra Sound technique employing a linear phased array probe. The delaminated area is correlated with both the impact energy and the measured indentation depth. The results showed a threshold energy for the beginning of the internal damage. Moreover, a linear relationship between the delaminated area, the energy and the indentation depth was found.

1. Introduction

The non-homogeneous and anisotropic nature of composite systems usually complicate the analysis of the damage evolution and monitoring. As well established [1–5] a wide variety of damage modes like indentations, interlaminar fractures, fiber cracks may occur in composite structures. Thus, a valid and simple tool to investigate the internal impact damage could help to understand the damage initiation and propagation as well as the complex interaction between failure modes [6–8].

The problem of damage is very important to be faced since the large use of these materials for structural applications in many fields, due to their high strength/weight ratios. On the other hand, the growing environmental awareness about the disposal of plastic items at the end of their useful life, ever more constitutes the driving force of the academic and industrial research toward the development of new low-cost and eco-friendly solutions, from biodegradable or renewable sources [9] or composite systems based on natural fibers.

Polymer matrix composites, particularly reinforced with fibers, have received an outstanding attention since the second world war, especially for civil and transport field of applications [10–12].

In this frame, among bio-resins, the poly (lactic acid) resins (PLAs), from renewable agricultural raw materials that are fermented into lactic acid, have acquired a growing interest being processable as polyolefin and other thermoplastic materials. Today PLAs, largely available on the market, are recognized as the most promising biomedical materials. However, some aspects such as brittleness, low impact resistance, low temperature and relatively low cost thermal distortion still limit their use in emerging fields. Many efforts have been spent to overcome these drawbacks like blending, use of fillers, fibers and so on. At this regard, the use of natural reinforcing fibers could be an interesting approach [13,14].

During the last decade, since the importance of the environmental aspect, there has been a renewed interest in the natural fibre taking into account the ecological advantages of using renewable resources [15–17]. The possible applications as a substitute of glass are under study [17–19], motivated by the weight saving which results in a higher specific strength and stiffness, lower raw material price and 'thermal recycling'. For example, flax, hemp and sisal have replaced glass in a number of components in

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the German automotive industries. Many automotive components are already produced in natural composites, mainly based on polyester or polypropylene resins [20,21].

However, some problems related to durability, moisture absorption and mechanical properties have to be solved even if recently developed fibre treatments have improved these properties considerably [22,23].

Moreover, they are producible with low investment at low cost, they are friendly processing and present good thermal and acoustic insulating properties: the use of natural fibres for technical composite applications has recently been the subject of intensive research in Europe to investigate their properties and thus the possible applications [17,21,22].

Among these kind of reinforcements, jute fibers are largely used for their low cost, abundance, malleability and mechanical performances as the high modulus and specific strength. In light of the above considerations, the production of reinforced polymer composites with vegetable fibers has been extensively studied by different groups of researchers in the world [24–30].

In the present contribution, a specific attention is devoted to the preparation and characterization of laminated structures based on a commercial PLA including a jute fabric as the reinforcement, even because of the limited availability of the reference literature. Internal damages, coming from low-velocity impact events carried out up to penetration, were detected with the help of an ultrasonic NDI technique and by the visual inspection. The delaminated area is correlated with both the impact energies and the measured indentation depth. The results showed a threshold energy for the beginning of the internal damage. Moreover, a linear relationship between the delaminated area, the energy and the indentation depth is found.

2. Experimental

2.1. Materials and methods

The investigated systems involve a poly (lactic acid) (PLA) resin supplied by Nature Works under the trade name Ingeo 7001D ($\rho = 1.24$ g/cc, MFR @210 °C/2.16 Kg = 6 g/10 min, Tg = 55–60 °C) as matrix and a plain weave type jute fabric with a specific mass of 250 g/m^2, supplied by Deyute (Alicante, Spain) as reinforcement.

2.2. Sample fabrication

Films of neat PLA were alternated with layers of jute fabric, predried in a vacuum oven at 70 °C for 4 h, using the film stacking and compression molding techniques to prepare laminates consisting of 8 balanced fabric layers 0°/90°, symmetrically arranged with respect to the middle plane of the laminate $[(0/90)_4]_S$. Each sample has an average thickness of 3.5 mm and a volumetric fraction of reinforcement equal to 50%.

2.3. Characterization techniques

Impact tests were carried up to the complete penetration of the coupon. The experimental low velocity impact tests have been performed by a Ceast Fractovis drop weight machine, allowing to vary the impact energy by changing the impactor mass and the drop height. The instrumented steel impactor, with a total minimum mass of 3.6 kg, is cylindrical in shape with hemispherical nose, 19.8 mm in diameter. Measurements were carried out on square samples simply supported on a steel cylindrical support with an internal hole 80 mm in diameter, according to the ASTM 3029.

The samples were then impacted at five different increasing impact energies, 2 J, 5 J, 10 J, 12 J and 15 J, measured on the load displacement curve (Fig. 1) in correspondence of load drops or changing in slope denoting internal damage [31] and useful to investigate the damage start and propagation. For each value of the impact energy, a minimum of 4 samples was tested reporting the average value of the results. The force-time and force displacement curves were recorded during each test by the DAS16000 acquisition program. They were accurately studied since they represent a map of the dynamic behavior of the laminates. At relatively low impact energies (2, 5, 10 J), the sample were not penetrated by the impactor; only at the highest level of the adopted impact energy (15 J), a complete penetration of the reinforcement occurred.

The indentation depths was measured by a confocal microscope Leica DCM3D to draw considerations about the damage achieved at all investigated levels of the impact energies. The microscope is equipped with different magnifications (5–150 X) and an x-y table; a dedicated software allowed measurements of indentation and shape values.

After each test, the delaminated areas were inspected using a US Multi2000 Pocket 16 × 64 system by M2M: examinations were performed with a Linear phased array Probe, 5 MHz, 64 Elements. The phased array systems could be used for all inspection types, traditionally made using conventional ultrasonic flaw detectors. The advantages of phased array technology, in comparison to conventional ultrasonic, derive from the possibility of being able to use several elements assembled in a single transducer to guide, focus and scan the beams. The orientation of the beams, generally called sector scan, can be used to map the components at an optimum angle. In this way it is possible to simplify the inspection of components with complex shapes. The choice of a low frequency probe (f = 5 MHz) is justified by an important decrease of the signal attenuation and a more efficient measurement [32].

The apparatus operates in the form of reflection: the probe is used for the emission and the reception of the ultrasonic waves. During the acquisition, the pulse Echo technique was adopted: short-duration ultrasound pulses are transmitted into the region to be studied, and echo signals resulting from scattering and reflection are detected and displayed. The depth of a reflective structure is inferred from the delay between pulse transmission and echo reception [33]. In this way, using an undamaged sample, the correct thickness plate is obtained (Fig. 2) and the acquisition system is calibrated. The propagation velocity, equal to 2400 mm/s, is registered according to Scarponi et al. [32].

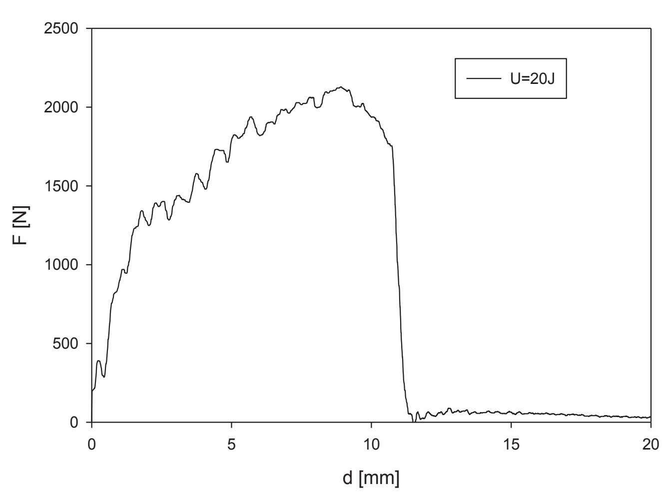

Fig. 1. Example of load–displacement curve up to complete penetration.

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