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Impact behavior of a fully thermoplastic composite

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ABSTRACT

Composites are materials of choice for lightweight structures due to their excellent strength/weight/and stiffness/weight/properties. For several years, the application of composite materials with continuous fiber was limited to those with thermosetting matrix. Recently, interest in composites with thermoplastic matrix is growing thanks to their considerable advantages also in terms of recyclability. The thermoplastic composites appear to be the right alternative to the materials currently used, replacing not only the non-structural parts, but also the structural components located in areas potentially subject to impacts.

This paper presents the results of an experimental campaign made on a fully thermoplastic composite, where both the reinforcement and the matrix are made in polypropylene. The target is to analyze its behavior under different impact loading conditions using a drop weight testing machine. The influence of the impact mass and of the velocity on the energy absorption capability of the material have been analyzed and discussed. During the tests, the material showed a ductile behavior and developed extended plasticity without a crack tip. The main observed damage mechanisms were the yarn sliding.

1. Introduction

Composites are materials used for lightweight structures due to their excellent weight/strength and weight/stiffness properties [1–3]. Composite materials are often used for impact applications [4]. The behavior of composite structures subjected to low velocity impact has received considerable attention in the recent literature [5–13]. Low velocity impact (defined as events in the range 1–10 m/s) can cause matrix cracking, delamination and fiber breakage. Experimental studies put in evidence as, during the low-velocity impacts, the damage initiates with matrix cracks. These cracks cause delamination at the interfaces between plies that have different fiber orientations than each other. For thin specimens, the bending stresses, due to the impact, cause matrix cracking in the lowest ply, and the damage propagates from the bottom through the other plies up to the impacted face. The damage is characterized by the matrix cracks and the delamination in the ply interfaces, like a reversed pine tree [14]. For stiffer specimens, the matrix cracks initiate on the impacted surface of the specimen due to the high contact stresses. The damage propagates from the top surface to the bottom one through the other plies like a pine tree [15]. Such damages are very difficult to be detected with the naked eye and can lead to severe reductions in the stiffness and the strength of the structures. Consequently, the study of the behavior of the composite structures subjected to low velocity impact is essential to avoid loss of performance.

In the past years, many researchers focused their interests on the impact behaviors, on the damage mechanisms and on the residual strengths of the composite structures. These studies are well summarized by Abrate [8,16] and Richardson [9]. Several researchers have devoted their investigations to model the damage development in the composite structures [17–19]. The low velocity impact behavior of the composite materials has been studied, from an experimental point of view, by several authors [10–12]. Between the others experimental methodologies, the drop weight impact tests have been used for this type of research. Other authors have proposed analytical formulations for the prediction of the impact behavior on composite laminates [8,16,21]. However, due to the complexities of the impact behavior and of the impact damage, the analytical methods often result in an oversimplification of the problem. Moreover, the solutions proposed are only applicable to simplified models. Furthermore, experimental approaches are both time consuming and expensive. Therefore, an efficient numerical analysis tool [20] is usually adopted to investigate this phenomenon. A number of studies have been performed to analyze, from a numerical point of view, the behavior of the composite plates over the last few years [11,12,19,22–24]. These studies mainly focused on the development of numerical methods to

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understand the impact behavior of the composite plates under low velocity impacts.

Moreover, in order to assess their capability to withstand load, the growing use of the polymeric materials in engineering applications demands new methodologies, such as the bulk resin modification and the interlaminar toughening. Nash et al. [25] have presented a review of the state-of-art about the incorporation of a thermoplastic phase into a fiber-reinforced thermosetting composite laminate in order to improve its damage resistance and tolerance properties, when subjected to a low-energy impact. It is well known that thermoplastics, even the toughened grades, are relatively susceptible to impact fracture [26]. Therefore, the impact testing is widely used to characterize the fracture resistance of the polymers in industry, because it attempts to simulate the most severe loading conditions to which a material can be subjected in the working environments. Furthermore, this type of test diminishes the effects of the matrix viscoelastic behavior, so that it becomes sufficiently reasonable to neglect them. However, the difficulty to obtain reliable data from the instrumented impact tests at various speeds is well known and pointed out in the literature [27–29].

In this perspective, the target of this work is to analyze the behavior of a fully thermoplastic composite under different impact loading conditions. Both the reinforcement and the matrix of the considered composite are made in polypropylene. The study has been carried out with a series of experimental drop dart tests. The influence of different parameters, like the velocity and the mass of the impact, on the structural behavior and on the energy absorption has been evaluated.

2. Producing laminated composites for experiment

The material studied in this work is a sealable, co-extruded triple layer polypropylene (PP) tape. It was provided by Lankhorst Pure Composites and produced via the patented PURE technology [30]. The PURE tapes were used for weaving into thermoformable plain fabric processes. A mono material concept, which is fully recyclable, has been achieved using PP fibers embedded in the same PP matrix. In Table 1, the main mechanical properties of the tape and the sheet configuration are reported according to the PURE technical data sheet.

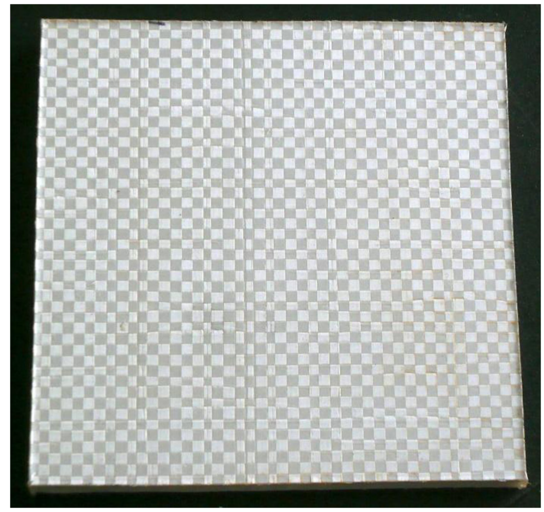

Fig. 1. PURE specimen before the test.

In our case, the PURE fabrics were consolidated into a 600 × 1200 mm sheet using 53 layers of material. The laminate was put into a hot press. The compaction process was carried out at the pressure of 100 bar and at the temperature of 130 °C for 2 h. After this process, the laminate was cut into specimens with square shape, with an edge length of 100 mm, using the waterjet technology. A specimen example is shown in Fig. 1. The final thickness of the composite specimens was about 6.9 mm.

3. Drop weight impact testing

To study the impact behavior of the thermoplastic composite object of this work, drop weight impact tests were carried out on the described specimens. The drop weight impact testing is a type of low velocity testing, and it is the most common test used to analyze the impact behavior of composite plates [31–35]. In this type of test, a defined mass is raised to a known height and released (Fig. 2 on the left). The mass is driven in its free fall with a couple of rails. A dart impactor with a hemispherical tip, fixed to the mass,

Table 1
Mechanical properties for the PURE tape and sheet. The authors declare that there is no conflict of interest regarding the publication of this paper.

PURE tape	Test method	Value	Unit
E-modulus	ISO 527	14	GPa
Tensile strength	ISO 527	500	MPa
Elongation	ISO 527	6	%
Shrinkage at 130°	ASTM D4974	< 5.5	%
Sealing range		130–180	°C
PURE sheet	**Test method**	**Value**	**Unit**
Bulk density	ASTM D792	0.78	g/cm^3
Tensile modulus	ISO 527-4	5.5	GPa
Tensile strength	ISO 527-4	200	MPa
Tensile strain to failure	ISO 527-4	9	%
Flexural modulus	ISO 178	4.5–5.5	GPa
Charpy impact (FN)	ISO 179	(N, no break)	kJ/m^2
Charpy impact (EP notched type A)	ISO 179	(P) 140	kJ/m^2
Izod impact (FN)	ISO 180	(N, no break)	kJ/m^2
Izod impact (EP notched type A)	ISO 180	(P) 126	kJ/m^2
Instrumented falling dart impact (23 °C)	ISO 6603-2	9.51	kN (peak)
(2.2 mm, clamped, 20 mm striker)		51.46	J (at failure)
Heat deflection temperature (1820 kPa)	ASTM D648	95	°C
Coefficient of thermal expansion (−20 °C to 100 °C)	ASTM E228	23	$10^{-6}\ K^{-1}$
Coefficient of thermal conductivity (2.25 mm)	EN-ISO 12567-1	0.044	W/m K
Fire behavior-burning rate (1.6 mm)	ISO 3795	29	mm/min