EFFECT OF STACKING SEQUENCE ON LOW VELOCITY IMPACT AND POST-IMPACT BEHAVIOR OF FLAX/POLYAMIDE 11 COMPOSITES

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Abstract
In this paper, a fully biosourced composite: flax/Polyamide 11 is studied. Different stacking sequences are studied in order to investigate the lay-up effect on the impact and post impact behavior of these composites. Impact energy applied is 3.6 J. The damage is assessed by visual inspection. The impact properties of composites are obtained from the evaluation of the impact force, the maximal displacement of falling dart and the absorbed energy. Impact tests show that the maximum absorbed energy is obtained with the "sandwich-like" stacking sequence $[0_2/90_2]$s. Moreover, tensile and compressive post-impact tests demonstrate that the multidirectional composite is the stacking sequence that shows the best residual mechanical properties.

1. Introduction

By an increasing environmental awareness and governmental sustainability policy and regulations, polymer composites reinforced with natural fibers has increased in the last few years. Natural fibers have been used to reinforce plastics due to their good specific strength, biodegradability, low density… Recent papers deal with the use of natural fibers such as bamboo, sisal, flax… in composites. In the most of cases, the resin comes from petrochemical industry. So, it is interesting to develop composites from natural resources for both the polymer and the fibres. In this context, in order to create a 100% bio-sourced composite, this study deals with a composite made of Polyamide 11 which is derived from the castor oil and flax fibers. A lot of works has been interested in static behavior of composite materials based on natural fibers [1,2] but few studies focus on their dynamic behavior.

One of the major concerns in the use of natural plant fibre reinforced polymeric composites is their response to impact damage and the capacity of the composites to withstand it during their service life. Low velocity impact is one of the most detrimental sollicitation for composite structures. Indeed, impact induced damage are particulary critical because it reduces the residual mechanical properties of the structure [3].

The goal of this study is to investigate the effect of stacking sequence on the impact and post-impact behavior of Flax/Polyamide 11. The figure 1 summarizes the four studied stacking sequences: a UD composite (1), a 0/90 alternated lay-up (2), a 0/90 "sandwich-like" lay-up (3) and a cross-ply laminate (4). Impact curve analysis and damage visual inspection have been performed.

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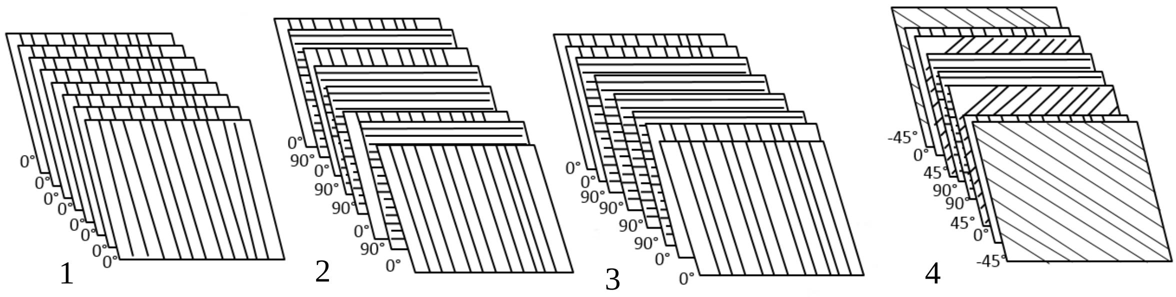

Figure 1. The different stacking sequences studied: unidirectional (1), alternated (2), sandwich (3) and multidirectional (4).

Compressive and tensile tests have also been realised to evaluate the composite properties before and after impact.

2. Experimental procedure

Composites were made from unidirectional flax fibres and Polyamide 11(PA11) polymer. UD fabrics were provided by Depestele and have an area of weight of 450g/m² and Polyamide 11 was provided by Arkema in the form of film "LMFO" with a thickness of 100 µm and a density of 1.02g/cm3. Composite plates were then manufactured using hot-pressing process with a fibre weight fraction of 50% and a plate thickness about 4 mm. Flax fibre fabrics layers and PA11 film were piled up alternatively and compressed in a mould with dimensions of $450x500x4mm^3$. Composites were compressed at 210°C, with a pressure of 25 bars during two minutes, 40 bars during two minutes and 65 bars until the end according to the optimized process parameters [4,5] .

Low velocity impact tests have been conducted at room temperature on 5 samples for each stacking sequences for impact energy of 3.6 J. The tests were conducted using a guided drop weight tester characterized by a hemispherical steel indentor with a diameter of 20mm.

Tensile tests were conducted with a mechanical testing machine (Instron 5884). Five standard impacted specimens with cross section dimensions of 25x4mm² were tested for each configuration. Glass composite tabs of dimension 50*25mm² were glued on the specimens and were placed in the clamped area. The loading was carried out at room temperature and with a displacement rate of 2 mm/min. Strain gauges of 5 mm length were bonded on specimen surfaces.

Compressive tests were conducted on the same mechanical testing machine. Five standards impacted specimens with dimensions of 100*150 mm² were tested. The loading was carried out at room temperature and with a displacement rate of 1 mm/min

3. Results and discussion

Force-displacement curves for the four stacking sequences studied are presented in figure 2.. For the four lay-ups, the first part of the curves has a similar linear increasing. Then, in the second part, the tested specimens show two different behaviors: for the alternated and multidirectional specimens, the contact force increases and then the curves go back to the initial position. On the contrary, another behavior can be observed for the unidirectional and sandwich composites: the force decreases and the displacement is significantly higher.

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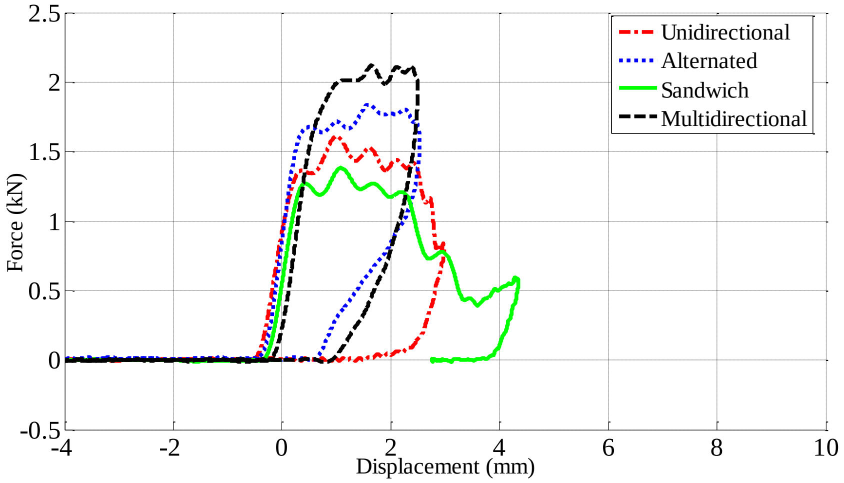

Figure 2. Typical force-displacement curves for the different stacking sequences of composites

Macroscopic observations of the front and rear sides of the four different composites are given in the figure 3. This figure gives information about the induced damage. In the unidirectional and the sandwich stacking sequences, one can observe large damage, leading to the composite perforation (Fig. 3a and c). For these two composites, on the front face, we can see the indentation corresponding to the hemispherical form of the impactor. On the contrary, for the alternated and the multirectional samples (Fig. 3b and d), there is no visible damage on the front sides. On the rear sides, macro cracks can be observed in the external layer. These cracks are oriented in the external fiber direction, and perpendicularly to the fiber direction (Fig. 3b and d). This phenomenon has also been observed in the study of Vieille et al. [3] in carbon composites.

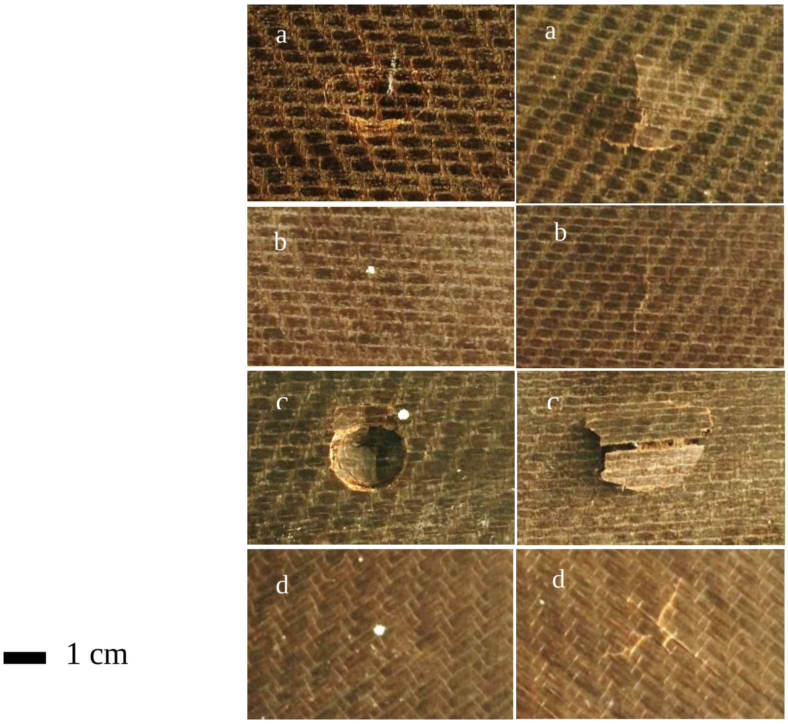

Figure 3. Pictures of front and rear faces of unidirectional (a), alternated (b), sandwich (c) and multidirectional (d) composites

Compressive and tensile tests have been realized on impacted specimens in order to investigate residual performance of each stacking sequence. The loss of tensile Young modulus and failure stress are detailed in table 1.

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Table 1. Loss of Young modulus and failure stress for compressive and tensile tests.

Specimen Type	Compressive properties loss (%)		Tensile properties loss (%)	
	E	σ	E	σ
Unidirectional	-23	-36	-50	-69
Sandwich	-61	-35	-78	-92
Alternated	-14	-7	0	-70
Multidirectional	-10	0	0	-16

Results concerning the residual compressive properties of composites show that the sandwich sample is the one with the highest loss values. On the contrary, for multidirectional sample, the loss is only of 10% for the compressive Young modulus and there is no loss for the failure stress in compression (Table 1).

Concerning the tensile results, the alternated and multidirectional samples keep the same Young modulus values, whereas the unidirectional looses 50% and the sandwich looses 78 % of their tensile Young modulus. As regards the tensile failure stress, the loss is of 92 % for the sandwich composite, and only of 16 % for the multidirectional one. These results confirm macroscopic observations and force-displacement curves analyses.

4. Conclusion

A comparative study of four flax/Polyamide 11 composite stacking sequences has been performed. Low velocity impact of 3.6 J has been applied. Results show that the multidirectional composite is the specimen which has the lowest induced damage according to macroscopic observations. Compressive and tensile post-impact tests confirm that this composite almost doesn’t loose its mechanical propertiesOn the opposite, results show that the sandwich composite is the one with the highest loss in residual properties. It demonstrates that, for flax/PA11 material, a cross-ply lay-up with several ply orientations is better than a composite with grouped plies of same orientation for withstanding low velocity impact.

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