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Study of damage and repair of flax/Elium biocomposites under dynamic loading

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Abstract. Laminated composites based on the new thermoplastic Elium 188 from Arkema and woven flax fibers has been manufactured by the infusion process at room temperature, still yet reserved to thermoset-based composites. The low velocity impact behaviour has been investigated between energy 7 to 22J for two stacking sequences $[0/90]_6$ and $[\pm 45]_6$.Repair after impact has been investigated too. The impact resistance was established by measuring load, deflexion, absorbed energy, contact duration and damage. Visual, high-speed images and microscopic observations were performed on impacted samples to show the effect of incident energy on the damage extension in the composites, by revealing the fiber/matrix debonding as principal damage mode. 3 points bending tests were carried out to assess the residual impact performance. In addition, a simple thermo-compression damage repair process was applied to carry out the multiple impact/repair cycles on the impacted plates. A significant recovery of stiffness and maximum impact force up to 4^{th} cycle at 4J of $[0/90]_6$ plate has been revealed, by highlighting the interesting potential of flax/Elium® bio-composite to its repair aptitude.

Introduction

A large number of composites using synthetic and non-synthetic fibres with different thermoset and thermoplastic matrices have been already investigated. But, thanks to their eco-friendly property and low cost production with interesting physical and mechanical properties natural fibres are gathering a growing scientific and economic interest [1].

Thus, some studies have been conducted over recent years to investigate the mechanical behaviour of natural fibre-based composites. Moreover, composite structures are loaded under static, cyclic and dynamic loadings during their life cycle. However, low Velocity Impact (LVI) is one of the most important loadings and it is difficult to set up these parameters because of its random nature. Understanding the behaviour of composite when subjected to LVI loading is necessary for designing structures as it is a common issue and damages are usually not apparent to the naked eye.

Finally, this study focuses on the LVI damage and the reparability of thermoplastic biocomposite plates. For this purpose, impact tests were carried out and post-impact bending tests as well. Moreover, to demonstrate repairability, two batches of impact tests were conducted with and without fibre breaks.

Material, manufacturing and samples

Material

The biocomposite used in this study is made of thermoplastic matrix with flax fibres. Fibres are available as woven twill flax fabric from the French company Depestele and with an area density of 360 g/cm^2. The matrix is a liquid thermoplastic matrix named Elium®188, recently formulated by Arkema company.

Plates, of dimensions 1000×750 mm^2 with a thickness between 4.5 and 4.8 mm, were manufactured by CMP Company using Vacuum Resin Infusion (VRI) (figure 1). This latter is usable although it used thermoplastic matrix because of the very low resin viscosity.

Two stacking sequences were considered for this study: $[0/90]_6$ and $[\pm45]_6$.

Fig. 1. biocomposite plate

Impact samples
Samples with dimensions of 100 x 150 mm^2 were cut from the previous plates according to Airbus standard AITM 1-0010 [2]. However, a main difference in our study is in the boundary conditions as discussed below.

Two batches have been prepared according to both stacking sequences.

Repair method
An in-house thermocompression device (Figure 2) was designed in our laboratory to manufactured thermoplastic-based composites. But, in our case, it has been used to repair the impacted plates. For that we put on the impacted sample a coupon of a comingled fabric with flax and polypropylene fibres. The size of this latter was approximately the damaged area. Using a temperature of 200 °C and a very low pressure to avoid changing the dimensions and more especially the thickness the plates were repaired.

Samples were put in between the two aluminium trays and we just added an weight of 5 kg on the upper plate. 5 minutes was enough to make flat again the impacted samples.

Fig. 2. Conventional hot press.

Devices

Drop tower

Low velocity impact (LVI) means that the velocity ranges from approximately 1 m/s to 10 m/s [3]. The falling weight impact setup, (so called drop tower), is the most powerfull device to reproduce low energy impacts.

Our drop tower (Figure 3) consists of two parts. The first one is the dropping mass and the second one is the boundary conditions. As mentioned previously, the boundary conditions used were not those recommended by the standard. We clamped the sample on two metallic supports closed to 3 points bending configuration.

Displacements (centre of the impacted plate and position of the striker) were measured using laser sensors and the force by a piezoelectric sensor.

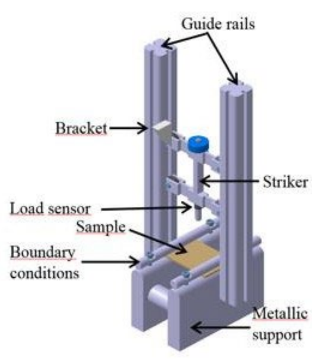


Fig. 3. Scheme of the Drop Tower.

The mass of the striker was around 1 kg and we used 3 heights: 1, 2 and 3 m. Moreover, one batch of samples with the stacking sequence $[0/90]_6$ was aged at 75%HR at room temperature.

Quasi-static tests

Quasi-static tests have been done to compare results to dynamical tests. To ensure the same experimental conditions in both cases, the plates were clamped with a similar support and the same hemispherical tip used for impact applied the quasi-static loading (Figure 4).

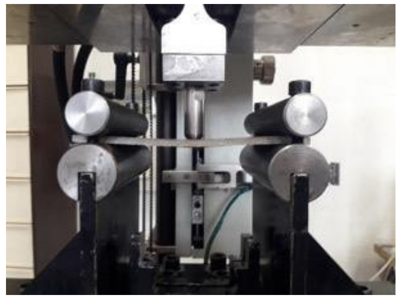


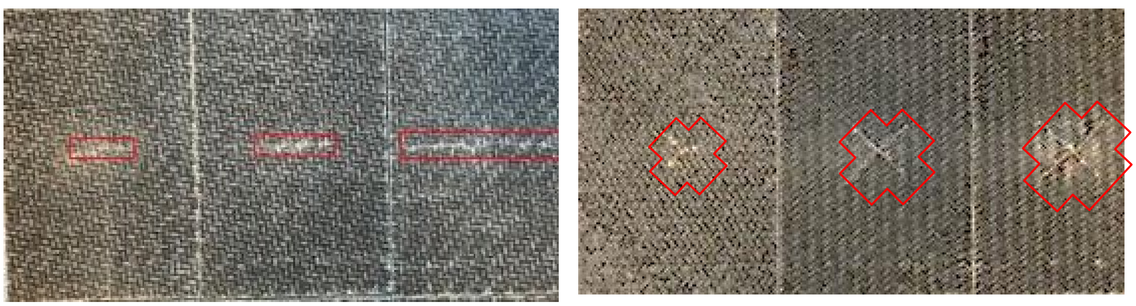
Fig. 4 Quasi-static device.

Finally, conventional 3 points bending tests were conducted to estimate the residual resistance. This test was chosen over the compression after impact (CAI) because in the thermoplastic- based composites delamination is not the main damage mode during an impact due to the ductility of the matrix.

Results and discussion

Post-impact visual inspections revealed an indentation on the impacted face which increase with the energy of impact for all impacted specimens even at 1 meter height.

The back face, as expected, exhibits a damage shape according to the stacking sequence (Figure 5).



1 m 2 m 3 m 1 m 2 m 3 m

(a) (b)

Fig. 5. Damage evolution from 1 to 3 m (a) $[0/90]_6$, (b) $[\pm 45]_6$.

Optical microscopy observations confirm that no large delamination occurred during the impact loading. It is why CAI is probably not the best test to estimate the residual properties. But we observed cracks inside the yarns or often at the border with the surrounding matrix (Figure 6).

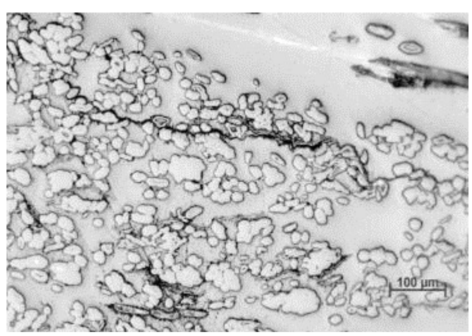


Fig 6 Crack in a yarn.

The force versus time curves for the 3 different energy levels for the 3 batches ($[0/90]_6$, $[\pm 45]_6$ and ([0/90]6 aged) are shown at Figure 7. Curves exhibit significant oscillations which can be mainly due to the vibration of the specimen according to its eigen modes [4].

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It can be observed that, for both stacking sequences, the contact duration between the sample and the striker during impact increases slowly with respect to time. This phenomenon is due to the decrease of the stiffness because of the growth of the macro-crack located at the back face as illustrated in the figure 5. Thus, it is well known that the contact duration depends strongly on the striker mass and on the stiffness of the impacted structure. It can be noted that the maximum force increases slightly with the incoming energy too. The maximum force increases slightly too with the incoming energy as expected.

Post-impact bending tests were preferred to compression as discussed above to evaluate the residual properties. The results (Figure 8) for both orientations. Indicate that the performance of the stacking $[0/90]_6$ is much more sensitive to specimens $[\pm 45]_6$ compared to the refence one. It is well known that he fibres angle has a strong influence on the mechanical responses and of course a angle of 0° increases strongly the young modulus but then these fibres break this latter decreases strongly too. This explanation is confirmed by the damage induced by the impact (figure 5). Effectively, we can observe that the crack for the $[0/90]_6$ is transverse to the span creating a strong effect on the sample stiffness contrary to the $[\pm 45]_6$ for which the damage is more located at the centre of the specimen.

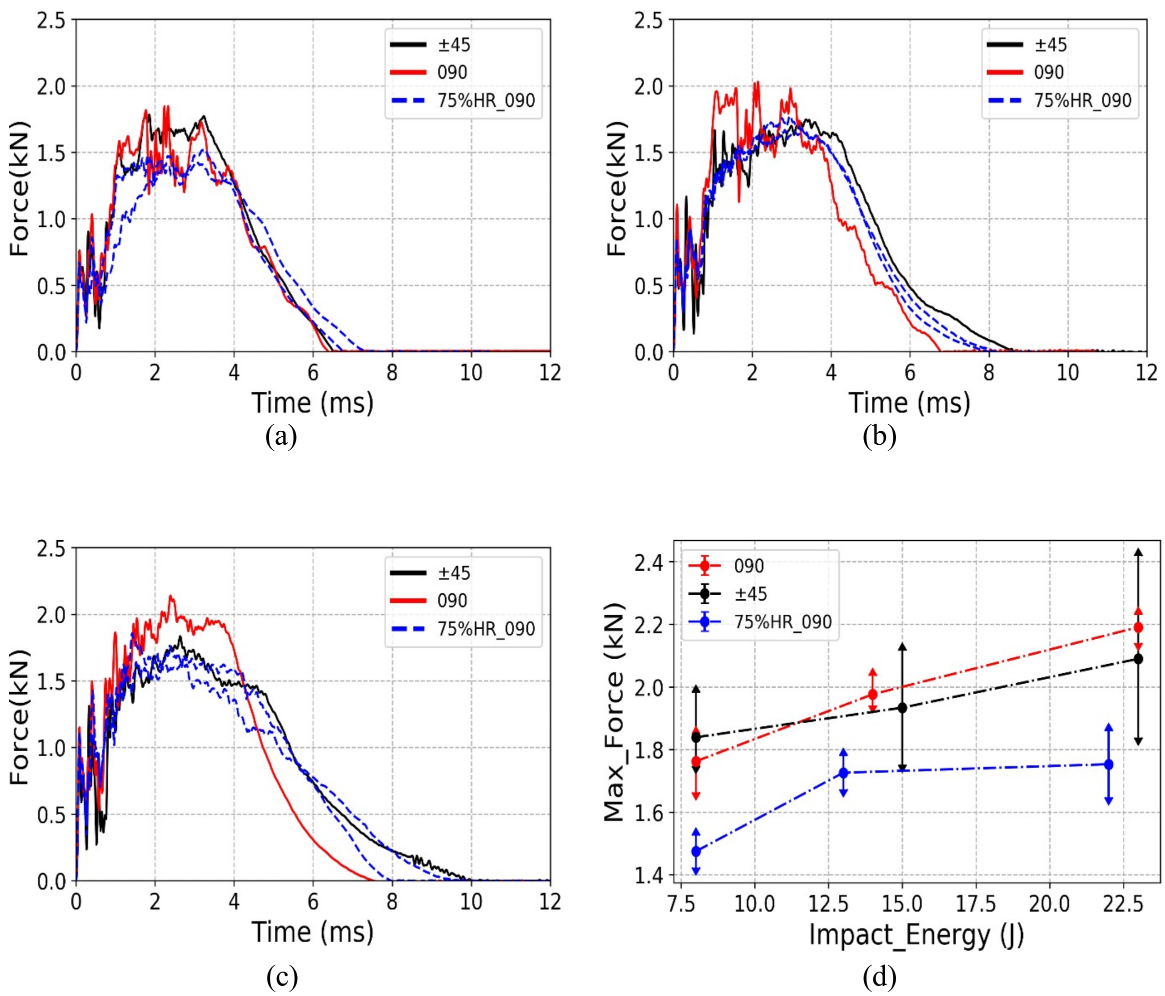
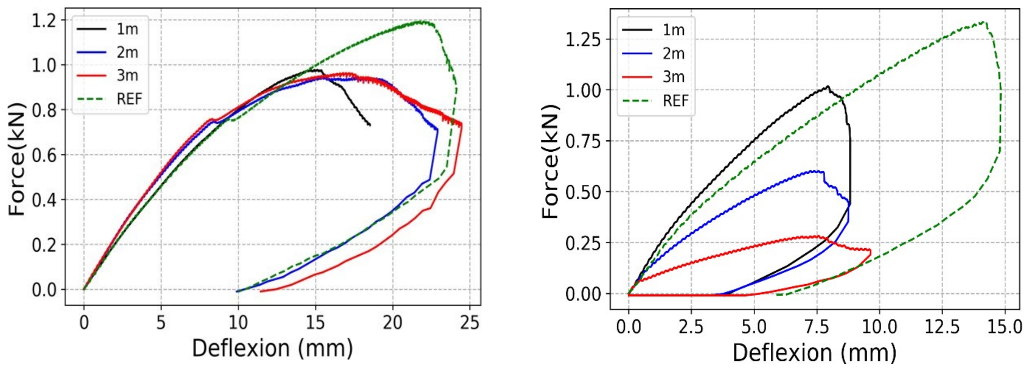


Figure 7. Load versus time during impact for around (a) 8 J, (b) 15 J, (c) 22J, (d) max force evolution versus impact energy.

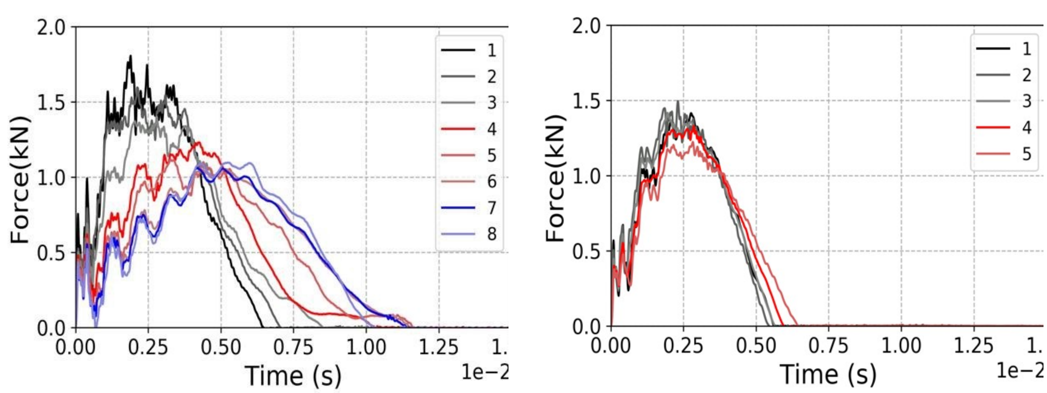


(a) $[\pm 45]_6$ (b) $[0/90]_6$

Figure 8. Residual performance after impact compared with the quasi-static test (called REF).

Finally, several cycles impact – repair have been done on the $[0/90]_6$ composite with two levels of the incoming energy (0,5 and 1 m). The main objective was to prepare samples with and without broken fibres on the back face but matrix cracks can exist.

The curves figure 9 show the evolution of the force versus time according to the number of cycle. It can be seen that in the case of the sample with broken fibres (a) the stiffness of the sample decrease with the number of cycles: the maximum force decreases and the contact duration increase. On the contrary, if the sample doesn't contain broken fibres (b) it can maintain the same stiffness even after several cycles impact-repairs (figure 9 – b). Moreover, we observed that the macro-cracks increase slightly with the number of cycles in both cases but the repair was sufficient to ensure constant mechanical properties in the case (b).



(a) 1m (b) 0.5m

Fig. 9. Force vs Time curves for the multiple impact - repair cycle on $[0/90]_6$ plate conducted at 1m (a) and 0.5m (b).

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Conclusion

This paper dealed with behaviour of flax/Elium composites LVI loading. The experiments have to main objective to determine the behaviour of plates, to identify damages and the reparability of thermoplastic bio-composite plates. Visual observations allowed to determine the damage mechanisms which was mainly microcracks and plastic deformation. Quasi-static tests have been conducted and had showed that specimens exhibit, barely the same response excepted of oscillations representing the vibratory response in case of the impacted specimens. Bending tests have been performed to evaluate the residual strength after impact in place of compression because specimens did not develop large delamination. The repair of the plates was successful for the impacted plates without broken fibres. Repetitive impact and repair cycles have shown that the force and time of impact are a function of the stiffness.

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