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Low Velocity Impact Response Of Carbon Fibre Laminates Made By Pulsed Infusion

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Abstract

Carbon fibre composites were subjected to low velocity impact tests. The scope was to investigate the response of laminates fabricated by a new vacuum assisted technology, labelled as "pulse infusion", under dynamic loads. At this aim, experimental tests up to complete penetration and at a different energy levels, were carried out. Some of the specimens were destined to CAI tests and the residual strength was evaluated. All the parameters involved in the phenomenon, like penetration energy and indentation depths, were studied to validate existing semi empirical models. By the comparison with results from literature, good agreements were found denoting the efficiency of the new fabrication method.

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Keywords: low velocity impacts; composite materials; indentation; pulsed infusion.

1. Introduction

Composites materials under dynamic loads can fail in a wide variety of modes. The integrity of the structural components can severely be reduced even if the visual damage is not evident.

The different impact damages can be collected in: a) external damages like indentation and b) internal damages (delamination), fibres cracks and matrix cracks. Moreover, the interaction between failure modes is very complex

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and important in the understanding of damage initiation and propagation [1, 2, 3]. A lot of efforts were already done [1, 2, 3, 4] at the aim to investigate about the influence of the large number of parameters involved in the dynamic phenomena on the different modes of failure and the very complex impact response of composites. A large number of experimental tests were carried out but a lot of questions remain unanswered yet. Moreover, since the influence of a variety of parameters on the complex interaction between the failure modes, the damage can be hardly predicted by analytical and numerical tools [5, 6, 7].

Another very critical aspect in this field is represented by the fabrication methods that are always too expensive or enable to obtain good quality laminates. Moreover, since the impact damage is not always a visible damage, the techniques, in particular the non destructive ones, to observe, measure and analyse the failures, are continuously under attention.

Semi empirical models could be an essential tool to reduce testing time and costs in the development phase, especially for impact tests on large structures too expensive to be carried out in the development stage.

In this work, low velocity impact tests have been carried out on composites with the aim to supply useful information to develop an impact oriented design methodology. The laminates made by carbon fibres in polymeric matrix RTM6 were manufactured by a new vacuum-assisted technology named Pulsed Infusion. Impact tests at complete penetration were carried out to record the complete load displacement curve to obtain the penetration energy. On this curve, different energy values in correspondence of load drops or changing in slope, were obtained for the indentation tests. The indentation measured by a confocal microscope and the penetration energy were used to validate existing semi empirical models for the prediction of the impact energy and the residual strength. The agreement was quite good denoting the goodness (o efficiency) of the new adopted techniques.

2. Materials and experimental set up

The laminates made by carbon fibres in polymeric matrix RTM6 have been manufactured by a new vacuum assisted technology called pulsed infusion based on the use of a proper designed pressure distributor to control the pressure of the vacuum bag on the dry fiber and induces a pulsed transverse action to promote the through the thickness resin flow.

Unidirectional layers of dry fibre were overlapped following the stacking sequence [(0)/(90)/(+45)/(-45)]s, resulting in a nominal thickness of 2.5 mm.

The experimental tests have been carried out on a Ceast Fractovis drop weight machine, allowing to vary the impact energy by changing the impactor mass and the drop height. Impact tests were, first, carried out up to the complete penetration of the coupons. The instrumented impactor was cylindrical shaped hemispherical nose, 19.8 mm in diameter. The rectangular specimens, 100x150 mm, were clamped using a clamping device suggested by the EN6038 standard. The force-time and force-displacement curves obtained by the complete penetration tests were recorded by the DAS16000 acquisition program and successively studied to evaluate the penetration energy and the variable energy values for the indentation tests. The latter allowed the study of the damage initiation and propagation. The variable energies were measured in correspondence of characteristic points of the load curves like load drops or changing in slope clearly evidencing a change in material behaviour like it is possible to find in correspondence of a damage.

The load curves recorded in all the test conditions were used to evaluate the main impact parameters involved in the phenomenon like penetration energies and maximum forces, so as the correspondent displacements. Penetration and absorbed energy, first failure and maximum force have been measured.

The indentation depth was measured by confocal microscope LEICA DCM3D. This equipment gives the possibility to extract and record the three-dimensional shape of the surface from that it is possible to extract the section in correspondence of which derive the information about the profile and the measurement of the indentation depth left by the indenter.

3. Results: indentation and penetration

In [8], plotting the indentation depth against the non dimensional energy, U/U_p, for different thicknesses and material systems, an exponential law was found to describe the master curve collecting all the experimental measurements. Plotting the same data in a log-log scale, a straight line passing through the origin allowed to obtain the constants appearing in the indentation law.

The indentation values obtained in the present research after impacting the carbon laminates with impact energies of 6, 10 and 13 J, were arranged in a log scale like what done in [8] adopting the k value found in [8] for carbon laminates, k=0,288, and plotted against the non dimensional energy. The data followed with a good approximation a straight line through the origin too (Fig. 1) that means the validity of the models and the fabrication technology.

In Fig. 1, in fact, it was done for the data generated inside the present research. A linear trend passing through the origin of the axes was observed to well approximate the trend (R^2=0.99) using the k=0.288 value valid for carbon laminates. From the slope, the γ=0.649 was measured.

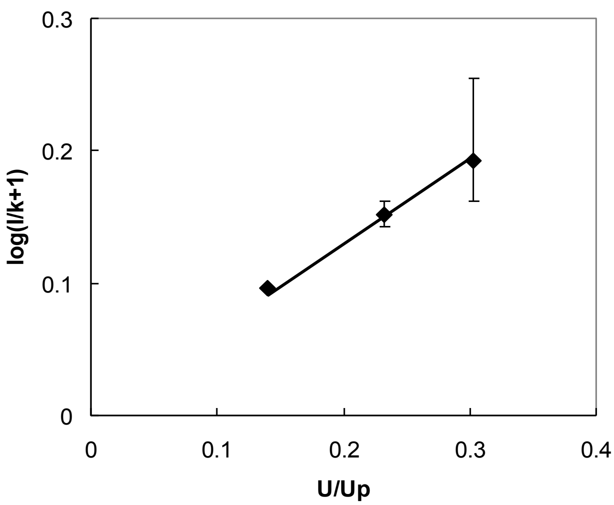

Fig. 1. Indentation law for the research of the constants k and γ.

In the figure, the single points represent the mean values of at least three tests and the vertical bars are the error bars. Even if the value γ=0.649 measured on the laminates here observed made of carbon fibre but obtained by a new infusion technology seems to be different from γ = 1.269 found for carbon and glass fibres from literature [8], comparing the experimental data with classical data from literature [8] obtained on different laminates (Fig. 2), and considering the scatter, the difference could be considered not too large.

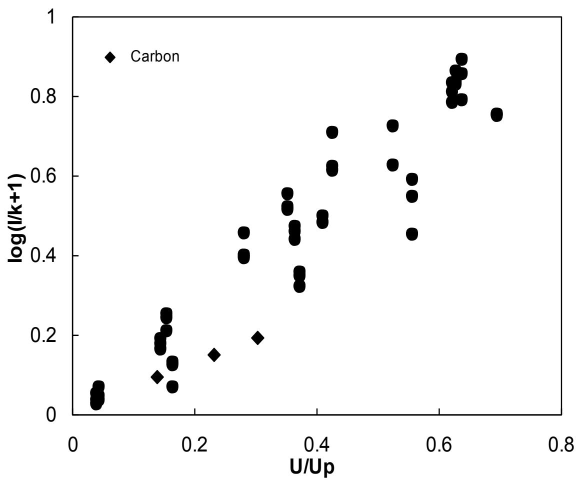

Fig. 2. Indentation law for the research of the constants k and γ: comparison with literature.

The indentation law seems to confirm the quite general applicability, being scarcely affected by the fibre type and orientations, and matrix type.

Of course, to predict the impact energy from a simple indentation measurement, also the power law previously found [8, 9] for the prediction of U_p has to be validated. Since the single thickness investigated, only one experimental point was here obtained. It was add to data from literature [8, 9] about carbon laminates different in thickness and impacted with different tup diameters, D_p, in Fig. 3: its location seems good together with the other points leading to a good thought about the validity of the model.

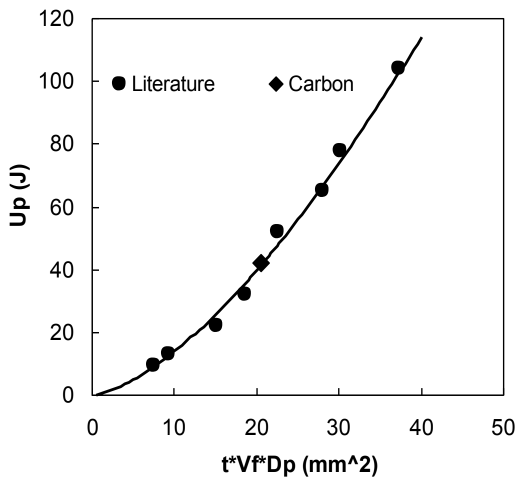

Fig. 3 – Model validation for the prediction of the penetration energy, U_p.

4. Conclusions

In this work, low velocity impact tests have been performed on composites laminates made by carbon fibres in polymeric matrix, manufactured by a new vacuum-assisted technology named Pulsed Infusion. Impact tests at complete penetration and at a different impact energies were carried out and the measured penetration energy and the indentation depths were used to validate existing semiempirical models for the prediction of the impact energy and the residual strength. The agreement was quite good denoting the efficiency of the new adopted fabrication method.

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References

[1] S. Liu, Z. Kutlu, and F. K. Chang, Matrix cracking and delamination propagation in laminated composites subjected to transversely concentrated loading. Journal of Composite Materials, 27 (5), (1993) 436-470.
[2] F.K. Chang, H.Y. Choi, and H.S. Wang, Damage of laminated composites due to low velocity impact, 31st AIAA/ASME/ASCE/AHS/ASC Structures, Struct. Dyn. and Mater. Conf., Long Beach, CA, April 2-4, 1990, pp. 930-940.
[3] M.G. Stout, D.A. Koss , C. Liu, J. Idasetima, Damage development in carbon/epoxy laminates under quasi-static and dynamic loading, Compos. Sci. and Technol., Vol. 59 (1999) 2339-2350
[4] G. Schoeppner, S. Abrate, Delamination threshold loads for low velocity impact on composite laminates, Compos. Part A, 31 (2000) 903–915.
[5] Y- Zhang, P. Zhu, X.M. Lai, 2006. Finite element analysis of low-velocity impact damage in composite laminated plates, Materials and Design, 27 (2006) 513-519.
[6] X. Zhang, Impact damage in composite aircraft structures-experimental testing and numerical simulation, Proc. of the Institute of Mechanical Engineers, 1998, pp. 245-259.
[7] G.A.O. Davies, X. Zhang, G. Zhou, S. Watson, Numerical modelling of impact damage, Composites, 25 (5) (1994) 342-350.
[8] G. Caprino, A. Langella, V. Lopresto, Indentation and penetration of carbon fibre reinforced plastic laminates, Compos. Part. B, 34 (2003) 319-25.
[9] G. Caprino and V. Lopresto, On the penetration energy of fibre-reinforced plastics under low-velocity impact conditions, *Compo.s Science and Techn.*, 61 (2001) 65-73.