HIGH VELOCITY IMPACT ON TEXTILE REINFORCED COMPOSITES

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1 Introduction

Failure behavior of fiber reinforced plastics is a complex issue. Under impact conditions, the behavior depends among other aspects, on the structure formed by the fibers, the impact velocity and the geometry considered.

A newly built gas-gun facility for high velocity impact (HSI) at the University of Twente was the opportunity to compare with existing equipment for quasi-static impact (QSI) and low velocity impact (LSI). For this purpose, three vinyl-ester glass fiber based composites with varying fiber structure (2-D and 3-D weaves, kindly supplied by 3TEX) were analyzed for their failure behavior at different velocities. In all cases the geometry and clamping conditions was not varied.

The damage development was observed in detail during the quasi-static test. Results obtained during these tests were used as a basis for comparison for the higher velocities. Analysis was made of the amount of damage of the different structure at the used velocities. Also the energy absorbed by the different specimens was considered.

2 Experimental procedures

2.1 Material

Three types of textiles were used to reinforce an elastomer modified Epoxy Vinyl Ester resin. Two 3D weaves were used in different configurations, as well as a plane weave as a reference. 70 mm x 70 mm specimens were produced with VARTM and supplied by 3TEX. Thickness varied depending on the structure between 4.7 mm and 5.7 mm.

2.2 Equipment

The tests were performed using the same clamping principle. This was made of two square plates with a circular hole of 50 mm diameter, which are clamped by means of four pneumatic cylinders.

A purpose made clamping device based on the same principle was built to fit at the end of the gas-gun.

An indenter with a spherical tup of 12.5 mm diameter was used for all tests. The indenter used for the quasi-static tests as well as the low-velocity impact was instrumented with a Kistler washer force cell. The non-instrumented indenter used for the high velocity impact test was guided in the gas gun by two plastic rings which were designed to fail in a brittle way before the impact, as illustrated in Fig. 1.

The servo-hydraulic machine used for the quasi-static tests measured force and deflection. A camera was also fitted under the plate in order to record some characteristics of the damage development. This was made possible by the translucent character of the composite used.

The Instrumented Falling Weight Impact Machine measured the force during impact. By double integration of the force-time-signal, deflection of the impacted plate and energy were evaluated.

The gas gun set-up used was fitted with two pressure transducers meant to measure the impact velocity, as well as two photoelectrical sensors to measure the indenter velocity after impact (Fig.1.)
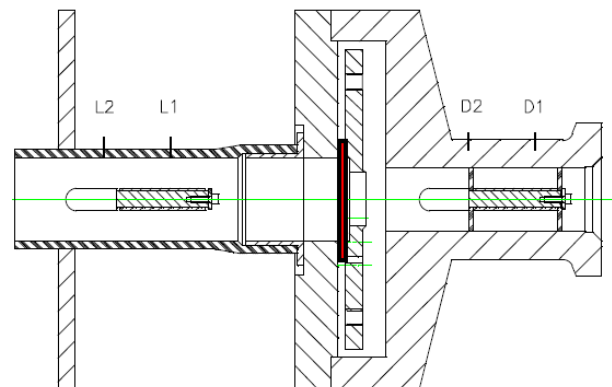

Fig. 1. Gas-gun set-up showing the indenter before impact (right) and after (left). Velocity are measured at D1 and D2, L1 and L2

2.3 Analysis

The data obtained at the different velocities and particularly the energy absorbed is analyzed using an energy subdivision approach proposed by Mines et al [1]. The energy is subdivided into three contributions, classified in order of occurrence. A delamination energy, involving the critical energy release rate under mode II of the material considered; a perforation energy, involving a critical shear energy; a friction component between the striker and specimen. The material properties necessary for evaluating these components were extracted from the quasi-static tests, as well as from Mines data for the rate dependent critical shear energy.

3. Results

3.1 Damage development

The quasi-static test providing force-deflection diagram as well as a video of the 'through-thickness' damage evolution gives a fair idea of the difference between the different structures. The onset of damage (matrix cracking followed by delamination) occurs at a later stage for the plane weave than for the 3D fabrics. However, the 3D structures manage to hold the maximum force over a wide deflection, absorbing therefore more energy.

The perforated plates show extra damage mechanisms for the 3D textiles, like bundle delamination (Fig.3), bundle pull-out and stitch fracture.
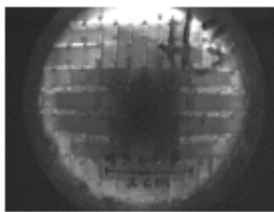
Fig. 3. Picture taken during the test of a 3D textile, showing delamination along the bundles

At low impact velocities (9m/s – 480J), the maximum force and the absorbed energy both increase compared to the quasi-static test results. Also the total damage area increases.

At high velocity (110m/s – 600J) again the total amount of damage seems to increase. The damage also goes beyond the clamping diameter, showing the limitation of the clamping technique and diameter.
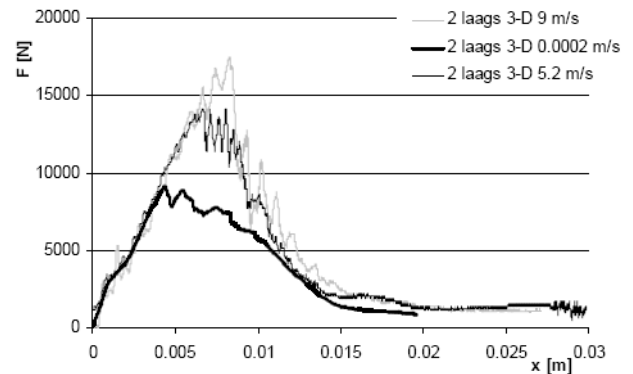
Fig. 4. Typical force – deflection diagrams at different velocities for the two layers 3D structure.

3.2 Energy analysis

The three energy terms described earlier were calculated for all experiments, and compared to the total measured absorbed impact energy. It shows here that delaminations play a minor role in energy absorption. Perforation is the most important energy consumer. The friction contribution depends on how far the indenter penetrated. After analyzing the results, one can conclude that both friction and penetration contributions increase with velocity. However, a large discrepancy exists between the sum of the three calculated components and the total absorbed energy. The missing part of the energy will contain contributions from non-described damage mechanisms like bundle pull-out, energy stored in the clamping system, etc. There is therefore room for improvement.

4. Conclusions

Three different kinds of textile reinforced plastics were tested under impact conditions at different velocities. 2D and 3D structures show distinct failure mechanisms. Onset of delamination is retarded with 2D fabrics, but the total amount of absorbed energy is higher with 3D textiles due to the presence of extra damage mechanisms. More energy is also absorbed when the velocity is increased. This is roughly confirmed by an energy contribution analysis, although this analysis requires some fine tuning to take into account the different failure mechanisms.

5. References

[1] Mines R., Roach A. and Jones N. "High velocity perforation behavior of polymer composite laminates". *Int. J. of Impact Engineering*, Vol. 22, pp 561-588, 1999.