CHARACTERISATION OF IMPACT BEHAVIOUR OF CARBON FIBRE LAMINATES

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Abstract

Impact is one of the most severe loading cases which a material may be subjected to. Specially within the automotive industry, where products must be developed to fulfil very demanding specifications concerning impact, the use of light and high performance materials such as composites is becoming more and more important.

In this communication a previously developed characterisation method is applied to a carbon epoxy unidirectional composite. This method is based on the instrumented tensile impact experimental technique and has enabled to obtain the iso-strain-rate stress-strain curves of this material.

The results show the material properties dependency on the strain rates.

1. Introduction

There are two clear trends during the development in the design of new vehicles. On one hand the reduction of emissions to the atmosphere and on the other one the vehicle safety [1].

Automobiles' weight reduction is one of the strategies to reduce CO_2 emissions. This has led to an increased use of lightweight materials (polymers and composites) in automotive components, replacing traditional materials such as metals.

In terms of vehicle safety, the trend in passive safety is the design of structures that are able to absorb as much kinetic energy as possible in the moment of impact, and do it in a controlled way. Currently, in order to dissipate the impact energy produced in a crash , mainly by mechanisms of plastic deformation, the normal trend is the use of heavy metallic structures.

However, the use of organic matrix fibre reinforced composites, placed in strategic areas, can also be very effective to design structures with large energy absorption ability [2]. Due to their fragile nature, the energy dissipation of this type of materials is produced by mechanisms of initiation and propagation of damage. This fact involves some difficulties in the design of vehicles from the point of view of: (i) choice of the type of composite used and in what amount, (ii) definition of the appropriate orientation of fibres for the composite layer and the optimal distribution of the layers and (iii) location of these materials along the vehicle to absorb as much energy as possible. Taking decisions in the design process of composite components submitted to impact loadings is virtually impossible without the use of numerical methods such as the finite element method. To resolve these issues, as well as elastic material behaviour, it is necessary to understand the mechanisms of degradation suffered by laminates and get relevant material behaviour laws that include both domains (elasticity and damage). Simulations of composite structures subjected to impact or crash thus require considering two main factors: on one hand the characterisation of the material and on the other one, the use of appropriate material models [3-5].

Due to the visco-elastic nature of the matrix, the mechanical properties of organic matrix composites reinforced with fibre depend on strain rate at which they are subjected [5]. Therefore, it is necessary to characterise the material within the range of strain rates appearing during the impacts which are simulated. In a specific standardised test drive for oriented fibre reinforced polymer materials [6] the strain rates reached are not higher than 0.1 s^{-1}. Higher strain rates, around 1 s^{-1}, may be achieved with the help of servo-hydraulic machines. However, in a low energy impact, strain rates can exceed 100 s^{-1} thus it is necessary to characterise the material in such conditions. A method for polymer characterisation has been proposed using the experimental technique of instrumented Pendulum tensile impact test. These tests result in force-time curves from which it is possible to quantify the influence of strain rate on material stress-strain curves [7]. In this paper the use of this method to characterise the composite material under tensile impact loadings is proposed to obtain the material elasticity modulus and strength as a function of the strain rate.

2. Materials

Two different materials have been tested: (i) carbon fibre reinforced epoxy composite and (ii) commercial (Curv™).

In the case of the carbon fibre reinforced epoxy composite, 4 reinforcement layers have been achieved from plates obtained by infusion, leading to a nominal thickness of 0.725 mm.

On the other hand, Curv™ is a woven polypropylene fibre embedded in a polypropylene matrix. This material manufacture involves heating the woven polypropylene fibre, so that fibres' outer surface melts generating the matrix that embeds the rest of the fibres and producing a perfect adhesion between fibre and matrix. It is a bidirectional material presented on a 0.63 mm thick coil, from where 0/90 samples have been removed.

3. Experimental tests

The tests have been fulfilled in 2 different conditions: (i) tensile tests at intermediate strain rates in a servo-hydraulic machine and (ii) instrumented Pendulum tensile impact tests under slow velocity impact conditions. Samples have been obtained in accordance with standard Test Method D 3039 for the tensile tests with intermediate strain rates. Figure 1 shows the dimensions for the samples used in instrumented Pendulum tensile impact tests.

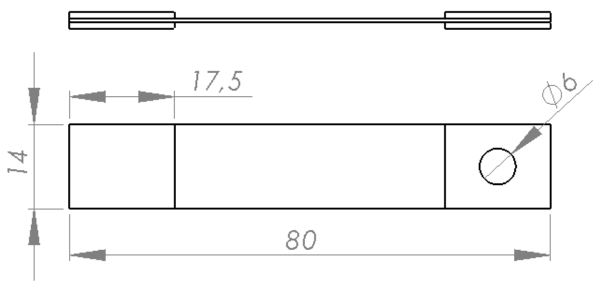


Figure 1. Geometry and dimensions for the carbon/epoxy tensile impact samples.

The tensile tests at strain rates have been fulfilled in a MTS 810 servo-hydraulic machine at 3 different velocities: 1 mm/min, 1000 mm/min and 5000 mm/min.

In instrumented Pendulum tensile impact tests, the samples have been clamped between the fixed and the mobile grips (Fig. 2). During this investigation, the mass of the pendulum has been 1.091 kg and the velocities which have been obtained have ranged from 0.35 to 1.64 m/s.

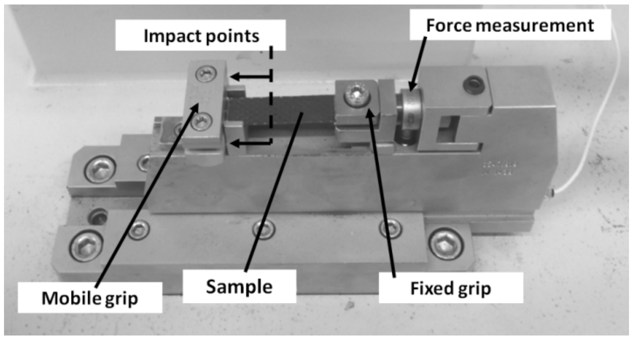


Figure 2. Test position in the tensile impact system.

The force-time signal enables to calculate the displacement-time diagrams after two successive integrations and therefore, the stress-strain diagrams can be obtained.

The method previously described considers the sample to be instantaneously accelerated by the pendulum, leading to bigger strains than the real ones [8]. In order to avoid this fact, a laser vibrometer has been used. This has enabled to measure the displacement in a more precise way.

In the case of Curv™, tests in 3 different conditions were undertaken: (i) quasi-static tensile tests using a universal testing machine, (ii) medium strain rates tensile tests using a servo-hydraulic testing machine and, finally, (iii) instrumented tensile-impact tests in low velocity impact conditions using in a pendulum impact machine (with a 1.091 kg weight pendulum). Samples were manufactured according to ISO 8256:1990 (type II) for quasi-static tests and tensile-impact tests, and according to the standard E 8M-04 for testing at medium strain rates. Figure 3 shows the samples' dimensions used in both cases.

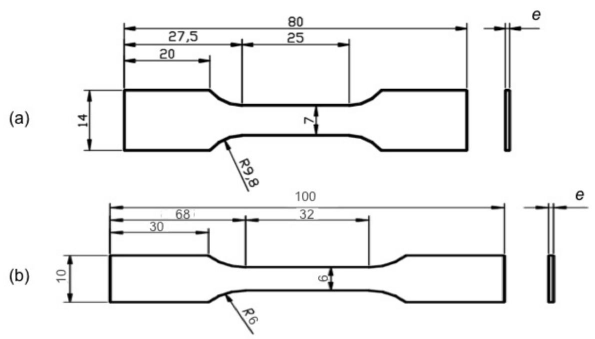


Figure 3. Samples' dimensions according to (a) ISO 8256:1990 y (b) E 8M-04.

4. Results and discussion

For carbon fibre reinforced epoxy composites, tests at intermediate velocities have been carried out with strain rates ranging from 3×10^{-4} to 1.7 s^{-1}. Figure 4 shows the results for the tests at intermediate velocities, where the increase of Young Modulus with growing strain rates is observed. The same tendency is observed for the maximum strength (Fig. 5). These values are coherent with theoretical ones obtained from micromechanical models.

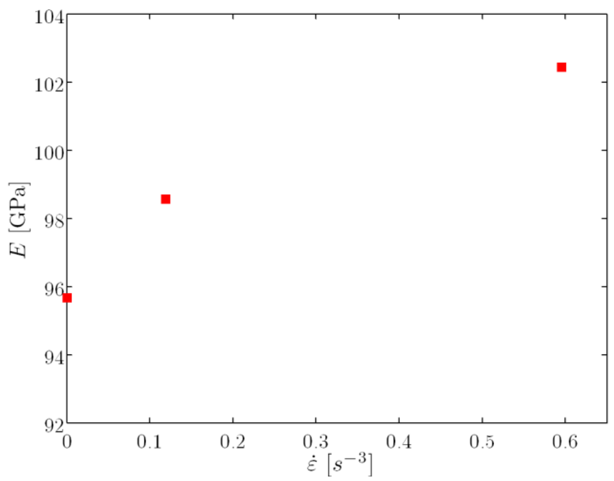


Figure 4. Strain rate effect on Young Modulus.

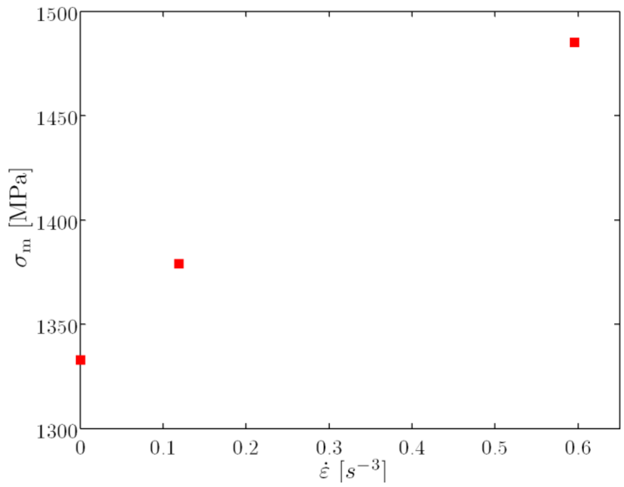


Figure 5. Strain rate effect on maximum strength.

The results for carbon fibre reinforced epoxy composites' Pendulum instrumented tensile impact tests are shown in figures 6 to 8.

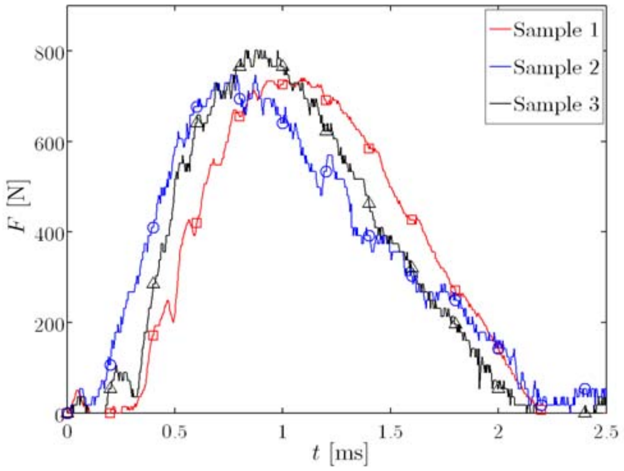


Figure 6. *F*-*t* diagrams at 0.58 m/s.

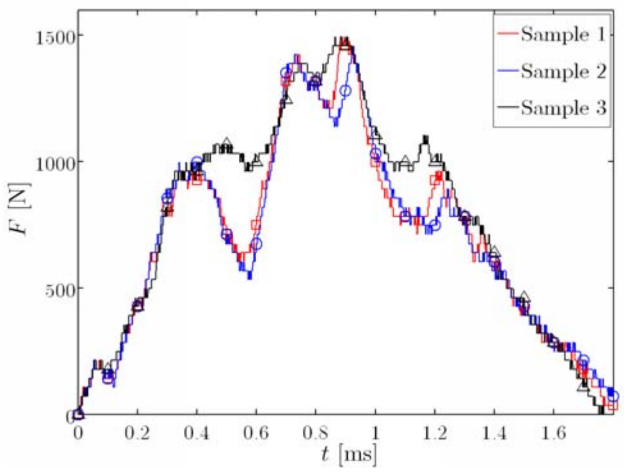


Figure 7. *F*-*t* diagrams at 1.01 m/s.

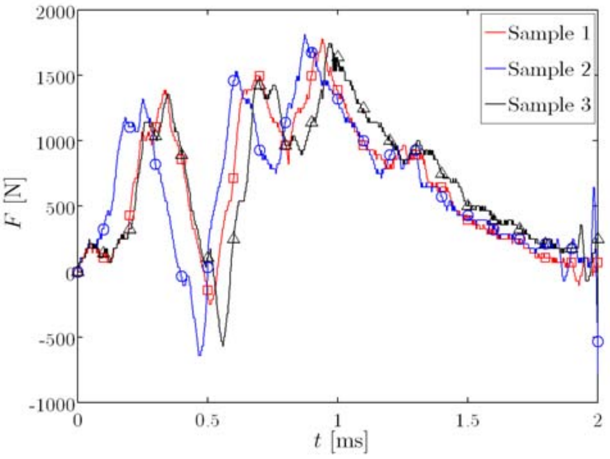


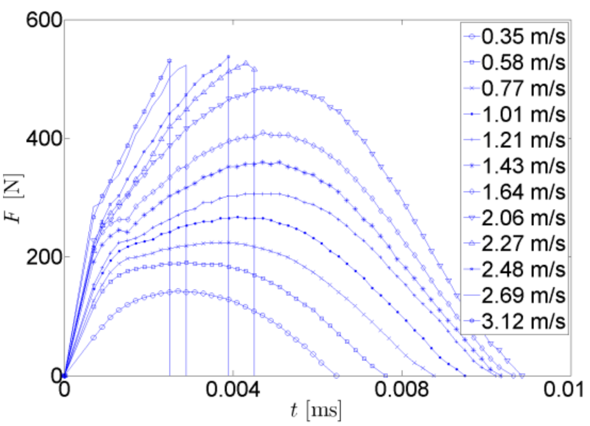
Figure 8. F-t diagrams at 1.48 m/s.

In the strain rate range considered in this investigation, relevant oscillations have been observed for the higher velocities. These may be due to the high stiffness of the samples relative to the one of the pendulum-grips system itself. Also, the values obtained for Young modulus are much lower than the ones obtained in intermediate velocity tests.

In order to test the validity of the characterisation method for composite materials, Curv™ , which is a material showing lower stiffness than the carbon fibre reinforced composite, has been used.

Figure 9 (a) shows Curv™ F-t curves obtained from the pendulum tensile impact tests at different impact velocities (from 0.35 to 3.12 m/s). The curves evolve based on the gradual increase in the impact velocity, changing the peak force F_{max} achieved, the contact time during impact t_c and the curves' shape.

a)



b)

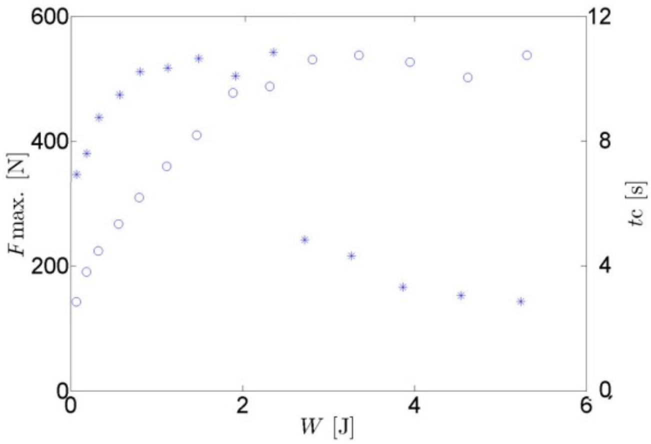


Figure 9. Tensile-impact tests results: (a) F-t curves at different impact velocities and (b) $F_{max.}$ evolution (o) and t_c (*) versus impact energy.

Peak force and contact time increase with impact velocity (Fig. 9 (b)), reaching an approximate value of 550 N at an impact velocity of 2.27 m/s, when the sample total crack takes place. For higher impact velocities, peak force remains constant while contact time decreases with impact velocity. Therefore, the tensile strength of Curv™ is 124.7 MPa and is independent of impact velocity from 2.27 m/s, when fracture takes place, to 3.12 m/s, maximum impact velocity studied.

From characterisation tests performed at quasi-static conditions and at medium strain rates (between $6.67 \cdot 10^{-4}$ s^{-1} and 0.667 s^{-1}) an average value of elastic modulus of 2.7 GPa, that is independent of strain rate in this range, was obtained. However, with the characterisation method proposed for tensile-impact tests (strain rates of about 60 s^{-1}) an increase in elastic modulus of 100% was observed (Fig. 10, values obtained by laser).

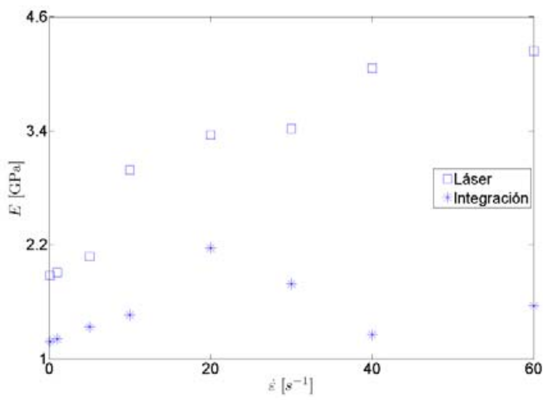


Figure 10. Elastic modulus evolution versus strain rate: measurement by laser (□) and by force integration (*).

Also, the difference of modules obtained between measuring the velocity with the laser and the integration of sensor force exceeds 200% in some cases. Furthermore, in the integration case, there is an incoherent module evolution with the strain rate as it decreases at higher strain rates. The reason is that the modulus values obtained at low strain rates by the iso-strain method [7] correspond to values obtained when peak force is reached and therefore, depending on the curve, plastic deformation might have already taken place in the material.

5. Conclusions

Experimental results for the carbon fibre reinforced composite at intermediate velocities have shown a stiffness values dependence on strain rate. The values obtained are in good correspondence with the theoretical ones. For higher velocities, such as the ones resulting from instrumented pendulum tensile impact tests, the stiffness values found are incoherent as they are much lower than the ones expected. During these tests, relevant oscillations have appeared in *F-t* diagrams, which may have arisen from the high stiffness modulus of the sample relative to the test-system.

The results for Curv™ have shown values of elastic modulus that are independent of strain rate for low velocities. For higher velocities, a strain rate dependence has been observed.

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