Study of transient wave propagation in plates using double pulse TV holography

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Summary

This work presents a numerical and experimental study of the transient response of an isotropic plate. A low mass impact is used to generate the bending wave propagation. Displacements due to the bending wave propagation were assessed using an out-of-plane double pulse TV holography set-up. A PZT transducer is used to record the impact force and its temporal evolution. A novel experimental technique is presented for determination of the stress field in the plate using the out-of-plane displacement field and image-processing techniques. A numerically simulation of the transient response on the plate was carried out with an explicit ABAQUS® module. Finally, the comparisons between numerical and experimental results are presented.

Introduction

Nowadays, the composite materials have a wide use in structural applications. The high stiffness/weight ratio makes them well adapted for industrial applications, especially for the aerospace, aeronautical, automotive, sport and biomedical. Despite their higher mechanical properties, when compared with metallic materials, they are highly dependable on structural integrity. In the last years, several Non-Destructive-Inspection (NDI) techniques were developed for defect detection in composite structures. Some of these defects are already present, caused by the manufacturing process the others are due to in service loads. In this case, the high strength components are submitted to transient loads, together with is vulnerability to damages justifies a strong need for the dynamic characterization these materials under impulsive loads. Therefore, a quick and reliable monitoring technique must be developed to test these structures under impact loads. The Data obtained from these tests may be used to optimize the numerical algorithms used to simulate the dynamic response and also in the defects detection presents in these structures. The impact response in plates is determined by the mass ratio between the impactor and the plate. Small mass ratio creates very short time impact, for the order of wave propagation time through thickness, resulting in dilatation waves in the plate mass. Longer time impact, higher mass ratio, will create a transient response with flexure wave's propagation. For high mass ratio, longer time impact, enough for the wave to reach the boundary, bending and shear waves are generated and the response will be identical to a "quasi-static" loading case [1], [2]. The main objective of this work is the development of a numerical-experimental methodology that can be used to dynamically characterize polymeric matrix composite materials. A first approach to this goal is presented in this work using an isotropic and homogeneous plate.

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This work presents a numerical and experimental study of bending wave propagation in an aluminium plate, submitted to a small mass impact, being the analysis performed until the bending waves reach the boundaries. A description of the TV holography set-up used on the experimental measurement is presented, as well as the way to record the time evolution of the impact force, the trigger system and temporal evolution of all signals. Information that's required for the numerical simulation of response of the plate with ABAQUS® Finite Elements Method (FEM) code. Also, a robust methodology for the calculation of the stress field based on Kirchhoff theory for plates is presented. This methodology involves the filtering and the differentiation of the experimental data. As a final point, a comparison between the experimental and numerical simulation results and the discussion is presented.

TV holographic interferometry

The TV holography is a non-contact field technique that can be used to assess, with very high resolution, the displacement/amplitude of an object surface. This technique is based on the interference between light wave fronts and can be applied over diffuse and complex geometry surfaces with a resolution of the order of a few tenths of a micrometer. Using continuous emission or pulsed lasers they can be applied in the study of quasi-static, periodic or transient phenomena [3] [4]. A CCD camera is used to record each hologram that results from the correlation between two or more wave fronts. In the interferogram, resulting from the correlation between holograms, a set of fringes indicate points undergoing equal displacement/amplitude. The correlation between holograms can be carried out in three different ways: real time, time-average and double exposure. The double exposure correlation is more committed to study transient dynamic phenomena and was used in this work. Double exposure correlation can be performed at any time after the recording of two or more holograms. However, the time between recordings should be carefully selected to capture the phenomena in the measurement range. From the wave fronts correlation a fringe pattern is obtained. These fringes represent points of equal displacement in the direction of the sensitivity vector [5]. These measurements generate an enormous quantity of Data that can be processed with image-processing techniques [6].

Experimental set-up

The experimental tests were performed using the double pulsed TV holography setup presented in figure 1. A LUMONICS Ruby laser generates pairs of pulses with a time separation ranging form 1μs to 800μs. The double pulse holograms are recorded by a CCD camera. The interferograms, obtained by double exposure correlation, were post-processed using image processing techniques. To obtain the hologram phase distribution a special algorithm, based on the demodulation of a spatial carrier introduced in the primary fringes, is used. The out-of-plane displacement field results from the unwrapping the phase difference spatial distributions calculated from the pair of recorded holograms.

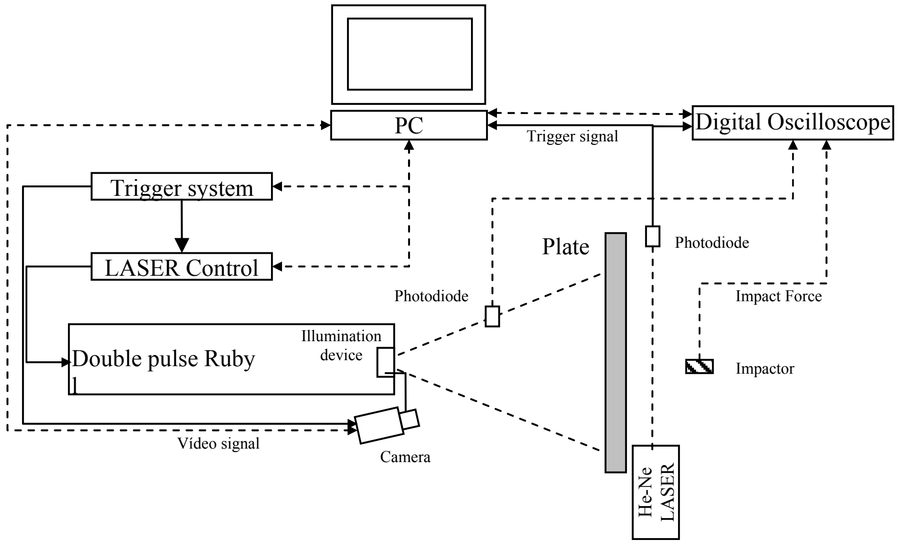

Figure 1: Double pulse TV-holography set-up;

A gravity pendulum hits the plate back side to generate the bending waves. The impact force evolution was measured with a force transducer and recorded in a digital oscilloscope to be inputted in the numerical simulation. A low-pass filter avoids the non-linearity response of the transducer force signal. The experimental set-up was triggered with a signal resulting from the interruption of a laser beam just before the impact. Varying the time between pulses and the laser fire time delay different instants of the wave propagation were recorded. The Figure 2 presents a general view of the set-up showing the aluminium plate and the LUMONICS Ruby laser used in this work.

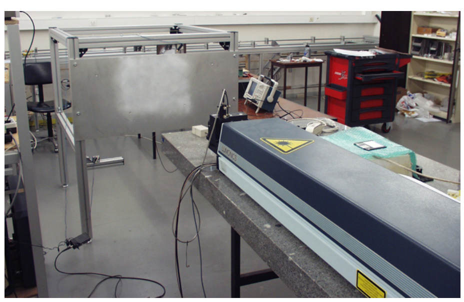

Figure 2: General view of the experimental set-up;

Experimental tests

The generation of bending waves is conditioned by high mass ratio impactor/plate [1], [2]. For this reason, an 8 mm thickness aluminium plate was selected for this experiment. The impact was made into the centre of plate back side the with 40g mass impactor. Several measurements were made with different time delays. In Figure 3, several phase maps recorded for different time delays are shown.

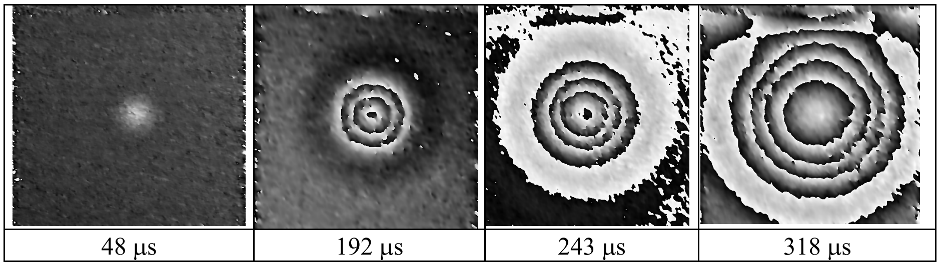

Figure 3: Different instants after impact of the bending wave propagation [7];

As expected, the bending waves are circular and concentric due to the isotropic properties of the aluminium. In the last image (318µs after impact), reflections from the top plate edge of the plate have already started. From the last figures, the displacement field can be obtaining by removing the discontinuities present in the phase maps as can be seen in Figure 4.

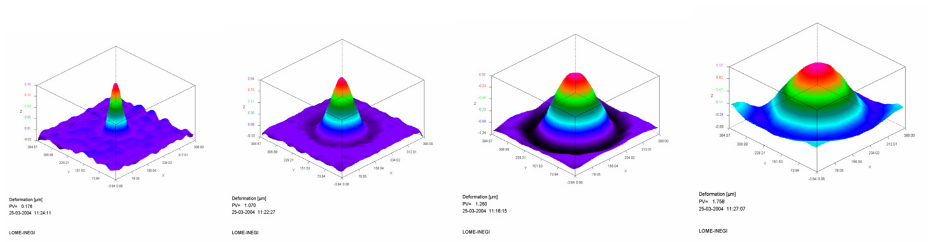

Figure 4: Displacement fields for different instants of the wave propagation.

Numerical simulation

The numerical simulation was performed with the explicit module of the ABAQUS® code. The plate was simulated with a 2800 (S4R) shell elements mesh. No damping was considered and the applied load results from the signal recorded experimentally. The displacement field for the time step 243µs is represented in Figure 6 a). The comparison between displacement fields obtained by the numerical simulation and the experimental measurements showed that amplitude calculated in impact point is smaller than the measured one, as can be seen Figure 6 b). The differences of amplitude can be explained by an incorrect adjustment of the numerical model due to imprecision the impact force introduced, as result of the filtering process on the measurements.

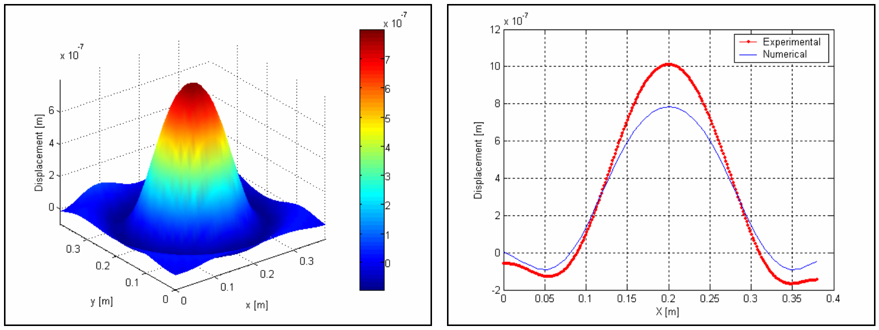

Figure 5: a) The displacement field in the time step 243μs b) The displacement profiles obtained in the same position by ABAQUS® and experimentally.

Stresses calculation

The stresses in the plate were calculated from the displacement field using a method based on the Kirchhoff plate theory. An algorithm was developed to obtain the spatial derivatives of the experimental displacements. Good results were achieved with the noisy data using a technique for simultaneous differentiation and filtering. After the adjustment of the displacement amplitude between the FEM calculation and the experimental data, the calculus of the stresses was carry out. The Figure 6 presents a comparison between the stress profiles obtained from experimental displacements and numerical simulation, 243 μs after impact.

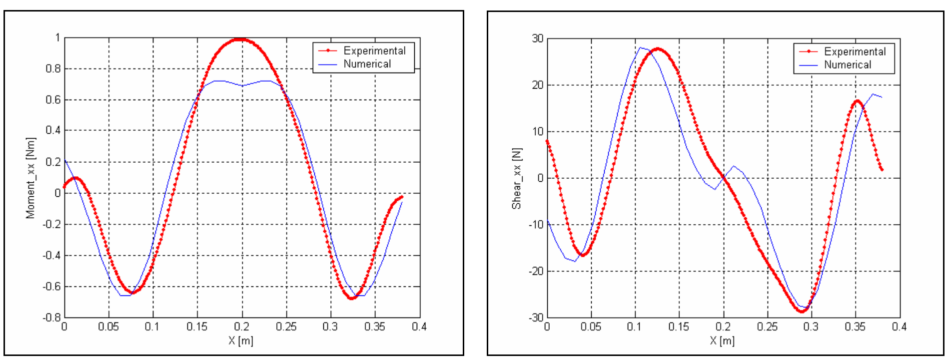

Figure 6: The stress profiles resulting from calculus and obtained from numerical differentiation of the experimental data.

As can be seen in the previous figures there is a good agreement between the results obtained from the calculation using FEM and experimental data. This proves that the methodology used for analysis of transient stresses in plates is appropriated for the proposed study.

Conclusions and discussion

From the results obtained in this work with an isotropic plate the selected methodology proved to be well adapted to the objectives of the research program.

The calculations already completed with ABAQUS® code can be considered a quite good approximation to the wave propagation.

The methodology presented for stress calculation from the experimental data proved to be robust and immune to the noise. Future developments will be implemented to extend the application of this methodology to anisotropic materials. Experimental techniques are used to access the displacement field, being the stress calculation based on that information. If the material properties are known, this last step can be achieved by two different ways, either using an hybrid experimental-numerical technique or by direct differentiation of the measured displacements field. A major challenge will be to solve the problem inversely by using the experimental data to extract the material properties.

Acknowledgments

This work was partially funded by Fundação para a Ciência e Tecnologia – FCT under the project POCTI/EME/40048/2001. Jaime Monteiro, Fernando Ferreira and Jorge Reis are acknowledged by their collaboration in the experimental set-up implementation.

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