Impact propagation study on composite plates

Estudo de propagação de impacto em placas compostas

Estudio de la propagación de impactos en placas de material compuesto

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Chaoufi Ali
Doctor in Mechanical Engineering
Institution: University Tahri Mohamed of Bechar
Address: Bechar, Algeria
E-mail: chaoufi.ali@univ-bechar.dz

Yamina Benkrima
Doctor in Physics
Institution: Ecole Normale Superieure de Ouargla
Address: Ouargla, Algeria
E-mail: b-amina1@hotmail.fr

ABSTRACT
Much research has already been done in the field of rapid dynamics, particularly with regard to impact stress, which remains of great importance. However, these challenges are compounded when it comes to studying composite materials, particularly with regard to their homogenization and characterization. With this in mind, our current study focuses on the analysis of the impact and propagation of the shock wave through plates made of composite materials, whether they are sandwich structures or laminated plates. We used a 16 mm diameter impactor with falling weight in our experiments. We also conducted vibration characterization tests, which allowed us to collect additional data essential for our different applications. The results obtained have been processed in such a way as to make them easily accessible and exploitable.

Keywords: Shock, Laminate Plate, Sandwich Plate, Strain, Drop Weight Impactor.

RESUMO
Muitas pesquisas já foram realizadas no campo da dinâmica rápida, principalmente no que diz respeito à tensão de impacto, que continua sendo de grande importância. No entanto, esses desafios são agravados quando se trata de estudar materiais compostos, especialmente com relação à sua homogeneização e caracterização. Com isso em mente, nosso estudo atual se concentra na análise do impacto e da propagação da onda de choque através de placas feitas de materiais compostos, sejam elas estruturas sanduíche ou placas...
laminadas. Usamos um impactador de 16 mm de diâmetro com peso em queda em nossos experimentos. Também realizamos testes de caracterização de vibração, o que nos permitiu coletar dados adicionais essenciais para nossas diferentes aplicações. Os resultados obtidos foram processados de forma a torná-los facilmente acessíveis e exploráveis.

Palavras-chave: Choque, Placa laminada, Placa sanduíche, deformação, impactador de queda de peso.

RESUMEN
Ya se ha investigado mucho en el campo de la dinámica rápida, sobre todo en lo que se refiere a la tensión de impacto, que sigue siendo de gran importancia. Sin embargo, estos retos se agravan cuando se trata de estudiar materiales compuestos, especialmente en lo que respecta a su homogeneización y caracterización. Teniendo esto en cuenta, nuestro estudio actual se centra en el análisis del impacto y la propagación de la onda de choque a través de placas fabricadas con materiales compuestos, ya sean estructuras sándwich o placas laminadas. En nuestros experimentos utilizamos un impactador de 16 mm de diámetro con peso descendente. También realizamos ensayos de caracterización de vibraciones, que nos permitieron recopilar datos adicionales esenciales para nuestras diferentes aplicaciones. Los resultados obtenidos se han procesado de forma que sean fácilmente accesibles y explotables.

Palabras clave: Choque, Placa Laminada, Placa Sándwich, Deformación, Impactador Drop Weight.

1 INTRODUCTION

Shock is a stress which may take different forms and may or may not have a known intensity. The effect of the shock can range from simple wave propagation to total structural collapse. For their part, composite materials have a very important economic advantage, especially in the fields of civil and mechanical engineering, which are used as reinforcing materials. They contribute to improved safety through better resistance to shocks and fire [1, 2, 3, 4].

In mechanics, shock is the application of a large force over a short period of time, usually accompanied by a sudden change in gear.

High-energy impacts often result in perforation and thus appear to cause severe damage. However, low energy impacts should not be neglected as they cause delamination (detachment) within composites that can propagate under cyclic stress [5, 8, 12]. This is insidious because there are no external signs that the composite structure will be damaged. In the case of an impact leading to the
perforation of a composite plate, the effect can be likened to that of a notch, i.e. a reduction in mechanical strength of approximately 50 %. [6, 7, 11, 14]

The dynamic behavior of the laminates in their transverse direction is studied on a traction machine. The deformation rate has only a limited influence on the elastic properties of the carbon/epoxy ply up to 103 s⁻¹ [15, 16, 17]. At a higher stress rate, the Hopkinson bar impact is also studied for carbon/epoxy composites [18]. More generally, the study of the effects of an impact (plate impact, explosive...) on this type of material begins in the 1990s until today [19, 20, 21, 22, 23]. These studies show that the transverse dynamic behavior of a unidirectional composite is comparable to that of its matrix. The response of the epoxy resin under impact is also studied and its dynamic properties are quantified [24, 25].

The work of V. Gupta and his team describes the potential of laser shock to control the adhesion of fold/inter fold interfaces [26, 27] and then fiber/matrix interphases [28]. The impact strength of Hercules AS4 carbon fiber 3502 / epoxy composites was evaluated at 214 MPa. I. Gilath’s team is interested in laser shock behavior of carbon/carbon [29] and then unidirectional carbon/epoxy [30] composites. It shows the linearity of the relationship between the composite thickness and the incident delamination threshold in a one-dimensional configuration [29, 31]. Z. Li [32] also studies the behavior of carbon/epoxy laminates under laser shock with a duration of the order of 30 ns, confined by a PMMA window. The relationship between light energy and incident pressure is given by pressure measurement with polyvinylidene fluoride strain gages. More recently, the J.-P. Monchalin team is investigating the behavior of short shock composites in the SATAC project. The laser impact configuration is 10 ns in a confined regime, the target is protected by black adhesive tape. Post-shock diagnosis of delamination is ensured by the ultrasound technique generated and detected by laser developed at IMI [33]. Using numerical simulation, the limit at which the interface breaks is quantified at 340 MPa [34].

The adhesion test of composite assemblies by impact lasting a few hundred ns is studied by R. H. Bossi [35], without however quantifying their dynamic behavior. His work highlights the advantages of laser shock technology for adhesion control [36, 37]. This study is concluded by a patent [37] and by the commercialization of the device in 2011 by LSP technologies Inc. The test
proposed by Bossi consists in emitting three laser-induced pulses at the surface of the target to be tested. A first ultrasonic wave characterizes the morphology of the assembly, the second imposes a calibrated mechanical loading, and the third diagnoses the possible decoupling following the mechanical effects of the shock. The tool is portable and equipped with a vacuum device, the processing of acquisitions is automated. Mr. Perton also worked on the application of ns laser shock to test the adhesion of composite assemblies bonded with Hysol® EA 9394 [38]. The samples are equipped with a protective black ribbon and the plasma is confined by water. Possible damage due to the effects of the shock is detected by the laser-induced ultrasound scanning technique (B-scan and C-scan). Weak joints are detected under ns conditions, their breaking limit is determined by simulation at approximately 150 MPa. Strong assemblies have the same adhesion as the interply, i.e. 340 MPa.

Our study focuses on the analysis of impact and shock wave propagation through composite plates. We are particularly interested in sandwich structures and laminated plates.

2 MATERIALS AND METHOD

2.1 MATERIALS

Composite materials which are the subject of our study are a material which has a wide use. They also enrich the possibilities of design by making it possible to lighten structures and to produce complex shapes capable of fulfilling several functions. In each of the application markets (automobile, building, electricity, industrial equipment, etc.), these remarkable performances are at the origin of innovative technological solutions. Numerous studies carried out in the literature relate to these fields and explain these uses [9].

In our case, we use two types of composite sandwich and laminate materials for our study.
2.2 USED MATERIAL LAYOUT

The composite sandwich material (Figure 1a) used and called composite aluminum panel, the skins are aluminum 0.5mm thick and the core is fluorine carbon 3mm thick which forms the sandwich panel 4mm thick.

The plates shown in FIG. 1 b are made of laminated composite materials. Of number three plies (03) oriented at an angle of (-45°, 0°, 45°). Consisting of wood fibers assembled by polyester resin.

The following two tables illustrate the different mechanical characteristics of the two laminate plates and sandwiches:

<table>
<thead>
<tr>
<th>Laminated composite material</th>
<th>Valeurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>YOUNG's modulus (GPa)</td>
<td>9.44</td>
</tr>
<tr>
<td>Shear modulus (GPa)</td>
<td>6.58</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>-0.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sandwich composite material</th>
<th>Valeurs dans les trois directions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>YOUNG's modulus (GPa)</td>
<td>8.085</td>
</tr>
<tr>
<td>Shear modulus (GPa)</td>
<td>3.48</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.16</td>
</tr>
</tbody>
</table>

2.3 METHOD

To do the impact tests, you have to use a shock test bench, the bench used is manufactured at our university.
First, the test bench was designed in Figure 2, and then the test bench was started in Figure 3.

![Figure 2. Design of the impact test bench.](image)

After completion, assembly and installation of the test bench in Figure 3, for data acquisition the Pulse system was installed with these accessories listed in the following table.

![Figure 3. Synoptic of the impact test bench with the acquisition chain.](image)
Table 2. Benchmark Nomenclatures

<table>
<thead>
<tr>
<th>Number</th>
<th>Designations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Impactor</td>
</tr>
<tr>
<td>2</td>
<td>Cells for a time clock</td>
</tr>
<tr>
<td>3</td>
<td>Counter</td>
</tr>
<tr>
<td>4</td>
<td>Electric motor</td>
</tr>
<tr>
<td>5</td>
<td>Acquisition Achene</td>
</tr>
<tr>
<td>6</td>
<td>Specimen</td>
</tr>
<tr>
<td>7</td>
<td>Test specimen holder</td>
</tr>
<tr>
<td>8</td>
<td>Laser vibrometer</td>
</tr>
<tr>
<td>9</td>
<td>Different plates for tests</td>
</tr>
</tbody>
</table>

Source: Authors.

2.4 GEOMETRIC AND BOUNDARY CONDITIONS

Figure 4, the data used in this example are presented, and can be seen in Figure 5, namely the geometrical characteristics of the material and support condition, the impact force applied in Table 3.

Figure 4. Geometric feature and bearing condition

The plate is recessed as shown in this photo:

Figure 5. The boundary conditions of the plate.
3 CONDUCT OF THE IMPACT TEST

Firstly, the installation of our sandwich or laminate plate; is held on the support table by a bi-recessed attachment using adjustable bites. The centering of the plate makes it possible to ensure the centering of the impact force. Using the reduction motor (winch), the impactor carriage of constant mass is lifted for all tests at a variable height H.

Since the acquisition of the data is ensured digitally by a pulse and a sensor placed above and in the middle of the plate, we present in what follows the tests with the results presented respectively the evolution of the displacement of the center of the plate as a function of time.

The mass of the impactor carriage is M=29 kg, varying the height of the carriage as indicated in Table 3.

4 RESULTS AND DISCUSSIONS

4.1 HEIGHT H = 1.70M

Figure 6. Displacement/time curve height 1.70m

Post-impact deformed sandwich plate with associated curve.
Source: Authors.
4.2 HEIGHT H = 2M

A strain just at the moment of the end of the impact, which is evaluated at 21 mm, after a period stabilizes at the value 25.1 mm. The impact energy is estimated at 568.98 J. We notice that the energy is higher, we notice a lower deformation.

4.3 HEIGHT H = 3M

A strain just at the moment of the end of the impact which is evaluated at 22 mm and after a period stabilizes at the value 27.1 mm The impact energy is evaluated at 853.47 J. We find that the deformation increases with the increase in energy.
4.4 HEIGHT H = 4M

We note a deformation just at the moment of the end of the impact which is evaluated at 21 mm and after a period stabilizes at the value 28.5 mm. The impact energy is evaluated at 1137.96 J. We find that the deformation increases with the increase in energy.

4.5 HEIGHT H = 1.5M

In this case we took the point of impact at the center of the free side of the test plate.

We note a deformation just at the moment of the end of the impact which is evaluated at 21 mm and after a period stabilizes at the value 29.5 mm. The impact
energy is evaluated at 426.73 J. We find that the deformation increases even with decreasing energy at the edge of the plate.

5 DEFORMATION OF THE PLATE AFTER IMPACT

The deformations of the sandwich plate with respect to some height which gives us different deformations.

5.1 DROP HEIGHT 1.70M

Figure 11. Plate deformation at h=1.7m

1) Upper face 2) Bottom face 3) Front

Source: Authors.

The first test shows that after impact of the sandwich plate there has been a deformation, the impactor strikes the plate and continues to push the plate downwards then there has been a deformation within the limit of displacement of the plate downwards.

Figure 11 of the front face shows the value of the displacement of the plate in comparison with the size of the pen with a Bic.
5.2 DROP HEIGHT 4.00M

Figure 12. Plate deformation at h=4 m

1) Face supérieure
2) Face inférieure
3) Face frontale

Source: Authors.

The fifth test shows that after impact of the sandwich plate it had a deformation at the lower face, because the impactor to strike the plate and finish pushed the plate downwards then there was a deformation within the limit of displacement of the plate downwards leaving a print on the upper face of the plate.

Figure 12 of the front side shows the value of the displacement of the plate by comparing it with the thickness of the angle.

5.3 HEIGHT H = 0.30M

Figure 13. Displacement/time curve

Strained laminated post-impact plate with associated curve.

In this case, we've taken a very small height. Despite this, we notice a case of rupture. We find that deformation increases with perforation even with decreasing energy.
5.4 HEIGHT H = 1.00M

The section of the plate was doubled with a bonding system.

Figure 14. Displacement/time curve height 1m

Preparation and gluing of two laminate Plates with displacement sensor position
Source: Authors.

In this case we took a height of 1m. We notice in this case that there is cracking and separation of the plates. Here again we have a case of rupture appearing on both plates.

6 DEFORMATION AND SHOCK PROPAGATION AFTER IMPACT : (FOR DIFFERENT IMPACT ENERGIES)

6.1 PRELIMINARY TESTING:

Figure 15. Drop height 2,00 m.

(a) Upper face         (b) Underside         (c) Front
Source: Authors.

Initial tests show that after the impact of the laminated plate there was a perforation, as the impactor struck the plate and pushed the plate downward which
gives us a perforation and a propagation of rupture within the limit of displacement of the plate downward Figure 13b and c.

6.2 ENERGY EQUAL TO 85,347 DAYS

Figure 16. Drop height 0,30 m

Figure 16 (c) of the front face shows the value of the rupture of the plate by comparing it with the thickness of the angle iron and Figure 16b shows a propagation of rupture on the plate.

6.3 ENERGY EQUAL TO 284.49

A perforation at the moment at the end of the impact of the upper plate, and a rupture with propagation of rupture up to the edge of the second plate.
7 IMPACT TEST RESULTS

Table 3. Energy applied for impact on both plates

<table>
<thead>
<tr>
<th>Sandwich plates</th>
<th>Theoretical energy (j)</th>
<th>Theoretical speed (ms⁻¹)</th>
<th>Height (m)</th>
<th>Time travelled (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate1</td>
<td>426.73</td>
<td>5.42</td>
<td>1.50</td>
<td>1.93</td>
</tr>
<tr>
<td>Plate2</td>
<td>483.63</td>
<td>5.77</td>
<td>1.70</td>
<td>2.11</td>
</tr>
<tr>
<td>Plate3</td>
<td>568.98</td>
<td>6.26</td>
<td>2</td>
<td>2.52</td>
</tr>
<tr>
<td>Plate4</td>
<td>853.47</td>
<td>7.67</td>
<td>3</td>
<td>2.92</td>
</tr>
<tr>
<td>Plate5</td>
<td>1137.96</td>
<td>8.85</td>
<td>4</td>
<td>3.33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Laminated plates</th>
<th>Theoretical energy (j)</th>
<th>Theoretical speed (ms⁻¹)</th>
<th>Height (m)</th>
<th>Time travelled (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate1</td>
<td>85.347</td>
<td>2.42</td>
<td>0.3</td>
<td>0.72</td>
</tr>
<tr>
<td>Plate2</td>
<td>284.49</td>
<td>4.42</td>
<td>1</td>
<td>1.48</td>
</tr>
</tbody>
</table>

Source: Authors.

8 CONCLUSION

Sandwich-type composite material plates have a high impact strength, making them suitable for demanding civil and mechanical engineering applications. On the other hand, laminated plates, despite their ability to withstand low impact energies, are better suited to less restrictive uses such as interior partitions or carpentry.

Our study provides crucial information on the rapid dynamics of composite materials, which could potentially lead to significant improvements in their use and application in various industrial fields.
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