# METHODS FOR INVESTIGATING POST-IMPACT DAMAGE TO COMPOSITES

Prof. Maryna Shevtsova (maryna.shevtsova@epfl.ch)

**Introduction**

The properties of composite materials depend on the nature of the matrix, the reinforcements, their interface as well as any defects. Indeed, the mechanism of reinforcement of a matrix by inclusions in general and fibers, in particular, is the transfer of the stresses of the matrix (which generally has a fairly low stiffness in the case of polymers) to the reinforcement part (very high stiffness) through the interface surface. This difference in stiffness implies very high shear stresses (strain) at the interface. It is therefore good cohesion properties of two composite elements and adhesion between them will be essential that the composite is tough.

Another type of interface is present in the case of laminated composites. When using such materials, it often happens that the region between two laminates is less rich in fibers, and has lower mechanical properties, which are defined by less resin (matrix) strength.

There are four main damage mechanisms for composites:

- Matrix cracking
- Interplies delamination.
- Fiber breakage and pull-out

During an impact on a composite material, the interfaces are often the first to suffer damage, whether it is a decohesion between the fibers and the matrix or delamination. In both cases, this damage may not be visible on the composite surface in difference from the metal article, when this damage will be shown on the outside as a dent or crack. It is, therefore, possible that a composite part visually appears to be in perfect condition, while it has significant internal damage, implying decreased strength. It is therefore an important question of testing the material in order to be able to estimate the extent of the damage and measure whether the part is still able to perform its function. These tests can be performed in two different ways non-destructive testing (NDT) or destructive testing.

An example of this type of problem is the fall of a tool on a composite part of an aircraft during its maintenance, a collision with a bird in the flying, or impacts of the stones during of the plane take off. How can the part quality can be guaranteed after an incident of this type?

**The purpose of this practical course** is to become familiar with the impact influence on the different kinds of composite materials and the estimation of the residual stresses of composite plates after impact by help destructive compression technique.

Several influences will be studied:

- Reinforcement: glass fibers or flax fibers, carbon fibers
- Fiber architecture : matte, unidirectional, fabric
- Manufacturing technique: contact molding or pre-impregnated
- Specific technology: Self-healing (Comppair) (will see self-healing repair after impact of the sample).

Their residual strength will be measured in compression.

**Theoretical bases**

An impact device (drop tower) will be used during this exercise followed by post-impact compression (CAI). The non-destructive technique will also be discussed to assess residual damage following impact testing.

**The drop tower:** A mass of defined geometry, held between two vertical rails, is dropped on a composite laminate and hits it at an energy defined by its initial height. The impact head is generally instrumented so that it can follow the force/displacement characteristics as a function of time. The impact device is shown schematically in Figure 1. This test method defines the damage resistance of multidirectional polymer matrix composite laminated plates subjected to a drop-weight impact event and makes in according with ASTM D7136/D 7136M.

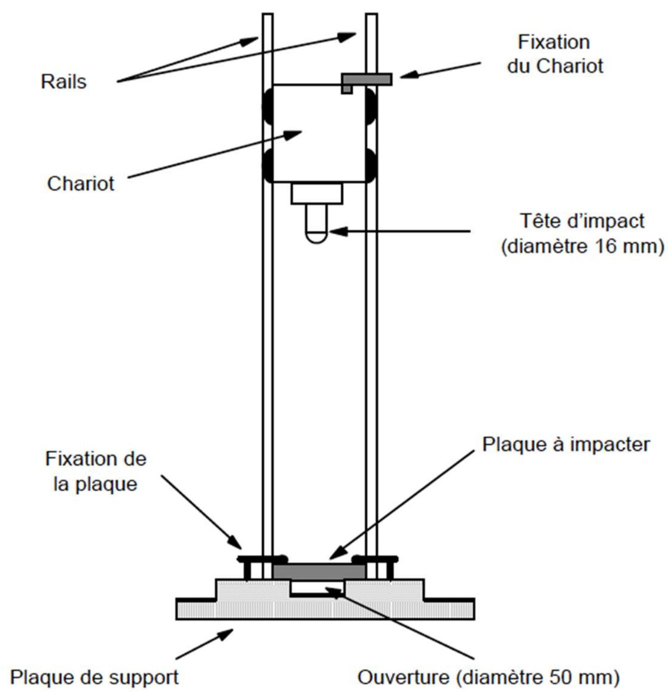


*Figure 1: Impact system.*

Impact tests can be grouped into two categories: low-velocity impacts (e.g. tool drops that damage the material) and high-velocity impacts (e.g., projectiles that destroy the sample). The first case is generally simulated by devices based on the fall of a weight or the swing of a pendulum (Charpy's pendulum, Izod test), the second using projectile launching systems (impact gun, Hopkinson technique).

The modes of rupture that may appear are multiple. They are briefly described below.

- Dent/depression
- Splits/cracks
- Combined splits and delamination
- Combined large cracks, fiber breakage and puncture

Figure 2 shows the influence of impact energy on defects created in a composite material.

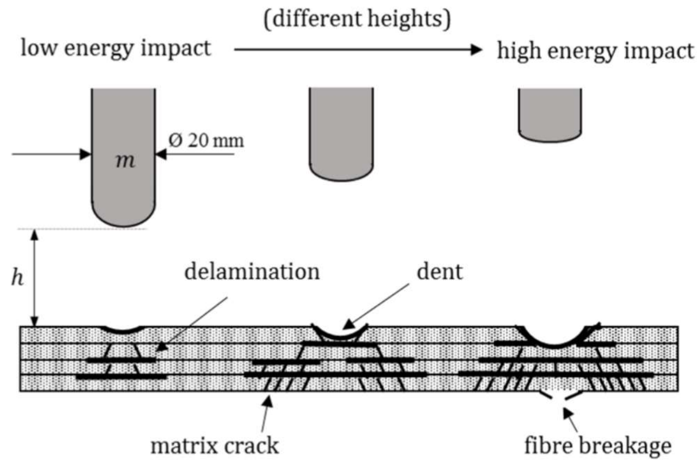


*Figure 2: Damage created in a composite material at different energy levels.*

Possible damage can be analyzed in two different ways:

- **Non-destructive evaluation (NDE)**, allowing the visualization of defects in a sample using, for example, an ultrasonic C-scan or X-ray method. The principle of this first method is to send a high-frequency acoustic wave into a sample. The wave that propagates inside the material is reflected by all free surfaces due to a difference in acoustic impedance.

An acoustic probe sends an acoustic pulse into a sample through water or a specific fluid that serves as support medium between the probe and the sample. When the wave encounters a defect (void, impurities) it is partially diffracted, depending on the size and nature of the defect, the part of the wave continuing without being affected by the defect will be of a greater or lesser amplitude. The method measures the intensity of this reflection according to the position of the defect. This intensity is translated into a color scale and is visualized on the screen of the device. The disadvantage of the S-scan is that it can only detect damage located in the path of the ultrasonic wave, meaning that any damage behind the first defect will be invisible to the C-scan. Therefore, X-ray imaging can penetrate through the entire sample thickness and provide a more comprehensive representation of damage within the composite material (as shown in Figure 3). This makes X-ray a suitable method for non-destructive inspection of component made from various composite materials, as depicted in Figure 4.

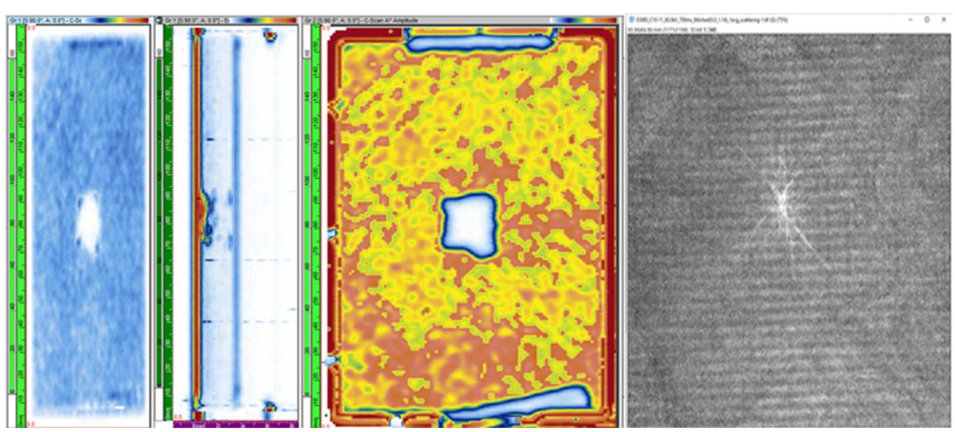

*Figure 3: C-scan and X-ray of samples after impact*

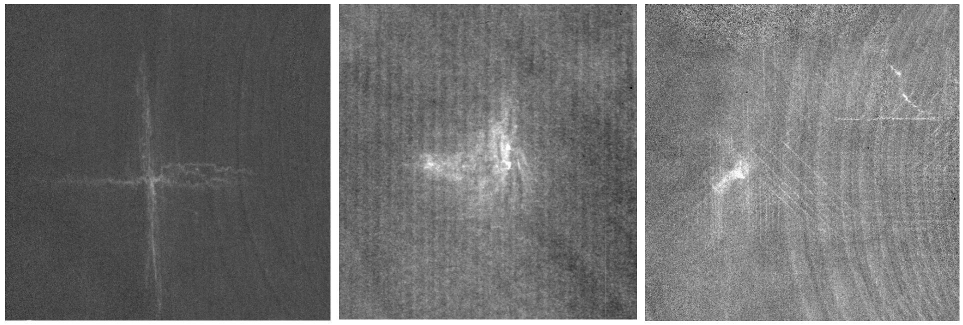

*Figure 4: X-ray images of composite samples from UD Flax, Glass Fabric and Carbon UD after impact*

- **Destructive evaluation** by compression after impact (CAI) for example, is a test that consists of measuring the residual compressive strength of a sample that has been subjected to an impact in accordance with ASTM D7137.

The residual strength of a damaged material depends strongly on the type of load applied because the sensitivity to defects is not the same depending on the stress state of the sample. For example, delamination between two plies will not have the same effect at all if the sample is tested in bending, compression, or tensile load. It is therefore a question of defining a test during which the defect will have the greatest effect, meaning where the residual resistance will be the lowest.

Impact is characterized by the application of a highly localized force in a very short time. The resulting high stresses can create damage to the upper surface of the sample, microcracking, transverse and longitudinal fractures (relative to fibers) due to compression and delamination due to shear. These can induce localized buckling of the fibers that will cause rapid ruin of the part. Since buckling is a mechanism that appears in compression, it is this type of test that will be used to characterize the residual strength of laminates after impact, despite the difficulties that this test presents, which are mainly geometric. When testing laminates, there are often thin samples, which have a strong tendency to buckle (at the sample level and not at the fiber level as described above) during loading, this leads to a fracture in bending and not in compression. A precise centering of the load, parallelism of sample surfaces and the use of supporting side plates avoid this kind of mechanism. The sample holder assembly used for this practical work is shown in Figure 5, it has been developed and used by Boeing (BSS 7260), and follows the test standard ASTM D7137.

Under such testing method, observed failure modes can be various, so they need to be adequately reported. Regarding, the fracture type, area, and location for each specimen. The standardized "Three-place" failure mode descriptors, as summarized in Table 1, must be employed. This notation utilizes the first position to describe the failure type, the second to specify the failure area, and the final position to denote the failure location.

All of the failure modes in the "First Character" column of Table 1 are acceptable, with the exception of end-crushing and panel instability.

Calculate the ultimate compressive residual strength using next equation and report the results to three significant figures.

$$F^{CAI} = P_{max}/A$$

with:

$F_{CAI}$ - ultimate compressive residual strength, MPa

$P_{max}$ - maximum force prior to failure, N

A - cross-sectional area of sample, mm$^2$

*Figure 5: CAI holder based on Boeing BSS 7260.*

**Table 1 - Three-Place Failure Mode Codes**

| First Character | | Second Character | | Third Character | |
|---|---|---|---|---|---|
| **Failure Type** | **Code** | **Failure Area** | **Code** | **Failure Location** | **Code** |
| Brooming | B | At end/edge | A | Bottom | B |
| End-Crushing | C | At/through Damage | D | Left | L |
| Delamination growth to edge at final failure, lengthwise | D | Gage, away from damage | G | Middle | M |
| Through-thickness | H | Multiple areas | M | Right | R |
| Panel Instability | I | Unknown | U | Top | T |
| Lateral | L | | | Various | V |
| Multimode | M | | | Unknown | U |
| Long, Splitting | S | | | | |
| Explosive | X | | | | |
| Other | O | | | | |

**Experimental part**

Impact tests are conducted on laminates, made of epoxy resin reinforced with different linen or glass fiber fabrics, UD carbon fibers and having *balanced layup.* The samples can be produced by contact molding or vacuum curing.

Each type of composite will be impacted with two different energies. It is important to take note of the damage mechanisms observed for each sample as well as a photo of both sides before and after each step.

The post-impact compression will be performed on a hydraulic machine with a capacity of 300 kN (Walter and Bai) to determine the residual stress of the samples. Loading will be done at a rate of 0.6 kN/s. Intact (non-impacted) samples will be tested in compression to have a reference value. Again, analyze closely the fracture types and behaviors.

Results of the experimental part also consist description of the sample (material, manufacturing process, sizes of sample, impact energy, maximum force of compression failure, failure mode code) and are presented in view of table 2. The sizes of samples are measured in a minimum of three points and written as an average in the table. The curves of dependence of compressive residual strength (normalized residual strength) on impact energy for each type of samples material must be shown in the report too.

**Table 2 – Results of CAI testing**

| № sample | Material | Manufacturing process | $h_{aver}$, mm | $b_{aver}$, mm | $l_{aver}$, mm | A, $mm^2$ | Impact energy, J | $P_{max}$, N | $F^{CAI}$, MPa | Failure Codes |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | | | | | | | reference | | | |
| …. | | | | | | | | | | |
| 3.3 | | | | | | | | | | |

**Discussions and Questions**

You can base your discussion of experiences on the questions discussed during the practical work. Some of the references below will be the subject of questions as well.

**References**

1. Impact Studies of Composite Materials/ Edited by Mohamed Thariq Hameed Sultan, Ain Umaira Md Shah, Naheed Saba - 2021.
2. Impact behaviour of fibre-reinforced composite materials and structures/ Edited by S R Reid and G Zhou/ 1st Edition - October 12, 2000
3. ASTM D7137 /D7137M – 17. Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates
4. ASTM D7136/D 7136M 15. Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event