METHOD FOR INVESTIGATING POST-IMPACT DAMAGE TO COMPOSITES

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1. Introduction

Composite materials have become an integral part of modern engineering due to their unique combination of strength, lightweight properties, and flexibility in design. These materials are extensively used in various industries such as aerospace, automotive, sports equipment, and renewable energy, where performance under dynamic and static loads is critical. One key area of interest is the **impact performance** of composites, particularly how these materials behave when subjected to sudden loads, which can induce damage that is both visible and hidden. The objective of this practical session is to investigate the **post-impact damage** of three distinct composite materials: **flax fibers**, **recycled fiberglass with sizing**, and **recycled fiberglass without sizing**, using the **Impetus4** for puncture testing machine.

Composite materials are composed of two or more distinct phases, typically fibers (reinforcement) embedded in a matrix (resin), working synergistically to provide enhanced mechanical properties. The matrix, in the studied case, a thermoset polymer epoxy, binds the fibers together and transfers stresses between them. The fibers whether natural like flax or synthetic like fiberglass primarily provide strength and stiffness.

In this session, we will explore two fiber types:

1. **Flax fibers**: As a natural, renewable resource, flax fibers are gaining popularity in composite applications due to their sustainability and environmental friendliness. Flax fibers possess good mechanical properties, though generally inferior to traditional synthetic fibers such as fiberglass. Nonetheless, flax composites are highly appealing for applications where **sustainability** is a critical factor.

2. **Fiberglass fibers**: Fiberglass is a widely used synthetic fiber in composite materials, offering excellent mechanical properties at relatively low cost. However, the production of virgin fiberglass is energy-intensive, and there is growing interest in recycling fiberglass for **environmental and economic benefits**.

Impact loading refers to the sudden application of force over a short duration, which can induce complex damage mechanisms in composite materials. Unlike metals, where impact damage often results in visible dents or cracks, composite damage is frequently internal, with **delamination** (separation between layers), **fiber breakage**, and **matrix cracking** being the predominant damage modes. This internal damage can significantly reduce the load-bearing capacity of the material, even if the damage is not immediately visible on the surface.

Impact damage in composites can be influenced by several factors, including:

- **Fiber type and architecture** (woven, unidirectional, or random mat).
- **Matrix type** and its mechanical properties.
- **Fiber-matrix interface** (adhesion between fibers and the matrix, which is often prononuced by the use of sizing).
- **Manufacturing quality**, including the presence of voids or resin-rich areas.

Sustainability overview:

The focus on sustainability has led to an increasing interest in recycling composite materials, particularly fiberglass, which is extensively used but difficult to recycle. Fiberglass composite recycling can be realized using pyrolysis where the composite is heated without the presence of oxygen. The resin will be cracked and transformed into oil that can be a raw material to reproduce polymers. The fibers are completely detached from the matrix and are covered with char layer mainly composed of carbon the residue of polymer transformation. To remove the char layer the fibers are heated at high temperatures with the presence of oxygen, calcination, where carbon will be transformed into CO^2 gas. One main drawback of the pyrolysis technique is the removal of the sizing layer, during the recycling process, which is an organic nano layer made generally from silanes. The absence of the sizing will result in surface damage of fiberglass when they are subjected to movement and low adhesion with resin matrix resulting in a negative impact on the final mechanical properties of the composite. Scanning Electron Microscopy, SEM, images of fiberglass are shown in Figure 1. This absence of sizing will lead to weaker mechanical properties and less effective stress transfer under load. Therefore, understanding how recycled fiberglass, with and without sizing, behaves under impact loading is crucial for assessing its suitability for reuse in structural applications.

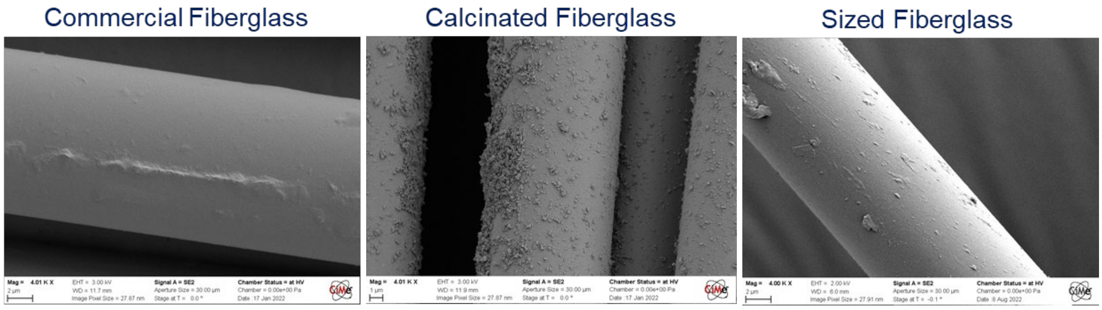

Figure 1: Scanning electron microscopy of fiberglass virgin, calcinated and sized

Flax fibers are among the most promising natural fibers used in composite manufacturing due to their **low density**, **biodegradability**, and **moderate mechanical properties**. However, while flax fibers are attractive for applications requiring sustainability, their **impact resistance** compared to synthetic fibers remains an area of research. The relatively lower stiffness of flax compared to fiberglass may result in different damage mechanisms, particularly under dynamic loads like impacts.

Puncture Testing Using Impetus4:

To simulate real-world impact scenarios and assess the damage resistance of composite materials, this session will employ the **Impetus4 puncture testing machine**. Puncture testing is a controlled method of applying force to a composite sample, simulating a concentrated impact load. The machine measures parameters such as:

- **Maximum force**: The peak load the material can withstand before failure.
- **Displacement**: The distance the puncture tool travels into the sample.
- **Energy absorption**: The amount of energy absorbed by the material during puncture, which is indicative of its toughness and damage tolerance.

The results of these tests provide critical insights into the material's ability to withstand impact without catastrophic failure. For this experiment, three energy levels will be used to compare the performance of the flax fiber composites and recycled fiberglass composites (both with and without sizing).

Aim of the Study:

The primary goal of this session is to compare the **impact resistance** and **post-impact damage** of flax fiber composites and recycled fiberglass composites with and without sizing. The analysis will focus on:

- The **effect of sizing** on the mechanical behavior of recycled fiberglass.
- The **sustainability vs. performance trade-off** when using natural fibers like flax.
- Understanding the **damage mechanisms** in each material type through non-destructive and destructive evaluations (surface inspection, optical microscopy if needed, and mechanical testing).

This investigation is particularly relevant for applications in industries such as automotive, aerospace, and sports equipment, where both lightweight materials and impact resistance are critical. Understanding how natural fibers and recycled materials perform under impact can aid in the development of more **sustainable** and **cost-effective** engineering solutions.

By the end of this session the following will be more familiar:

- The fundamental damage mechanisms in composite materials under impact loading.
- The use of **puncture testing** to evaluate composite material behavior.
- The comparison between **natural fibers** and **recycled synthetic fibers**, focusing on sustainability, material performance, and potential applications.

2. Theoretical bases

Impetus4 Puncture Testing:

The **Impetus4** machine, Figure 2, simulates impact loading by applying a controlled puncture force on the composite samples. It measures parameters such as **force-displacement**, **impact time**, and **energy absorbed**, providing detailed insights into the material's response under impact. Puncture testing provides information on:

- **Impact force resistance**.
- **Absorbed and elastic energy**.
- **Damage propagation**.

This testing method complements traditional drop-weight impact tests by allowing more controlled conditions and more detailed measurements.

A mass of defined geometry (20 mm), held on the movable arm, is dropped on a composite laminate and hits it at an energy defined by its initial height, angle and speed. The impact head is generally instrumented so that it can follow the force/displacement characteristics as a function of time. This test method defines the damage resistance of multidirectional polymer matrix composite laminated plates subjected to a weight impact event.

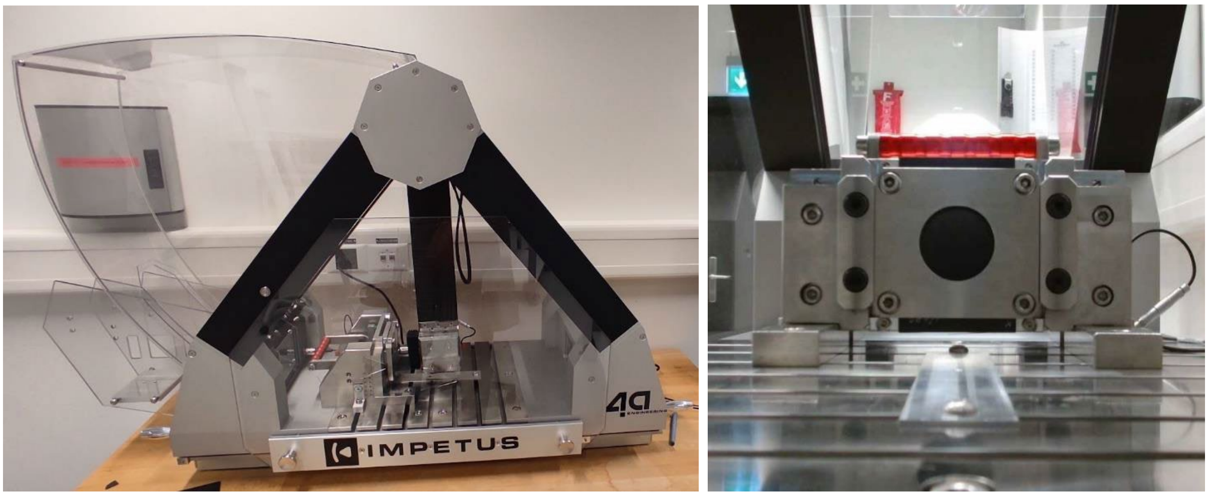

Figure 2:Impetus4 for puncture testing and the sample is fixed in the jaw of the machine

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

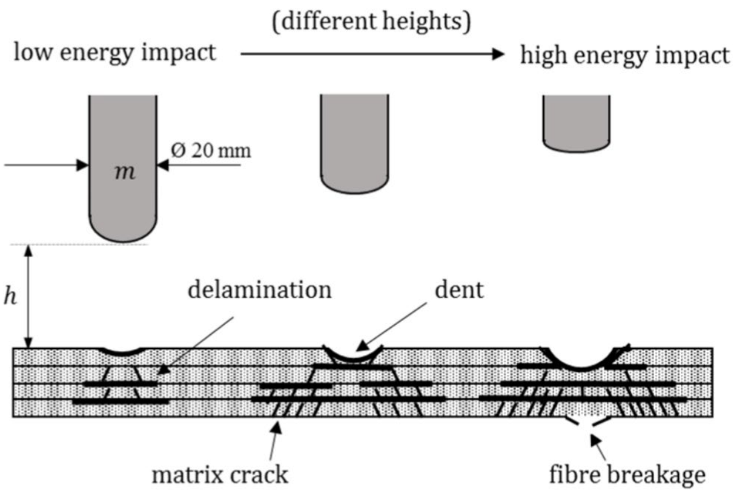

Figure 3: Damage created in a composite material at different energy levels.

3. Materials

Composite Samples (prepared in TP ***Mise en œuvre des composites):***

Resin used for all composites: **Epoxy resin** (L-235) with hardener mixed at a 100:35 ratio

- **Flax Fiber Composite**: Manufactured using pre-preg flax fiber twill, vacuum bagged and cured at 80°C for 2 hours.
    - Material: Twill weave flax fibers
    - Fiber volume fraction : ~52%
- **Recycled fiberglass Composites**: Manufactured using hand lay-up followed by vacuum bagging for 24 hours at room temperature.
    - **With sizing**:
    - Material: Fiberglass nonwoven with sizing
    - Fiber volume fraction : ~12%.
    - **Without sizing**:
    - Material: Fiberglass nonwoven without sizing
    - Fiber volume fraction: ~12%.

4. Experimental Procedure

4.1. Sample Preparation:

- Measure and record the **thickness**, **width**, and **length** of each sample using calipers.
- Weigh each sample and calculate the **fiber volume fraction** to verify the sample's material composition.

4.2. Pre-Test Inspection:

- **Visual inspection**: Document the surface condition of each sample. Look for resin-rich zones or air bubbles.

4.3. Puncture Testing Using Impetus4:

- Set up the **Impetus4 machine** for puncture testing, ensuring proper alignment and clamping of each sample (use a circular clamp with a 20 mm diameter).
- Perform puncture tests at three energy levels (To be defined during TP):
    - **3.42 J** (low energy impact)
    - **6.85 J** (medium energy impact)
    - **13.75 J** (high energy impact)
- Record the **force-displacement** and **force-time** data for each impact test.
- For each sample, note the **maximum impact force**, **energy absorbed**, and **displacement** at peak load.

4.4. Post-Impact Analysis:

Surface Damage Analysis:

Inspect each sample for visible cracks, delamination, or fiber breakage. Capture images using the digital microscope for detailed damage analysis (TBD). 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.

- **Measure the damage area**: Use calipers to measure the diameter of the puncture hole and record the size of the damage zone.

Internal Damage Analysis:

- **Compare the internal damage** across the three types of materials: flax fiber, recycled fiberglass with sizing, and recycled fiberglass without sizing.

*4.5. **Data Collection and Analysis:***

- Create tables to compare the key performance metrics across all samples:
  - **Maximum impact force**.
  - **Absorbed energy**.
  - **Damage diameter**.

Table 1 : example of data documenting

Sample Number	Material	Sample dimensions (l,w,t) (mm)	Puncture Energy (J)	Impact time (ms)	Max force (N)	Absorbed energy (N)	Damage diameter (mm)	elastisity (rebound) energy, J (from the curve)
	Flax Fiber							
	Fiberglass, Sized							
	Fiberglass, Unsized							

- Plot **force-displacement curves** for each test and analyze differences in material behavior
- **Impact Resistance:** Compare the maximum force withstood by each composite material at different energy levels.
- **Damage Mechanisms**: Identify the types of damage observed in each sample, such as fiber breakage, matrix cracking, and delamination.
- **Effect of Sizing**: Assess how the presence of sizing in the fiberglass samples impacts energy absorption and damage resistance. Samples with sizing should exhibit better fiber-matrix adhesion and therefore improved impact resistance.
- **Comparison with Flax Fiber**: Discuss the performance of flax fibers relative to the recycled fiberglass samples, focusing on the sustainability benefits and the mechanical trade-offs.

Discussions and Questions

- Influence of Fiber Recycling: Recycled fibers often suffer from reduced mechanical properties due to fiber degradation and loss of surface treatments like sizing. Analyze the difference in performance between sized and unsized recycled fiberglass.
- Sustainability vs. Performance: Compare the environmental benefits of flax fibers versus their mechanical performance. Flax fibers are more sustainable, but how do they compare in terms of impact resistance?
- You can base your discussion of experiences on the questions discussed during the practical work. Some of the references can help in the subject.

References

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