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# INFINITE

Aerospace composites digitally sensorized from manufacturing to end-of-life

# D6.1
# Test plan definition, for both coupons and final demonstrator

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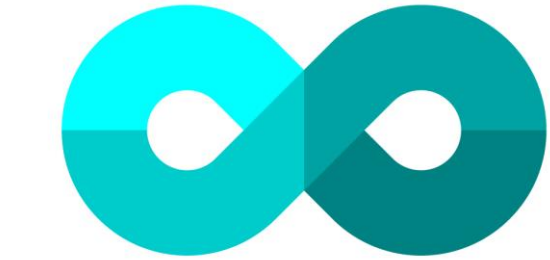

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Aerospace composites digitally sensorized
from manufacturing to end-of-life

| Participant number | Participant organisation name | Type | Country |
|---|---|---|---|
| 1 (leader) | Titania | SME | Spain |
| 2 | GAIKER | RTO | Spain |
| 3 | USFD | RTO | UK |
| 4 | | | |

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## 2. INTRODUCTION

This deliverable aims to define the proposed test plans to be performed on coupons, sensorised and non-sensorised, and the final demonstrator.

Regarding coupons, the plan is intended to evaluate the influence that the inclusion of microwires may have on the properties of the studied composite. To this end, sensorised and non-sensorised (used as reference) panels will be manufactured. After testing, the differences between both conditions will be evaluated. This test plan will include mechanical, physico-chemical, microscopic and ultrasound tests.

Panels will be manufactured using NCF provided by Teijin, both non-sensorised and sensorised samples. Panels with embedded microwires will include a laminate of non-sensorised NCF and a ply, integrated into the laminate, with the microwire included in it. The position of the sensorised ply in the lay-up will be defined according to results obtained in previous work packages of this project. Lay-up and dimensions of panels will depend on that specified on the applicable standards. Initially, available NCF are biaxial with an orientation of ±45 plies.

Regarding demonstrators, several structural tests will be performed on them. Since each test requires an individual demonstrator, different elements are required for this test plan.

## 3. TEST PLAN TO COUPONS

This section includes the description of all tests that will be performed at coupon levels. As commented in the introduction, this test plan will be performed to reference material (non-sensorised panels) and the sensorised material.

Table 1 includes all tests included in this test plan. Information related to the applied standard, the number of panels to be tested and the number of coupons per panel are also included in this table.

Test conditions can be varied according to the test. Initially, four testing conditions characterized by temperature and moisture and ageing conditions will be studied. The following are described testing conditions:

- Low temperature, LT: Test performed a -55°C.
- Room temperature, RT: Test performed at room temperature.
- High temperature, HT: Test performed at, initially, 150°C.
- As received, AR: Samples tested without ageing step.
- WET: Samples previously subjected to ageing step, 70°C/85% RH.

In general, for each test, **three panels** will be tested for the **non-sensorised reference** conditions and **five panels** will be tested for the **sensorised condition**.

The main characteristics of panels for each test are described below. Since most of the standards are not specific to NCF, some adaptations have been made to make the standards and materials compatible.

It shall be considered that the sizes of panels included in following paragraphs are indicative and theoretical. When manufacturing panels, the dimensions will be oversized considering the material which is removed during the cutting operation (around 2.5 mm of material removed per cut).

Table 1. Test plan for coupons.

| TEST | TEST METHOD | LAY UP | COUPONS PER PANEL | TEST CONDITION | | | |
|---|---|---|---|---|---|---|---|
| | | | | LT/AR | RT/AR | HT/AR | HT/WET |
| Resin content and fibre areal weight | UNE-EN 2559 | Any | 3 | No | Yes | No | No |
| Cured ply thickness | I+D-E 243 | Any | 3 | No | Yes | No | No |
| Glass transition temperature, DMA | ISO 6721-11 | Any | 3 | No | Yes | No | No |
| Glass transition temperature, DSC | AITM 3-0027 | Any | 3 | No | Yes | No | No |
| Ultrasonic inspection | I+D-E 280 | Any | 3 | No | Yes | No | No |
| Void content | AITM 4-0003 | Any | 3 | No | Yes | No | No |
| Void content | AITM 4-0003 | All manufactured | 3 | Yes | Yes | Yes | Yes |
| Microscopic inspection | AITM 4-0005 | All manufactured | 3 | Yes | Yes | Yes | Yes |
| Interlaminar shear strength (for 0°/90°) | EN 2563 | [(0°/90°),(90°/0°)]s | 5 | Yes | Yes | Yes | Yes |
| Interlaminar shear strength (for +45°/-45°) | EN 2563 | [(+45°/-45°),(-45°/+45°)]s | 5 | Yes | Yes | Yes | Yes |
| In-plane shear strength (for 0°/90°) | AITM 1-0002 | [(0°/90°),(90°/0°)]2s | 5 | Yes | Yes | Yes | Yes |
| In-plane shear strength (for +45°/-45°) | AITM 1-0002 | [(+45°/-45°),(-45°/+45°)]2s | 5 | Yes | Yes | Yes | Yes |
| Tensile strength and modulus | ISO 527-4 | [(+45°/-45°),(90°/0°)]3s | 5 | Yes | Yes | Yes | Yes |
| Compression strength and modulus | AITM 1-0008 | [(+45°/-45°),(90°/0°)]3s | 6 | Yes | Yes | Yes | Yes |
| Interlaminar fracture toughness energy, GIC | AITM 1-0005 | (0°/90°)3s | 6 | Yes | Yes | Yes | Yes |
| Open hole-Tension | AITM 1-0007 (OHT) | [(+45°/-45°),(90°/0°)]3s | 6 | Yes | Yes | Yes | Yes |
| Open hole-Compression | AITM 1-0008 (OHC) | [(+45°/-45°),(90°/0°)]3s | 6 | Yes | Yes | Yes | Yes |
| Filled hole - Tension | AITM 1-0007 (FHT) | [(+45°/-45°),(90°/0°)]3s | 6 | Yes | Yes | Yes | Yes |
| Filled hole- Compression | AITM 1-0008 (FHC) | [(+45°/-45°),(90°/0°)]3s | 6 | Yes | Yes | Yes | Yes |
| Flexion | ASTM D790 | [(+45°/-45°),(-45°/+45°)]s | 5 | No | Yes | No | No |
| Compression after impact | AITM 1-0010 | [(+45°/-45°),(90°/0°)]3s | 18 | No | Yes | No | No |
| Tension after impact | AITM 1-0010 | [(+45°/-45°),(90°/0°)]3s | 6 | No | Yes | No | No |

## 3.1 PHYSICO-CHEMICAL TESTS

### 3.1.1 RESIN CONTENT AND FIBRE AREAL WEIGHT

**Resin content and fibre areal weight** test will be performed according to UNE-EN 2559 "Aerospace series – Carbon, glass and aramid fibre preimpregnates. Determination of the resin and fibre content and the mass of fibre per unit area".

According to this standard, **three coupons** will be tested for each panel. Each coupon shall have an area of 100 $cm^2$, with a square geometry. This way, samples shall be **squares of 100 (0°) x 100 mm**, Figure 1. For this test, the thickness is not a requirement, since the coupons are solved during the test.

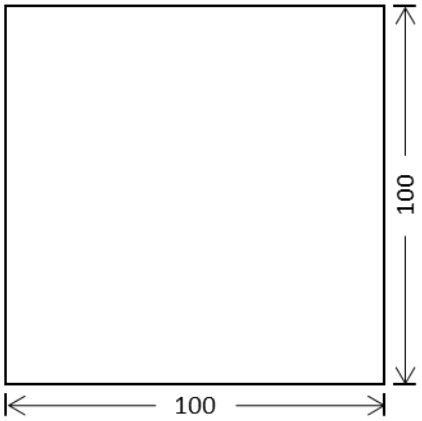


Figure 1. Coupon geometry for resin content and fibre areal weight test, according to UNE-EN 2559. All dimensions are expressed in mm.

Considering the structure of this material, which is more similar to wide woven, and the information from the standard, the following positioning of specimens in the test panel will be used for this test, Figure 2.

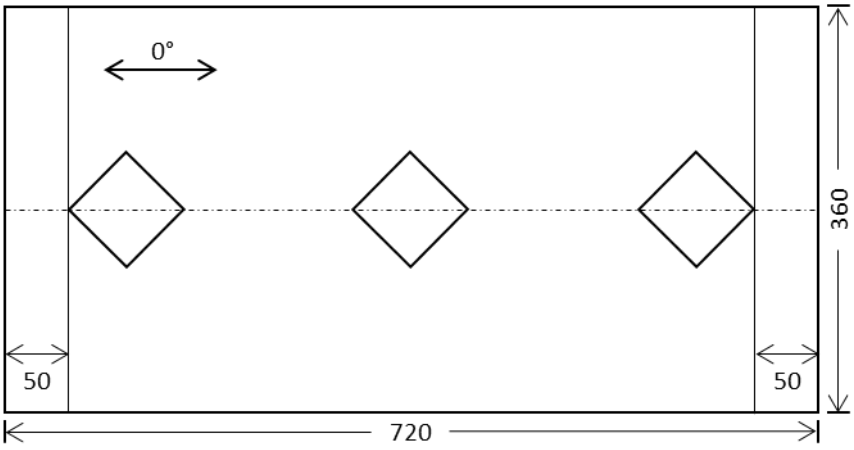


Figure 2. Positioning of the coupons on the test panels for resin content and fibre areal weight test. All dimensions are expressed in mm.

### 3.1.2 CURED PLY THICKNESS

**Cured ply thickness** test will be performed according to I+D-E 243 "Physical test on carbon fibre laminates".

For this test, samples taken from representative areas of the manufactured panels are used. **Three coupons** of **100 (0°) x 100 mm** shall be cut from different areas of each manufactured panel. At least, ten measurements of the thickness of each specimen shall be made.

### 3.1.3 GLASS TRANSITION TEMPERATURE, DMA

**Glass transition temperature (DMA)** test will be performed according to ISO 6721-11 "Plastics. Determination of dynamic mechanical properties. Part 11: Glass transition temperature".

According to this test standard, **three coupons** will be tested for each panel. Each coupon shall be a rectangle of **35 (0°) x 10 x 2 mm**, Figure 3.

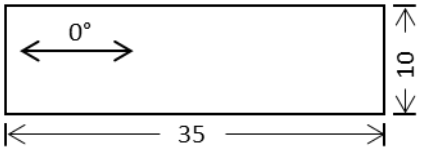


Figure 3. Coupon geometry for glass transition temperature (DMA) test, according to ISO 6721-11. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 4.

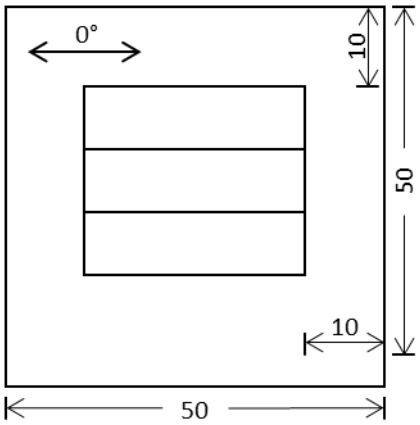


Figure 4. Positioning of the coupons on the test panels for glass transition temperature (DMA) test. All dimensions are expressed in mm.

### 3.1.4 GLASS TRANSITION TEMPERATURE, DSC

**Glass transition temperature (DSC)** test will be performed according to AITM 3-0027 "Determination of the Melting Behaviour and the extent of Crystallinity of Semi-crystalline Materials by Differential Scanning Calorimetry (DSC)"

According to this test standard, **three coupons** will be tested for each panel. Each coupon shall be a rectangle of **20 (0°) x 10 x 2 mm**, Figure 5.

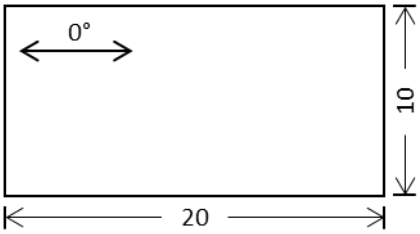


Figure 5. Coupon geometry for glass transition temperature (DSC) test, according to AITM 3-0027. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 6.

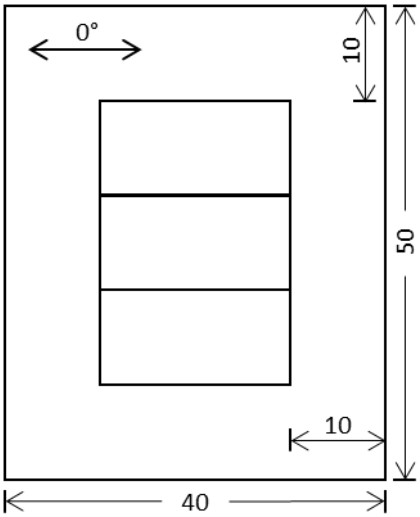


Figure 6. Positioning of the coupons on the test panels for glass transition temperature (DSC) test. All dimensions are expressed in mm.

#### 3.1.5 VOID CONTENT

**Void content** test will be performed according to UNE-EN 2564 "Aerospace series- Carbon fibre laminates. Determination of the fibre, resin and void contents".

According to UNE-EN 2564, **three coupons** will be tested for each panel. Each coupon shall weigh between **1 and 5 grams**. To ensure the required amount of material, a panel of **150 (0°) x 150 x 2 mm** shall be necessary.

### 3.2 MICROSCOPY TESTS

#### 3.2.1 MICROSCOPIC INSPECTION

**Microscopic inspection** test will be performed according to AITM 4-0005 "Macroscopic and Microscopic Examination of Fiber Reinforced Plastic".

Applicable standard does not specify the size or locations of coupons to be tested. It has been decided to cut **three coupons** from different locations of every manufactured panel, with dimensions of **25 (0°) x 10 mm**.

#### 3.2.2 VOID CONTENT

**Void content** test will be performed according to AITM 4-0003 "Test Method for Determining the Pore Content of Fiber Reinforced Plastics using Automatic Image Analysis".

According to AITM 4-0003, **three coupons** will be tested for each panel. Each coupon shall have a minimum test **surface area of 20 mm$^2$**, and the microsection width should exceed 25 mm. To obtain this, three coupons of **25 (0°) x 10** mm will be cut from every manufactured panel.

### 3.3 ULTRASONIC INSPECTION TEST

**Ultrasonic inspection** test will be performed according to I+D-E 280 " Pulse-echo ultrasonic inspection of elements made of carbon fiber composite materials".

Despite the standard specifying the inspection of at least three coupons for each manufactured panel, it has been decided to perform ultrasonic inspection of the **whole surface** of **all manufactured panels**.

Additionally, once coupons are machined, another ultrasonic inspection will be performed on them, to ensure that no damages have been produced during the machining process.

## 3.4 MECHANICAL TESTS

### 3.4.1 INTERLAMINAR SHEAR STRENGTH, ILSS

**Interlaminar shear strength** test will be performed according to UNE-EN 2563 "Aerospace series. Carbone fibre reinforced plastics. Unidirectional laminates. Determination of the apparent interlaminar shear strength". For this test, two different lay up will be tested:

- [(0°/90°),(90°/0°)]2s
- [(+45°/-45°),(-45°/+45°)]2s.

According to UNE-EN 2563, **five coupons** will be tested for each panel. Each coupon shall be a rectangle of **20 (°) x 10 x 2 mm**, Figure 7.

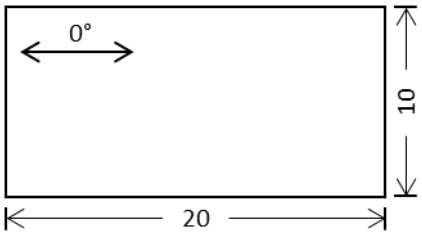


Figure 7. Coupon geometry for interlaminar shear strength test, according to UNE-EN 2563. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 8.

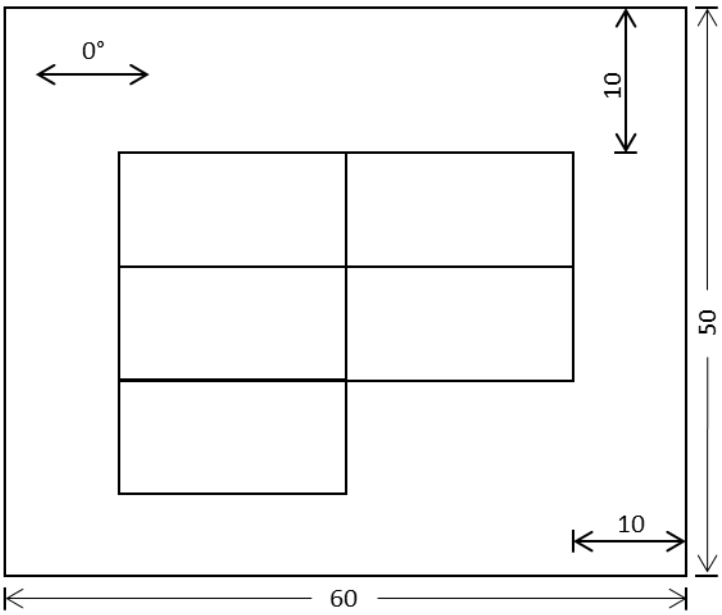


Figure 8. Positioning of the coupons on the test panels for interlaminar shear strength test. All dimensions are expressed in mm.

### 3.4.2 IN-PLANE SHEAR STRENGTH

**In-plane shear** test will be performed according to AITM 1-0002 "Determination of in-plane shear properties (±45° tensile test)". For this test, two different lay up will be tested:

- [(0°/90°),(90°/0°)]2s

- [(+45°/-45°),(-45°/+45°)]2s

According to AITM 1-0002, **five coupons** will be tested for each panel. Each coupon shall be a rectangle of **230 (0°) x 25 x 4 mm**. Furthermore, this test requires the use of **tabs** of **50 x 25 mm**. Thus, the free area to be tested is of 130 x 25 mm, Figure 9.

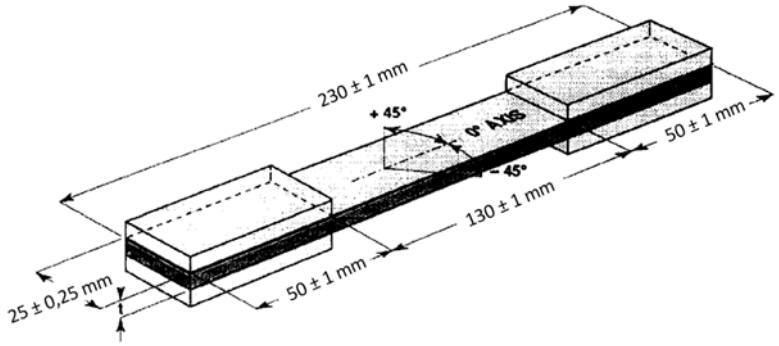


Figure 9. Coupon geometry for in-plane shear test. Image extracted from AITM 1-0002.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 10.

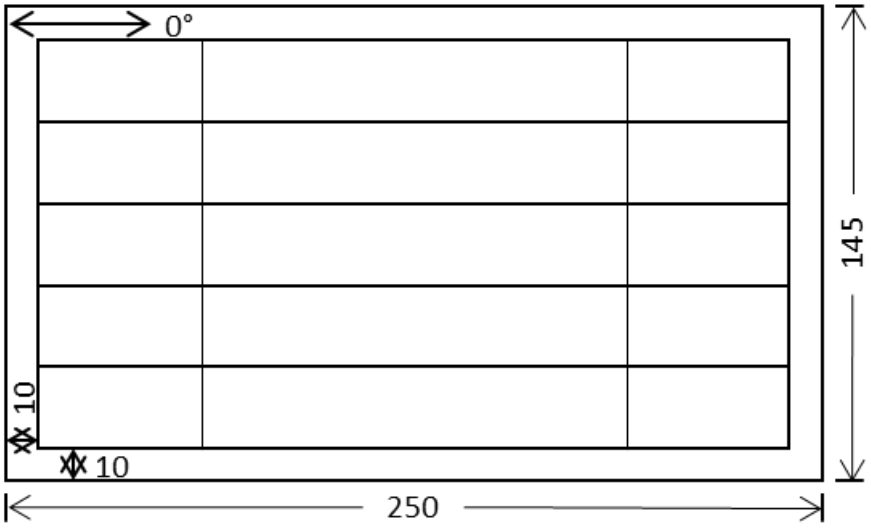


Figure 10. Positioning of the coupons on the test panels for in-plane shear strength test. All dimensions are expressed in mm.

### 3.4.3 TENSILE STRENGTH AND MODULUS

**Tensile test** will be performed according to UNE-EN ISO 527-4 standard "Plastics. Determination of tensile properties. Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites". For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s.

According to ISO 527-4, **five coupons** will be tested for each panel. Each coupon shall have a **dog bone geometry**, with dimensions of **150 (0°) x 20 x 6 mm**, Figure 11.

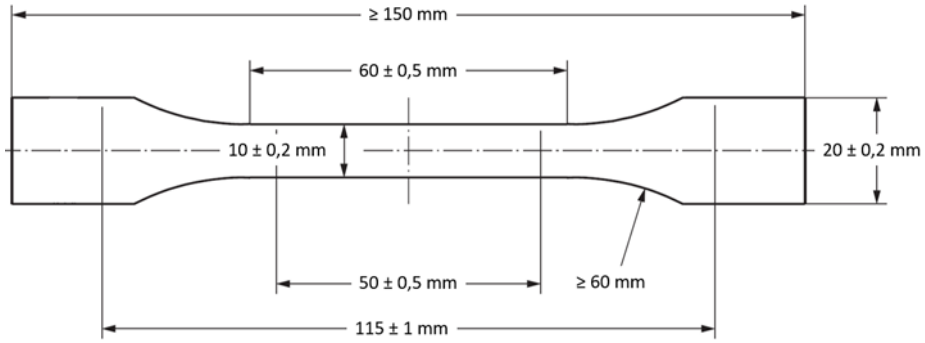


Figure 11. Coupon geometry for tensile test. Image extracted from ISO 527-4.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 12.

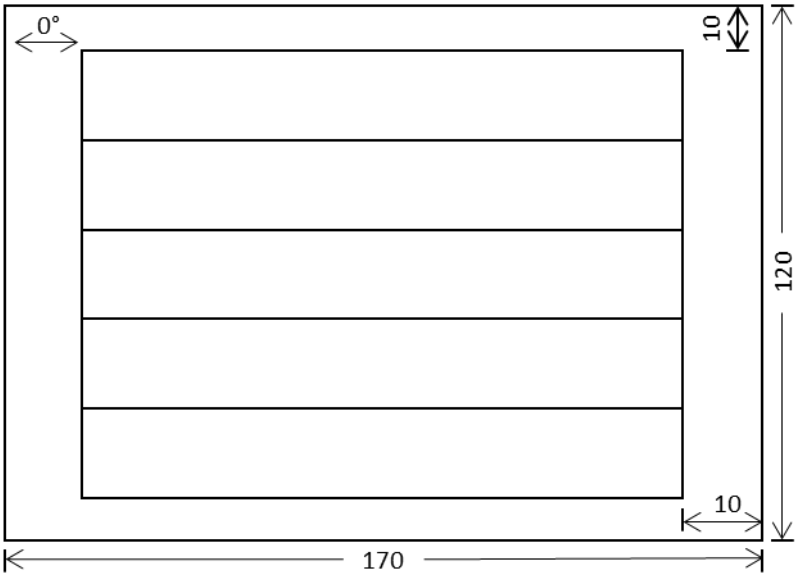


Figure 12. Positioning of the coupons on the test panels for in-plane shear strength test. All dimensions are expressed in mm.

### 3.4.4 COMPRESSION STRENGTH AND MODULUS

**Compression test** will be performed according to AITM 1-0008 "Determination of Plain, Open Hole and Filled Hole Compression Strength". For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

According to AITM 1-0008, **six coupons** will be tested for each panel. Each coupon shall be a rectangle of **152 (0°) x 22 x 6 mm**. Furthermore, this test requires the use of **tabs** of **65 x 22 mm**. Thus, the free area to be tested is 22 x 22 mm, Figure 13.

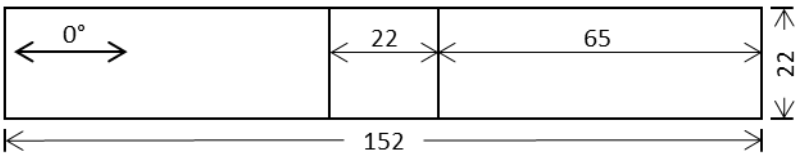


Figure 13. Coupon geometry for compression test, according to AITM 1-0008. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 14.

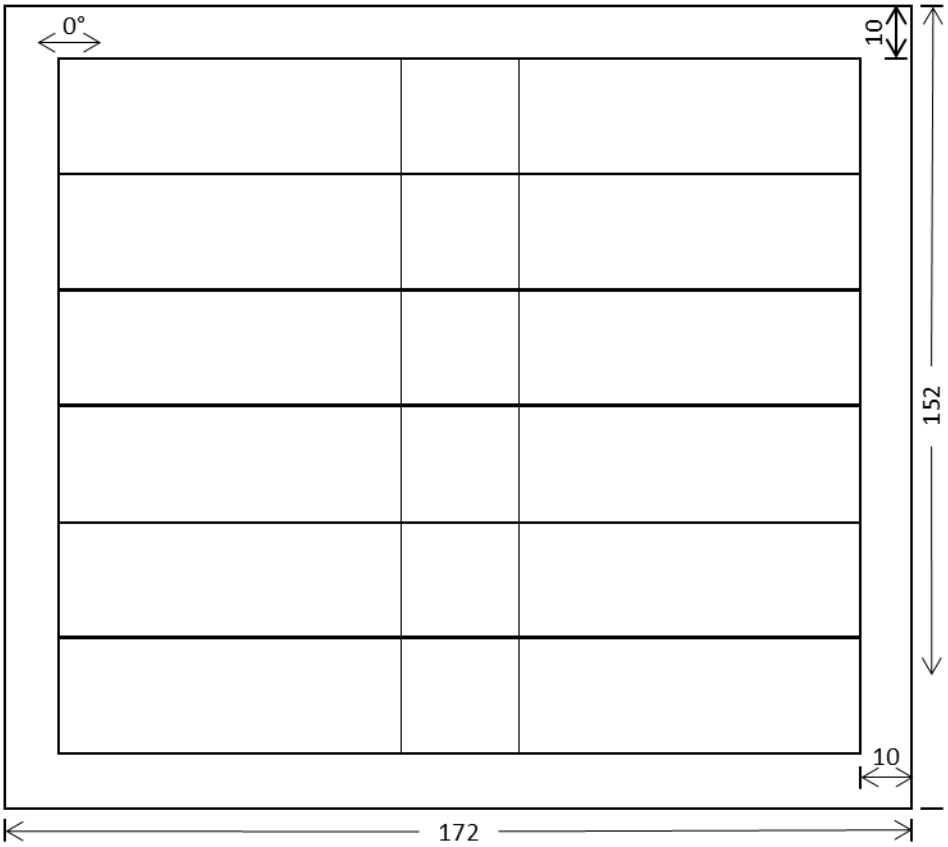


Figure 14. Positioning of the coupons on the test panels for compression test. All dimensions are expressed in mm.

### 3.4.5 INTERLAMINAR FRACTURE TOUGHNESS ENERFY, G1C

**Interlaminar fracture toughness energy test (GIC)** will be performed according to AITM 1-0005 "Carbon Fibre Reinforced Plastics. Determination of interlaminar fracture toughness energy – Mode I ($G_{1c}$ Test)". For this test, one lay up will be tested:

- (0°/90°)3s

According to AITM 1-0005**, six coupons** will be tested for each panel. Each coupon shall be a rectangle of **250 (0°) x 25 x 3 mm**. One of the edges of the coupon shall have a line of **40 mm** length in which a **release film** is placed, and acts as crack initiator. On this same edge, specific GIC **tabs** are (**20 (0°) x 25 mm**) joined to the coupon, Figure 15.

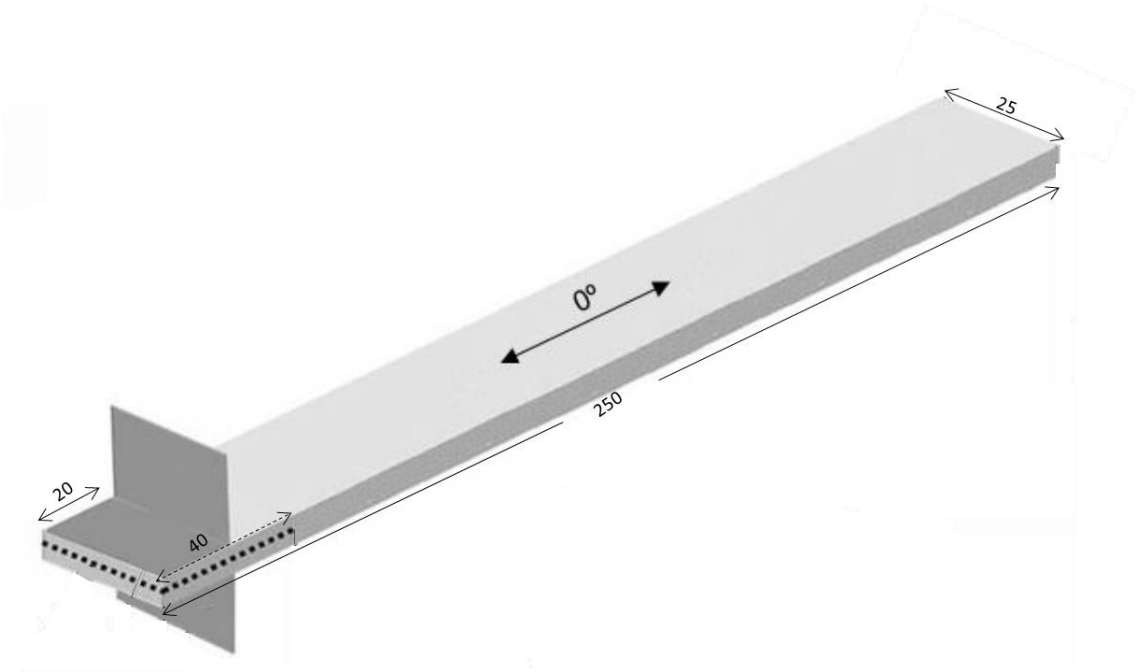


Figure 15. Coupon geometry for GIC test. Image adapted from AITM 1-0002

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 16.

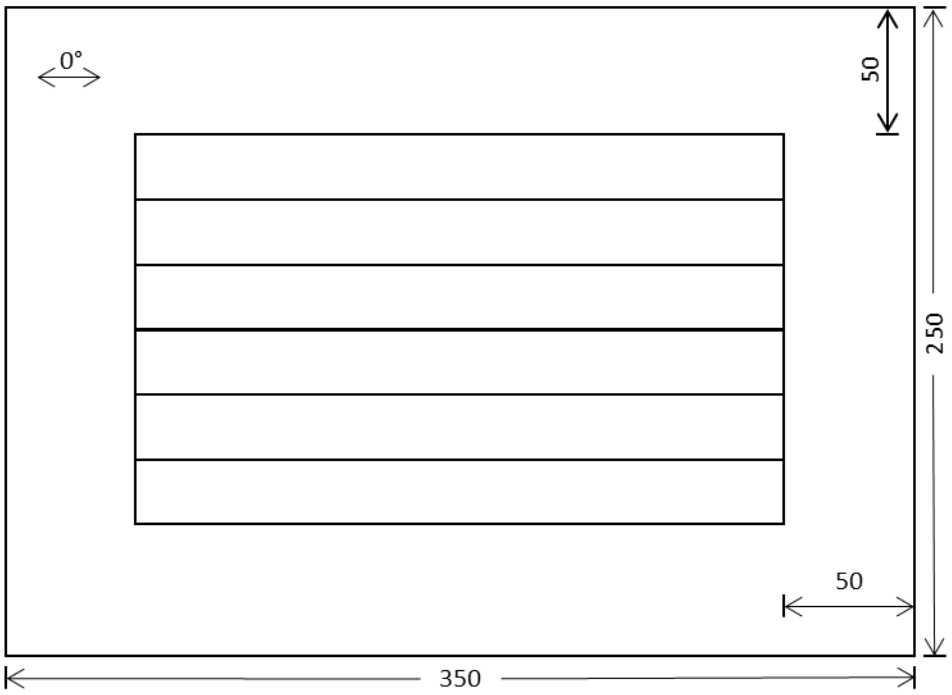


Figure 16. Positioning of the coupons on the test panels for GIC test. All dimensions are expressed in mm.

### 3.4.6 OPEN HOLE TENSILE

**Open hole tensile test** will be performed according to AITM 1-0007 “Determination of Plain, Open Hole and Filled Hole Tensile Strength”. For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

According to AITM 1-0007, **six coupons** will be tested for each panel. Each coupon shall be a rectangle of **250 (0°) x 22 x 3 mm**. This test requires the use of **tabs** of **50 (0°) x 22 mm**. Thus, the free area to be tested is 130 x 25 mm. In this test, a hole shall be performed in the centre of the coupon. This **hole** shall have a diameter ranging between **4.815 and 4.848 mm**, Figure 17:

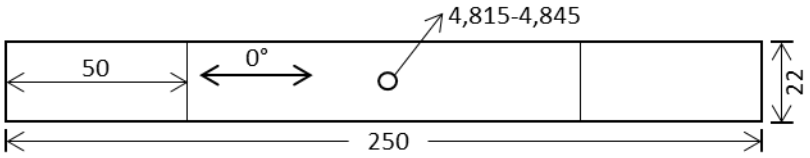


Figure 17. Coupon geometry for open hole tensile test, according to AITM 1-0007. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 18.

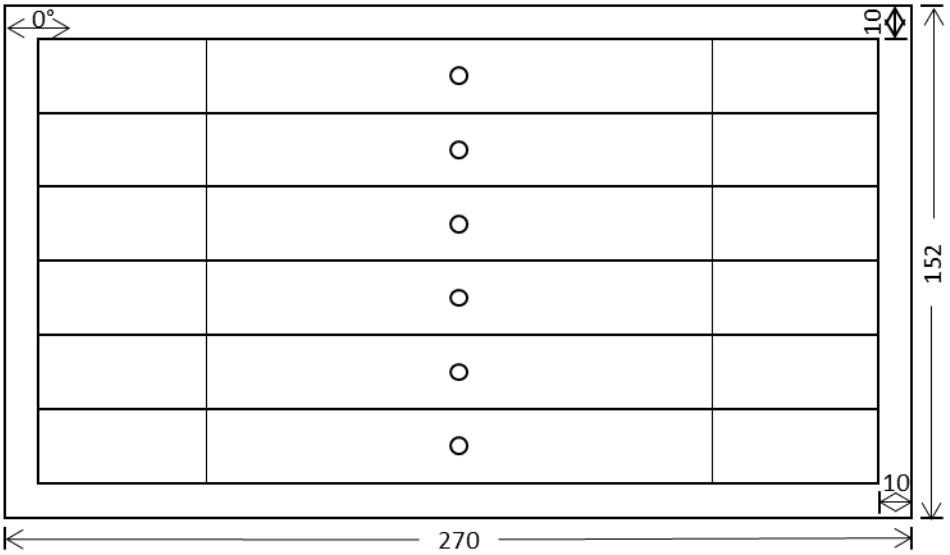


Figure 18. Positioning of the coupons on the test panels for open hole tensile test. All dimensions are expressed in mm.

### 3.4.7 OPEN HOLE COMPRESSION

**Open hole compression test** will be performed according to AITM 1-0008 "Determination of Plain, Open Hole and Filled Hole Compression Strength". For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

According to AITM 1-0008, **six coupons** will be tested for each panel. Each coupon shall be a rectangle of **152 (0°) x 22 x 6 mm**. Furthermore, this test requires the use of **tabs** of **65 x 22 mm**. Thus, the free area to be tested is 22 x 22 mm. In this test, a hole shall be performed in the centre of the coupon. This **hole** shall have a diameter ranging between **4.815 and 4.848 mm**, Figure 19.

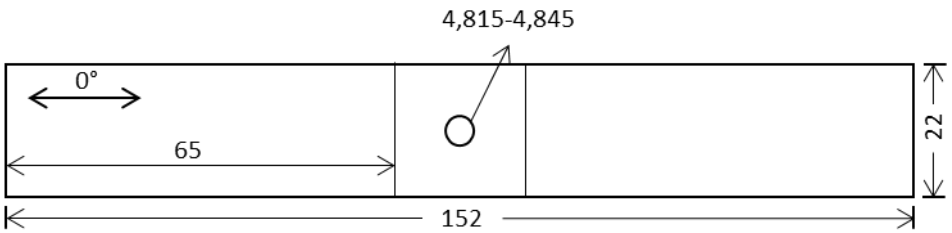


Figure 19. Coupon geometry for open hole compression test, according to AITM 1-0008. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in

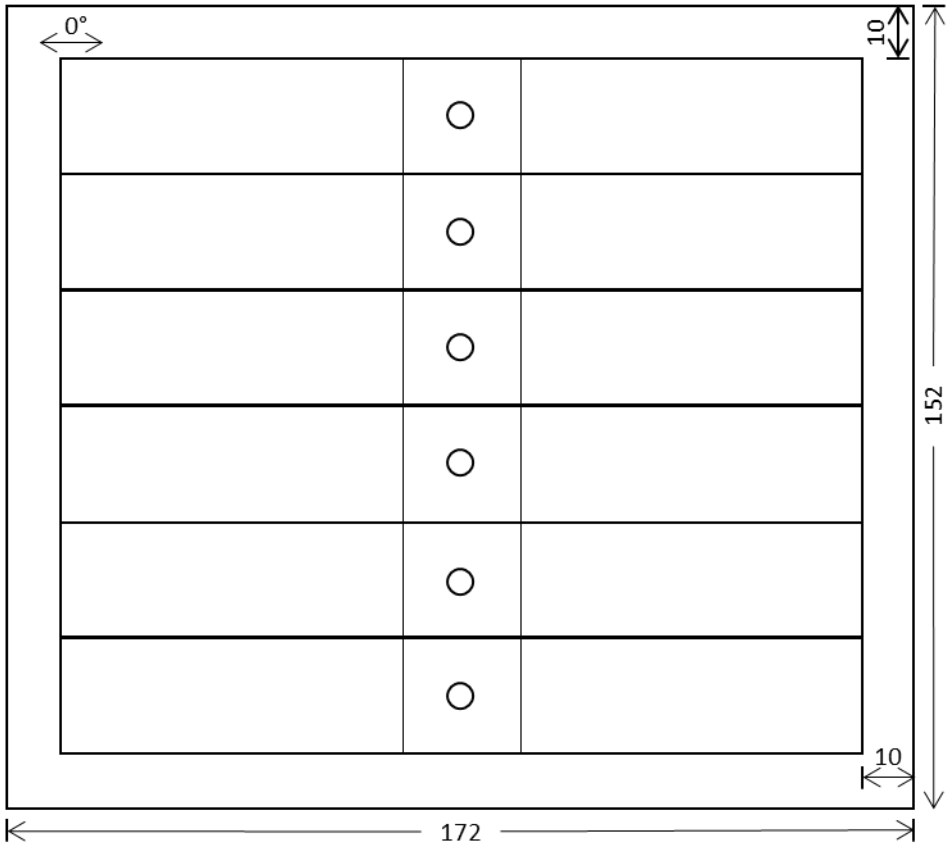


Figure 20. Positioning of the coupons on the test panels for open hole compression test. All dimensions are expressed in mm

### 3.4.8 FILLED HOLE TENSILE

**Filled hole tensile test** will be performed according to AITM 1-0007 "Determination of Plain, Open Hole and Filled Hole Tensile Strength". For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

According to AITM 1-0007, **six coupons** will be tested for each panel. Each coupon shall be a rectangle of **250 (0°) x 22 x 3 mm**. This test requires the use of **tabs** of **50 (0°) x 22 mm**. Thus, the free area to be tested is 130 x 25 mm. In this test, a hole shall be performed in the centre of the coupon. This **hole** shall have a diameter ranging between **4.815 and 4.848 mm.** In this test, the hole is **filled** with a protruding bolt or with a countersunk bolt. The element to be used will be decided at the moment of performing the test, Figure 21.

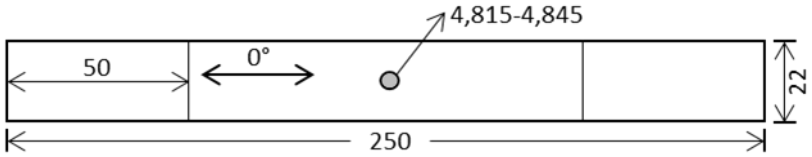


Figure 21. Coupon geometry for filled hole tensile test, according to AITM 1-0007. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 22.

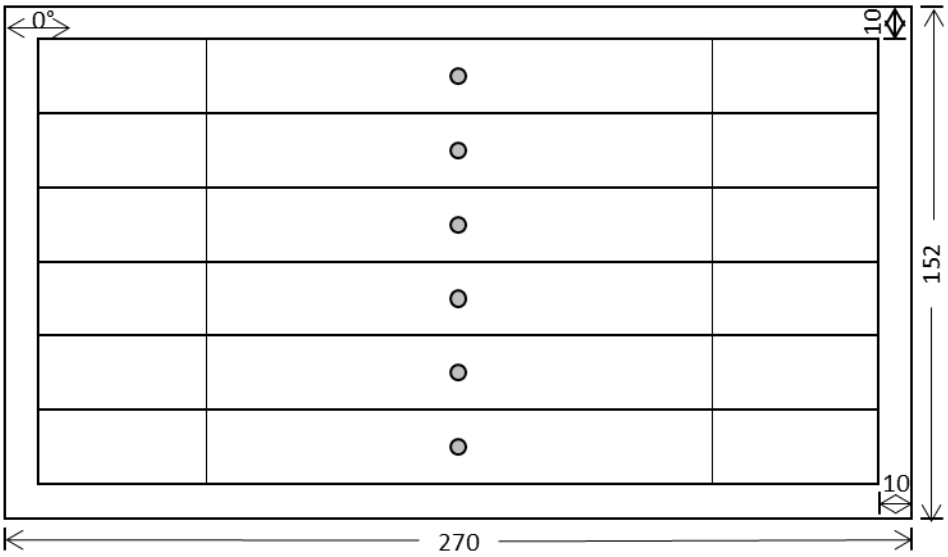


Figure 22. Positioning of the coupons on the test panels for filled hole tensile test. All dimensions are expressed in mm.

### 3.4.9 FILLED HOLE COMPRESSION

**Filled hole compression test** will be performed according to AITM 1-0008 " Determination of Plain, Open Hole and Filled Hole Compression Strength". For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

According to AITM 1-0008, **six coupons** will be tested for each panel. Each coupon shall be a rectangle of **152 (0°) x 22 x 6 mm**. Furthermore, this test requires the use of **tabs** of **65 x 22 mm**. Thus, the free area to be tested is 22 x 22 mm. In this test, a hole shall be performed in the centre of the coupon. This **hole** shall have a diameter ranging between **4.815 and 4.848 mm**. In this test, the hole is **filled** with a protruding bolt or with a countersunk bolt. The element to be used will be decided at the moment of performing the test, Figure 23.

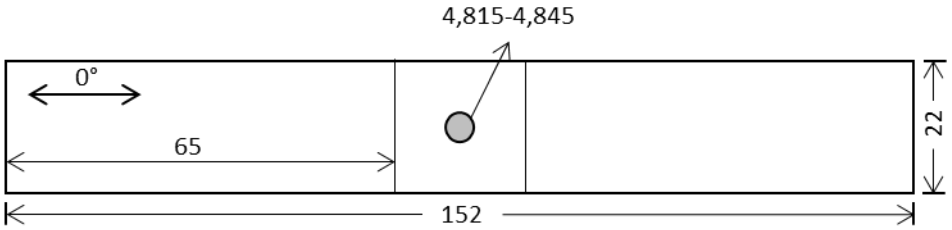


Figure 23. Coupon geometry for filled hole compression test, according to AITM 1-0008. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 24.

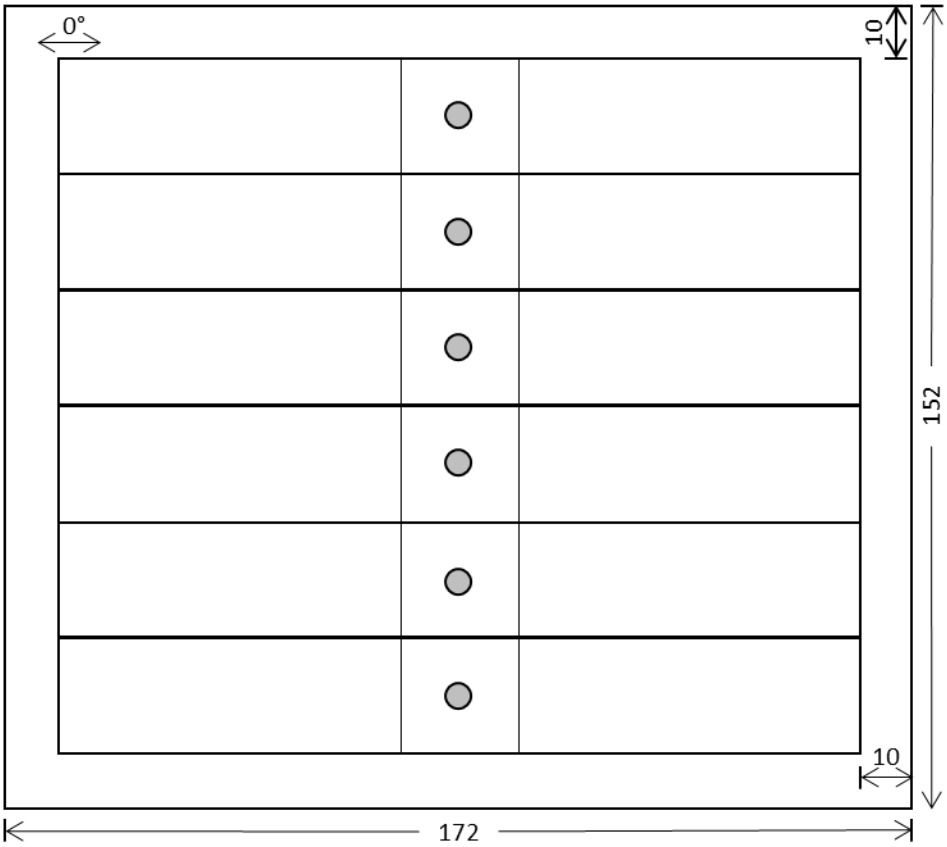


Figure 24. Positioning of the coupons on the test panels for filled hole compression test. All dimensions are expressed in mm.

### 3.4.10 FLEXURE

**Flexure test** will be performed according to ASTM D790 "Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials". For this test, one lay up will be tested:

- [(+45°/-45°),(-45°/+45°)]s

According to ASTM D790, **five coupons** will be tested for each panel. Each coupon shall be a rectangle of **40 (0°) x 12.7 x 2 mm**.

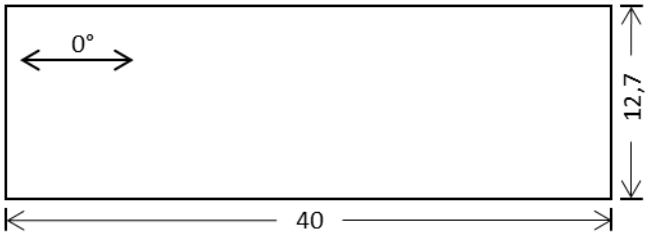


Figure 25. Coupon geometry for flexure test, according to AITM 1-0008. All dimensions are expressed in mm.

The test panel from which coupons will be cut has the geometry and dimensions shown in Figure 26.

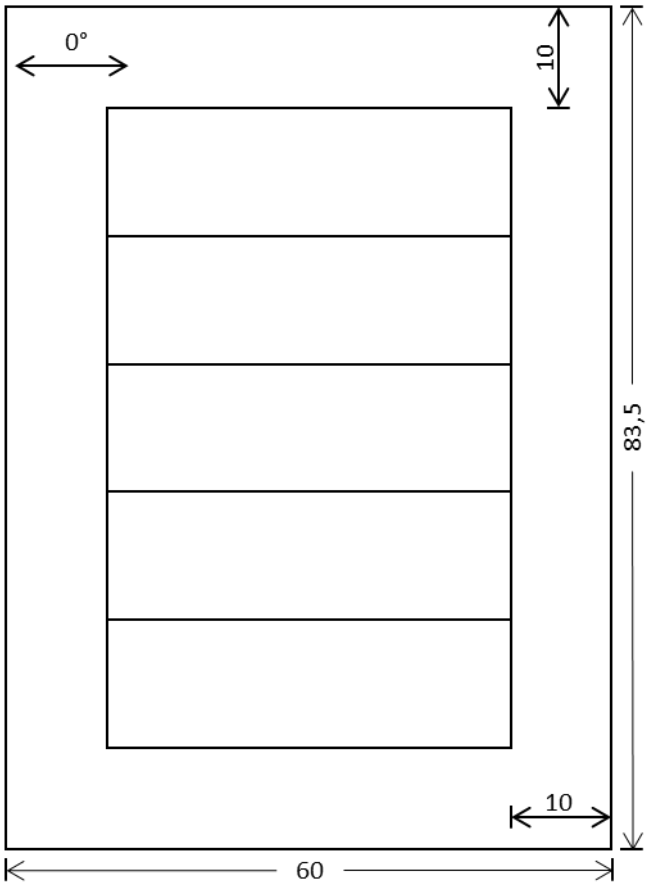


Figure 26. Positioning of the coupons on the test panels for flexural test. All dimensions are expressed in mm.

### 3.4.11 COMPRESSION AFTER IMPACT

Compression after impact test (CAI) will be performed according to AITM 1-0010 “Fibre Reinforced Plastics. Determination of Compression Strength After Impact“. For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

According to AITM 1-0010, initially, six coupons are tested after **impact at different energies**, to select the best one, and **three coupons** are tested after **impact at 30 J**. This part of the assay will be performed with non-sensorised samples. Once the **energy** has been **chosen**, **three coupons** will be tested. Each coupon shall be a rectangle of **150 (0°) x 100 x 3 mm**, Figure 27.

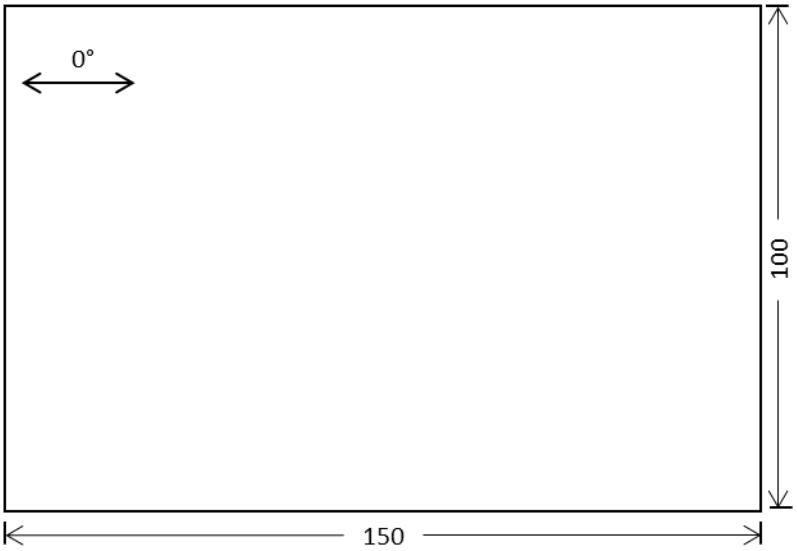


Figure 27. Coupon geometry for CAI test, according to AITM 1-0010. All dimensions are expressed in mm.

### 3.4.12 TENSION AFTER IMPACT

**Tension after impact test (TAI)** will be performed according to AITM 1-0010 “Fibre Reinforced Plastics. Determination of Compression Strength After Impact“ and AITM 1-0007 “Determination of Plain, Open Hole and Filled Hole Tensile Strength“. For this test, one lay up will be tested:

- [(+45°/-45°),(90°/0°)]3s

For this test, six coupons will be impacted with the energy value decided CAI test. Each coupon shall be a rectangle of **100 (0°) x 80 x 3 mm**, Figure 28.

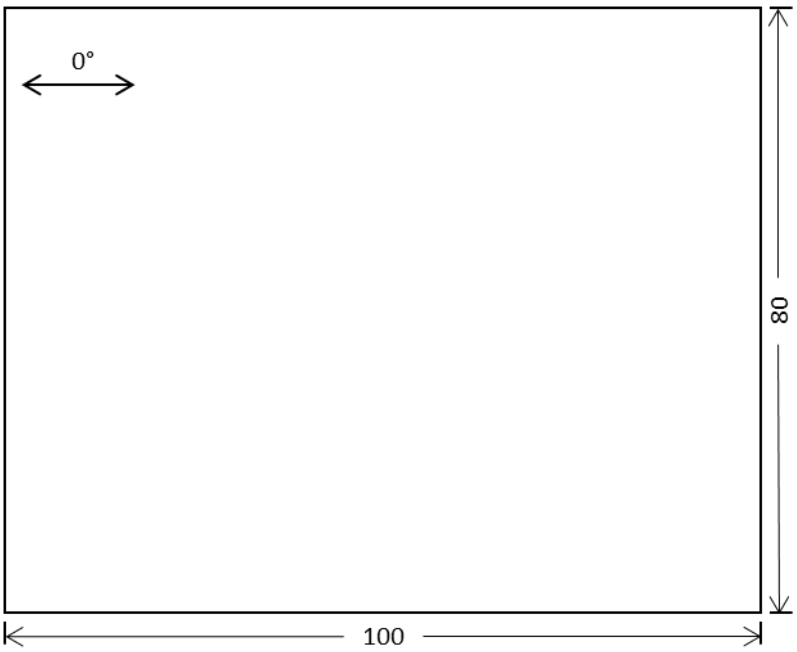


Figure 28. Coupon geometry for TAI test. All dimensions are expressed in mm.

# 4. TEST PLAN FOR DEMONSTRATORS

The last step in the validation process will be the test to the final demonstrator. The demonstrator will be a semi-complex structure which simulates a real part of the aircraft.
At the time of writing this deliverable, no final demonstrator has been defined. Two options have been proposed to the consortium. These are included in Figure 29.

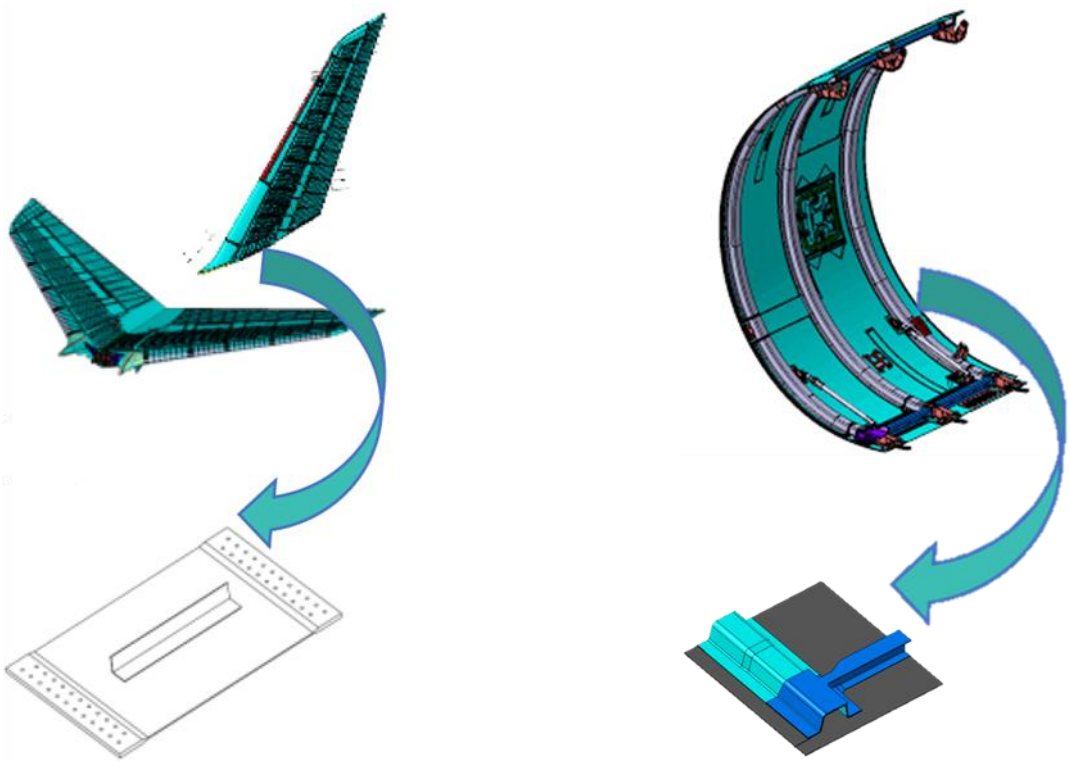

Figure 29. Left: Demonstrator based on VTP and HTP. Right: Demonstrator based on fan cowl.

These demonstrators are composed by:

- VTP and HTP:
  - Flat skin
  - L-stringer
  - Adhesive join

- Fan cowl:
  - Flat skin
  - Longitudinal Ω stiffener
  - Transversal Ω stiffener

Regardless of the final demonstrator geometry, the chosen one will be subjected to the following tests:

- Tensile test
- Compression test
- Shear test

Since these are destructive tests, **three demonstrators** will be required for this task.