# Prepreg termoestable desarrollado para actuar como barrera térmica local formando parte del laminado estructural principal de CFRP.

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**RESUMEN:** (200-500 palabras)

Los composites poliméricos de fibra de carbono (CFRP) son ampliamente utilizados en la industria aeronáutica ya que poseen excelentes propiedades. Sin embargo, también presentan algunas limitaciones derivadas, principalmente, de la naturaleza polimérica de su matriz. Una de las más significativas es su pobre resistencia a altas temperaturas (>130ºC) ya que restringe su uso a aplicaciones estructurales alejadas de focos de calor, evitando así, las zonas próximas a los motores o turbinas. Esta problemática, hasta la fecha, es solventada por dos vías.
La primera es el uso de metales para la fabricación de estos componentes, principalmente titanio. Las prestaciones a altas temperaturas son buenas, pero da lugar un amento en el peso del avión y, con ello, un aumento en el consumo de combustible y las emisiones derivadas.
La otra vía explorada es el recubrimiento de las estructuras con mantas térmicas. Con ello se consigue proteger y aislar al composite estructural pero el proceso de fabricación resulta ineficiente debido al alto coste de la materia prima y a las numerosas operaciones necesarias para llevar a cabo su instalación y montaje/encolados.

El presente trabajo apuesta por el desarrollo de un CFRP multifuncional diseñado a partir de un prepreg de resina termoestable comercial y ampliamente utilizado en aeronáutica que, junto con una la combinación de ciertos materiales, permitirán la obtención **de un CFRP que pueda actuar de barrera térmica y, a la vez, cumplir con sus requerimientos mecánicos y de protección al fuego y a los rayos.**
Además de la selección del material adecuado, se ha estudiado el procesado del material determinando que tanto el proceso de laminado como el curado se puede realizar en conjunto, de igual forma que se lleva a cabo la fabricación de CFRP convencionales. Esto permitirá una rápida industrialización, la ejecución un reducido número de operaciones y, por consiguiente, una reducción en los costes.

**Palabras clave:** prepreg termoestable, composite estructural multifuncional, barrera térmica, retardante de llama, protección contra rayos

# Thermoset prepreg materials to act as local thermal barrier for the main CFRP structural laminate

**ABSTRACT:**

Carbon fibre polymer composites (CFRP) are widely used in the aeronautical industry thanks of their excellent properties. However, they also have some limitations mainly due to the polymeric nature of their matrix. One of the most significant is their poor resistance to high temperatures (>130ºC), which restricts their use to structural applications away from heat sources, thus avoiding areas close to engines or turbines. To date, this problem has been solved in two ways.

The first one is the use of metals for the manufacture of these components, mainly titanium. Performance at high temperatures is suitable, but this generates in an increase in the weight and, with it, an increase in fuel consumption and emissions.

The other possibility explored is the covering of structures with thermal blankets. This protects and insulates the structural composite, but the manufacturing process is inefficient due to the high cost of the raw material and the numerous operations required for installation and assembly/taping.

The present work is committed to the development of a multifunctional CFRP designed from a commercial thermosetting resin prepreg widely used in aeronautics which, together with a combination of certain materials, will make it possible to obtain **a CFRP that can act as a thermal barrier and, at the same time, meet its mechanical, fire and lightning protection requirements**.

In addition to the selection of the appropriate material, the processing of the material has been studied and it has been determined that both the lamination and curing processes can be carried out together, in the same way that conventional CFRP is manufactured. This will allow rapid industrialisation, the execution of a reduced number of operations and, consequently, a reduction in costs.

**Keywords:** thermoset prepreg, multifunctional structural composite, thermal barrier, flame retardancy, lightning protection

## 1. Introduction

Epoxy Polymeric composites with carbon fibre (CFRP) in the aeronautical sector to replace metals has been implemented for several decades. In fact, it has been the sector that has given the greatest impetus to the use of these materials. One of the main motivations has been the need to lighten and reduce consumption and environmental emissions without penalising properties. This has been achieved, but to date, there are some components that cannot be manufactured with these materials due to certain limitations. One of the limitations is the **thermal resistance** required by certain components above 130ºC, such as those exposed to a continuous heat source produced by aircraft turbines or engines. This source emits convective heat and heats the component compartment affecting the integrity of the component directly (Figure 1).

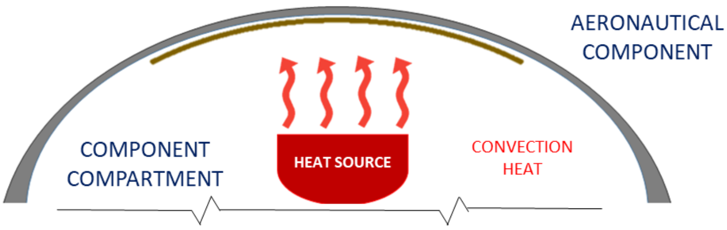


Figure 1. Heating mechanism of components close to engines or turbines

These components are currently made of metal or composites coated with insulating mesh that protects the material and inhibits its degradation. Both solutions generate an extra weight contribution to the aircraft and, in the case of the mesh, an increase in the number of manufacturing and riveting operations.

Some new resin developments with higher temperature resistance have been carried out [1] but have not achieved the expected results. The main drawback of them is the difficulty of industrialisation due to the cost of the raw material and the toxicity that complicates operations and manufacturing times, being more profitable the use of metals. This is the reason why this problem has yet to be solved and is still under study [2].

In addition to improved thermal resistance, to be part of these demanding components, the composites must met some additional requirements, such as **flame retardancy and lightning protection**.

Generally, polymeric materials are flammable and generate smoke and noxious gases [3]. This is a major limitation when it comes to components in the cabin or in the hold as they present a risk to both lives and luggage. To overcome this, some studies reports the resin modification by adding flame-retardants [4] or the insertion of insulation blankets taped or riveted to the composite structure. However, when it comes to components that are not in contact with people or baggage, it has been proven that the use of glass fibre allows flame retardancy and smoke reduction [5] to meet the requirements of parts close to turbines or engines. The introduction of one or more layers of glass fibre will promote this property as it has been shown that glass fibre acts as an inert filler [6].

As for the lightning protection, a bronze mesh is currently placed on the inside of the composite, preventing lightning from propagating through the structure and causing damage to the aircraft and endangering its integrity [7].

This paper presents the progress of the project dedicated to the fabrication of a multifunctional composite capable of acting as a thermal insulator together with the other relevant and desired properties, while maintaining high mechanical properties and manufacturing efficiency.

## 2. Materials and Process

### 2.1. Materials

The multifunctional composite materials, in laminated form, were designed and manufactured with a specific configuration to provide some additional functions: **thermal insulation, flame retardancy and lightning protection properties**. This configuration (see Figure 2) is formed by stacking seven layers of the base material that provides the material with the mechanical properties needed for the final application and three additional layers to provide the functions.

The base material was a unidirectional carbon fibre tape widely used in the aerospace industry (Hexel UD Tape, 190sgm). On top of the top layer was the insulating layer (3M ceramic oxide fabric), underneath it a glass fibre fabric (Hexcel, 109gms) to provide the retardant properties and on the outside underside of the laminate a layer of bronze mesh to provide lightning protection. The specimens' dimensions were 200x300x1,7 mm.

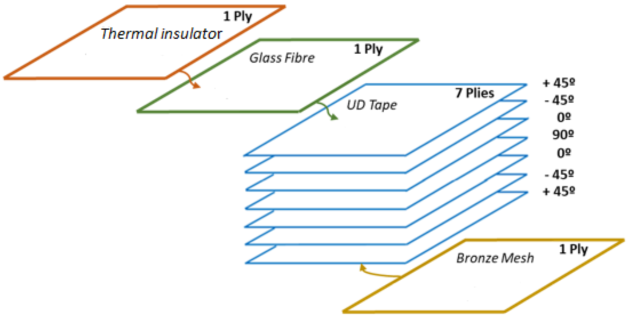


Figure 2. Multifunctional laminate configuration

### 2.2. Composite manufacturing process

The specimens were manufactured by hand-lay-up and, during the stacking process, k-type thermocouples (Figure 3) were placed between the different layers. The introduction of these elements allowed the thermal shielding capacity of the designed laminate and the temperature uniformity of the part to be validated. After lamination, they were subjected to a curing process at 180°C in an autoclave.

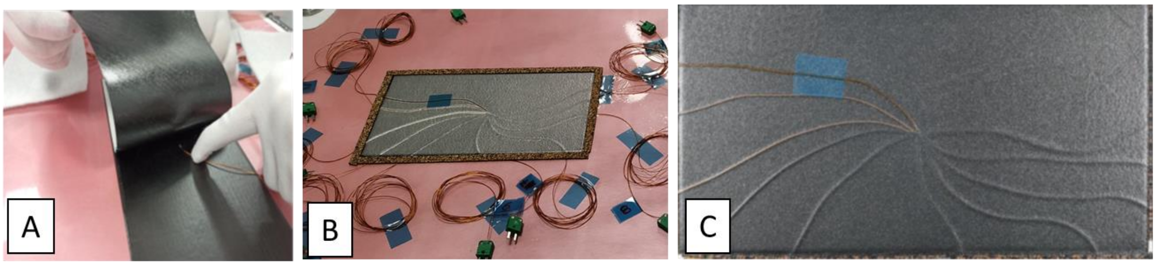


Figure 3. A) Positioning of thermocouples B) Material stacking C) Final laminate after curing.

In order to evaluate the **temperature delta or enhancement range**, two types of specimens were manufactured:

- *Type 1*: configuration described in Figure 2.
- *Type 2*: configuration described in Figure 2 with the exception of the insulating layer.

Figure 4 shows both configurations and the placement of the thermocouples inside and outside the specimens for full temperature control over the laminate.

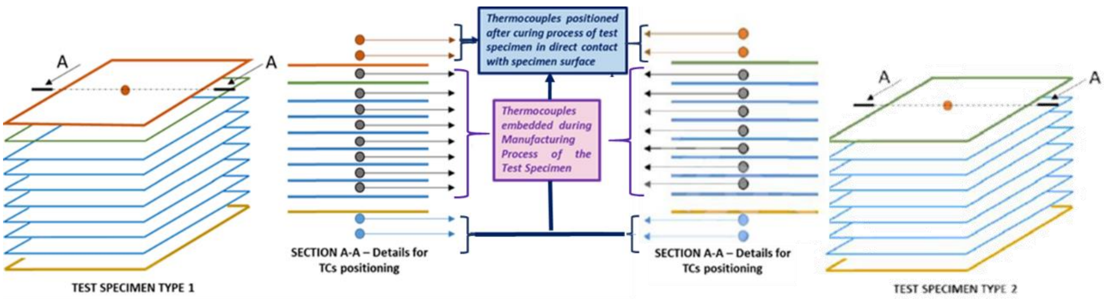


Figure 4. Type 1 and Type 2 configuration and the positioning of thermocouples.

After the stacking, the materials were cured in an autoclave according to the process parameters described in Table 1 and the temperature cure cycle in Figure 5.

| Parameter | Value |
|---|---|
| Vacuum bag (mbar) | ≥ 650 |
| Autoclave Pressure (bar) | 3.5-7.2 |
| Heating rate (°C/min) | 0.2-3.5 |
| Cure time (min) | 120-210 |
| Cure temperature (°C) | 180 ± 5 |
| Cooling rate (°C/min) | 0.2 -3.5 |
| Note: Vent the vacuum bag to the atmosphere when the autoclave pressure reaches 1.4bar | |

Table 1. Autoclave process parameters

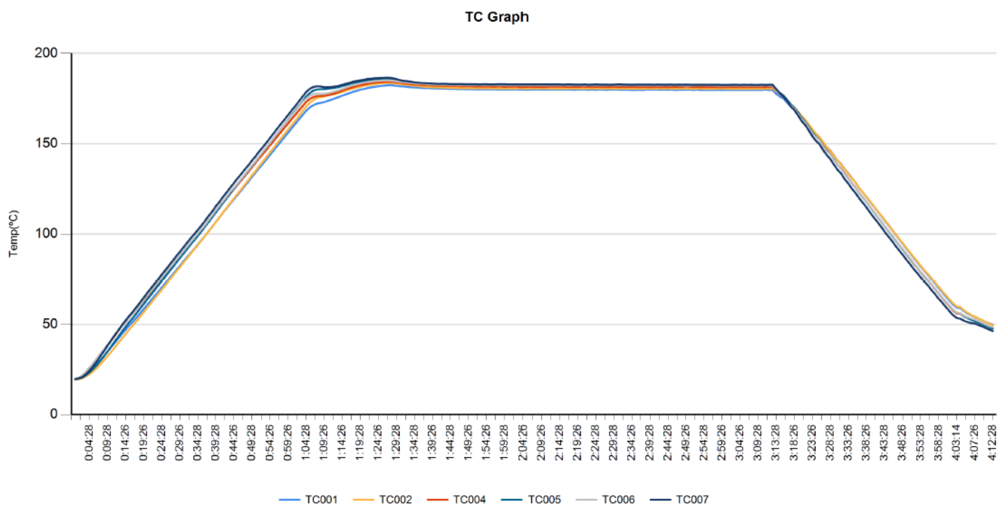


Figure 5. Curing cycle

## 3. Experimental

### 3.1. Non- destructive inspection

The inspections by non-destructive techniques allow detecting the presence of defects (such as delamination, porosity, areas without resin, excess resin, discolouration...) without damaging the specimens. These inspections were carried out before and after the curing cycling.

After the curing process, the specimens obtained were inspected visually and by non-destructive techniques, specifically ultrasound to validate their quality.

### 3.2. Thermal cycle

The specimens were subjected to four thermal cycles designed to simulate the working conditions to which the materials would be subjected. For this purpose, the tests were carried out in a modified and instrumented oven in order to monitor the temperature (Figure 6).

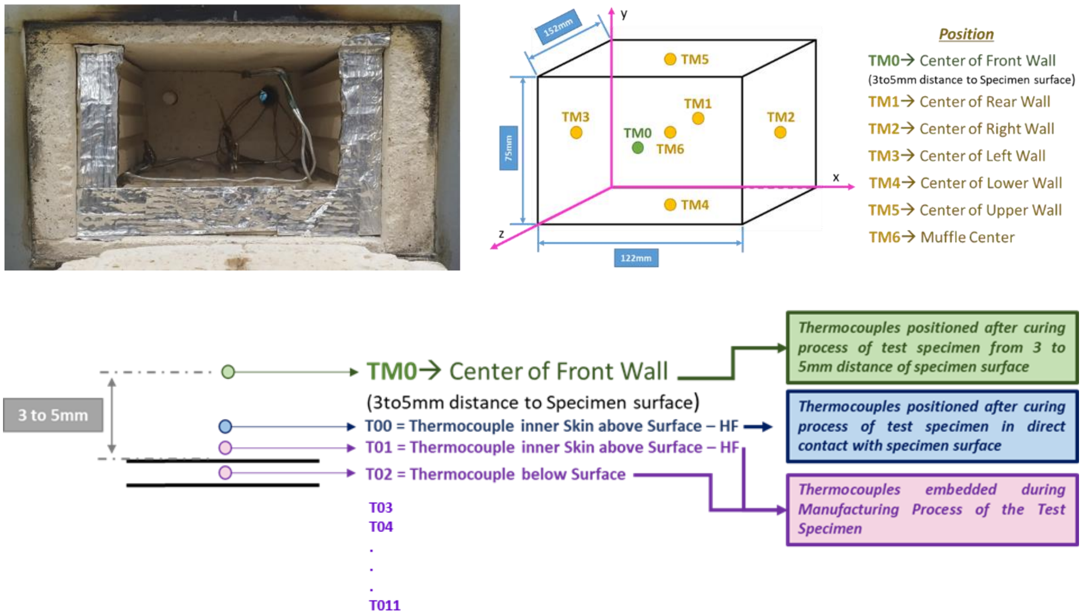


Figure 6. Instrumented oven and thermocouples position

The thermal cycles evaluated were:

i) **Thermal cycle V1** (Figure 7)

Stage 1: The specimens were subjected to a progressive heating (~3.5°C/min) starting from room temperature until reaching 170°C recorded by the thermocouple placed on the surface of the specimen (T00). We assume that this value corresponds to the air temperature in the oven. The temperature was then maintained for 30 minutes.

Stage 2: An increase in temperature was carried out in the oven until the thermocouple T01 (first thermocouple embedded in the laminate) reached 170ºC. The temperature was then maintained for 30 minutes.

Stage 3: The oven set point was increased until the thermocouple T01 reached 180°C. The temperature was then maintained for 30 minutes.

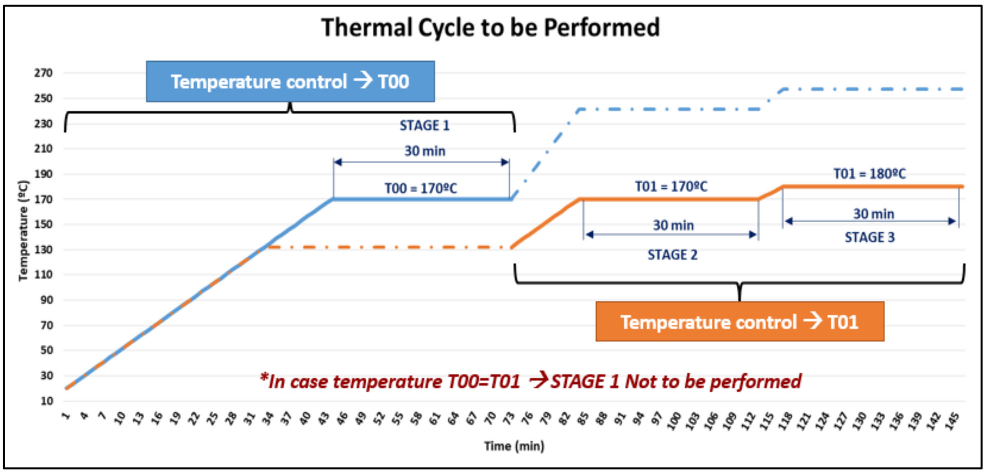


Figure 7. Thermal cycle V1

i) **Thermal cycle V2**
The cycle is the same as cycle 1 but the starting temperature was 120°C.

## 4. Results

### 4.1. Non-destructive inspection

The following tables show the results of the ultrasonic inspection (Table 2) and the visual inspection (Table 3).

| Type-Specimen- Cycle | Results |
|---|---|
| Before exposure thermal cycle | |
| T1-S1 | No discontinuity is detected in the inspection |
| T1-S2 | No discontinuity is detected in the inspection |
| T2-S1 | No discontinuity is detected in the inspection |
| T2-S2 | No discontinuity is detected in the inspection |
| Before exposure thermal cycle | |
| T1-S1-V1.1 | No discontinuity is detected in the inspection |
| T1-S1-V1.2 | No discontinuity is detected in the inspection |
| T1-S2-V2.1 | No discontinuity is detected in the inspection |
| T1-S1-V2.2 | No discontinuity is detected in the inspection |
| T2-S1-V1.1 | No discontinuity is detected in the inspection |
| T2-S1-V1.2 | No discontinuity is detected in the inspection |
| T2-S2-V2.1 | No discontinuity is detected in the inspection |
| T2-S1-V2.2 | No discontinuity is detected in the inspection |

Table 2. Ultrasonic inspection results

| Type-Specimen- Cycle | Results |
|---|---|
| Before exposure thermal cycle | |
| T1-S1 | No surface defects are noted |
| T1-S2 | No surface defects are noted |
| T2-S1 | No surface defects are noted |
| T2-S2 | No surface defects are noted |
| Before exposure thermal cycle | |
| T1-S1-V1.1 | Colour changes are noted in the inspection |

| Type-Specimen- Cycle | Results |
|---|---|
| T1-S1-V1.2 | Colour changes are noted in the inspection |
| T1-S2-V2.1 | Colour changes are noted in the inspection |
| T1-S1-V2.2 | Colour changes are noted in the inspection |
| T2-S1-V1.1 | Colour changes are noted in the inspection |
| T2-S1-V1.2 | Colour changes are noted in the inspection |
| T2-S2-V2.1 | Colour changes are noted in the inspection |
| T2-S1-V2.2 | Colour changes are noted in the inspection |

Table 3. Visual inspection results

The inspection tests on the specimens showed that they do not show manufacturing defects (before the curing process). After curing, a colour change on the top surface of the specimen is denoted as shown in Figure 8. This change in colour seems to be generated by the volatiles in the auxiliary materials used to position the test tubes in the muffle.

The colour change was detected in both types of laminate, however, the degree is high if the thermal insulation material is absent in the configuration. This could be a consequence of a decrease in heat transmission due to the presence of the insulating layer introduced in the composite.

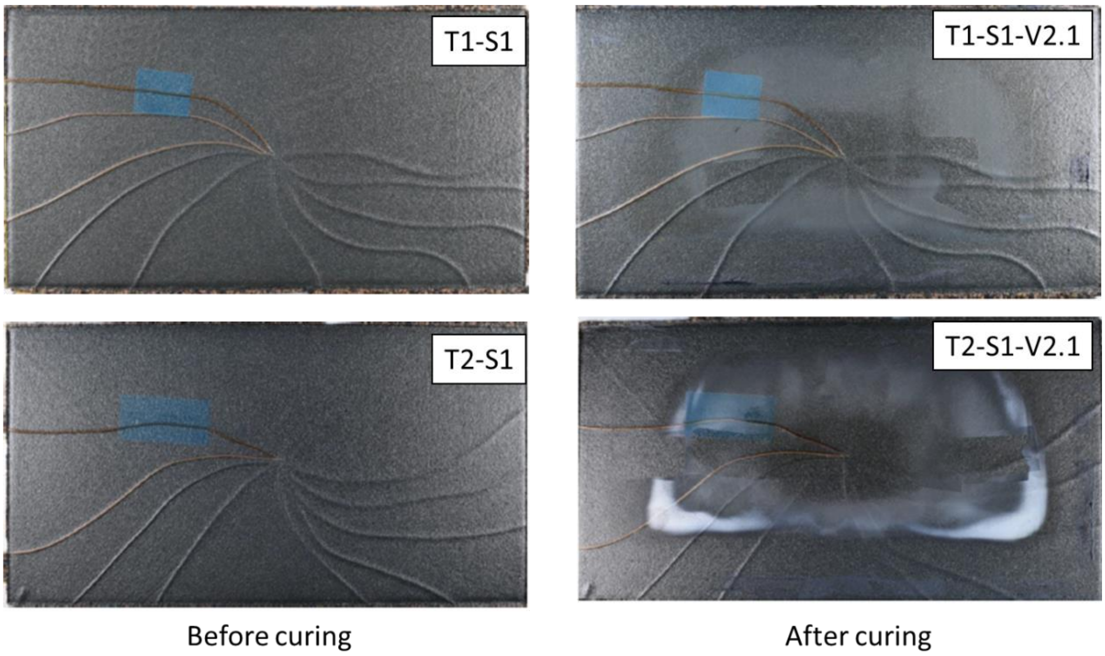


Figure 8. Colour changes detected by visual testing

### 4.2. Thermal cycle

The specimens were subjected to the defined thermal cycles and the values detected by the thermocouples were collected and analysed. Representative examples of the thermocouple graphs for each reference are shown in the figures below.

The graphs show three groups of measurements (see Figure 9); those provided by the thermocouples in the muffle (upper part) and below those indicated by the thermocouples inside the specimens. The observed temperature differential (TD) between the two types of specimens provides the delta value to identify the degree of improvement in thermal insulation. These values and the delta analysis are shown in Table 4 an in Figure 13.

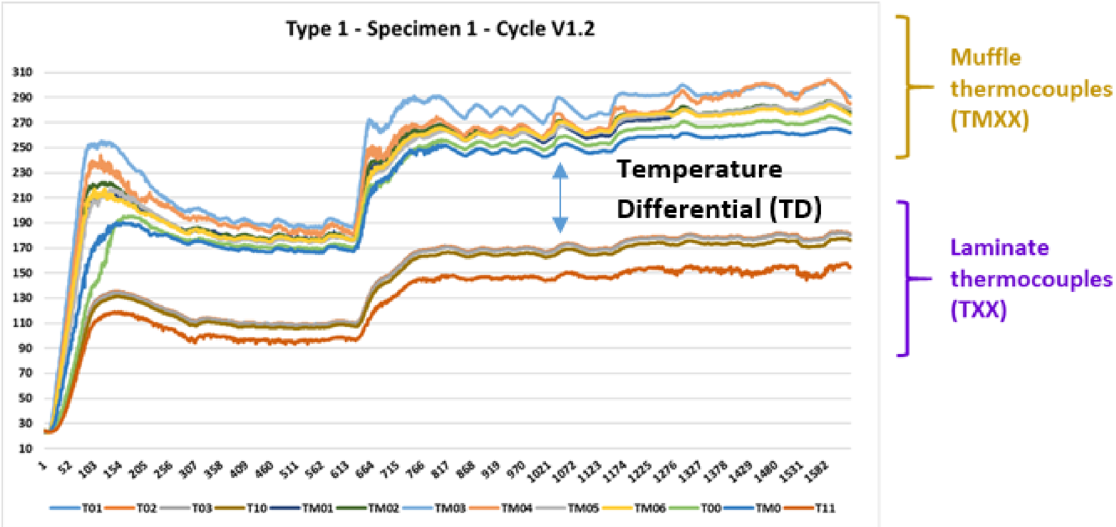


Figure 9. Thermal behaviour of T1-S1-V1

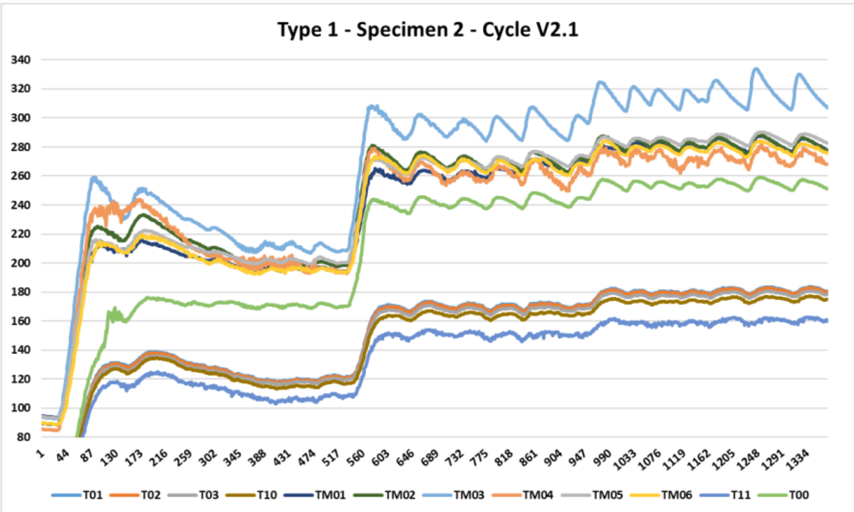


Figure 10. Thermal behaviour of T1-S2-V2

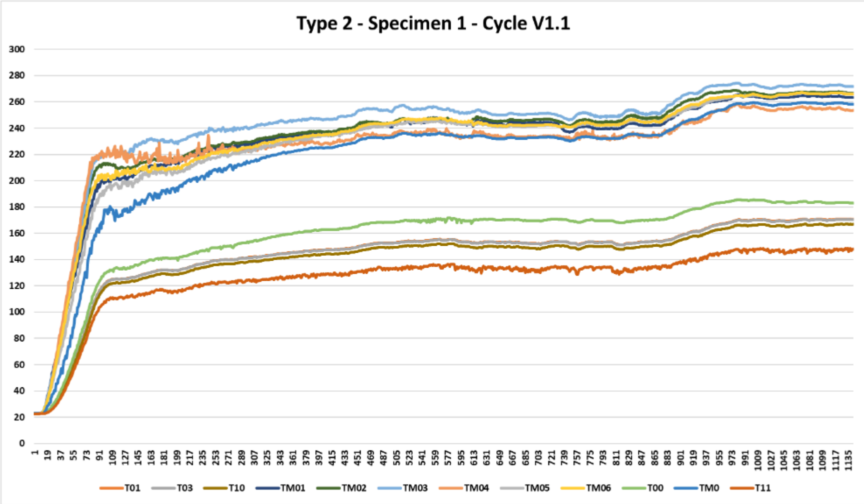


Figure 11. Thermal behaviour of T2-S1-V1

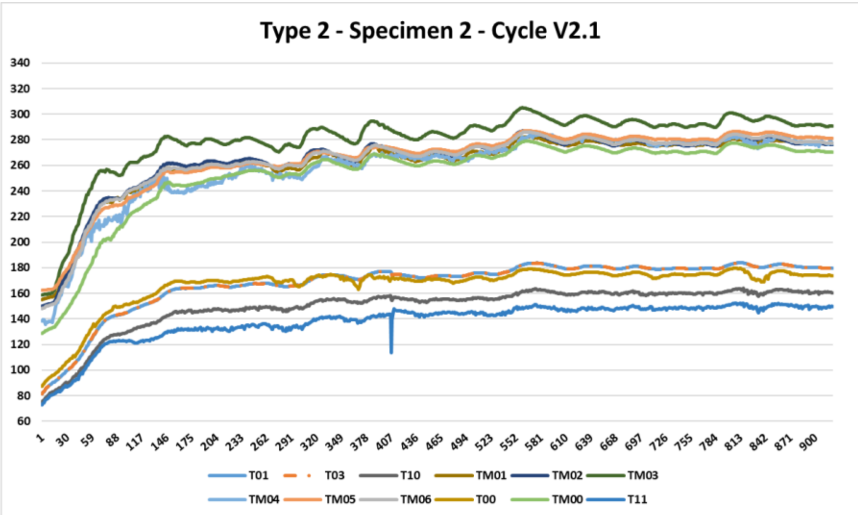


Figure 12. Thermal behaviour of T2-S2-V2

| Type-Cycle | Results | |
|---|---|---|
| | TD (°C) | ΔT (°C) |
| T1-V1 | 72,06 ± 8,71 | 58,4 |
| T2-V1 | 13,66 ± 2,61 | |
| T1-V2 | 69,85 ± 12,22 | 48,9 |
| T2-V2 | 20,90 ± 1,55 | |

Table 4. Thermal cycle results

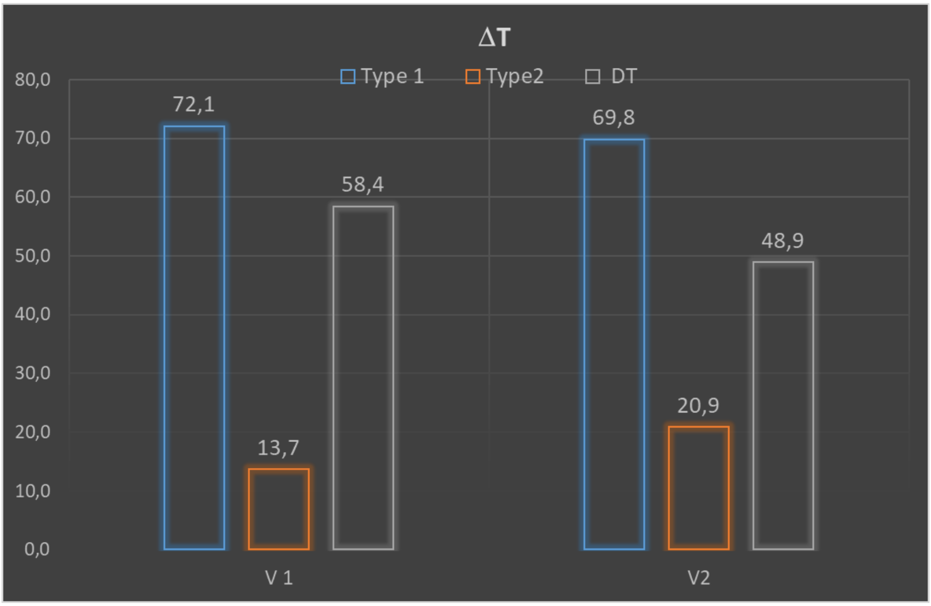


Figure 13. Delta of temperature results

The results show **a significant improvement when the insulating material is added to the laminate configuration**, achieving a delta 58.4 °C when the specimens are subjected to the V1 thermal cycle and 48.9°C when subjected to the V2 cycle. This is evidence of an improvement in insulating properties of at least a ΔT of 30ºC.

## 5. Conclusions

The first tests carried out on the materials designed in this project lead to the conclusion that the range of CFRP can be greater than that used today. The analysis of the results obtained shows:

- The designed material can be stacked and cured together. Non-destructive testing shows that the designed composites have an optimal quality where no defects such as delaminations, missing material or bubbles are visible.

- The designed material can act as a thermal barrier per se. The temperature control in the different thermal cycles to which the materials have been subjected has shown to reach an average ΔT value of 30ºC.

However, in order to certify this material for use in aeronautics, it is necessary to carry out a campaign of tests as contemplated in future work.

## 6. Future work

In order to validate the ΔT and certify the material for use in aeronautics, a testing campaign shall be developed as future work within the project. These tests will include the study of the degradation of the material during specific temperature cycles, mechanical characterisation of the material, thermal conductivity, flame retardancy and electrical and thermal conductivity tests.

## 7. Acknowledgments

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