TITLE: **Thermal test of panels of pyramids manufactured by Off. Pasquali**

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CHANGE RECORD

Issue	Date	Sheet	Description of Change
0.1	June, 2004	All	First issue of this document
0.2	June, 14, '04	4	changed legend in Figure 3 and Figure 4
		10-end	added data for cycles 2,3,4
		3	updated with sensor accuracy
0.3	June, 25, '04	12-14	plots added
			preliminary analysis added
0.4	June, 30, '04		Plots added
1.0	April 10, 2012		Final Configuration as Internal Report

TABLE OF CONTENTS

1 SCOPE

1.1 Purpose

Purpose of this test is to verify the bonding concept of ECCOSORB panels of pyramids at operating temperature (approximately 4K). This activity is made under contract by Officine Pasquali.
Purpose of this report is to describe the test setup and test results.
In addition a preliminary thermal study is presented.

1.2 Document Overview

Two different bonding scheme are simultaneously tested inside a 4K cryofacility.
Nine thermal cycles have been performed to check the thermal and structural behaviour of the two samples. The cryo facility is opened and visual inspections of the samples are performed after the first, the fourth and the last cycle.
In this document, we report the test instrumentation, the mounting design and the sample preparation in Section 3 and 4.
In Section 5, details about all the cycles, together with temperature curves and pictures taken during the visual inspections, are reported.
In Section 6, a preliminary analysis of the temperature distribution on the samples is presented.

1.3 TERMS and ACRONYMS

CF: Cryo Facility
SUT: Sample under test

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable documents

AD 1: ECCOSORB pyramid panels fixation study: thermal cycle test procedures, IASF-BO-IR-04/002, Ver 1.0

2.2 Reference documents

RD 1: Lakeshore DT670 data sheet
RD 2: *The 4KRL cryo facility*, PL-LFI-TES-TN-010

3 Test setup

Test is performed in the IASF-Bo 4K cryo facility, fully described in RD 2. Parts are manufactured by Officine Pasquali and delivered to IASF on May, 31st, 2004.
A support structure, consisting of 4 supporting flanges made of Al6061 (well visible in Figure 1 and Figure 2), was prepared to hold the parts.

3.1 Temperature sensor characteristics and location

Sensor ID	Type	type of fixation	Location
C1	-	-	Not in use
C2	Si-diode	taped with kapton, thermal grease	Sample 2 (screws), pyramid tip
C3	Si-diode	taped with kapton, thermal grease	Sample 1 (Hysol), ECCOSORB base
C4	Si-diode	taped with kapton, thermal grease	Sample 1 (Hysol), Pyramid tip
D1	Si-diode	taped with kapton, thermal grease	Sample 1 (Hysol), Al substrate
D2	Si-diode	taped with kapton, thermal grease	Sample 2 (screws), ECCOSORB base
D3	Si-diode	taped with kapton, thermal grease	Sample 2 (screws), Al substrate
D4	Si-diode	screwed	CF cold flange (for reference)

Table 1: Temperature sensor location

The temperature sensors used are LakeShore DT670 silicon diode; their accuracy is ±0.25K, as reported in RD 1.

4 Sample preparation

4.1 Sample identification

Three samples are delivered for testing:

- Sample 1: ECCOSORB panel of pyramids, bonded with Hysol 9394EA on Al 1050 substrate. One M4 screw is mounted at the center of the panel.
- Sample 2: ECCOSORB panel of pyramids screwed on Al 1050 substrate. Four M4 screws are used.

4.2 Preliminary inspection of the parts

Parts were inspected before their mounting on the flanges.

- Sample 1: no crack is observed, no flaking is observed. Some pyramids are damaged since this is a test panel. The actual status of the panel has no influence on this kind of test. Temperature sensor is mounted at the tip of one pyramid with manufactured nominal quality.
- Sample 2: no crack is observed, no flaking is observed. The quality of the panel is the ‘standard’ for the Planck cold load.

4.3 Panels' mounting

Sample 1 interface with the CF cold finger was cleaned with alcohol. Apiezon N cryogenic thermal grease was used to improve thermal contact between the sample's Al substrate and the CF cold finger. Temperature sensors were mounted as reported in Table 1.
Sample 2 screws were tightened with low torque, to avoid damages to the threaded hole in the ECCOSORB panel. The Al panel was hand tightened to a higher torque. Temperature sensors were mounted as reported in Table 1.
Stainless Steel screws are used. Panels were mounted with pyramids' tips facing down, to test the bonding and the fixation under 1g gravity effect.

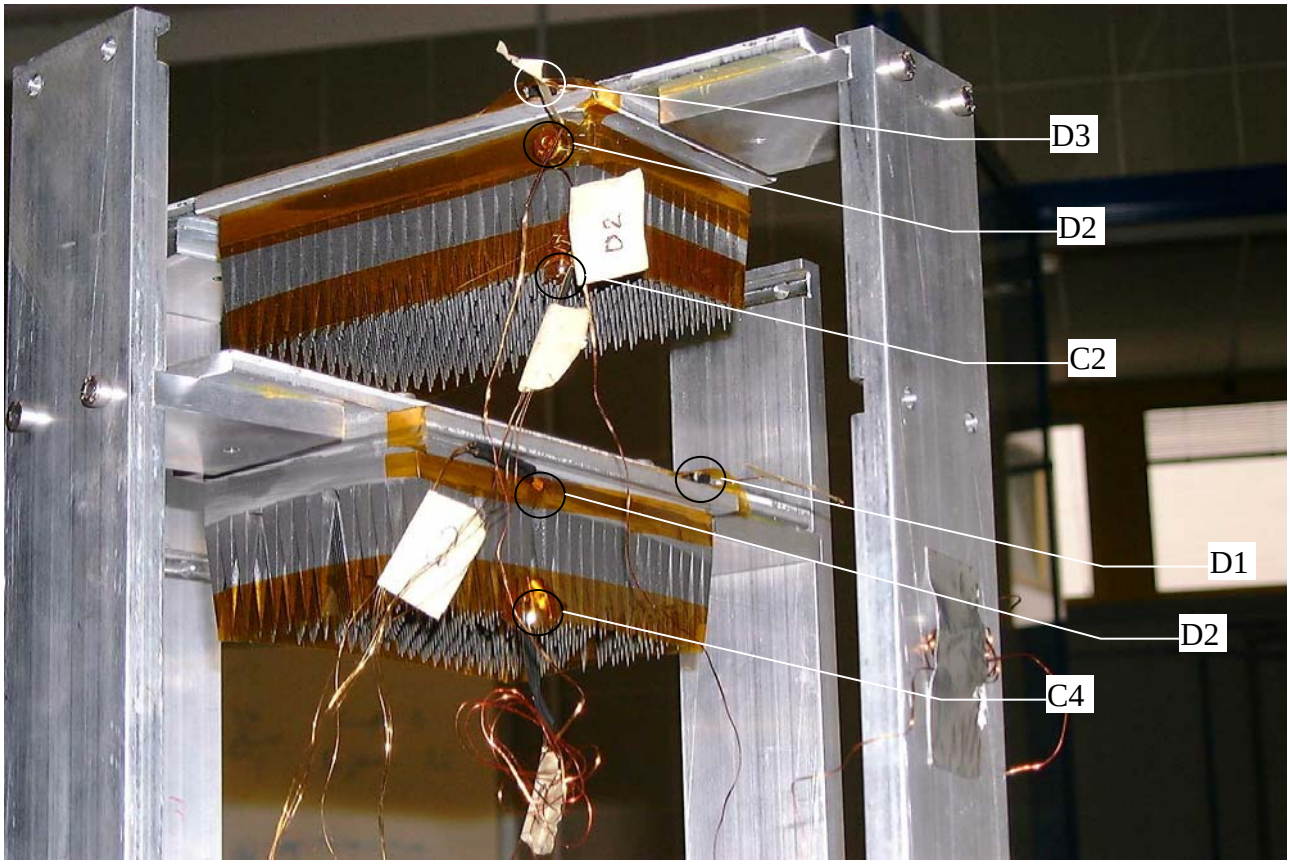

Figure 1: Samples assembly in the CF: Sample 1: lower, sample 2: upper. The position of temperature sensors is shown.

Kapton tape is used to hold the temperature sensors in good thermal contact with the samples.

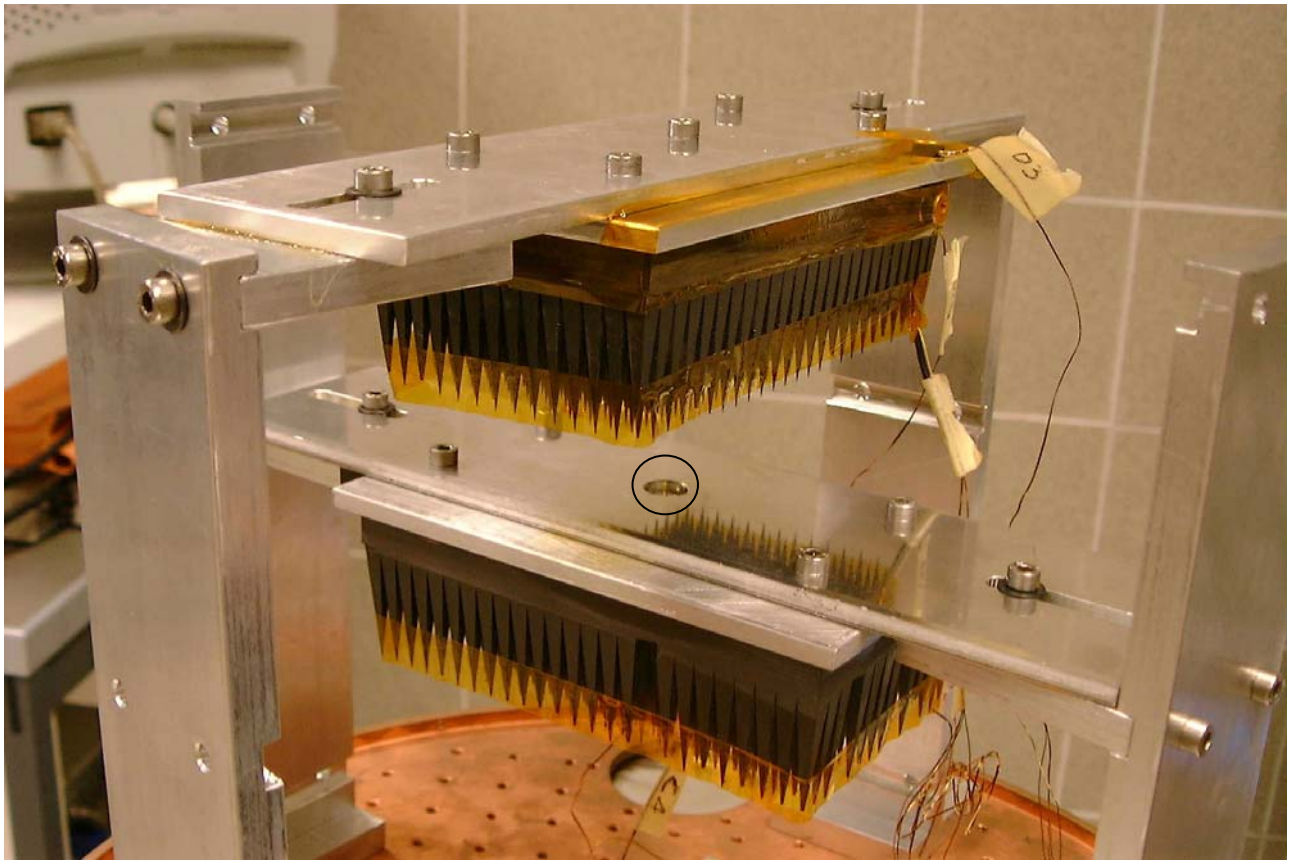

Figure 2: View of the assembly. The position of the central screw on sample 1 is shown (circle on the lower sample).

5 Thermal cycles

5.1 Cycle 1

The test started on June, 1st, 2004 at 12:30. The CF was evacuated using a dry rotative pump. Acquisition of temperature sensor was started at 15:08. Acquisition period was set to 60s.
When a pressure of 1.1E-1 mbar was reached, the cryo-Cooler was started at 15:08. The pump was stopped when the pressure reached 2.2E-2 mbar. Cool-down data are reported in Figure 3.

On June 2nd, 2004, the cryocooler was turned off at 10:28. Warm-up procedure was started. Additional heating (6.6W) was introduced using resistors mounted on the cold flange. Warm-up profile is reported in Figure 4.
Once the temperature of 295K was reached by the reference sensor (C2), the CF was filled with dry air and opened.
Temperature sensors were still in place and appeared in good physical contact with samples. Sensor location was re-checked.

Pictures were taken before de-assembling the samples (Figure 5).

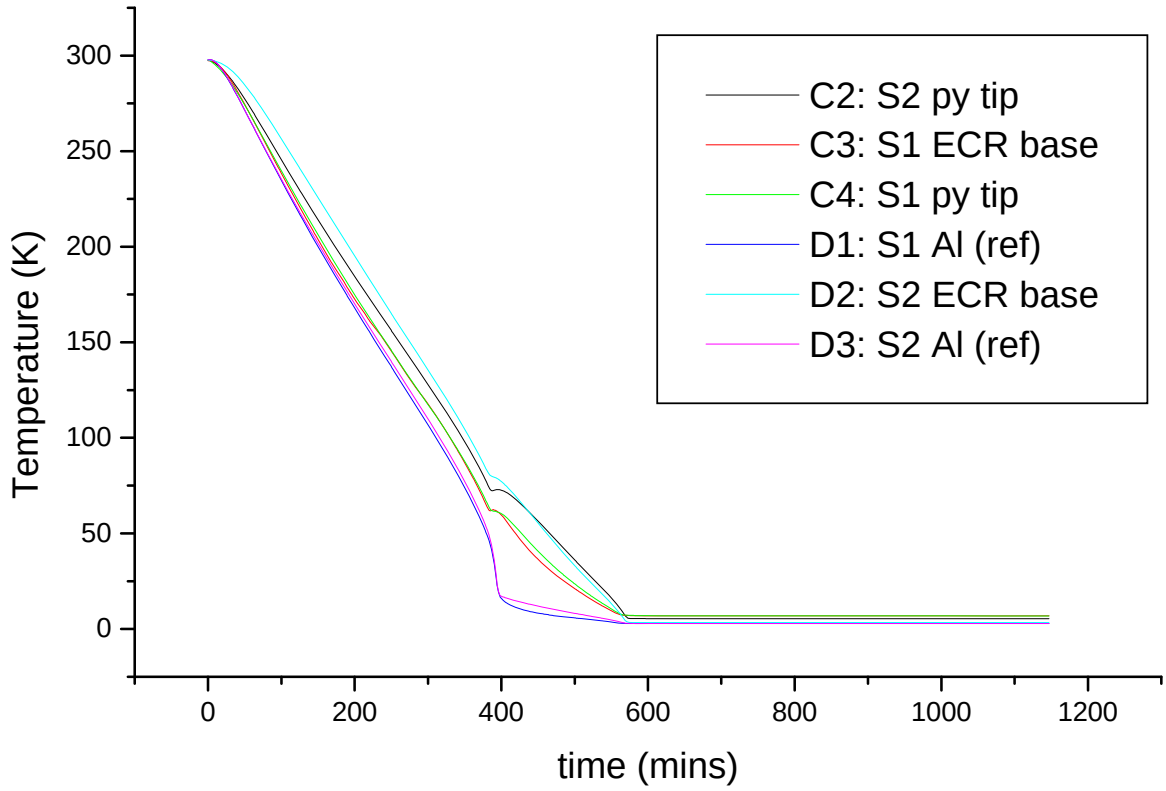

Figure 3: Overall view of the cool-down of first thermal cycle

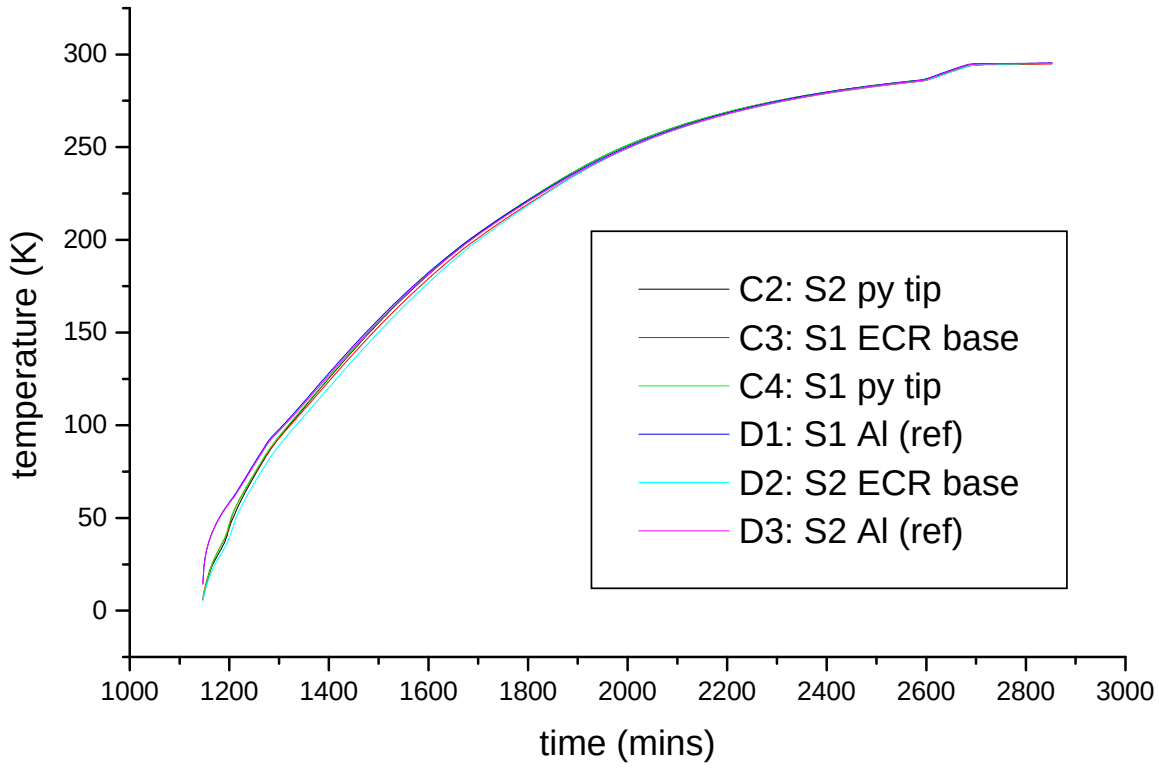

Figure 4: Overall view of the warm-up of the first cycle

5.2 Inspection 1

5.2.1 Sample 1: Panel bonded with Hysol

Some cracks appeared on the ECCOSORB base. It is possible to establish how deep these cracks are. The ECCOSORB base is disconnected from the Al substrate at the corners of the panel, spacing is approximately 0.5 mm. Photographs of the panel are taken (Figure 6-Figure 8).
Pyramid panel is de-mounted from the CF (not foreseen in the test procedure AD 1) to carefully inspect it. The bonding was checked by pulling the sides of the ECCOSORB base. No movement was observed. The pyramid panel still appears strongly bonded to the Al panel.
Cracks are marked and pictures are taken.
No flaking is observed, no change in color is observed.
Since the bonding still appears solid, it is decided, according to the contractor, to go on with the test to verify the panel behavior from the mechanical and thermal point of view.

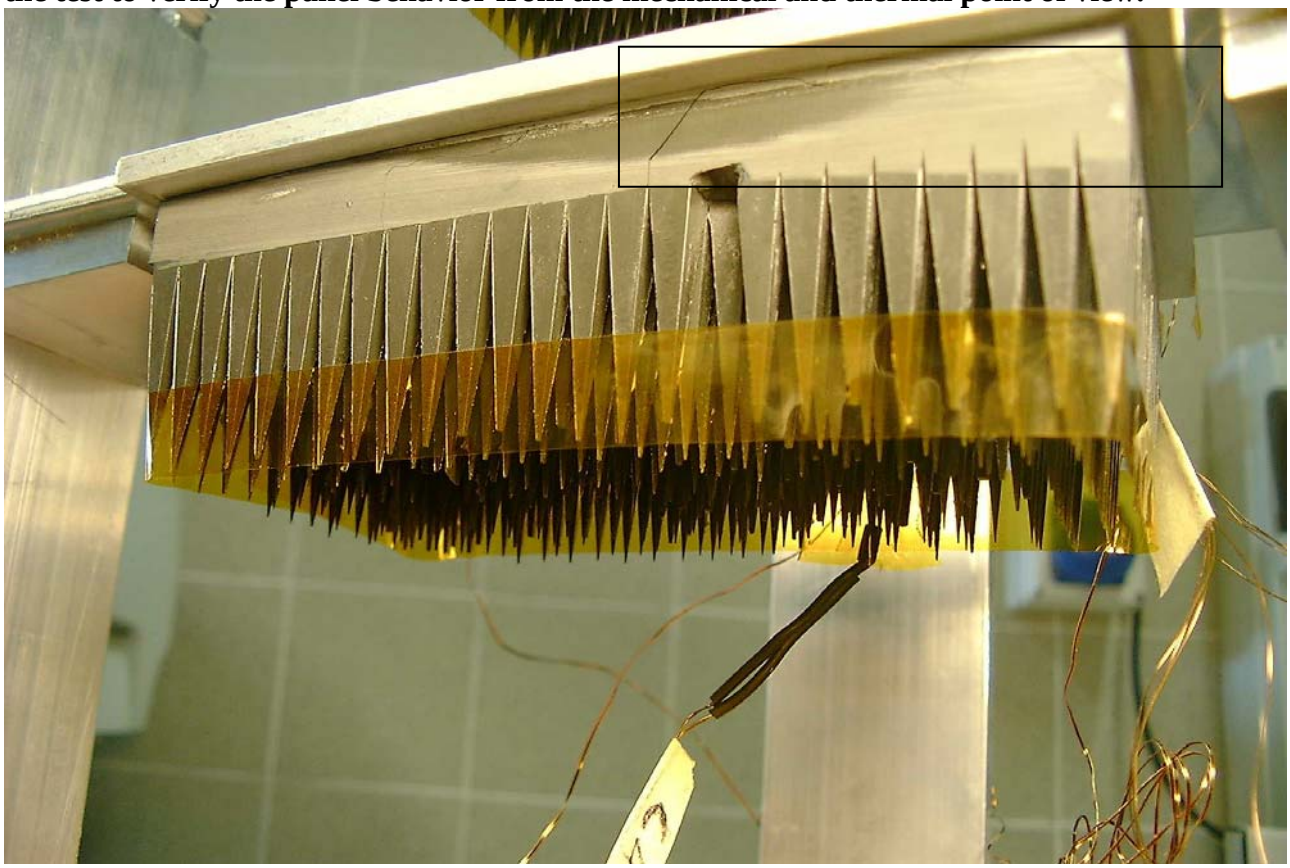

Figure 5: Sample 2: the area of one of the cracks is marked. The pyramid was already missing before the first cycle.

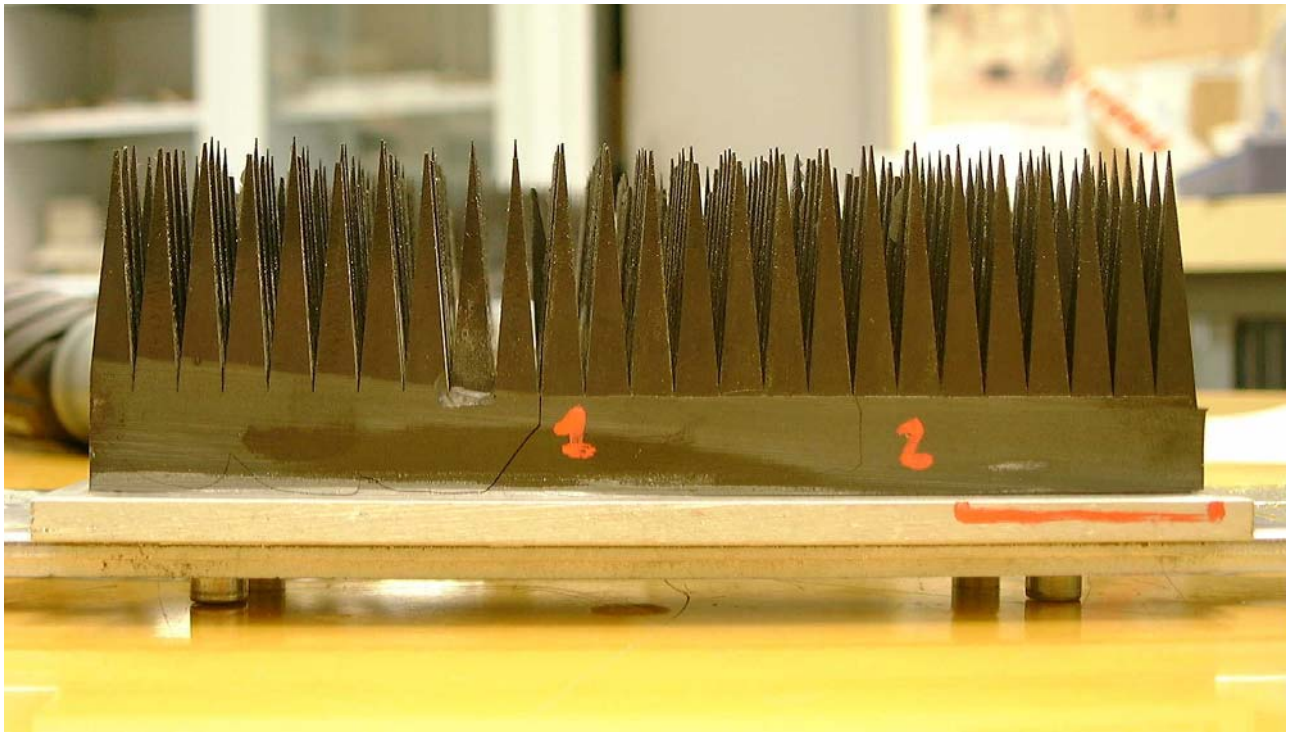

Figure 6

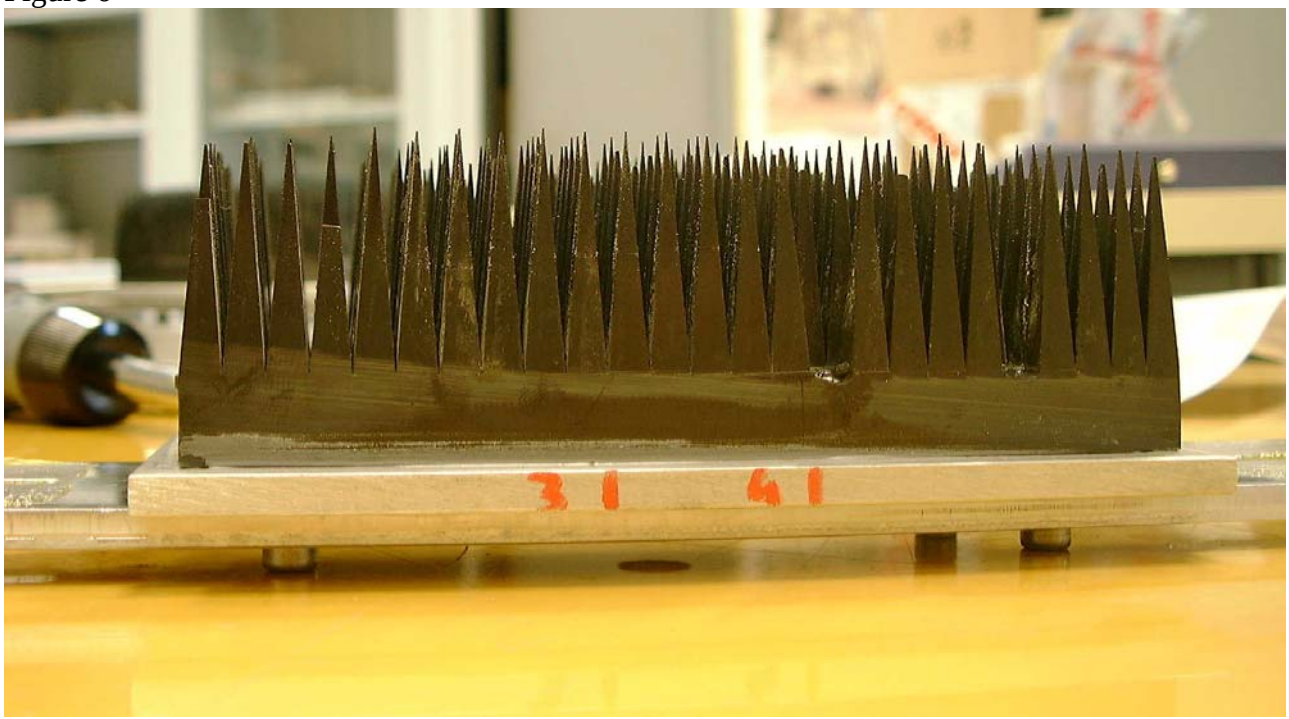

Figure 7

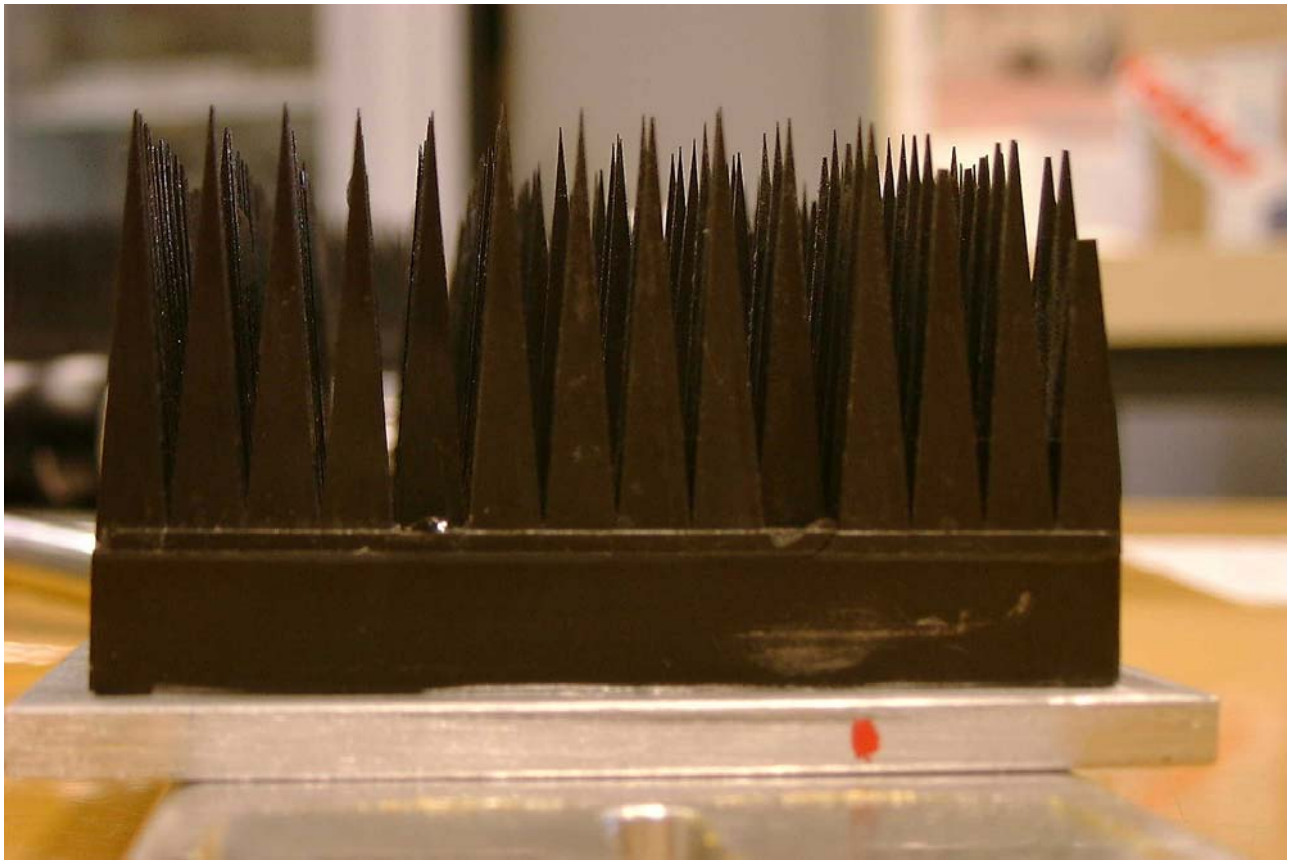

Figure 8

5.2.2 Sample 2: screwed panel

No crack is observed, no flaking is observed, no change in color is observed. Sample 2 is de-mounted from the CF (not foreseen in the test procedure AD 1) to carefully inspect it. The fixation torque of the screws between the Al substrate and the ECCOSORB base is checked. Value is 0.75 N·m.
Threaded holes on the Al substrate appear damaged. Therefore, Helicoils are mounted in the screw holes.

5.3 Cycles 2-4

5.3.1 Sample preparation

All parts in their contact surfaces were cleaned with ethylic alcohol.
ECCOSORB pyramid panel of sample 2 was mounted on its Al support, using 3 M4 Al screws and 1 M4 SS screw. The mounting torque was set to 0.8 N·m.
The Al substrate was screwed its Al support using 5 M4 SS screws. Apiezon N thermal grease was interposed. Torque was set to 1.2 N·m..
Sample 1 (Figure 9) and Sample 2 (Figure 10Figure 1) were re-mounted in the CF. Temperature sensors were mounted with the same philosophy of the first cycle, according to AD 1.

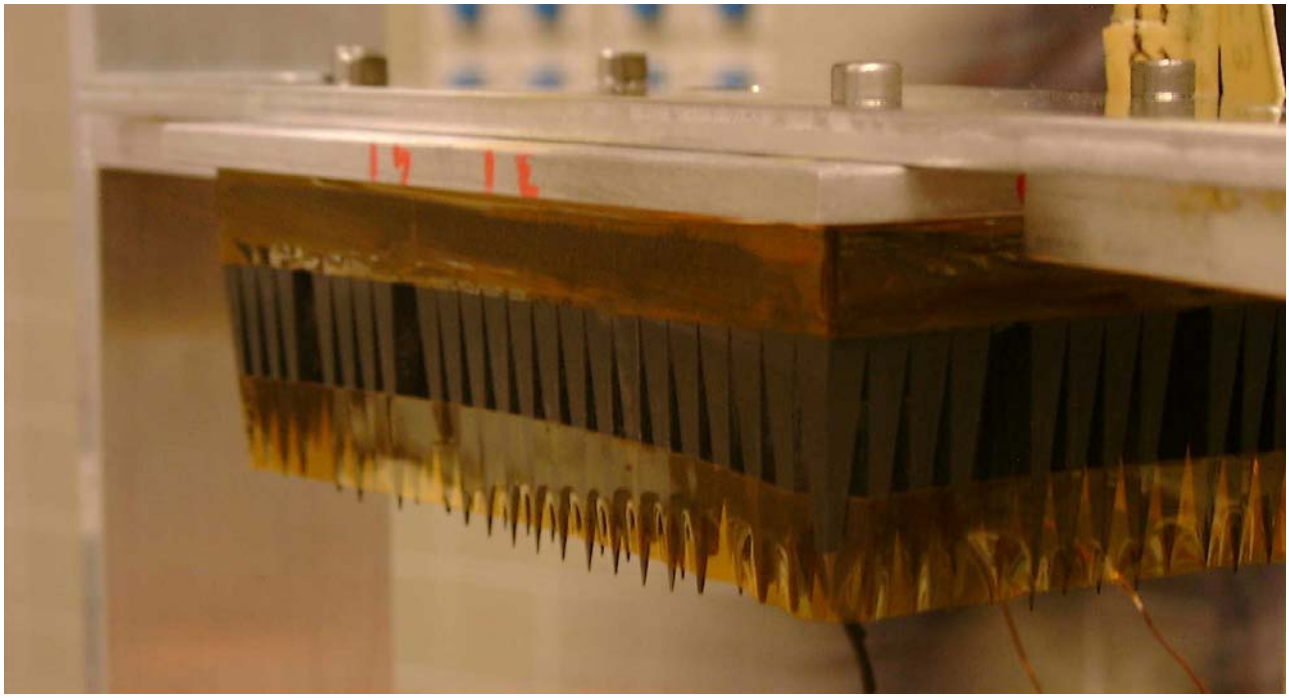

Figure 9: Sample 1 mounted in the CF for the second set of thermal cycles.

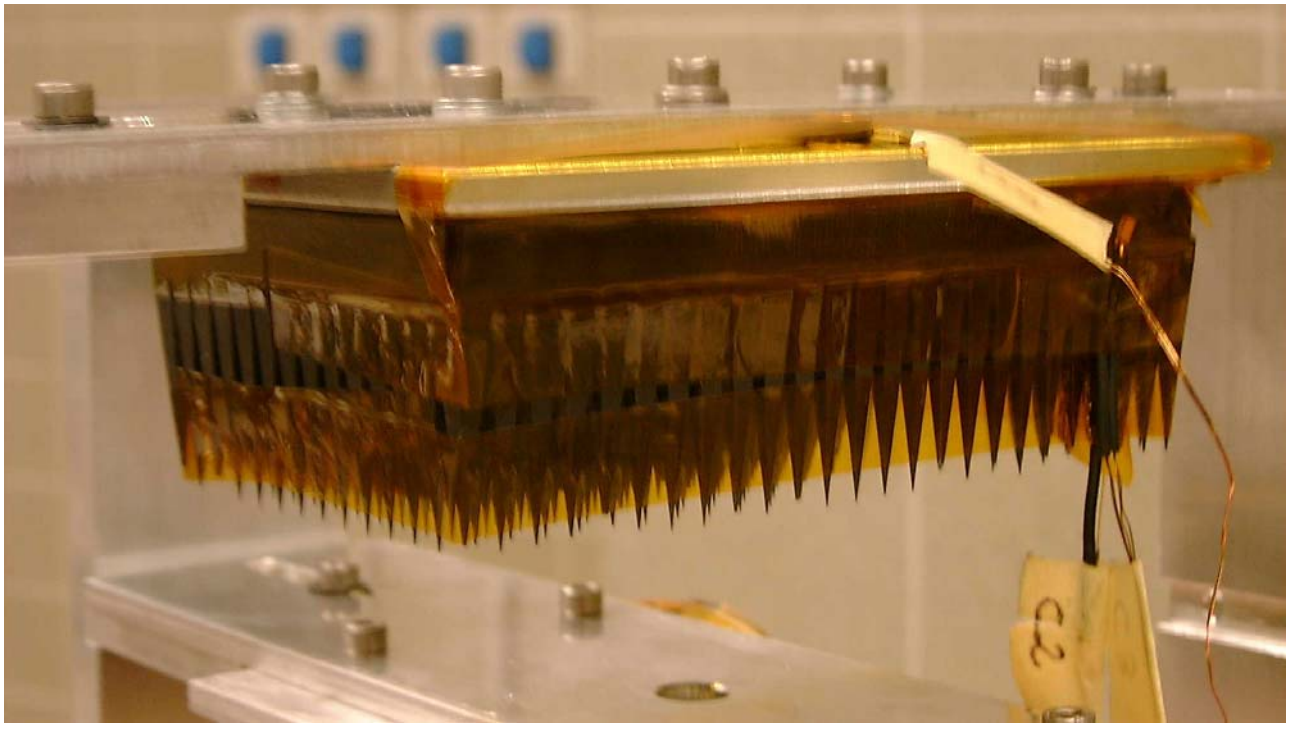

Figure 10: Sample 2 mounted in the CF for the second set of thermal cycles.

5.3.2 Thermal cycle 2

The thermal cycle is performed in compliance with the procedure described in AD 1.

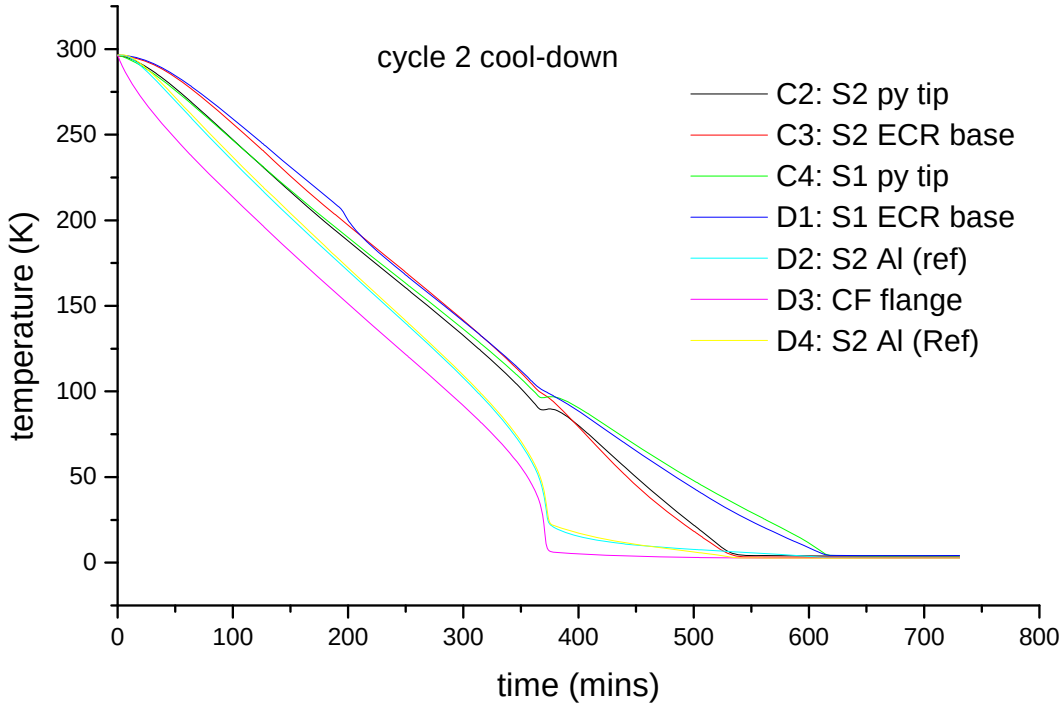

Figure 11: Cycle 2 cool down data.

5.3.3 Thermal cycle 3

The thermal cycle is performed in compliance with the procedure described in AD 1.

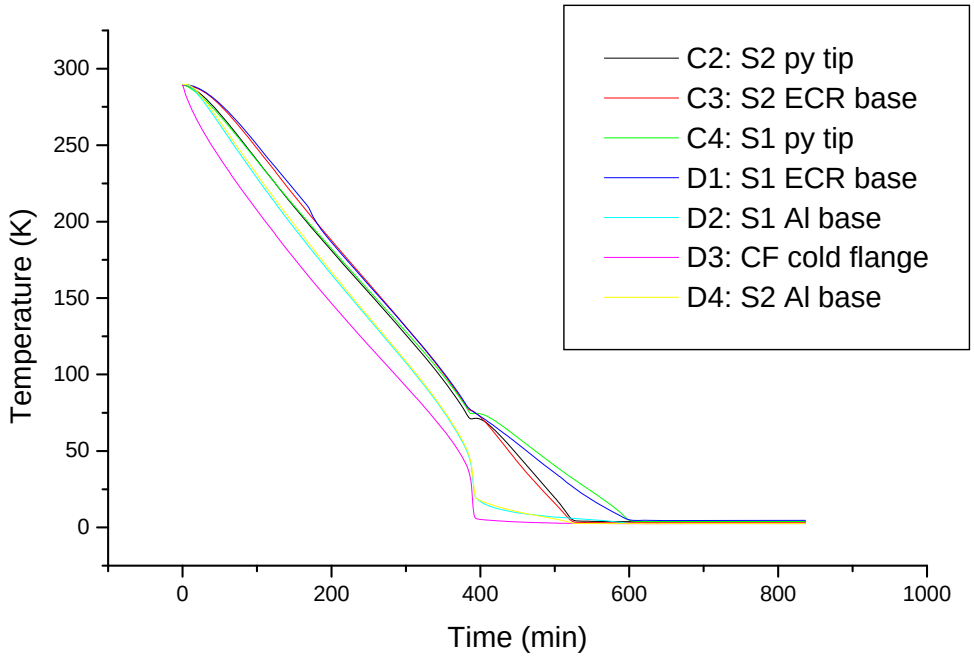

Figure 12: Thermal cycle 3 data.

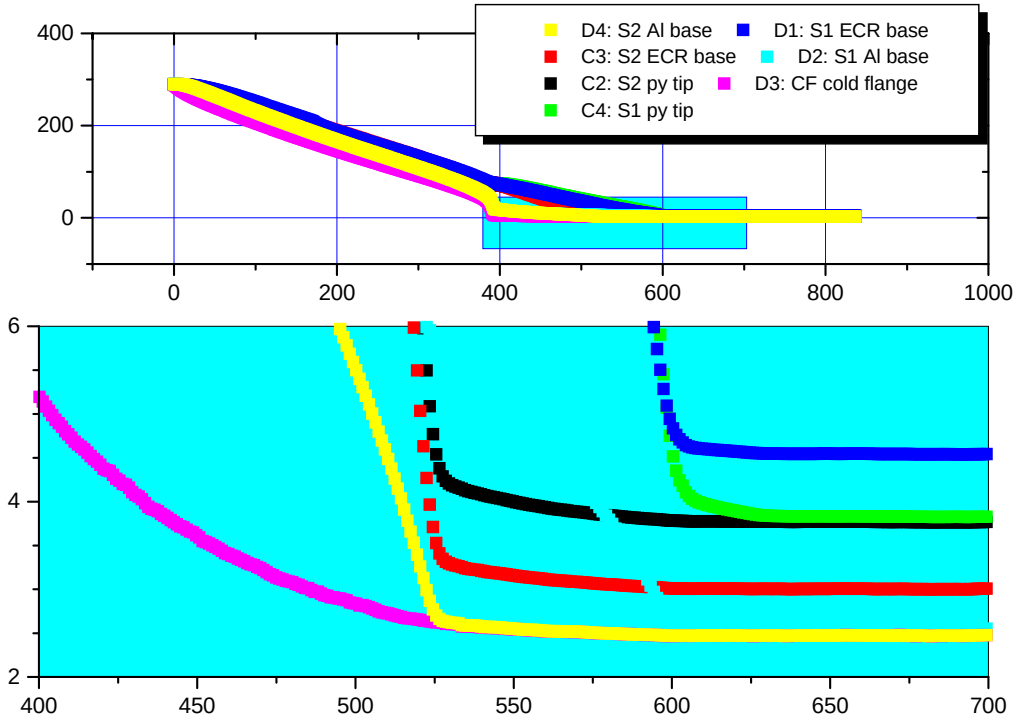

Figure 13: Details of the 3rd thermal cycle. Horizontal axis reports time in minutes, vertical axis the temperature in K.

5.3.4 Thermal cycle 4

The thermal cycle is performed in compliance with the procedure described in AD 1.

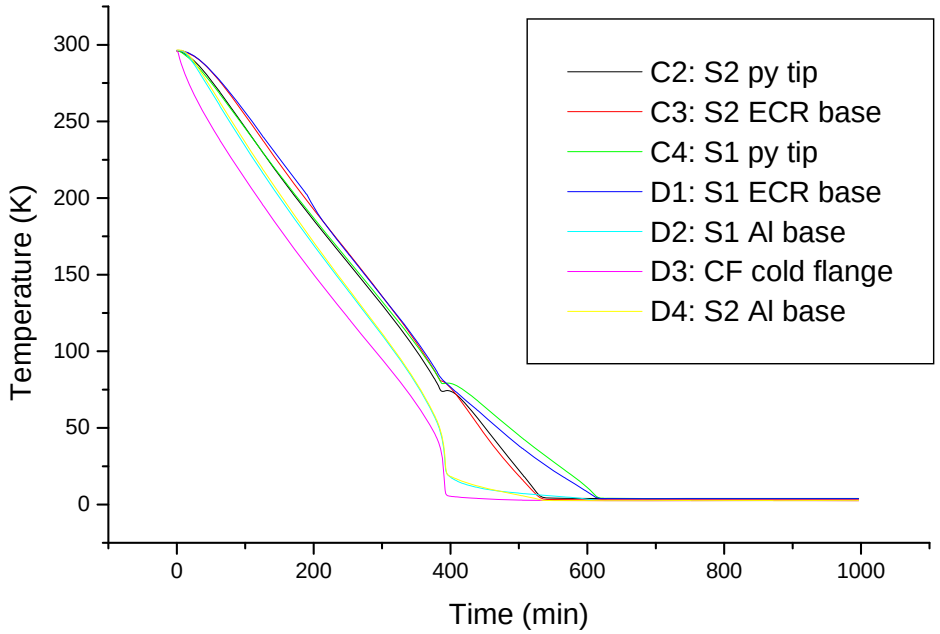

Figure 14: Thermal cycle 4 data.

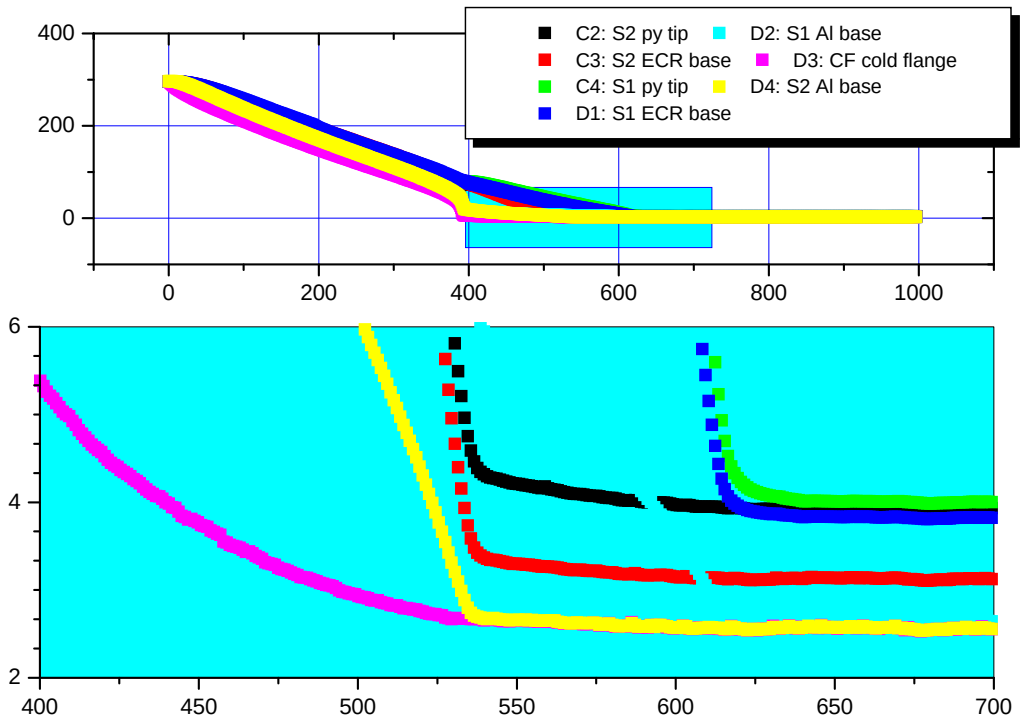

Figure 15: Details of the 4th thermal cycle. Horizontal axis reports time in minutes, vertical axis the temperature in K.

5.4 Inspection 2

5.4.1 Sample 1: Panel bonded with Hysol

Two pyramids were found broken on the cold flange (Figure 16). Another pyramid were broken but still attached to the panel.

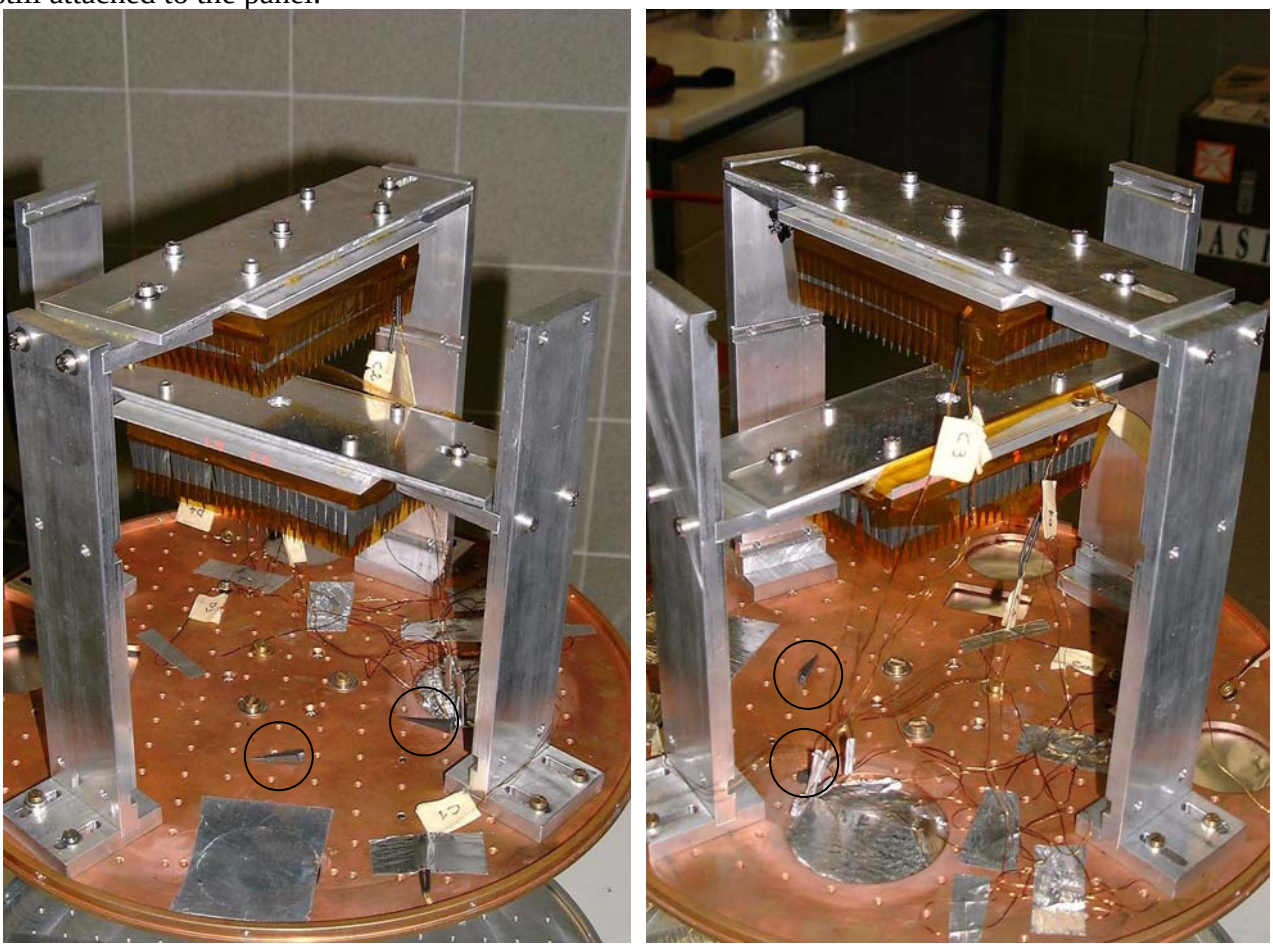

Figure 16: Views of the samples before de-mounting for inspection 2. Broken pyramids are marked with circles.

Sample 1 was de-mounted from its support and carefully inspected.
No additional crack in addition to those found during inspection 1 were found. Cracks appears with the same shape and dimension (Figure 17-Figure 20).

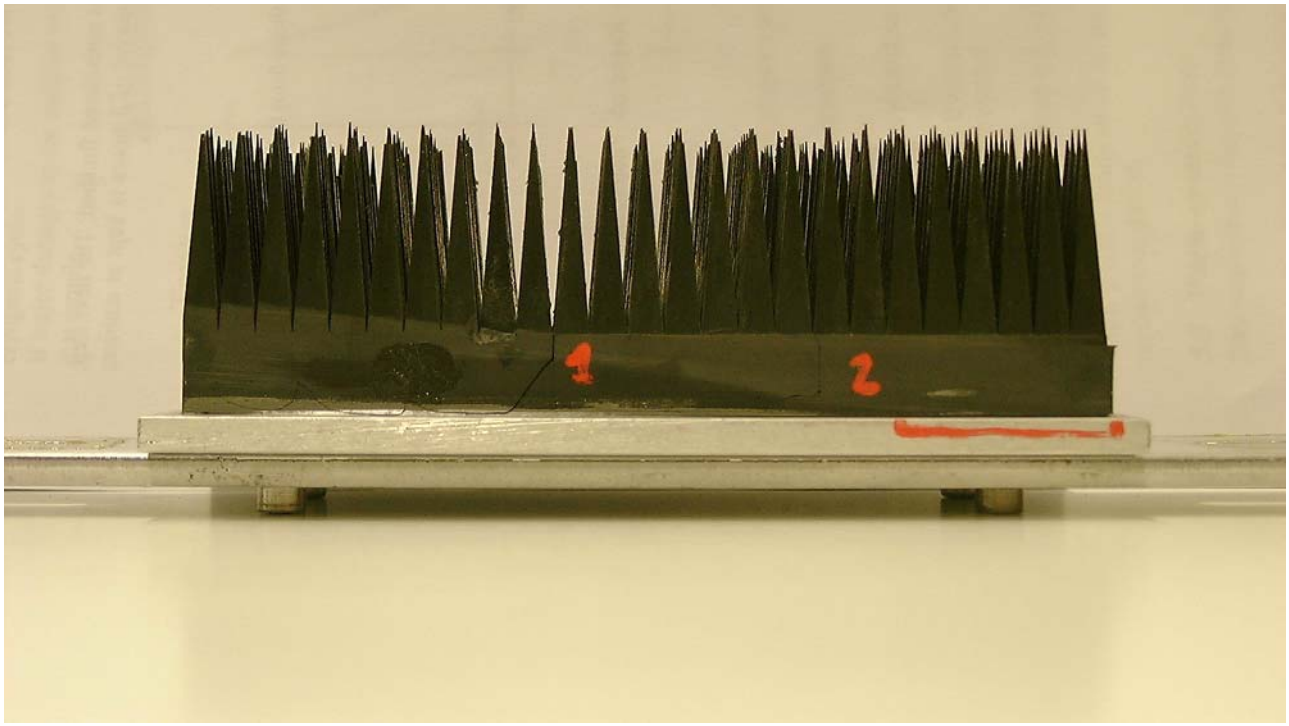

Figure 17:

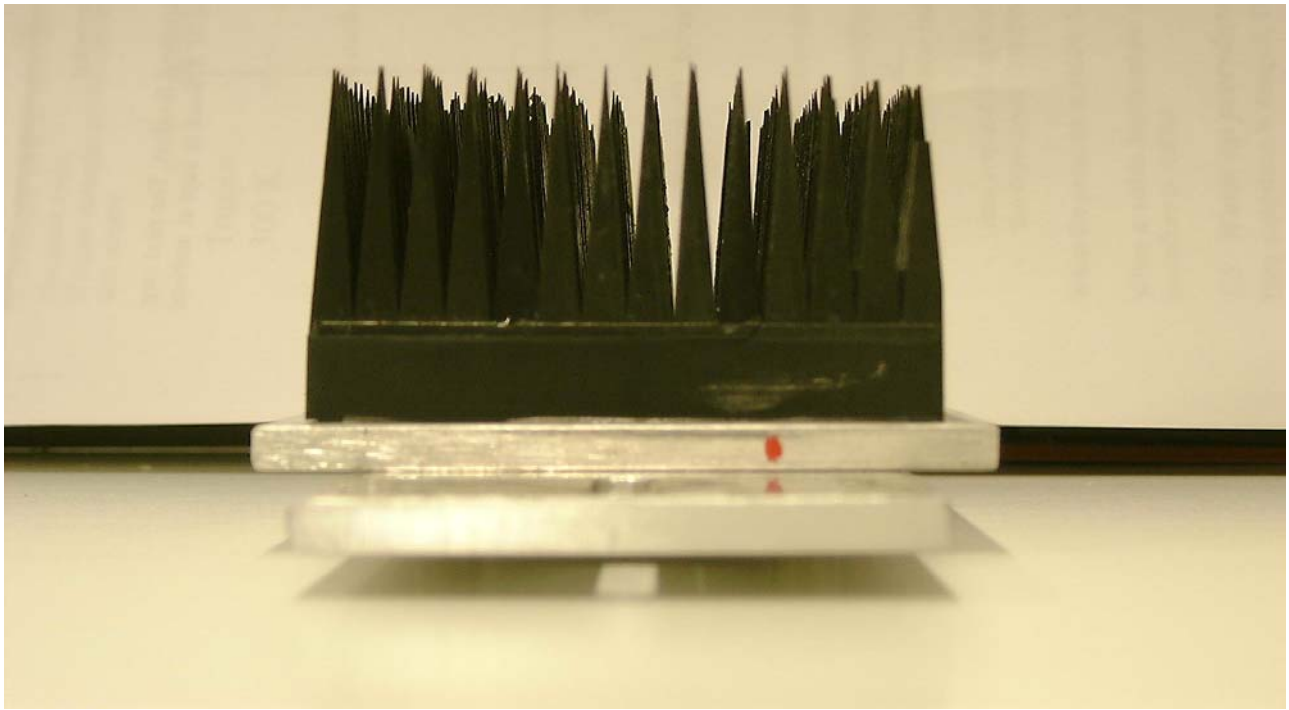

Figure 18

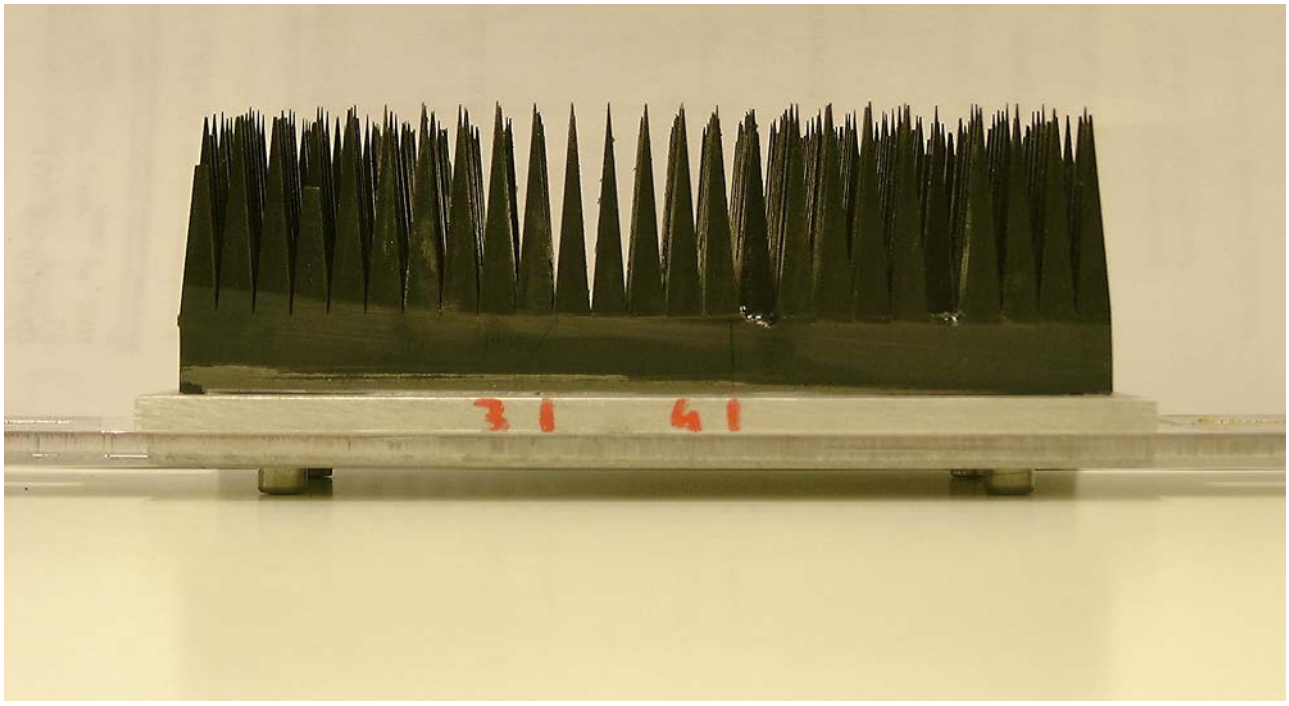

Figure 19

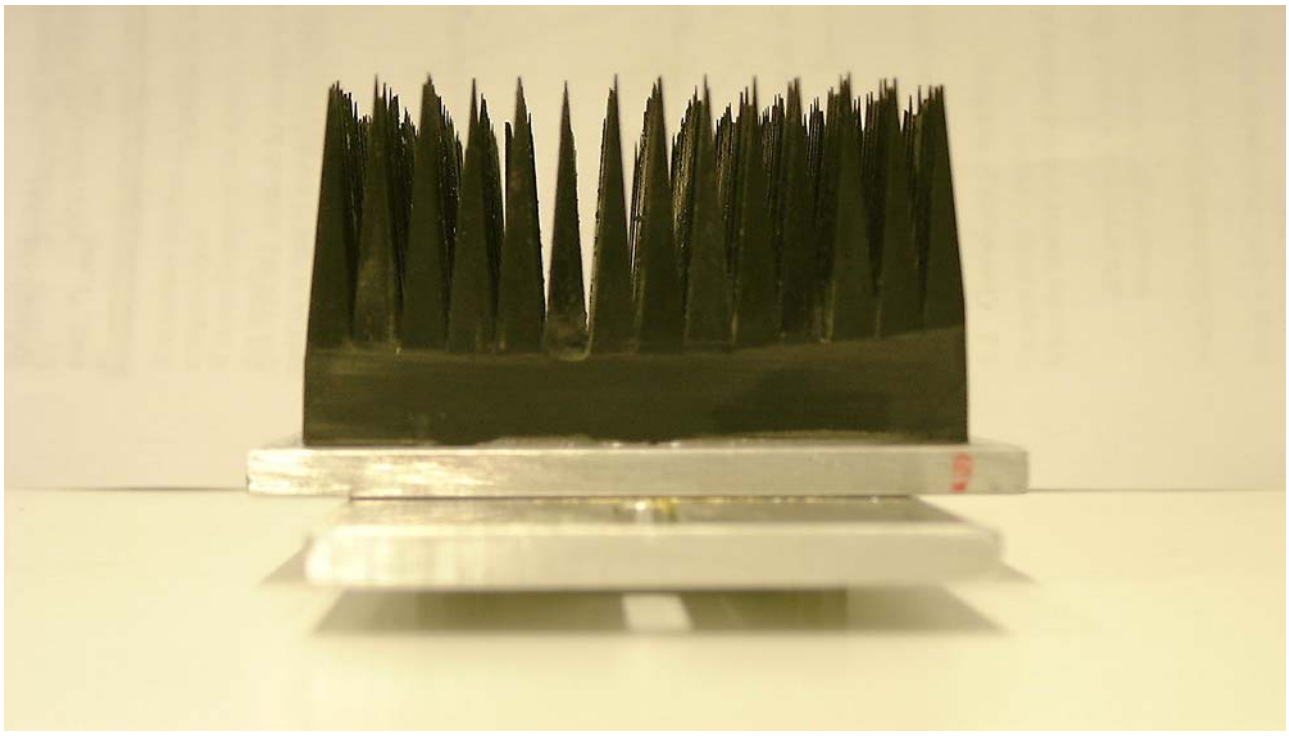

Figure 20

5.4.2 Sample 2: screwed panel

No crack is observed, no flaking is observed. Sample 2 is de-mounted from the CF (not foreseen in the test procedure AD 1) to carefully inspect it. The fixation torque of the screws between the Al substrate and the ECCOSORB base is checked. Value is equal to the original one (0.8 N· m) within measurement errors (±0.1 N· m).
Change in color is observed in the back, flat surface. It is due to the thermal contact grease leaked through the screw holes. This feature disappears by cleaning the part with alcohol.

5.5 Cycles 5-9

5.5.1 Sample preparation

All parts in their contact surfaces were cleaned with ethylic alcohol.
ECCOSORB pyramid panel of sample 2 was mounted on its Al support, using 3 M4 Al screws and 1 M4 SS screw. The mounting torque was set to 0.8 N·m.
The Al substrate was screwed to its Al support using 5 M4 SS screws. Apiezon N thermal grease was interposed. Torque was set to 1.2 N·m.
Sample 1 and Sample 2 were re-mounted in the CF. This time, temperature sensors were mounted only on the screwed panel in order to better monitor its temperature distribution. Six sensors were used: one on the cold flange, three sensors were located on the same thermal path (TP) from the Aluminum support to the Eccosorb base and then to the pyramid tip, while two sensors were mounted on the panel Eccosorb base and on a pyramid far from the TP. Three screwed holes were built to fix the sensors on the Aluminum support and to the Eccosorb base.
Corresponding locations are reported in Table 2.

Sensor ID	Type	type of fixation	Location
C1	-	-	Not in use
C2	Si-diode	taped with kapton, thermal grease	Pyramid tip
C3	Si-diode	taped with kapton, thermal grease	Thermal Path (TP), pyramid tip
C4	-	-	Not in use
D1	Si-diode	Screwed	Eccosorb base
D2	Si-diode	Screwed	Thermal Path (TP), Al substrate
D3	Si-diode	Screwed	CF cold flange (for reference)
D4	Si-diode	Screwed	Thermal Path (TP), Eccosorb Base

Table 2: Temperature sensor location in cycles 5-9

5.5.2 Thermal cycle 5

The thermal cycle is performed in compliance with the procedure described in AD 1.

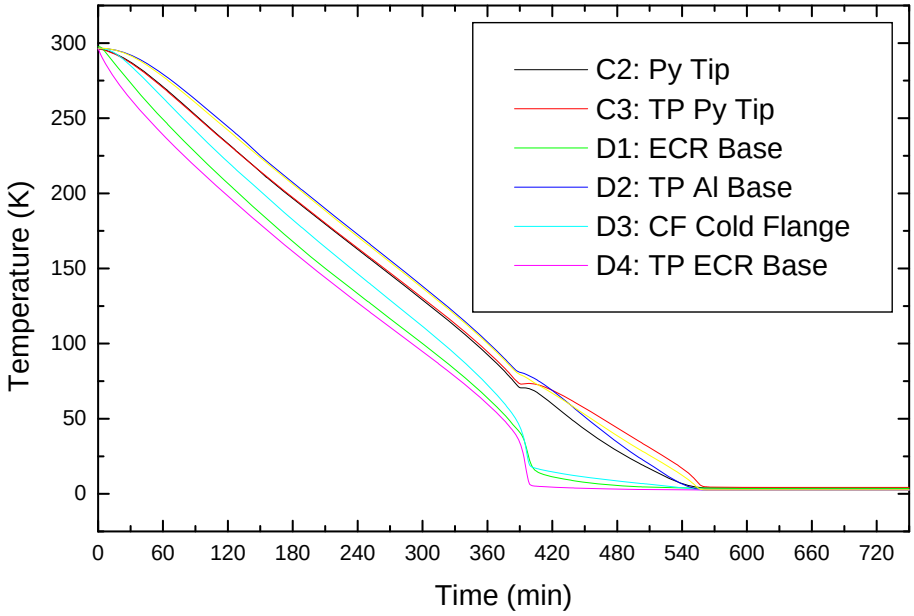

Figure 21: Thermal cycle 5 cooldown data.

5.5.3 Thermal cycle 6

The thermal cycle is performed in compliance with the procedure described in AD 1.

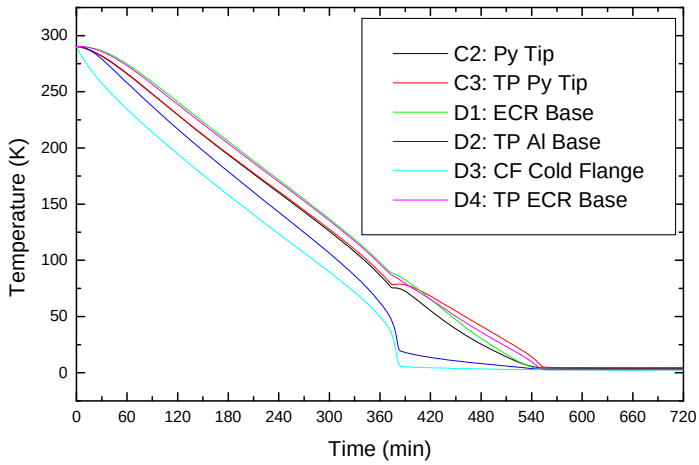

Figure 22 Thermal cycle 6 cooldown data.

5.5.4 Thermal cycle 7

The thermal cycle is performed in compliance with the procedure described in AD 1.

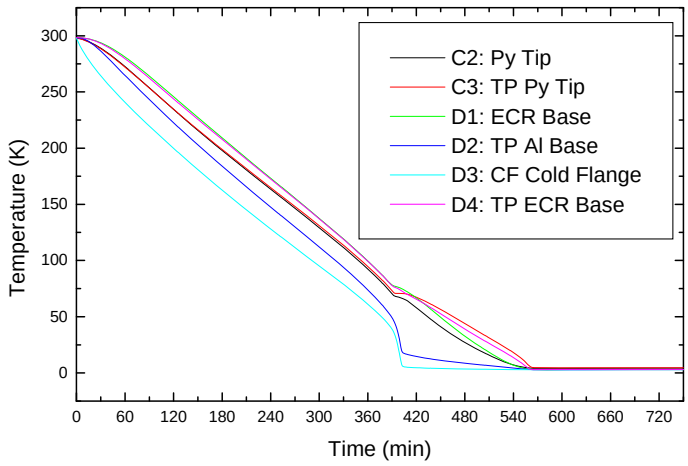

Figure 23 Thermal cycle 7 cooldown data.

5.5.5 Thermal cycle 8

The thermal cycle is performed in compliance with the procedure described in AD 1.

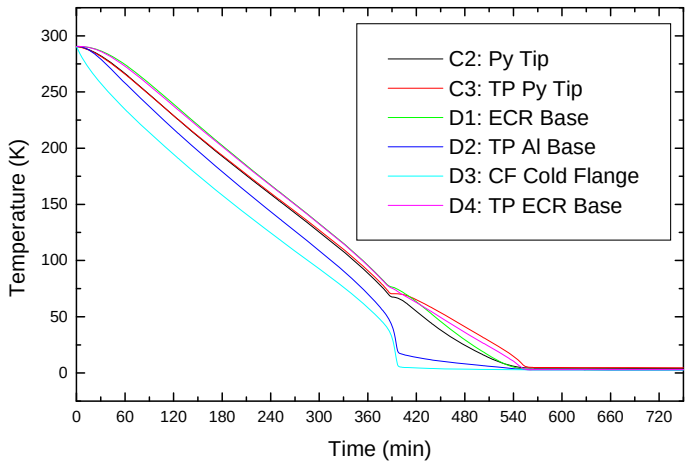

Figure 24 Thermal cycle 8 cooldown data.

5.5.6 Thermal cycle 9

The thermal cycle is performed in compliance with the procedure described in AD 1.

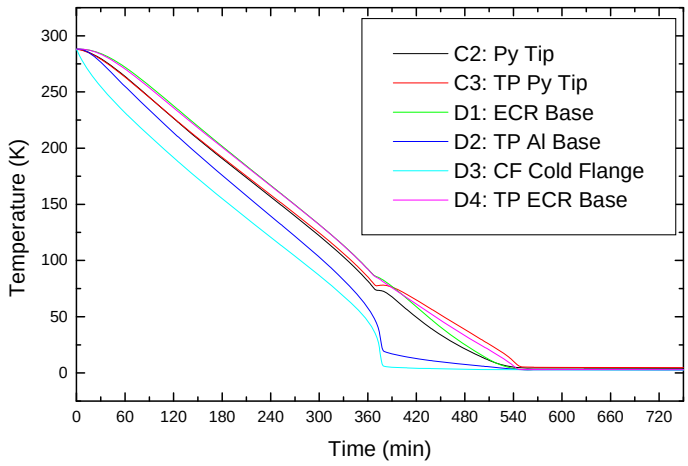

Figure 25 Thermal cycle 9 cooldown data.

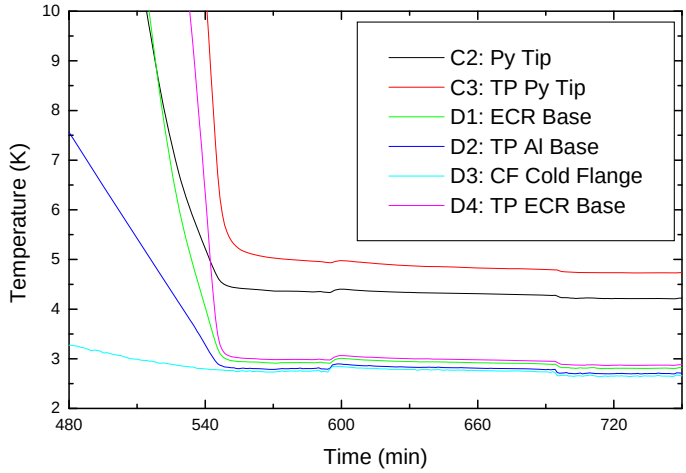

Figure 26 Thermal cycle 9: details of the steady state low temperature data.

5.6 Inspection 3

5.6.1 Sample 1: Panel bonded with Hysol

One pyramid was found broken on the cold flange (Figure 27- Figure 28).

Figure 27 Global view of the samples mounting after opening the CF. In the right picture, the broken pyramid is visible.

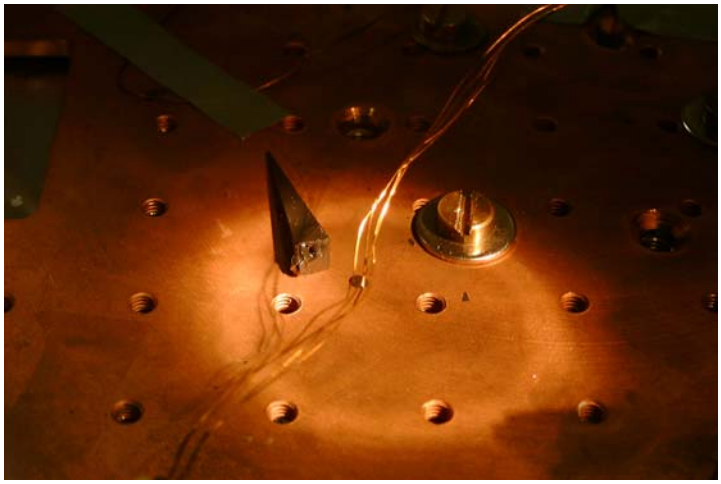

Figure 28 Detailed view of the broken pyramid.

5.6.2 Sample 2: Screwed Panel

No relevant difference respect to previous inspections was found. No cracks are evident. No flaking is present. The M4 screws fixing the panel to the Al substrate decreased their torque to 0.6 N·m.
In a following mounting the fillet where the SS screw was mounted is broken out.

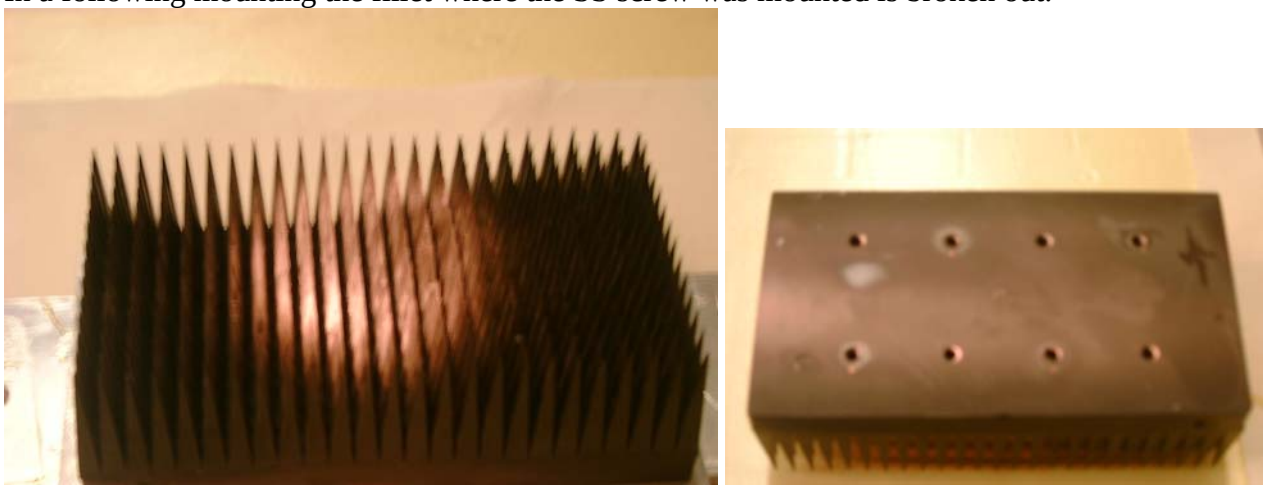

Figure 29 Sample 2 after last cycle. Particular of the pyramids and of the back part.

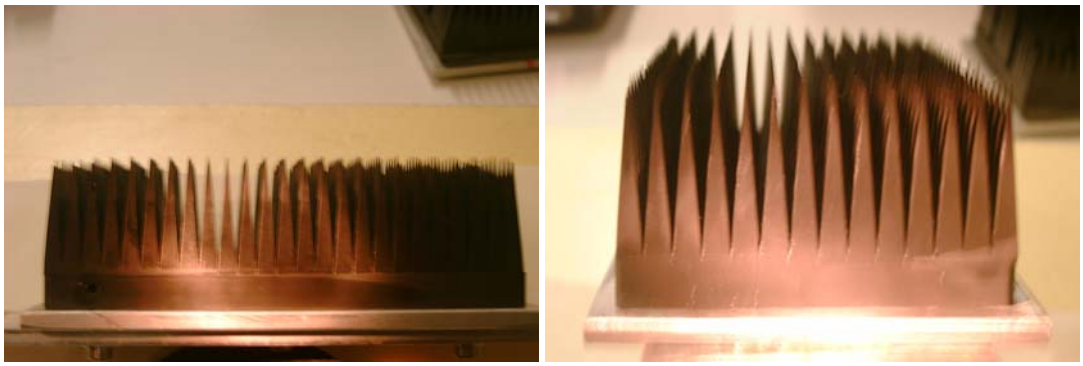

Figure 30 Short and long side views of the Sample 2.

6 Data analysis

6.1 Preliminary analysis of the temperature difference between the Al base and the pyramid tip

Our preliminary data analysis is focused on the issue of the temperature difference between the aluminum support and the pyramid tips observed in the tests.
A set of simulations of the pyramid panel was performed to check this effect.
The setup is reported in Figure 31

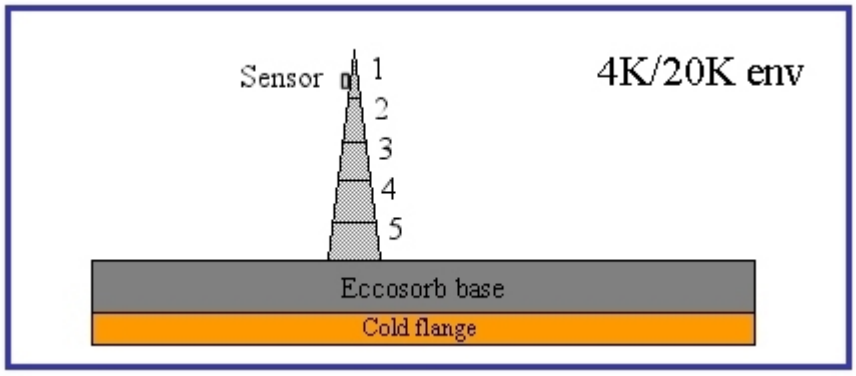

Figure 31 Simulation setup: the system envelop is at a temperature of 4.5 K for the first simulation and 20 K for the second simulation. The pyramid is divided into 5 nodes enumerated as displayed in the figure. Also the Eccosorb base is divided into five layers

A pyramid and the Eccosorb base are divided into five nodes each. The thermal contact resistance is assumed negligible in this case, while the 20 μW dissipated by the DT670 sensor at 4 K are applied to the pyramid tip.
Simulations assume, as initial condition, the system at the boundary temperature of 4.5 K and then power load is applied.
The temperatures reached at the steady state under this assumptions are reported in Figure 32.

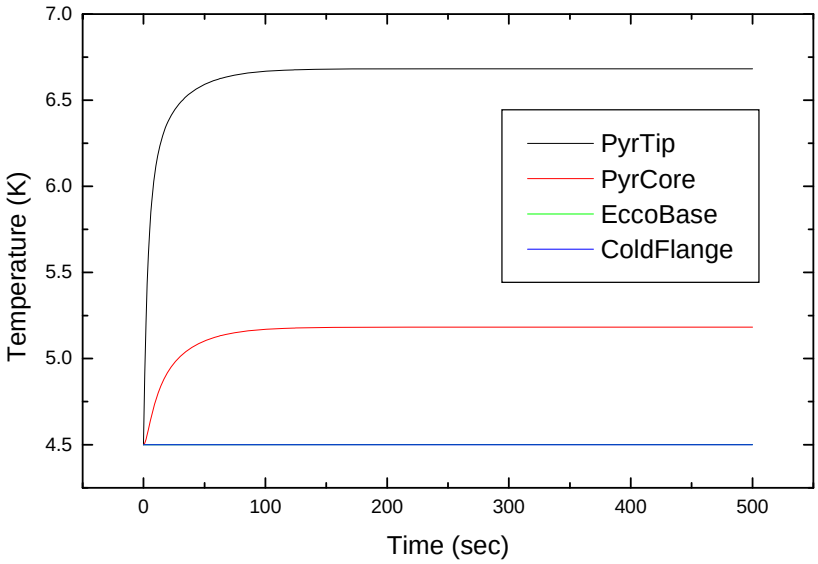

Figure 32: . Temperature curves resulting by applying a heat load of 20 μW to the pyramid tip (Node 1). Temperature rise of the tip is of more than 2 K while the difference between Node 2 (red line) and cold flange is of about 0.7 K. The EccoBase curve refers to the Eccosorb base layer adiacent to the pyramid base and is quite coincident with cold flange temperature.

Results are interesting because the temperature rise of the pyramid is evident (more than 2 K on the tip). Considering that

- the heat transfer from sensor to pyramid could not be perfect, due to parasitic dissipation along wires;
- the position of the sensor can not be accurately fixed and this can be a relevant parameter of uncertainty, also considering that the high temperature difference reached by two adiacent pyramid nodes (1 and 2 at a distance of 6 mm)
- the sensor accuracy at 4K is 0.25 K

we can be confident that the main cause of the temperature gap observed in our tests is due to the temperature sensor heat load.

A further simulation of the same setup starting from a temperature of 4.5 K, in a temperature environment of 20 K (with ideal emissivity) and without the heat load of the sensors, shows an important outcome: the radiative load does not affect significantly the pyramid temperature. In fact, in this case, the temperature difference between the pyramid tip and the reference temperature, at the steady state, is of about 40 mK (Figure 33).

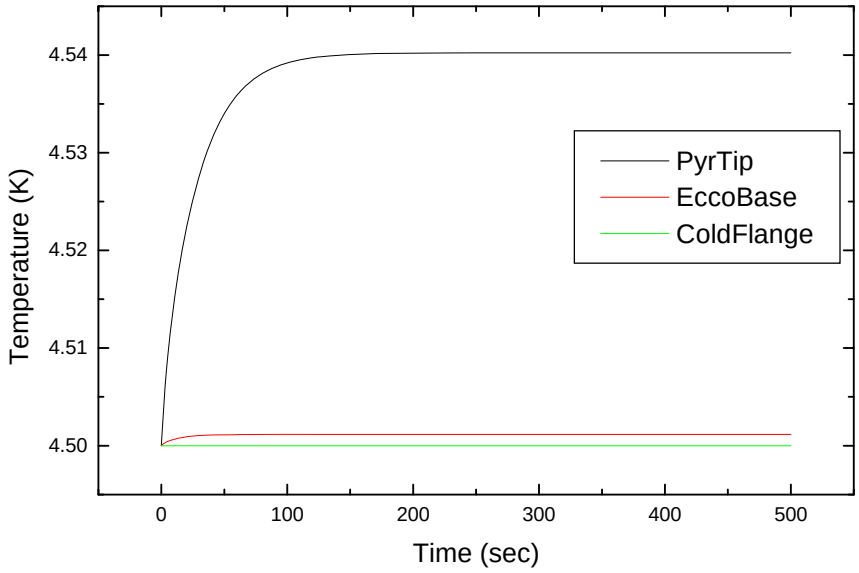

Figure 33: Temperature curves of the pyramid tips and Eccosorb base top layer radiated by an environment at 20 K.

7 Conclusions

At the end of the thermo/structural tests on the two types of samples (eccosorb pyramids glued with Hysol and the screwed ones), it appears evident that the glued version cannot be accepted as element of the Planck cold load, while the screwed panels have passed all the tests identified in chapter 5.
The LFI team therefore suggests the implementation of the screwed design.