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N. Cocheteau

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Shock and vibration tests of space lightweighted corner cubes manufactured with adhesion process

N. Cocheteau*[a], C. du Jeu[a], M. Voisin[b], A. Maurel-Pantel[b], F. Lebon[b], S. Begoc[c]
[a]Thales-SESO, 530 rue Frédéric Joliot 13290 Aix-les-Milles, France; [b] Laboratory of Mechanics et Acoustics (LMA), 4 impasse nikola tesla 13013 Marseille, France ; [c] CNES, 18 avenue Edouard Belin 31401 Toulouse, France

ABSTRACT

The interferometer of the third generation meteorological satellite is composed by two corner cubes. The specifications, in terms of optical performances - wave front error (WFE) - and mechanical and thermal environments are very stringent compared to the actual knowledge. To answer to the mass, optical and mechanical specifications, a lightweighted hollow corner cube have been designed. An integration process based on enhanced molecular adhesion have been developed and tested in collaboration with CNES and LMA. This process required a fine polishing of the three mirrors of the corner cube before adhesion in order to obtain a very low flatness, roughness and angle precision. The mechanical resistance of the enhanced molecular adhesion process have been validated on three mockups submitted to shock and vibrations. The optical performances have been demonstrate on flight model corner cubes.

Keywords: Corner cube, molecular adherence, wave front error, vibrations, shock, interferometer, lightweighting, polishing

1. INTRODUCTION

In the frame of the third generation meteorological satellite (MTG), EUMETSAT and ESA have chosen to innovate on observation satellites by developing a new satellite able to measure humidity profile (IRS) from its geostationary orbit. The MTG-IRS satellite is composed by interferometer and telescopes (see Figure 1). The interferometer is composed by two corner cubes and one beam splitter.

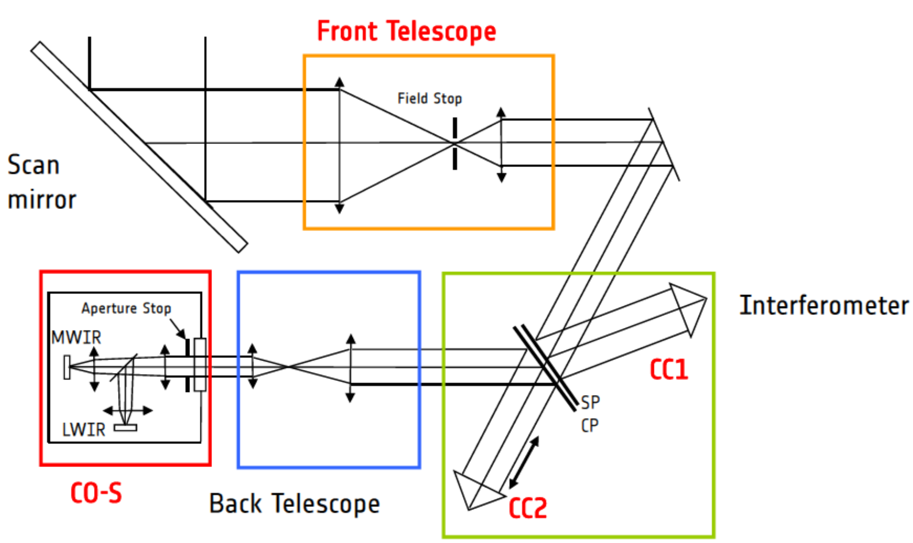

Figure 1: Scheme of the MTG satellite

With MTG-IRS, which is a fixed satellite with a more complex thermal environment, it will be able to obtain:

- Detailed images of Europe every 30 min
- Full earth could be measured in one hour
- Spatial resolution of 4 km (nadir)

Corner cube consists of three perpendicular mirrors assembled together. Because of the orthogonality of each mirror, the incident light is reflected directly back to its source. Thus the performances of the interferometer is directly linked to performances of each mirror and to the perpendicular angle quality.

In order to meet the MTG-IRS requirements – which are twice stringent compared to the actual knowledge - the interferometer needs two corner cubes with high stability, mechanical resistance in accordance with mechanical and thermal environment of fixed geostationary orbit with following optical performances:

- Each angle of the corner cube need to be at 90°<1''
- Wave Front Error (WFE) < 250 nm RMS

Two kinds of corner cubes exist, the field corner cube and the hollow corner cube. Field corner cube presents a high mechanical stability with a important field of view and they are also easier to manufacture. Field corner cube presents lots of advantages: no integration concern, only one summit to realise with precision, the possibility to deal with one angle or the mechanical strength limited by the material and not the integration process.

However, for space applications, it is important to use lightweighted components for purpose of mass reduction. Thus, fields corner cubes cannot be used for the interferometer.

The solution chosen is a lightweighted hollow corner cube design. Indeed, with hallow corner cube it is possible to manufacture large corner cube with low mass. With the specified dimension, the mass of a field corner cube is ten time heavier than the mass of the Thales SESO lightweited corner cube.

This paper will first presents the lightweighted hollow corner cube innovation, then the tests performed on mockup in order to determine the mechanical resistance of the adherence. To conclude, the optical performances of the corner cube obtained will be presented.

2. LIGHTWEIGHTED HOLLOW CORNER CUBE

The major difficulty was to develop an integration process in order to obtained a corner cube compatible with the mechanical specifications and with the very stringent optical needs. Indeed, the assembly of the two first mirrors is not a concern but the assembly of the third one conduct to non-conformity on angle.

Molecular adherence is the best candidate to solve the corner cube integration issues.

Molecular adherence or optical bonding is a well-known process and consists in joining two surfaces without the use of any adhesive or additional material [1]. The main applications of this adherence process are on micro-electronics devices and optics. Recently, this process was used in the manufacturing of high performance optical system for terrestrial application such as Fabry-Perot interferometers, prism assemblies, etc. The advantages of the process is to be a high-precision production process, and assemblies obtained present a dimensional stability due to the absence of mechanical part or glue. In addition, since no adhesive materials are used in those processes, the risks of contamination associated with degassing are avoided, which is another advantage in spatial context.

Mechanical strength of those bonded interfaces depends on the interface defects and the nature of bonds involved. Indeed, molecular adhesion is possible as long as the two surfaces have similar geometries with very low flatness and roughness and requires clean surfaces free of contaminants on surfaces [2, 3]. Two solids with well-polished flat surfaces, when brought into close proximity, locally attract to each other by Van der Waals or hydrogen bonds (bond between a hydrogen atom and a negative polarized atom such as oxygen atom) and adhere or bond. However, room temperature bonding is usually relatively weak. In order to obtain a stronger or irreversible sealing by increasing the number of covalent bonds, it is necessary to change the nature of bonds at the interface [4]. One well known solution to improve the mechanical resistance of molecular adhesion interface is to apply a thermal treatment after adherence.

Thus, the integration process chosen for hollow lightweighted corner cube is thermal enhanced molecular adherence using fused silica material for mirrors. Indeed, due to transparency of fused silica, it is easy to control the interface during integration. Thus, after adherence of the corner cube, a thermal treatment is applied.

In order to determine the optimal thermal parameters to apply, static test (traction and shear) and shock test have been performed on unitary samples adhered with different thermal process parameters in collaboration with the CNES and LMA. Influence of the optimal thermal treatment have been studied in traction and shear with modified Arcan assembly [5] (Figure 2). A shock bench have been developed for this study and some unitary samples have also been tested in shock. The results show the influence of the thermal treatment on the mechanical resistance of the adherence.

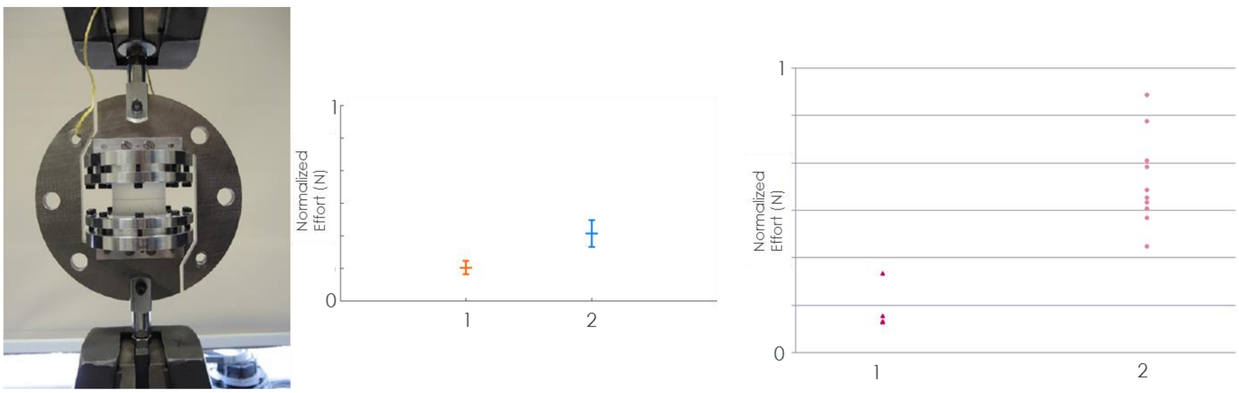

Figure 2: Unitary sample in the traction machine (left), comparison of rupture for samples without thermal treatment (1) and sample with the thermal treatment (2) in traction (average values) [5] (middle) and in shear (right)

3. TESTS ON CORNER CUBE MOCKUP

After determination of optimal parameters for the thermal treatment applied, three corner cubes mockup have been manufactured and bond onto Mirror Fixation Device (MFD). The corner cube are composed by three fused silica mirrors with very stringent angle, flatness and roughness performances obtained using polishing as described above.

The objective of these mockups is to determine the mechanical resistance of the enhanced molecular adherence. Indeed, in the frame of the corner cube development, mechanical analysis are performed on the flight design in order to evaluate the margins in the adherence zone (and on the other parts of the corner cube) for the different environment specified. Thus, before test on mockup, Finite Element (FE) Models have been made for test prediction.

After test, to evaluate the mechanical resistance, FE model is correlate with the tests results in order to determine the stress in the adherence area for the load seen by the corner cube during test.

3.1 Mockup description

The design of the fused silica corner cube mockup is presented in figure 3. The mockup is not lightweighted but the adherence area is representative of the flight model in terms of dimension, roughness, flatness and angle.

Two corner cubes have been tested in vibration until rupture. The third one have been submitted to shock until rupture. The three corner cubes are identical but mounted on different titanium MFD for vibration and shock.

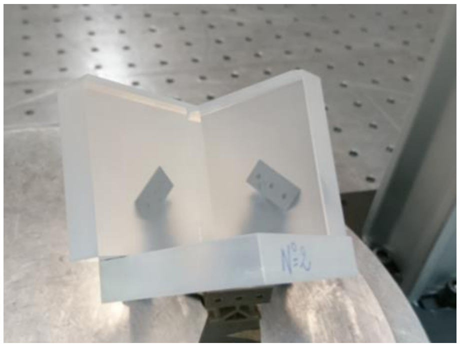

Figure 3: Hollow corner cube mockup put on the titanium shock MFD

3.2 Sinus and shock test

For sinus tests, the corner cube mock up bonded to its MFD is mounted on a simplified titanium bracket compared to the flight design.

The objective of this test is to determine the maximum level of acceleration to obtain a rupture in the adherence zone.

The two corner cubes tested have been submitted to the test following sequence:

- Sweep sine test at 0.1g to detect the first frequency resonnant
- Sweep sine test at 0.5g at 1st frequency (detected at n°1)
- Sweep sine test increase by 0.5g until rupture at 1st frequency

The figure 4 presents the corner cube on the vibration plate.

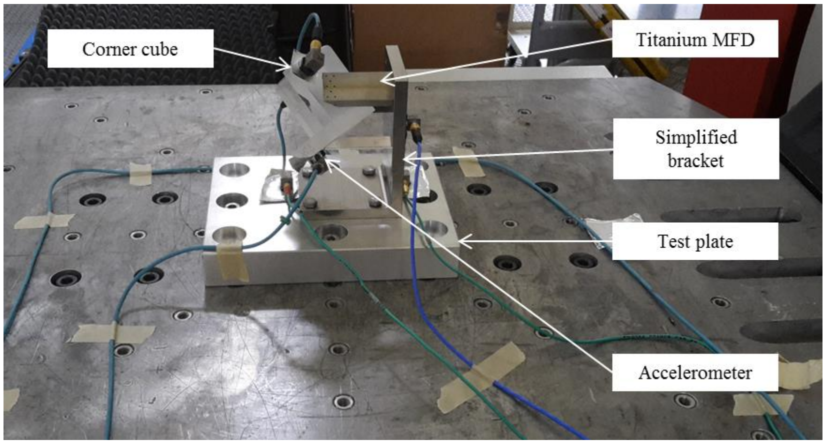

Figure 4: Corner cube on the electrodynamics shaker for sine test

For the first corner cube, rupture appear at 5.5 g and for the second at 3.5g. For the both corner cube, rupture appear on the edge of the adherence area as predicted by the finite element analysis as presented in figures 5 validating the FEM model.

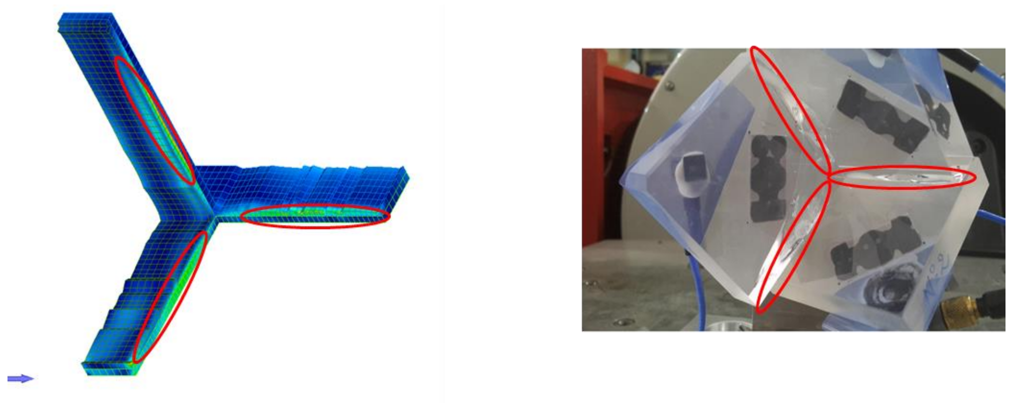

Figure 5: maximum of stress in FE model compared with rupture location after sine test.

The following table resumes the maximum stress RMS in the adherence area with no margins stem from the correlation between the model and the sinus tests.

Table 1: Resume

Load case	Type of stress	Computed stress
Corner cube n°1 (5.5 g)	Von Mises	4.5
	Shear	1.8
Corner cube n°2 (3.5 g)	Von Mises	4.8
	Shear	1.9

For shock tests, the corner cube mockup bonded to its MFD is mounted on representative titanium bracket compared to the flight design.

The objective of this test is to determine the maximum level shock without rupture in the adherence zone or bonding zone. Shock test have been performed with the CNES pyrotechnic bench. The figure 6 presents the corner cube on the pyrotechnic bench.

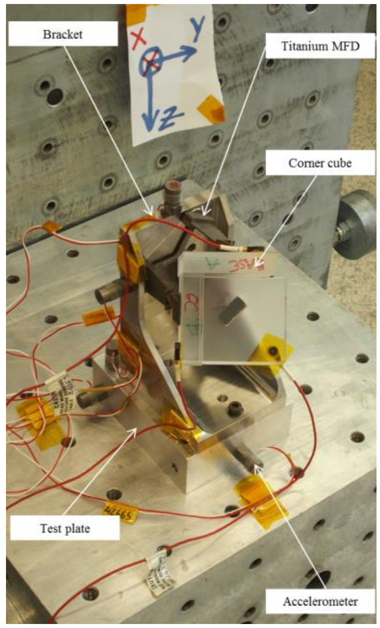

Figure 6: Corner cube on the pyrotechnic bench for shock test

Nine shocks at different level have been performed before rupture starting from level slightly inferior to 150g and the last one at 700g. The following table resumes the nine shocks performed and the level associated at the base of the bracket and at the top of the three mirrors (figure 7).

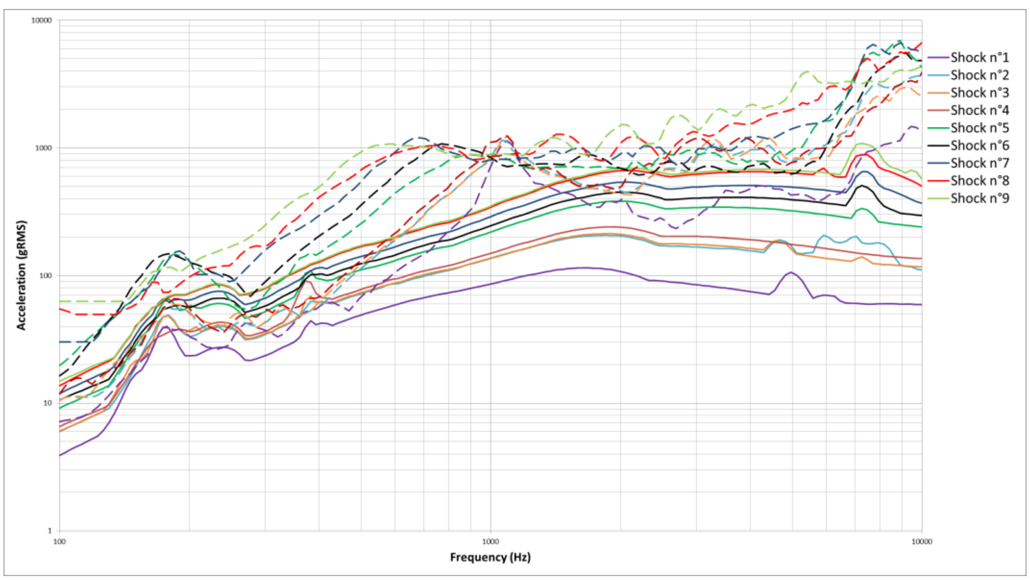

Figure 7: SRS of the 9 shocks at the base of the bracket (full line) on top of one of the three mirror (dot line)

A defect appear during the 8th shock (650g) on the bottom of the corner cube due to contact of the corner cube with the MFD. Rupture appear during the 9th at 700g starting from the same location.

The weakest point of the adherence was the knowledge of the shock resistance. This shock test demonstrates that the adherence is able to resist to shock level specified and to several successive shocks.

Based on the sine and shock tests performed on the three corner cubes, FE model have been validated and applied for the flight model design. Margins have been calculated taking into account for adherence mechanical admissible the smallest value obtained during tests (4.5 MPa for Von Mises and 1.8 MPa for shear). With this admissible, margins for all environment specified are positive.

4. CONCLUSION

After unitary mechanical tests, a molecular adhesion process for integration of the corner cube with three fused silica mirrors – with very low unitary flatness, roughness and angles – have been developed and test in collaboration with CNES and LMA.

Based on this work and on the knowledge of polishing, lightweigthing and adherence, Thales SESO have been able to manufacture a corner cube meeting the ESA requirements for MTG satellite. The optical performances obtained are in agreement with the MTG-IRS requirements, the WFE obtained before bonding on MFD is 200 nm RMS on Φ78mm. The WFE at the end of the integration is under 250 nm RMS on Φ78mm. Moreover, the two corner cubes needed for the interferometer can be matched in order to decrease the delta WFE. Thus the flight design have been validated in terms of optimal performances. Flight model design corner cube have been tested in sine, random and shock with qualification level and passed test with success without WFE degradation.

5. AKNOWLEDGEMENTS

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