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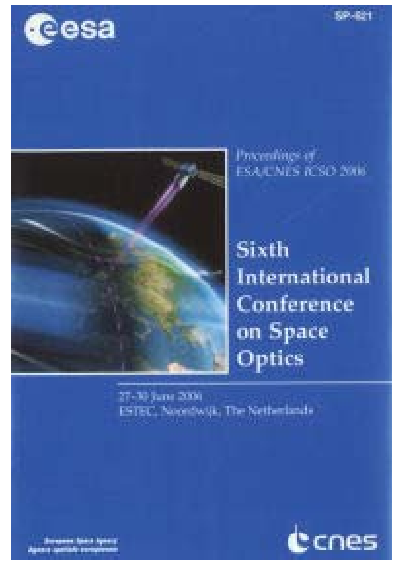

CeSiCò - a new technology for lightweight and cost effective space instruments structures and mirrors

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CESIC® - A NEW TECHNOLOGY FOR LIGHTWEIGHT AND COST EFFECTIVE SPACE INSTRUMENTS STRUCTURES AND MIRRORS

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ABSTRACT

Alcatel Alenia Space and ECM have jointly developed a new ceramic material to produce lightweight, stiff, stable and cost effective structures and mirrors for space instrument the Cesic®. Its intrinsic properties, added to ample manufacturing capabilities allow to manufacture stiff & lightweight cost effective mirrors and structure for space instruments. Different scale 1 flight representative Cesic® optical structures have been manufactured and successfully tested under very strong dynamic environment and cryogenic condition down to 30K Cesic® is also envisaged for large and lightweight space telescopes mirrors, a large Cesic® 1 meter class mirror with an area mass of less than 25 Kg/m2 has been sized again launch loads and WFE performance and manufactured. Cesic® applicability for large focal plane have been demonstrated through different scale 1 breadboards. Based on these successful results, AlcatelAleniaSpace and ECM are now in position to propose for space this technology with new innovative concepts thanks to the Cesic® manufacturing capabilities. Cesic® has therefore been selected for the structure and mirrors parts of a flight instrument payload and the manufacturing of the flight hardware is already underway. An high temperature high gain lightweight antenna breadboard is also under manufacturing for Bepi colombo mission. Cesic® is therefore a good candidate for future challenging space instruments and is currently proposed for Japan and US space projects.

1. Cesic® interesting Key properties

Ceramic materials present a strong interest for space instruments due to theirs mechanical performances :

- ➢ High specific stiffness and large mechanical dimensional stability

and thermal and thermo elastical performances :

- ➢ High thermal conductivity, homogeneity, low coefficient of thermal expansion and remarkable cryogenic behaviour .

Among different ceramic materials, Cesic® from ECM (G) has been selected by AlcatelAleniaSpace as the most favourite candidate for the development of structures and mirrors of space instruments.

Cesic® is a composite ceramic made of SiC , Si and C. This material is obtained from the transformation of Carbon in SiC, due to the reaction at high temperature between C/C greenbody and liquid silicon (Figure 1) .

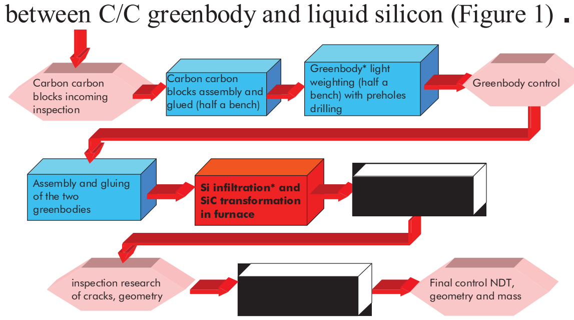


Figure 1 Cesic manufacturing flow chart

Cesic® is now a mature technology offering high structural capacity thank to its high mechanical performances associated to very high manufacturing capabilities :

- Reliable Isotropic material: all properties are independent of surface status, raw initial C/C blocks & infiltration runs, independent of direction,
- Very high ratio ExInertia /M well above other advanced material, E=255 Gpa, d=2,65 giving an high specific bending stiffness : $E/\rho^3 > 13{,}7$,
- High mechanical strength, σ> 130Mpa: insensitivity to fatigue, no impact of internal C/C junction, insensitivity to surface status, Strength in bi-axial bending : 160 Mpa : No impact of biaxial stress, compatible of screwed link under large loads,
- High fracture toughness for a ceramic : K1c>4,6,
- High thermal conductivity : 160 W/mK at 300K & 35 W/mK at 40 K ,
- Isotropic & Quasi null CTE on a large cryo temperature range from 20 K to 100 K, CTE<0,003 10-6 m/m°C (Figure 2) ,

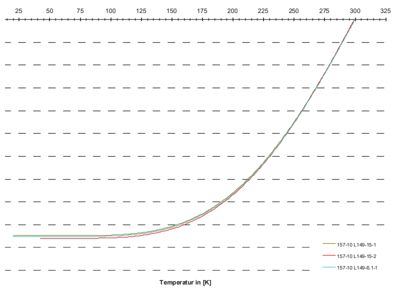


Figure 2 Cesic DL/L in function of temperature & directions

2. Cesic® High manufacturing capabilities

The use of C/C greenbody manufacturing is one of the key technologies of the Cesic® process : during this manufacturing step ECM has a lot of positive features to create complex stiff and lightweight structures.
Through the use of a large CNC controlled milling machine, ECM is able after the joining of C/C blocks, to manufacture by milling large lighweighted panels of flight structure.

The C/C being not fragile, the panel lightweighting on CNC machine is easy and fast with no risk of greenbody failure. Large ribs with less than 1,5 mm thickness are easily shaped, and the machining time for a full reinforced panel is less than 15 days for 1 m^2 (Figure 3).

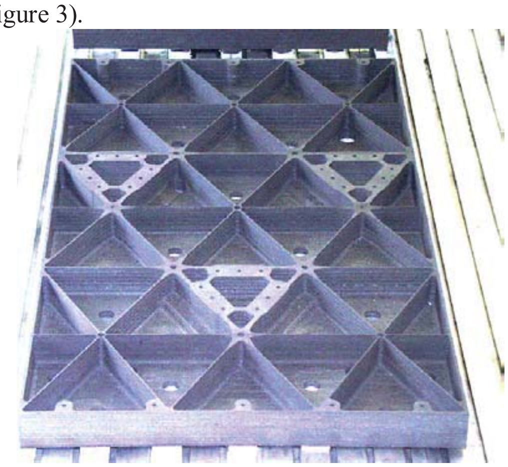


Figure 3 view of a 1 meter milled panel

Due to the specific joining technology, it is possible to manufacture very easily and fast C/C parts with conventional tools and join them prior to the silicon infiltration process. Such process allows to obtain in one part a very stiff monolithic structure with great geometrical inertia like structure in "I" shape. Through the infiltration process this joined structure will become afterwards a monolithic piece without discontinuities and differences of thermal and mechanical properties.

External extension like mirror support mounts could be machined separately from others bocks and then joined to the central structural part to obtain the final structure shape in one element allowing to have a full monolithic complex structure. After the assembly the greenbody part is machined to final structure shape especially for the I/F area.

Greenbody part is then infiltrated at high temperature with liquid Silicon which penetrates inside the C/C and then react with the C to form the SiC.
The Cesic® manufacturing process is a direct to shape process, greenbody structure will be manufactured close to the final CeSiC structure in shape and size. In fact, during the infiltration process, the material has a controlled low shrinkage of 0.2% and the transformation from C/C to SiC is a transformation solid to solid with all the time a high structural capabilities (no deformation due to gravity or others effect).
The low shrinkage allows the manufacturing of high precise structures and mirrors. Especially for the manufacturing and preparation of high accurate interface areas for big and large structures, this small dimension change is an important advantage of CeSiC® compared to other silicon carbide materials.

The current existing ECM XL furnace allows the infiltration of part up to a diameter of 2,4 m (Figure 4).

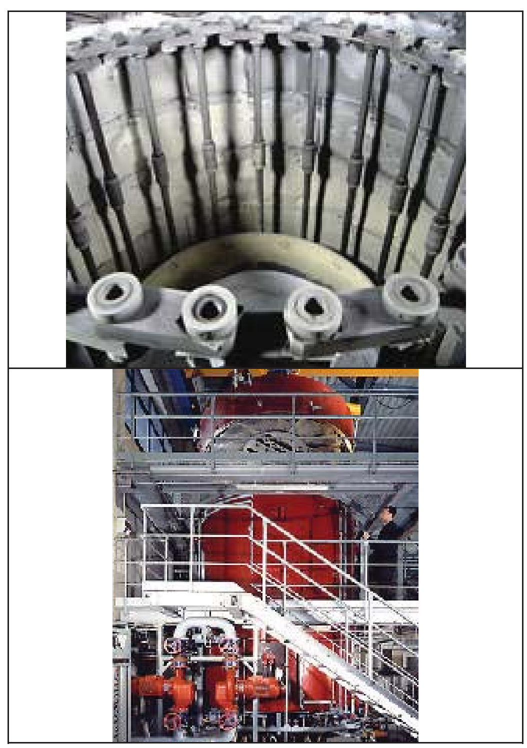


Figure 4 view of ECM 2,4 m infiltration furnace

After infiltration the structures are cleaned by sandblasting to remove the remaining silicon from the structure's surfaces.

According to the properties of Cesic® it is possible to use different methods for final machining for the I/F preparation or other functional areas :

- Grinding with diamond tools
- Electron Discharge Machining (EDM) and wire erosion machining.

The possibilities of EDM machining and wire erosion gives the opportunity to have a precise method with no risk to realize good surface qualities at such areas. Therefore the low dimensional change during infiltration process combined with the possibility of EDM machining is a big advantage of Cesic® compared to other ceramic materials.

I/F surfaces are finalised by EDM with precise pad, giving the flatness and the location of the I/F (flatness of less than 10µm with a position of +-20µm are easily achievable on large size) .

Holes could be precisely located by EDM machining through cost effective wire erosion process and without any risk for the piece (typical accuracy are H7 on hole with a locating +- 10 µm).

We can therefore summarize the manufacturing properties of Cesic® process as :

- Capacity to built large structure in one piece with semi closed back design offering a high bending stiffness, as greenbody junction offers same strength and others properties guarantying the homogeneity of the structure
- Machining by EDM (electro discharge machining) offering precise I/F at low risk,
- Schedule and cost attractive with an easy direct to shape greenbody manufacturing.

3. Cesic® Optical bench structure development for space instrument

During development phase for future cryo instrument projects, large development have been launched under ESA contract supported by Alcatel Space and ECM own funding.

For this purpose an optical structure fully representative of an instrument optical bench except in size was designed, sized & successfully manufactured. The manufactured bench size was 1045 mm x 600mmx 100mm

The bench was designed and sized vs optical and launch loads constraint but also taken into account all the manufacture capabilities offered by the CeSiC® process (half closed back design maximising stiffness , thin ribs with lightweight holes , C/C blocks junction I/F and holes made by EDM …) (Figure 5).

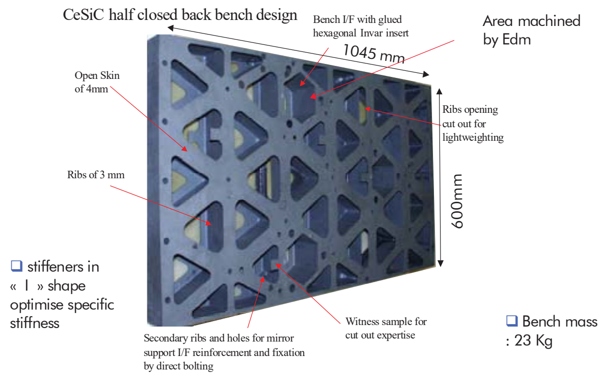


Figure 5 view of the manufactured structure

The full bench has been then tested under vibration to validate its behavior and strength .

For this last aim the bench has been conducted successfully up to the maximum sinus level allowed by the shaker (more than 80g at shaker level), such level exceeding largely by a factor 2 the qualification loads see by the full size flight bench, qualifying with margins such bench for flight application (Figure 6).

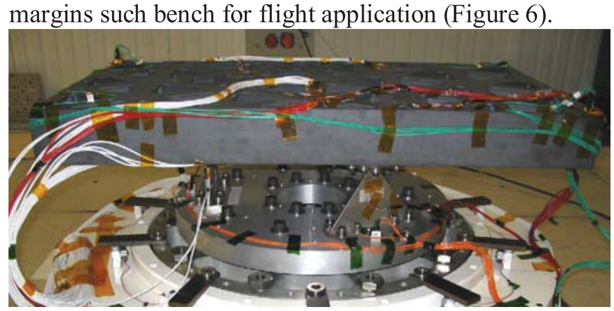


Figure 6 view of the bench on the shaker

FEM prediction was fully in line with test results, confirming material properties, and the availability to predict stiffness, stress and strength behavior. Bench eigen frequency is above 500Hz and the amplification factor measured during OBB sine test is less than Q=30, limiting loads induced on critical equipment under vibrations and notching needs.

The stability of the optical bench has been also demonstrated by a cryo test from 300 K down to 30 K for which the in plane contraction and the out of plane stability has been measured by an accurate speckle holographic interferometric methods (accuracy around about 1 µm on the whole cycle with a resolution of 0,1 µm), measures performed by HOLO3.

The test was performed in CSL (Belgium) in focal V chamber. The bench was cooled through cryo helium panels by radiative and conductive link (Figure 7).

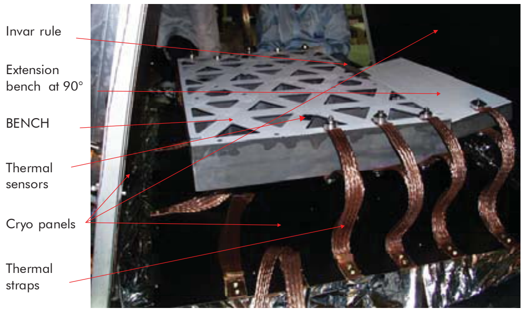
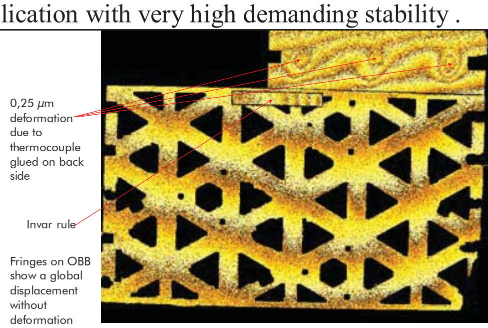


Figure 7 view of the bench in cryo chamber

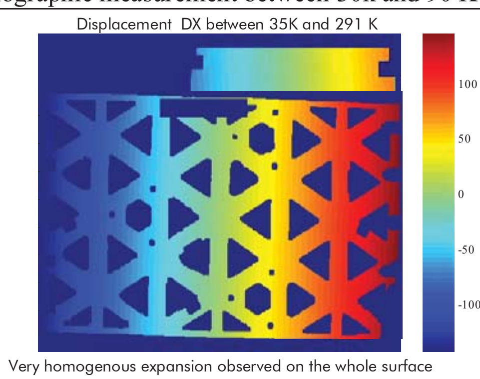
During the test all success criteria have been met :

- Temperature of less than 30 K has been reached on OBB,
- Thermal contraction was fully in line with samples measurement and is homogeneous on the whole bench surface (Figure 8),
- bench deformation was null from 100K to 30K,
- Out of plane deformation was quasi null between 293K and 30 K (Figure 9)
- no hysteresis was observed during the whole cycle .

CeSiC® structure are fully compatible for a cryo application with very high demanding stability .



Holographic measurement between 30k and 90 K



Bench homogenous contraction

Figure 8 bench measurement under cryo tests

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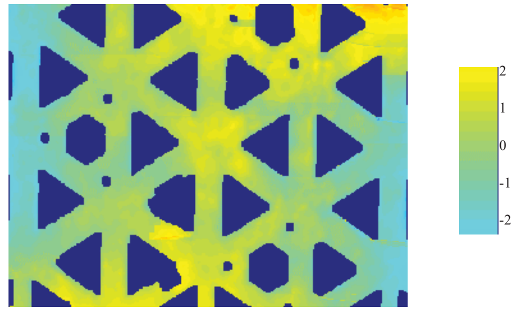

Figure 9 view of Bench out of plan deformation between 300K and 30 K

Figure 9 shows the quasi null out of plane deformation observed on the whole bench from 300 K to 30 K. This will allow to keep during the cold down from 300K to 40 K relative good optical alignment..

4. Cesic® Mirror development results

Cesic® features are also of great interest for mirror application :

- Substrate easily machinable at greenbody level allowing high inertia,
- thin ribs (up to 1 mm), great height (200 mm) : lightweighting greater than other ceramics for same stiffness vs quilting & general bending,
- possibility of half closed-back ==> increase the ratio EI/M,

Thank to assembly at greenbody and to EDM capacity Cesic® offers the possibility to have integrated filtering mirror fixation device (MFD) :

machining of elementary parts at greenbody level (

- Figure 10)

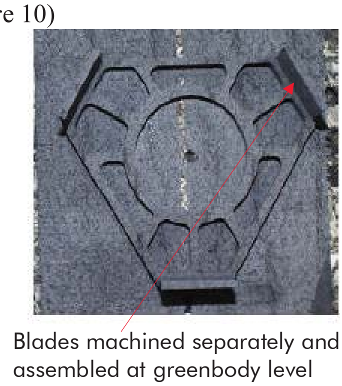

Figure 10 MFD during machining

- assembly of pieces at C/C stage, and machining
- infiltration and coating (Figure 11)

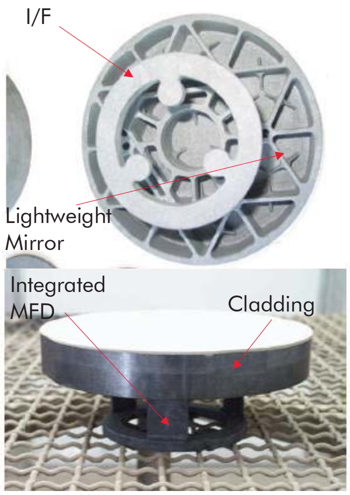

Figure 11 Mirror with integrated foot

- lightweighting MFD by EDM (wire or pad) before end of polishing (Figure 12)

Figure 12 EDM of MFD

SiC CVD Polishable cladding on Cesic® has been developed and qualified through :

- Strength tests and microanalyses on the adherence of SiC CVD deposit on Cesic® ,
- Polishing tests ,
- Radiation tests ,
- Ion beam figuring tests .

Mirrors of 300 mm have been also successfully coated and polished (Figure 13) . All these tests have showed the good behaviour of the coating and WFE of less than 20 nm with a roughness lower than 0,2 nm has been reached .

Figure 13 View of rear face mirror with Sic CVD coating

During the Sic CVD application at Schunk the shape of the mirror has been carefully measured and no noticeable deformation has been observed.

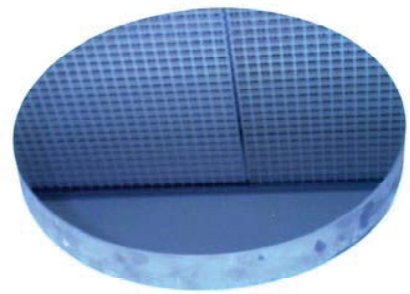

Figure 14 View of 300mm polished mirror

In order to demonstrate the ligthweigthing capabilities of large mirror, the study & manufacturing of a large Cesic® mirror demonstrator has been performed under Alcatel Space and ECM self funding.
The mirror has been designed in order to guarantee a WFE lower than 20 nm vs polishing quilting effect, large I/F deformation, to be able to sustain up to 20 g and to offer a high stiffness with an eigen frequency above 280 Hz including MFD softness.
The mirror design has the following features :

- D=950 mm, Skin of 3 mm,
- Ribs of h=80 mm max and with a thickness of 2 to 1,5 mm, secondary ribs of 30 mm and th=1,5 mm vs quilting deformation,
- Mirror mass : 15 kg ,ie < 25 Kg/m2.

The full greenbody machining & infiltration has been mastered and successfully performed in less than 2 months (Figure 15).
Geometrical measurement performed after infiltration have showed no deviation vs the shape design (radius of curvature , tolerance vs best shape)

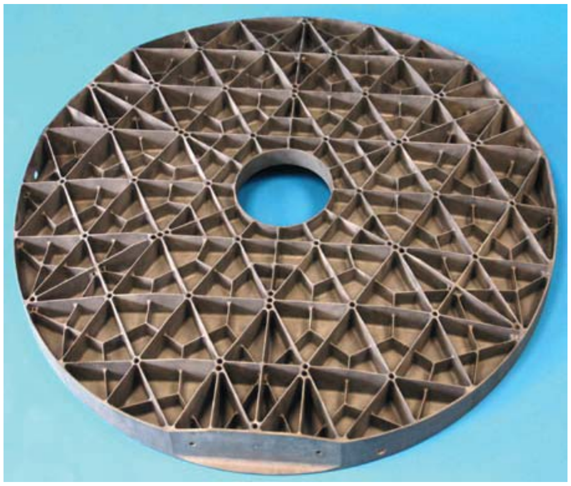

Figure 15 View of the mirror after infiltration

The mirror is now ready for future operations : SiC CVD cladding deposit and polishing operation.

5. Cesic® focal plane development results

Cesic® is also an interesting material for the realisation of large focal plane holding high number of dissipative detectors.

Indeed Cesic® assure a high stiff and stable focal plane interface to detectors and thank to its high thermal conductivity ensure through thermal conduction the heat evacuation issued from the detectors.

Thank to EDM manufacturing capabilities, flat & complex detectors I/F could be machined, including calibrated shims. Detectors could be directly in plan located thank to small precise locating holes performed by EDM after infiltration.

A full size demonstrator holding 16 CCD has been successfully manufactured, then detectors integrated and tested .

The focal plane is 650 mm length by 350 mm width with integrated stiffeners having numerous I/F, the plate having more than 100 I/F holes. The Cesic plate has only a mass of 4,1Kg for an equipped mass of 17 Kg with eigen frequencies of 220 Hz and 317Hz for the first 2 modes.

The equipped focal plane has been successfully tested under qualification vibration level : ie 28 G sinus and 18 G Rms under Random on the shaker.

Thermal test has been also performed confirming the good thermal transfer inside the focal plane.

Very Large focal plane could be done also in Cesic® holding more than 180 matrix CCD (Figure 16).

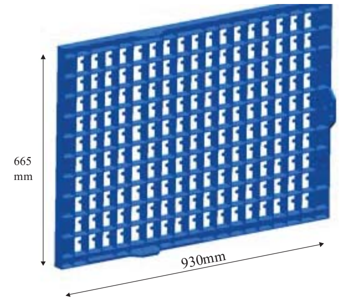

Figure 16 View of ultra large Cesic® focal plane frame

To demonstrate its ability, a full scale very large focal plane demonstrator for future missions has been designed and successfully manufactured (Figure 17) . Its huge shape stability during manufacturing process allows to obtain as fired a quasi plane surface allowing a very limited final machining of the detectors surface.

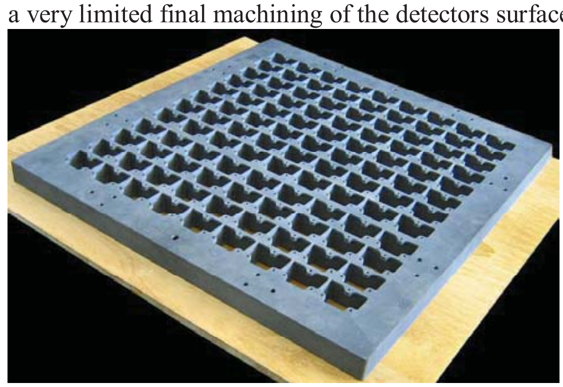

Figure 17 view of ultra large focal plane

6. Cesic® High Ultra stable structure

Cesic® has been selected by AlcatelAleniaSpace for the most demanding structural elements in terms of stability. Among them a large monolithic structure holding two large entrance mirrors with a stability of few picoradians has been designed using Cesic® features.

To validate this stability, under an ESA contract, a Cesic® flight representative 3D monolithic structure has been already successfully manufactured and then tested to demonstrate its stability (Figure 18).

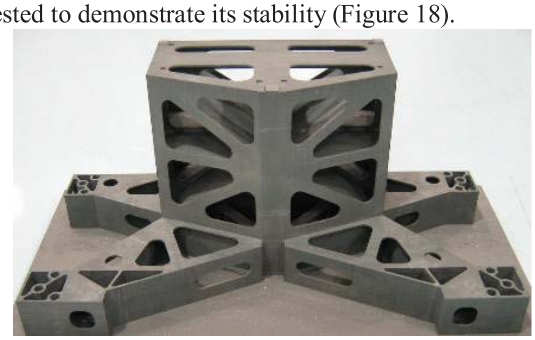

Figure 18 Ultra stable Cesic® mast structure

The tests have been done under ultra stable vacuum environment and the structure has been instrumented with very precise optical device (Michelson interferometer with phase shift determination). Results have demonstrated the sufficient homogeneity of Cesic® to ensure a very stable line of sight of the instrument, measured deformation being well below the requirements.

7. Cesic® todays & future applications

All the development activities have now concluded to the high maturity status of Cesic® technology for the application of space instruments for structure parts as for mirrors or focal planes.

Therefore Cesic® technology has been selected for the realisation of a small full integrated space flight instrument , structure and mirrors being made in this material .

Thank to the high integration capabilities of Cesic, the structure is made in one single piece and M1 & M2 also, therefore a full telescope has been manufactured and will be assembled with only 3 main parts (Figure 19).

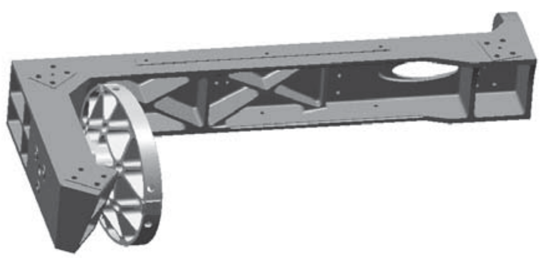

Figure 19 monolithic Cesic® telescope

The monolithic structure hold all the elements (mirrors, detection units and dioptres) and have therefore numerous I/F which will be fine machined thanks to EDM (Figure 20). In order to be stiff enough and notably in torsion , the central part of the structure has a closed box design . This has been made possible only thank to the geenbody assembly capabilities before infiltration

Flight Mirrors have been also manufactured. As they are off axis mirror, the front shape has been carefully and very precisely machined by EDM in close relation vs the I/F. Then the mirrors have been coated by Sic CVD before to be polished (Figure 21).

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Figure 20 view of the 2 flight structures

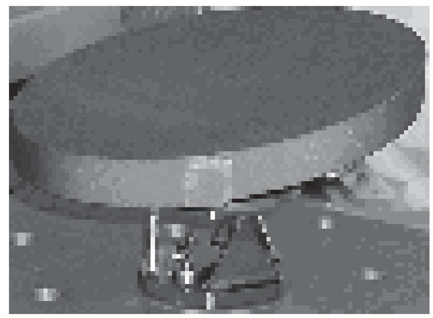

Figure 21 flight mirror ready to be polished

Thanks to all its high positive features Cesic® will be also one of the most interesting technology to save the high technology breakthrough requested by the next large future space missions like BEPI COLOMBO and Darwin projects.

For Bepi, thanks to its high stiffness, low mean CTE and high manufacturing capabilities, we are in position to propose a very lightweight accurate and very stable High Gain Antenna made in Cesic® (see Figure 22) .

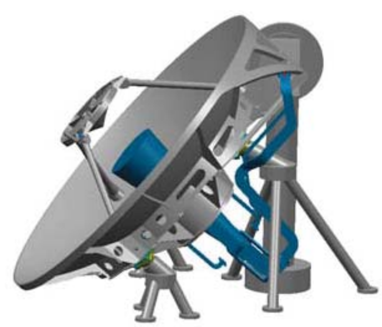

Figure 22 Bepi Colombo Cesic® HTHGAntenna

The main part is a Cesic® monolithic main reflector 1 m diameter with a skin and ribs of less than 2 mm in thickness. Such antenna is able to sustain temperature change from –180°C up to 350°C with thermal gradient up to 250°C on the surface, while maintaining a very accurate shape (less than 100 µm Rms). Such 1m main reflector will weight less than 8 kg and will be nevertheless be able to sustain vibro-acoustic and 25G quasi-static loads due to the launch condition.

In order to demonstrate these performances, AAS/ECM, under ESA/KDA TDA contract has started the design and the manufacturing of a scale 1 fully flight representative of the 1 m main reflector.
In order to validate all the manufacturing process a 60° segment has been already successfully manufactured , the mass being only 2,4 kg (see).

Figure 23 60° Cesic® monolithic segment demonstrator

The C/C greenbody of the reflector is under final lightweighting stage (ribs being 1,5 mm and skin 2,2 mm before final front face machining) and will be soon infiltrated (see Figure 24).

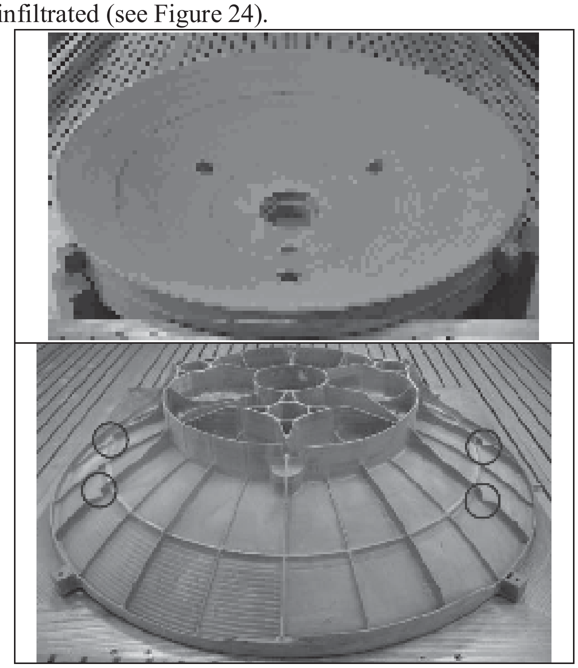

Figure 24 view of 1m reflector C/C greenbody

After manufacturing the antenna main reflector will be submitted to vibration and thermoelastical test sequences .

Conclusion

Thank to large development effort performed conjointly by AlcatelAleniaSpace and ECM and supported by ESA, Cesic® is now a mature technology offering :

- Large structural capacity thanks to its high mechanical properties associated to its large manufacturing capacity : very high EI/M ratio,
- High mechanical strength : insensitive to fatigue, junction, and surface status, compatible of bolted link under high loads ,
- Machining by EDM offering high precise I/F,
- Unequalled mirror manufacturing capabilities : large lightweight and stiff mirror, mirror with integrated filtering MFD,
- Ultra high stability performance for cryo application ,
- Cost and manufacturing time competitive,
- Potential of evolution (manufacturing of more complex structure, enhanced properties..) .

Cesic® is available for all future space applications or others.