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Study of joining of carbon/carbon composites for ultra stable structures

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Abstract

The aim of this work is to study joining materials and innovative bonding technologies for ultra stable joints of carbon/carbon composite (C/C) sandwich panels for the manufacturing of next generation space instruments. The proposed solutions have low coefficient of thermal expansion (CTE) and coefficient of moisture expansion (CME), and a good mechanical strength, in order to guarantee the dimensional stability and mechanical reliability of the joined C/C panels.

Keywords: A. Joining; B. Composites; C. Mechanical properties; E. Space instruments

1. Introduction

Future large optical instruments will be based on interferometric and optical aperture synthesis (according to the ESA science program for 2015–2025 named “Cosmic Vision”[1]). Such instruments will require ultra high stability large structures (some square meters) and a near to zero CTE is necessary for both in-orbit and ground-and-orbit operations.

Carbon/carbon composites (C/C) have been selected as key materials for the future instruments as their properties can be tailored to the application requirements detailed below[2]:

- very high thermo-elastic stability: C/C CTE is close to zero (in a quasi isotropic lay-up configuration);
- low density with good mechanical properties: they are not brittle materials and allow simple and reliable design;
- moisture insensitivity (null coefficient of moisture expansion, CME);
- various architectural possibilities: thin and large size cylinders, skins and honeycomb sandwiches, which can be adapted to several efficient structural concepts;
- industrial maturity: large industrial facilities up to 2.5 m^2.

To fully benefit from the potential given by C/C, it is important to select a joining material having the same properties of C/C, in particular a quasi-zero CTE and CME, in addition to a good mechanical strength.

With this purpose, several joining materials and technologies have been selected. The requirements for the joining materials are mainly given by the strict dimensional stability requirements of the future high performance space instruments.

The requirements of the joints established by the end-user are reported in Table 1.

Several types of bonding materials and technologies between honeycomb C/C cores and C/C skins (sandwich panels) have been tested at Thales Alenia Space (TAS). Although pyrolitic bonding, obtained through co-densification of C/C skins and honeycomb C/C core, gave promising results at small sample level, the mechanical strength of such bonding was low on large samples.[3]

Consequently, for large size panels, the assembly of C/C skins and honeycomb C/C cores relies today on organic bonding. Organic bonding is applicable to whatever size of sandwich and skins thickness, but the resulting assembly is sensitive to moisture absorption, leading to distortion of the structure.

The aim of this work is to study joining materials and innovative bonding technologies for ultra stable joints of C/C sandwich panels for the manufacturing of next generation space instru-

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Table 1
Requirements set by end-user for the joints.

Preferred joining process temperature (°C)	<300 °C[a]
Operating T range (°C)	from −50 to 50
CTE ($\times 10^{-6}$ °C^{-1}) in [−50 °C, 50 °C]	≤5
Shear strength at RT (MPa)	≥12
Young modulus, E (GPa)	1–30
Coefficient of moisture expansion (CME)	0
Joint thickness (μm)	100–200
CTE × E × thickness ($\times 10^{-6}$ °C^{-1} GPa mm)	<120[b]

[a] Compatible with end-user standard processing equipments.
[b] From Ref. 11.

ments. The results obtained by using different joining materials (metals and adhesives) are described and discussed.

2. Experimental

2.1. Sandwich sample description

The C/C to be joined are sandwich panels composed of two C/C skins joined to a honeycomb C/C core (Fig. 1).

2.1.1. C/C skins and honeycomb C/C cores

C/C skins are produced by Chemical Vapour Infiltration (CVI) of a quasi-isotropic lay-up (0°/45°/−45°/90°) of ex-PAN fibres; an adequate high temperature treatment confers to the material a quasi-null CTE.

The typical properties of C/C skins, measured at room temperature, are about 60 GPa (tensile modulus) and about 160 MPa (tensile strength).

During the CVI process a 10–15 μm pyrocarbon "seal coat" grows at the surface of the C/C skin, with a smooth laminar orientated structure. The coating is usually removed by polishing C/C skins before joining them to honeycomb C/C cores, nevertheless, its influence on the joining material wettability and shear strength of joined samples was investigated for comparison purposes. Some C/C skins were polished to remove the coating before wettability and joining tests and the results were compared with those obtained on as-received samples.

Honeycomb C/C cores are made of ex-PAN T300 fibres, fabric plain weave and lay-up 45°/−45°.

2.2. Joining materials

The joining materials selected, taking into account the requirements in Table 1, are listed below:

- Metal brazing
  - (i) TiCuNi brazing alloy (70 wt.% Ti, 15 wt.% Cu, 15 wt.% Ni) supplied by Wesgo Metals;
  - (ii) Si (silicon powder <150 μm supplied by MERCK); Si was applied on C/C substrates as a slurry (Si powder/ethanol).
- Adhesives (polymeric precursors of ceramic)
  - (i) Carbon fibre reinforced commercial adhesive (CFA);
  - (ii) CFA + 65 vol.% (5 wt.%) of fumed silica (99.8% supplied by Aldrich);
  - (iii) CFA + 25 vol.% (40 wt.%) negative CTE glass–ceramic powder (GC).

The composition of GC is BaO 33.3 mol.%, B_2O_3 33.3 mol.% and Al_2O_3 33.3 mol.%.[4,5]

The GC was produced as a glass material by melt/quenching at 1500 °C for 1 h then heat treated (720 °C, dwelling time 24 h + 780 °C, dwelling time 8 h) to obtain a glass–ceramic.

GC has been added to CFA as follows: CFA + 25 vol.% glass–ceramic powder (<105 or <44 μm).

2.3. Wetting tests

The wetting tests were performed by heating microscopy (hot stage microscope Leitz GmbH AII) equipped with a Leica DBP (Ernst Leitz GmbH, Wetzlar, Germany) camera; the wetting behaviour on C/C skins was studied by contact angle measurements from pictures acquired by the camera. The authors characterized the wettability parameters basically to meet the practical demands of brazing rather than for a study of the wetting mechanisms or ceramic–metal interactions.

Table 2
Joining materials, their CTE and Young modulus, the thermal treatment used to obtain the joined structures and the average shear strength of joints (C/C skin without seal coat).

Joining material	Coefficient of thermal expansion ($\times 10^{-6}$ °C^{-1})	Young modulus (GPa)	Thermal treatment for the joining process	Average shear strength (MPa)
TiCuNi brazing alloy	20.3[a,9]	144[a,9]	1000 °C, 10 min, 10 °C/min, Ar flow	24 ± 2
Pure Si	3.6[16]	112[17]	1450 °C, 10 min, Ar flow	15 ± 4
CFA (carbon fiber reinforced adhesive)	<8[b]	18 ± 3	130 °C, 4 h + 260 °C, 2 h; in air	14 ± 3
CFA + 65 vol.% silica	2.9[c]	–	130 °C, 4 h + 260 °C, 2 h; in air	9 ± 3
CFA + GC[d]	5.3[c]	17	130 °C, 4 h + 260 °C 2 h; in air	17 ± 3

[a] Properties of TiCuNi before brazing process, from Ref. 9.
[b] Supplier data sheet.
[c] Calculated by using the rule of mixture.
[d] Negative CTE glass–ceramic powders.