Some notes on C/SiC

V1.0
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1 Introduction

Carbon/Silicon carbide is a composite material ("ceramic matrix composite") consisting of silicon carbide reinforced by carbon fibres. The most common term for it seems to be C/SiC[1]. (CeSiC® is the trade name for the C/SiC produced by ECM and GEn.)

C/SiC materials produced by different companies vary in their composition and properties. The advantage of C/SiC over the more conventional C/C materials is the increased hardness and oxidation resistance of SiC over C [2].

C/SiC products are normally manufactured by machining the "greenbody" (precursor material); unlike C/SiC, this is easily machined ("the milling of C/SiC greenbodies is similar to the milling of wood" [2]). When the final shape has been produced, the greenbody is infiltrated with silicon to produce C/SiC. Infiltration is normally carried out either by chemical vapour infiltration (CVI) or liquid phase infiltration (LPI)[3]. There is some shrinkage at this stage, but it is small (e.g. 0.2% [4]) and controlled. If further machining is required (for example to precisely locate screw holes), it is possible either by EDM (spark erosion) or diamond machining. It is also possible to join greenbody sections with

[1] Fibre reinforced composite materials are normally described in the form "fibre/matrix"; as well as carbon-fibre/carbon composites (C/C), it is possible to obtain SiC/C and SiC/SiC.

[2] "[C/SiC] combines the strength and tenacity of carbon fiber materials, with the hardness and the oxidation resistance of silicon carbide (SiC)" — Ref. [1]).

[3] Reference [3] describes an additional technique: a liquid silicon infiltration method (LSI)

the properties of the joint in the finished structure being similar to that of bulk, or to glue finished materials together and re-process to achieve a similar result.

1.1 Cesic

For further information, I'll take ECM Cesic as an example (this material is produced by the German company ECM, and has been licensed by GE for the US market [5])

The material is isotropic on scales greater than 2 mm. (Ref. [5])

> "Cesic is a composite ceramic produced by infiltrating a carbon/carbon (C/C) greenbody with high purity liquid silicon at high temperatures, leading to the reaction of the Si with the C to form SiC. The resulting Cesic is composed predominately of SiC along with residual Si and C." (Ref. [5])

> "The starting material in the manufacturing of Cesic is a felt of short, chopped, randomly oriented carbon fibres. The felt is impregnated with a phenolic resin and moulded at high pressure into a blank.. Upon machining and joining – necessary for meter-plus-class mirrors and structures – the greenbody is infiltrated under vacuum conditions with liquid silicon at temperatures above 1600 °C. Capillary forces wick the silicon throughout the porous greenbody, where it reacts with the carbon matrix and the surface of the carbon fibres to form carbon-fiber reinforced SiC – Cesic...The Cesic structure can then be micro-machined with suitable diamond tools or by EDM machining to achieve the required surface ... EDM machining is possible because of Cesic's electrical conductivity. This machining method is fast compared to grinding, it is relatively inexpensive, and it yields a surface and location (e. g., screw holes and mounts) accuracy of about 10 μm tolerance over a large area." (Ref. [4])

1.2 Manufacturers

This is an incomplete list of companies that manufacture C/SiC. Additions welcome!

- ECM (Ge in the US): Cesic
- HITCO (http://www.hitco.com/products/temperature/carbsil/index.html)
- SGL Carbon group (http://www.sglcarbon.com/sgl_t/industrial/sigrasic/index.html) - SIGRASIC and TAVCOR
- AIBG (http://www.iabg.de/index_en.php) (see Ref. [2])
- BOOSTEC?

1.3 Material properties

Material property values for C/SiC have been reported in various reports and papers. Figure 1 shows the range of values at room temperature for different properties. The variation is likely to be due to differences between materials made using different processes as well as to experimental error. The sources are references [7], [8], [9], [10], [11], [2], [12] and [6].

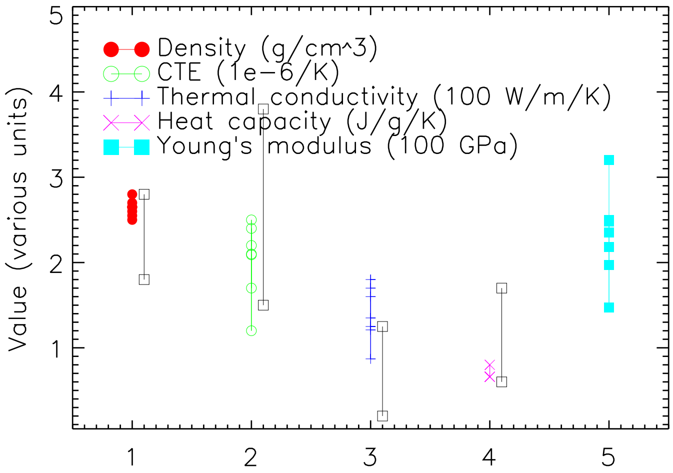

Figure 1: Variation in reported values of various thermal and mechanical properties of C/SiC at room temperature. The black lines between open squares show the ranges quoted for SGL SIGRASIC®, which is available in different forms covering a range of properties [6].

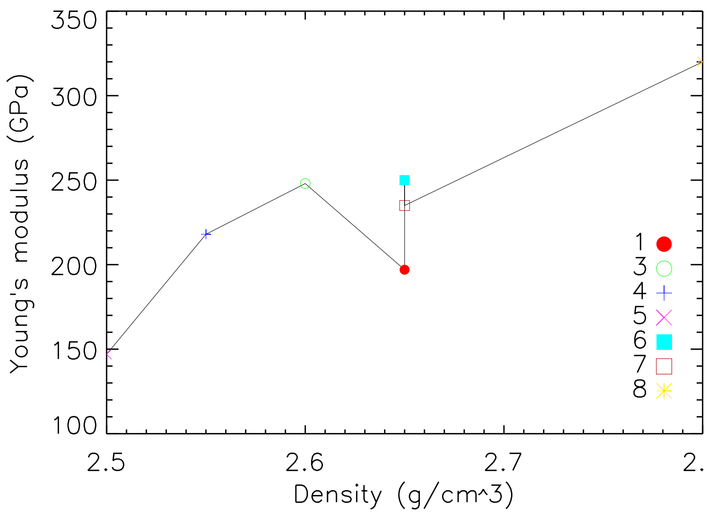

Figure 2: Young's modulus as a function of density for material property data from different sources.

Figure 2 shows the Young's modulus as a function of density for the different reported sets of values. There is some indication that increasing density results in increased Young's modulus; these results should however be treated with caution because for most sets of quoted values there is no reason to believe that the results presented for different properties actually correspond to the same type of material.

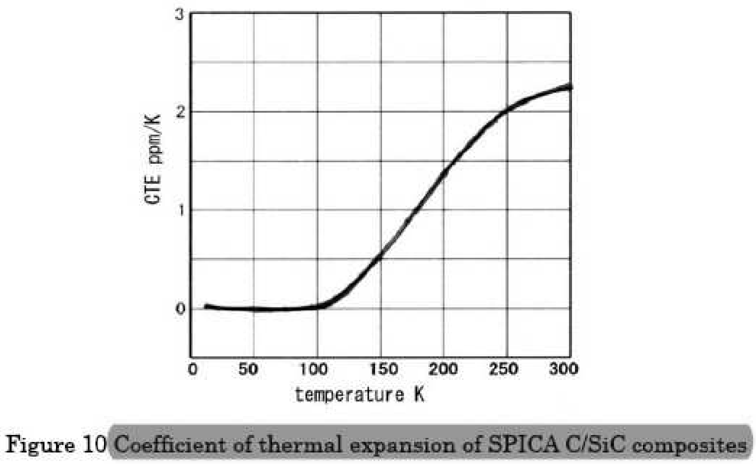

Figure 3: Cryogenic CTE measurements from Ref. [12].

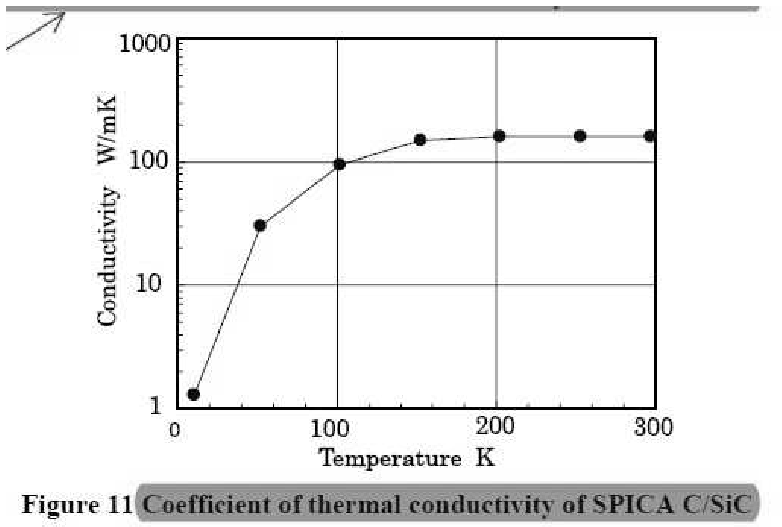

Figure 4: Cryogenic thermal conductivity measurements from Ref. [12].

1.4 Cryogenic properties

I've found a few papers describing measurements at cryogenic temperatures. In Ref. [12], the coefficient of thermal expansion (Fig. 3) and thermal conductivity (Fig. 4) were measured down to approximately 4 K for a particular type of C/SiC sample (developed for possible use as the SPICA[4] mirror); this material had properties that are somewhat different from conventional C/SiC, and therefore cannot be taken as typical (it's the material with highest density and Young's modulus in Fig. 2). Reference [13] gives cryogenic CTE measurements on two different samples of C/SiC (Fig. 5).

[4] A potental Japanese far-infrared astronomy space mission

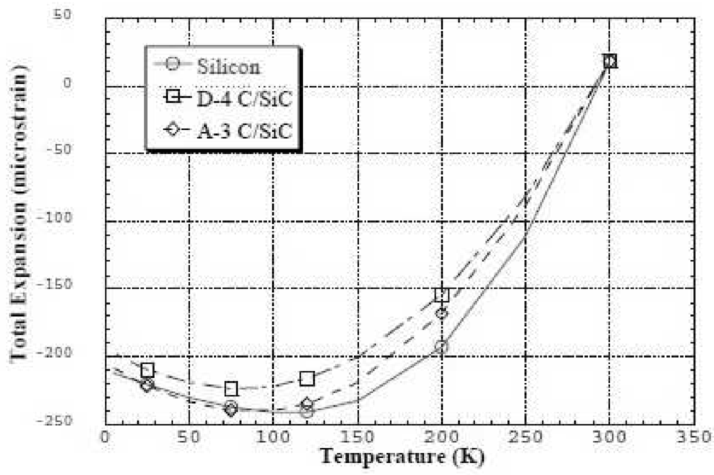

Figure 5: Cryogenic CTE measurements from Ref. [13].

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