DEVELOPMENT OF ENHANCED INTERLAMINAR STRENGTH CARBON-CARBON MATERIALS FOR HIGH TEMPERATURE PROPULSION COMPONENTS

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Introduction

The design of carbon-carbon components is a challenging proposition, which is made more difficult by the low interlaminar strength properties of these 2D composites. Carbon-carbon materials are inherently anisotropic, a fact which exacerbates the thermal stresses in both the in-plane and through thickness directions. To accommodate the low interlaminar strength properties, component designs rely on a variety of different methods, including "shingle angle" layups, needled preforms, stretch-broken fiber reinforcement, and matrix fillers. In this effort, in addition to the needled fabric, stretch-broken fiber reinforcement, and graphitic filler methods, another approach for obtaining enhanced interlaminar properties in C-C composites was investigated, specifically the use of a reinforcement interleaf (RIL), a product devised by Energy Sciences Laboratory, Inc. (ESLI). This is discussed in the following section of this paper.

The use of graphite filler particles to enhance interlaminar properties of C-C materials has been used before and is not a novel approach. Indeed, most recently the C-C hot structure control surface components used for the X-37 orbiting vehicle were successfully fabricated using graphite filler particles to enhance interlaminar properties [1]. Tufted preforms, in which some surface fibers are frayed to promote fuzziness and thereby obtain a degree of matrix interlaminar reinforcement, were also prepared.

Alternative Interlaminar Reinforcement Method: Reinforcement Interleaves

ESLI developed a process of transferring flocked fiber interleaves onto a carbon fabric ply at the prepreg state. The final reinforcement interleaf transfer (RIT) configuration used DKD fibers. The reinforcement fibers were then trimmed to a uniform height selected to pierce through the thickness of the fabric ply. When using this procedure on the 2x2 twill prepreg material, ESLI was able to get good uniformity with low fiber debris. The procedure involves the transfer of the reinforcement fibers onto the carbon fabric prepreg by means of an ESLI proprietary process. This procedure was used to transfer the reinforcement fibers onto all plies of 12" x 12" prepreg required for the fabrication of the C-C panels using this interlaminar reinforcement approach. Some prepreg plies were prepared with flocked DKD fibers applied to one surface (single RIT), while other prepreg plies were prepared with the RIT applied to both surfaces of the T-300 plies (double RIT). Figure 1 shows an image of the Allcomp prepreg after transferring pitch fibers from the RIT. Note that there are "footprints" in the prepreg where it appears that fibers were inserted, but were pulled out with the RIT. However, the majority of the fibers are oriented either vertically or at some angle to the pregreg, as desired.

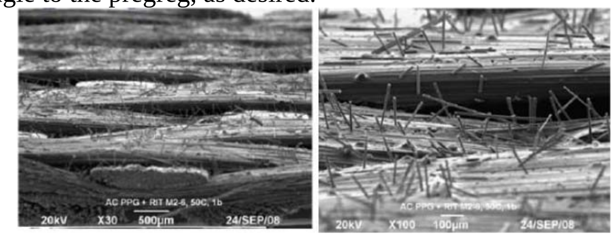

Figure 1. SEM images of the Allcomp prepreg with transferred DKD fibers at 30x (left) and 100x (right).

TEAM performed the fabrication of the preforms including baseline continuous, tufted, needled, and stretch-broken. The continuous fabric served as the fabric subjected to the needling operation. The intent of the needle punched fabrics was to attempt to obtain an increase in interlaminar properties due to some degree of the filaments being pushed out of the plane of the fabric. At the same time, the desire was to obtain as little of a knockdown in in-plane properties as possible. Note that the fabrics were needle punched in a continuous line operation, as opposed to being needled together as a stacked block, which is the typical manner in which needle punched preforms are prepared.

Note that the baseline 19 epi x 19 ends per inch (epi) T-300-3K fabric was used for fabricating unreinforced C-C panels as well as for the fabrication of the RIL panels using the ESLI-developed RIT process described above. The items of most uncertainty were the tufted fabrics. The tufted fabrics were prepared through selected and repeated slicing of yarns at the fabric preform stage, while the fabric was still on the loom. All of the fabrics were completed and shipped to Allcomp for preparation for prepregging.

Carbon-Carbon Fabrication

Allcomp completed fabrication of all of the C-C panels with various types of reinforcement. A minimum of two 6" x 12" panels for each of the various modified preform reinforcement concepts and the baseline material were pitch densified at AFRL at Edwards Air Force Base. In addition, Allcomp also fabricated one panel from each concept using CVD densification for future comparison. Note that the layups for all of the panels fabricated in this program were warp-aligned (0/90) fabric layups. Panels were completed and delivered to Southern Research Institute for material property testing.

Carbon-Carbon Testing

The measured mechanical properties are presented in Table 1 below, with all of the data normalized to the results obtained for the Baseline T300-3K fabric preforms. The highest interlaminar and matrix dominated properties are obtained for the 100% stretch-broken preform reinforced C-C composites. As expected, due to the loss of the original continuous filaments in these preforms, the in-plane tensile strength for these composites is the lowest of all of the C-C.

Table 1. Summary of all Measured Mechanical Properties of Baseline and Interlaminar Reinforced C-C Composites.

Concept	ILT Strength		ILS Strength		0˚ Tensile Strength		45˚ Tensile Strength		0˚ Compression Strength	
	Normalized Average	COV (%)	Normalized Average	COV (%)	Normalized Average	COV (%)	Normalized Average	COV (%)	Normalized Average	COV (%)
Baseline 3k	0.481	49.3	1.000	17.4	1.0	2.6	1.0	0.9	1.0	4.6
Single RIT 3k	0.787	13.2	0.772	21.4	0.9	16.4	1.0	2.2	-	-
Double RIT 3k	0.903	9.6	1.091	7.9	1.1	4.5	1.0	5.4	-	-
100% SB	2.368	3.7	2.141	6.2	0.6	4.8	1.4	2.2	-	-
Single Needled 3k	0.787	13.7	1.034	4.9	1.2	4.3	1.4	5.9	-	-
Baseline 1k	1.415	18.4	-	-	-	-	-	-	-	-
Single RIT 1k	2.116	13.6	-	-	-	-	-	-	-	-

Photomicroscopy images of many of the preforms were taken as part of the mechanical property measurements. Figure 2 and Figure 3 below provide representative microscopy images for the single RIT T-300 3K preform and the 100% stretch-broken preform reinforced C-C composites.

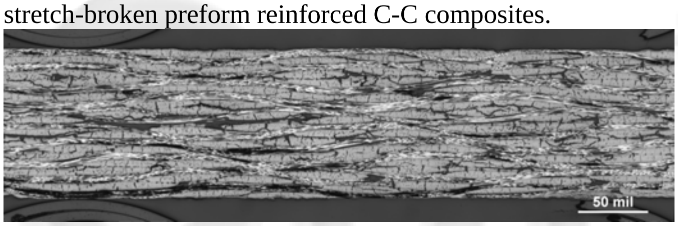

Figure 2. Optical Micrograph of 2x2 Twill Single Sided RIT T300-3K Preform Reinforced C-C.

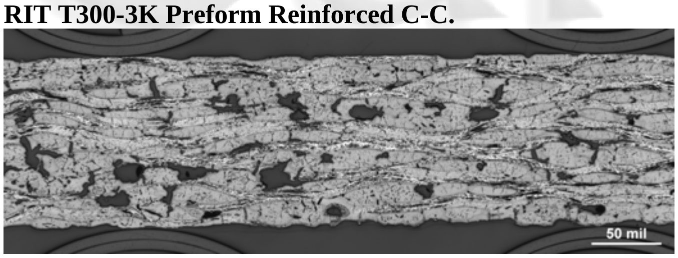

Figure 3. Optical Micrograph of 100% Stretch-Broken T300-3K Preform Reinforced C-C.

For the Baseline and RIT reinforced C-C composites, bands of porosity exist mostly (but not entirely) in the interior of the panel. In the 100% stretch-broken preform reinforced C-C composites, the porosity is located in larger pockets and porous regions do not appear connected.

Images of post-tested C-C tensile specimens, as shown in Figure 4 and Figure 5 below, show the nature of the failure surfaces resulting from the tensile fractures in the single RIT and 100% stretch-broken C-C composites, respectively.

In the Baseline and RIT reinforced C-C composites, the post-tested tensile specimens of Figure 4 show evidence of a large amount of "brooming" and extent of delamination, while

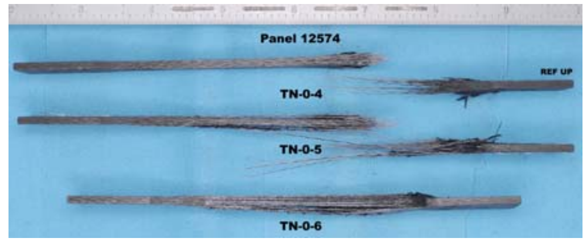

Figure 4. Post-test 2x2 Twill T-300 3K HT Single RIT Reinforced C-C Tensile Specimens.

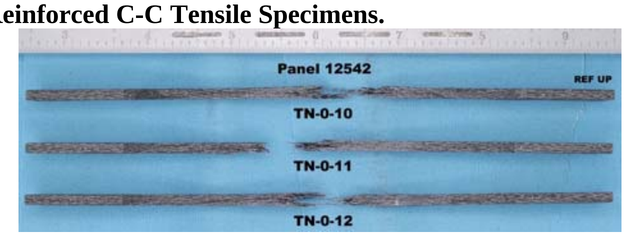

Figure 5. Post-test 100% Stretch-Broken T-300 3K Preform Reinforced C-C Tensile Specimens.

the 100% stretch broken preforms do not show this. Generally speaking, for all of the composites other than the 100% stretch-broken preform reinforced C-C composites, the tensile stress-strain curves of the baseline and RIT reinforced C-C materials do not look like stress-strain curves of other C-C materials. It is speculated here that the low matrix strengths are causing pre-mature tensile failures and a "rolling" over of the stress-strain curve, not typically seen in standard C-C tensile curves. Moreover, it appears that the broken ends split apart at the in-plane tensile failure point. This is not the case for the higher interlaminar strength stretch-broken specimens.

Conclusions

The single RIT preform reinforced C-C materials performed significantly better than the Baseline for both T-300 3k and T-300 1k C-C materials. Also the double RIT preform reinforced C-C performed slightly better than single RIT preform reinforced C-C materials. Most likely, the same trend would apply for T-300 1k. Overall, the best performing C-C was the 100% stretch broken preform reinforced C-C. However, a substantial decrease in in-plane properties is probable, based on existing data for similar preform reinforced C-C materials.

The expected property trade-off was realized only for 100% stretch-broken preform reinforced C-C. All other specimens (single-sided and double-sided RIT, single needled preform) did not experience significant interlaminar property increases nor significant in-plane property decreases. The single needled preform reinforced C-C materials did not behave as expected. There were no significant IL increases, slightly higher in-plane tensile strength, and an increased 45^o in-plane tensile strength.

Reference

[1] Jortner, J., "Estimation of Provisional Allowable Stresses for a Quasi-Isotropic ACC-6 Carbon-Carbon Composite Made with a Particulate-Carbon-Filled Matrix and a Conversion Coating," JRE Report to SAIC, 21 May 2004.