Carbon Fiber Efficiency in Thin Carbon-Carbon Panels

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Abstract. Carbon fiber efficiencies in thin carbon carbon panels fabricated with P100 and T300, MF55, and IM6 yarns as calculated from tensile tests were 35, 39, and 22%, respectively. The low fired PAN IM6 panels were adversely affected by the moderate CVD temperature most panels received. MF55 panels were unaffected by a lower CVD temperature. P100 panels which were reimpregnated with a resin increased in strength by 26%.

Introduction

Commercially available carbon fibers can be very strong. How well these properties are carried over to the tensile strength of thin carbon carbon panels will be discussed in terms of fiber efficiency. Fiber efficiency is a coefficient used to quantify how well these fibers contribute to the properties of the composite on the basis of a volumetric rule of mixtures. It is expressed as follows:

$$UTS_c = UTS_f \times V_f \times e_f$$

where UTS_f is the ultimate tensile strength of the composite. A similar equation exists relating the modulus of the fiber and the composite. Because the matrix is mostly hard carbon and hardly monolithic, the matrix is assumed to contribute nothing to the composite properties. Since the volume fraction of fiber in the tensile direction V_f is limited by geometry, and the ultimate tensile strength of the fiber UTS_f is limited by the technology and is beyond the scope of this paper, the efficiency is the only parameter that is influenced by processing. The efficiency dependence on degradation of the coupling between fibers through the matrix due to voids and cracks will be explored by filling the voids with an epoxy resin. Thermal damage to fiber due to processing will also be considered, but mechanical damage due to weaving and handling will be neglected.

Experimental

Thin panels were fabricated at Hitco of Gardena, CA using a number of yarns. Panels were constructed as follows: IM6-12k yarn in a 2 ply 5-harness satin weave, MF55-3k yarn in a 2 ply 8-harness satin weave, and P100-2k yarn as the warp and T300 as the fill in a 2 or 4 ply weave. All panels underwent phenolic resin rigidization, pyrolysis, and chemical vapor deposition of pyrolytic carbon at a moderate temperature. Some process experimentation was done. Since IM6 is a low-fired PAN yarn, some panels were heat set at 2500°C before resin impregnation. Some MF55 panels also underwent a lower temperature CVD.

Panels were received at LPARL as 12-in. x 12-in. sheets. These were cut into 0.75-in. strips in the warp direction and cut in half to give 6-in. specimens. Aluminum tabs 1.5 in. long were bonded to the strips with epoxy to give a 3-in. gage length. Specimens were pulled apart at 0.05 in./min. per ASTM standard D3039 and the outputs of a strain gage bonded to the specimen and a load cell were continuously recorded on a chart. As cured panel tensile data were similarly obtained by Hitco. Some of the panel strips were vacuum impregnated with UCC ERL 4221 resin with 3 pph BF_3-MEA as a catalyst and cured at 125°C overnight.

Discussion

Panel data is given in the tables. Ultimate tensile strengths for the P100 panels averaged more than 40 ksi, with a highest strength of 77 ksi. The tensile efficiency was 35%. MF55 panels had a tensile strength of 52 ksi and an efficiency of 39%. Panels made with IM6 had strengths and efficiencies well below those for P100 and MF55 panels though the as-cured efficiencies compare favorably. The average modulus of the P100 panels was 38 Msi (with a maximum of 42 Msi), consid-

erably more than the MF55 and IM6 panels. The fiber modulus efficiency was over 80% for all panels.

Processing variables will affect the efficiency. Past experience with low-fired PAN fiber such as IM6 has shown that serious delamination and/or warping results from thermal strains. Consequently, some of the IM6 panels were heat set at 2500°C, well over the moderate CVD temperature used, to try to mitigate the problem. Fibers in the heat set panel shrank in diameter such that the panel was no longer tightly woven, resulting in misalignment of the fill fibers and other problems. As can be seen in Table 1 for both the as-cured and post-CVD data, heat setting the fiber while in the preform was not a successful solution.

Table 1 also shows that the porosity, a function of the impregnation procedure, resin curing and charring properties, and the pyrolysis process was significant (~9%) in nearly all the panels as measured by mercury porosimetry. Porosity appears not only as voids but also as cracks running both parallel and perpendicular to the plane of the panel. CVD can heal some of the cracks, but cannot fill the voids. Low temperature CVD of MF55 panels did not adversely affect the mechanical properties.

Some panels were subjected to the bimatrix approach, wherein as indicated in Table 2, the porosity has been reduced to ~2% by vacuum impregnation with a resin. The table shows that a marked increase of 26% in the tensile strength of P100 panels occurred, but that no such improvement occurred for any of the other panels.

Conclusion

The implications of this paper for thin carbon carbon panels are:

1. Only fiber fired at temperatures higher than the greatest composite processing temperature should be used.

2. Lower CVD processing temperatures can be used with deleterious effects.

3. Voids and cracks play a role in reducing fiber efficiency, which in some cases can be mitigated by the bimatrix approach.

4. Thin carbon carbon panels are viable structural materials with tensile strengths approaching 80 ksi.

Table 2. Bimatrix Thin Panel Data

panel	por %	UTS ksi	mod Msi	UTS/UTS$_{p\text{-}CVD}$ %
P100(0_2)	2.32	49.3 ±7.6	38.2 ±4.5	126
P100(0_4)	1.71	57.9 ±13.2	40.8 ±2.2	126
MF55(0_2)	2.37	50.6 ±5.0	11.9 ±0.7	99
IM6(0_2)	2.13	37.4 ±8.6	11.6 ±1.0	99

Table 1. Thin Carbon Carbon Panel Data

				post-CVD				as cured	
panel	t mil	por %	V_f %	UTS ksi	mod Msi	e_f^s %	e_f^m %	UTS ksi	mod Msi
P100(0_2)	34	8.7	35	39.1 ±7.5	36.1 ±3.7	34	104	-	-
P100(0_4)	60	10.0	40	46.1 ±6.4	39.3 ±2.7	35	98	61.9 ±6.7	49.9 ±5.9
MF55(0_2)	21	9.8	24	51.1 ±4.0	12.2 ±0.6	39 39	88 82	83.6 ±8.6	18.0 ±1.5
MF55(0_2)LT	20	9.5	25	53.2 ±3.3	11.9 ±1.4	39	82	-	-
IM6(0_2)	32	6.8	27	37.8 ±6.9	11.3 ±1.1	22	104	120.7 ±8.7	12.3 ±0.7
IM6(0_2)HS	31	-	28	19.5 ±1.4	13.5 ±1.4	11	118	50.4 ±6.6	17.9 ±0.7