TOB-NOTE 00.7
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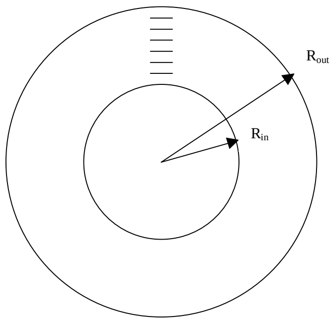
Material Evaluation for the Tracker Outer Barrel (TOB)

Mechanical, thermal and moisture behavior of different epoxy matrix carbon fiber composites is considered. Structure layout (end view) and main dimensions are presented in Figure 1.



Layer	Radius [mm]
R_{in}	550
1	610
2	696
3	782
4	868
5	965
6	1080
R_{out}	1165

Figure 1. TOB layout and main dimensions.

1 In-plane elastic modulus and coefficient of thermal expansion (CTE) of the laminate

The laminate used for the skins of the disk in the TOB should be symmetric balanced. The laminate should also be quasi-isotropic i.e. the Young´s modulus, CTE, and coefficient of moisture expansion (CME) are constant in the plane of the laminate. Laminate thickness *h* should be approximately 2 mm. Some general prepregs and feasible lay-ups are presented in Table 1.

Table 1. Prepregs and lay-ups. /1, 2/

Nlam	Laminate	Lay-up
1	T300;Epoxy;UD-.425/298/40	(0a/+60a/-60a)SE
2	T800;Epoxy;UD-.425/306/40	(0a/+60a/-60a)SE
3	T300;Epoxy;UD-.340/298/50	(0a/+60a/-60a)SE
4	T800;Epoxy;UD-.340/306/50	(0a/+60a/-60a)SE
5	T300;Epoxy;UD-.200/210/60	((0a/+60a/-60a)2)SE
6	T800;Epoxy;UD-.200/216/60	((0a/+60a/-60a)2)SE
7	IM6;3501-6;UD-.140/ /62	(0/+π/7/-π/7/+2π/7/-2π/7/+3π/7/-3π/7)SE
8	AS4;3501-6;UD-.1469/145/62 modified for CERN	(0/+π/7/-π/7/+2π/7/-2π/7/+3π/7/-3π/7)SE
9	AS4;3501-6;UD-.1469/145/62 verified mech. Prop.	(0/+π/7/-π/7/+2π/7/-2π/7/+3π/7/-3π/7)SE
10	GY-70;934;UD-.140/ /57	(0/+π/7/-π/7/+2π/7/-2π/7/+3π/7/-3π/7)SE
11	M40;Epoxy TRT Endcap (ATLAS)	(0/+π/7/-π/7/+2π/7/-2π/7/+3π/7/-3π/7)SE
12	M40J;954-2A cyanate ester	(0/+π/7/-π/7/+2π/7/-2π/7/+3π/7/-3π/7)SE

High modulus fibers have more negative CTE as shown in Figure 2. The elastic properties of fibers AS4 and IM6 (from Hercules) are about in the same range than T300. The M40/J fibers are in the category of High Modulus fibers (350…440GPa). Respectively, GY-70 fiber is in the upper limit of this category.

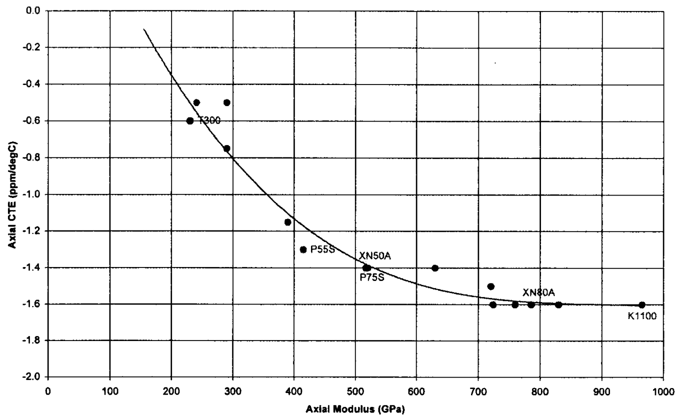


Figure 2. Modulus-CTE correlation in high modulus carbon fibers.

The laminate consists of layers of unidirectional (UD) prepreg tape. The higher the fiber volume content of the UD-tape and the final laminate the smaller the CTE.

In the transverse direction of the UD-tape CTE is characterized by the matrix material. For example, plies used in the first 6 laminates have equal CTE in the transverse direction due to the same matrix material. Same fact is also valid for plies used in laminates 7&8.

Laminate thickness, Young’s modulus, CTE and CME of the laminates presented in Table 1 are shown in Table 2.

Table 2. Laminate data. /1, 2/

Laminate	h [mm]	E_x [GPa]	alpha_x [ppm]	beta_x [e-2/w%]
1	2.55	33.94	2.48	-
2	2.55	41.19	2.09	-
3	2.04	41.19	2.12	-
4	2.04	50.11	1.75	-
5	2.4	48.44	1.85	0.0453
6	2.4	59.03	1.5	-
7	1.96	61.44	1.14	-
8	2.06	55.64	1.62	-
9	2.06	46.99	1.62	0.0249
10	1.96	104.23	0.58	0.00779
11	-	83.99	1.94	0.0104
12	1.82	79.63	1.43	0.00505

Laminate undergoes internal loads while cooling down from RT to the operative temperature, which is approximately -20°C. The shrinkage due to this temperature variation in different layers for different laminates is presented in Table 3.

Table 3. Displacements [μm] in different layers for different laminates due to the temperature difference of -40°C.

Layer	1	2	3	4	5	6	7	8	9	10	11	12
R_{in}	55	46	47	39	41	33	25	36	36	13	43	31
1	61	51	52	43	45	37	28	40	40	14	47	35
2	69	58	59	49	52	42	32	45	45	16	54	40
3	78	65	66	55	58	47	36	51	51	18	61	45
4	86	73	74	61	64	52	40	56	56	20	67	50
5	96	81	82	68	71	58	44	63	63	22	75	55
6	107	90	92	76	80	65	49	70	70	25	84	62
R_{out}	116	97	99	82	86	70	53	75	75	27	90	67

2 Moisture expansion of the laminate

Also CME of the UD-tape in the fiber direction is characterized by the fiber. Practically, the fibers prevent expansion of the matrix material in this direction. In the transverse direction of the UD-tape CME is characterized by the matrix material and this is usually by factor of about 50 bigger than in the principal 1-direction. The maximum moisture absorption of epoxy matrix materials is typically 2 weight percent. The saturation process can take for months. CME is evaluated for laminates 5, 9 through 12 (Table 2). The elongation/shrinkage due to moisture saturation of 1 w% in different layers for the epoxy resin based laminates is presented in Table 4. For laminate 12 (cyanate ester resin) the evaluated moisture saturation is 0,5%. /1, 3/

Table 4. Displacements [μm] in different layers for laminates 5, 9 through 12 due to the moisture absorption.

Layer	5	9	10	11	12
R_{in}	249	137	43	57	14
1	276	152	48	63	15
2	315	173	54	72	18
3	354	195	61	81	20
4	393	216	68	90	22
5	437	240	75	100	24
6	489	269	84	112	27
R_{out}	528	290	91	121	29

3 CTE and CME in sandwich structures

In a sandwich structure the skins carry the in-plane and bending loads. Respectively, core material carries out-of-plane loads. A honeycomb core (e.g. Nomex) has no mechanical properties in the *xy*-plane of the laminate. Therefore, CTE and CME of a sandwich structure are characterized by the CFRP skins. In the out-of-plane direction thermal and moisture loads will cause no harm.

4 About stresses

For the laminate number 9 (AS4;3501-6;UD-.1469/145/62) that is used in the Big Wheel prototype internal stresses due to the temperature difference (-40 °C) are ~6 MPa. The bigger the mismatch of CTE in the principal directions of the UD-tape the bigger thermal stresses will be introduced in the structure. For example, for the laminate 7 that has the same matrix (3501-6) but different fibers (IM6) the internal stresses would be ~8 MPa. However, these stresses are only about half of the stresses due to the dead weight and rod weights.

Higher stresses will be induced due to the moisture absorption (1 w%). For the Big Wheel laminate stresses are ~14 MPa, and for the laminate 5 as high as ~44 MPa.

5 Conclusions

The material selection is a compromise between cost and desired properties. High modulus fibers are expensive but they provide more stable structures. The other issue is the choice of resin material. Epoxy matrix materials are well known to absorb more humidity than cyanate esters. Again, moisture absorption is highly concentration dependent process, i.e. what is the relative humidity and temperature of the atmosphere.

6 References

1 ESAComp Databank
2 Hercules Product Data
3 Carbon/Graphite Database. *http://composite.about.com/industry/composite/library/data/blcarbon.htm#AS4/3501-6-1*