European Union Aviation Safety Agency

Annex E Heat Resistance Test Results

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1.1 General Test Set Up

To simulate the worst-case heat condition that the float bag material will be subjected to during flight, float and composite material samples will be layered such that the composite material is nearest the heating element, simulating the system's final pod/cover and float bag layup. Three thermocouples will be placed along the simulated cross-section; one on the surface of the composite sample, another between the float material and composite sample and the third behind the float material sample, see Figure 1 for a schematic. The heating element will increase in temperature until the worst-case heat condition (200C/392F) is measured at the surface of the composite sample (thermocouple 1). Each float material test sample will be fastened in the test rig such that it acts as the pressure retaining end of a pressure chamber, the sample's air retention properties can be documented during its exposure to the high temperature via an internal pressure sensor. Thermocouples will be placed on both sides of the sample to track the heat flux of each material.

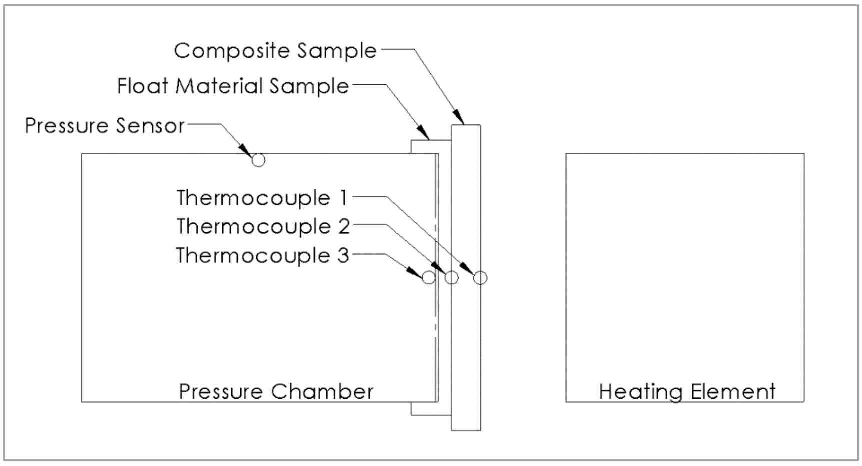

Figure 1: Heat Resistance Test Set Up

1.2 Composite Sample Results

All composite samples withstood the worst-case condition without any major physical deterioration. Temperature vs time graphs generated for each composite sample showed that each sample had a consistent heat resistance during the test with no evidence of material degradation during tests. Table 1 shows the comparison of the average thermocouple values for the composite samples tested during the 30-minute sustained heat portion of the test. The average temperature delta was calculated by averaging the values of the thermocouples on both faces of the materials and taking the difference. Additionally, the heat flux value shows the materials effectiveness at resisting heat per cross section thickness allowing better comparison between materials. While Material C had the largest overall average temperature difference the significantly thinner Material E had the largest temperature difference per material thickness. Therefore, it was concluded that the Material E sample was most efficient at resisting heat, thus was selected as the best candidate for stage 2 testing and would be used during all stage 2 float bag material tests.

Table 1: Stage 1 Composite Material Test Results

Material	Coupon Material	Thickness (in.)	Average T1 (C)	Average T2 (C)	Average Temp. Delta	Heat Flux (Avg. Temp. Delta per Thickness) (C/in)
Material A	Epoxy Carbon Prepreg	0.084	203.57	171.50	32.07	381.78
Material B	Epoxy Carbon Prepreg	0.084	203.84	167.57	36.26	431.70
Material C	Epoxy Carbon Prepreg	0.140	204.28	160.68	43.60	311.44
Material D	Epoxy Fiberglass Prepreg	0.145	207.06	166.00	41.06	283.16
Material E	Epoxy Fiberglass Prepreg	0.065	204.09	171.39	32.70	503.09

1.3 Float Bag Material Test Results

All fabric material samples withstood the worst-case condition without any major physical deterioration. A non-destructive tensile test was performed on all samples before and after the test to identify immediate fabric strength degradation. The tensile test consisted of a 1.6 inch circular probe on a force gauge pressed against the fabric to at least 25 lbs of force and maintained for at least five seconds. Since the nominal operating pressure of the float bag is 1.75 PSI, the tensile test, which tested to 12.4 PSI, had a FOS of 7. To maintain consistency between all the fabric tests composite Material B was used as the mock pod/cover for all the stage 1 tests, due to material availability. Table 2 shows each fabric material's properties and recorded temperature difference between the material's cross section. From the air retaining materials, Material B had the highest temperature delta through the material, as well as the best heat resistance per thickness.

Table 2: Stage 1 Fabric Material Test Results

Material	Coupon Material	Air Retention	Thickness (in)	Tensile Test	Average Temp. Delta (C)	Heat Flux (Avg. Temp. Delta per Thickness) (C/in)
Material A	Silicone Coated Woven Nylon	No	0.027	Pass	10.32	382.22
Material B	Woven Nylon	Yes	0.024	Pass	32.64	1360.00
Material C	Urethane Nylon	Yes	0.009	Pass	7.53	836.87
Material D	Silicone Coated Fiberglass	Yes	0.047	Pass	18.47	397.14
Material E	Silicone Coated Fiberglass	Yes	0.048	Pass	12.68	264.21
Material F	Silicone Coated PTFE	No	0.011	Pass	4.95	449.94
Material G	Silicone Coated Fiberglass	No	0.014	Pass	19.99	1427.71
Material H	Silicone Coated Fiberglass	No	0.013	Pass	19.49	1499.46
Material I	Woven Fiberglass	Yes	0.021	Pass	22.87	1088.82

During stage 1 testing it was observed that due to the test fixture's fabric material fastening system there was a 0.4 inch air gap between the back of the composite panel and the front face of the fabric sample. Therefore, an additional thermocouple was added to track the effect the gap had on the overall system temperature gradient. Since the final system would have portions of the fabric press directly against the composite, the effect of the gap was deemed significant enough to warrant an additional test method be performed. Additionally, because the air retention quality of all the samples had already been documented, the test fixture set up was changed so the fabric material was placed directly behind the composite. Each material was retested with the new material stack method to add another point of comparison between all of the fabric samples and further determine which fabric sample has the best heat resistance.

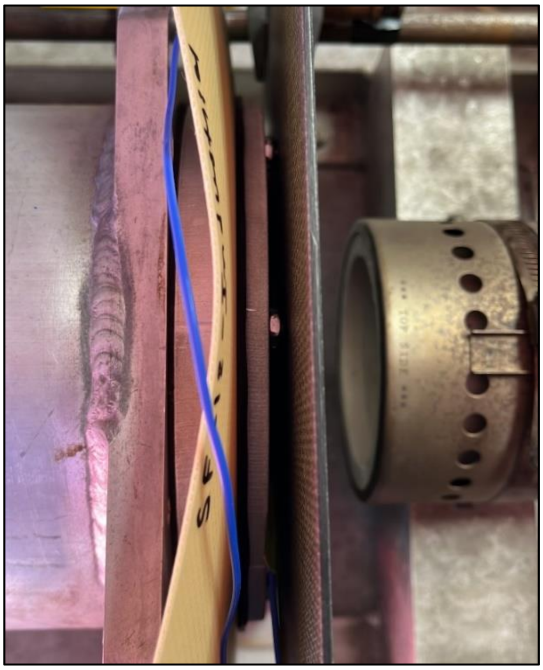

Figure 2: Fabric Fixture Gap

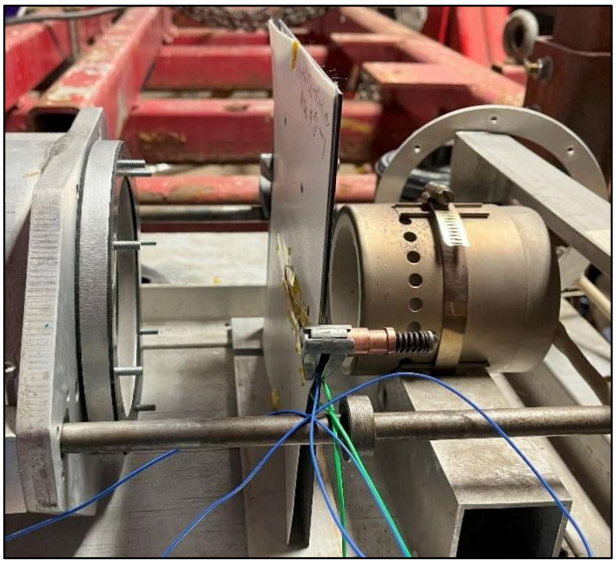

Figure 3: Fabric Test, Method 2, "No Gap" set up

Table 3 shows the average temperature deltas and heat flux for each material for the second method of fabric testing. With the new no-gap test set up, the fabrics were exposed to a higher overall heat condition, as a result the materials were able to resist more heat compared to the first test method; the average temperature delta for each material was higher for the second method. Material B still had the best temperature delta, but Material C had the best heat resistance per thickness. Both Material B and C were selected to be used in Stage 2 of testing.

Table 3: Stage 1 Fabric Material Method 2 Test Results

Material	Thickness (in)	Average Temp. Delta (C)	Heat Flux (Avg. Temp. Delta per Thickness) (C/in)
Material A	0.027	42.23	1564.22
Material B	0.024	83.36	3473.32
Material C	0.009	44.57	4951.67
Material D	0.047	39.65	852.77
Material E	0.048	77.64	1617.41
Material F	0.011	39.79	3617.22
Material G	0.014	31.24	2231.66
Material H	0.013	21.77	1674.86
Material I	0.021	34.99	1666.15

2. Stage 2 Test Results

The objective of the second stage of testing is to subject the material samples to a simulated flight scenario. The test used the same test rig as stage 1 testing, but the duration and procedure of the test will be altered to simulate a helicopter ditching manoeuvre. The test has four phases: ascent, flight, descent, and inflation. During the ascent phase the heating element will increase its temperature until the worst-case heat condition is measured on the surface of the composite sample. During the flight phase, the heating element will remain on and maintain the worst-case heat condition for 2.5 hours. During the descent phase, the heating element will be turned off but in order to test the float bag material at the most conservative heat condition the inflation phase will occur quickly after to ensure minimal heat loss. During the inflation phase the pressure chamber will be inflated to 2.0 PSI with shop air to test the materials air retention. These test phases simulate a full-length helicopter flight followed by an emergency ditching manoeuvre. The assumptions made during this test, temperature ramp rate, maintained temperature during flight, flight duration, minimal decent time, and high temperature at inflation are conservative estimates to subject the materials to worst-case conditions.

In an effort to make the thicknesses of Material B and C more comparable, two layers of the significantly thinner Material C were used during testing. Additionally, Material C is often used as pod liner to reduce abrasions inside the pod, thus a second layer used in testing more closely reflects existing EFS construction.

Both fabric materials passed the pre/post tensile test and air retention test. The composite sample experienced some discoloration at the heat focal point during the 2.5 hour heat exposure, but the temperature data showed no change to the materials ability to resist heat. The fabric samples had no noticeable physical changes when examined after the test. Table 4 shows a direct comparison of the average values at each thermocouple for both stage 2 tests. The T2b/T3 data, which is the heat transfer value through the fabric material sample, shows that the Fabric Material C sample was 1.25C more effective at resisting heat. However, with such a small margin it can be concluded that both materials were comparable in terms of heat resistance. Therefore, manufacturability was the deciding factor for stage 3 material selection. With comparable heat resistance properties, based on manufacturability, Fabric Material C is the more favourable material and was selected for stage 3 testing.

Table 4: Stage 2 Temperature Data

Material	Avg. T1 Temp(C)	Avg. T2a Temp(C)	Avg. T2b Temp(C)	Avg. T3 Temp(C)	T1/T2a Delta(C)	T2a/T2b Delta(C)	T2b/T3 Delta(C)	Total Delta(C)
Composite Material E + Fabric Material B	205.28	180.61	101.12	73.93	24.66	79.49	27.20	131.35
Composite Material E + Fabric Material C	205.90	174.80	94.19	65.73	31.10	80.61	28.45	140.17

3. Stage 3 Test Results

The objective of the third stage of testing is to subject the float bag material samples to cyclical testing by simulating numerous flights followed by one inflation. Due to the extensive length of each flight cycle (2.5 hours) a limited yet representative number of 15 consecutive cycles at 150C was agreed with EASA to assess if thermal cycling has unacceptable impact on material properties. Both pressure retention and tensile strength will be evaluated following the inflation. If the data displays a change of 5% or greater from nominal the data will be extrapolated to determine the number of cycles that the material can endure. If a change of 5% or greater is not observed an additional 15 cycles will be performed.

The Composite Material E paired with two layers of the Fabric Material C withstood all 15 of the 2.5 hour cycles of the cyclical testing with some discoloration occurring in the composite sample and no visual changes in the fabric sample. The fabric sample passed the tensile and air retention test before and after the thermal cycles. Table 5 shows the thermocouple average values for all 15 cycles of testing, as well as the calculated temperature deltas for the composite and fabric samples.

Figure 4 shows the composite and fabric sample's temperature delta per cycle; these values describe the materials' performance during the test. The trendline for each materials' temperature delta data defines the direction of the data and can be used to analyse the materials' overall performance and the expected performance using the greater relationship of the collected data. The general shape of the trendline is down sloping line, which is expected since the material will see a decline in performance as it is subjected to more cycles. Comparing the values of the trendline equation at cycle 1 and cycle 15 will determine the overall change in material performance. At cycle 1 the trendline value of the temperature delta of the composite was 19.01 C and 11.61 C for the fabric. At cycle 15 the trendline value of the temperature delta of the composite was 17.46 C and 7.46C C for the fabric. The composite saw an 8.1% change and the fabric saw a 35.8% change in heat resistance. Since values above 5% was observed a second round of cyclical testing was not performed.

Table 5: Thermocouple Data for 15 Thermal Testing Cycles

Cycle	Avg T1 (C)	Avg T2 (C)	Composite Delta (C)	Avg T3 (C)	Avg T4 (C)	Fabric Delta (C)
Cycle 1	156.62	138.00	18.61	70.29	56.46	13.83
Cycle 2	155.90	137.66	18.23	69.33	58.74	10.59
Cycle 3	155.10	136.66	18.44	68.20	57.01	11.19
Cycle 4	157.24	138.78	18.46	69.00	59.94	9.06
Cycle 5	155.90	137.66	18.23	69.33	58.74	10.59
Cycle 6	155.97	137.17	18.80	68.76	55.48	13.28
Cycle 7	157.35	138.84	18.52	69.17	59.11	10.07
Cycle 8	155.60	136.91	18.70	67.48	60.63	6.85
Cycle 9	158.25	138.90	19.35	68.00	58.17	9.83
Cycle 10	156.88	137.69	19.20	67.07	60.54	6.54
Cycle 11	156.75	137.74	19.00	66.72	61.45	5.27
Cycle 12	156.89	138.03	18.85	69.06	58.43	10.63
Cycle 13	158.35	142.26	16.09	68.26	60.88	7.38
Cycle 14	157.92	141.50	16.42	66.80	61.10	5.70
Cycle 15	156.57	139.92	16.65	68.99	56.77	12.22

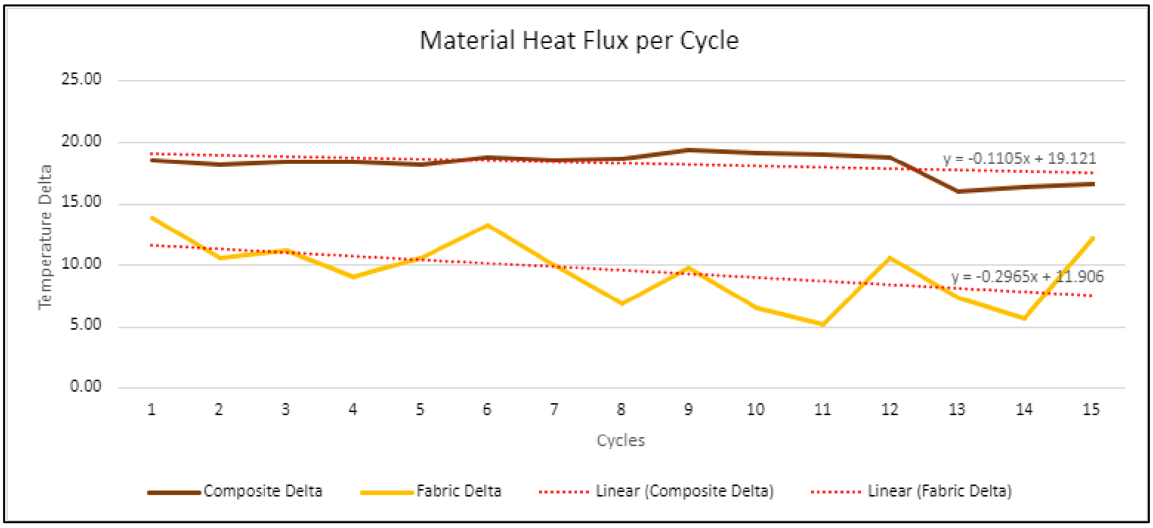

Figure 4: Material Temperature Delta per Heat Cycle and Trendlines

In an effort to further validate the fabric material, another round of cyclic testing was performed with a single layer of Fabric Material C. Table 6 shows the recorded thermocouple values and the associated material deltas. As expected, the single layer of fabric material had a significantly lower temperature change, however the single layer withstood all 15 of the 2.5 hour cycles and passed the post-test air retention test and tensile test. Similar to the first stage three test, some discoloration was observed in the composite sample and no visual changes in the fabric sample. The combination of Composite Material E and a single layer of the Fabric Material C produced positive cyclical testing result since the fabric retained the key quality of air retention post test.

Table 6: Thermocouple Data for 15 Thermal Testing Cycles (Single Layer)

Cycle	Avg T1 (C)	Avg T2 (C)	Composite Delta (C)	Avg T3 (C)	Avg T4 (C)	Fabric Delta (C)
1	156.36	138.49	17.87	61.79	60.40	1.39
2	156.99	138.83	18.16	63.02	61.61	1.41
3	156.49	138.53	17.96	63.13	61.72	1.41
4	159.81	141.06	18.76	62.99	61.49	1.50
5	158.32	139.89	18.43	64.40	62.90	1.50
6	158.05	139.79	18.26	64.55	63.02	1.53
7	156.72	138.29	18.43	61.43	59.94	1.49
8	159.04	140.49	18.56	63.99	62.44	1.56
9	158.94	140.36	18.58	64.05	62.46	1.59
10	159.33	140.58	18.75	63.06	61.50	1.57
11	159.65	141.06	18.59	64.67	63.00	1.66
12	158.10	139.74	18.37	64.13	62.44	1.69
13	155.41	137.34	18.07	61.50	59.90	1.59
14	158.38	139.79	18.59	63.54	61.84	1.70
15	159.24	140.73	18.51	64.13	62.37	1.76

4. Hardware Test Results

The objective of the hardware test is to validate hardware that is currently used in existing float systems for use in the heat condition of the High Mounted EFS. Representative Inlets and Pressure Release Valves (PRVs) were tested to determine their heat resistance. The inlet and PRV were attached to the final selected float material using standard methods used in standard floats. The inlet will be bonded directly to the float material. The PRV screws into a PRV collar that is bonded to the float material, this test will also validate the PRV collar material which is currently made of a urethane polymer. The representative hardware samples were subjected condition similar to stage 2 testing, 200C for 2.5 hours and a mock inflation occurred immediately after the heating phase, the pressure chamber was filled with shop air to 2.00 PSI to evaluate the air retention characteristics of the samples. Both the inlet and PRV representative assemblies were able to operate normally after being subjected to the worst-case heat condition with no noticeable physical deterioration.

Figure 5: Representative Inlet

Figure 6: Representative PRV and PRV Collar

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