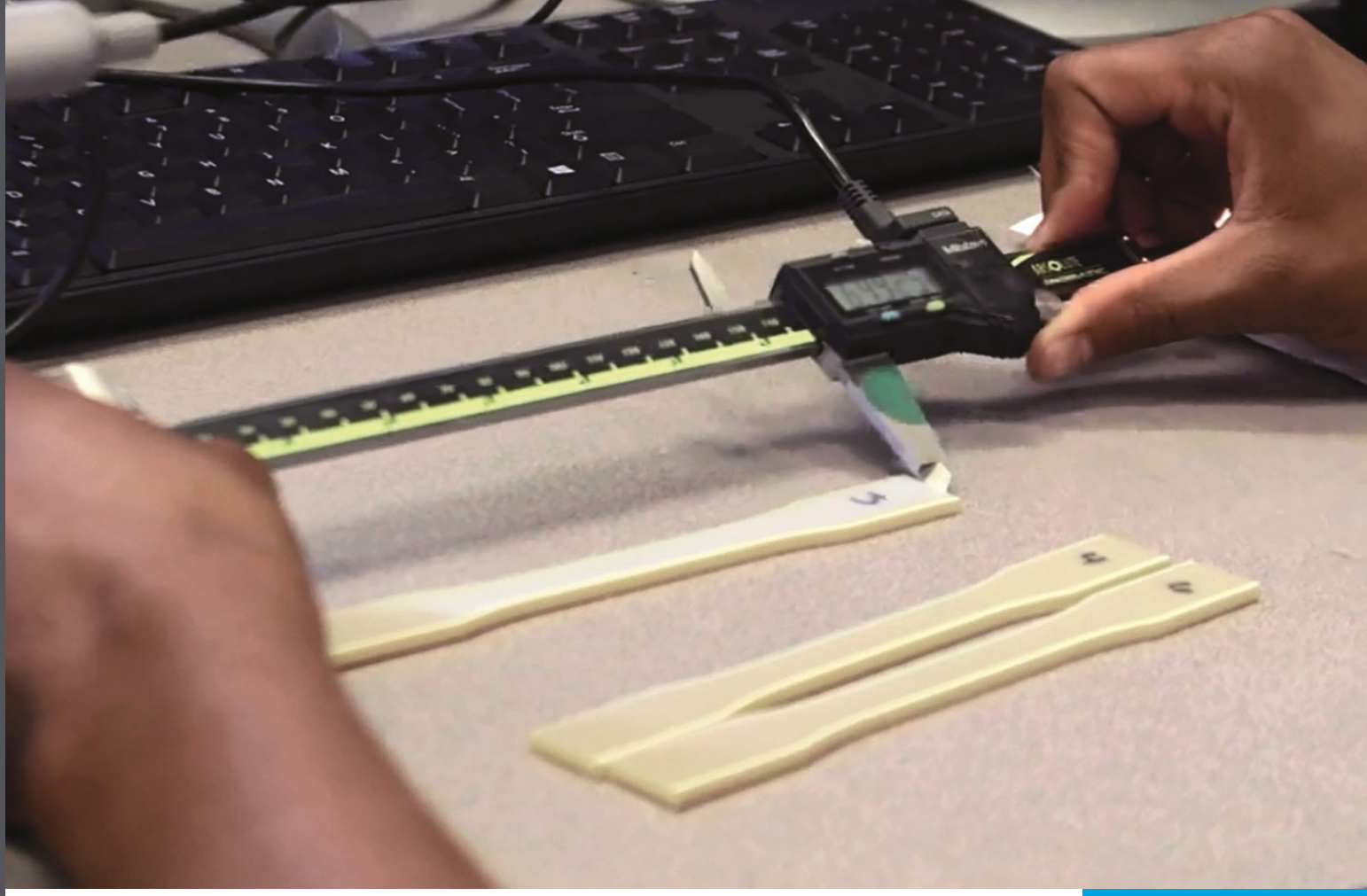

The Effect of Temperature on FDM Material Strength

White Paper

stratasys

Introduction

Not all use cases see parts performing at room temperature. A study of several high performing Stratasys materials such as Antero® 800NA, Antero® 840CN03, FDM® Nylon 12CF, and ULTEM™ 9085 resin, measured their upright tensile strength at temperatures above and below room temperature. This report provides the results of that study.

Test Set Up

Upright, ZX orientation, ASTM D638 coupons were printed on the Fortus® F900™ with the 0.010 in. (0.254 mm) slice height. See Table 1 for the tips used for each material. Ten coupons of each material were printed for each temperature tested, shown in Table 2. Individual coupons were pre-processed with Insight™ software using the default parameters and stabilizer walls as detailed in the Material Testing Procedure. The build packs contained ten coupons and one density cube to maintain the same layer time as the mechanical coupon in the material datasheets.

Material	Tip
Antero 800NA	T20F
Antero 840CN03	T20F
Nylon 12CF	T20C
ULTEM 9085 resin	T16

Table 1: 0.010 in. (0.254 mm) Slice Tips Used

The temperature test points were chosen after looking at each material's dynamic material analysis, or DMA, scans. Temperature sweep graphs were used to verify all phenomena were captured. The maximum tested temperature did not exceed the material's HDT.

Material	Temperatures (°F)	Temperatures (°C)
Antero 800NA	-65, -40, 120, 180, 220, 270	-54, -40, 49, 82, 104, 132
Antero 840CN03	-65, -40, 120, 180, 220, 270	-54, -40, 49, 82, 104, 132
Nylon 12CF	-65, -40, 110, 180, 220, 270	-54, -40, 43, 82, 104, 132
ULTEM™ 9085 resin	65, -40, 120, 180, 220, 270, 300	-54, -40, 49, 82, 104, 132, 149

Table 2: Temperatures Tested for Each Material

The specimens were allowed to condition at standard laboratory conditions of 73 ± 4 °F (23 ± 3 °C) and 50 ± 5% relative humidity for at least 40 hours prior to exposure. Specimens were conditioned at the test temperature for at least 24 hours prior to testing. Upon removal from the conditioning chamber, each specimen was immediately placed in the test chamber on the universal tester. Once the test chamber reached the target test temperature, the specimen was allowed to dwell for five minutes before the testing began.

Results

In Table 3, the 70 °F temperature data comes from each material's datasheet on an F900 machine in 0.010 in. (0.254 mm) slice. The same is true for the 21 °C temperature data in Table 4. The test house was not able to measure modulus or elongation at or above 300 °F (149 °C). Those values are marked as 'NA' in the tables.

Material	Temperature (F)	Peak Stress (psi)	Break Stress (psi)	Elongation at Break (%)	Modulus (ksi)
Antero 800NA	-65	9800	9800	2.3	498
	-40	10230	10230	2.5	477
	70	8650	8650	2.3	402
	120	9500	9500	2.8	434
	180	9090	8870	3.2	443
	220	7780	7060	3.4	420
	270	6280	5460	3.4	405
Antero 840CN03	-65	7570	7570	1.7	500
	-40	7620	7620	1.7	499
	70	7690	7690	1.9	418
	120	7240	7240	1.9	437
	180	7550	7550	2.1	431
	220	7380	7350	2.4	428
	270	5970	5830	2.5	421
Nylon 12CF	-65	8370	8370	1.8	549
	-40	7600	7600	1.7	555
	70	4750	4750	1.2	434
	110	4500	4500	2.3	347
	180	3180	3160	5.2	176
	220	2390	2370	6.7	132
	270	1650	1630	7.7	92
ULTEM™ 9085 resin	-65	8950	8950	2.6	438
	-40	8910	8910	2.8	416
	70	5710	5710	1.9	350
	120	6960	6960	2.6	343
	180	5820	5820	2.3	332
	220	4960	4960	1.9	319
	270	4000	3990	1.9	286
	300	3140	3130	NA	NA

Table 3: Average Physical Properties (English Units)

Material	Temperature (C)	Peak Stress (MPa)	Break Stress (MPa)	Elongation at Break (%)	Modulus (GPa)
Antero 800NA	-54	67.6	67.6	2.3	3.43
	-40	70.6	70.6	2.5	3.29
	21	59.7	59.7	2.3	2.77
	49	65.5	65.5	2.8	2.99
	82	62.7	61.2	3.2	3.06
	104	53.7	48.7	3.4	2.90
	132	43.3	37.7	3.4	2.79
Antero 840CN03	-54	52.2	52.2	1.7	3.45
	-40	52.6	52.6	1.7	3.44
	21	53.1	52.6	1.9	2.88
	49	49.9	49.9	1.9	3.01
	82	52.1	52.1	2.1	2.97
	104	50.9	50.7	2.4	2.95
	132	41.2	40.2	2.5	2.90
Nylon 12CF	-54	57.7	57.7	1.8	3.79
	-40	52.4	52.4	1.7	3.83
	21	32.7	32.7	1.2	3.00
	43	31.0	31.0	2.3	2.39
	82	21.9	21.8	5.2	1.21
	104	16.5	16.3	6.7	0.91
	132	11.4	11.2	7.7	0.63
ULTEM™ 9085 resin	-54	61.7	61.7	2.6	3.02
	-40	61.4	61.4	2.8	2.87
	21	39.4	39.4	1.9	2.41
	49	48.0	48.0	2.6	2.37
	82	40.1	40.1	2.3	2.29
	104	34.2	34.2	1.9	2.20
	132	27.6	27.5	1.9	1.97
	149	21.7	21.6	NA	NA

Table 4: Average Strength Properties (Metric Units)

Overall, as the temperature increased, the tensile strength at break and tensile modulus of all the materials decreased. For most materials the elongation at break increased as the temperature increased. For ULTEM™ 9085 resin, it decreased as the temperature rose.

Except for the highest two test temperatures, Antero 800NA tested higher than the control data, which is the room temperature data from the datasheet, across all properties. The control data was tested at a different lab and the lab variation could cause the discrepancy in the trend data from being more linear. In some cases, test house differences has shown discrepancies on the scale of 200-400 psi.

Table 5 compares the tensile-strength-at-break average for each temperature and material to the values from the room temperature testing.

Tensile Stress at Break (%)					
Temperature (F)	**Temperature (C)**	**Antero 800NA**	**Antero 840CN03**	**Nylon 12CF**	**ULTEM™ 9085 resin**
Room Temp	**Room Temp**	**8650**	**7690**	**4750**	**5710**
-65	-54	113%	98%	176%	157%
-40	-40	118%	99%	160%	156%
110	43	-	-	95%	-
120	49	110%	94%	-	122%
180	82	103%	98%	66%	102%
220	104	82%	96%	50%	87%
270	132	63%	76%	34%	70%
300	149	-	-	-	55%

Table 5: Tensile Stress at Break Compared to Room Temperature

Figures 1 through 4 show the tensile stress at break versus the temperature for each material.

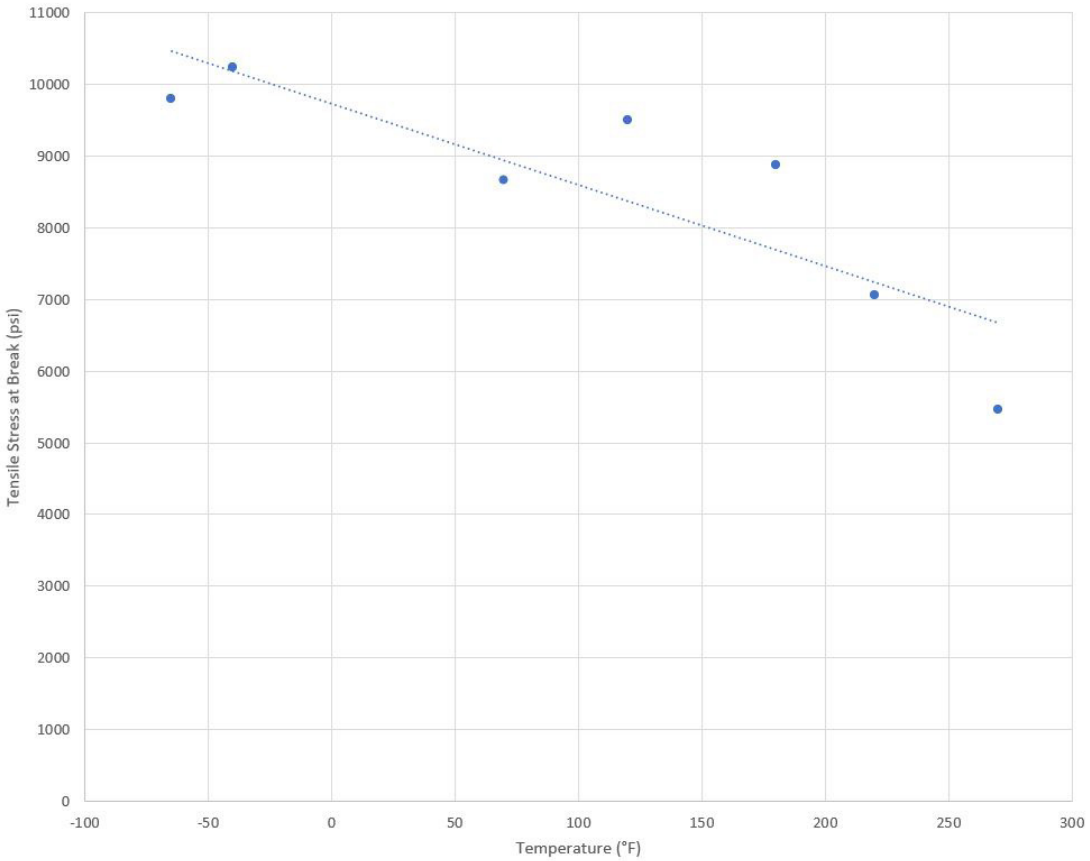

Figure 1: Antero 800NA 0.010 in. (0.254mm) T20F Tip, Tensile Strength vs. Temperature

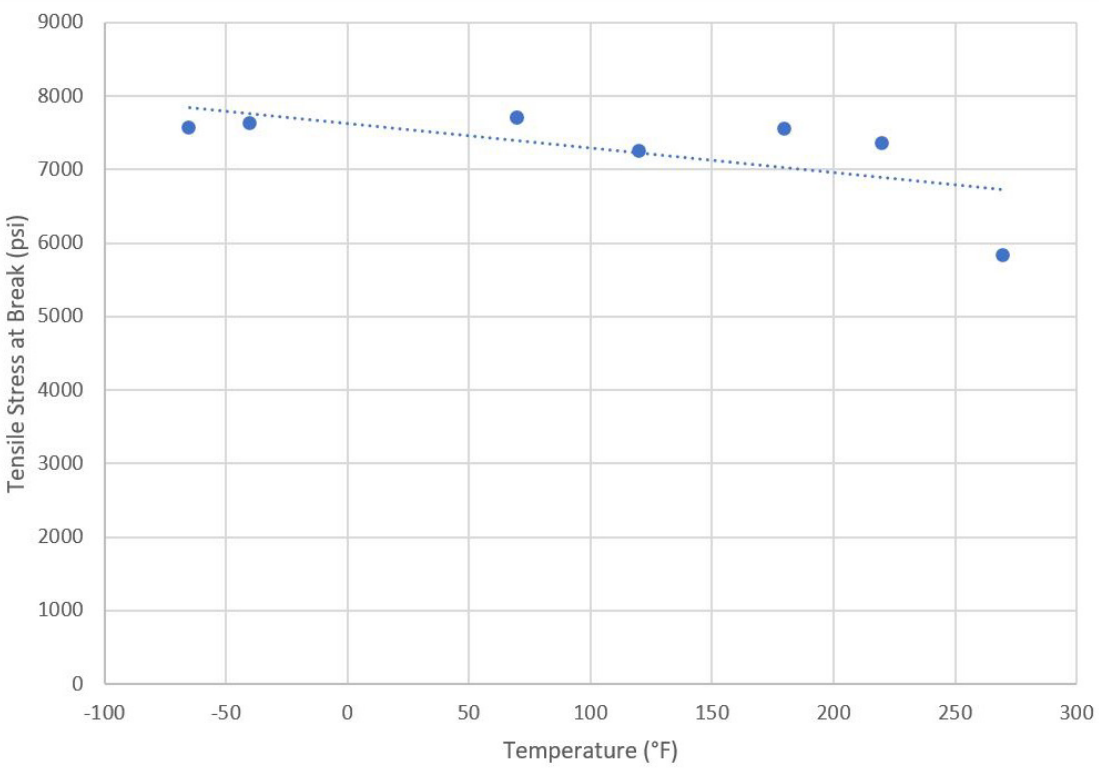

Figure 2: Antero 840CN03 0.010 in. (0.254 mm) T20F Tip, Tensile Strength vs. Temperature

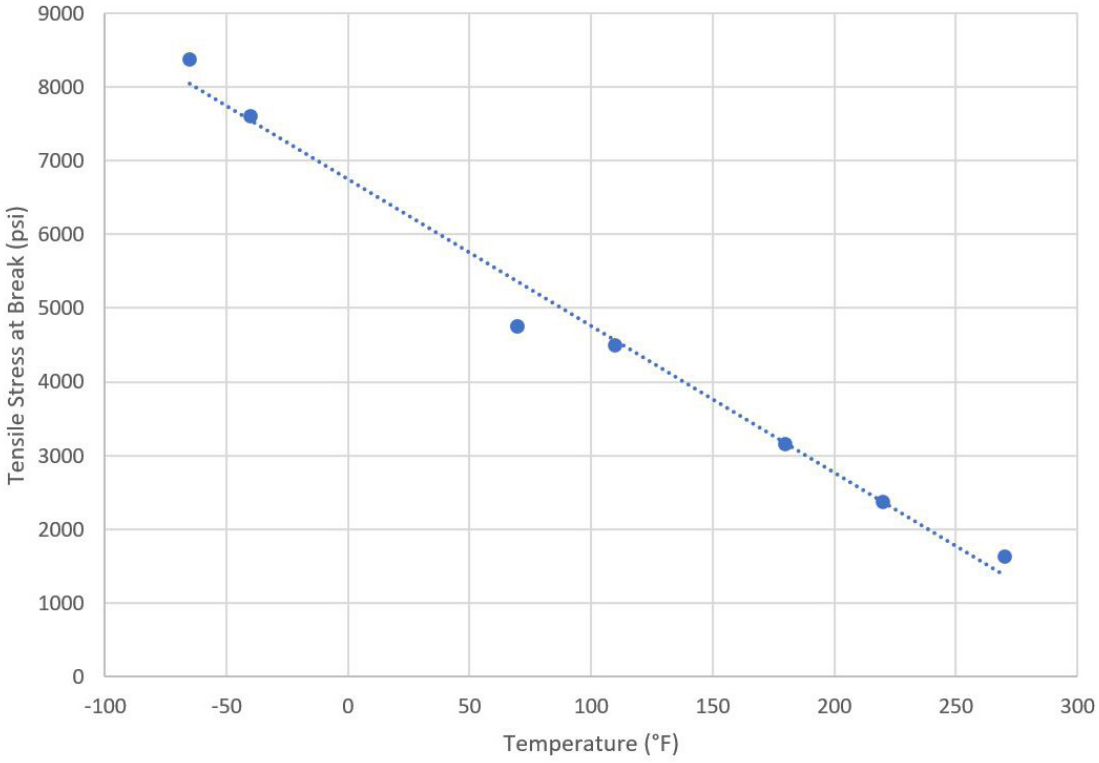

Figure 3: Nylon 12CF 0.010 in. (0.254 mm) T20C Tip, Tensile Strength vs. Temperature

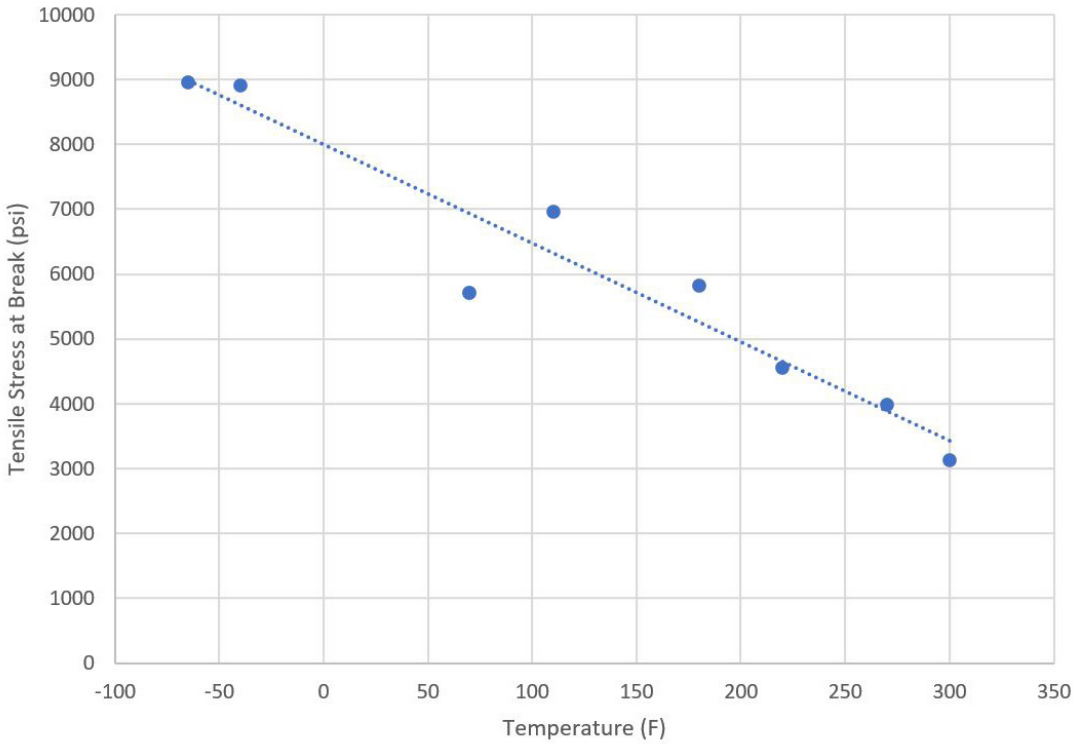

Figure 4: ULTEM™ 9085 resin 0.010 in. (0.254 mm) T16 Tip, Tensile Strength vs. Temperature

Conclusion

Overall, as the temperature increases, the tensile strength at break and tensile modulus of all the materials decreased. For most materials the elongation at break increased as the temperature increased. For ULTEM™ 9085 resin, it decreased as the temperature rose.

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