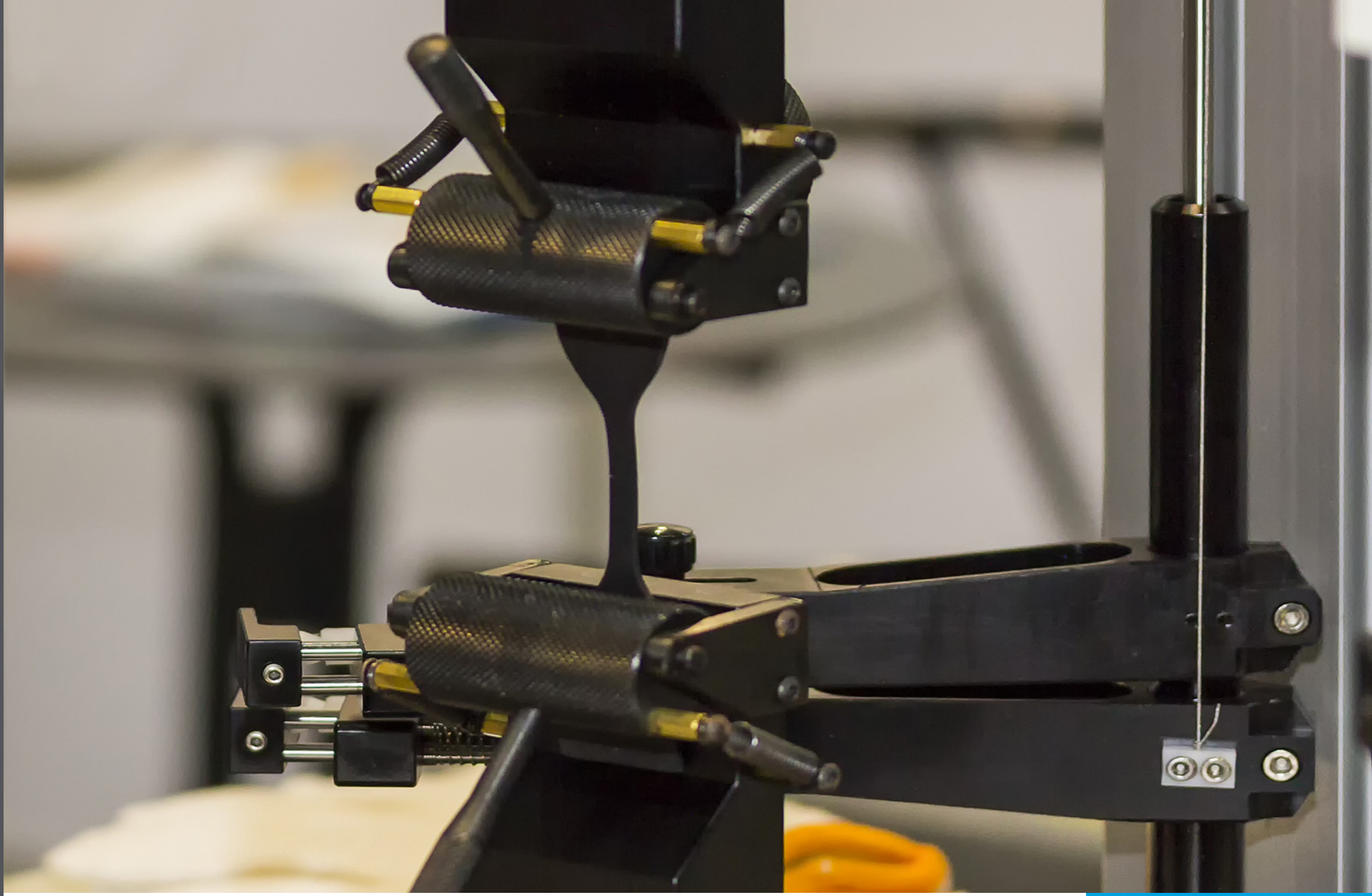

White Paper

Impact of UV Exposure on FDM Materials

stratasys

Introduction

Stratasys FDM® materials are used to create parts that are used in a variety of environmental conditions. To evaluate the impact of exposure to these conditions, FDM materials were exposed to UV light and humidity within a QUV environmental test chamber to imitate the damage from sun and rain. The change in material color and mechanical performance (tensile strength) was compared between control samples and those that experienced UV exposure. The results are included in this white paper.

Procedure

The materials tested for the impact of UV exposure are listed in Table 1, as well as which FDM printer and tip size was used to build the parts. For each material, 4 plaques were built in the flat (XY) orientation and 20 ASTM D638 coupons in the upright (ZX) orientation. For TPU, the tensile coupons were printed in the flat (XY) orientation. Individual coupons were pre-processed with Insight™ software using default parameters and stabilizer walls as detailed in the Material Testing Procedure. The tensile coupons were built in 2 builds, each containing 10 coupons.

Material	Printer	Tip
ABS-CF10	F370®	T14 (F123 Head)
Antero® 800NA	F900™	T20F
Antero® 840CN03	F900	T20F
ASA (natural color)	F900	T16
Diran™ 410MF07	F370	T14 (F123 Head)
FDM® Nylon 12CF	F900	T20C
PC (polycarbonate)	F900	T16
PC-ABS	F370	T14 (F123 Head)
FDM® TPU 92A	F370	T14 (F123 Elastomeric Head)
ULTEM™ 9085 resin	F900	T16A
ULTEM™ 1010 resin	F900	T14

Table 1. Printer and tips used to print each material for UV testing.

From the printed coupons in each material, one build of 10 D638 coupons and two plaques experienced UV exposure while the remaining two plaques and build of 10 D638 coupons were used as a control. A QUV chamber was used to provide consistent UV exposure. The samples were cycled in the QUV chamber per ASTM G154 - Standard Practice for Operation Fluorescent Light Apparatus for UV Lamp Apparatus Exposure of Nonmetallic Materials – for 1000 hours, alternating for eight hours at 60 °C (140 °F) and four hours at 50 °C (122 °F) with humidity and condensation.

To quantify the color changes of the materials, Commision Internationale de l'Eclairage (CIE) L*a*b* coordinates were utilized. The coordinates are modeled so that a color cannot be both red and green, or blue and yellow at the same time. The L* coordinates indicate how light/dark the color is, the a* is the red/green coordinate, and the b* is the blue/yellow coordinate. The delta of each coordinate (ΔL*, Δa*, Δb*) can be compared between two colors to indicate the change in hue or darkness. The total color difference (ΔE*) is the root-square of all of the differences ($\Delta E^*_{ab}=\sqrt{(L^*_2-L^*_1)^2-(a^*_2-a^*_1)^2-(b^*_2-b^*_1)^2}$). (See https://sensing.konicaminolta.us/us/blog/identifying-color-differences-using-l-a-b-or-l-c-h-coordinates/ for further details on the CIE L*a*b* coordinates). Control plaques and those exposed to UV were both measured to see part color change.

Tensile coupons were conditioned for a minimum of 40 hours at 23 °C (73 °F) and 50% RH prior to testing. The coupons were tested per ASTM D638 – Standard Test Method for Tensile Properties of Plastics.

The Antero 840CN03, Nylon 12CF, and ABS-CF10 plaques were also tested for ESD properties per ASTM D257. Both surface and volume resistance were measured on the front and back of each plaque.

Results

Visual Results

To show the color change from UV exposure of each material, a picture of a plaque was taken as well as a microscope image. Figures 1 to 11 show the images of each material.

Table 2 contains the CIE L*A*b coordinate data that confirms the visual observations and quantifies the magnitude of change for each material. Nylon 12CF experienced the least amount of change in color from the UV exposure. ASA, Antero 800NA, and ULTEM™ 1010 resin had minor color changes. PC, ABS-CF10, PC-ABS, TPU, Antero 840CN03, and ULTEM™ 9085 resin have more notable color changes from the UV exposure.

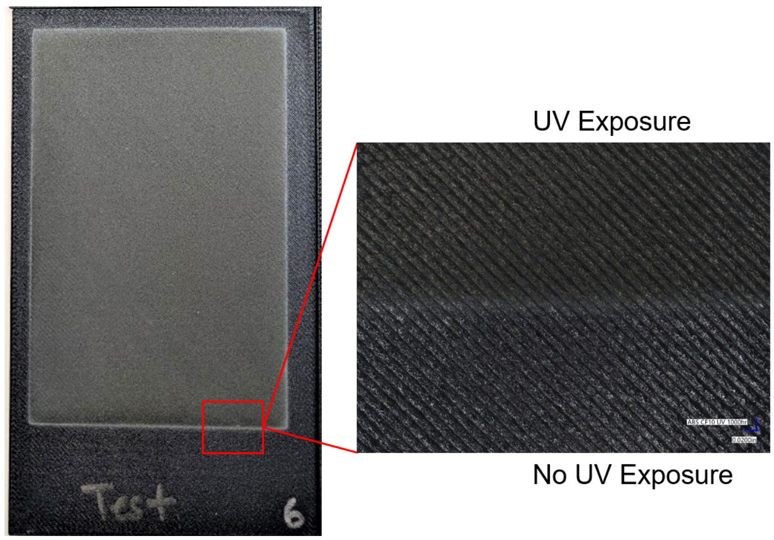

Figure 1. ABS-CF10 plaque with rectangular area that was exposed to UV. The exposed area experienced significant yellowing.

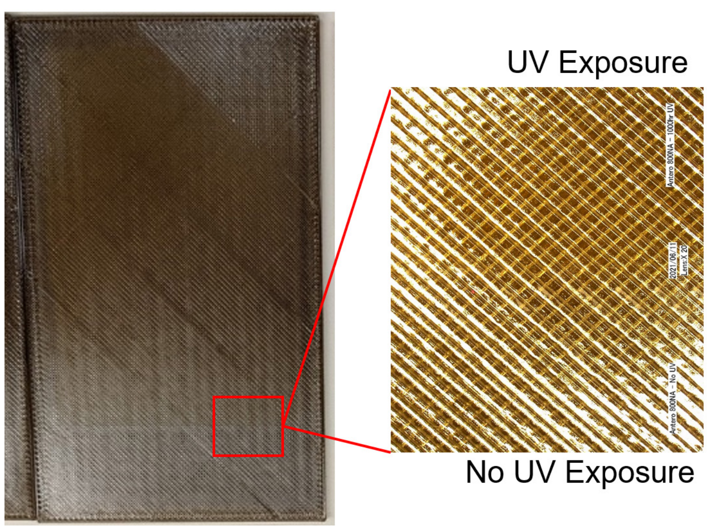

Figure 2. Antero 800NA plaque with rectangular area that was exposed to UV. Antero 800NA lightens and yellows slightly from the UV exposure.

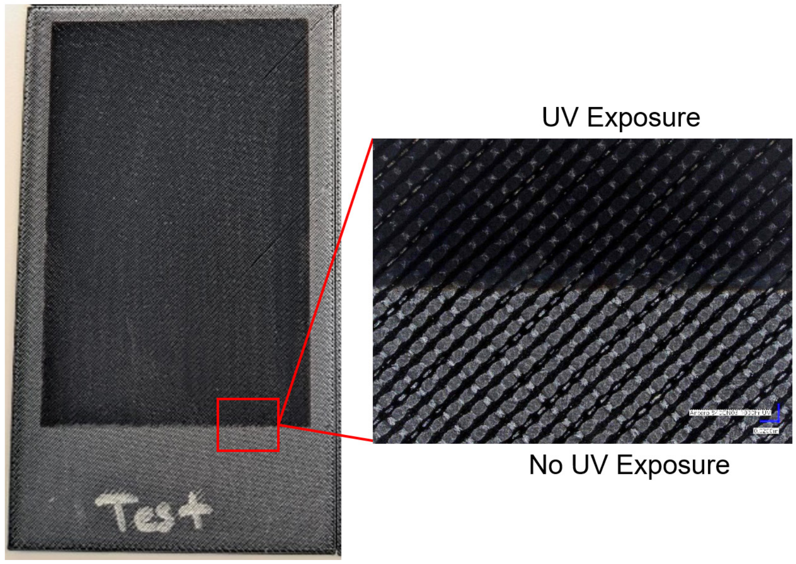

Figure 3. Antero 840CN03 plaque with rectangular area that was exposed to UV. The exposed area significantly darkened in color.

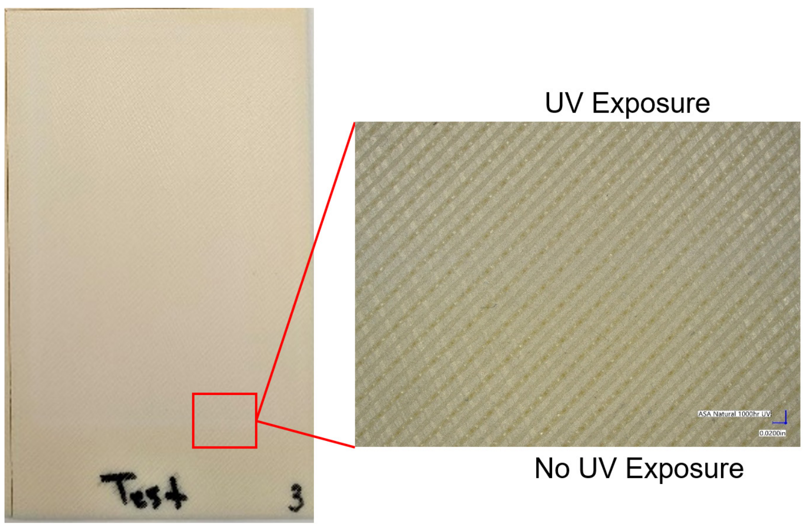

Figure 4. ASA plaque with rectangular area that was exposed to UV. Not much color change was observed on natural ASA.

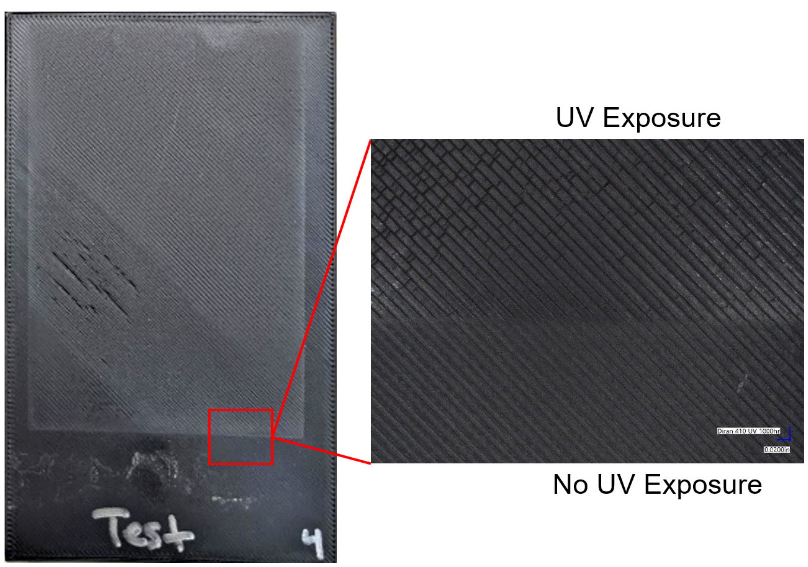

Figure 5. Diran 410MF07 plaque with rectangular area with UV exposure. Color difference and cracking was observed on the area exposed to UV.

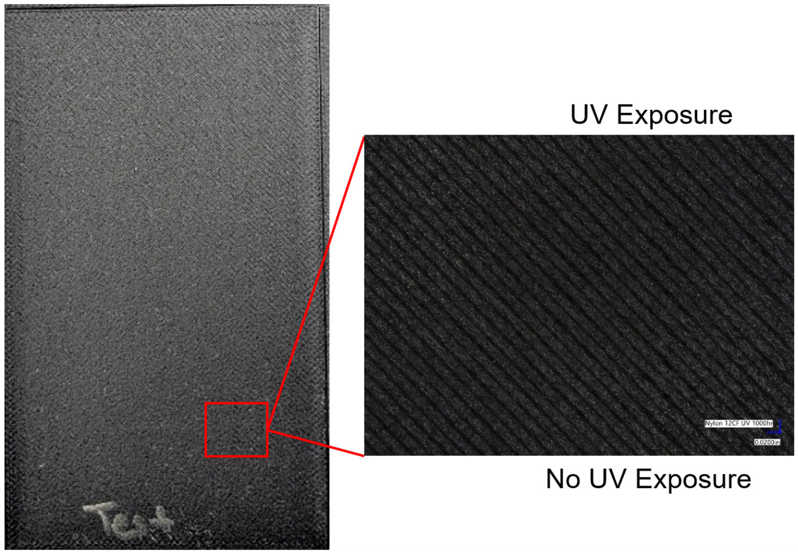

Figure 6. Nylon 12CF plaque with rectangular area that was exposed to UV. Nylon 12CF exhibited the least visual change of all the materials tested.

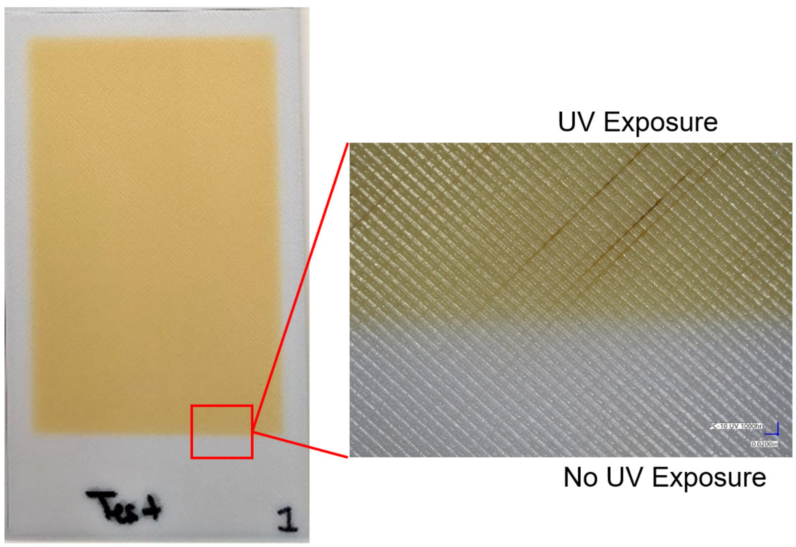

Figure 7. PC plaque with rectangular area that was exposed to UV. The exposed area exhibited darkening and a more yellow appearance.

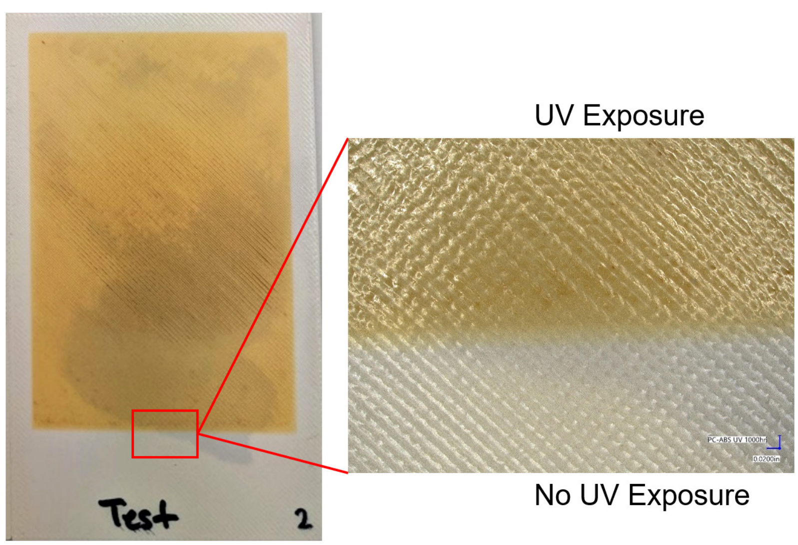

Figure 8. PC-ABS plaque with rectangular area that was exposed to UV. The exposed area exhibited darkening and yellowing.

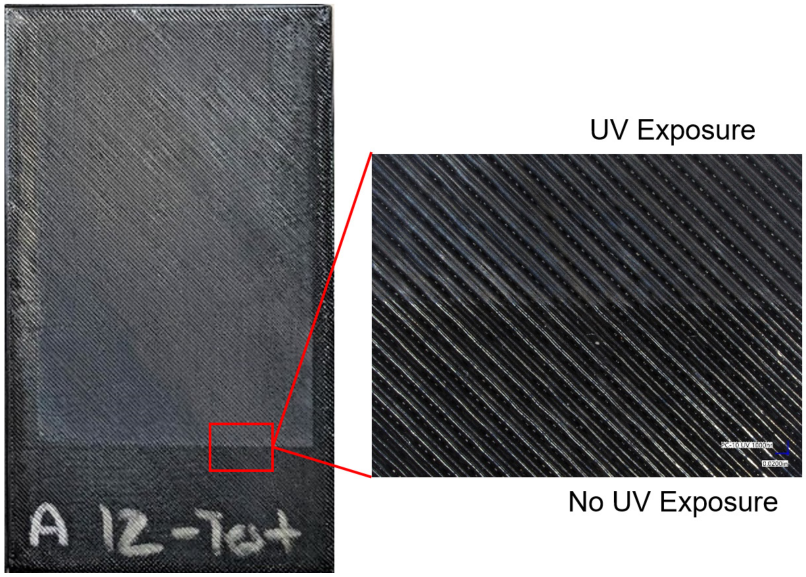

Figure 9. TPU plaque with rectangular area that was exposed to UV. The exposed area darkened, as well as increasing the red and blue CID L*a*b* coordinates.

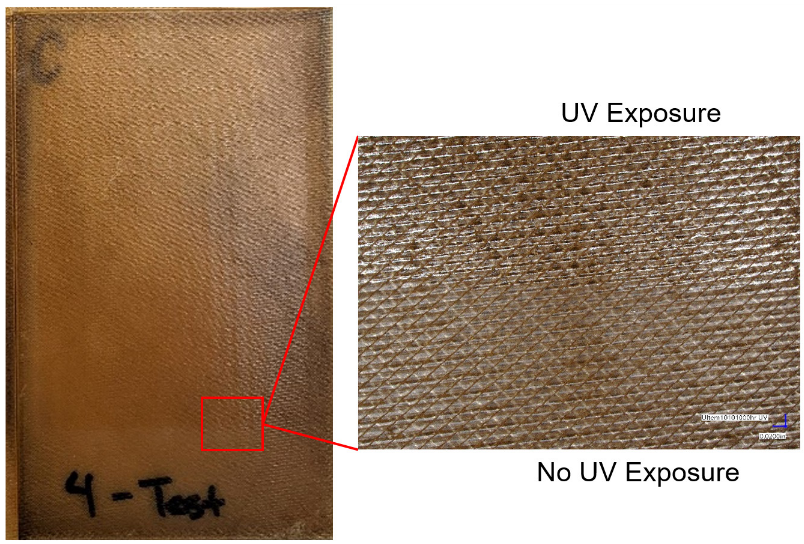

Figure 10. ULTEM™ 1010 resin plaque with rectangular area that was exposed to UV. The exposed area showed a higher gloss than the non-exposed area.

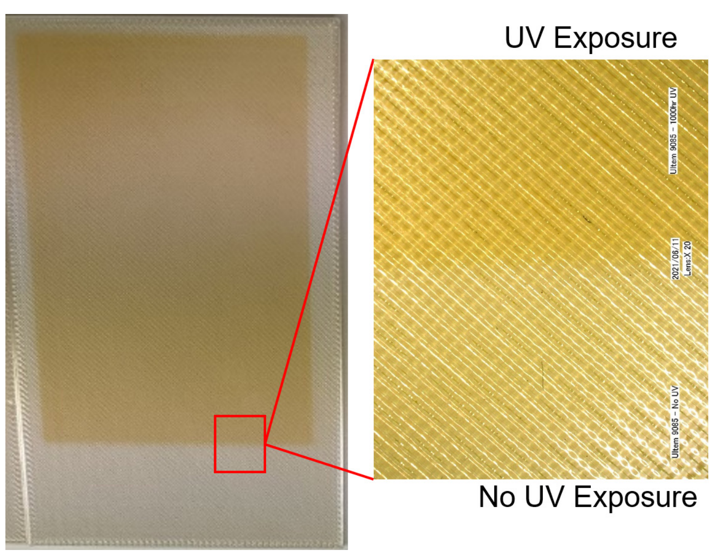

Figure 11. ULTEM™ 9085 resin plaque with rectangular area that was exposed to UV. The ULTEM™ 9085 resin material appears to have darkened and yellowed from the UV exposure.

Material	Conditioning	Plaque 1				Plaque 2			
		L*	a*	b*	ΔE	L*	a*	b*	ΔE
ABS CF10	No UV Exposure	38.14	-0.46	-3.18		38.13	-0.56	-3.13	
	UV Exposure	41.04	-0.84	1.22		36.11	-0.6	2.26	
	Delta	2.9	-0.39	4.41	5.29	-2.02	-0.04	5.39	5.75
	Color Change	Lighter	Greener	Yellower		Darker	Greener	Yellower	
Antero 800NA	No UV Exposure	41.32	2.73	7.55		41.51	2.72	7.59	
	UV Exposure	42.78	3.52	12.79		43.56	3.5	12.81	
	Delta	1.46	0.78	5.24	5.49	2.06	0.79	5.22	5.66
	Color Change	Lighter	Redder	Yellower		Lighter	Redder	Yellower	
Antero 840CN03	No UV Exposure	23.48	0.38	-1.55		26.13	0.35	-1.45	
	UV Exposure	10.97	0.21	-2.07		13.31	0.42	-2.37	
	Delta	-12.51	-0.17	-0.51	12.52	-12.82	0.07	-0.93	12.85
	Color Change	Darker	Greener	Bluer		Darker	Redder	Bluer	
ASA	No UV Exposure	81.56	0.41	13.84		90.57	-0.4	14.27	
	UV Exposure	90.66	-0.9	14.67		90.74	-1.09	14.76	
	Delta	9.1	-1.31	0.84	9.23	0.17	-0.69	0.49	0.86
	Color Change	Lighter	Greener	Yellower		Lighter	Greener	Yellower	
Diran 410MF07	No UV Exposure	36.19	0.32	-0.76		36.96	0.23	-0.87	
	UV Exposure	37.73	0.55	-0.6		37.06	0.41	-0.67	
	Delta	1.54	0.23	0.15	1.57	0.1	0.17	0.2	0.28
	Color Change	Lighter	Redder	Yellower		Lighter	Redder	Yellower	
Nylon 12CF	No UV Exposure	31.63	0.27	0.09		31.96	0.13	-0.1	
	UV Exposure	32.07	0.29	0.75		31.4	0.22	0.33	
	Delta	0.44	0.01	0.66	0.79	-0.55	0.09	0.43	0.71
	Color Change	Lighter	Redder	Yellower		Darker	Redder	Yellower	
PC	No UV Exposure	88.89	-1.17	-1.02		89.11	-1.16	-1.13	
	UV Exposure	81.26	0.16	31.55		81.22	0.04	30.58	
	Delta	-7.63	1.33	32.57	33.48	-7.89	1.2	31.71	32.7
	Color Change	Darker	Redder	Yellower		Darker	Redder	Yellower	
PC-ABS	No UV Exposure	98.2	0.85	10.44		98.24	0.85	10.26	
	UV Exposure	89.37	4.95	39.79		81.28	5.14	35.1	
	Delta	-8.83	4.1	29.35	30.93	-16.96	4.29	24.84	30.38
	Color Change	Darker	Redder	Yellower		Darker	Redder	Yellower	
TPU 92A	No UV Exposure	25.71	-0.49	-0.86		24.72	-0.5	-0.96	
	UV Exposure	24.37	-0.35	-1.38		23.15	0.08	-1.1	
	Delta	-1.34	0.14	-0.52	1.44	-1.57	0.58	-0.13	1.68
	Color Change	Darker	Redder	Bluer		Darker	Redder	Bluer	
ULTEM™ 1010 resin	No UV Exposure	46.69	3.19	12.93		52.08	3.65	15.67	
	UV Exposure	47.9	5.17	15.97		45.95	6.12	16.02	
	Delta	1.22	1.98	3.05	3.83	-6.13	2.47	0.35	6.62
	Color Change	Lighter	Redder	Yellower		Darker	Redder	Yellower	
ULTEM™ 9085 resin	No UV Exposure	78.78	-2.66	12.22		78.93	-2.61	11.55	
	UV Exposure	74.05	-0.65	26.54		73.97	-0.55	26.49	
	Delta	-4.73	2.01	14.32	15.21	-4.96	2.06	14.94	15.87
	Color Change	Darker	Redder	Yellower		Darker	Redder	Yellower	

Table 2. Color differences of each material with and without UV exposure.

Mechanical Results

Table 3 and Table 4 contain the mechanical data summaries for each material with and without UV exposure in English and metric units respectively. Figures 12 and 13 show the effect of the UV exposure on the stress at break for the upright (ZX) coupons. Figure 14 shows the impact of UV exposure of the ultimate tensile strength of the flat (XY) TPU coupons.

The impact of UV exposure on mechanical performance varies based on the material. Nylon 12CF and ULTEM™ 1010 resin parts show increased strength after UV exposure. The tensile strength of ULTEM™ 9085 resin coupons remained about the same. The tensile strength of PC and TPU decreases by more than 10%. The remaining materials had minor changes to the mechanical performance. See Table 5 for a summary of change in tensile strength following UV exposure.

Material	Conditioning	Yield Strength (psi)	Stress at Break (psi)	Elongation at break (%)	Modulus (ksi)
ABS CF10	No UV Exposure	3150	3140	1.5	284
	UV Exposure	3010	2990	1.3	295
Antero 800NA	No UV Exposure	8320	8360	2.4	392
	UV Exposure	8310	8670	2.4	399
Antero 840CN03	No UV Exposure	8270	8400	2.4	396
	UV Exposure	8050	8040	2.2	401
ASA	No UV Exposure	4430	4420	2.8	264
	UV Exposure	4390	4290	2.3	283
Diran 410MF07	No UV Exposure	3760	3780	2.5	195
	UV Exposure	3830	3840	2.3	227
Nylon 12CF	No UV Exposure	4760	4720	1.7	361
	UV Exposure	6500	6460	2.2	421
PC	No UV Exposure	6370	5940	3.0	258
	UV Exposure	4230	4200	1.6	289
PC-ABS	No UV Exposure	3880	3870	2.4	224
	UV Exposure	3710	3720	2.1	230.
TPU 92A*	No UV Exposure	2730	2740*	520*	3.23
	UV Exposure	2330	2330*	480*	3.16
ULTEM™ 9085 resin	No UV Exposure	8130	8080	3.5	293
	UV Exposure	8060	8070	3.7	302
ULTEM™ 1010 resin	No UV Exposure	8280	8570	2.6	375
	UV Exposure	9630	9530	2.9	378

Table 3. Average tensile performance of each material with and without UV exposure (English units).

Note:

*For TPU, the flat coupons were used. The coupons did not break so the elongation at end of test and UTS were reported for elongation at break and break strength, respectively.

Material	Conditioning	Yield Strength (MPa)	Stress at Break (MPa)	Elongation at break (%)	Modulus (GPa)
ABS CF10	No UV Exposure	21.7	21.7	1.5	1.96
	UV Exposure	20.8	20.6	1.3	2.03
Antero 800NA	No UV Exposure	57.4	57.6	2.4	2.70
	UV Exposure	57.3	59.7	2.4	2.75
Antero 840CN03	No UV Exposure	57.0	57.9	2.4	2.73
	UV Exposure	55.5	55.4	2.2	2.76
ASA	No UV Exposure	30.5	30.5	2.8	1.82
	UV Exposure	30.3	29.5	2.3	1.95
Diran 410MF07	No UV Exposure	26.0	26.0	2.5	1.34
	UV Exposure	26.4	26.5	2.3	1.56
Nylon 12CF	No UV Exposure	32.8	32.5	1.7	2.49
	UV Exposure	44.8	44.5	2.2	2.90
PC	No UV Exposure	43.9	40.9	3.0	1.78
	UV Exposure	29.2	29.0	1.6	1.99
PC-ABS	No UV Exposure	26.7	26.7	2.4	1.54
	UV Exposure	25.6	25.7	2.1	1.59
TPU 92A*	No UV Exposure	18.8	18.9*	520*	0.0223
	UV Exposure	16.0	16.0*	480*	0.0217
ULTEM™ 9085 resin	No UV Exposure	56.0	55.7	3.5	2.02
	UV Exposure	55.5	55.6	3.7	2.08
ULTEM™ 1010 resin	No UV Exposure	57.1	59.1	2.6	2.59
	UV Exposure	66.4	65.7	2.9	2.61

Table 4. Average tensile performance of each material with and without UV exposure (metric units).

Note:

*For TPU, the flat coupons were used. The coupons did not break so the elongation at end of test and UTS were reported for elongation at break and break strength, respectively.

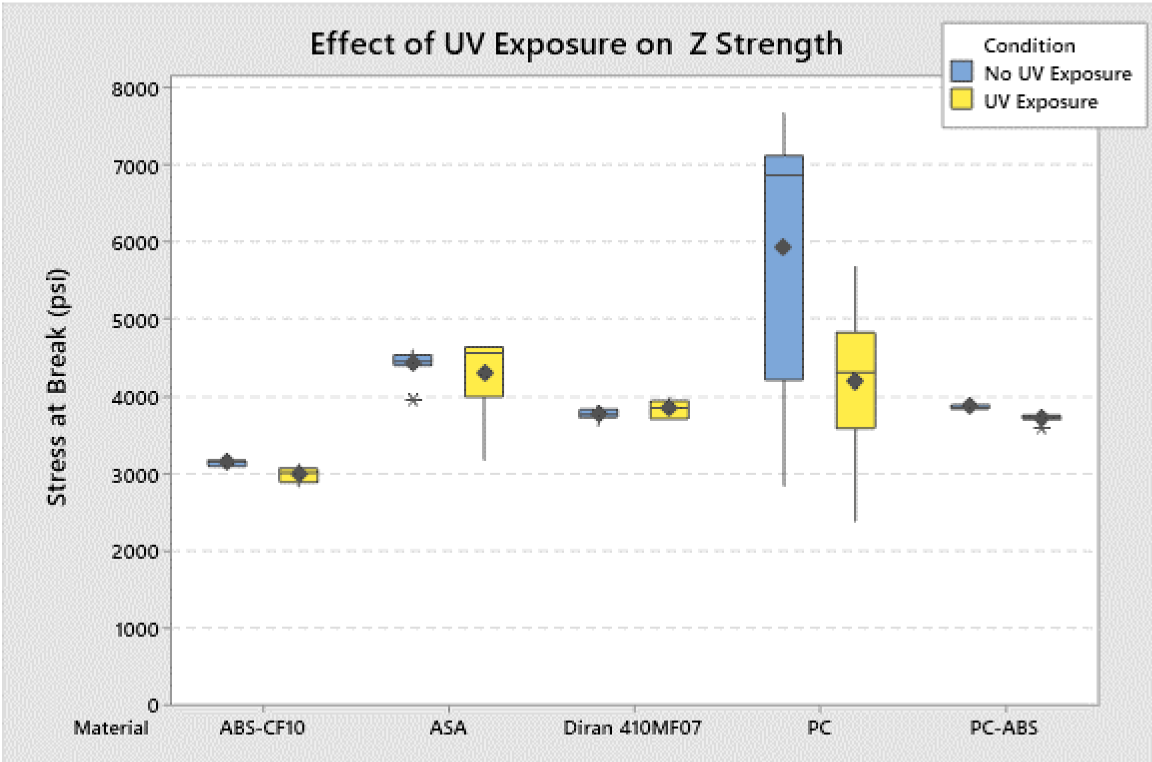

Figure 12. Effect of UV exposure on Z strength of tensile coupons.

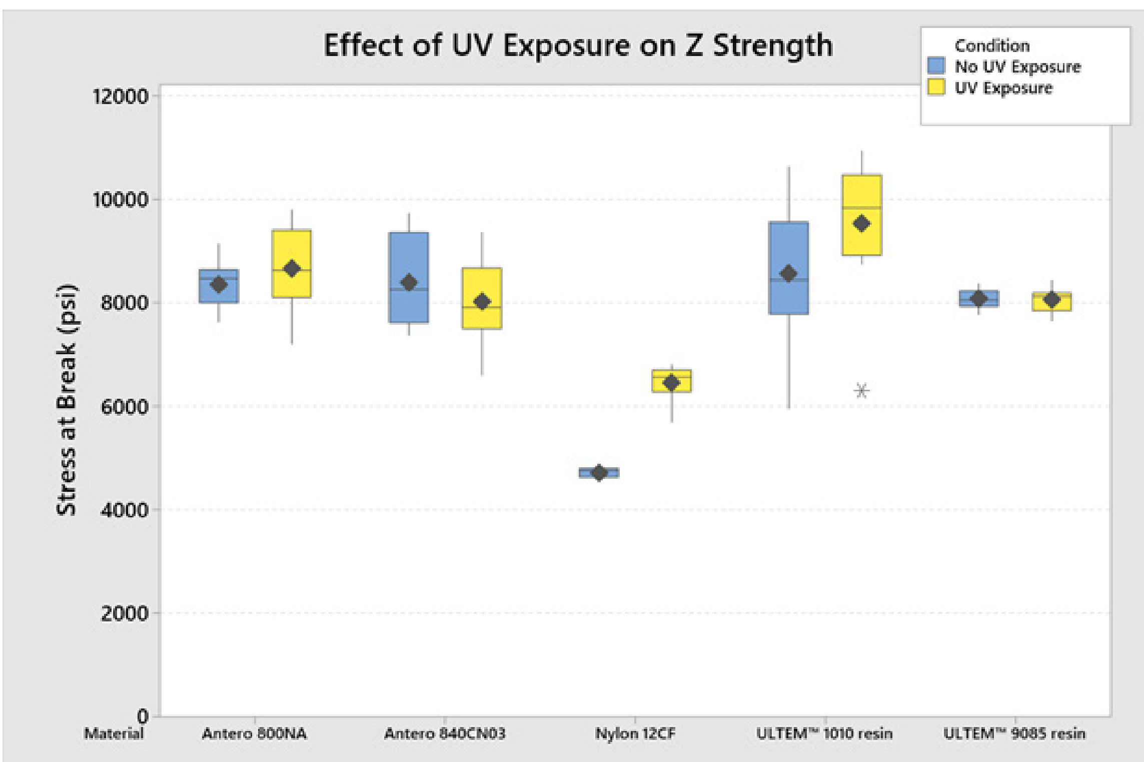

Figure 13. Effect of UV exposure on tensile Z strength for high performance materials.

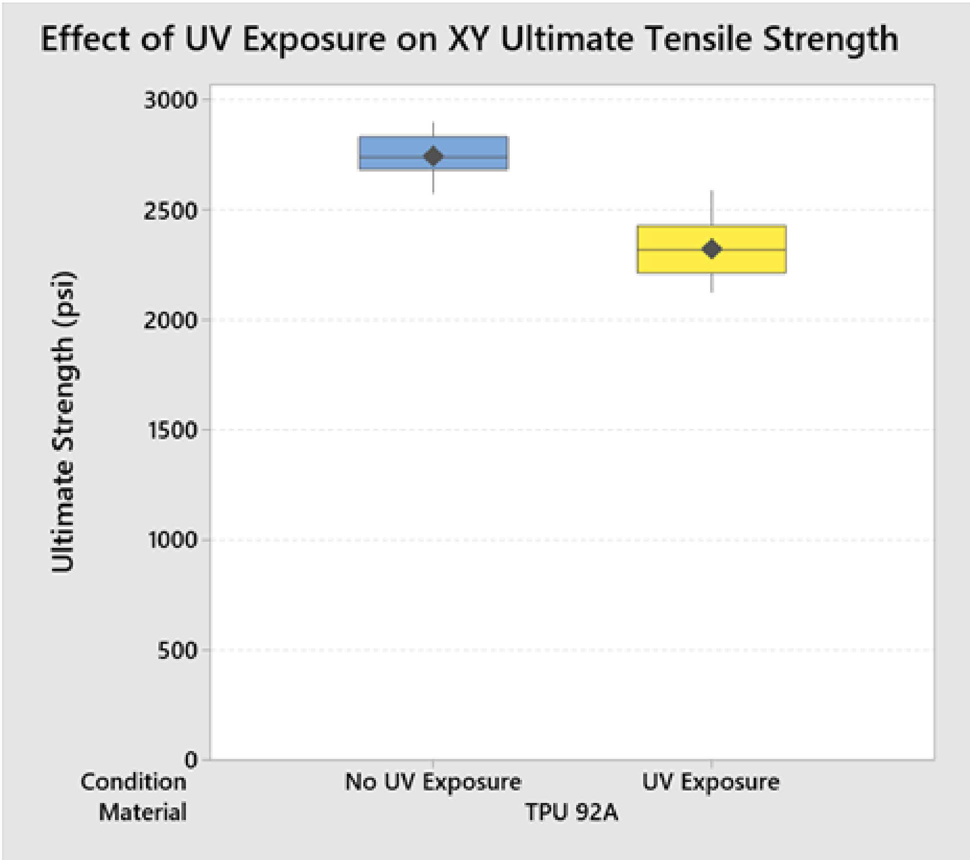

Figure 14. Effect of UV exposure on XY UTS of TPU.

Material	Stress at Break
ABS-CF10	-4.9%
Antero 800NA	3.6%
Antero 840CN03	-4.3%
ASA	-3.0%
Diran 410MF07	1.8%
Nylon 12CF	36.8%
PC	-29.2%
PC-ABS	-3.8%
TPU 92A	-15.3%
ULTEM™ 9085 resin	-0.1%
ULTEM™ 1010 resin	11.2%

Table 5. Percent increase of stress at break after UV exposure.

ESD Resistivity

The ESD resistivity was measured for Antero 840CN03, ABS-CF10, and Nylon 12CF with the measurements as shown in Table 6. Antero 840CN03 and Nylon 12CF show a slight decrease in the resistance on the face that was exposed to the UV, despite Nylon 12CF not having apparent degradation of the surface as indicated by a color change.

Material	Conditioning	ESD Properties: Surface & Volume Resistance						
		Plaque	Surface (Ω/square)			Volume (Ω-cm)		
			Front[1]	Back	Ave. Δ[2]	Front[1]	Back	Ave. Δ[2]
ABS CF10	No UV Exposure	1	1.1E+13	1.6E+12	3.64E+13	2.1E+13	5.7E+13	1.78E+13
		2	9.7E+12	1.1E+13		3.5E+13	4.3E+13	
	UV Exposure	1	3.8E+13	2.4E+13		5.1E+13	5.5E+13	
		2	5.6E+13	6.1E+13		6.2E+13	5.9E+13	
Antero 840CN03	No UV Exposure	1	3.1E+05	3.8E+05	-2.23E+05	4.2E+05	4.9E+05	-2.53E+05
		2	1.6E+05	4.1E+05		3.1E+05	3.3E+05	
	UV Exposure	1	1.8E+04	1.2E+05		4.6E+04	2.1E+05	
		2	1.2E+04	2.2E+05		3.2E+04	2.5E+05	
Nylon 12CF	No UV Exposure	1	1.3E+05	1.3E+05	-1.04E+05	8.4E+04	4.9E+04	-6.83E+04
		2	9.9E+04	1.7E+05		6.7E+04	1.6E+05	
	UV Exposure	1	2.3E+04	3.2E+04		2.4E+04	2.2E+04	
		2	2.3E+04	3.7E+04		2.7E+04	1.4E+04	

Table 6. ESD properties resistivity data.

Note:

1. Front (exposed) for coupons with UV exposure.
2. Average Δ is the difference between the average non-exposed faces from the faces exposed to UV. A negative ave. Δ indicates a decrease in the average of the volume or surface resistance.

Conclusion

Following 1000 hours of UV and humidity exposure, there is now greater understanding of material performance that can aid in material selection for applications. Not all materials performed similarly. Some experienced few changes while others experienced declines in strength. PC and TPU had the least favorable impacts of UV exposure with changes in color, as well as tensile strength decreases of greater than 15%. ULTEM™ 9085 resin yellowed and darkened in color, but tensile strength was not impacted.

The UV exposure had the most favorable impacts on Nylon 12CF, ULTEM™ 1010 resin, and Antero 800NA. Antero 800NA had minimal color changes and increased tensile strength by 3.6%. ULTEM™ 1010 resin increased tensile strength by 11.2% and had minimal color change to the material. Nylon 12CF faired the best with UV exposure with a 36.8% increase in tensile strength, slight increase in conductivity, and the least amount of color change of all materials. The suggested hypothesis for the increase in the strength is the impact of extended conditioning due to exposure to temperature and moisture. Moisture would typically decrease the strength of nylon, but the increased elongation at break suggests that the material underwent toughening.

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