UV-C Degradation of Plastics: Comparison of ElectroClave LEDs versus Low-Pressure Mercury Lamp

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Abstract

Seal Shield conducted experiments on ABS plastics exposed to UV-C light from a low-pressure mercury lamp. Visually, the ABS noticeably yellowed from UV damage. Mechanically, ABS loses significant tensile strength and elongation at break reduces by 40%, meaning the UV damage makes it more brittle. Further evidence of damage can be observed from thermal analysis techniques. Other materials exposed to UV-C LEDs in the Seal Shield ElectroClave were not damaged by their exposure at an equivalent time period. This suggests that the ElectroClave is a better choice to preserve the working life of devices needing UV disinfection.

Introduction

In prior work, Seal Shield irradiated materials from Vocera badges with UV-C light generated by LEDs in an ElectroClave unit, and subsequently tested those materials with a thermogravimetric analyzer (TGA) at ATS Labs. The Vocera materials remained unaffected from 3 days (~72 hours) continuous UV-C LED exposure within the ElectroClave, and there was no visual difference (such as discoloration) observed either.

Results

This study expanded upon the prior work by examining the effects of UV exposure from a traditional low-pressure mercury lamp (LPML) on ABS plastic plaques from Togran (a supplier in China) through tensile testing and thermogravimetric analysis. The plaques were continuously exposed for at least 3 days to UV-C light in a Vioguard Cubby system with four LPMLs to match the time from the prior work. Visual inspection was performed by Seal Shield. Tensile testing was performed at Briem Engineering using an Instron mechanical test unit. SEM images were taken at Briem Engineering's optical lab. TGA testing was performed at ATS Labs using a TA Instruments 5500 unit.

Visually, the samples exposed to the UV-C light from the LPMLs were substantially yellowed and darkened. This initial detail immediately confirms material degradation on its own.

Tensile testing showed a loss of at least 10% of normal mechanical strength and elongation at break reduced by 40%, presented in Table 1.

Briem Engineering also obtained SEM images of the surfaces of the UV-exposed and non-exposed ABS plaques. The results were rather dramatic: While non-exposed ABS of course displayed plain, smooth results, ABS exposed to the mercury lamps clearly formed a complex network of microfissures. These microfissures appear as relatively long "canyons", with length scales anywhere from 20-200+ microns in length and 1-10 microns in width. Even the relatively small aspect is large enough that pathogenic microorganisms could become lodged in the fissure and form biofilm and colonies. This would make devices containing ABS (or other similar polymers) very difficult to be disinfected by UV-C (since the radiation cannot reach the microorganism as easily), and thus become a more significant long-term threat for infection transmission as more degradation occurs.

The TGA results showed a substantial difference in the weight loss profile for the ABS plaques exposed to UV-C. Comparing these new TGA results to the prior work, the materials exposed to the UV-C LEDs showed far less effects from UV degradation (virtually none) compared to those materials exposed to LPMLs for the same exposure time. While the absolute dosages were different, devices in the field disinfected by these UV sources will tend to spend roughly the same amount of time within them to achieve sufficient efficacy.

Visual Inspection (Figure 1)

Figure 1: Fresh (no UV exposure) ABS plaques

(Figure 2)

Figure 2: Yellowed ABS Plaques after UV exposure for three days

Tensile Testing Results

The base ABS resin had a tensile strength of 6.45 psi. Following three days of UV-C exposure, the damaged UV-C plaque had a tensile strength of 5.86 psi, a loss of ~10% mechanical strength. Elongation at break also reduced by 40%.

Table 1: No UV-C Exposure

ABS Plain Tensile Results:

Item	Width, in	Thickness, In	Area, in²	% Elongation, 2 in	Max Load, lbs.	Tensile Strength, psi
1	0.5110	0.1045	0.0534	17.0	345	6,461
2	0.4700	0.1040	0.0489	8.0	315	6,442
3	0.4525	0.1045	0.0473	9.5	307	6,490
4	0.4600	0.1040	0.0478	5.5	306	6,402
5	0.4720	0.1045	0.0493	7.5	319	6,471
Avg.				9.5		6,453

Test Method: ASTM D638
Equipment Used: Instron Model #1122, Serial #5434, Calibration Due August 12, 2021

Table 2: Following Three Days UV-C Exposure

ABS Plain Tensile Results:

Item	Width, in	Thickness, In	Area, in²	% Elongation, 2 in	Max Load, lbs.	Tensile Strength, psi
1	0.5085	0.10285	0.0523	3.5	288	5,507
2	0.4995	0.10450	0.0522	4.0	288	5,517
3	0.5015	0.10380	0.0520	5.5	308	5,923
4	0.4905	0.10410	0.0511	6.5	314	6,145
5	0.5085	0.10250	0.0521	6.5	325	6,238
Avg.				5.2	305	5,866

Test Method: ASTM D638
Equipment Used: Instron Model #1122, Serial #5434, Calibration Due August 12, 2021

Microfissure Formation Seen via SEM Imaging

Figure 3: Before UV-C Exposure from Mercury Lamp:

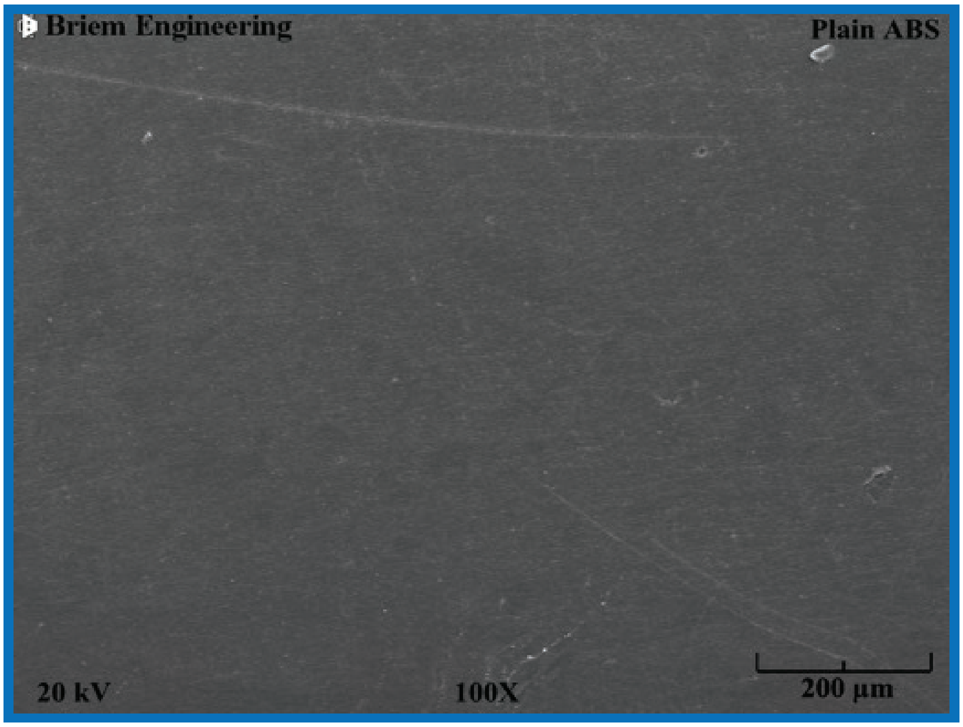
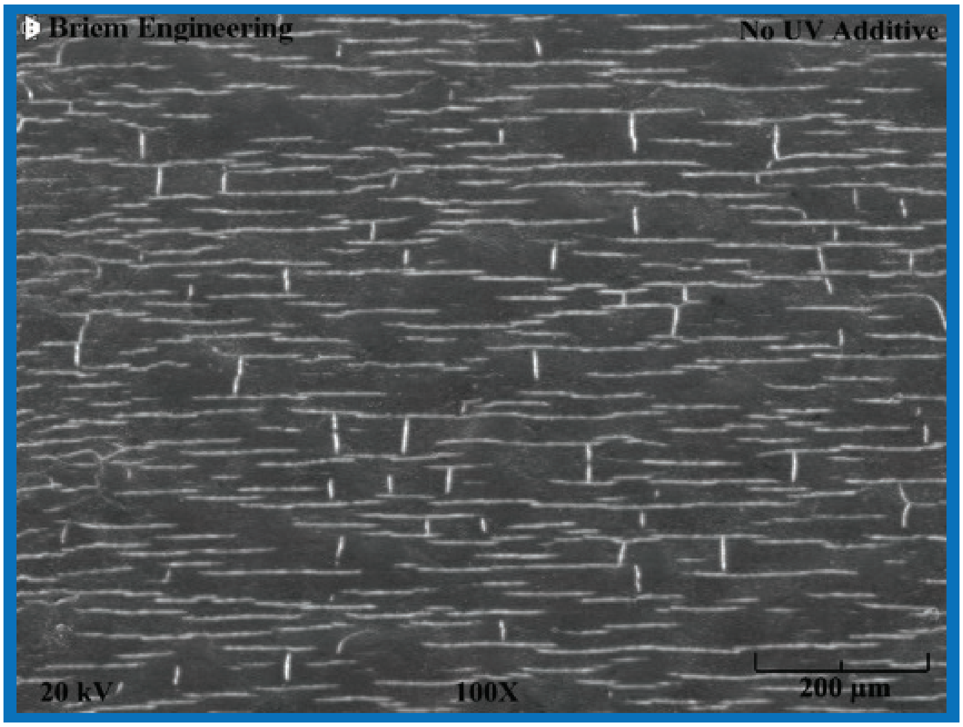


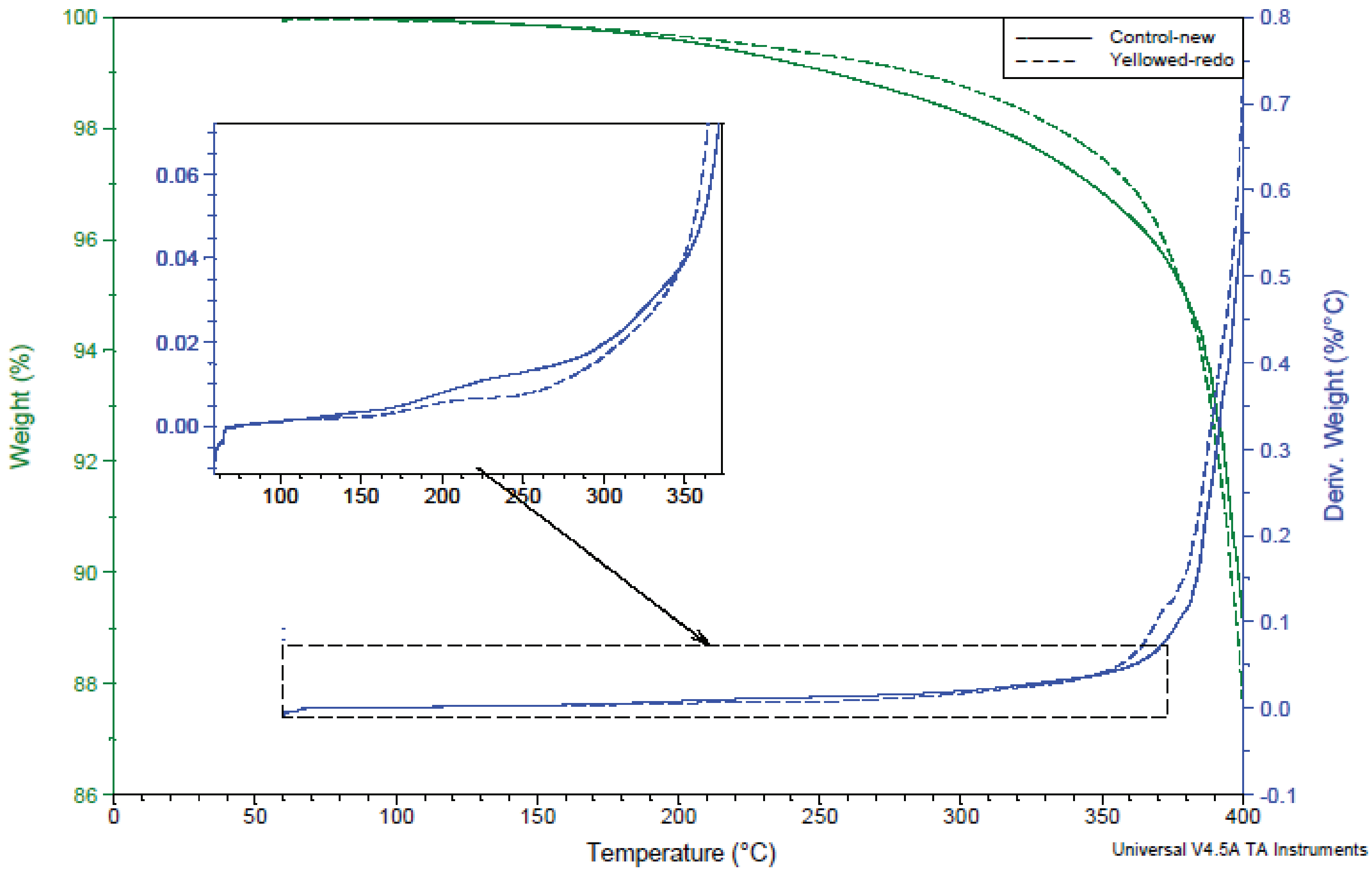
Figure 3: Before UV-C Exposure from Mercury Lamp:



TGA Results

The UV damaged "Yellowed" sample deviated from the control in both the Weight loss (%) profile and in the derivative weight (%/C). This suggests that there is a substantial difference the material structure, evidenced most in the 200-250 °C range where there is greatest first derivative deviation. This might be attributed to PAN cyclization initiated by UV energy, but more advanced testing would be required to determine if this is exactly the case.

Figure 5: Comparison of TGA weight-loss curves for UV-exposed ABS and ABS control.



Comparison TGA Results from Vocera Badges

Figure 6: Comparison of TGA curves for UV-exposed PA12 and PA12 control.

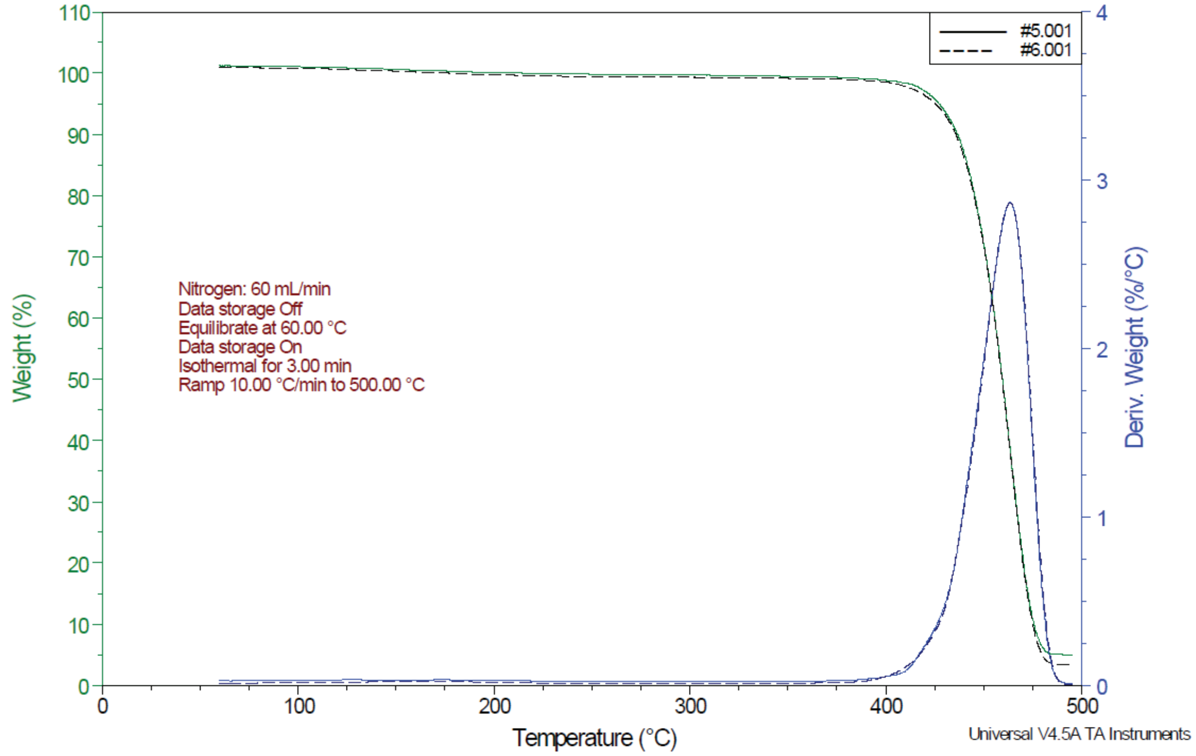


Figure 7: Comparison of TGA curves for UV-exposed TPU-Silicone and TPU-Silicone control.

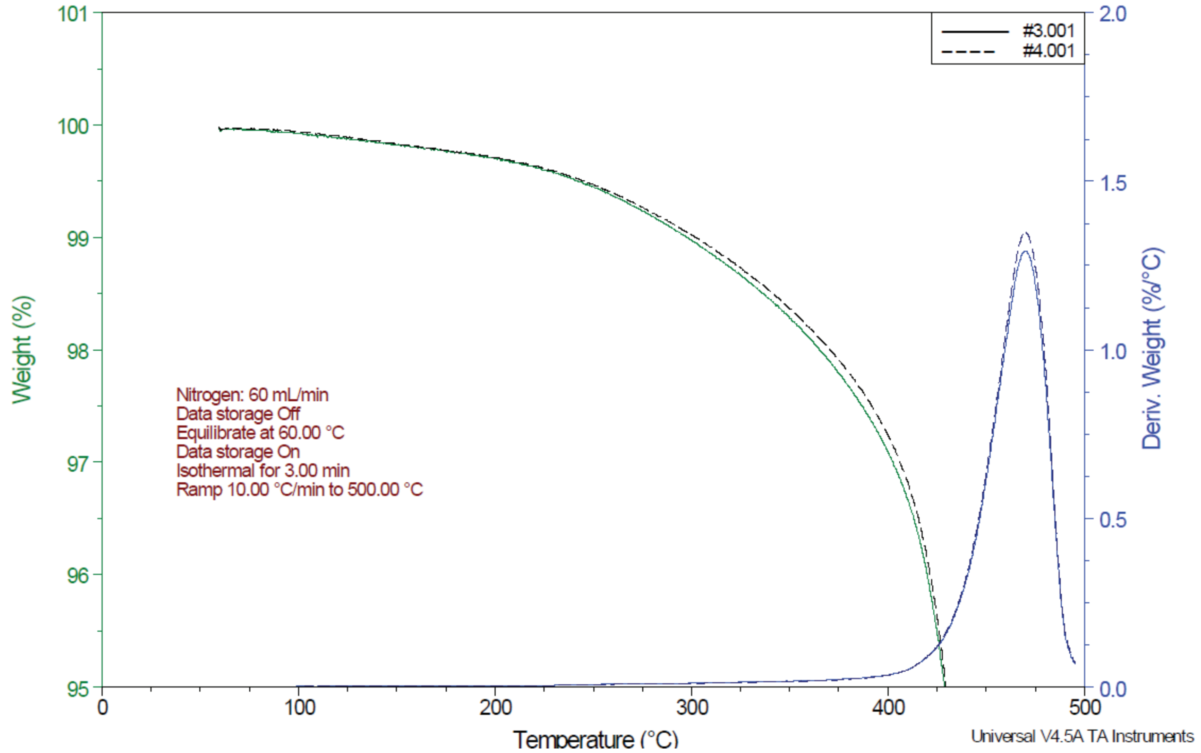
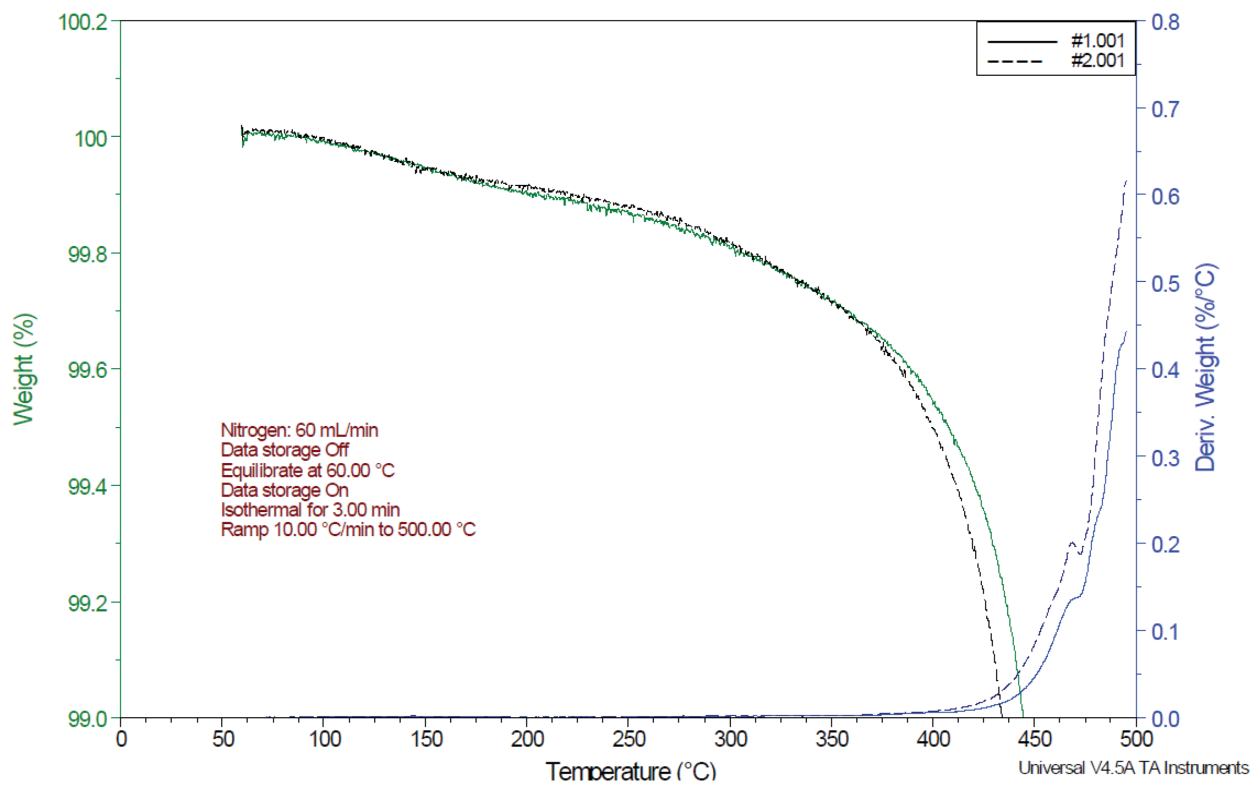


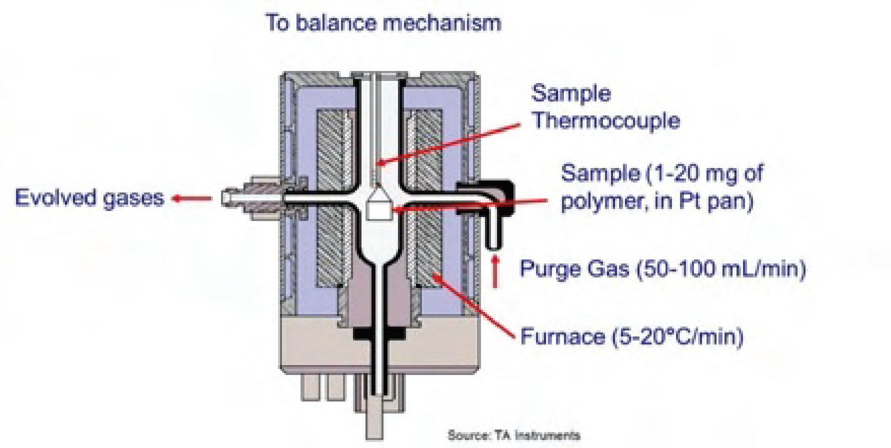
Figure 6: Comparison of TGA curves for UV-exposed PA12 and PA12 control.



Additional Notes on Methods

UV Exposure Protocol: For the TGA experiments, the ABS plaques were exposed to UV light within the Vioguard Cubby unit continuously for 3 days, or 4320 minutes, using the standard light intensity for disinfection settings. For the tensile tests, the ABS plaques were exposed for 4 days.

Thermal Analysis: Thermogravimetric analysis (TGA) is a method whereby increase the temperature of a sample at a known rate (or hold at a high temperature for extended time) and observe the change in weight with temperature and time. Weight measurements are taken from an extremely precise balance suspended from above, held in place with a platinum dish. The surrounding gas environment typically consists of an inert gas such as nitrogen or argon unless oxidation is desired specifically (in which case air can be used). The following diagram depicts the general apparatus operation.



The TGA instrument conditions was set to 50 mL/min of N2 as a purge and the ramp was set to 10°C/min, starting at 60°C and ending at 400°C. A comparison sample of material that has not been exposed to UV was used as a control. Besides the weight loss vs. temperature plot (W vs. temp), the first derivative plot (dW/dT vs. temp) sometimes gives additional insight into the decomposition mechanism as well, if present.

Visual Inspection: Polymers occasionally exhibit discoloration upon UV degradation. The testing engineer will take pictures using the same camera under identical lighting before and after UV exposure.

Tensile Testing: "Dogbones" were cut by the test lab from the plaques and their aspects measured for calculations. The samples were immobilized and then pulled apart while the force to cause breakage was measured. Stress, strain, elongation at break, and tensile strength can then be calculated from the results.