

Polycarbonate Glazing: Maximum and Effective Temperatures for Outdoor Weathering Exposure in the Desert of Arizona

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ABSTRACT

We define an effective temperature (T_{eff}) as an irradiance-weighted average temperature of a material during weathering. It is the constant temperature that would give the same amount of damage as the sample sustains during natural cycling and serves as a benchmark for predicting lifetimes. It is weakly dependant on the activation energy (E_a) of the degradation process. The annual effective ambient and black panel temperatures at an Arizona test site were 30° and 42°C, respectively, for $E_a = 4\text{--}7$ kcal/mol. Privacy color polycarbonate minivan sunroof windows had surface $T_{eff} = 45\text{--}46^\circ\text{C}$ exterior, $54\text{--}58^\circ\text{C}$ interior, and $49\text{--}52^\circ\text{C}$ exterior blackout surfaces. Maximum recorded temperatures were 73°C, 87°C, and 81°C, respectively.

INTRODUCTION

Lifetime prediction requires translation of accelerated laboratory weathering data to outdoor weathering conditions. Irradiance, temperature, and moisture are critical parameters. Irradiance and radiant exposure are fairly straightforward to measure and quantify under both laboratory and standard outdoor exposures. Moisture and temperature can be less well defined. Temperature seems easy enough, but the question arises as to what temperature to use. If the photodegradation rate has some activation energy (E_a), then the temperature of the sample when the sun is shining on it is the important variable. Conventional weather data are reported as minimum, maximum, and average, and it is not clear that these are appropriate metrics for photodegradation.

We and others [1,2] have suggested using average daily high temperatures as a benchmark since these data are readily available and should be coupled to irradiation since sunny days generally are warmer than cloudy days. These values are about 30°C for ambient and 46–50°C for black panels (BP) at both Miami and Phoenix test sites [3].

A more rigorous method is to use finely parsed irradiance and temperature data (hourly or less) and calculate the contribution of each time period to the total degradation over the course of a year. One then finds the constant temperature that gives the same amount of degradation as the naturally varying temperature from the same light dose. We call this the effective temperature (T_{eff}) of the sample. It requires only the set of weather data, an estimate of the E_a of photodegradation, and knowledge of the relationship between measured temperatures and sample temperature. We have reported this in full elsewhere [4], and here report a summary of the procedure and our findings as they relate to polycarbonate (PC) automotive glazing.

EXPERIMENTAL

OUTDOOR EXPOSURES - A silver 2001 Chrysler Town and Country van with a gray interior was equipped with two sunroof windows made of 4 mm coated polycarbonate (PC) resin. The other windows were OEM original except the rear quarter panels, which were also 4 mm PC. The PC windows were a dark “privacy” color with approximately 18% light transmission. A

blackout area approximately 10 cm wide was printed on the interior side perimeter with Exatec PIX black ink. The windows were treated on both sides with Exatec 900™ coating system, which is a weatherable silicone hardcoat with a plasma-deposited abrasion layer. One window was a standard PC grade while the other contained an IR-absorbing additive. Thermocouples were imbedded into the surface of the panels on the exterior, interior, and on the exterior over a blackout area near the perimeter. A thermocouple was also located inside the van near the headliner to record the interior air temperature. The thermocouple values as well as ambient temperature and black panel (BP) temperatures were recorded at 10-minute intervals on data loggers. The exposure commenced on May 10, 2006 at AZTEST, 21212 West Patton Road, Wittmann, Arizona and concluded on May 11, 2007. Ambient and BP temperature collection began May 24, 2006 and Nov. 14, 2006, respectively.

BLACK PANEL TEMPERATURE CALCULATIONS – Black panel temperature data were missing from portions of the datasets. Missing values were calculated by fitting a quadratic function to the irradiance and ambient temperatures of the remaining data during daylight hours. The dataset with 10-minute parsing fit Eq. 1 with $R^2 = 0.98$ and 99% of the data within $\pm 5^\circ\text{C}$ where I is the average 5° south global light intensity in W/m^2 during the time period. An hourly-parsed dataset fit Eq. 2 with $R^2 = 0.94$ and 99% of the values within $\pm 5^\circ\text{C}$. Effective temperatures using calculated BP temperatures were identical to those using measured values for the periods in which BP was recorded.

$$T_{BP} = T_{ambient} - 3.843 \times 10^{-6} I^2 + 0.0237 I - 3.25 \quad \text{Eq. 1}$$

$$T_{BP} = T_{ambient} - 5.713 \times 10^{-6} I^2 + 0.0256 I - 3.42 \quad \text{Eq. 2.}$$

CALCULATION OF EFFECTIVE TEMPERATURE – Data were loaded into Excel™ spreadsheets. A column was created containing Eq. 3 where I is the global radiance (W/m^2), E_a is the activation energy (kcal/mol), R is the gas constant 1.987, T_{eff} is the assumed effective temperature, T_{meas} is the measured temperature, and Δt is the time interval (s). This column is summed, and the T_{eff} is adjusted using the ‘Goal Seek’ tool to make the sum equal the measured radiant exposure (J/m^2) for the time period. Full details are reported in Reference 4.

$$= I \exp\left(\left(E_a / R\right)\left(1 / \left(273 + T_{eff}\right) - 1 / \left(273 + T_{meas}\right)\right)\right) \Delta t \quad \text{Eq. 3}$$

RESULTS

EFFECTIVE TEMPERATURES – Temperature data and 5° global irradiance data were recorded at 10 minute intervals for PC sunroof windows installed in a minivan and exposed at the AZTEST site in Wittmann, Arizona from May 2006 through May 2007. Black panel temperature collection did not begin until November, 2006, and the missing data were calculated using Eq. 1.

In addition, Joe Robbins of AZTEST provided us with a datasets of hourly parsed irradiance, and ambient and BP temperature data for 2005 as well as irradiance and ambient temperatures for 2003. Missing BP data in the 2005 dataset were calculated using Eq. 2. The ambient and BP T_{eff} assuming several activation energies (E_a) are shown in Table 1. The calculated T_{eff} is only weakly dependant on the E_a over the range of 3-10 kcal/mol and shows good agreement among datasets. The E_a of photodegradation for many engineering thermoplastics including PC is approximately 5 kcal/mol [5], so this value will be used in subsequent calculations.

The sunroof windows were a dark ‘privacy’ tint of both standard and IR-absorbing PC and included blackout areas. The T_{eff} calculated for interior and exterior locations are shown in Tables 2 and 3.

Table 1. Effective black panel (BP) and ambient air temperatures ($^\circ\text{C}$) assuming different activation energies.

	E_a (kcal/mol)			
	3	5	10	15
5° BP 2006-7	40.7	41.1	42.0	42.8
5° BP 2005	40.9	41.5	42.9	44.3
ambient air 2006-7	29.6	29.9	30.6	31.3
ambient air 2005	29.7	30.1	31.0	31.9
ambient air 2003	29.3	29.7	30.8	31.7

Table 2. Annual effective, maximum, and minimum temperatures of standard PC sunroof panels ($^\circ\text{C}$). Assumes $E_a = 5$ kcal/mol.

color	blackout	privacy	privacy
location	exterior	exterior	interior
T_{eff} ($^\circ\text{C}$)	48.6	44.6	54.4
T_{max} ($^\circ\text{C}$)	76.4	72.2	83.8
T_{min} ($^\circ\text{C}$)	-12.8	-13.9	-12.0

Table 3. Annual effective, maximum, and minimum temperatures of IR-absorbing PC sunroof panels. Assumes $E_a = 5$ kcal/mol.

color	blackout	privacy	privacy
location	exterior	exterior	interior
T_{eff} ($^\circ\text{C}$)	51.7	46.0	57.8
T_{max} ($^\circ\text{C}$)	81.0	72.9	87.3
T_{min} ($^\circ\text{C}$)	-12.4	-12.4	-11.6

The window temperatures are all higher than the black panel. The backs of the windows face the warm van interior while the black panel is open to the ambient air. The IR-absorbing resin is warmer than the resin without the additive by a few degrees. Interestingly, the blackout area of the IR-absorbing window is warmer than the