Correlation of Accelerated Weathering, Natural Weathering, and Field Lenses for Protective Coatings Utilized in Forward Lighting

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The growth of the plastics industry in the last few decades has been accompanied by a significant expansion in the use of plastic materials in outdoor applications. Due to stability limitations of most plastics upon exposure to climate (e.g., solar radiation, moisture, temperature), the use of protective coatings for stabilization[1] and prevention of premature product failure has received much attention. One industry in which the use of plastics continues to grow is the automotive market. Plastic components provide weight savings, thereby increasing efficiency, and allow designers great freedom in styling a prototype or an existing model. Plastic can be styled in a variety of ways for both aesthetics and functionality, without greatly affecting the cost of production. This is especially true with automotive headlamps, where shape has changed over the years from square and vertical to wrap-around designs that flow directly into the hood of the automobile.

The most common polymer used in the manufacture of headlamps is polycarbonate. Polycarbonate is typically used in applications requiring impact resistance, temperature resistance and excellent optical properties. Like most polymers, polycarbonate is sensitive to UV light[2] and tends to haze or discolor through exposure. Any deterioration of an automotive headlamp due to yellowing, haze or discoloration can negatively affect its inherent and important safety function. As the polycarbonate deteriorates, the amount of light transmitted onto the road is reduced and may eventually prove hazardous if properties deteriorate significantly. In order to make the use of polycarbonate viable in headlamp application, a protective coating is required for maintenance of the optical performance in this application.

The near horizontal design of headlamps has further increased the need for weathering protection. It is well established that a horizontal surface undergoes faster degradation due to higher direct UV incidence relative to a vertical surface, which receives less direct and more diffuse/reflected UV incidence. Figure 1 shows a comparison of UV irradiance levels on parts at 5°, 45°, and 90° to the horizontal in Florida. A part at 5° to the horizontal receives over 1.5 times the UV radiation as a part at 90° to the horizontal.[3]

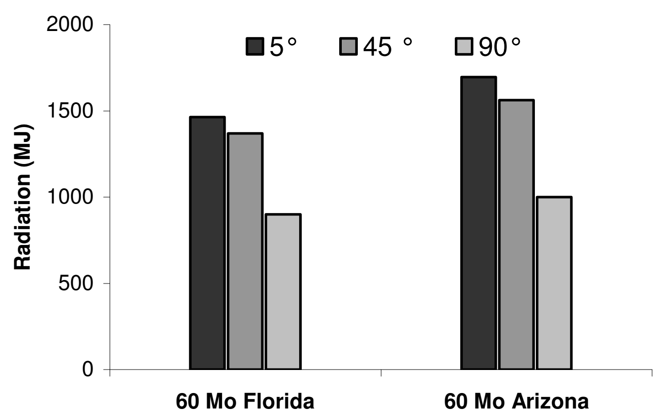

Figure 1. Relative radiation difference based on part angle to horizontal.[3]

Controlled natural weathering in Florida and Arizona is the benchmark of performance required for a coating to be listed by the Automotive Manufacturing Equipment Certification Agency (AMECA). This test requires exposure at a controlled angle for three years without significant deterioration of the coated part.[4] Today, several OEMs are looking ahead to headlamps that can achieve five or even ten years performance in a controlled Florida test. These increasing performance requirements for weatherability have raised the need for a test method that can accelerate natural weathering in order to screen commercial candidates on a reasonable time scale. Xenon accelerated weathering is a rapid method for achieving this acceleration and has been widely accepted by automotive OEMs as a reliable predictor, when performed correctly, of real weathering performance. The combination of Florida exposure and Xenon accelerated weathering of test plaques can be used to predict the field performance of a coated part. Ultimately, the true performance is established during the "real world" end use of the coated part. Therefore, to validate performance in the field, this study also evaluated coated lenses from vehicles with known histories in Florida and correlated this performance to controlled Florida and accelerated Xenon exposures.

This paper investigates the weathering techniques used to predict lifetime performance of hard-coated headlamps to establish suitability in *current* headlamp design. Three methods for evaluating weatherability performance are investigated: (i) Xenon accelerated weathering, (ii) Florida controlled exposure on test plaques, and (iii) real world lenses from Florida vehicles.

Experimental

Sample Preparation:

Laboratory samples for weathering testing were prepared on 1/8" injection molded LS2-111 Lexan* polycarbonate. Samples were flow coated with UVHC3000 hardcoat following the recommendations from Momentive Performance Materials. Production lens samples were cut from commercially available headlamps.

Accelerated Xenon Testing:

Historically, major automotive OEMs have specified SAE J1960 as a standard accelerated Xenon test method.[5] The parameters of this method are listed in Figure 2. The SAE J1960 method utilizes quartz inner and borosilicate outer filter combination that generates a spectral distribution containing unrealistic short wavelength radiation (which does not occur in the natural sunlight on earth). Due to the high energy of lower wavelength radiation, artificial damaging effects in organic materials can occur, resulting in misleading material performance. As a result, the automotive industry has accepted the use of borosilicate inner and outer filter combination as it provides a better match to natural sunlight, limiting the lower wavelength light emission. A comparison of the spectral distribution versus sunlight for the two filter combinations is shown in Figure 3. Some U.S. OEM's have adapted further modified methods based on the ASTM G155, which is favored by many European automotive manufacturers. ASTM G155 differs from the SAEJ1960 in that it does not have a dark cycle to mimic nighttime wetting, utilizes borosilicate inner and outer filters, and utilizes higher irradiance to increase the acceleration factor. In this study, sample exposure was carried out under the ASTM G155 method and performance readings on samples were taken every 900-1000 kJ/cm^2 at 340nm of exposure.

Test Standard: SAE J1960/J2527

Light Cycle:
- Filters: Quartz/Boro (Inner/Outer)
- Irradiance: 0.55 w/cm^2
- Black Panel Temp: 70 ℃
- Chamber Temp: 47 ℃
- Relative Humidity: 50%

Dark Cycle:
- Relative Humidity: 95%
- Chamber Temperature 38 ℃

4 Segments:
1. 60 minute Dark Cycle with $H_2 0$ spray
2. 40 min Light Cycle no spray
3. 20 min Light Cycle with $H_2 0$ spray
4. 60 min Light Cycle no spray

Test Standard: Modified ASTM G155

Light Cycle:
- Filters: Boro/Boro (Inner/Outer)
- Irradiance: 0.75 w/cm^2
- Black Panel Temp: 63 ℃
- Chamber Temp: 43 ℃
- Relative Humidity: 45%

2 Segments:
1. 102 minute Light Cycle
2. 18 minute Light Cycle with $H_2 0$ Spray

Figure 2: Test protocol for SAEJ1960 and Modified ASTM G155 accelerated Xenon methods.

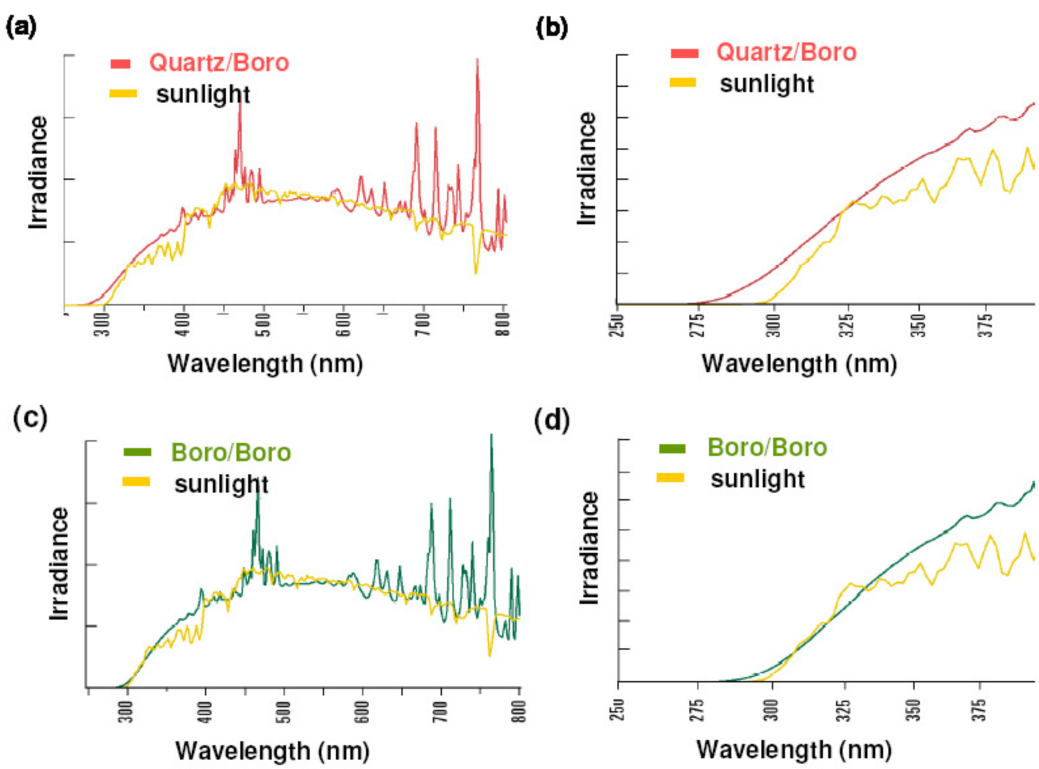

Figure 3: Comparison of sunlight vs. Boro/Boro & Quartz/Boro UV filtration[4].

Controlled Natural Florida Weathering:

Natural Florida weathering testing was carried out following SAE J576 test protocol for outdoor exposure at 45° with no backing. Arizona testing has also been completed, however the scope of this work focuses on Florida testing as it has been found to be a more severe environment for this UV cured hardcoat. Atlas Material Testing Solutions managed sample exposure at their outdoor test site in Miami, FL. Sample readings were taken at 12-month intervals for the first 2 years and every 6 months for the remainder of exposure.

Field Lens Sampling:

Collecting headlamps from used vehicles in Florida was the basis of this part of the study. The following steps were followed to collect and evaluate the used lamps:

1. Headlamp assemblies were removed from vehicles with known registration histories.
2. For each lamp, the VIN #, year, make, model, registration information, and mileage were recorded.
3. A performance assessment of each lamp assembly was done. This included measuring haze, transmission, yellowness index, and film build across the face of the headlamp.

For the purpose of quantitative analysis, each headlamp was cut to generate a representative sample. Each sample was taken from the front of the light beam, encompassing regions above and below the light beam as well. Three readings were taken on each of the cutout samples. These reading locations are labeled as top, middle, and bottom.

Sample Evaluation:

All samples were tested for haze, transmission, and yellowness index. Haze and transmission was measured with a BYK-Gardner Haze-gard Plus following the ASTM D1003 test standard. Yellowness Index was measured using a Macbeth ColorEye 7000 Spectrophotometer. This instrument conforms to ASTM E313 for yellowness index.

Results and Discussion

Injection molded LS2 clear polycarbonate test plaques coated with Momentive's weatherable UV-curable coating were weathered via accelerated Xenon G155 (modified) as well as natural Florida exposure. All Florida exposures were completed at Atlas Material Testing at a controlled test field in Miami, FL. Haze, transmission and yellowness index as a function of exposure time are reported in Figure 4 and 5. Data points represent the average of 3 replicate samples.

In headlamp applications, haze is a critical performance metric as it is the first mode of visible degradation in weathering. As shown in Figure 4, the coated plaques easily met the requirement mandated from the automotive industry for forward lighting (FMVSS108) – less than 7% haze on reflex reflectors. This performance metric is achieved in both accelerated Xenon testing as well as in natural Florida exposure. Note, in order to correlate the accelerated Xenon testing to Florida exposure, kJ of exposure at 340nm in a Xenon Weatherometer™ were converted to "years equivalent in Florida" using a correlation factor.[3] Because the total UV exposure varies in Florida from year to year, this is an approximation. Nonetheless, the data show that accelerated Xenon testing is a conservative predictor of performance with regard to haze. Both data sets overlap nicely, showing good correlation between these two test methods.

A further verification of the correlation was obtained from field lenses collected from Florida registered vehicles. Only one data point for these lenses could be obtained, as vehicles could not be tracked throughout their service lifetime. Lenses collected from the field at just over three years service were evaluated. These lenses show approximately 1% less haze than the control plaques exposed in Florida, showing excellent passing performance at three years with regard to haze, transmission as well as YI. The slightly improved performance in field lenses can be expected due to the inherent variability of a vehicle's exposure. The positive results are critical, as weatherability is not an inherent material property, but rather a system property. Therefore, the system as a whole is affected not only by the chemical composition of the protective coating, but also by the processing of the coating, by the stress state of the substrate to which the coating is applied, as well as by the final application/use of the coated part. To avoid product failure, the coating system must encompass a degree of robustness such that variations in these system parameters do not disrupt the overall performance. Correlating data from accelerated Xenon and controlled Florida exposure to field lenses helps confirm the robustness of the system design.

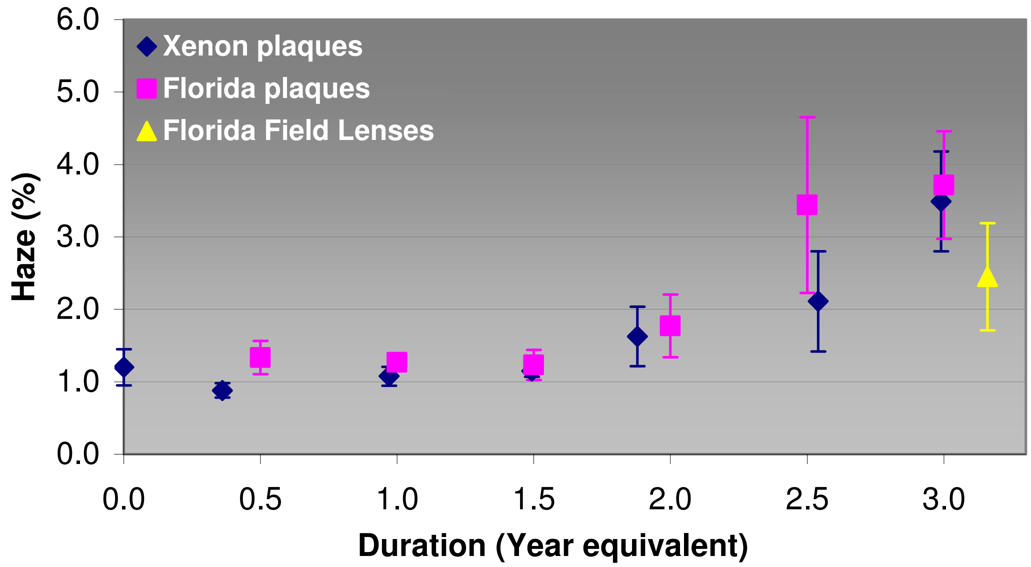

Figure 4. Haze performance in Xenon accelerated weathering plaques, Florida exposure plaques (45 degrees) and Florida "field" lenses. Data represents average of at least three sample measurements.

Similar to haze, measured transmission and YI of the weathered samples showed excellent correlation between accelerated and natural weathering (Figure 5). The data again show that accelerated weathering is a good and conservative predictor of real life (field) performance with this coating system.

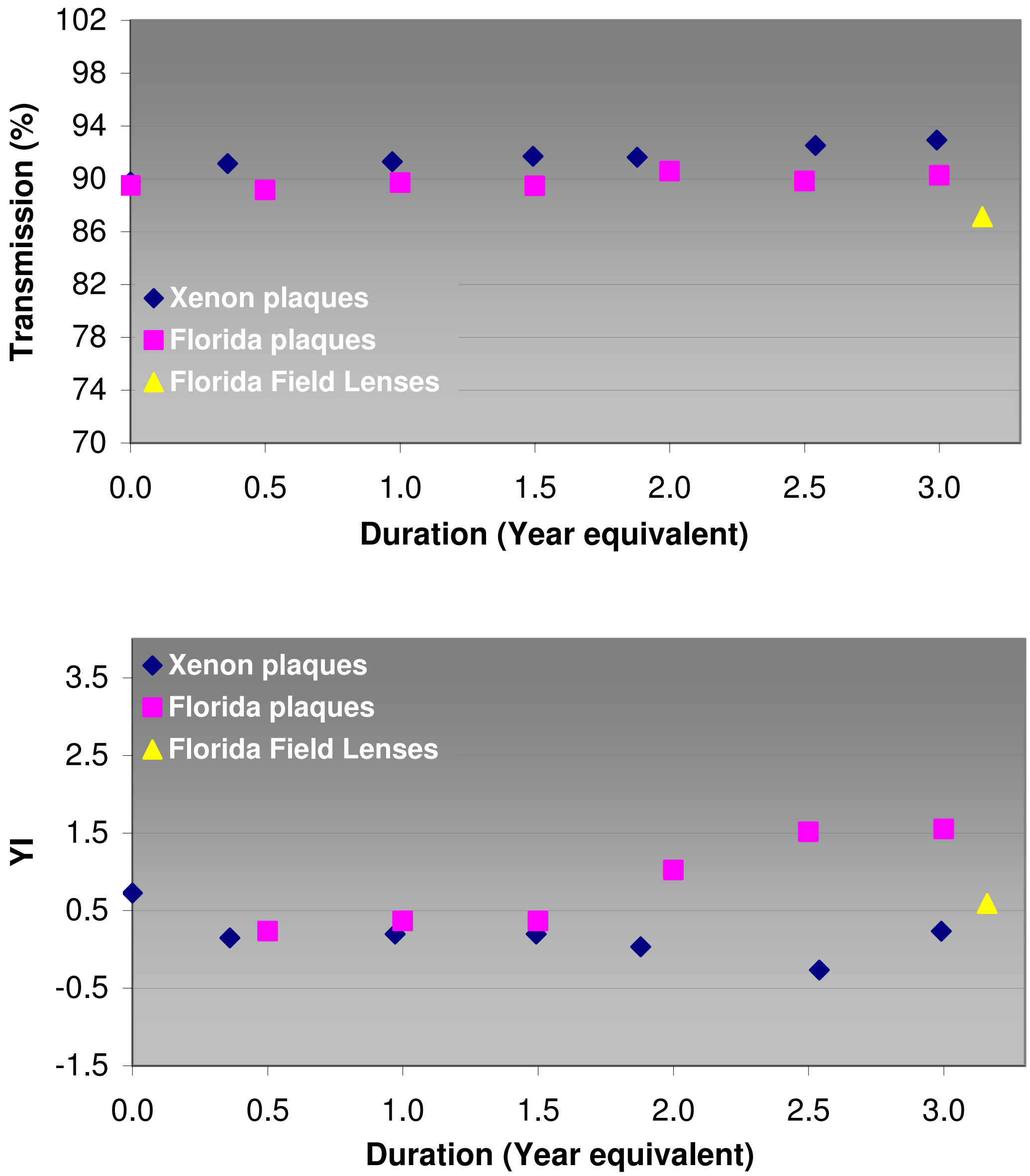

Figure 5: Comparison of transmission and YI in Xenon accelerated weathering plaques, Florida exposure plaques (45 degrees) and Florida “field” lenses. Data represents average of at least three sample measurements.

A more thorough study of field lenses has been completed to evaluate lens performance from top to bottom for both Momentive and other unknown competitive coatings. Figures 6, 7, and 8 show performance of multiple lenses with averaged performance for Haze, YI, and Transmission. The measurements for the lenses were taken from the top one-inch border of the lens, the middle (directly in front of the headlamp beam), and the bottom one inch. It was noted that coating degradation, when present, consistently started at the top of the lenses where the coating was approaching a horizontal orientation to sunlight. Similarly, performance loss with respect to haze and other properties tended to develop toward the top of the lens, and in severe cases, to proliferate down to the center, as with coating system A. Although AMECA and other

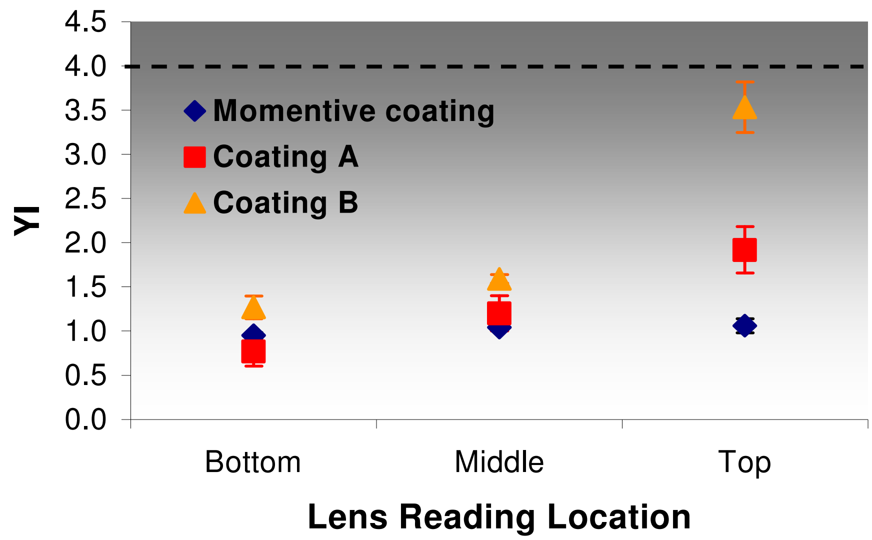

Figure 8: YI comparison of three coating systems with ca. 3 years in Florida. Readings were taken at top, middle, and bottom locations in front of headlamp beam. Dashed line designates limit for YI with regard to failure.

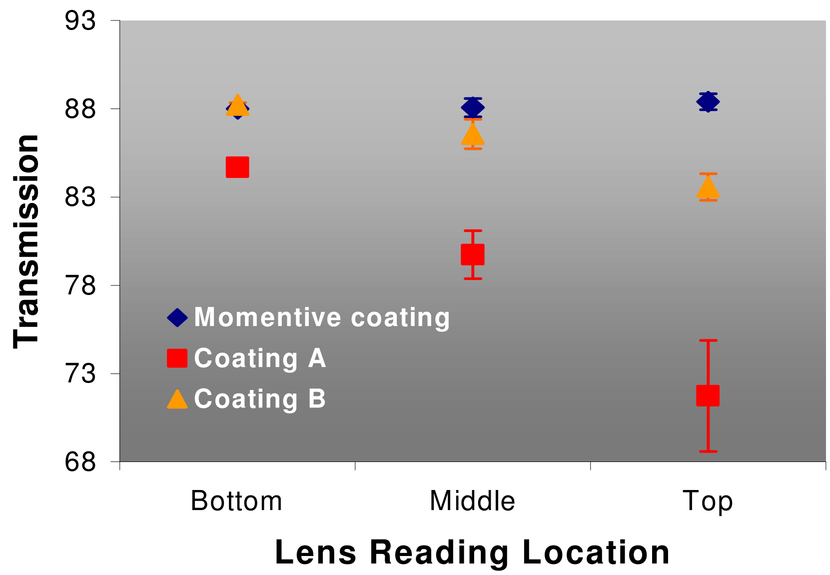

Figure 7: Transmission (%) comparison of three coating systems with ca. 3 years in Florida. Readings were taken at top, middle, and bottom locations in front of headlamp beam.

test protocols specify exposure angles of 45º (Florida) for automotive coatings, newer headlamp designs have steeper angles and, as a result, demand even greater weathering stability. Quantitative analysis of various lens areas exemplifies this fact.

The Momentive coating achieved passing performance with regard to haze, yellowness and transmission at all lens locations, demonstrating robust performance even at the top of the lenses. Failure of competitive coatings is difficult to attribute to a specific mechanism. Because weatherability is a system property, encompassing coating chemistry as well as the coating application process, substrate variability, etc., a design weakness may exacerbate the impact of any one of these elements and lead to premature coating failure.

Conclusions

Different weathering techniques have been compared on a UV curable hard coating system. This work has shown that Xenon weathering can be an acceptable, conservative predictor of real world performance when the proper testing methods and UV filters are utilized. Controlled weathering in Florida on the same coating validated this correlation. The performance of production lenses from vehicles in Florida was also investigated, and the analysis shows a slight improvement in absolute haze relative to controlled natural weathering in Florida at a comparable exposure time. This should be expected given the variable exposure that a car in use may experience relative to a controlled sample. These results confirm that, when properly executed, both controlled natural weathering and Xenon accelerated weathering can be used to conservatively predict performance of production lenses.

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