

Development of an Enhanced Accelerated Weathering Test Cycle for Automotive Coatings

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ABSTRACT

Laboratory accelerated weathering test methods, such as SAE J2527 and JIS D 0205, are used to predict long term durability in the development and approval of automotive coatings. However, recent studies have shown that these methods are deficient with respect to spectral match to sunlight, simulation of water, and temperature profile. These deficiencies can limit the confidence of the laboratory accelerated test, and as a result the user needs to rely more heavily on long term natural exposure results. To increase the confidence of laboratory accelerated weathering testing, a new xenon arc light source filter and test protocol were investigated. Through a combination of natural weathering studies and prototype method testing, an improved accelerated weathering test cycle has been developed. The key characteristics of the improved method include the application of a new light source filter for spectral match to sunlight in the UV spectrum and an optimized water spray cycle that can create realistic moisture related coating damage. This new method has enabled improved laboratory accelerated weathering test confidence while reducing the total accelerated weathering test time.

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INTRODUCTION

Automotive manufacturers are under constant demand to further enhance coatings. Research and development of new coating systems is necessary to achieve not only quality and customer appeal but also environmental regulations while maintaining a reasonable cost and manufacturability. To meet these demands, an assessment needs to be done of the coating service life in the harsh environments to which they are exposed. One of the most critical yet time-consuming service life assessment methods is accelerated weathering. Laboratory accelerated weathering tests for automotive coatings can take over 5 months and are expected to provide confidence in the natural accelerated weathering results. However, researchers at automotive manufacturers and coating suppliers have exposed flaws in accepted laboratory protocols for accelerated weathering testing [1]; therefore, it is increasingly clear that a new approach is necessary.

To develop an enhanced laboratory accelerated weathering protocol for automotive coatings, a long-term weathering research program was undertaken. The goal was to create an accelerated weathering test method based on natural weathering characteristics with improved speed of test, accuracy of weathering prediction, and lower cost of operation.

As shown in Figure 1, research was broken down into three main areas: (1) natural weathering of automotive coating specimens in various environments, (2) replication of natural weathering characteristics, and (3) comparison of physical coating damage in natural exposure environments versus new prototype laboratory accelerated weathering cycles.

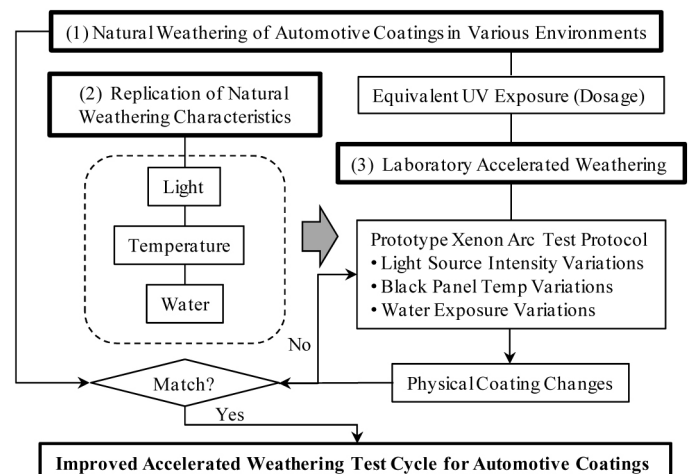


Figure 1. Long-term Weathering Research Program

The study of natural weathering conditions and replicating them in laboratory accelerated weathering devices is covered in other literature [2]. Additionally, a two-year natural weathering program that evaluated automotive coatings that were exposed to three different environments was also completed [3]. Results of these previous studies were used as inputs for the creation of prototype xenon arc test methods.

In this work, the development of prototype xenon arc tests will be described and the test results versus current accelerated test methods and natural weathering methods will be shown.

METHOD DEVELOPMENT

INPUTS FOR PROTOTYPE TESTS

In order to have improved accuracy in the new laboratory accelerated weathering method, a key item was studying natural weathering conditions and replicating them in laboratory accelerated weathering devices. As shown in Table 1, the key weathering conditions studied were light source, temperature, and water. The light source study involved new xenon arc filter technology. The temperature and water studies each required year-long field and laboratory studies. These natural weathering conditions can be replicated and controlled using commercial xenon arc accelerated weathering devices. Through this approach, an understanding of natural weathering characteristics was obtained and used as inputs for the prototype test methods.

Table 1. Study Items and Control Methods

Item	Sub-Item	Study Method	Control Method
Light Source	Quality of Light	SPD of Filters	Xenon Arc Light Filter
	Quantity of Light	Historical Data	Irradiance Setpoint
Temperature	Temperature Value	Historical Data	Black Panel Temperature
	Distribution by Color	Field and Lab Study	Xenon Arc Light Filter
Water	Quantity of Water	Field and Lab Study	Water spray time and temperature
	Frequency	Historical Data	Test Cycle Design

Light Source

Selection of light source inputs for the prototype tests included two sub-items: quality of light and quantity of light.

Quality of Light

The quality of light in a laboratory accelerated weathering device, defined by its spectral power distribution (SPD), is typically obtained by the combination of a light source and filter combination. As shown in Figure 2, the SPD for the light source plus filter combinations for both JIS D 0205 and SAE J2527 do not adequately remove short wave UV below 295 nm when compared with natural sunlight. This can lead to unrealistic accelerated weathering results [4]. However, as shown in Figure 2, recent improvements in xenon arc light source filter technology allow for improved match to natural

sunlight in the UVA and UVB range [5]. In addition to improved spectral match, the proposed new xenon arc filter technology has been shown to replicate the chemistry of degradation that occurs in natural sunlight exposures [6]. Accounting for improvements in SPD match to natural sunlight and improved replication of the chemistry of degradation, it is expected that the proposed filter technology will lead to more accurate accelerated weathering test results.

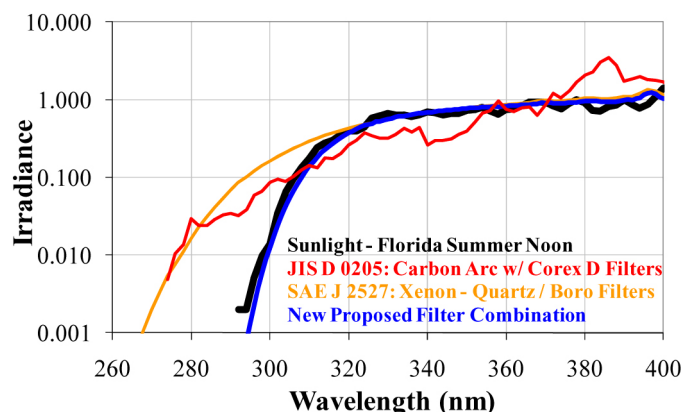


Figure 2. SPD of Light Source / Filter Combinations

Quantity of Light

For natural accelerated weathering, the quantity of light delivered to a weathering specimen, typically referred to as dosage, is expressed as MJ/m² of UV (295-385 nm). In contrast, the dosage delivered in a xenon arc device is typically expressed in kJ, either at 340 nm or over a range of 300-400 nm. In designing the test cycle, it was desired to have each light cycle be equivalent in dosage to what a specimen would be subjected to in one day of natural accelerated weathering. To obtain this value, historical data from South Florida exposures at 5 deg [7] were studied to obtain the annual MJ/m² of UV (295-385 nm) in order to calculate the average daily UV dosage. As shown in Table 2, this could then be converted from MJ/m² of UV (295-385 nm) per day to kJ at 340 nm per light cycle. This value was used as a target dosage per light cycle for the purposes of test cycle design.

Table 2. Target UV dosage Calculation

Calendar Year	Annual UV (MJ/m ²)	Average UV/Day (MJ/m ²)	Xenon Equivalent kJ at 340nm
2000	296.81	0.81	8.92
2001	287.73	0.79	8.67
2002	286.66	0.79	8.64
2003	274.16	0.75	8.26
2004	334.46	0.91	10.05
2005	299.41	0.82	9.02
2006	299.32	0.82	9.02
2007	326.32	0.89	9.83
2008	314.24	0.86	9.44
2009	335.72	0.92	10.12
2010	343.51	0.94	10.35

The rate at which the dosage is accumulated is dependent upon the intensity of the light source, also known as the irradiance. In JIS D 0205, the irradiance of the device cannot be controlled and is determined by the size of the carbon arc light source and the distance the specimens are from the light source. For a device running JIS D 0205 with Corex D filters, this irradiance is about 0.26W/m^2 at 340 nm. With a xenon arc device capable of running SAE J2527, the irradiance can be controlled by a user set point. Current SAE J2527 calls for 0.55W/m^2 at 340 nm. In order to optimize the speed of the new accelerated weathering test, maximum irradiance setpoints greater than 0.55W/m^2 were investigated. However, as shown in Figure 3, the relative time to reach equivalent dosage begins to level off above 0.80W/m^2 . In addition to minimal improvement in test time, when running at high irradiance values, the temperature within a xenon arc device becomes challenging to control and therefore puts an upper limit on the maximum irradiance that can be used.

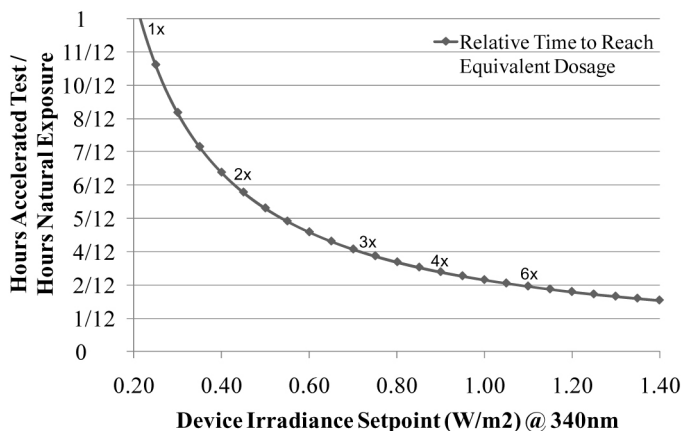


Figure 3. Acceleration Factor based on Irradiance Setpoint

Temperature

Selection of temperature inputs for the prototype tests included two sub-items: black panel temperature value and temperature distribution by color.

Temperature Value

While the light source is responsible for the initiation of damage in coatings, the subsequent damage and propagation is a temperature-driven process; therefore, in designing a laboratory accelerated weathering test, it is critical to replicate the temperatures that a sample is subjected to in natural exposures. To obtain this value, historical data from South Florida exposures at 5 deg [7] were studied to obtain the peak black panel temperature and monthly maximum black panel temperature. These values were compared with JIS D 0205 and SAE 2527 black panel temperatures of 63°C and 70°C respectively. As shown in Table 3, the currently applied black panel temperatures adequately represent what occurs in natural exposure environments. For the purposes of

this work, maximum black panel temperatures between 60°C and 70°C were studied to identify which temperature control method yielded the most accurate test results when compared with outdoor exposure panels.

Table 3. Historical Black Panel Temperature Values

Calendar Year	Peak Temperature ($^\circ\text{C}$)	Monthly Maximum ($^\circ\text{C}$)
2000	64	55
2001	62	54
2002	60	53
2003	57	51
2004	58	52
2005	67	59
2006	65	57
2007	69	63
2008	70	60
2009	71	60
2010	72	60

Temperature Distribution by Color

It is important to note that temperature is more than just a black panel set point on the accelerated weathering device. The set point merely represents the surface temperature of the black panel itself, and serves as a baseline for controlling the temperature of the device. A variety of factors can affect specimen-specific surface temperature. It has been documented that the temperature separation of colored specimens exposed outdoors depends primarily on total solar irradiance [8]. Therefore, in replicating temperature in an accelerated weathering device, it is very critical to understand the relationship between the light source and the resultant specimen-specific surface temperature. To study this relationship and gain full understanding of specimen-specific surface temperatures under different weathering conditions, a year-long field study was conducted in South Florida and compared with specimen surface temperatures obtained in different accelerated test methods [2].

In the previous study, it was concluded that the proposed filter combination can not only aide in spectral match to sunlight but also improve the match to temperature distribution by color found outdoors. The improvement in temperature distribution by color using the proposed filter combination is shown in Figure 4. The proposed filter combination allows for more accurate representation of surface temperatures for light colored specimens.