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Laboratory and Accelerated Weathering Spectra Compared to Sunlight Through Automotive Glass

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Introduction

Sunlight is an important cause of damage to materials exposed outdoors. The shorter the wavelength of sunlight, the greater the damage. The shortest wavelengths in sunlight are the ultraviolet. Although ultraviolet light makes up only about 5% of the total solar energy that falls on the earth's surface, it causes almost all of the damage to durable materials exposed outdoors[1].

Glass acts like a filter on sunlight. It is essentially transparent to visible light, but filters out much of the ultraviolet. Automotive glass is a more efficient filter than ordinary window glass and consequently filters out even more of the damaging UV. However, UV light remains an important cause of damage to interior automotive materials.

Deterioration from sunlight is only one aspect of weathering. For many materials, moisture and temperature may be of even greater importance. No single device can reproduce all of the variables found in different environments. Consequently, any choice of test parameters is somewhat arbitrary. Accelerated test results are always relative. Even the most elaborate weathering tester should be viewed as a screening device.

Sunlight

Figure 1 shows the spectral energy distribution (SED) of summer sunlight compared to the SED of winter sunlight. The low end, UV cut-off of summer sunlight is at 295 nm.

From summer to winter there are changes in both the intensity and the spectrum of sunlight. Most significant is the loss of short wavelength UV radiation during the winter months.

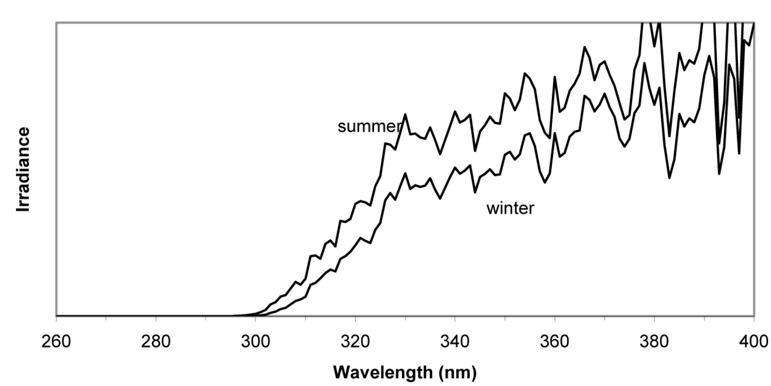

Figure 1 - Sunlight, Summer vs. Winter

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Sunlight energy is normally divided into infrared, visible, and ultraviolet light. Infrared consists of wavelengths beyond the visible red (longer than 760 nanometers). Visible light falls between 400 nm and 760 nm. UV light consists of radiation below 400 nm[2]. The UV region is further subdivided into UV-A, UV-B and UV-C as shown below.

Wavelength Regions of the UV Spectrum

Designation	Wavelengths	Significance
UV-A	400 to 315 nm	Causes polymer damage
UV-B	315 to 280 nm	Includes the shortest wavelengths found at the earth's surface - responsible for severe polymer damage - absorbed by automotive glass
UV-C	280 to 100 nm	Found only in outer space - filtered out by the earth's atmosphere - germicidal[3]

The Importance of Spectral Cut-Off in Evaluating Accelerated vs. Natural Exposures

Photochemical degradation is caused by photons of light breaking chemical bonds. For each type of chemical bond there is a critical threshold wavelength of light with enough energy to cause a reaction. Light of any wavelength shorter than the threshold can break the bond, but longer wavelengths of light cannot break it - regardless of their intensity (brightness). This concept is critical for understanding the importance of spectral "cut-off".

For example, if a particular polymer is only sensitive to UV light below 295 nm (the solar cut-off point), it will never experience photochemical deterioration outdoors. If the same polymer is exposed to a laboratory light source that has a spectral cut-off of 280 nm, it will deteriorate. As will be shown, the spectral cut-off of sunlight filtered through automotive glass is about 315 nm. Any tester whose spectrum contains wavelengths shorter than 315 nm will, inevitably, cause some deterioration that will not be seen in actual service. As Fischer[4] has demonstrated, test speed and accuracy tend toward opposition. Compromises must be made. But it is dangerous to use a tester with a light source that has a spectral cut-off significantly below that of the material's target environment. This is the challenge for laboratory testers - to accelerate without unnaturally stressing materials.

Accelerated Light Sources Compared to Direct Summer Sunlight

Two categories of accelerated weathering testers are widely used for predicting weathering damage: Arc Type and Fluorescent UV. Arc Type testers attempt to reproduce the entire spectrum of sunlight. Fluorescent testers don't try to reproduce sunlight, just it's damaging effects. They confine their output to the UV portion of the spectrum.

__Xenon Arc.__ The xenon arc was first adapted for laboratory accelerated weathering in Germany in 1954. Some models of xenon arcs have a light monitoring system to compensate for the inevitable light output decay due to lamp aging. Two important concepts should be understood when examining the xenon arc.

1. Effect of Irradiance Level - Common irradiance settings for the xenon arc are .35 or .55 W/m^2 at 340 nm. Most non-automotive users select a setting of .35 for reasons of practicality. As shown in Figure 2, .55 compares reasonably well with summer sunlight, but .35 is more like winter sunlight. Figure 2 shows the xenon arc with borosilicate filters.

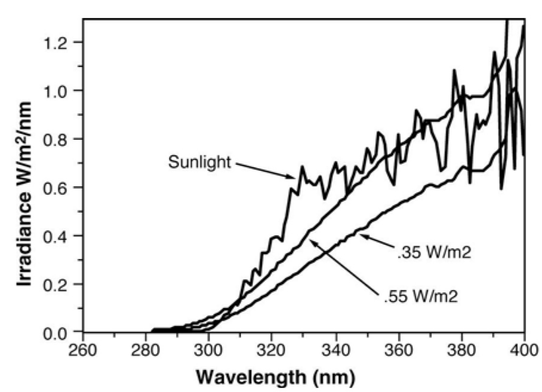

Figure 2 - Xenon Arc Effect of Irradiance Level

2. Effect of filters - Xenon arcs require a combination of filters to reduce unwanted radiation. Most common are borosilicate inner and outer filters. This combination, operated at the .55 irradiance level, can be used to simulate the entire sunlight

spectrum. However it emits some unrealistic, short wavelength radiation between 280 and 295 nm.

Automotive tests often specify quartz/borosilicate filters. This combination allows even more unrealistic short wavelength UV to attack the specimen. Figure 3 shows the different filter combinations compared to summer sunlight.

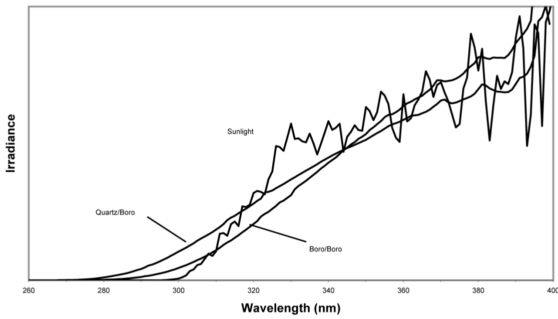

Figure 3 - Xenon Arc Effect of Filters

Fluorescent UVA-340 Lamps. The UVA-340 fluorescent lamp was introduced in 1987 to enhance the correlation between fluorescent testers (ASTM G-53) and outdoor weathering. Figure 4 is a graph of the UVA-340 compared to the xenon arc and to summer sunlight. In the critical, short wavelength UV portion of sunlight, from about 365 nm down to the solar cut-off of 295 nm, the UVA-340 gives a closer reproduction of direct sunlight than the xenon arc.

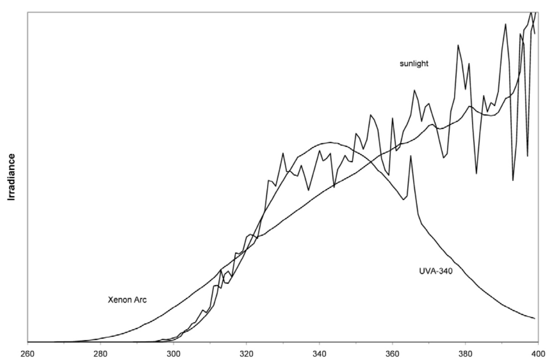

Figure 4 - UVA-340, Xenon Arc, & Sunlight

Filtering Effect of Glass on Sunlight. Common window glass - Glass is essentially transparent to visible light but filters out much of the ultraviolet from sunlight. The shorter the wavelength, the greater the filtering effect. UV below about 310 nm is completely filtered out by common 1/8" window glass (Figure 5).

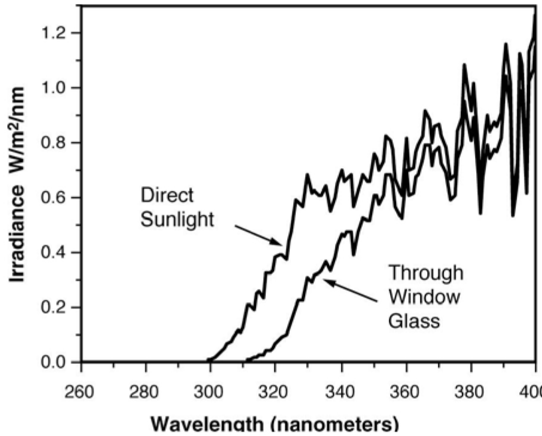

Figure 5 - Direct Sunlight vs. Sunlight Through Window Glass

Automotive Glass. Windshield glass - Automobile windshield glass is relatively thick. It is often tinted and contains a layer of plastic for safety enhancement. This increases the glass's filtering efficiency. Figure 6 shows the SED's of direct sunlight compared to sunlight through automotive windshield glass (expanded to 500 nm). Windshield glass cuts off around 380 nm. Almost all of the damaging ultraviolet light is filtered out by windshield glass. This data is in good agreement with that previously reported by Robbins[5] and Donald et. al[6].

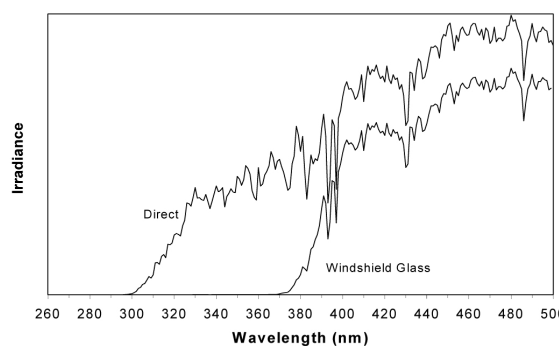

Figure 6 - Direct Sunlight vs. Windshield Glass

Side and rear window glass - Automotive glass used for side and rear windows is thinner than windshield glass. Its light transmission characteristics are different. Figure 7 shows direct sunlight compared to side and rear windows from Ford and GM vehicles. The glass that filtered out the least UV (i.e. had the best transmission) cut off at about 315 nm.

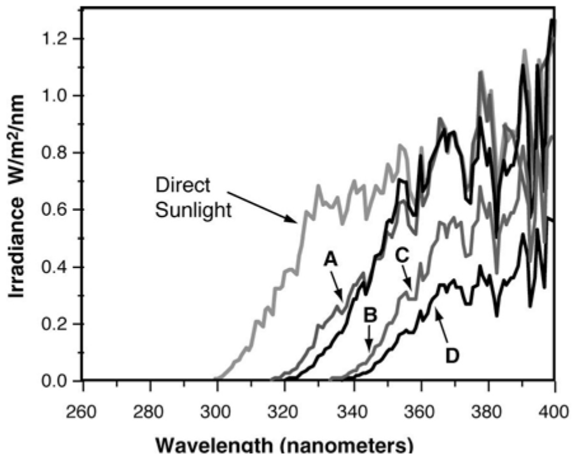

Figure 7 - Direct Sunlight vs. Sunlight Through Auto Glass

A = .128" Thick, Clear
B = .228" Thick, Clear
C = .159" Thick, Lightly Tinted
D = .194" Thick, Tinted

Measurements of Sunlight Through Auto Class Compared to Laboratory Light Sources

The auto glass used for the comparisons below is one that filters out the least amount of UV light. It can be considered somewhat of a "worst case" auto glass.

Enclosed Carbon Arc. The enclosed carbon arc has been used for laboratory weathering and lightfastness testing since 1918. Some test methods still require its use.

The UV spectrum of the enclosed carbon arc consists primarily of two very large spikes of energy, with very little output below 350 nm. Figure 8 compares the enclosed carbon arc to sunlight filtered through auto glass. Since the shortest UV wavelengths are the most damaging, the enclosed carbon arc gives very slow tests on most materials and poor correlation on materials sensitive to short wavelength UV.

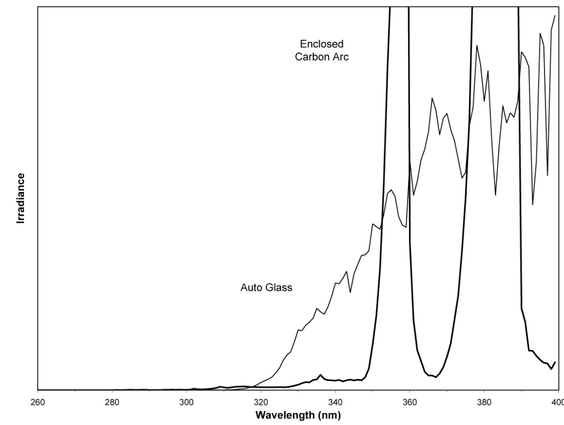

Figure 8 - Enclosed Carbon Arc vs. Sunlight Through Auto Glass

Sunshine Carbon Arc. The sunshine carbon arc has been used for laboratory weathering since 1933.

The most serious problem with the spectrum of the sunshine carbon arc is found in the short wavelengths. This carbon arc emits significant UV-C energy down to (and sometimes below) 260 nm. This is well below the behind auto glass cut-off point of 315 nm, and can cause unrealistic results compared to actual automotive interior exposures. Figure 9 shows the sunshine carbon arc (with Corex D filters) compared to sunlight through automotive glass.

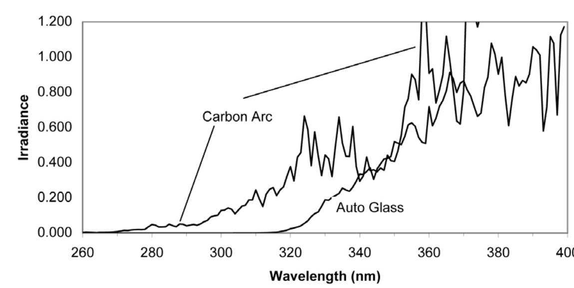

Figure 9 - Sunshine Carbon Arc vs. Sunlight Through Auto Glass

Xenon Arc. The current automotive test method for textiles and soft trim specifies a xenon arc with a quartz/borosilicate filter combination operated at .55 W/m^2 at 340 nm. Figure 10 shows sunlight through automotive glass compared to the xenon arc. As illustrated, the xenon lamp's short wavelength cut-off is approximately 280 nm. Sunlight through auto glass cuts off at about 315 nm.

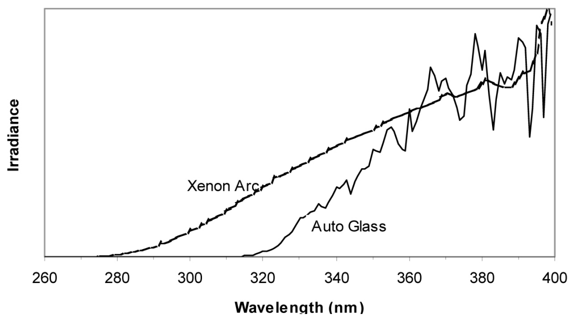

Figure 10 - Xenon Arc vs. Sunlight Through Auto Glass

UVA-351 Fluorescent Lamps. The UVA-351 is used fluorescent UV weathering testers. Figure 11 shows sunlight through auto glass compared to the UVA-351. This lamp has a short end cut-off at about 305 nm. While this is slightly lower than the 315 nm cut-off of sunlight through glass, the UVA-351 is a good simulation of sunlight through glass.

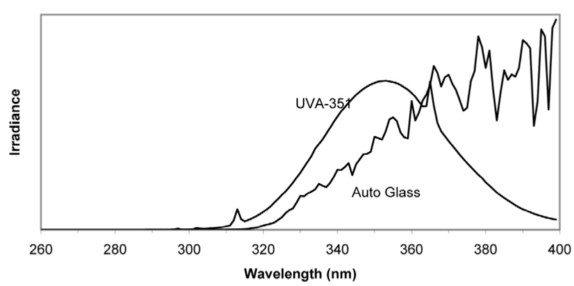

Figure 11 - UVA-351 vs. Sunlight Through Auto Glass

Conclusions

There will probably always be controversy about the correlation between laboratory and natural exposures. Laboratory light sources that use short wavelength UV give great acceleration, but may not always be accurate. But when they are wrong, they're usually wrong on the safe side. Conversely, light sources that eliminate wavelengths below the spectral cut-off of the service environment will give more accurate results. But the price for this increased realism is reduced acceleration. The user (or specifier) must educate himself to make this choice.

References

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