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Weathering - a practical approach

Introduction

Many applications are exposed to a variety of climatic or outdoor elements, in many cases combined with increased temperatures as a result from light bulbs or other heat sources. This prolonged exposure may lead to undesirable changes in aesthetics and mechanical performance.

Polycarbonate, like many other polymers, is sensitive to weathering and may show discoloration and a reduction in ductility. However, a variety of applications made with Lexan resin have proven very successful both in indoor and harsh outdoor environments, still performing without failures after many years of service.

Affect

Penetration

Unlike with many other polymers, UV radiation is unable to penetrate deeply into polycarbonate. Hence, UV induced damage is limited to a very thin layer of about 25 microns. The remainder is just subject to the natural aging of the part. However, as the degraded surface has very small micro-cracks, it can serve as a crack initiator and can reduce the overall ductility of the material after very long exposure. It is possible to restore some of the properties, such as impact and gloss by removing this top layer by polishing, though practically it is almost never done.

Weathering cannot be stopped completely, but it can be slowed down by proper material selection and the use of additives to improve the photo stability of materials. Selection of additives is dictated by matrix compatibility, solubility, thermal stability, and price. UV protection additive families are Absorbers: Organic compounds that preferably absorb and dissipate UV radiation Blockers: Classically, these are inorganic particles that are sized and dispersed to limit depth of UV penetration. Scavengers: Molecules that react and "cap" UV generated free radicals before they react with the plastic.

Color

Change in color is usually the first indication of weathering followed by surface flaws which eventually becomes stress centers for crack initiation. A slightly discolored part likely has still an excellent mechanical performance. The color change depends strongly on the initial color and color pigments used.

A typical discoloration pattern due to UV exposure is the following:

- induction period (little or very slow visible change)
- fast discoloration, reaching almost the final color
- very slow discoloration

Gloss/transmission

- Gloss of the polymer will reduce over time due to erosion of the surface
- For transparent materials, the haze increases and transmission reduces over time due to erosion of the top surface

Physical properties

- Physical properties, in particular ductility may reduce over time, when exposed to weather and UV light.
- It is strongly dependent upon type of polymer and the actual formulation.

Factors affecting weathering

Color and mechanical property retention are critical requirements in every application and should be known or predicted well. Color and property retention of most polymers are affected by (in order of severity) UV radiation, temperature, moisture and the surrounding environment (e.g.. air pollution). It is critical to determine the magnitude of these factors on the application for a proper selection.

UV light
• UV radiation is the main cause of discoloration of thermoplastics.
• UV light is generated by the sun as well as other light sources.
• Direct sunlight is more aggressive than sunlight filtered through glass.
• UV rays attack only the very top surface, while discoloration due to high temperatures is throughout the whole thickness.
• UV light in most accelerated weathering tests is more aggressive than natural light and therefore may over-predict the discoloration.

Temperature
• In various applications (auto interior, lighting devices), the high temperature is a major contributor for discoloration.
• The higher the temperature, the faster the discoloration.
• Discoloration occurs throughout the whole thickness of the part, whereas UV light only affects the top surface.

Moisture
• Moist climates accelerate the degradation process.
• Moisture primarily affects the gloss and haze of materials, in combination with heat it can also decrease impact resistance.

Air pollution
• Acid rain and a variety of gases will accelerate the degradation of many polymers.
• Fine dust or sand can damage the surface and result in a reduction in gloss level.

Variation
Many of these factors vary greatly by the geographical location, time of year and industrialization level. In heavy industrialized areas, factors such as air pollution and moisture will greatly influence the effect on plastic parts, while sites in Arizona will be largely determined by high levels of sun light and high temperatures. In Florida's climate, the high humidity (moisture) is an additional factor.

Transparency
The effect of weathering is more severe in transparent grades compared to opaque grades, as many pigments used in opaque colors (such as titanium dioxide) shield the polycarbonate from UV rays by UV absorption or reflection.

Flame retardancy
Halogenated flame retardants generally have a negative effect on color retention, other FR additives tend to be neutral.

Viscosity
As higher viscosity grades exhibit better initial and retention of mechanical performance, the highest viscosity grade is recommended for use. Of course, the generic molding guidelines should be followed. Viscosity has usually no influence on color or color retention.

Color undertone
Engineering thermoplastics tend to become yellow under influence of UV radiation. It is, therefore, recommended to start with colors that already have a yellow undertone (the human eye is less sensitive for color changes in the same direction as the original color than for distinct color changes).

Pastel colors
A creme white that goes slightly yellow is acceptable but a bluish white that shows the same amount of yellowing will be perceived as "gone green" (blue + yellow = green). Yellowish greens are better than bluish greens. Orange tints are better than purple tints for the same reason.

Chromatic colors
Chromatic colors will perform better than pastel colors because the color itself has a much better hiding power (the resin discolors but is hidden by the strong color). For chromatic colors the same rules apply as for pastel colors, colors with a yellow undertone are visually more stable.

Dark/light colors
As a rule of thumb, dark colors are more stable than light colors, as dark colors will show the least color shift.

Testing
Natural weathering
The resistance to weathering can be determined by natural weathering and artificial- or accelarated weathering. Natural weathering provides the most accurate information of the behaviour of the plastic, but is usually takes many years to generate the information. In addition, the results are highly dependent upon the geographic location of exposure as a result of the dramatic climatic differences. One also has to consider how the application actually is exposed to the weather, e.g. (semi) exposed, facing north or south, angle of exposure. Natural weathering data usually is generated at various test sites around the world with different climates.

We make no attempt to guarantee the life expectancy of any resin when exposed to the weather. This is because the type and severity of such exposure, and the requirements for different applications, can vary widely. A prediction of the life time must be based on the combined evaluation of the available exposure data and specific requirements of each applications. From this, an estimate of the suitability of resin for the parts must be made.

Standards

Accelerated weathering

Most artificial weathering tests are performed according to an international standard procedure. Many international standards, such as DIN, ASTM, SAE and BSI, describe a weathering procedure to determine the behavior of plastics under different conditions.
ISO 4892 2/A : General, outdoor UV weathering
ISO 4892 2/B : General, indoor UV aging
SAE J 1960 : Auto exterior
SAE J 1885 : Auto interior
ASTM D 4459/D4672 : Business machines

Main differences include the type of light used and the filter system, the temperature, and the presence of water or moisture (rain cycle). With these combinations, harsh outdoor and mild, dry indoor environments are simulated.

A clear description of test methods and customer needs is essential to run a UV weathering test because of this wide variety of test methods.

UV radiation below 350 nm is aggressive to many thermoplastics. UV light in many accelerated weathering tests contains a higher percentage short wavelengths than natural sun light. Accelerated UV weathering tests may therefore over-predict the discoloration to some extent, in particular for PC and PC blends because of their special sensitivity to the unnaturally short wavelength light.

Standard	Application	Weathering or UV aging	Irradiance	Light/dark cycle	light/rain cycle (min)	Temperature
ISO 4892 part 2, method A or DIN 53387	general	weathering	60 W/m2 at 300-400 nm 0.50 W/m2 at 340 nm	cont. light	102/18	65 +/-2
ISO 4892 part 2, method B	general	UV aging	50 W/m2 at 300-400 nm 1.42 W/m2 at 420 nm 0.44 W/m2 at 340 nm	cont. light	no rain	65 +/-2
SAE J 1960	auto exterior	weathering	0.55 W/m2 at 340 nm	40 min. light, 20 min. light with front spray, then 60 min. light, 60 min. dark with back spray	front spray back spray	70 +/-2 70 +/-2 70 +/-2 39 +/-3
SAE J 1885	auto interior	UV aging	0.55 W/m2 at 340 nm	3.8 hrs light/1 hr. dark	no rain	89 +/-3
ASTM D4459	business machines	UV aging	0.30 W/m2 at 340 nm	cont. light	no rain	55 +/-2
ASTM D4674	business machines	UV aging	-	cont. light	no rain	40 -45
ASTM G53 UVA or UVB	general	weathering	-	light.dark 4hrs/4hrs	condensation mechanism	50 +/-3

UV Aging / Weathering Standards Overview

An approximate correlation factor between accelerated tests and natural weathering is given for ISO 4892 part 2/A and SAE J1960. As example, 1000 hours exposure time, according to ISO 4892, equals approximately 4000 hours natural exposure in Arizona and 8000 hours in the Netherlands. For reference, 1 year equals 8736 hours.

Measurements

A variety of tests can be done to quantify any change in mechanical behavior or color shift and gloss upon weathering. For transparent materials, the change in transmission and haze can be measured as well. A summary of common test methods is listed below.

Delta E (dE) (CIE lab 1976)
Delta E (dE) is a calculated value which represents the total change in color of a sample versus a reference (unexposed) sample. It is calculated with the L, a, b values, where these are measurables for: L= lightness/darkness, a = red/ green, b = blue / yellow.

Yellowness index (YI) (ASTM E313/ASTM D1925)
YI is the calculated value of the degree of yellowness.

Grey scale (ISO 105-A02)
Determination of changes in color as specified by a range of standard non glossy grey color chips.

Gloss (ASTM D523/ISO 2813)
A beam of light is directed towards a surface. The amount of light that is reflected under an angle opposite to the incoming beam is measured.

Transmission (ASTM D1003)
Determination of percentage light passing through a sample. The ratio of the luminous flux transmitted by a body to the flux incident upon it

Haze (ASTM D1003)
Determination of light scattering. Haze is the percentage of total transmitted light which, in passing through the specimen, deviates from the incident beam by more than 2.5 °.

Falling dart impact / Flexed plate impact (ISO 6603-2)
Multi-axial impact test to determine the ductility of the material. Most important parameter is the energy needed to penetrate the materials at a fixed speed.

Charpy impact (ISO 179)
Impact test(mostly performed without a notch) to determine the ductility of a material under high speed loading conditions in three point bending.

Tensile properties (ISO 527) Detemination of material behavior during uni-axial deformation at constant speed
Stress: resistance against deformation
Strain: relative elongation
Modulus: Stiffness of the material

EFFECT OF PAINT ON MECHANICAL PROPERTIES
If the appropriate coating is chosen, typically there will be no effect on mechanical properties.

However poor impact performance of painted parts may be related to:
- a too aggressive solvent composition of the paint system
- the flexibility of the paint system
- the exact ratio of curing agent
- refinishing (sanding and repainting)