9 Polyvinyls and Acrylics

9.1 Polyvinyls and Acrylics

This chapter focuses on polymers made from monomers that contain a carbon–carbon double bond through which the polymer is made by addition polymerization as discussed in Section 2.1.1. An alkene, also called an olefin, is a chemical compound made of only carbon and hydrogen atoms containing at least one carbon-to-carbon double bond. The simplest alkenes, with only one double bond and no other functional groups, form a homologous series of hydrocarbons with the general formula C_nH_{2n}. The two simplest alkene of this series is ethylene. If one of the hydrogens on the ethylene molecule is changed to chlorine, the molecule is called vinyl chloride, the basis of polyvinyl chloride (PVC), commonly called PVC. There are many other vinyl monomers that substitute different functional groups onto the carbon–carbon double bond. Vinyl alcohol is a particularly important one. Acrylic polymers are also polymerized through the carbon–carbon double bond. Methyl methacrylate is the monomer used to make poly(methyl methacrylate).

This chapter covers those addition polymers that are not strictly hydrocarbons, containing only carbon and hydrogen.

9.2 Ethylene–Vinyl Alcohol Copolymer

Ethylene–vinyl alcohol copolymer (EVOH) is a copolymer of ethylene and vinyl alcohol. The structure is shown in Fig. 9.1. These materials are highly crystalline, and are produced with various levels of ethylene content.

The predominant product line is EVAL Company of America (Kuraray) EVAL™. The general classes of the EVAL™ product line are shown in Table 9.1. The films are often heat treated and oriented. These processes can dramatically affect the properties.

EVOH film has many desirable properties that are summarized:

- Antistatic Properties: since EVOH resin is a highly antistatic polymer, dust is prevented from building up on the package when used as a surface layer.
- Luster and Transparency: EVOH resins produce a high gloss and low haze, resulting in outstanding clarity characteristics. The use of EVOH resin as the outer surface of a package provides excellent sparkle for improved package appearance.
- Printability: with an –OH group in its molecular chain, the EVOH resin surface can be easily printed without special treatment.
- Resistance to Oil and Organic Solvents: EVOH resins resist oils and organic solvents, making them particularly suitable for packaging oily foods, edible oils, mineral oils, agricultural pesticides and organic solvents.
- Weather Resistance: EVOH resins display excellent weatherability. Even when exposed to outdoor conditions, the polymer retains its color, and does not yellow or become opaque. Mechanical property changes are minimal, demonstrating an overall high resistance to weather effects.
- Permeability: EVOH resins offer outstanding gas (oxygen, carbon dioxide, nitrogen and helium) barrier properties and maintain their barrier property over a wide range of humidity. The oxygen-barrier properties of EVOH will vary according

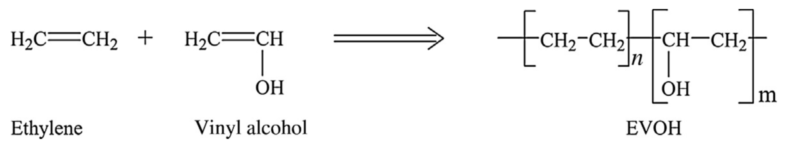


Figure 9.1 The formation and structure of ethylene-vinyl alcohol copolymer (EVOH).

The Effect of UV Light and Weather on Plastics and Elastomers, 3e. http://dx.doi.org/10.1016/B978-1-4557-2851-0.00009-8

Table 9.1 EVAL™ Ethylene–Vinyl Alcohol Copolymer (EVOH) Polymer Grade Series[1]

EVAL™ Series	Ethylene Content (mol%)	General Characteristics
L Series	27	Has the lowest ethylene content of any EVOH, and is suitable as an ultra high-barrier grade in several applications.
F Series	32	Offers superior barrier performance and is widely used for automotive, bottle, film, tube and pipe applications.
T Series	32	Specially developed to obtain good layer distribution in thermoforming, and has become the industry standard for multilayer sheet applications.
J Series	32	Offers thermoforming results even superior to those of T, and can be used for unusually deep-draw or sensitive sheet-based applications.
H Series	38	Has a balance between high barrier properties and long-term run stability. Especially suitable for blown film, special "U" versions exist to allow improved processing and longer running times even on less sophisticated machines.
E Series	44	Has a higher ethylene content that allows for greater flexibility and even easier processing. Different versions have been especially designed for cast and blown films as well as for pipe.
G Series	48	Has the highest ethylene content, making it the best candidate for stretch and shrink film applications.

to the ethylene content in the polymer. Packages containing EVOH resins can effectively retain fragrances and preserve the aroma of the contents within the package. At the same time, undesirable odors are prevented from entering or leaving the package.

Weather Resistance: EVAL™ resins display excellent weatherability. Even when exposed to outdoor conditions, the polymer retains its color, does not yellow or become opaque. Mechanical property changes are minimal, demonstrating an overall high resistance to weather effects.[1]

Kuraray R&D center has studied the UV-resistance or weatherability of EVAL™ films in comparison with other polymers.

The following properties were examined:

- The evolution of the film appearance after outdoor exposure;
- The evolution of the permeability to helium versus the time of exposure;
- The retention of the tensile strength versus the time of exposure; and
- The retention of the elongation at break versus the time of exposure.

The results indicate that EVAL™ resins display excellent UV-resistance. Even when exposed to outdoor conditions, the polymer retains its color. It will not turn yellow or become opaque. Mechanical property changes are minimal, demonstrating an overall high resistance to weather effects.

Manufacturers and trade names: EVAL Company of America (Kuraray) EVAL™, Soarus L.L.C Soarnol®.

9.3 Polyvinyl Chloride

PVC is a flexible or rigid material that is chemically nonreactive. Rigid PVC is easily machined, heat formed, welded and even solvent cemented. PVC can also be machined using standard metal working tools and finished to close tolerances and finishes without great difficulty. PVC resins are normally mixed with other additives such as impact modifiers and stabilizers, providing hundreds of PVC-based materials with a variety of engineering properties.

There are three broad classifications for rigid PVC compounds: Type II, Chlorinated polyvinyl chloride (CPVC) and I. Type II differs from Type I due to greater impact values, but lower chemical resistance. CPVC has greater high-temperature resistance. These materials are considered "unplasticized", because they are less flexible than the plasticized formulations. PVC has a broad range of applications, from high-volume construction related products to simple electric wire insulation and coatings. CAS numbers are 9002-86-2, 8063-94-3, 51248-43-2, and 93050-82-9.

Many of the ingredients contained in typical PVC formulations affect the weatherability. Some ingredients have "weatherable" and "nonweatherable" grades. For example, every PVC article undergoes a certain amount of thermal degradation on the way to becoming a finished product. The amount of thermal degradation depends on the total heat history of the resin, from manufacture to formulation in the extruder. PVC heat stabilizers are typically added. Tin mercaptide heat stabilizers are commonly used for PVC-building products. The mercaptide portion of the stabilizer is detrimental to a long-term weathering of vinyl compounds. Therefore, while it is important to have enough stabilizer present to prevent the thermal decomposition of the PVC resin, an excess should be avoided so that the weathering of the finished product is not affected by an excess of sulfur. Most pigments are defined as "weatherable" or "nonweatherable".

Titanium dioxide, the most widely used pigment, functions also as an opacifier and, most importantly, a UV stabilizer. Impact modifiers are also classified as "weatherable" or "nonweatherable". In the "weatherable" category are acrylics, modified acrylics and chlorinated polyethylene. In the "nonweatherable" category are methyl acrylate-butadiene-styrene and acrylonitrile-butadiene-styrene impact modifiers.

Weathering: Chemical structure of PVC includes three bonds: C−H, C−Cl, and C−C. None of these bonds can be broken by the energy of radiation present in the sunrays. For this reason, PVC is known to be one of more stable polymers in outdoor use. However, PVC is still affected by sunlight exposure. A big reason for this is PVC materials are damaged by processing, mostly by heat used to mold or extrude. The severity of the processing conditions determines the extent of material damage. Heat can lead to dehydrochlorination, which can lead to the formation of single and conjugated double bonds of various lengths that depend on conditions (length and severity of processing). This reaction is shown in Fig. 9.2. Presence of oxygen during processing contributes to further damage because it may oxidize double bonds, create radicals (Fig. 9.3) and then carbonyl groups. On top of that, thermal stabilizers are added to minimize thermal decomposition and these can become photosensitizers.

Typical results of photodegradation include changes in molecular weight, yellowing, loss of mechanical properties and gel formation.

Stabilization: Most important stabilizers:

- **UVA:** 2-hydroxy-4-octyloxybenzophenone;
- **Screener:** carbon black, titanium dioxide and zinc oxide;
- **Acid scavenger:** hydrotalcite;
- **HAS:** 1,3,5-triazine-2,4,6-triamine, *N*,*N‴*[1,2-ethane-diyl-bis[[[4,6-bis[butyl(1,2,6,6-pentamethyl-4-piperidinyl)amino]-1,3,5-triazine-2-yl] imino]-3,1-propanediyl]bis[*N′*,*N″*-dibutyl-*N′*,*N″*-bis(1,2,2,6,6-pentamethyl-4-piperidinyl)-;
- **Phenolic antioxidants:** ethylene-bis(oxyethylene)-bis(3-(5-tert-butyl-4-hydroxy-m-tolyl)-propionate);
- **Phosphite:** trinonylphenol phosphite;
- **Thiosynergist:** 2,2′-thiodiethylene bis[3-(3,5-ditert-butyl-4-hydroxyphenyl)propionate];
- **Optical brightener:** 2,2′-(2,5-thiophenediyl) bis(5-tert-butylbenzoxazole); 2,2′-(1,2-ethylene-diyldi-4,1-phenylene)bisbenzoxazole;
- **Manufacturing and trade names:** Polyone Geon™, Fiberloc™, VPI LLC Mirrex®;
- **Applications and uses:** Building siding, fence and packaging are major markets for PVC. Rigid grades are blown into bottles and made into sheets for thermoforming boxes and blister packs. Flexible PVC compounds are used in food packaging applications because of their strength, transparency, processability, and low raw material cost.

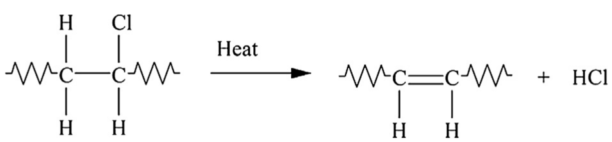


Figure 9.2 Dehydrochlorination of polyvinyl chloride by heat.

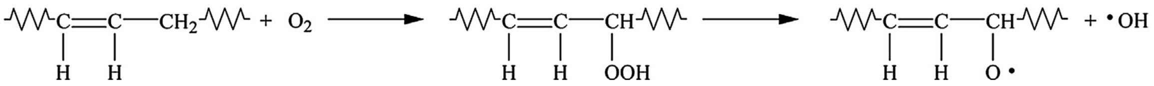


Figure 9.3 Radical generation in polyvinyl chloride.

PVC film can be used in marine/boat windows, recreational vehicle windows, tents and awning windows, industrial curtains/enclosures, spray booths, rack covers, weld screens and partitions, clean rooms, golf cart covers, binder covers, tags and sign holders, menus, apparel and clothing, packaging and bags.

Data for PVC plastics are found in Table 9.2 and Figs 9.4–9.36.

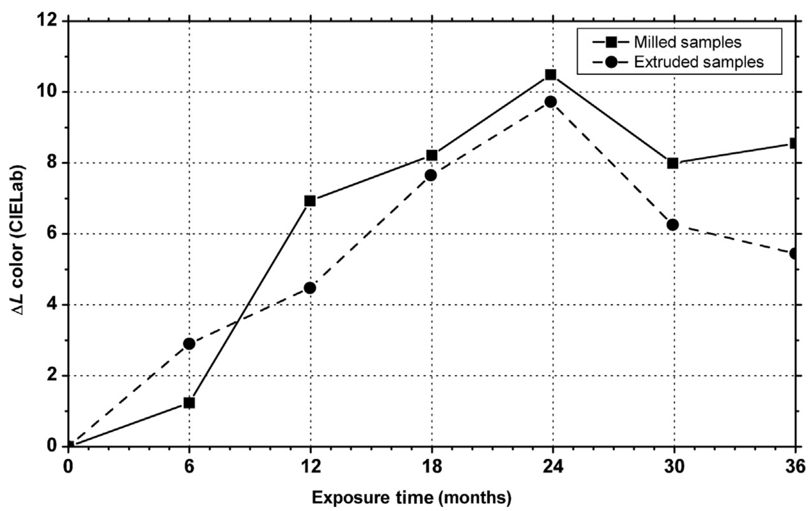
9.4 Polyacrylics

While a large number of acrylic polymers are manufactured, polymethyl methacrylate (PMMA) is by far the most common. The structure of PMMA is shown in Fig. 9.37. Nearly everyone has heard of Plexiglas®. PMMA has two very distinct properties that set the products apart from others. First, it is optically clear and colorless. It has a light transmission of 92%. The 4% reflection loss at each

Table 9.2 Impact Modifiers for PVC Can Affect the Weatherability. Base PVC Formulation for Figs 9.14–9.24[2]

Ingredients	White	Almond
PVC Resin (K65)	100.00	100.00
Thermolite® 340	1.0	1.0
Calcium Stearate	1.5	1.5
Paraffin Wax (165 °F mp)	1.0	1.0
Calcium Carbonate (0.8 μm)	5.0	5.0
Titanium Dioxide	10.0	10.0
Plastistrength® 501	0.5	0.5
Impact Modifier	5.0	5.0
Almond Pigment System	–	3.5

Figure 9.4 Color change in milled and extruded dark-gray PVC samples weathered in Pennsylvania (standard system).[3]



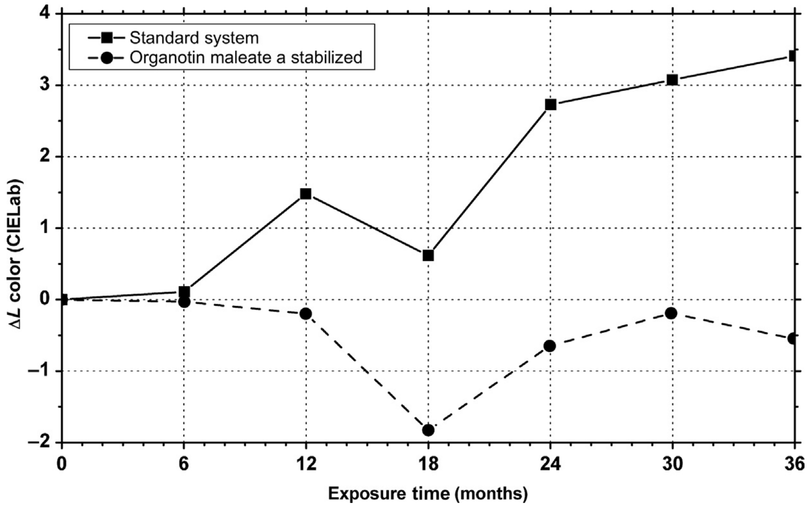


Figure 9.5 Color change with the weathering in Pennsylvania of milled light-gray-blue PVC samples.[3]

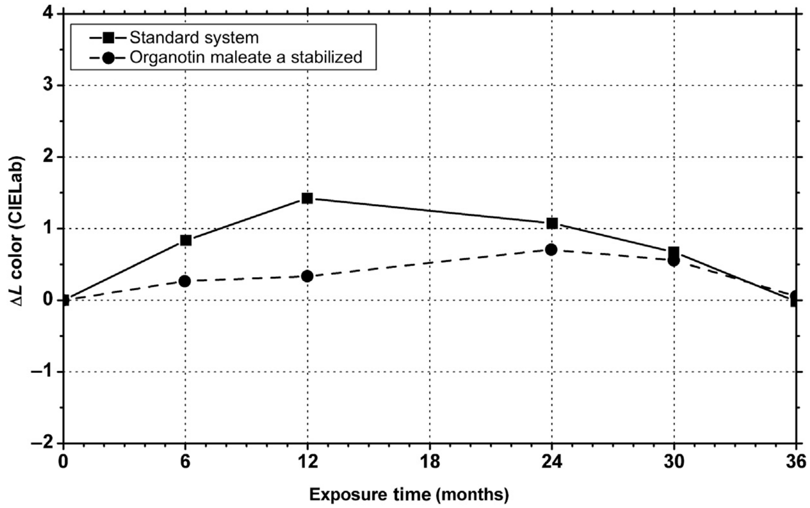


Figure 9.6 Color change with the weathering in South Florida of milled light-gray-blue PVC samples.[3]

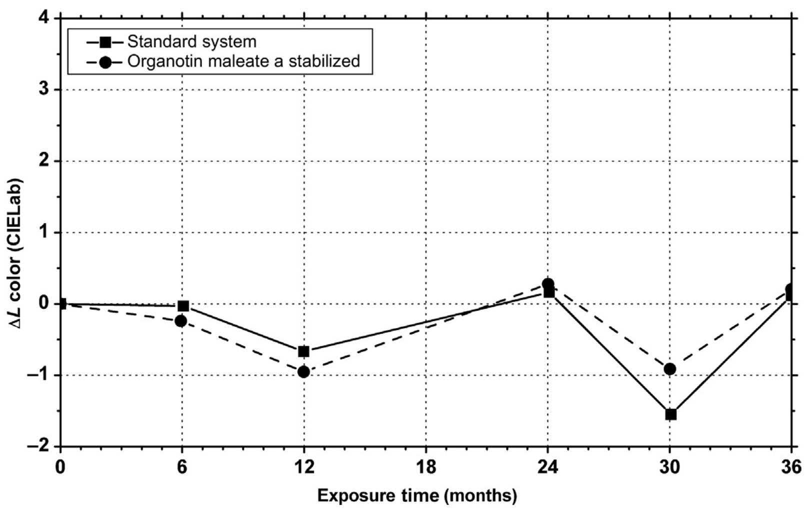


Figure 9.7 Color change with the weathering in Arizona of milled light-gray-blue PVC samples.[3]

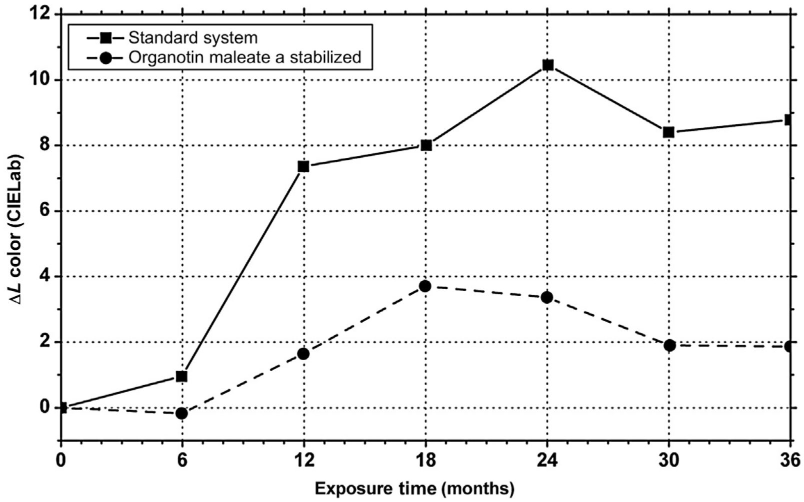


Figure 9.8 Color change with the weathering in Pennsylvania of milled dark-gray PVC samples.[3]

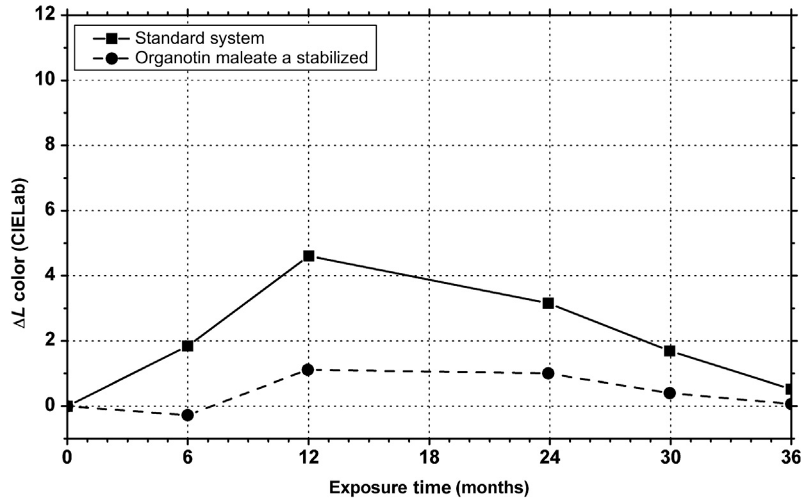


Figure 9.9 Color change with the weathering in South Florida of milled dark-gray PVC samples.[3]

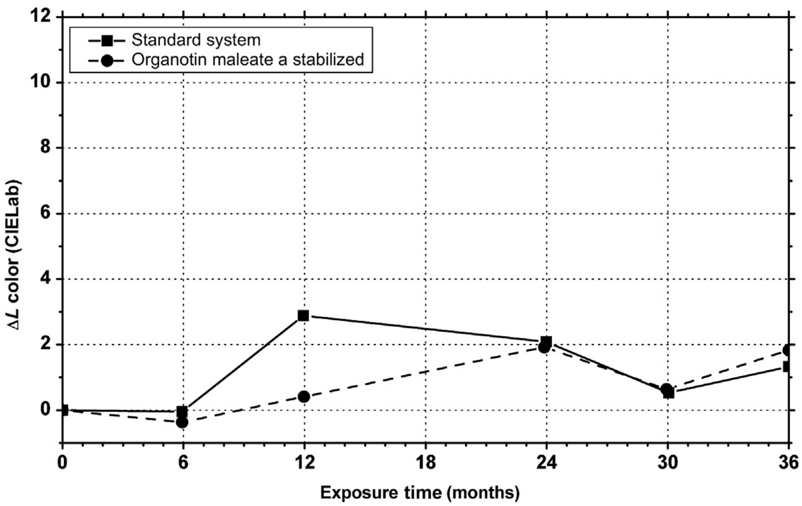


Figure 9.10 Color change with the weathering in Arizona of milled dark-gray PVC samples.[3]

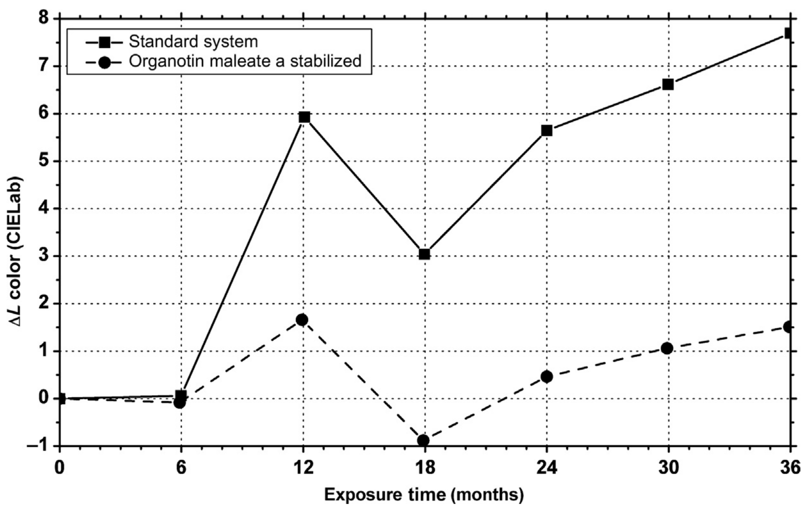


Figure 9.11 Color change with the weathering in Pennsylvania of milled dark-beige PVC samples.[3]

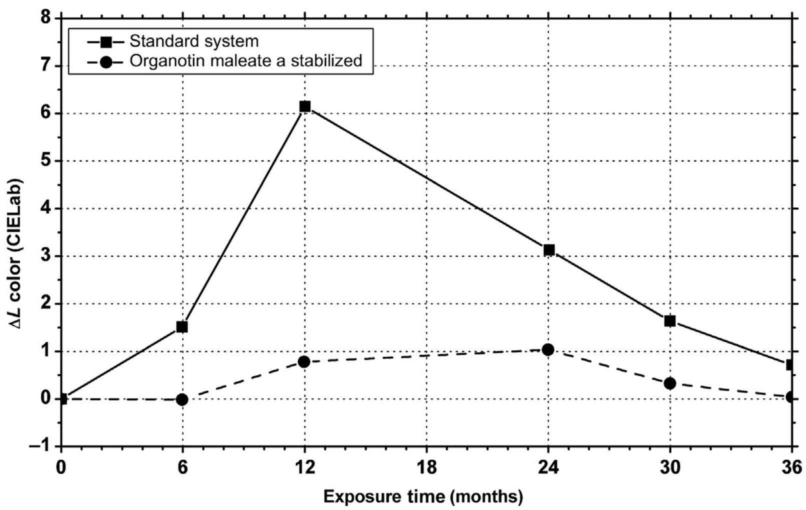


Figure 9.12 Color change with the weathering in South Florida of milled dark-beige PVC samples.[3]

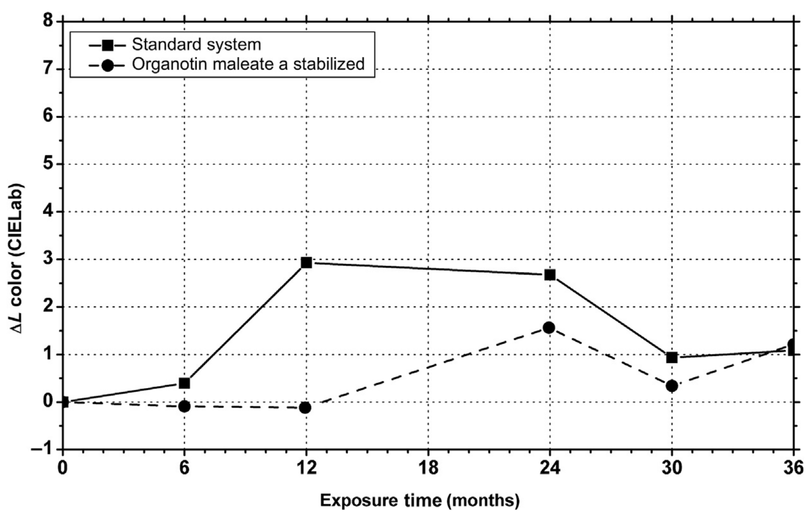


Figure 9.13 Color change with the weathering in Arizona of milled dark-beige PVC samples.[3]

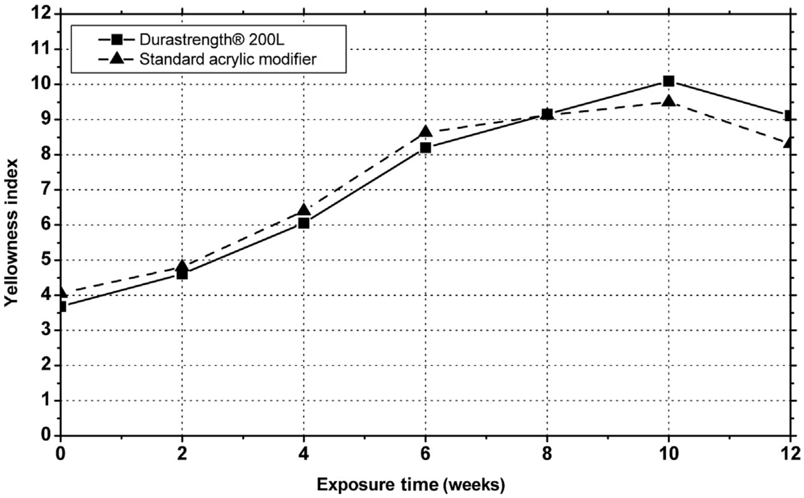


Figure 9.14 Yellowness index of Q-Panel QUV® UVB-313 eathering of Durastrength® 200 vs. acrylic impact modifier in PVC resin formulation (Table 9.2).[2]
Note: QUV® weathering tests were performed on the white samples using UVB-313 bulbs. QUV® conditions were 4 h of light and 4 h of condensation. QUV® temperature was set at 50 °C.

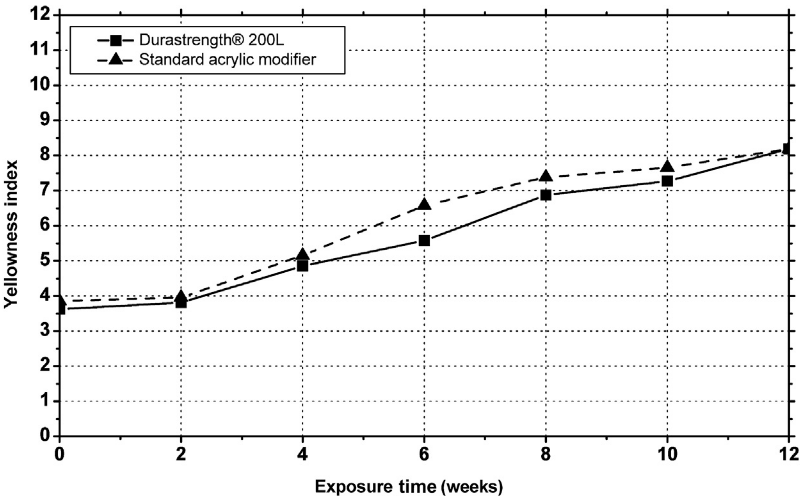


Figure 9.15 Yellowness index of QUV® Q-panel UVB-340 weathering of Durastrength® 200 vs. acrylic impact modifier in PVC resin formulation (Table 9.2).[2]
Note: QUV® weathering tests were performed on the white samples using UVB-313 bulbs. QUV® conditions were 4 h of light and 4 h of condensation. QUV® temperature was set at 50 °C.

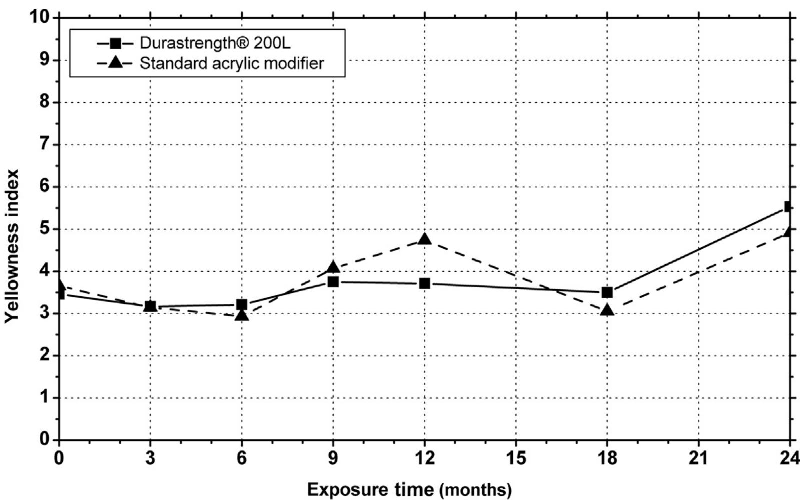


Figure 9.16 Yellowness index of Florida weathering of durastrength® 200 vs. acrylic impact modifier in white PVC resin formulation (Table 9.2).[2]

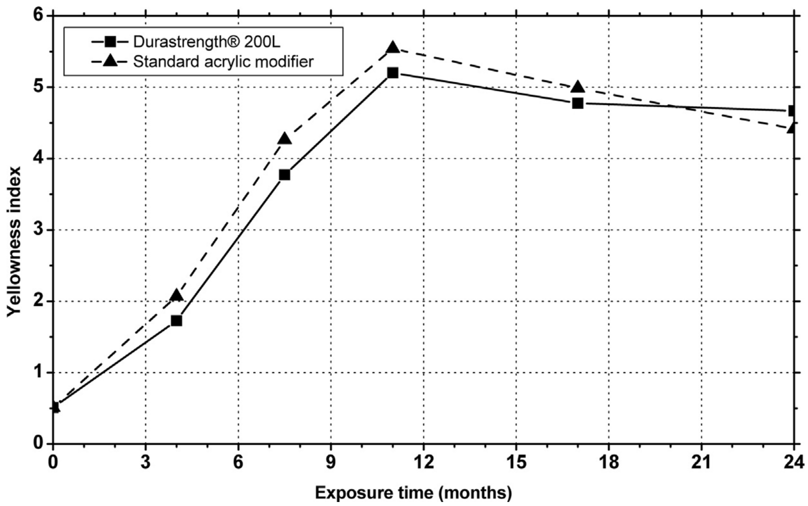


Figure 9.17 Yellowness index of Florida weathering of Durastrength® 200 vs. acrylic impact modifier in almond PVC resin formulation (Table 9.2).[2]

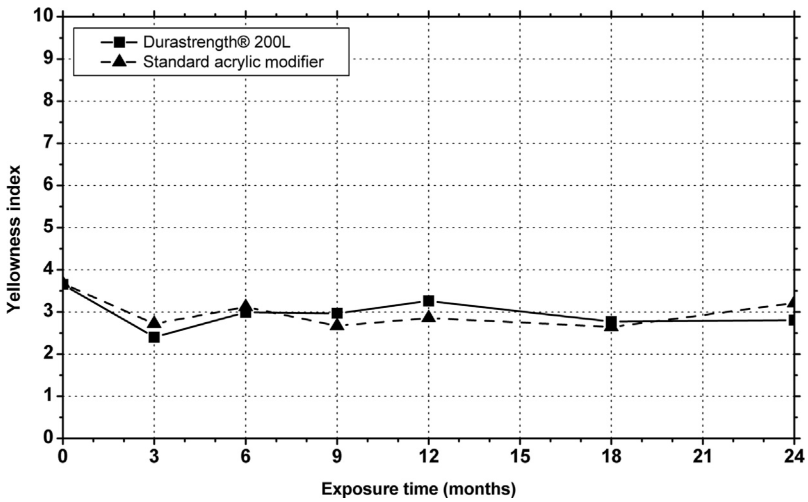


Figure 9.18 Yellowness index of New Jersey weathering of Durastrength® 200 vs. acrylic impact modifier in white PVC resin formulation (Table 9.2).[2]

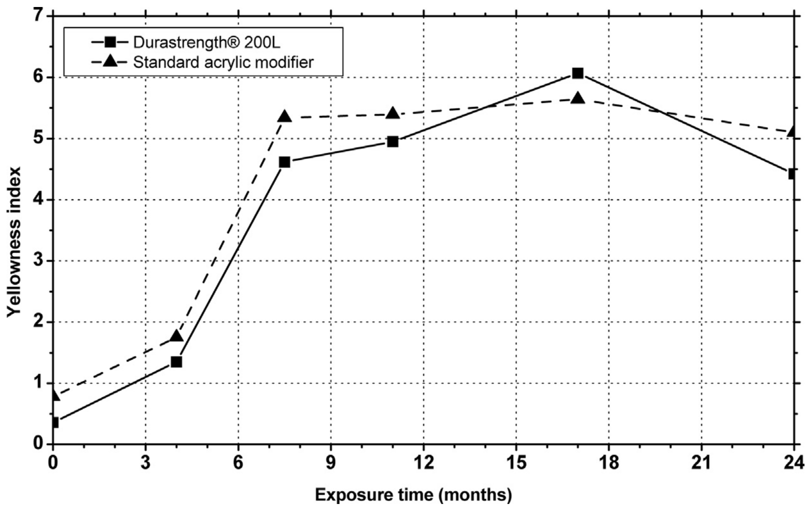


Figure 9.19 Yellowness index of New Jersey weathering of Durastrength® 200 vs. acrylic impact modifier in almond PVC resin formulation (Table 9.2).[2]

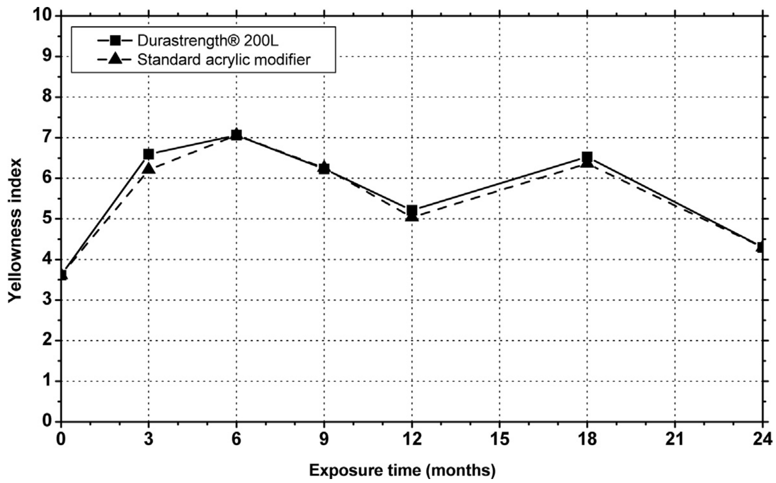


Figure 9.20 Yellowness index of Arizona weathering of Durastrength® 200 vs. acrylic impact modifier in white PVC resin formulation (Table 9.2).[2]

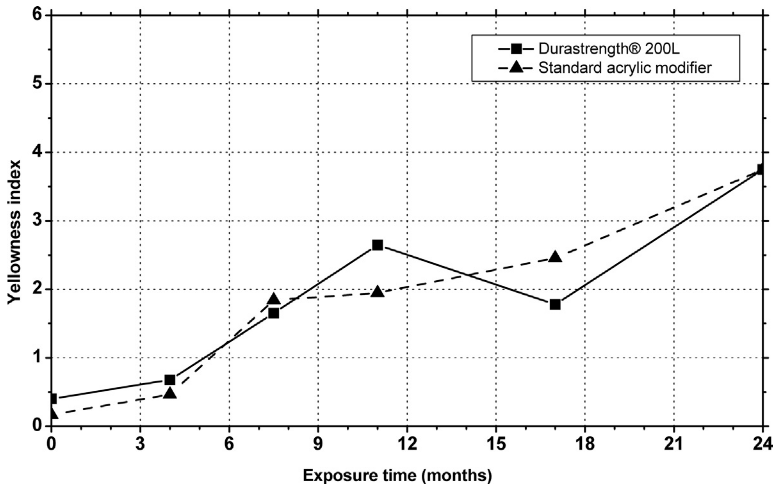


Figure 9.21 Yellowness index of Arizona weathering of Durastrength® 200 vs. acrylic impact modifier in almond PVC resin formulation (Table 9.2).[2]

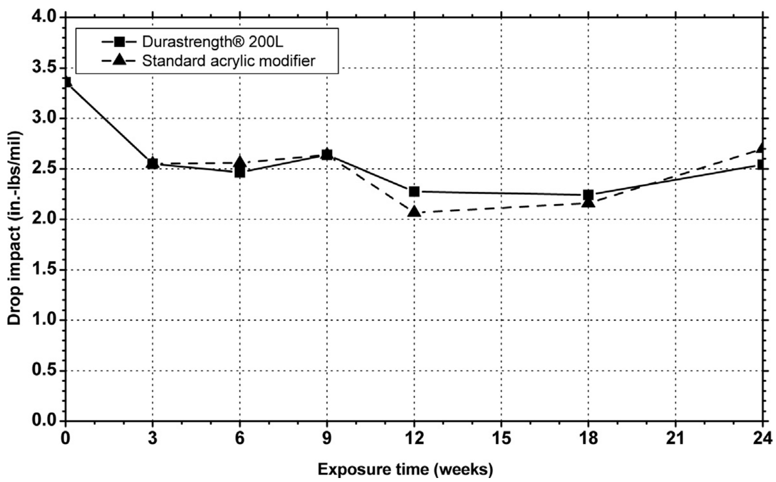


Figure 9.22 Drop impact of Florida weathering of Durastrength® 200 vs. acrylic impact modifier in white PVC resin formulation (Table 9.2).[2]

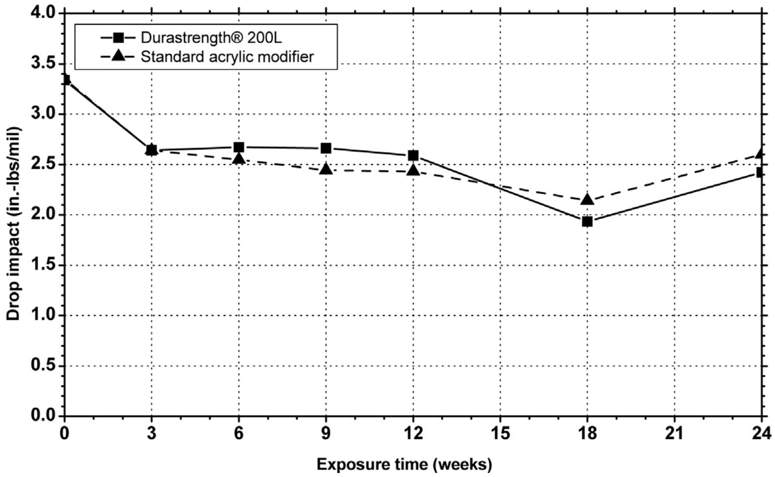


Figure 9.23 Drop impact of New Jersey weathering of Durastrength® 200 vs. acrylic impact modifier in white PVC resin formulation (Table 9.2).[2]

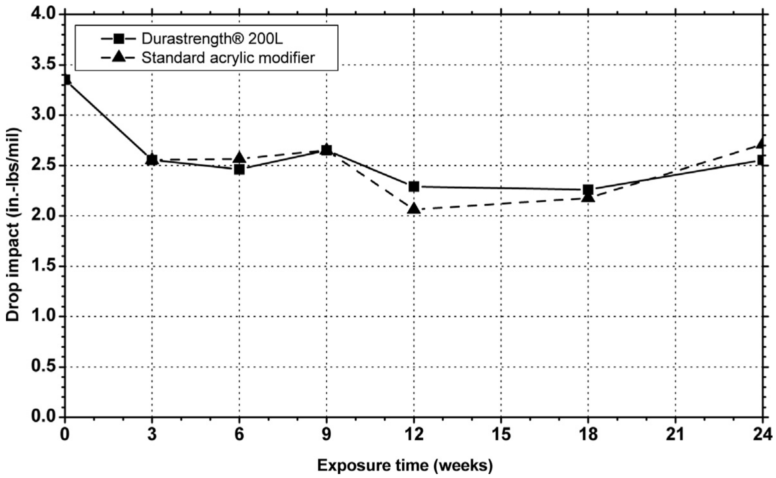


Figure 9.24 Drop impact of Arizona weathering of Durastrength® 200 vs. acrylic impact modifier in white PVC resin formulation (Table 9.2).[2]

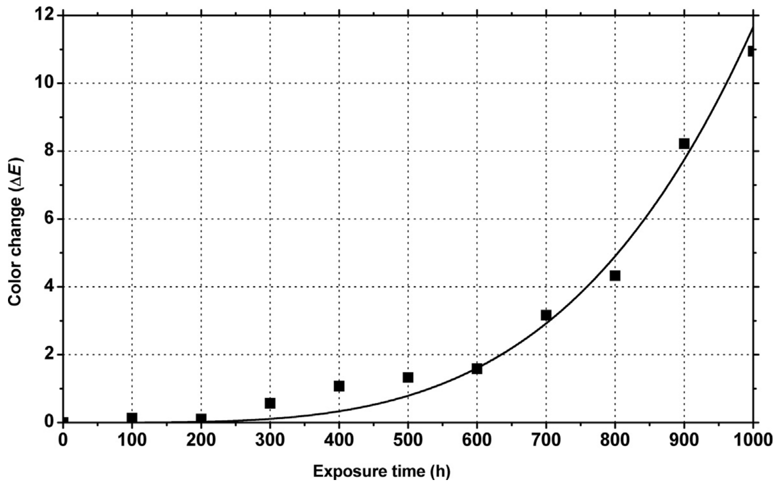


Figure 9.25 Color change vs. QUV® exposure of beige Jain EX-CEL® PVC foam sheet.[4]

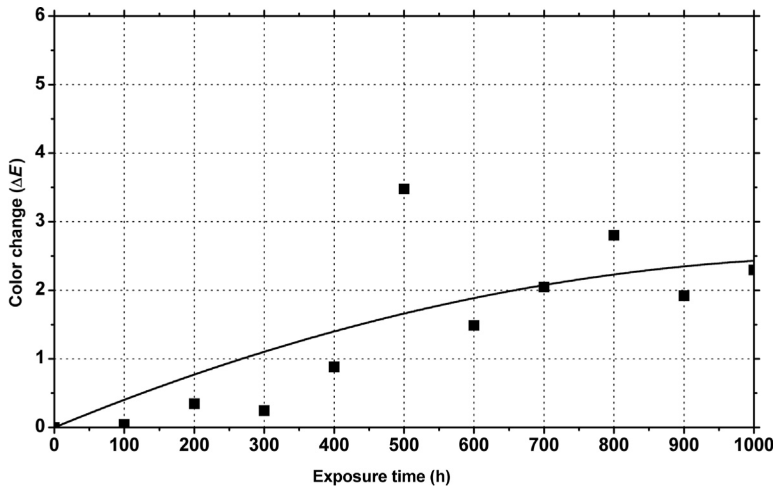


Figure 9.26 Color change vs. QUV® exposure of black Jain EX-CEL® PVC foam sheet.[4]

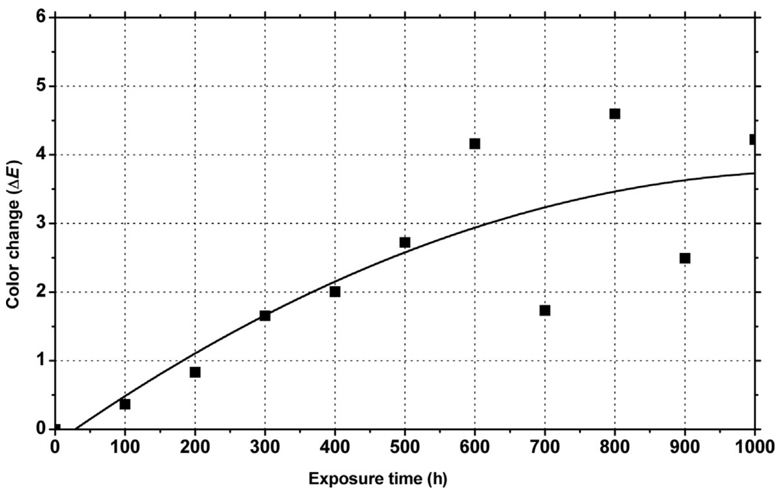


Figure 9.27 Color change vs. QUV® exposure of gold Jain EX-CEL® PVC foam sheet.[4]

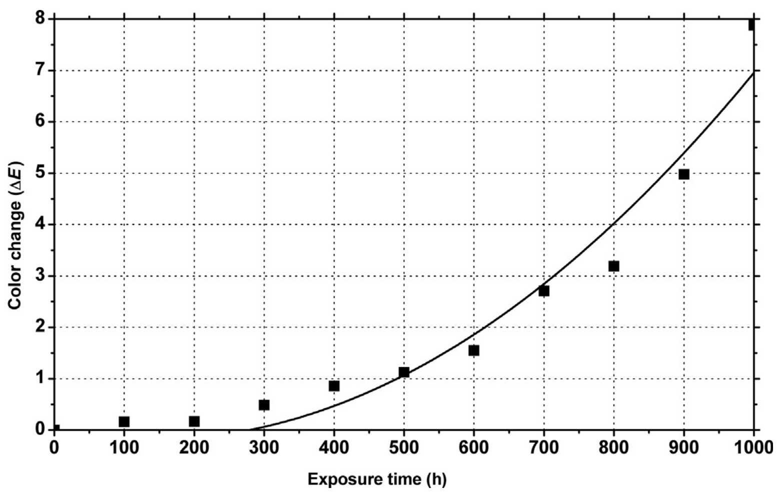


Figure 9.28 Color change vs. QUV® exposure of gray Jain EX-CEL® PVC foam sheet.[4]

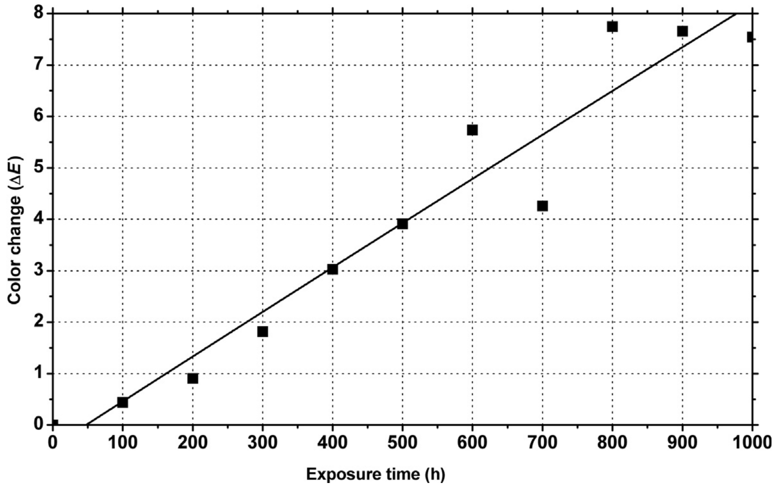


Figure 9.29 Color change vs. QUV® exposure of green Jain EX-CEL® PVC foam sheet.[4]

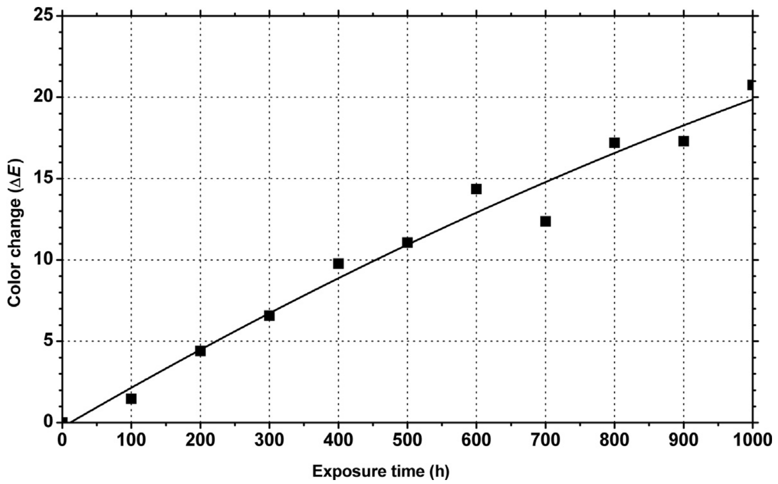


Figure 9.30 Color change vs. QUV® exposure of orange Jain EX-CEL® PVC foam sheet.[4]

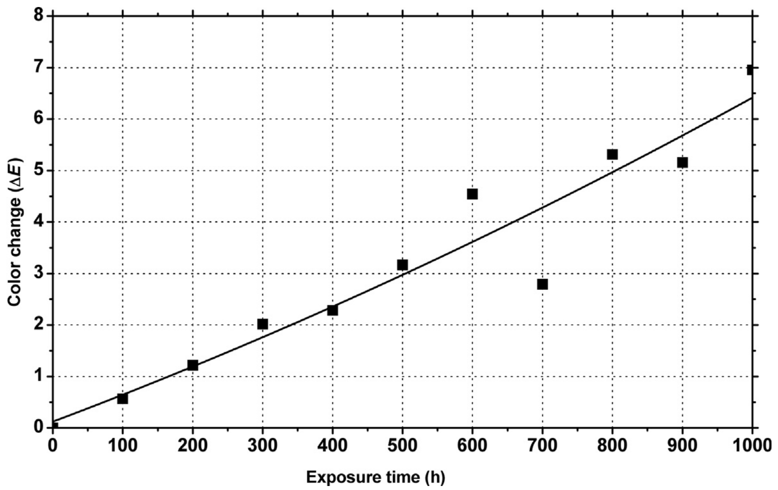


Figure 9.31 Color change vs. QUV® exposure of red Jain EX-CEL® PVC foam sheet.[4]

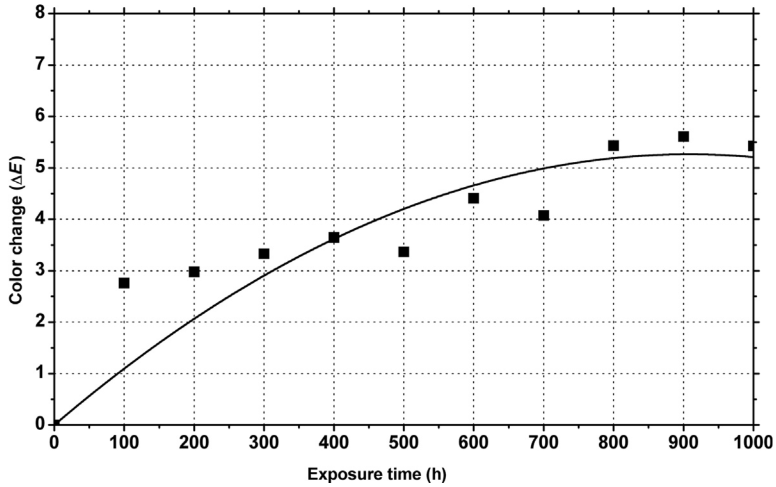


Figure 9.32 Color change vs. QUV® exposure of royal blue Jain EX-CEL® PVC foam sheet.[4]

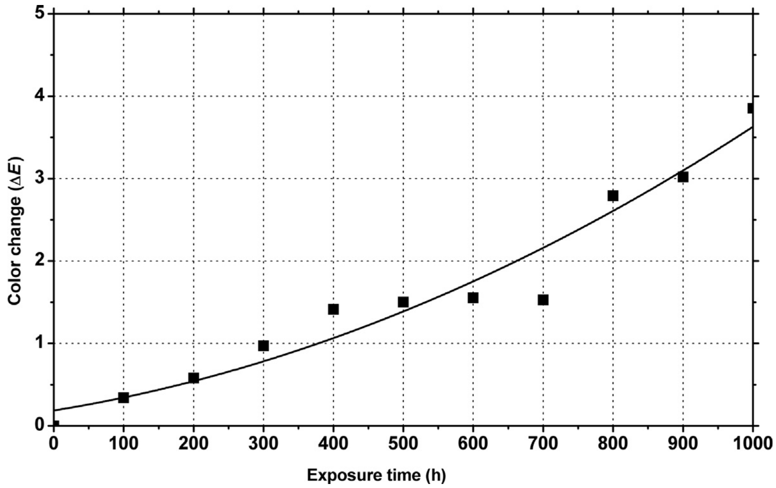


Figure 9.33 Color change vs. QUV® exposure of ruby red Jain EX-CEL® PVC foam sheet.[4]

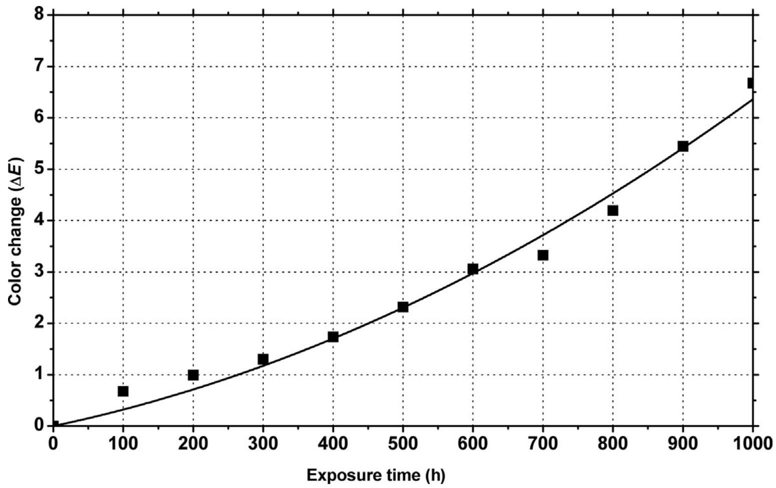


Figure 9.34 Color change vs. QUV® exposure of sky blue Jain EX-CEL® PVC foam sheet.[4]

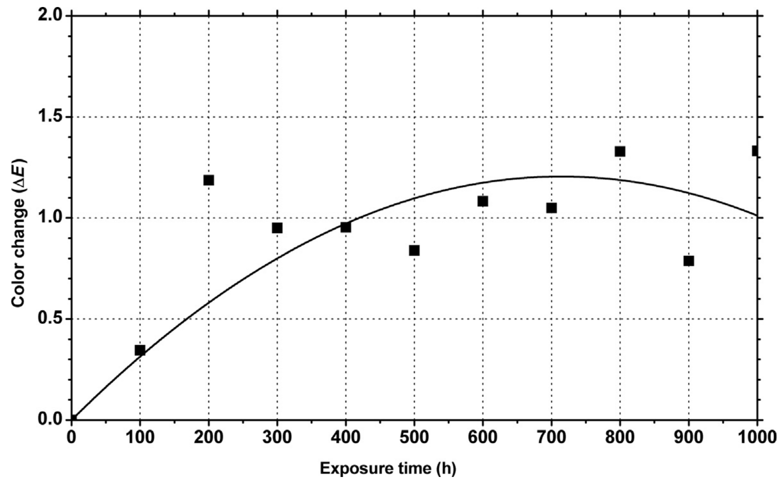


Figure 9.35 Color change vs. QUV® exposure of white Jain EX-CEL® PVC foam sheet.[4]

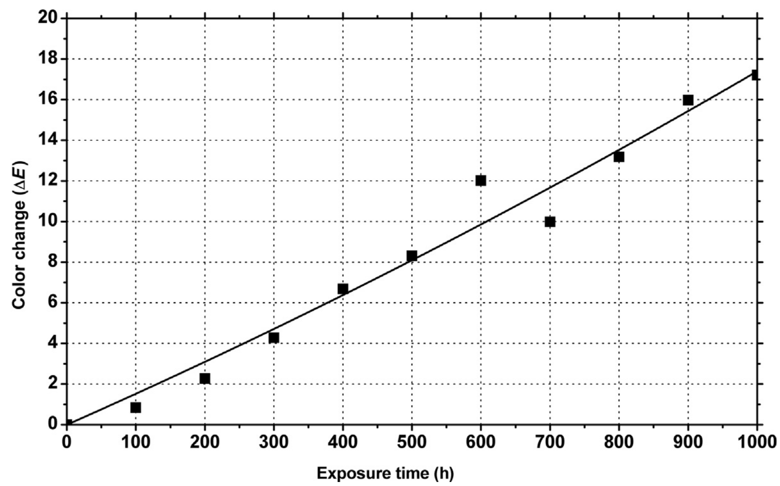


Figure 9.36 Color change vs. QUV® exposure of yellow Jain EX-CEL® PVC foam sheet.[4]

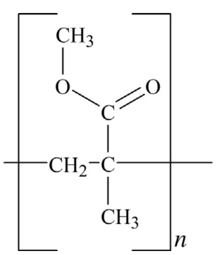


Figure 9.37 Structure of PMMA.

surface in unavoidable. Second, its surface is extremely hard. They are also highly weather resistant. PMMA has a CAS Number of 9011-14-7.

PMMA films show very good abrasion resistance, weather resistance (with a UV absorber) and are absolutely colorless.

Acrylic resins are available as homopolymer (primarily PMMA), copolymer and terpolymer. Each of these is discussed separately in the following sections.

Applications and uses: optical parts, display items, tube and profile extrusion, automotive rear lights and dashboard lenses, extruded sheet, copying equipment and lighting diffusers and UV protective films for exterior laminates.

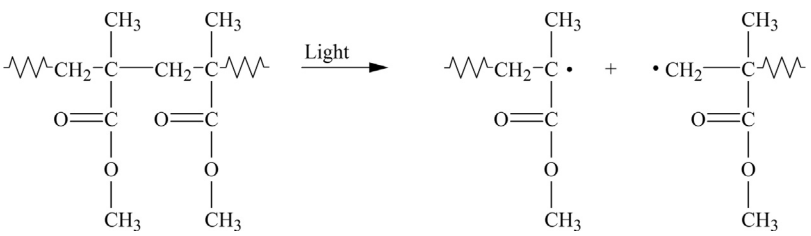


Figure 9.38 Polymethyl methacryate chain scission as a result of UV photolysis.

Weathering: As stated earlier, acrylic polymers may be made from a mixture of a fairly wide variety of monomers. The acrylic polymers all have a similar polymer backbone chemical structure and UV light affects that similarly, though the pendent groups can affect the sensitivity. The pendent groups differ for each monomer and those may have their own chemical response to UV light.

The primary effect on the acrylic polymer backbone is scission as shown in Fig. 9.38.

The cleavage can also occur between the oxygen and the carbonyl, or between the oxygen and the rest of the pendant side groups generating other radicals. In this case, these radicals may form gaseous products such as carbon monoxide (CO) or carbon dioxide (CO_2) as shown in Fig. 9.39.

The polymer radicals shown in the bottom of Fig. 9.39 can cross-link as shown in Fig. 9.40, particularly if no oxygen is present.

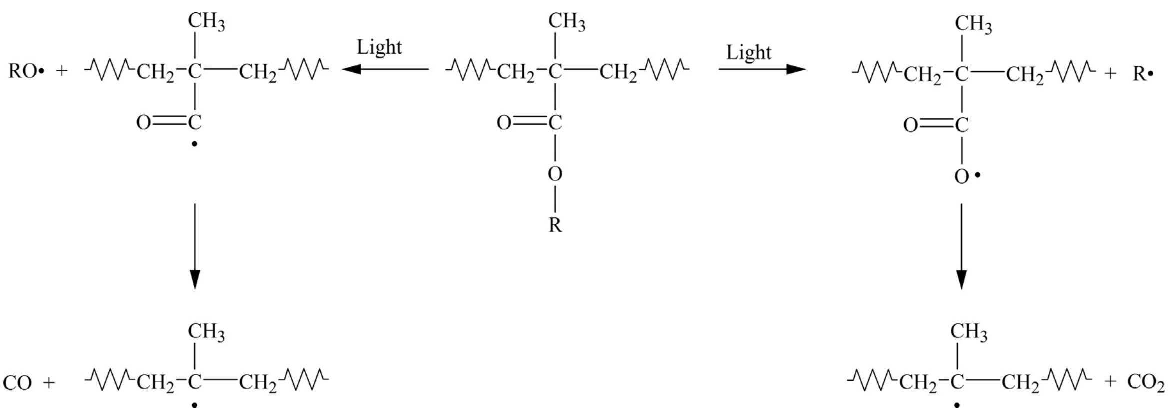


Figure 9.39 Acrylic side-chain scission as a result of UV photolysis can lead to generation of small volatile molecules.

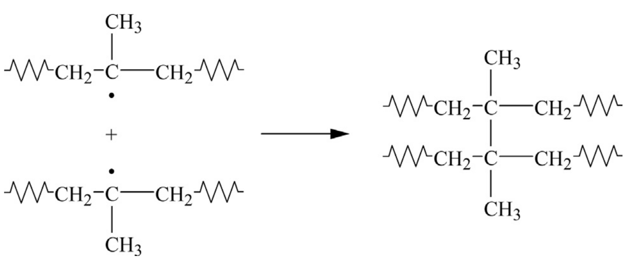


Figure 9.40 One type of cross-linking in acrylics can occur as a result of the photolysis reactions.

The products of photodegradation include hydroperoxides, hydroxyl groups, carbonyl groups, aldehydes, cross-links, formaldehyde, methanol, hydrogen, CO and CO_2.

Stabilization: Example stabilizers:

- **UVA:** 2-hydroxy-4-octyloxybenzophenone;
- **Screeners:** ZnO; cerium oxide, cerium−titanium pyrophosphate;
- **HAS:** bis (1,2,2,6,6-pentamethyl-4-piperidinyl)-[[3,5-bis(1,1-dimethylethyl)-4-hydroxyphenyl] methyl]butylmalonate;
- **Phenolic antioxidant:** isotridecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl) propionate;
- **Optical brightener:** 2,2′-(2,5-thiophenediyl) bis(5-tert-butylbenzoxazole)
- **Manufacturers and trade names:** Lucite International, Lucite Diakon and Perspex®, Evonik Industries LLC Plexiglas®, Acrylite®, Europlex® and Rohaglas®, Arkema Oroglas, Rowland Technologies, Inc. SolaTuf®, Mitsubishi Rayon Co., Ltd Shinkolite®, Altuglas International Plexiglas; Novacor.

Data for acrylic plastics are found in Tables 9.3−9.5 and Figs 9.41−9.49.

9.5 Ionomers

An ionomer is a polymer that comprises repeat units of both electrically neutral repeating units and a fraction of ionized units. Only ethylene acrylic acid copolymer is discussed in this section.

Starting with selected various grades of copolymers such as ethylene/methacrylic acid, manufacturers add zinc, sodium, lithium, magnesium or other metal salts. Acid neutralization (for instance of the methacrylic acid in an ethylene methacrylic acid copolymer) results in the formation of ion clusters (hence the general term, "ionomer") within the resulting polymer matrix. The chemical structure of this process is shown in Fig. 9.50.

Table 9.3 Cyro Acrylite® General Purpose F Acrylic Sheet after Xenon Arc-Accelerated Weathering[5]

Features	Red 2149-4	Orange 3141-5	Green 564-9
Number of years of Florida outdoor weathering exposure required for the material to undergo significant changes in color or edge appearance			
Years	3−4	1−2	0.5

Table 9.4 Cyro Acrylite® General Purpose FL Acrylic Sheet after Xenon Arc-Accelerated Weathering[5]

Features	Red 2149-4	Orange 3105-5
Number of years of Florida outdoor weathering exposure required for the material to undergo significant changes in color or edge appearance		
Years	5	3

Table 9.5 Cyro Acrylite® General Purpose FLW Acrylic Sheet after Xenon Arc-Accelerated Weathering[5]

Features	Red 2130-2	Dark Red 2135-1	Orange 3127-2	Yellow 4073-8	Green 5143-8	Blue 6157-9
Number of years of Florida outdoor-weathering exposure required for the material to undergo significant changes in color or edge appearance						
Years	5	1−2	3	1−2	0.5	3

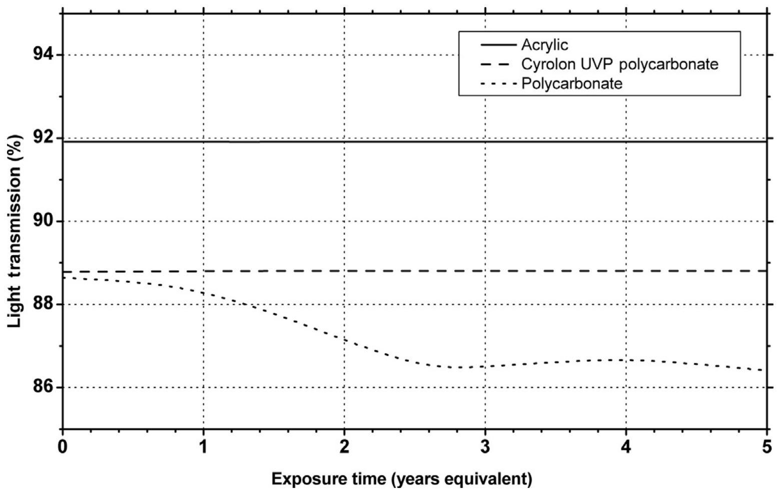


Figure 9.41 Light transmission for acrylic, Cyrolon® UVP polycarbonate sheet, and polycarbonate after weathering exposure. *Note: 1/8″ sheet (nominal) EMMAQUA accelerated weathered (AZ), DSET Laboratories Inc. as per ASTM D1003.*[6]

The ionomer resins incorporate many of the performance features of the original ethylene-based copolymers, such as chemical resistance, melting range, density and basic processing characteristics. However, with the alteration forming the ionomer resin, the performance is significantly enhanced in such areas as:

- Low-temperature impact toughness;
- Abrasion/scuff resistant
- Chemical resistance;
- Transparency/clarity
- Melt strength;
- Direct adhesion of epoxy and polyurethane finishes, to metal, glass and natural fibers by heat lamination.

Weathering Properties: Ionomers have poor weathering resistance and must be stabilized if they are exposed to sunlight or outdoor weather.

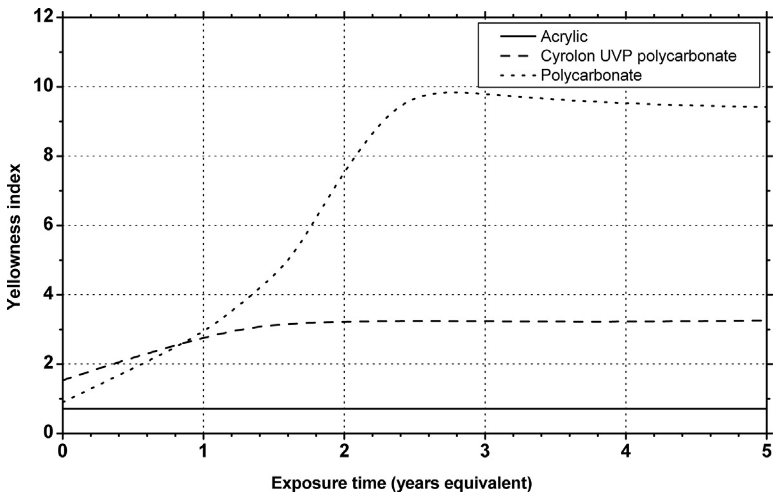


Figure 9.42 Yellowness index for acrylic, Cyrolon® UVP polycarbonate sheet, and polycarbonate after weathering exposure. *Note: 1/8″ sheet (nominal) EMMAQUA accelerated weathered (AZ), DSET Laboratories Inc. as per ASTM D1925.*[6]

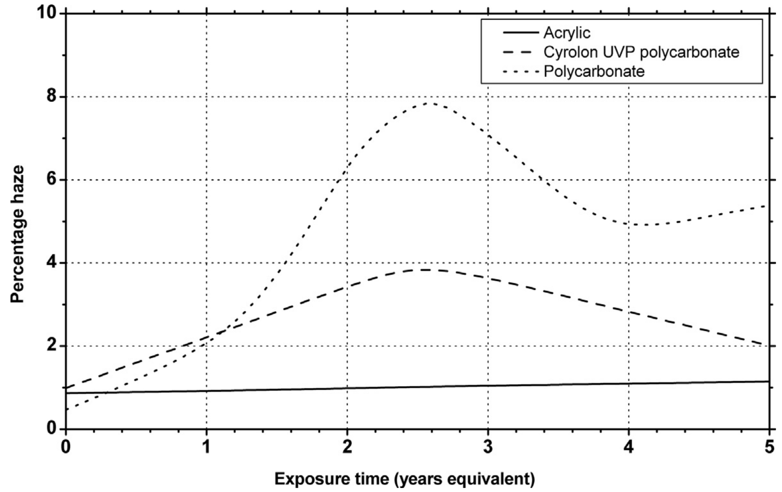


Figure 9.43 Percentage haze for acrylic, Cyrolon® UVP polycarbonate sheet, and polycarbonate after weathering exposure. *Note: 1/8″ sheet (nominal) EMMAQUA accelerated weathered (AZ), DSET Laboratories Inc. as per ASTM D1003.*[6]

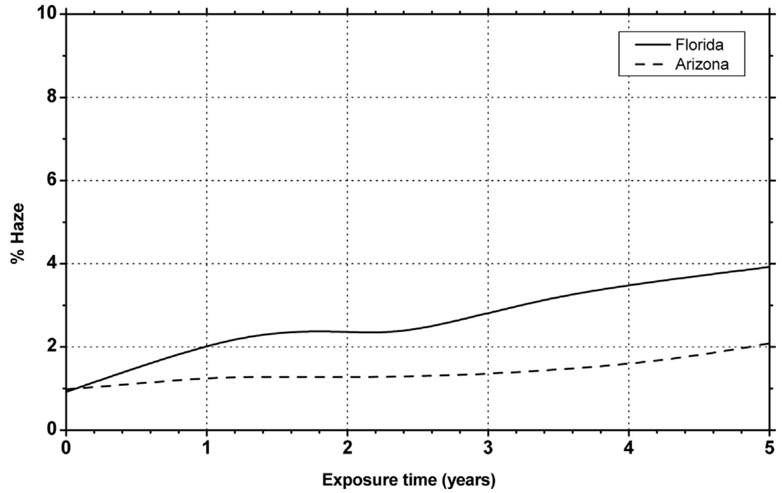


Figure 9.44 Haze of Plexiglas® V825 after Florida and Arizona weathering.[7]

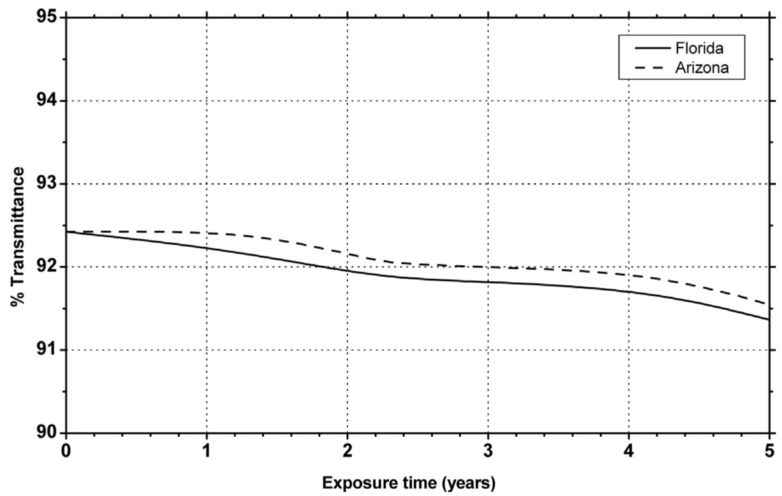


Figure 9.45 Luminous transmittance of Plexiglas® V825 after Florida and Arizona weathering.[7]

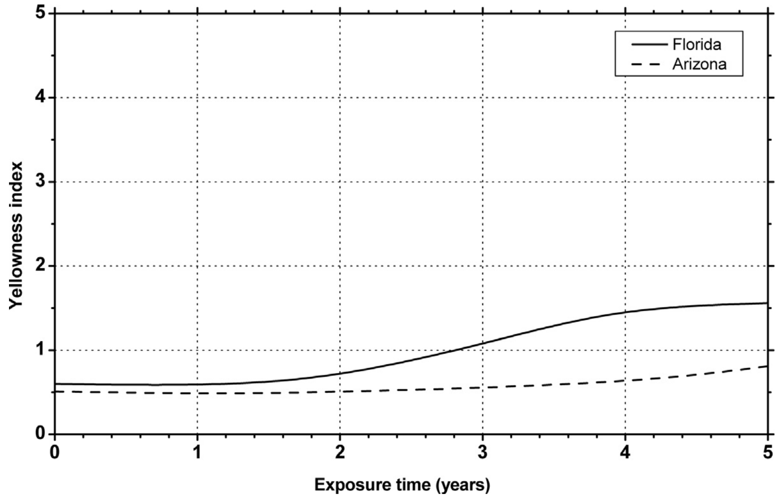


Figure 9.46 Yellowness index of Plexiglas® V825 after Florida and Arizona weathering.[7]

Outdoor weathering experience has confirmed the outstanding performance of UV-stabilized DuPont Surlyn®. Parts containing carbon black have been in service and exposed to all types of weather for over 10 years with no significant change in physical integrity or appearance. Other pigmented parts have retained their physical integrity and appearance after five years of exposure to an Arizona environment.[10]

The six basic rules for UV protection in ionomers are[10]:

1. Use zinc-type ionomers for a more stable base and long-term performance.
2. It is essential to use antioxidants with all stabilizer systems.
3. Both sodium- and zinc-type ionomers may be modified for protection from occasional exposure to sunlight (less than 200 h/year).
4. For maximum retention of tensile and impact properties, a combination of an antioxidant (UV absorber) and an energy quencher must be used. In pigmented parts, this should not present any limitations in product appearance. However, in clear, transparent applications, the presence of currently recommended UV

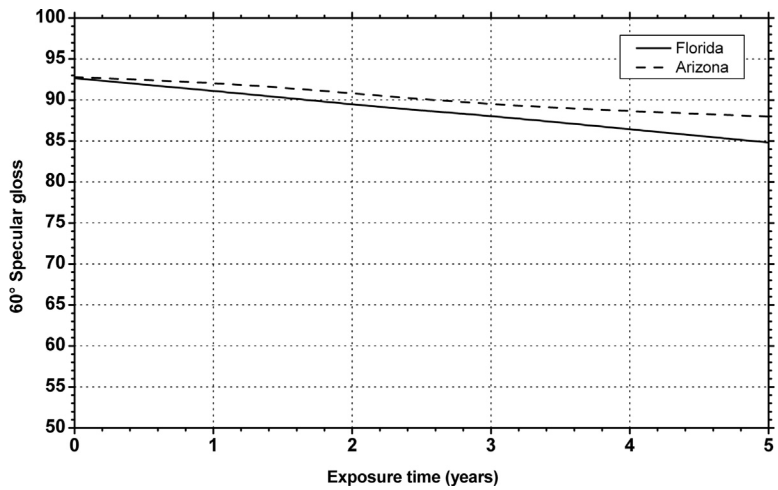


Figure 9.47 Surface gloss of Plexiglas® V825 after Florida and Arizona weathering.[7]

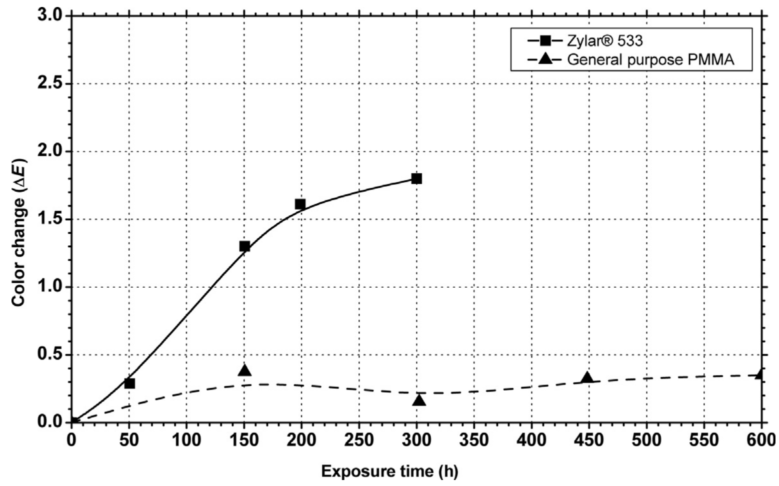


Figure 9.48 Color change, E, after Atlas Weather-Ometer® exposure of Ineos Nova Zylar® 533 clear impact modified UV stabilized acrylic copolymer and general purpose PMMA.[8]
Note: ASTM D4459-99 testing was performed in accordance with Method G155-00a (Table 9.3, Cycle #4) on an Atlas Ci65A Weather-Ometer® at a xenon irradiance of 0.30W/m² and a black panel temperature of 55 °C.

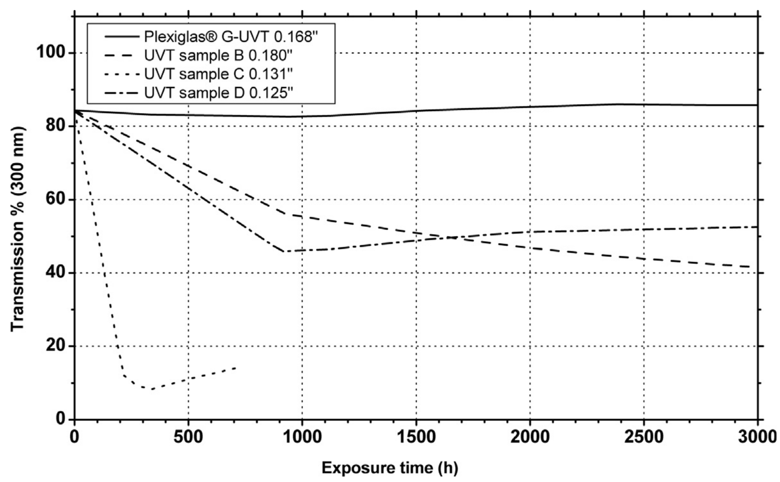


Figure 9.49 UV transmission at 300 nm for Plexiglas® G-UVT acrylic sheet and various commercial UVT samples as a function of UVB exposure.[9]
Note: Reference test method: ASTM G-154.

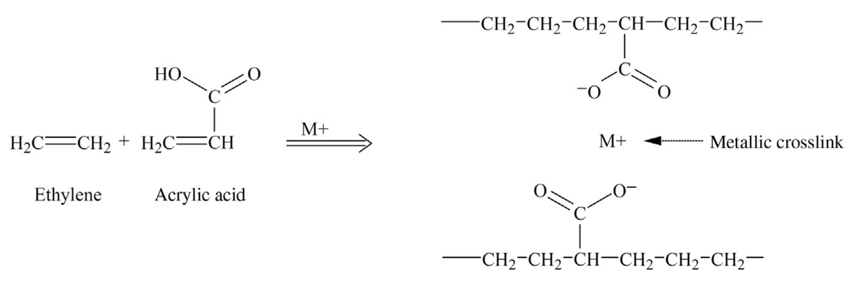


Figure 9.50 Structure of ethylene acrylic acid copolymer ionomers.

Table 9.6 Physical Properties and Visual Appearance after Florida and Arizona Outdoor Weathering for UV-Stabilized DuPont Surlyn® Ionomer[10]

Grade	Surlyn® 9520	Surlyn® 9520	Surlyn® 9520	Surlyn® 9520	Surlyn® 9910	Surlyn® 8528	Surlyn® 8920
Material Composition (wt%)							
Irganox® 1010				0.3	0.3		0.3
Santonox R	0.2	0.2	0.2			0.2	
Cyasorb® 531		1.0	1.0				
Tinuvin® 770				0.5	0.5		0.5
Argent Pigment			0.2				
Black Pigment	5.0					5.0	
Bronze Pigment		0.5					
Ion type	Zinc	Zinc	Zinc	Zinc	Zinc	Sodium	Sodium
Exposure conditions							
Exposure Location	Florida	Florida	Florida	Florida	Arizona	Florida	Florida
Exposure Time (Days)	1095	1825	913	913	365	1095	365
Properties retained (%)							
Physical Properties	>90	No change apparent, but no quantitative test data	87	No change apparent, but no quantitative test data	No change apparent, but no quantitative test data	No change apparent, but no quantitative test data	50
Surface and appearance							
Visual Appearance	Slightly dull	Slightly dull	Slightly dull	Slight haze	No visible change	Slightly dull	Slight haze

Note: (1) Irganox® 1010 (antioxidant—BASF). (2) Santonox® R (antioxidant—Monsanto). (3) Cyasorb® 531 (UV absorber—Cytec). (4) Tinuvin® 770 (hindered amine light stabilizer—BASF).

absorbers may create unacceptable levels of yellowness, depending upon the part thickness.

5. When maximum retention of clarity, surface brilliance and absence of color formation are the primary end-use considerations, a combination of an antioxidant and an energy quencher is recommended. In this system, tensile and impact characteristics will decline to one-third the level of natural grade properties.
6. In either of the above cases (4 and 5), addition of 2−10 ppm of Monastral blue or violet (transparent pigment) will neutralize the observation of slightly yellow tints.

Manufacturers and trade names: DuPont™ Surlyn® and Bexloy® (ethylene-methacrylic acid); Exxon Iotek™ (Ethylene-acrylic acid); Goodrich Hycar® (butadiene-acrylic acid)-discontinued; Dow Amplify™ (Ethylene-acrylic acid).

Data for ionomer plastics are found in Tables 9.6−9.10.

Table 9.7 Physical Properties and Visual Appearance after Accelerated Weathering in an Atlas Weather-Ometer® for Zinc Ion Type UV-Stabilized DuPont Surlyn® Ionomer[10]

Material Grade	**Surlyn® 9910**	**Surlyn® 9910**	**Surlyn® 9910**	**Surlyn® 9910**	**Surlyn® 9910**	**Surlyn® 9720**	**Surlyn® 9020**	**Surlyn® 9020**	**Surlyn® 9020**
Features								Unstabilized	Unstabilized
Material Composition (wt%)									
Irganox® 1010	0.1	0.1	0.1	0.1	0.1		0.1		
Santonox R						0.2			
Cyasorb® 531						0.4	0.2		
Tinuvin® 328				0.3	0.3				
Tinuvin® 770	0.3	0.6	0.6	0.3	0.3		0.2		
Orange Pigment							0.2		
Sulfur Pigment						2.0			
Ion type	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc
Exposure conditions									
Exposure Time (Days)	125	208	125	208	125	340	42	4	42
Properties retained (%)									
Physical Properties	22	25	29	33	38	46	No change apparent, but no quantitative test data	No change apparent, but no quantitative test data	Poor
Surface and appearance									
Visual Appearance	Moderately yellow	Slightly yellow, slightly crazed	Slightly yellow	Slightly yellow, slightly crazed	Slightly yellow	No visible change	Slightly dull	No visible change	Yellow, crazed

Note: (1) Filtered carbon arc. (2) 60° dry, 50° wet; Irganox® 1010 (antioxidant—BASF). (3) Santonox® R (antioxidant—Monsanto). (4) Cyasorb® 531 (UV absorber—Cytec). (5) Tinuvin® 328 (UV absorber—BASF). (6) Tinuvin® 770 (hindered amine light stabilizer—BASF).

Table 9.8 Physical Properties and Visual Appearance after Accelerated Weathering in an Atlas Weather-Ometer for Zinc Ion Type UV- and Antioxidant-Stabilized, Pigmented DuPont Surlyn® 9520 Ionomer[10]

Material Composition								
Irganox® 1010			0.2	0.21	0.2			
Santonox R	0.2	0.2					0.2	0.2
Cyasorb® 531			1.0		0.1		1.0	1.0
Tinuvin® 770				0.2	0.1			
Argent Pigment								0.2
Black Pigment	2.7	5.0						
Bronze Pigment							0.5	
Ion Type	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc
Exposure Conditions								
Exposure Time (Days)	292	67	58	58	58	58	67	67
Properties Retained (%)								
Physical Properties	89	>90	100	80	100	50	No change apparent, but no quantitative test data	87
Surface and appearance								
Visual Appearance	Slightly dull	Slightly dull	Good	Good	Good	Slightly crazed	Slightly dull	Slightly dull

Note: (1) Filtered carbon arc. (2) 60° dry, 50° wet. (3) Irganox® 1010 (antioxidant—BASF). (4) Santonox® R (antioxidant—Monsanto). (5) Cyasorb® 531 (UV absorber—Cytec). (6) Tinuvin® 770 (hindered amine light stabilizer—BASF).

Table 9.9 Physical Properties and Visual Appearance after Accelerated Weathering in an Atlas Weather-Ometer® for Sodium Ion Type UV- and Antioxidant-Stabilized, Pigmented DuPont Surlyn® Ionomer[10]

Grade	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8528**	**Surlyn® 8920**	**Surlyn® 8920**	**Surlyn® 8920**	**Surlyn® 8920**
Features							Unstablized				Unstablized	Unstablized
Material Composition (wt%)												
Lrganox 1010				0.2	0.2	0.2				0.1		
Santonox R	0.2	0.2	0.2									
Cyasorb® 531			1.0		0.1	02				0.2		
Tinuvin® 770				0.2	0.1	0.1		1.0	1.0	0.2		
Black Pigment	5.0	2.7										
Orange Pigment						0.1				0.2		
Ion Type	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium
Exposure Conditions												
Exposure Time (Days)	67	292	58	58	58	58	58	100	67	42	4	42
Properties Retained (%)												
Physical Properties	No change apparent, but no quantitative test data	100	100	60	65	75	25	No change apparent, but no quantitative test data	No change apparent, but no quantitative test data	No change apparent, but no quantitative test data	No change apparent, but no quantitative test data	0
Surface and Appearance												
Visual Appearance	Slightly dull	Slightly dull	Yellow	Good	Yellow	No visible change	Yellow, crazed	Slight haze	No visible change	Slightly dull	No visible change	Yellow, crazed

Note: (1) Filtered carbon arc. (2) 60° dry, 50° wet; Irganox® 1010 (antioxidant—BASF). (3) Santonox® R (antioxidant—Monsanto). (4) Cyasorb® 531 (UV absorber—Cytec). (5) Tinuvin® 770 (hindered amine light stabilizer—BASF).

Table 9.10 Physical Properties and Visual Appearance after Accelerated Weathering in a QUV® Weather-Ometer® for Zinc Ion Type DuPont Surlyn® 9910 Ionomer[10]

Features				**Unstabilized**					
Material Composition (wt%)									
Irganox® 1010	0.1	0.1	0.1	0.2	0.2	0.1	0.1		
Cyasorb® 531	02	0.5							
Tinuvin® 328	0.3								
Tinuvin® 770	0.3	0.2	0.2	0.2	02	0.6	0.3		
Ion Type	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc	Zinc
Exposure Conditions									
Exposure Time (Days)	125	125	125	83	84	83	84	125	125
Properties Retained (%)									
Physical Properties	22	46	66	0	28	18	36	15	70
Surface and appearance									
Visual Appearance	Moderately yellow	Slightly yellow	Slight haze	Crazed	Crazed	Good	Good	Slightly yellow, slightly crazed	Slightly yellow, slightly crazed

Note: (1) Filtered carbon arc. (2) 8 h at 71 °C dry, 4 h at 48 °C wet. (3) Irganox® 1010 (antioxidant—BASF). (4) Santonox® R (antioxidant—Monsanto). (5) Cyasorb® 531 (UV absorber—Cytec). (6) Tinuvin® 770 (hindered amine light stabilizer—BASF).

References

1. EVAL™* Ethylene Vinyl Alcohol Copolymer Explained, EVAL™ Europe. 2002.
2. Durastrength® Acrylic Impact Modifier. In: *Siding topcoat and window profile yields maximum impact and color retention*. Arkema; 2005.
3. Girois Stephane, Schipper Peggy S. *Enhanced weatherability of exterior PVC building products*. Arkema Inc.; 900 First Ave King Prussia PA, 19406; 2004.
4. *PVC sheets weatherability.* Jain Americas, Inc.; 2008.
5. *Acrylite® GP acrylic sheet fluorescent colors and weatherability.* CYRO Industries; 2005.
6. *Comparing the weatherability of Acrylite sheet vs. polycarbonate sheet*. CYRO Industries; 2005.
7. *Plexiglas® acrylic molding resin*. The Arkema Group; 2005.
8. UV stability of NAS® And ZYLAR®. Nova Chemicals; 2005.
9. *Plexiglas® G-UVT high ultraviolet (UV) transmitting cell cast acrylic sheet, Altuglas International*. Arkema; 2005.
10. Resistance to ultraviolet irradiation for Surlyn ionomer resins, supplier technical report (E-78693−103520/A). DuPont Company; 1986.