Acrylic Materials in PV Applications:

Making an Informed Choice

Evonik Cyro LLC
Acrylic Polymers
Peter Colburn

NREL PV Reliability Workshop Feb 17, 2011

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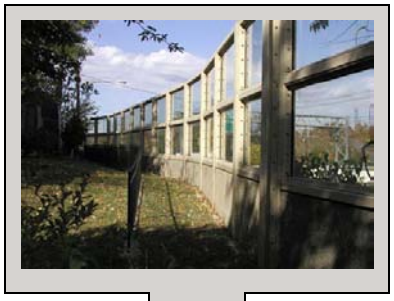
Topics

1. Outdoor Acrylic Applications
2. What is Acrylic?
3. UV Absorption Characteristics
4. Degradation Mechanisms
5. Protection Systems
6. Weathering Performance

Acrylic Use History



1930 1950 1970 1990 2010

Reliability: Proven Weatherability of Acrylic

Automotive

- Lighting
- Pillar covers
- Mirror housings

Reliability: Proven Weatherability of Acrylic

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Architectural Glazing

Limited (10 Year) Warranty

Acrylite® ACRYLIC SHEET

Reliability: Proven Weatherability of Acrylic

Aircraft Glazing

- Helicopter glazing
- General aircraft glazing
- Commercial aircraft cabin windows
- Fighter canopies and windshields
- Glider canopies

Reliability: Proven Weatherability of Acrylic

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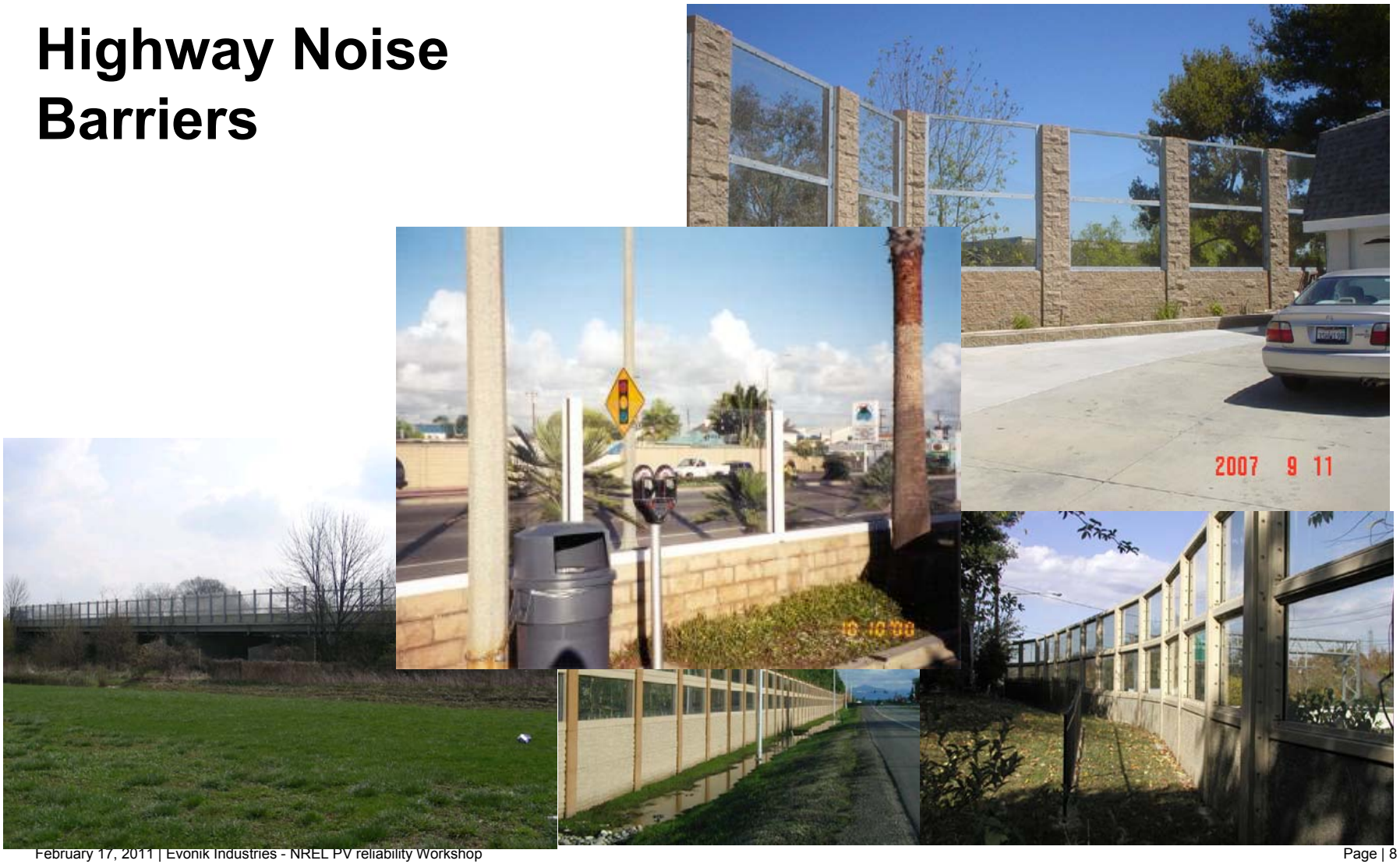
Signage

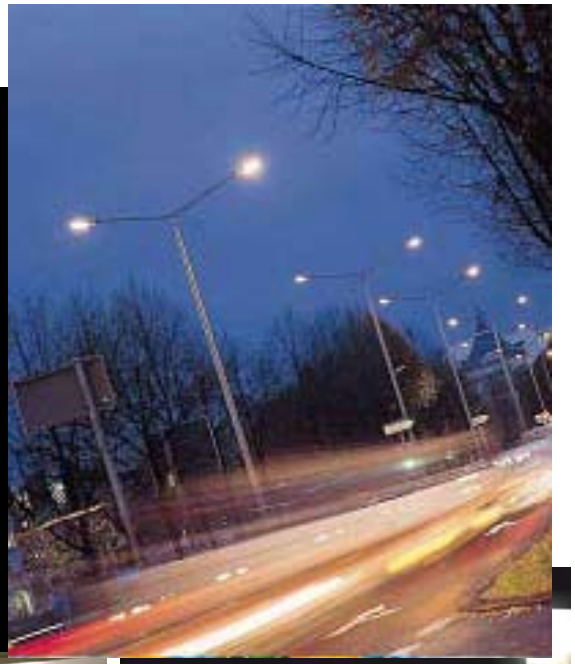
Reliability: Proven Weatherability of Acrylic

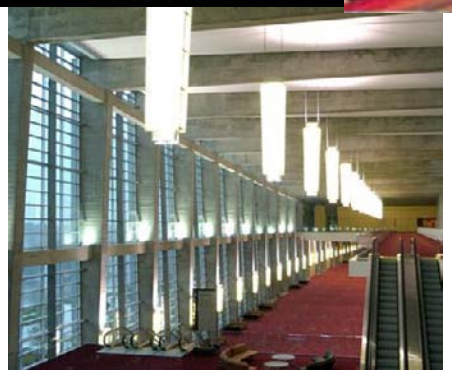
Highway Noise Barriers



Reliability: Proven Weatherability of Acrylic

HID & Outdoor Lighting Applications





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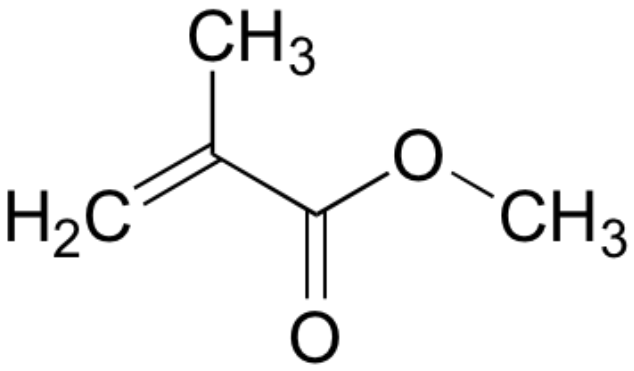
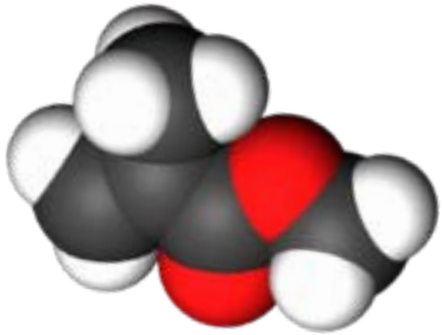
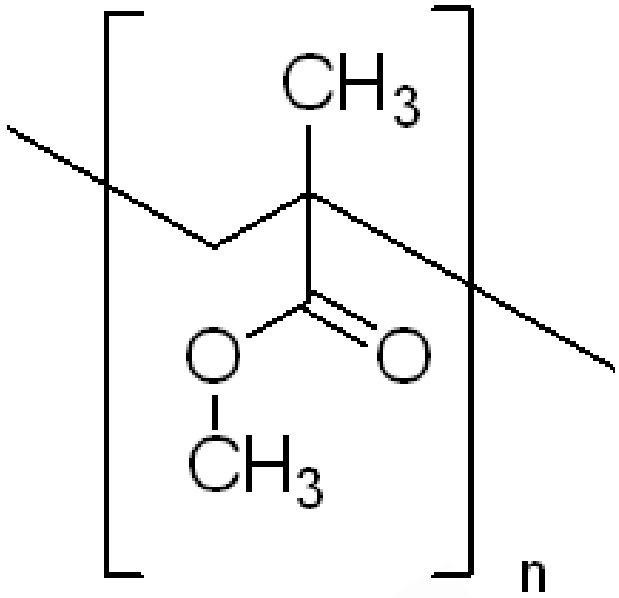
What is Acrylic?

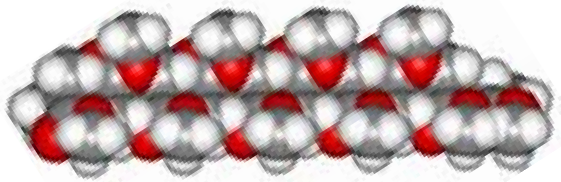


methyl methacrylate



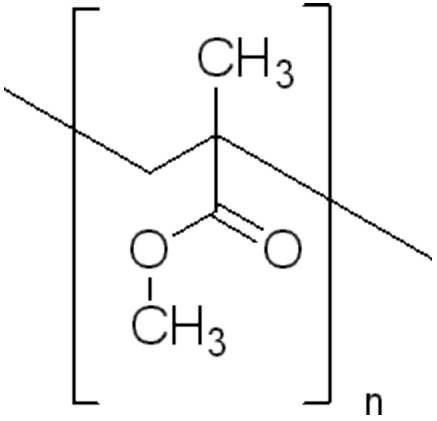


Polymethyl methacrylate



What is “acrylic”?

- Polymethylmethacrylate: -(MMA)$_n$-
  - PMMA is an ester
- Monomer – Methyl methacrylate
- Comonomer (methyl or ethyl –acrylate)
- Additives
  - Lubricants
  - Stabilizers
  - Colorants



Key Performance Characteristics

- Long Term Stability in Outdoor Environments
- Additional Protection Systems
- Excellent Surface Hardness
- Light Weight
- Outstanding Transmittance & Optical Clarity
- Optical Design Flexibility and Control

Topics

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3. **UV Absorption Characteristics**
4. Degradation Mechanisms
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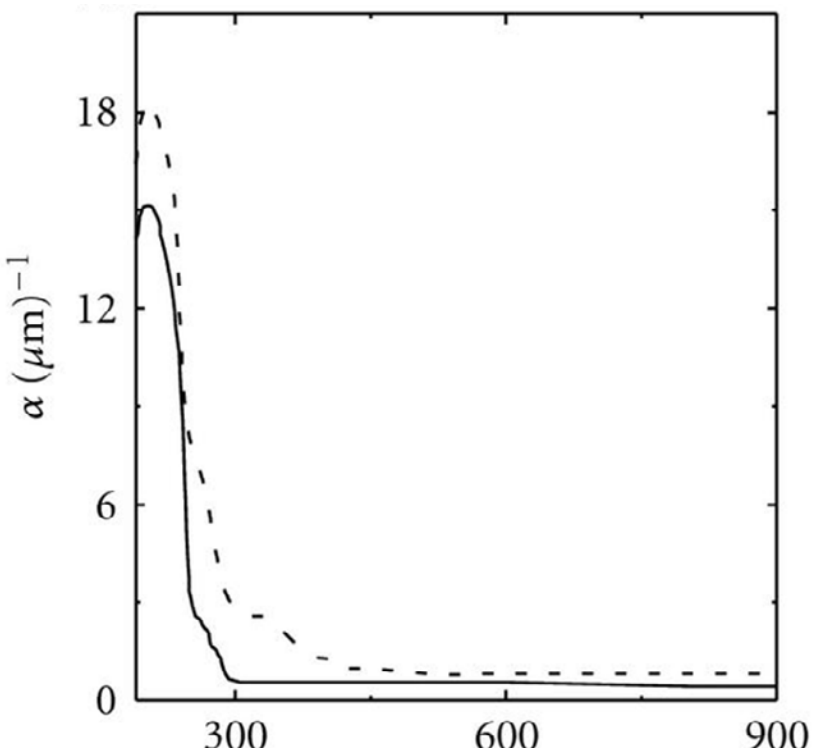
6. Weathering Performance

UV Stability

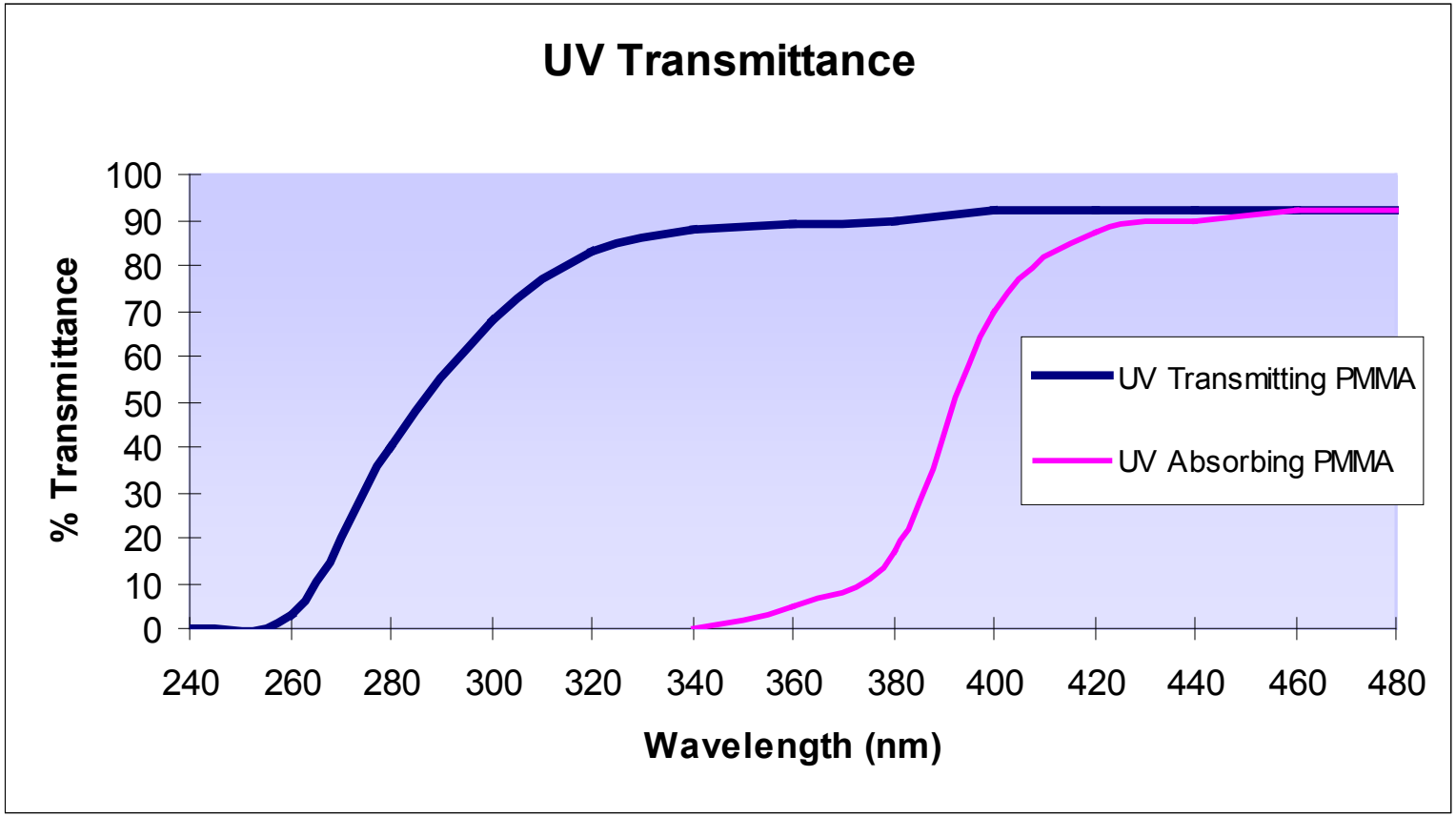
The outstanding stability of PMMA to sunlight results primarily from weak absorption of acrylic in the UV-region.



R.M. Ahmed, International Journal of Photoenergy, Volume 2009 (2009), Article ID 150389, "**Research ArticleOptical Study on Poly(methyl methacrylate)/Poly(vinyl acetate) Blends**

UV Stability

Acrylic is naturally UV transmitting, and can be modified with UV protection systems.



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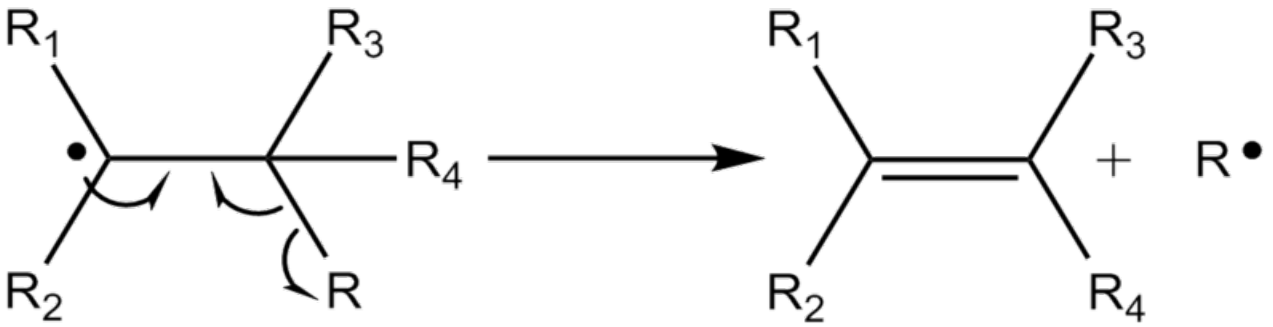
Degradation Mechanisms

Chain scission by exposure to extreme temperature or radiation conditions produces alkyl radicals that can react with oxygen to form peroxy radicals, chain termination can lead to creation of aldehydes, ketones or alcohols. Activation energy is ~260 kcal/mole at 130,000 mw. **Thermal degradation of polymeric materials**, Krzysztof Pielichowski, James Njuguna, 2005, pg 101

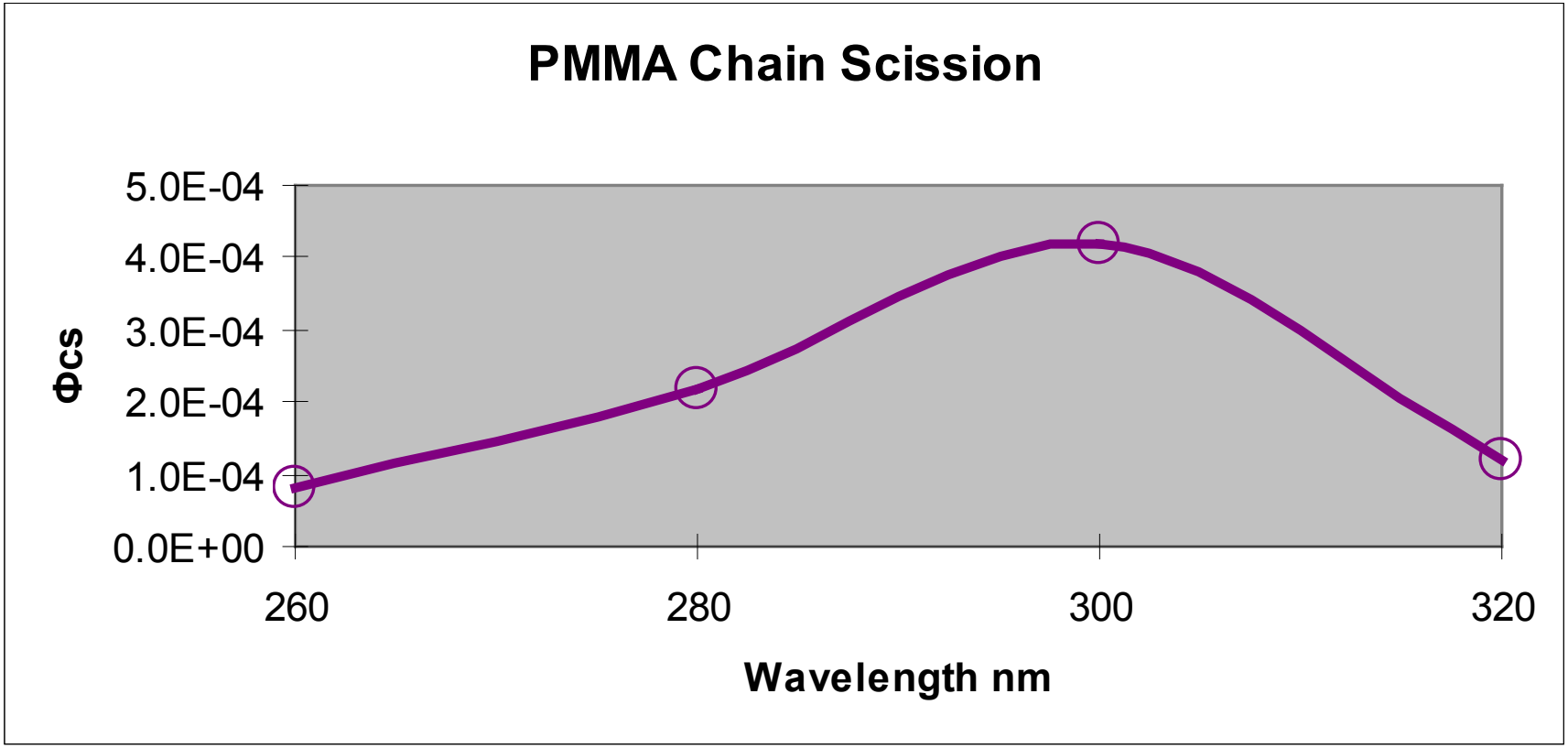
Alkoxy radicals may abstract H or undergo beta-scission. (unlikely).



Beta scission mechanism

Degradation Mechanisms
Main Chain Scission - PMMA

The quantum yield for main-chain scission of polymethylmethacrylate shows a maximum at 300 nm.



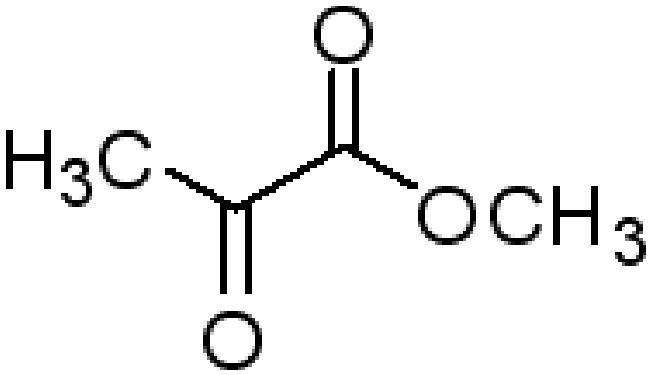
Mitsuoka, T.; Torikai, A.; Fueke, K. *J. Appl. Pol. Sci* **1993**, *47*, 1027

Photo-oxidation

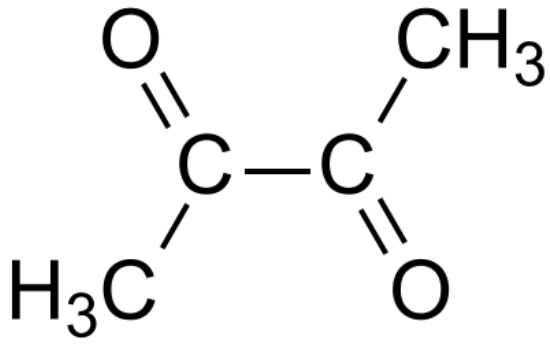
- Initiation of PMMA photo-oxidation is attributed to the decomposition of the ester groups by radiation in the range of 300-330 nm.
- In the presence of oxygen, radical-initiated oxidation occurs with the onset of photolysis.
- Another initiation scenario is the sensitizer effect of MMA-monomer: A photo-excited residual monomer transfers its energy to oxygen yielding singlet O_2 which reacts with monomer to form a hydroperoxide.

Oxidation of Residual MMA

In pyrolysis, polymethylmethacrylate can degrade via oxidation of by-products into methyl pyruvate or diacetyl.[1] Oxidation of residual MMA can produce these products as well. These materials are chromophores that can cause yellowing.



Methyl pyruvate

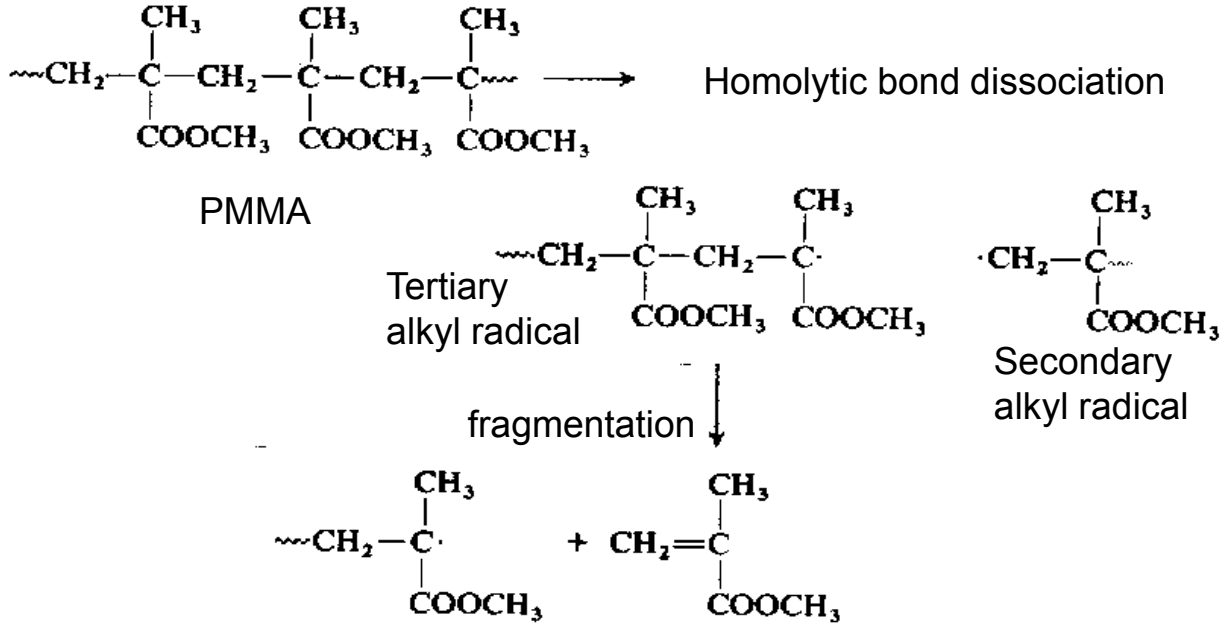


Diacetyl (2,3-butanedione)

1. Mukundan, Thekkekara and Kishore, Kaushal (1987) *Structure and pyrolysis of poly(methyl methacrylate peroxide): a thermochemical approach.* In: Macromolecules, 20 (10). pp. 2382-2385.

Thermal Effects

- Degradation occurs in processing above 300°C.
- Oxidation and chain scission can be accelerated at temperatures above 90°C in the presence of intense UV radiation in the range of 300-330nm.



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Protection Systems

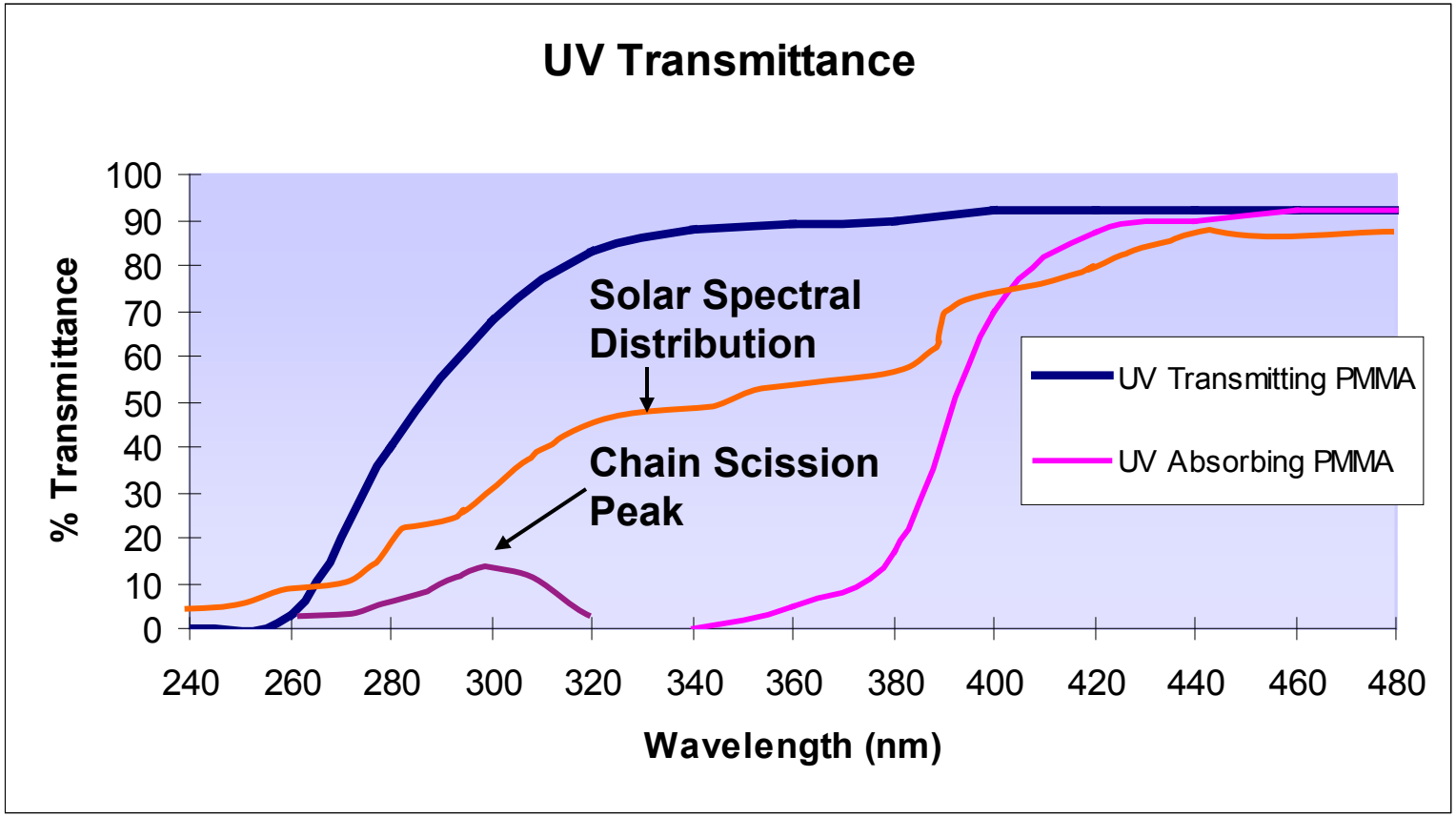
UV Absorbers

STABILIZERS

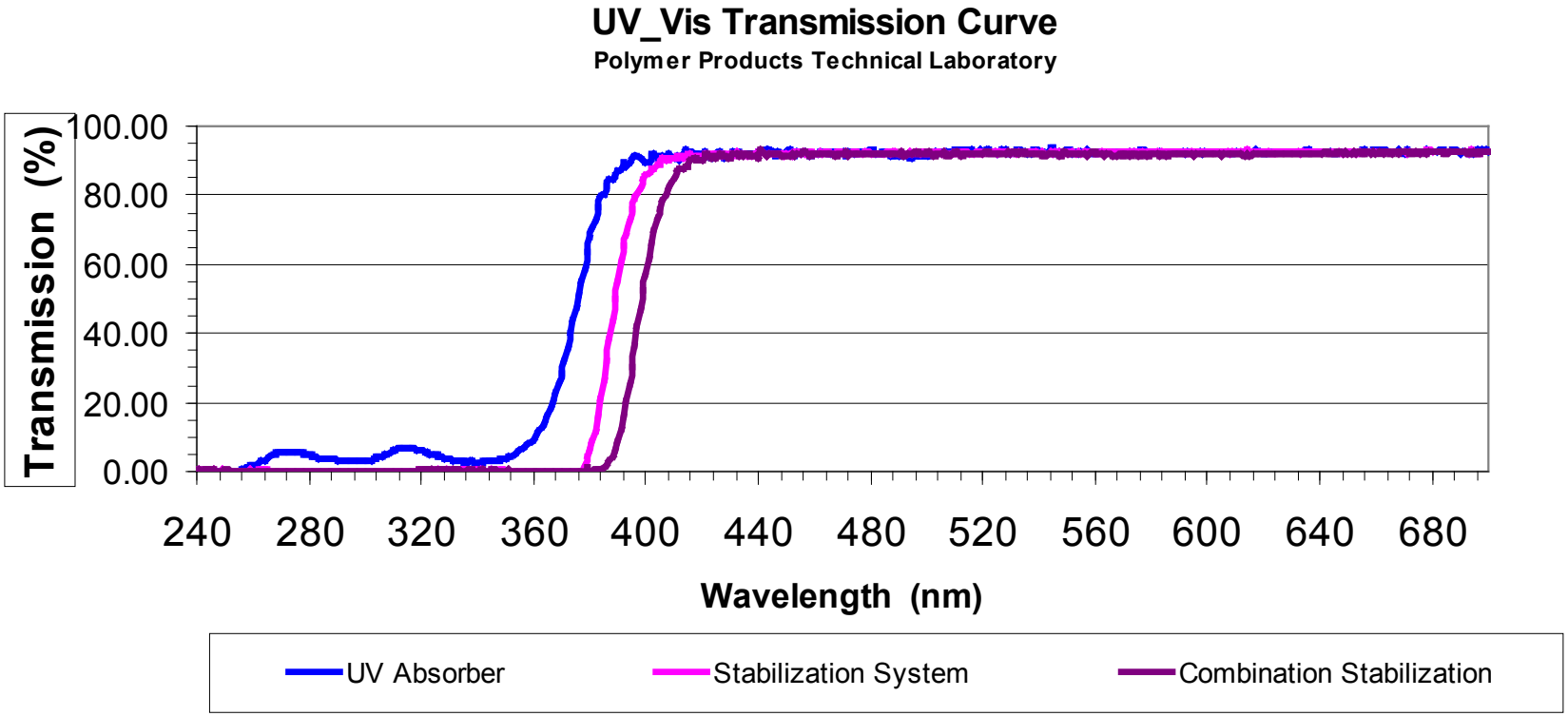
Combination Systems

Protection Systems

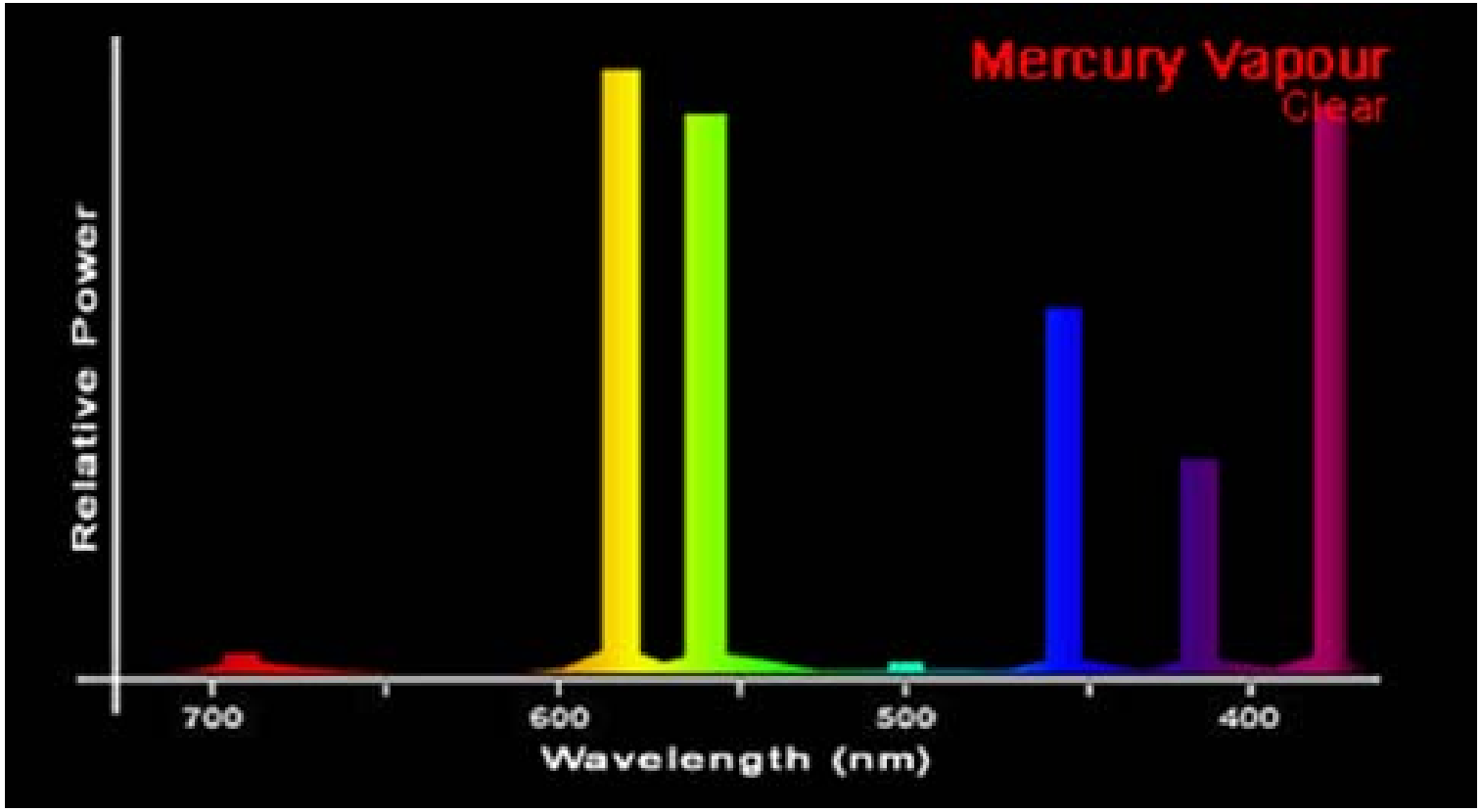
UV Absorbing PMMA blocks UV light in the region at which chain scission peaks.



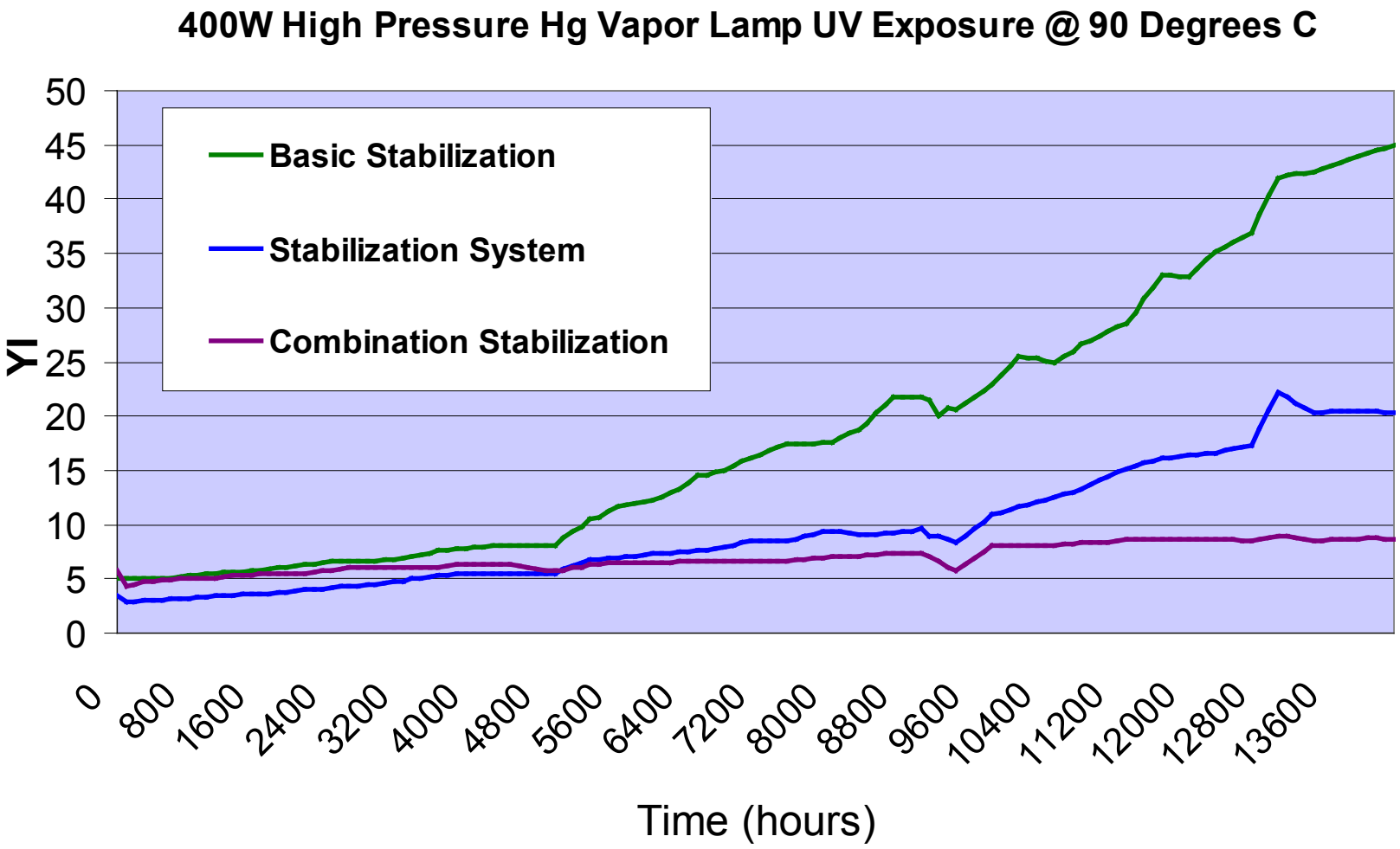
Protection Systems



High Pressure Hg Vapor Lamp



High Intensity UV and Heat Exposure



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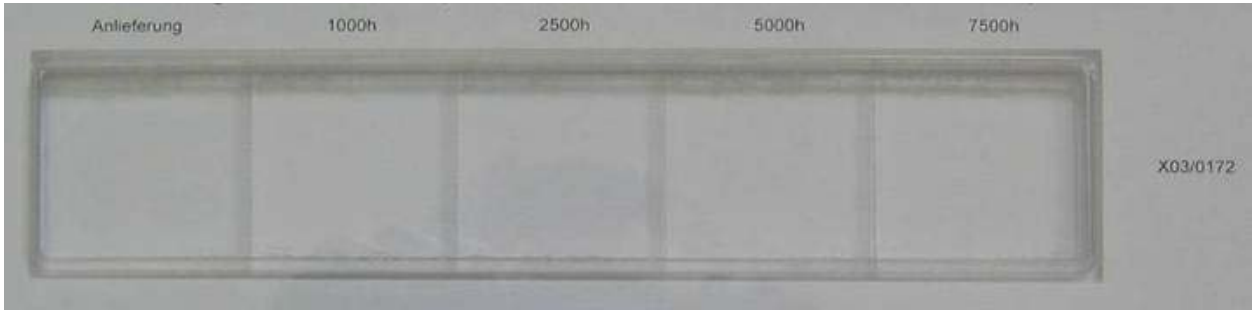
Weathering Variables

sun radiation (UV + vis + IR)
+ water (moisture)
+ mechanical stress (from diffusion, temperature, …)
+ temperature changes
+ microorganisms (algae, fungi, …)
+ time (1a, 2a, 3a, 5a, 10a and more)

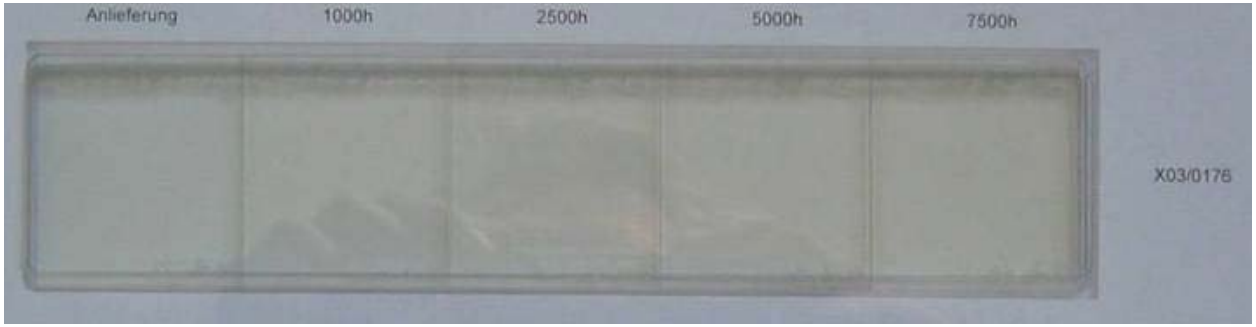


7500 hrs Xenon Arc Weathering

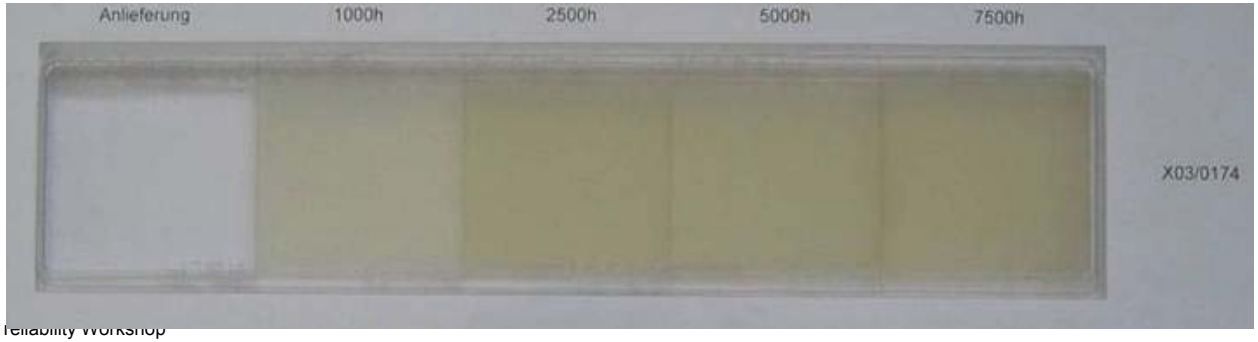
ACRYLITE®



PC UV-protected

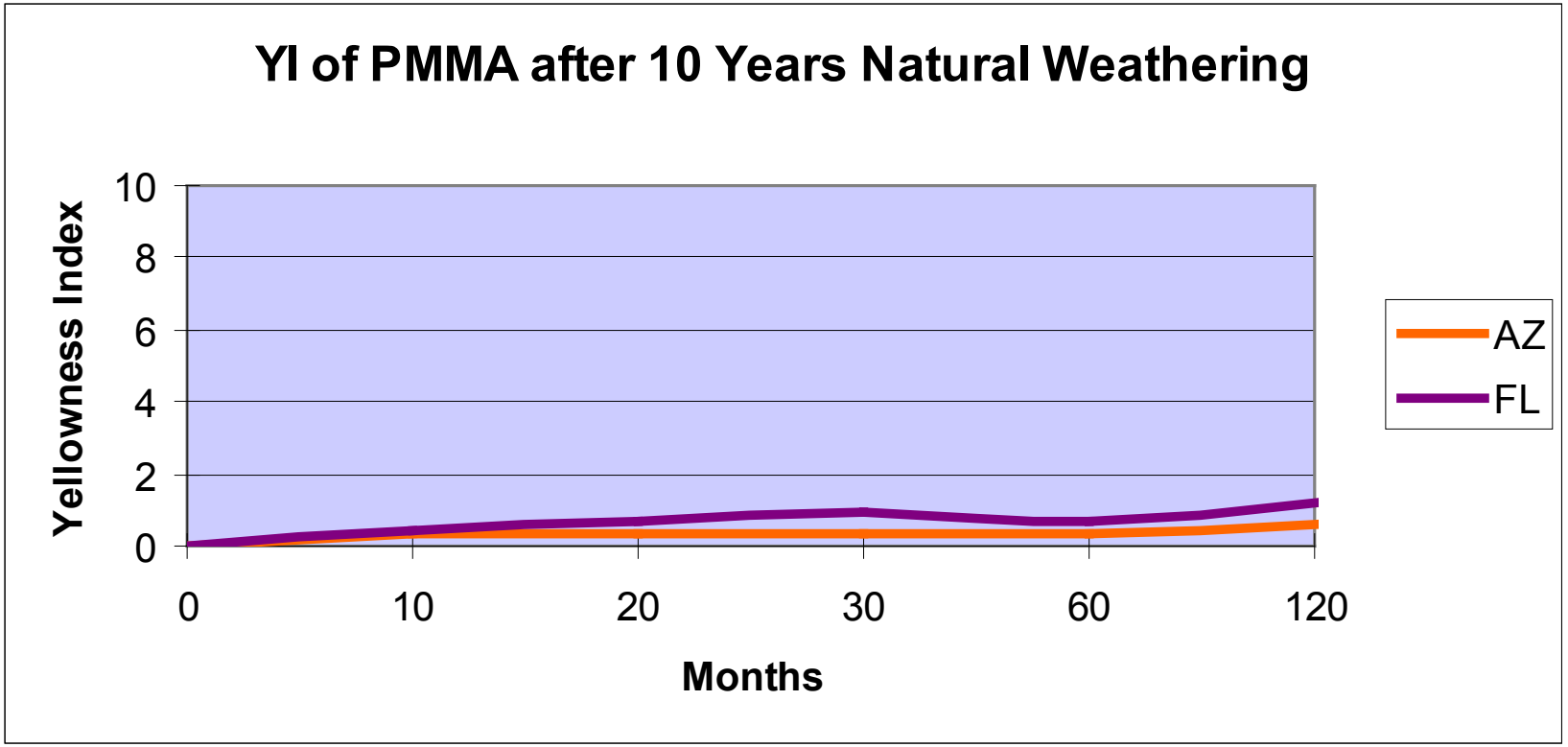


PC



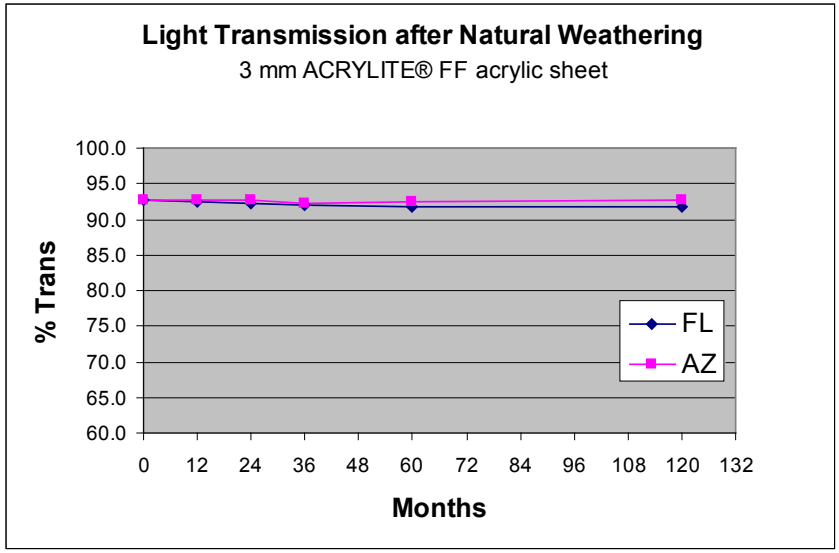
PMMA
10-Year On-Sun Weathering Results

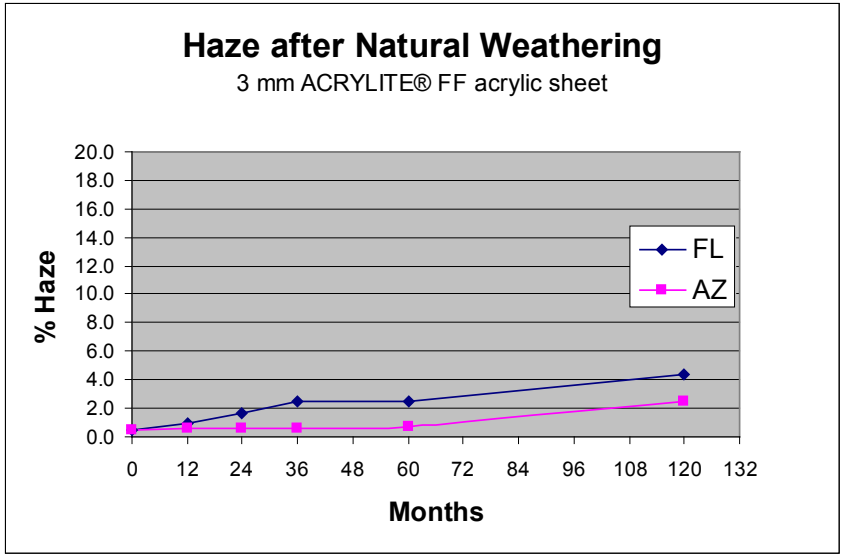
- Virtually no yellowing of acrylic in 10-year outdoor weathering in AZ and FL
- YI = 1.0 is nearly imperceptible to the eye when viewed through the material



10-Year On-Sun Weathering Results

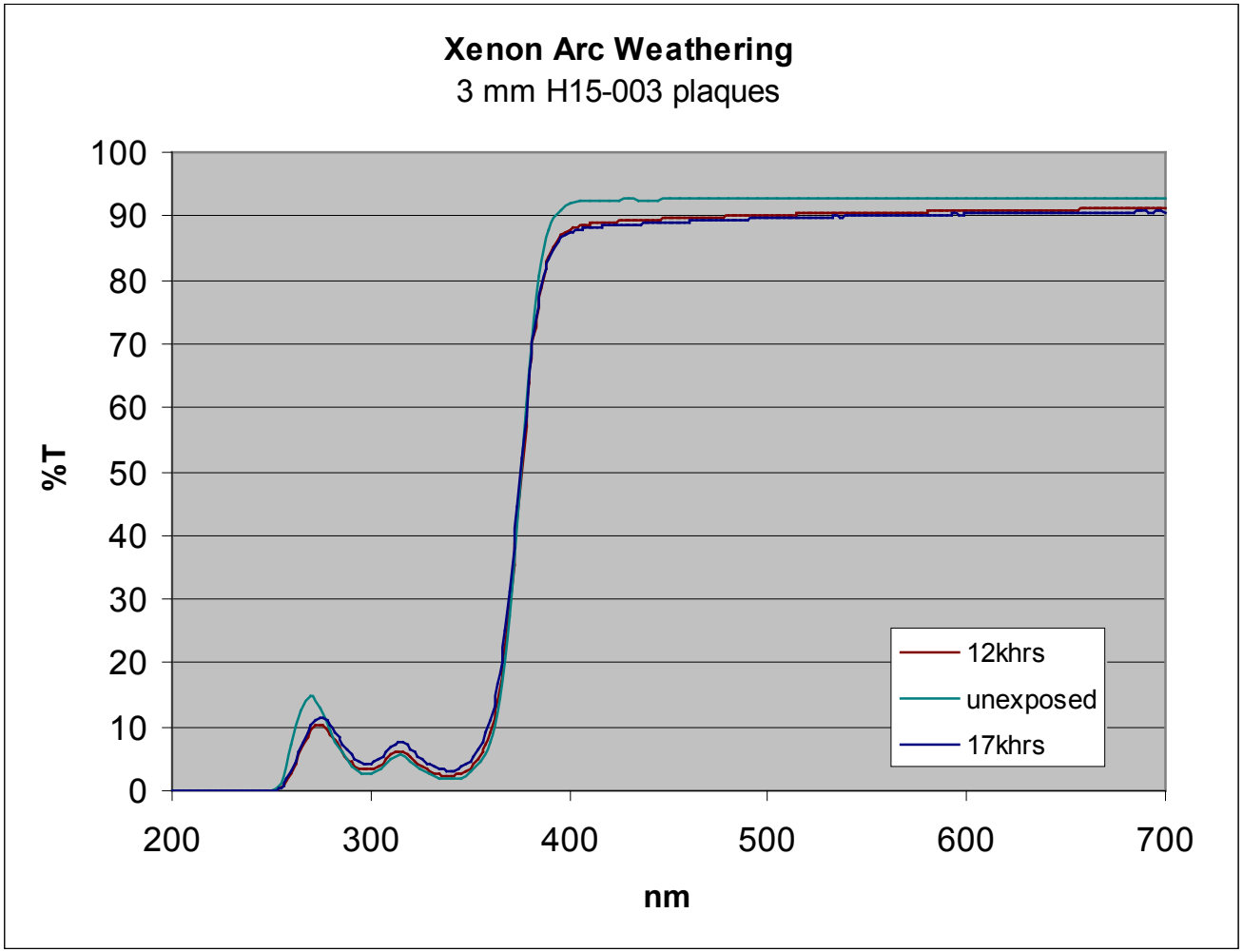
- Overall light transmission remains high and haze remains low after 10 years in outdoor weathering environments
- Florida environment has much more moisture and tends to increase haze somewhat





Xenon Arc Weathering Results

Long term stability



1khr = 1 year; “17-year” Xenon Arc Weathering %T = 88.1% @ 410 nm

Probability of Failure

Failure Mode	Mechanism	Probability
Yellowing from UV Exposure	Oxidation of residual Monomer	High if monomer is present in sufficient quantities
Weakness from UV Exposure	Chain Scission	Low – Insufficient UV Exposure at Earth's Surface
Yellowing from processing	Chain Scission and oxidation of low molecular weight fractions from processing at temperatures above 300°C	Low – Depends on process conditions
Yellowing from UV exposure at High temperatures	Chain Scission and oxidation of low Mw fractions with intense UV radiation and heat	Depends on material, design and ambient temperature conditions
Mechanical (cracks)	High stress level and stress concentration point	Depends on application design and material preparation.

What Does This All Mean?

- Application design relative to material properties is important.
- High Residual MMA can cause yellowness through oxidation that creates chromaphores.
- Chain scission occurs at very low levels, if at all, creating minor low molecular weight fractions.
- Protective formulation systems can be used to minimize oxidative, thermal, and UV influences on molecular structure.
- All polymethyl methacrylate materials are not created equal.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