For industrial protective coating applications, a two-component, epoxy-based coating has many advantages over other chemistry-based systems like acrylics or polyurethanes.

# UV-Resistant Epoxy

## FOR INDUSTRIAL PROTECTIVE COATING

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Two-component epoxy coatings have long been used for industrial protective applications due to their excellent adhesion to a wide range of substrates, superior chemical resistance, and various mechanical properties.[1] However, one major drawback of epoxy-based coatings is their poor UV resistance; polyurethane or acrylic-based coatings are often used as a topcoat over epoxy coatings to produce good UV-resistant properties.

Several unique cycloaliphatic epoxy resins and amine-curing agent combinations have been developed, which provide low color, outstanding non-yellowing properties, and excellent gloss retention. These advancements make it feasible to use only epoxy-based coatings to achieve excellent UV resistance, eliminating the need for polyurethane or acrylic topcoats. This article will describe the comprehensive benefits of these UV-resistant epoxy systems and include performance comparisons with an industrial standard polyurethane topcoat, specifically in terms of dry time, gel time, hardness, and accelerated QUV-A weathering tests.

### Introduction

For industrial protective coating applications, a two-component, epoxy-based coating has many advantages over other chemistry-based systems such as acrylics or polyurethanes. Bisphenol A-type epoxy coatings have an excellent adhesion to various substrates, superior chemical resistance, and improved thermal and mechanical properties. However, their aromatic ring structure leads to poor UV resistance, and the amine-curing agents cause increased yellowness in the system.

Driven by end-user demand, there is a strong need for UV-resistant epoxy

# Systems
## APPLICATIONS

systems in various cosmetic applications. Even so, compromises in coating performance are unacceptable for the sake of low yellowing. Utilized in several demanding applications and environments, epoxies are an important class of coatings that are also expected to provide high-performing aesthetic properties. Using a cycloaliphatic epoxy resin paired with a cycloaliphatic-based amine is one common method to enhance the UV resistance of epoxy systems, eliminating the need to use polyurethane or acrylic topcoats. A variety of innovative combinations of cycloaliphatic epoxy resins and amine-curing agents have been developed, offering low color, outstanding non-yellowing properties, and superior gloss retention.

We provide detailed information on these UV-resistant epoxy systems, and by using a clear coating formulation, compare their performance with an industrial standard polyurethane topcoat in terms of dry times, adhesion, hardness, and accelerated QUV-A weathering tests.

## Experimental

### Raw materials and testing panel preparation

A commercially available, solventborne, aliphatic-type polyurethane clear coating was chosen in this study as the commercial benchmark, referred to as PU Clear. An industrial standard Bisphenol A-type liquid epoxy resin was used as a baseline control, referred to as Control. The physical properties of the materials below are described in **Table 1:**

- Control—Industrial standard Bisphenol A-type liquid epoxy resin
- Epoxy 1, Epoxy 2, and Epoxy 3—Three Huntsman cycloaliphatic epoxy resins
- Amine 1, Amine 2, and Amine 3—Three Huntsman cycloaliphatic curing agents

The two-component coatings were prepared by mixing cycloaliphatic epoxy resins and cycloaliphatic amine-curing agents on an overhead mixer on the 100-to-300-gram scale without adding any other additives. The epoxy-to-amine index ratio we used is 1:1 for each formula.

Testing panels were prepared by drawing down the two-component coatings over glass substrate, generally using an 8-mil gap 3-inch drawdown bar. The panels were typically allowed to cure for 7 days at 23 ˚C and 50% relative humidity before testing, unless otherwise noted. The dry film thickness of the testing panel is about 5 mil.

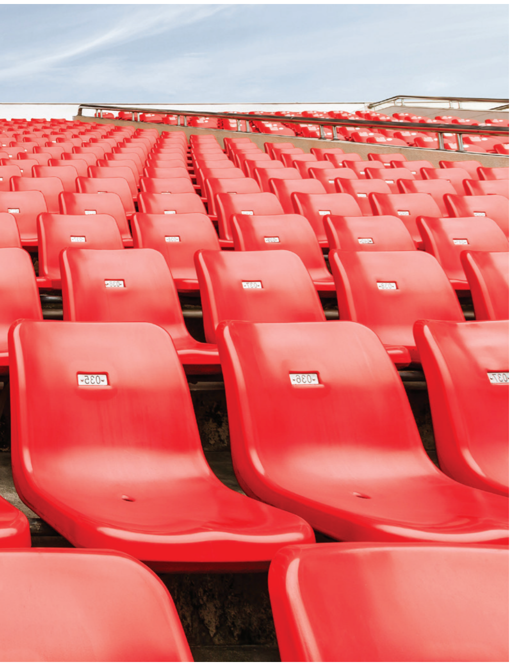


**TABLE 1**
**Physical Properties**

| Properties | Type | Solids Content% | Color Gardner | Viscosity @ 25°C, cp | EEW g/eq | AHEW g/eq |
|---|---|---|---|---|---|---|
| Control | Aromatic | 100 | < 1 | 12500 | 187 | |
| Epoxy 1 | Cycloaliphatic | 100 | < 100, APHA | 1900 | 220 | |
| Epoxy 2 | Cycloaliphatic | 100 | < 3 | 3250 | 200 | |
| Epoxy 3 | Cycloaliphatic | 100 | < 100, APHA | 800 | 170 | |
| Amine 1 | Cycloaliphatic | 100 | < 1 | 610 | | 115 |
| Amine 2 | Cycloaliphatic | 100 | < 60, APHA | 275 | | 115 |
| Amine 3 | Cycloaliphatic | 100 | < 100, APHA | 500 | | 95 |

Note: EEW = Epoxy Equivalent Weight, AHEW = Amine Hydrogen Equivalent Weight.

## Testing Procedures

### Gel time

Gel time is measured using a gel timer with 150-gram total mass, according to ASTM D2471.

### Dry time

Coatings were drawn down onto glass substrates with a wet film thickness of 150 µm and set on a B.K. Linear Drying Time Recorder. The dry-to-touch and dry-through times were visually assessed after dragging a needle through the coating over the course of 24 hours, according to ASTM D5895.

### Gloss

Gloss is measured using a BYK-micro-TRI-gloss instrument. Gloss is a measure of light reflectance of a coating at defined angles, according to ASTM D523. Gloss is measured at 20° and 60°. Gloss retention is calculated using post-exposure measurement divided by pre-exposure measurement.

### Color

Color is measured using a CM-5 Spectrophotometer according to ASTM D1209. Color measurements include yellow index (YI) and CIE L, a, b color space values. To calculate the total color difference (Delta E), first square the difference between each of the L, a, and b values; then add them together; then take the square root of the sum.

### Crosshatch adhesion

Adhesion of the coatings on the metal substrates was measured according to ASTM D3359. A comb-like metal template was put on the surface of the testing panel, and a utility knife was passed through each slit, inscribing 11 parallel cuts in the paint film. The template is then rotated 90º and placed over the same area, and a second set of 11 cuts are made. One-inch-wide tape with a 4-inch overlap at one end to form a pull tab is applied over the test area. The tape is rubbed with an eraser to ensure thorough contact over the test area. Then, using the overlap for a grip, the tape is pulled quickly from the substrate at an 180º angle. The coating was then visually inspected to determine how much coating was removed from the substrate. The scale follows:

- 5A No peeling or removal
- 4A Trace peeling or removal along incisions or at their intersection
- 3A Jagged removal along incision up to 1.6 mm on either side
- 2A Jagged removal along most of incision up to 3.2 mm on either side
- 1A Removal from most of the cutting area under the tape
- 0A Removal beyond the cutting area

### König hardness

König hardness was measured using a TQC SP0500 Pendulum Hardness Tester, according to ASTM D4366, and reported in seconds. Three measurements were taken for each testing panel and the average was recorded. The König hardness was measured after 7 days of cure.

### Shore D hardness

Shore D hardness was measured using a Durometer according to ASTM D2240. Three measurements were taken for each testing panel and the average was recorded. Measurements were recorded at various intervals over the course of one week of cure.

## Coating Weatherability

Coating weatherability was tested using QUV weathering chamber according to ASTM G53. The weather testing schedule used was a cycle of UVA exposure for 8 hours at 50 ˚C and condensing humidity at 40 ˚C for 4 hours. Color and gloss were measured every 500 hours to indicate how the coating progresses under UVA exposure.

## Results and Discussion

The basic coating properties of the experimental formulations are listed in **Table 2**. As we know, aromatic epoxy resin reacts faster than cycloaliphatic epoxy resin. From the data for the three curing agents we evaluated here, the Control gives the shortest gel time, fastest dry-to-touch time, and dry-through time. In addition, it achieves the highest pendulum hardness and Shore D hardness.

Compared with Epoxy 1, Epoxy 2 brings shorter gel time and dry time, as well as better pendulum hardness and Shore D hardness. Compared with Amine 2 and 3, Amine 1 provides the shortest gel time and dry time, along with the best pendulum hardness and Shore D hardness.

It shows a cycloaliphatic-type epoxy system can achieve similar performance as an aromatic-type system in terms of dry time and hardness development.

The initial color and gloss data of PU Clear (the commercial benchmark) and all experimental formulations are listed in **Table 3**. Due to the surface defects, the Epoxy 1/Amine 2 formula could not be evaluated.

From the data, we can see all the systems have similar initial color results, while gloss varies system by system. The Control epoxy resin gives the highest initial gloss values for all three amine-curing agents.

The color and gloss retention data after 500 hours QUV-A exposure are shown in **Table 4**.

After 500 hours of QUV-A exposure, the gloss of the PU Clear increased from around 80 to over 100 at both 20° and 60°, resulting in a gloss retention exceeding 100%. The same effect occurred with the Epoxy 2/Amine 2 system, which also exhibits the lowest yellow index and Delta E among all the experimental formulations. The Epoxy 2/Amine 1 and Epoxy 2/Amine 3 systems are the next best performing formulations, demonstrating low yellow index, low Delta E, and high gloss retentions.

**TABLE 2**
**Basic Coating Properties**

| Systems | Gel Time, minutes | Dry To Touch, hours | Dry Through, hours | 7 Days Pendulum Hardness, seconds | 7 Days Shore D Hardness | Crosshatch Adhesion |
|---|---|---|---|---|---|---|
| Control/Amine 1 | 21.8 | 2 | 3 | 319 | 85 | 5A |
| Epoxy 1/Amine 1 | 56.3 | 3 | 4 | 218 | 79 | 5A |
| Epoxy 2/Amine 1 | 30.6 | 2.5 | 4 | 258 | 83 | 5A |
| Epoxy 3/Amine 1 | 23.5 | 3 | 4 | 209 | 85 | 5A |
| Control/Amine 2 | 114.3 | 3 | 7.5 | 317 | 78 | 5A |
| Epoxy 1/Amine 2 | 237.7 | 9 | 13 | 110 | 70 | 5A |
| Epoxy 2/Amine 2 | 215.7 | 8 | 12 | 127 | 75 | 5A |
| Epoxy 3/Amine 2 | 124.7 | 3.5 | 8 | 87 | 65 | 5A |
| Control/Amine 3 | 117.9 | 4.5 | 8 | 301 | 83 | 5A |
| Epoxy 1/Amine 3 | 605.2 | 9 | 13 | 67 | 79 | 5A |
| Epoxy 2/Amine 3 | 246.1 | 8 | 12 | 134 | 81 | 5A |
| Epoxy 3/Amine 3 | 158.8 | 9 | 11 | 62 | 70 | 5A |

**TABLE 3**
**Initial Color and Gloss Data**

| System | L | A | B | YI | Gloss @ 20° | Gloss @ 60° |
|---|---|---|---|---|---|---|
| PU Clear | 96.585 | -0.355 | 0.26 | 0.265 | 83.8 | 86 |
| Control/Amine 1 | 96.225 | -0.26 | 0.16 | 0.105 | 113.9 | 117.8 |
| Epoxy 1/Amine 1 | 96.425 | -0.29 | 0.15 | 0.09 | 70.2 | 71.05 |
| Epoxy 2/Amine 1 | 96.41 | -0.295 | 0.205 | 0.175 | 79.45 | 81 |
| Epoxy 3/Amine 1 | 96.44 | -0.28 | 0.125 | 0.05 | 105.2 | 108.6 |
| Control/Amine 2 | 96.27 | -0.26 | 0.11 | 0.025 | 114.95 | 118.95 |
| Epoxy 2/Amine 2 | 96.515 | -0.275 | 0.11 | 0.03 | 91.45 | 94.7 |
| Epoxy 3/Amine 2 | 96.585 | -0.26 | 0.075 | 0.03 | 107.15 | 110.8 |
| Control/Amine 3 | 96.24 | -0.26 | 0.14 | 0.08 | 112.4 | 116.1 |
| Epoxy 1/Amine 3 | 96.41 | -0.27 | 0.16 | 0.1 | 88.7 | 91.6 |
| Epoxy 2/Amine 3 | 96.48 | -0.27 | 0.12 | 0.04 | 87.8 | 90.6 |
| Epoxy 3/Amine 3 | 96.51 | -0.27 | 0.1 | 0.01 | 108.2 | 111.6 |

**TABLE 4**
**500 Hours QUV-A Exposure: Yellow Index, Delta E, and Gloss Retention**

| System | YI | Delta E | 20° Gloss Retention | 60° Gloss Retention |
|---|---|---|---|---|
| PU Clear | 0.63 | 0.13 | 127.7% | 122.0% |
| Control/Amine 1 | 26.09 | 16.26 | 40.6% | 41.9% |
| Epoxy 1/Amine 1 | 12.46 | 11.20 | 38.5% | 42.1% |
| Epoxy 2/Amine 1 | 7.10 | 4.16 | 79.0% | 78.0% |
| Epoxy 3/Amine 1 | 7.42 | 4.38 | 15.0% | 13.5% |
| Control/Amine 2 | 24.05 | 19.93 | 34.8% | 33.7% |
| Epoxy 2/Amine 2 | 4.86 | 2.90 | 111.3% | 111.9% |
| Epoxy 3/Amine 2 | 5.43 | 3.27 | 45.1% | 44.3% |
| Control/Amine 3 | 30.48 | 21.81 | 12.4% | 19.4% |
| Epoxy 1/Amine 3 | 5.22 | 3.16 | 48.6% | 47.6% |
| Epoxy 2/Amine 3 | 5.82 | 3.47 | 75.3% | 73.8% |
| Epoxy 3/Amine 3 | 5.65 | 3.31 | 64.1% | 63.8% |

**Figure 1** is the graphical representation of comparisons in color and gloss retention of the testing panels exposed to QUV-A exposure for 500 hours.

**Figure 2** shows some of the testing panels after 500 hours QUV-A exposure. In **Figure 2**, we can see the Control/Amine2 panel shows the most yellowness due to the aromatic structure. All three experimental formula panels show a hint of yellowness while the PU Clear panel still looks very clear. This confirms the yellow index data shown in **Table 4.**

**Table 5** shows the color and gloss retention data after 1000 hours QUV-A exposure. According to the data, PU Clear still maintains a very low yellow index, low Delta E, and more than 100% gloss retention. The best performing experimental formula, the

**FIGURE 1**
**A comparison of yellow index, Delta E values, and gloss retention after 500 hours QUV-A exposure.**

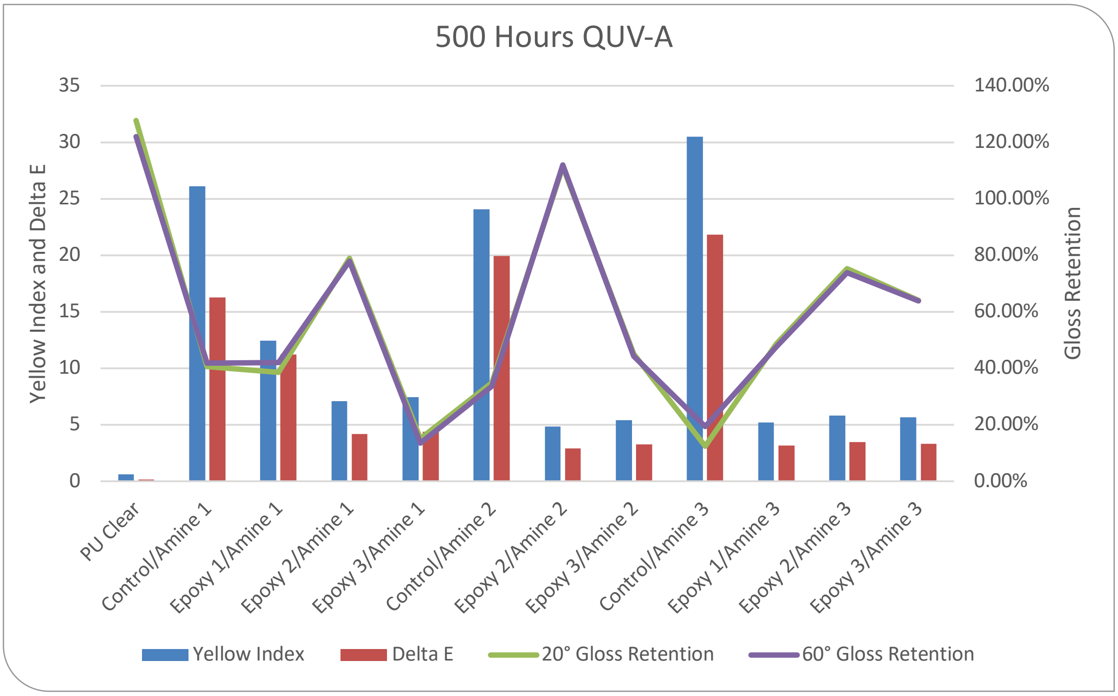
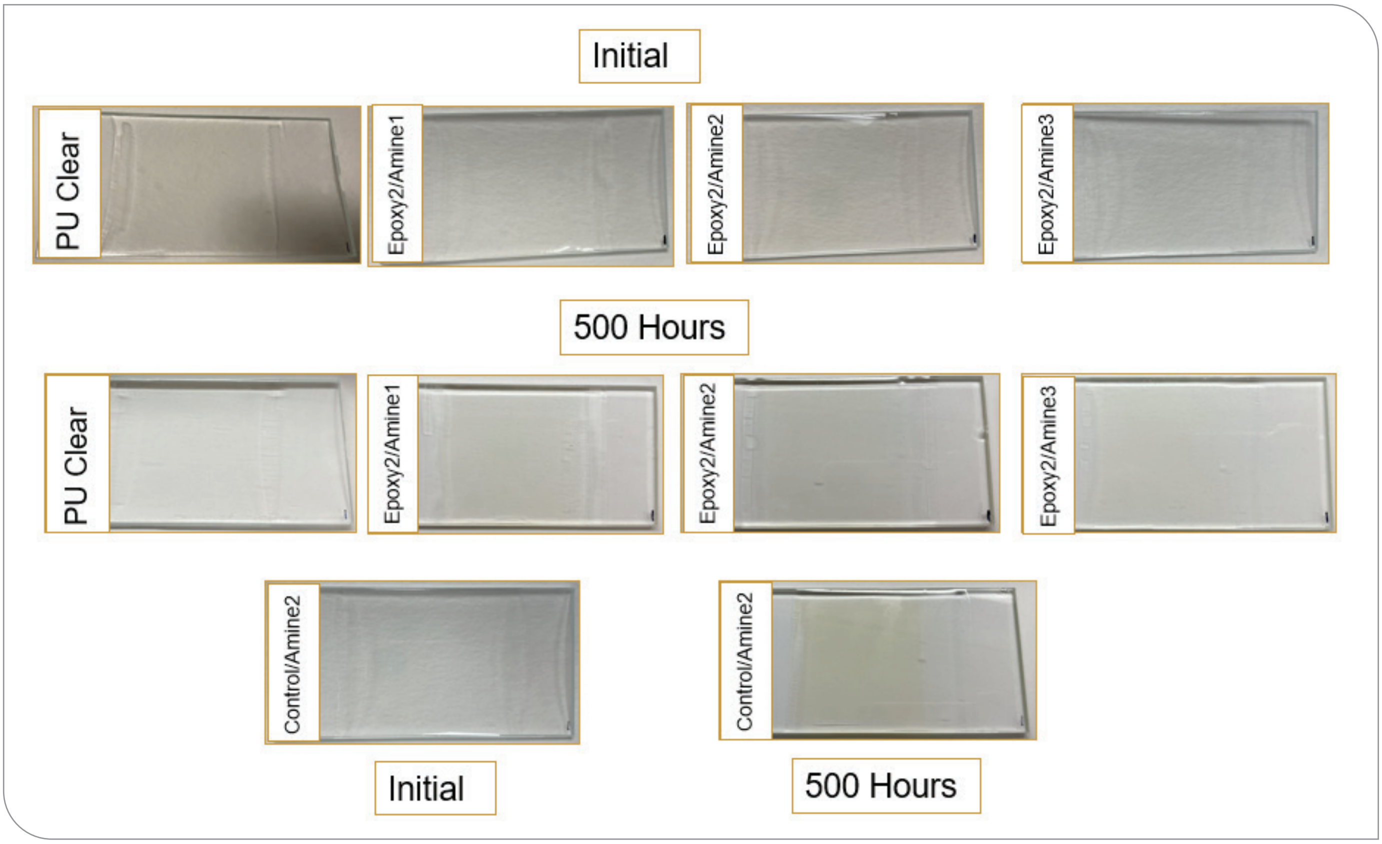



**FIGURE 2**
**Some of the testing panels after 500 hours of QUV-A exposure.**



Epoxy 2/Amine 2, also has more than 100% gloss retention, while the yellow index and Delta E value are slightly increased. The Epoxy 3/Amine 2 and Epoxy 2/Amine 3 systems are the next best performing formulations, exhibiting low yellow index, low Delta E, and more than 50% gloss retentions.

**TABLE 5**
**1000 Hours QUV-A Exposure: Yellow Index, Delta E, and Gloss Retention**

| System | YI | Delta E | 20° Gloss Retention | 60° Gloss Retention |
|---|---|---|---|---|
| PU Clear | 0.68 | 0.19 | 126.60% | 127.80% |
| Control/Amine 1 | 31.46 | 19.36 | 20.20% | 19.20% |
| Epoxy 1/Amine 1 | 10.34 | 8.65 | 22.00% | 18.80% |
| Epoxy 2/Amine 1 | 8.9 | 5.08 | 33.80% | 32.70% |
| Epoxy 3/Amine 1 | 8.45 | 4.94 | 13.00% | 12.80% |
| Control/Amine 2 | 35.4 | 25.11 | 11.30% | 10.40% |
| Epoxy 2/Amine 2 | 6.31 | 3.73 | 106.80% | 106.60% |
| Epoxy 3/Amine 2 | 7.69 | 4.23 | 58.10% | 56.70% |
| Control/Amine 3 | 24.43 | 14.79 | 8.50% | 7.90% |
| Epoxy 1/Amine 3 | 6.97 | 3.79 | 25.10% | 23.70% |
| Epoxy 2/Amine 3 | 7.43 | 4.38 | 50.90% | 50.00% |
| Epoxy 3/Amine 3 | 8.54 | 5.45 | 17.00% | 15.60% |

**Figure 3** is the graphical representation of comparisons in color and gloss retention after the testing panels were subjected to QUV-A exposure for 1000 hours. **Figure 4** shows some of the testing panels after 1000 hours QUV-A exposure.

From **Figure 4,** the Control/Amine2 panel exhibits the most yellowness, with the coating becoming opaque and delaminated from the substrate. Because of that, all the Control epoxy resin-based testing panels were removed from the QUV-A chamber. All three other experimental formula panels show a little more yellowness, while the PU Clear panel also shows a slightly yellowness.

**Table 6** shows color and gloss retention data after 2000 hours QUV-A. From the data, PU Clear still maintains a very low yellow index, low Delta E, and more than 100% gloss retention. The best performing experimental formula, the Epoxy 2/Amine 2 system, also has more than 100% gloss retention, while the yellow index and Delta E value are almost the same as after 1000 hours. The Epoxy 3/Amine 2 and Epoxy 2/Amine 3 systems are the next best performing formulations, providing low yellow index, low Delta E, and more than 50% gloss retention.

**Figure 5** is the graphical representation of comparisons in color and gloss retention of the testing panels subjected to QUV-A exposure for 2000 hours. **Figure 6** shows some of the testing panels after 2000 hours QUV-A exposure**.**

In **Figure 6**, all three experimental formula panels show more yellowness but still maintain transparency, while the PU Clear panel shows a slight yellowness.

**FIGURE 3**
**A comparison of yellow index, Delta E, and gloss retention after 1000 hours QUV-A exposure.**

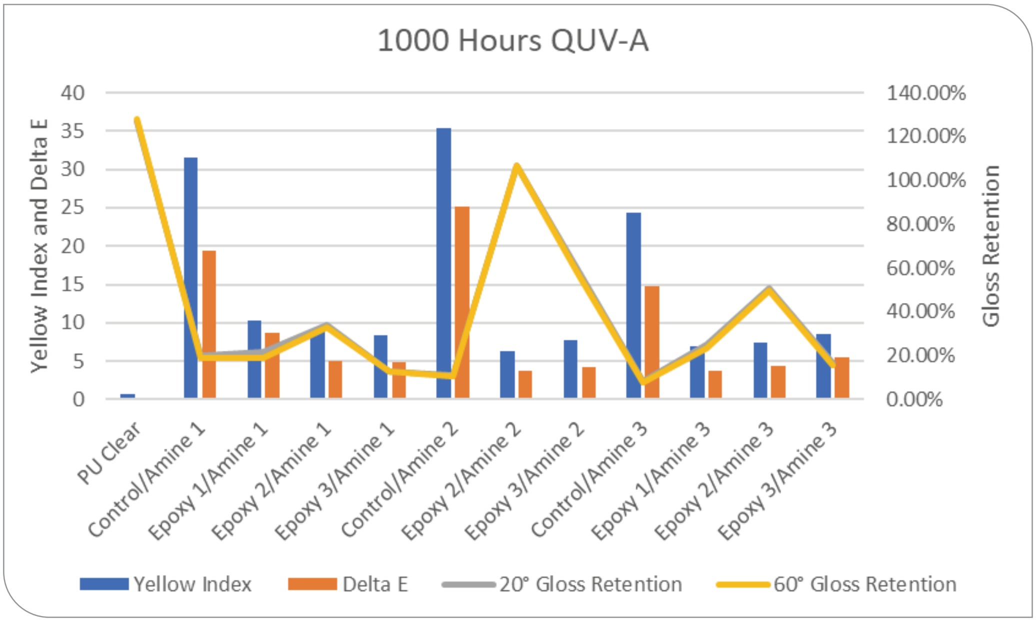



**FIGURE 4**
**Some of the testing panels after 1000 hours QUV-A exposure.**

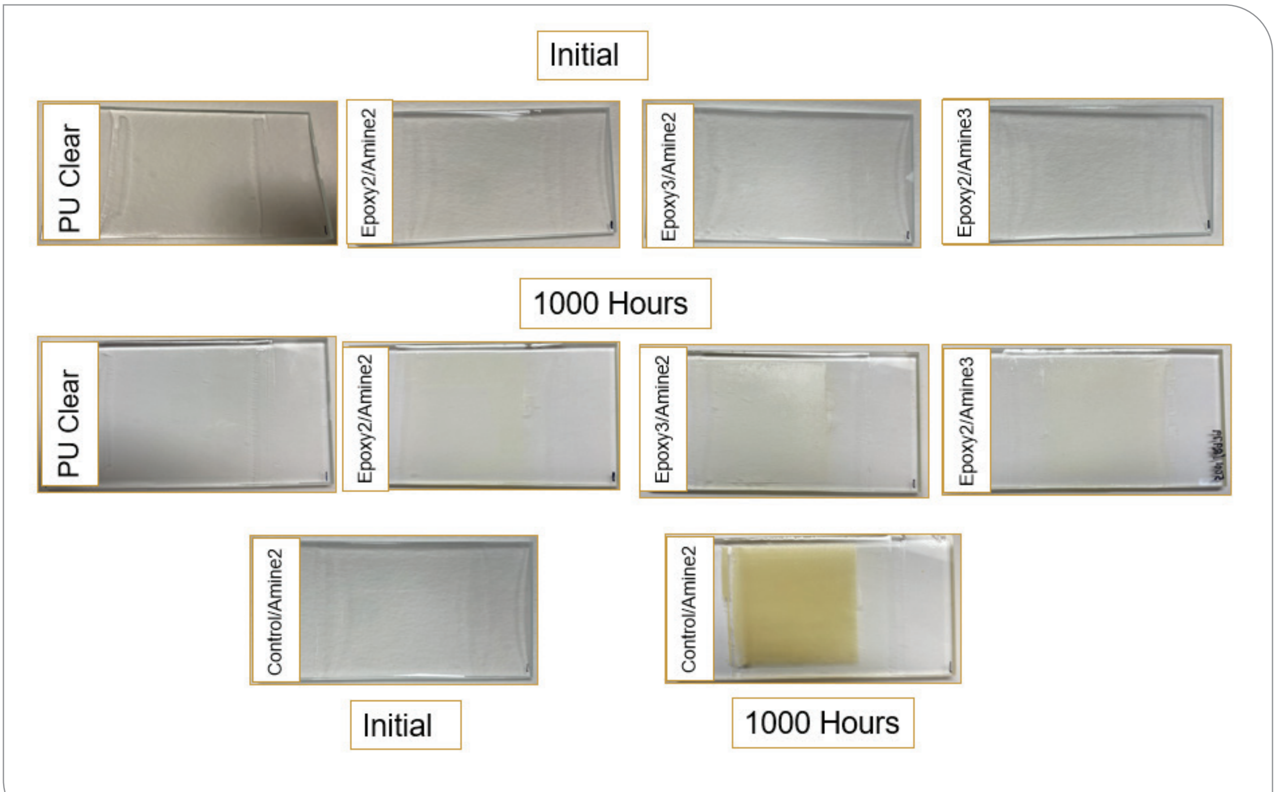


**TABLE 6**
**2000 Hours QUV-A Exposure: Yellow Index, Delta E, and Gloss Retention**

| System | YI | Delta E | 20° Gloss Retention | 60° Gloss Retention |
|---|---|---|---|---|
| PU Clear | 0.65 | 0.16 | 126.00% | 127.30% |
| Epoxy 1/Amine 1 | 10.37 | 8.73 | 21.00% | 19.40% |
| Epoxy 2/Amine 1 | 8.5 | 4.87 | 33.50% | 32.30% |
| Epoxy 3/Amine 1 | 8.49 | 4.97 | 13.70% | 12.50% |
| Epoxy 2/Amine 2 | 6.18 | 3.77 | 109.90% | 109.90% |
| Epoxy 3/Amine 2 | 5.45 | 3.27 | 58.30% | 56.90% |
| Epoxy 1/Amine 3 | 7.05 | 3.86 | 15.20% | 13.60% |
| Epoxy 2/Amine 3 | 7.47 | 4.48 | 51.50% | 50.60% |
| Epoxy 3/Amine 3 | 5.22 | 3.09 | 19.60% | 18.20% |

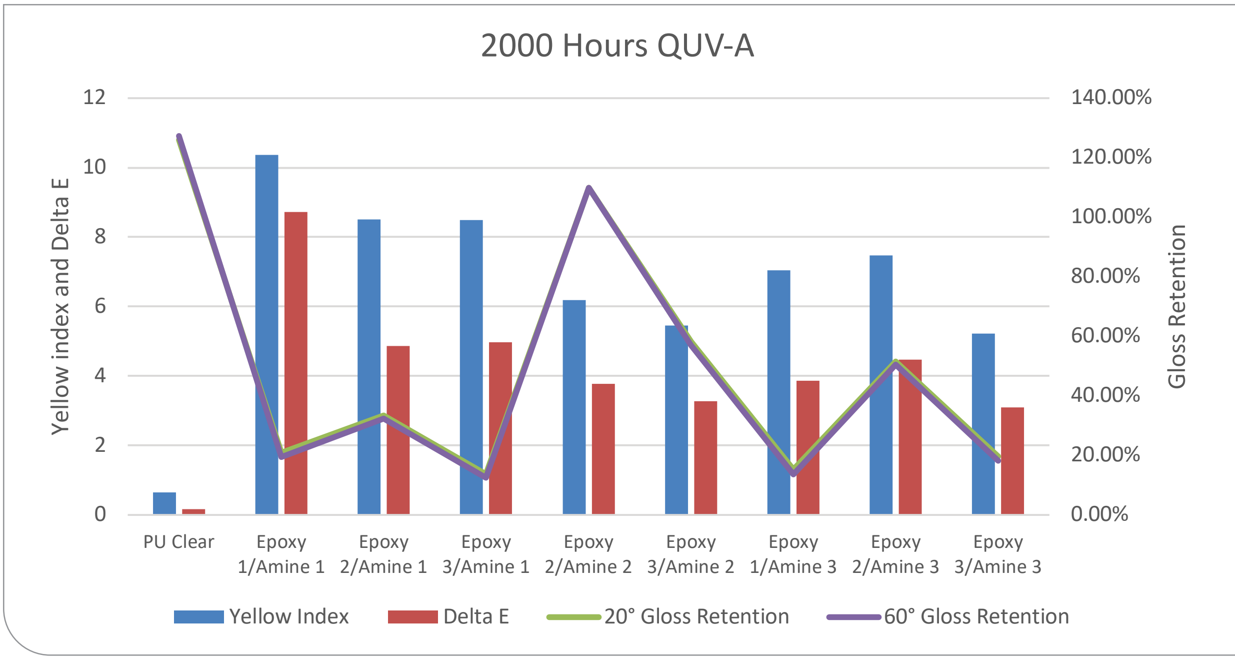



**FIGURE 5**
**A comparison of yellow index, Delta E values, and gloss retention after 2000 hours of QUV-A exposure.**

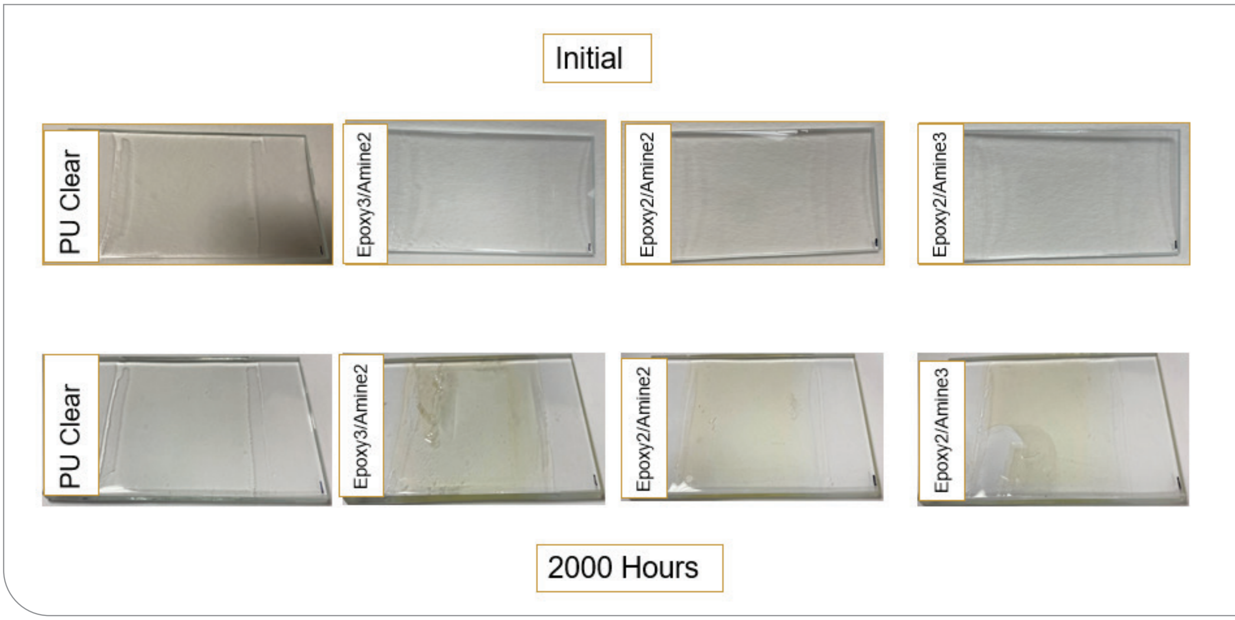



**FIGURE 6**
**Some of the testing panels after 2000 hours QUV-A exposure.**

## Conclusions

Examining all the data, we can see the aromatic type of epoxy resin showed very poor UV resistance, its yellow index is already 26.09 just after 500 hours exposure, and the testing panels were delaminated before reaching 1000 hours. At the same time, cycloaliphatic-type systems showed very good UV resistance even without the use of any UV additives, such as UV absorbers and HALS, unlike PU Clear, the commercial benchmark.

After 2000 hours QUV-A exposure, Epoxy 2/Amine 2—the best experimental formula—has Delta E values less than 4 and gloss retention of more than 100%. Epoxy 3/Amine 2 and Epoxy 2/Amine 3 also exhibit good performance, with Delta E values less than 4 and 5, and gloss retention close to 60% and more than 50%, respectively.

For the curing speed and hardness development, cycloaliphatic-type systems are not as effective as the aromatic type. However, Amine 1 and Epoxy 2 demonstrate the capability of achieving performance comparable to the Control-based system.

The results of all the tests demonstrate that cycloaliphatic epoxy resins and curing agents offer significant advantages over the aromatic systems in terms of low color, excellent gloss retention, and non-yellowing. These benefits offer potential customers the ability to formulate higher performance, enhanced UV-resistant epoxy coatings, potentially eliminating the need for polyurethane or acrylic topcoats. ❊

## Reference

1. Hare, C. H. Protective Coatings. *Fundamentals of Chemistry and Composition*; Technology Publishing Company: Pennsylvania, 1994; Chapter 15, Epoxy Systems.

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