



Torlon[®] AI-10 Coatings

Torlon[®] AI-10 is a soluble polyamide-imide sold in powder form. The polymer is tough, chemically resistant, and thermally stable. It has thermal capabilities similar to many polyimides, at a lower price. Coatings based on Torlon[®] AI-10 have been shown to be cost effective in electrical/ electronic, high-temperature decorative, and corrosion prevention applications.

Magnet wire insulation and protective coatings for printed circuit boards are some of the electrical uses. Industrial applications include primers and decorative topcoats for cookware, appliances, and housewares. Torlon® AI-10 has been combined with fluoropolymers to produce highperformance, low-friction, corrosion-resistant coatings that provide protection to saw blades, gears, carburetor needles, and lawn and garden tools.

Torlon[®] AI-10 is also used for high-strength, high-temperature adhesives. Excellent bond strengths have been observed with stainless steel, aluminum and titanium alloys, and polyimide films.

This bulletin will briefly discuss amide-imide chemistry and the preparation of Torlon[®] Al-10 solutions and coatings based on them. In addition, the performance properties of the coatings, including corrosion resistance, will also be presented.

Product Description and Chemistry

Torlon[®] AI-10 is a reactive polyamide-imide designed to have a relatively low initial molecular weight for easy solubility and application ease. Typical properties of Torlon[®] AI-10 polymer are shown in Table 1.

Table 1: Typical properties of Torlon® AI-10

Property	Value ⁽¹⁾	Test Method ⁽²⁾
Appearance	Yellow powder	
Volatile content	10 %	TTM 6510
Viscosity of solution with 25 % polymer	800 cps	TTM 6520 TTM 6535
Acid number	80 mg KOH/g	TTM 6540

⁽¹⁾ Properties of individual batches will vary within specification limits.

⁽²⁾ Test methods can be provided as necessary.

The polymer is composed of trimellitic, aromatic amide, and aromatic imide moieties. As supplied, approximately 50 % of the polymer is in the un-imidized or amic acid form. When heated, the polymer will undergo cyclization to the imide form. Figure 1 shows the generalized structures for both forms.

Most Torlon[®] AI-10 polymer applications are coatings or films. The powder is dissolved in an appropriate solvent, formulated if desired, applied to a substrate, and then heated to achieve drying and cure.

Figure 1: Structure of Torlon® AI-10



Amic Acid Form

Imide Form

Heat treatment or curing is required to develop the high-performance properties of the polyamide-imide. Three processes occur during curing: removal of the solvent, imidization, and chain extension or molecular weight increase. At 93 °C - 149 °C (200 °F - 300 °F), the imidization reaction occurs through cyclization of the ortho carboxylic acid with the amide to form the five-membered imide ring with the evolution of water. Continued heating at 149 °C - 232 °C (300 °F - 450 °F) will remove most of the solvent with some chain extension occurring. Peak temperatures of 249 °C – 260 °C (480 °F – 500 °F) should be used to remove final traces of solvent and to develop optimum molecular weight and properties. A typical cure schedule for a clear film approximately 0.025 mm (0.001 inch) thick is 60 minutes at 149 °C (300 °F), 15 minutes at 260 °C (500 °F), and 5 minutes at 315 °C (600 °F).

The removal of the evolved water is the factor limiting cure speed. Thin films of uniform thickness can be cured rapidly. In general, if bubbling occurs reduce the rate of temperature increase. Torlon® Al-10 polymer is quite thermally stable, therefore it is quite difficult to "overcure".

Properties of Torlon® AI-10 films

Torlon[®] AI-10 is stronger and tougher than other thermally stable polymers, such as polyimides and polybenzimidazoles. Films made from Torlon[®] AI-10 have high flexural modulus and hardness, low coefficient of friction, and good adhesion.

Torlon[®] Al-10 polymers provide excellent electrical insulating properties at brief excursions to 454 °C (850 °F) without significant damage or severe loss of properties. Magnet wire coated with Torlon[®] Al-10 is rated for 20,000 hours at 225 °C or 437 °F (Class 220, ASTM D 2307). Electrical properties are retained in high humidity. Some typical properties of a cured Torlon[®] Al-10 film are shown in Table 2.

Table 2: Typical Torlon® AI-10 film properties

Property	Value
Color	Light amber
Refractive index	1.656
Glass transition temperature	272 °C (522 °F)
Tensile strength	117 MPa (17,000 psi)
Tensile modulus	3,032 MPa (440,000 psi)
Tensile elongation	23 %

When properly cured, Torlon® AI-10 polymers are highly resistant to most solvents and chemicals. Immersion tests have shown that the following chemicals have little or no effect:

- Acetone
- Benzene
- Dilute acids
- Dimethylacetamide
- Ethanol
- Hydraulic fluids
- Jet fuel
- Methylene chloride
- Perchloroethylene
- Refrigerants Toluene
- Xylene

Mild caustic solutions used at moderate temperatures, such as detergents, will not damage an Torlon® AI-10 film, but strong oxidizing acids, such as fuming sulfuric acid, or strong caustics will cause degradation.

Preparing AI-10 Solutions

Only strong aprotic materials are true solvents for polyamide-imide. Table 3 lists the usual solvents for Torlon® AI-10 polymer and the viscosity of a 32 weight percent solution. Of the listed solvents, N-methyl pyrrolidone (NMP) is preferred because it has low odor and a relatively low level of toxicity.

Table 3: Solvents for Torlon® AI-10

Solvent	Viscosity at 25 °C, poise
Dimethyl acetamide	13-21
Dimethyl sulfoxide	35-60
Dimethylformamide	Poor storage stability
N-methyl pyrrolidone	45-75
Acetone	Insoluble
Formamide	Insoluble

Because the true solvents for Torlon® AI-10 are relatively expensive, lower-cost materials, called diluents, are often used to reduce the viscosity of polyamide-imide solutions. Diluents can only be used within their solubility limits. Table 4 lists typical diluents and the solubility limits.

Table 4: Diluents for Torlon® AI-10 solutions

Diluent	% of Total Solvent (maximum)
Aromatic hydrocarbons	40-50
Ethyl acetate	40-50
Acetone	60
Cycolhexanone	80
Acetanilide	40

To prepare a solution of Torlon® AI-10 in NMP, add the AI-10 powder slowly to the solvent while stirring for 15 to 30 minutes. Continue stirring for 1 to 2 hours and then filter. The solution should be stirred again the day after preparation and again prior to use. Solution viscosity will increase with time; the rate depends upon the solvent used, the polymer concentration, and the storage conditions.

Figure 2: Viscosity vs. storage time*



* AI-10 solution in N-methly pyrrolidone, 35 % polymer

Figure 2 shows the change in viscosity of a 35 wt. % Torlon® Al-10 solution over a four-month period. The viscosity increase is not detrimental to polymer performance. Usually the solution's viscosity can be adjusted with additional solvent and the solution used without loss of performance.

High-Temperature, Corrosion-Resistant, Decorative Enamels

To demonstrate the exceptional performance of enamels based on Torlon[®] Al-10 polymer, our laboratory has formulated four enamels, applied them to various substrates, and evaluated their performance. Prior to preparation of the enamels, a solution of Torlon[®] Al-10 in NMP at a concentration of 35 wt. % polymer was prepared. See Table 5 below.

Table 5: Properties of the Torlon[®] AI-10 solution

 used in enamel preparation

Property	Value
Appearance	Amber liquid
Viscosity ⁽¹⁾ at 25 °C (77 °F)	4,520 centipoise
Density	9.42 pounds/gallon
Actual % polymer	35
Measured % polymer ⁽²⁾	37

⁽¹⁾ ASTM D2196, Brookfield Viscometer, Model HAT, Spindle #2 at 10 rpm

⁽²⁾ Measured by weighing residue after heating 2 grams for 2 hours at 200 °C (392 °F) in an aluminum weighing dish.

The formulations of the enamels are shown in Table 6 and can be considered "starting points" for the development of commercially acceptable coatings.

The enamels were prepared by adding the silicone resin to the Torlon® AI-10 solution and then dispersing the pigments with a high speed disperser to a Hegman 7 grind. Additional solvent was then added to achieve spraying viscosity. The enamels were then spray applied to untreated cold rolled steel, Bonderite B-37 treated steel, and aluminum test panels. All panels were cured for 15 minutes at 260 °C (500 °F). The white and yellow enamels were air flashed for 15 minutes, and the red and green enamels were oven flashed for 10 minutes at 82 °C (180 °F) before curing.

The physical properties of the enamels on the various substrates are shown in Tables 7 through 9. The coatings show excellent adhesion and hardness with very good gloss and flexibility. Also shown is the effect of overbake, exposing the coating to two and three times the normal cure time. This test gives an indication of thermal stability, as well as processing flexibility. After overbake, the only effects observed were slight yellowing and minor loss of flexibility.

Table 10 lists the results of our evaluation of corrosion resistance by the salt spray technique. The results show excellent corrosion resistance, with very little rust creepage, or adhesion loss.

Table 6: Enamel formulations [parts by weight]

Formulation	White	Yellow	Red	Green
AI-10 polymer solution (Table 5)	538.2	577.0	576.9	576.9
Silicone resin ⁽¹⁾	3.4	3.3	3.5	3.5
Titanium dioxide ⁽²⁾	188.3	100.9	100.9	100.9
Red iron oxide ⁽³⁾			30.4	
Nickel titanate yellow ⁽⁴⁾		30.4		
Chrome oxide green ⁽⁵⁾				30.4
Grind on Cowles Dissolver, then add:				
N-methyl pyrrolidone	194.0	207.7	207.6	207.6
150 type aromatic solvent ⁽⁶⁾	76.0	80.8		
Total	1,000.0	1,000.0	1,000.0	1,000.0
Non volatile	38.0	33.7	33.7	33.7
Pigment/binder ratio	1.0	0.65	0.65	0.65

⁽¹⁾ SR-112, General Electric, Silicones Division
 ⁽²⁾ Ti-Pure[®] R-900, E. I. duPont de Nemours and Co.

⁽⁴⁾ #14, Shepard Chemical Company
 ⁽⁵⁾ G-6099, Pfizer Minerals, Pigments and Metals Division

⁽³⁾ R-3200, Pfizer Minerals, Pigments and Metals Division

⁽⁶⁾ Hi-Sol[®], 15, Ashland Chemicals

Table 7: Physical properties of Torlon® AI-10 enamels applied to aluminum

Property	White		Yel	low	R	ed	Gre	een	ASTM Test Method
Hardness, sward	30		18		22		28		D2134
Hardness, pencil	2H		2H		ЗH		4H		D3363
Impact, direct [in-lbs]	3	0	3	80	4	0	30		D2794
Impact, reverse [in-lbs]	2	20	2	20	4	0	3	0	D2794
Crosshatch-adhesion [% pass]	1(00	1(00	100		100		D3359B
Conical bend [% pass]	1(00	1(00	1(00	1(00	D522
Yellowness index	41	1.4	51	1.1					E313
Gloss, 20°	39		4	-8	6	2	7	6	D523
Gloss, 60 °	8	34	8	89		98)2	D523
Overbake* [%]	100	200	100	200	100	200	100	200	
Hardness, sward	22	20	22	26	26	26	24	28	D2134
Hardness, pencil	ЗH	ЗH	2H	ЗH	ЗH	ЗН	ЗН	2H	D3363
Impact, direct [in-lbs]	20	10	20	20	20	30	30	40	D2794
Impact, reverse [in-lbs]	10	10	30	20	30	20	30	30	D2794
Crosshatch-adhesion [% pass]	100	100	100	100	100	100	100	100	D3359B
Conical bend [% pass]	95	95	100	100	100	100	100	100	D522
Yellowness index increase [%]	5	16	5	7					E313
				0.0	07	07	00	07	DE00
Gloss, 20 ⁻ ; retention [%]	103	95	96	96	97	97	96	97	D023

* 15 min at 260 °C (500 °F)

Table 8: Physical properties of Torlon® AI-10 enamels applied to Bonderite 37

									ASTM Test
Property	W	nite	Yel	low	R	Red		een	Method
Hardness, sward	24		28		30		34		D2134
Hardness, pencil	> 5H		> 5H		> 5H		> 5H		D3363
Impact, direct [in-lbs]	1(00	12	120		00	120		D2794
Impact, reverse [in-lbs]	6	60	12	20	5	30	5	60	D2794
Crosshatch-adhesion [% pass]	1(00	1(00	1(00	1(00	D3359B
Conical bend [% pass]	1(00	1(00	ç	90	ę	0	D522
Yellowness index	42	2.4	49	9.6					E313
Gloss, 20°	41		5	57	5	51	4	-6	D523
Gloss, 60 °	92		98		97		98		D523
									1
Overbake* [%]	100	200	100	200	100	200	100	200	
Overbake* [%] Hardness, sward	100 30	200 32	100 22	200 26	100 30	200 32	100 22	200 36	D2134
Overbake* [%] Hardness, sward Hardness, pencil	100 30 > 5H	200 32 > 5H	100 22 > 5H	200 26 > 5H	100 30 > 5H	200 32 > 5H	100 22 > 5H	200 36 > 5H	D2134 D3363
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs]	100 30 > 5H 70	200 32 > 5H 80	100 22 > 5H 100	200 26 > 5H 120	100 30 ≥ 5H 70	200 32 > 5H 60	100 22 > 5H 80	200 36 > 5H 80	D2134 D3363 D2794
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs]	100 30 > 5H 70 20	200 32 > 5H 80 30	100 22 >5H 100 80	200 26 > 5H 120 70	100 30 > 5H 70 40	200 32 > 5H 60 40	100 22 >5H 80 50	200 36 > 5H 80 60	D2134 D3363 D2794 D2794
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass]	100 30 > 5H 70 20 100	200 32 > 5H 80 30 100	100 22 > 5H 100 80 100	200 26 > 5H 120 70 100	100 30 > 5H 70 40 100	200 32 > 5H 60 40 100	100 22 > 5H 80 50 100	200 36 > 5H 80 60 100	D2134 D3363 D2794 D2794 D3359B
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass] Conical bend [% pass]	100 30 > 5H 70 20 100 70	200 32 > 5H 80 30 100 75	100 22 > 5H 100 80 100 90	200 26 > 5H 120 70 100 80	100 30 > 5H 70 40 100 100	200 32 > 5H 60 40 100 100	100 22 > 5H 80 50 100 100	200 36 > 5H 80 60 100 100	D2134 D3363 D2794 D2794 D3359B D522
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass] Conical bend [% pass] Yellowness index increase [%]	100 30 > 5H 70 20 100 70 9	200 32 > 5H 80 30 100 75 8	100 22 > 5H 100 80 100 90 2	200 26 > 5H 120 70 100 80 9	100 30 > 5H 70 40 100 100	200 32 > 5H 60 40 100 100	100 22 > 5H 80 50 100 100	200 36 > 5H 80 60 100 100	D2134 D3363 D2794 D2794 D3359B D522 E313
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass] Conical bend [% pass] Yellowness index increase [%] Gloss, 20 °; retention [%]	100 30 > 5H 70 20 100 70 9 100	200 32 > 5H 80 30 100 75 8 97	100 22 > 5H 100 80 100 90 2 94	200 26 > 5H 120 70 100 80 9 9	100 30 > 5H 70 40 100 100 93	200 32 > 5H 60 40 100 100 96	100 22 > 5H 80 50 100 100 93	200 36 > 5H 80 60 100 100 100	D2134 D3363 D2794 D2794 D3359B D522 E313 D523

*15 min at 260 °C (500 °F)

Table 9: Physical properties of Torlon® AI-10 enamels applied to cold rolled steel

					_		•		ASTM Test
Property	wr	nite	Yel	Yellow		Red		een	Method
Hardness, sward	24		24		32		40		D2134
Hardness, pencil	> 5H		> 5H		> 5H		> 5H		D3363
Impact, direct [in-lbs]	1(00	14	140		60	160		D2794
Impact, reverse [in-lbs]	6	60	1:	20	10	60	160		D2794
Crosshatch-adhesion [% pass]	1(00	1(00	1(00	1(00	D3359B
Conical bend [% pass]	1(00	1(00	1(00	1(00	D522
Yellowness index	49	9.4	54	4.1					E313
Gloss, 20°	39		7	'2	2	11	4	-8	D523
Gloss, 60 °	94		108		ç	99		02	D523
Overbake* [%]	100	200	100	200	100	200	100	200	
Overbake* [%] Hardness, sward	100 26	200 24	100 24	200 30	100 28	200 28	100 26	200 24	D2134
Overbake* [%] Hardness, sward Hardness, pencil	100 26 > 5H	200 24 > 5H	100 24 > 5H	200 30 > 5H	100 28 > 5H	200 28 > 5H	100 26 > 5H	200 24 > 5H	D2134 D3363
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs]	100 26 ≥ 5H 60	200 24 > 5H 60	100 24 > 5H 120	200 30 > 5H 120	100 28 > 5H 100	200 28 > 5H 60	100 26 >5H 120	200 24 > 5H 120	D2134 D3363 D2794
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs]	100 26 > 5H 60 20	200 24 > 5H 60 30	100 24 > 5H 120 70	200 30 > 5H 120 50	100 28 > 5H 100 50	200 28 > 5H 60 40	100 26 > 5H 120 80	200 24 > 5H 120 70	D2134 D3363 D2794 D2794
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass]	100 26 > 5H 60 20 100	200 24 > 5H 60 30 100	100 24 > 5H 120 70 100	200 30 > 5H 120 50 100	100 28 > 5H 100 50 100	200 28 > 5H 60 40 100	100 26 > 5H 120 80 100	200 24 > 5H 120 70 100	D2134 D3363 D2794 D2794 D3359B
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass] Conical bend [% pass]	100 26 > 5H 60 20 100 90	200 24 > 5H 60 30 100 90	100 24 > 5H 120 70 100 100	200 30 > 5H 120 50 100 100	100 28 > 5H 100 50 100 100	200 28 > 5H 60 40 100 100	100 26 > 5H 120 80 100 100	200 24 > 5H 120 70 100 100	D2134 D3363 D2794 D2794 D3359B D522
Overbake* [%] Hardness, sward Hardness, pencil Impact, direct [in-lbs] Impact, reverse [in-lbs] Crosshatch-adhesion [% pass] Conical bend [% pass] Yellowness index increase [%]	100 26 > 5H 60 20 100 90 7	200 24 > 5H 60 30 100 90 5	100 24 > 5H 120 70 100 100 5	200 30 > 5H 120 50 100 100 8	100 28 > 5H 100 50 100 100	200 28 > 5H 60 40 100 100	100 26 > 5H 120 80 100 100	200 24 > 5H 120 70 100 100	D2134 D3363 D2794 D2794 D3359B D522 E313
Overbake* [%]Hardness, swardHardness, pencilImpact, direct [in-lbs]Impact, reverse [in-lbs]Crosshatch-adhesion [% pass]Conical bend [% pass]Yellowness index increase [%]Gloss, 20 °; retention [%]	100 26 > 5H 60 20 100 90 7 98	200 24 > 5H 60 30 100 90 5 97	100 24 > 5H 120 70 100 100 5 97	200 30 > 5H 120 50 100 100 8 8 95	100 28 > 5H 100 50 100 100	200 28 > 5H 60 40 100 100 100	100 26 > 5H 120 80 100 100 100 96	200 24 > 5H 120 70 100 100 100 98	D2134 D3363 D2794 D2794 D3359B D522 E313 D523

*15 min at 260 °C (500 °F)

Table 10: Salt spray resistance of enamels (ASTM B-177)

Property	White		Yellow		R	ed	Green	
Substrate	CRS	B37	CRS	B37	CRS	B37	CRS	B37
Test length [hours]	96	240	96	240	96	240	96	24
Rust creepage [32nds inch]	1	2	2	2	2	1-2	2	1-2
Adhesion loss [32nds inch]	0	1–2	4	1-2	4	0	4	0

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