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 capability similar to many polyimides, at a lower price. Coatings based on AI-10 polymer 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. AI-10 polymer has been combined with fluoropolymers to produce high-performance, 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 solutions of AI-10 polymer 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 Polymer

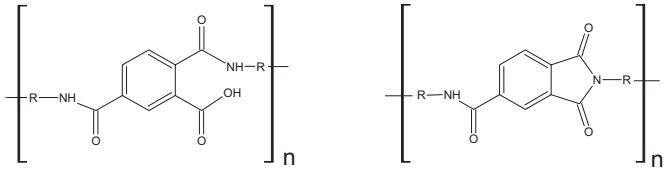
Property	Value[1]	Test Method[2]
Appearance	Yellow Powder	
Volatile Content	10 %	TTM 6510
Viscosity of Solution with 25% polymer	800 cps	TTM 6520, TTM 6535
Acid Number	80 mg KOH/g	TTM 6540

[1] Properties of individual batches will vary within specification limits.

[2] Test methods can be provided as necessary.

Figure 1

Structure of Torlon AI-10 Polymer



Amic Acid Form Imide Form

The polymer is composed of trimellitic , aromatic amide, and aromatic imide moieties. As supplied, approximately 50 percent 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.

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 200°-300°F (93°-149°C), 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 300°-450°F (149°-232°C) will remove most of the solvent with some chain extension occurring. Peak temperatures of 480°-500°F (249°-260°C) 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 0.001 inch (0.025 mm) thick is 60 minutes at 300°F (149°C), 15 minutes at 500°F (260°C), and 5 minutes at 600°F (315°C).

The removal of the evolved water is the factor limiting cure speed. Thin films of uniform thickness can be cured rapidly, but thick films must be cured more slowly or bubbling will occur. In general, if bubbling occurs reduce the rate of temperature increase. Torlon AI-10 polymer is quite thermally stable, therefore it is quite difficult to “overcure”.

Properties Of Torlon AI-10 Polymer Films

AI-10 polymer is stronger and tougher than other thermally stable polymers, such as polyimides and polybenzimidazoles. Films made from AI-10 have high flexural modulus and hardness, low coefficient of friction, and good adhesion. AI-10 polymers provide excellent electrical insulating properties at temperatures from cryogenic to 500°F (260°C), and can survive brief excursions to 850°F (454°C) without significant damage or severe loss of properties. Magnet wire coated with AI-10 is rated for 20,000 hours at 437°F or 225°C (Class 220, ASTM D 2307). Electrical properties are retained in high humidity. Some typical properties of a cured AI-10 film are shown in Table 2.

Table 2

Typical AI-10 Film Properties

Property	Value
Color	Light Amber
Refractive Index	1.656
Glass Transition Temperature	522°F (272°C)
Tensile Strength	17,000 psi (117 MPa)
Tensile Modulus	440,000 psi (3,032 MPa)
Tensile Elongation	23

When properly cured, 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	ethanol	perchloroethylene
benzene	hydraulic fluids	refrigerants
dilute acids	jet fuel	toluene
dimethyl acetamide	methylene chloride	xylene.

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

Preparing AI-10 Polymer Solutions

Only strong aprotic materials are true solvents for polyamide-imide. Table 3 lists the usual solvents for 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 Polymer

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

Because the true solvents for AI-10 polymer 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 AI-10 Polymer Solutions

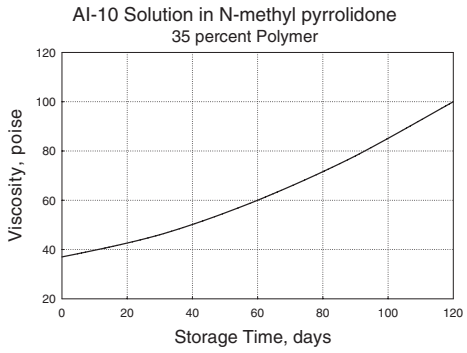
Diluent	% of Total Solvent (maximum)
Aromatic hydrocarbons	40-50
Ethyl acetate	40-50
Acetone	60
Cyclohexanone	80
Acetanilide	40

To prepare a solution of AI-10 polymer in NMP, add the AI-10 powder slowly to the solvent while stirring over a period of 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 shows the change in viscosity of a 35 weight percent AI-10 polymer 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.

Figure 2

Viscosity vs. Storage Time



High-Temperature, Corrosion-Resistant, Decorative Enamels

To demonstrate the exceptional performance of enamels based on Torlon AI-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 AI-10 polymer in NMP at a concentration of 35 weight percent polymer was prepared. The characteristics of that solution are shown in Table 5.

Table 5

Properties of the AI-10 Solution Used in Enamel Preparation

Property	Value
Appearance	amber liquid
Viscosity [1] at 77°F (25°C)	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 392°F (200°C) 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 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 500°F (260°C). The white and yellow enamels were air flashed for 15 minutes before curing, and the red and green enamels were oven flashed for 10 minutes at 180° F (82 ° C) 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

Formulation, parts by weight	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	80.7	80.7
Total	1000.0	1000.0	1000.0	1000.0
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.
[3] R-3200, Pfizer Minerals, Pigments and Metals Division
[4] #14, Shepard Chemical Company
[5] G-6099, Pfizer Minerals, Pigments and Metals Division
[6] Hi-Sol® 15, Ashland Chemicals

Table 7

Physical Properties of AI-10 Enamels Applied to Aluminum

Property	ASTM Test Method	White		Yellow		Red		Green	
Hardness, Sward	D2134	30		18		22		28	
Hardness, Pencil	D3363	2H		2H		3H		4H	
Impact, Direct, in-lbs	D2794	30		30		40		30	
Impact, Reverse, in-lbs	D2794	20		20		40		30	
Crosshatch-Adhesion, % pass	D3359B	100		100		100		100	
Conical Bend, % pass	D522	100		100		100		100	
Yellowness Index (YI)	E313	41.4		51.1					
Gloss, 20°	D523	39		48		62		76	
Gloss, 60°	D523	84		89		98		102	
Overbake, 15 min at 500°F (260°C)									
% Overbake		100	200	100	200	100	200	100	200
Hardness, Sward	D2134	22	20	22	26	26	26	24	28
Hardness, Pencil	D3363	3H	3H	2H	3H	3H	3H	3H	2H
Impact, Direct, in-lbs	D2794	20	10	20	20	20	30	30	40
Impact, Reverse, in-lbs	D2794	10	10	30	20	30	20	30	30
Crosshatch-Adhesion, % pass	D3359B	100	100	100	100	100	100	100	100
Conical Bend, % pass	D522	95	95	100	100	100	100	100	100
Yellowness Index Increase, %	E313	5	16	5	7				
Gloss Retention, 20°, %	D523	103	95	96	96	97	97	96	97
Gloss Retention, 60°, %	D523	100	102	101	97	101	100	100	100

Table 8

Physical Properties of AI-10 Enamels Applied to Bonderite 37

Property	ASTM Test Method	White		Yellow		Red		Green	
Hardness, Sward	D2134	24		28		30		34	
Hardness, Pencil	D3363	>5H		>5H		>5H		>5H	
Impact, Direct, in-lbs	D2794	100		120		100		120	
Impact, Reverse, in-lbs	D2794	60		120		80		80	
Crosshatch-Adhesion, % pass	D3359B	100		100		100		100	
Conical Bend, % pass	D522	100		100		90		90	
Yellowness Index (YI)	E313	42.4		49.6					
Gloss, 20°	D523	41		57		51		46	
Gloss, 60°	D523	92		98		97		98	
Overbake 15 min at 500°F (260°C									
% Overbake		100	200	100	200	100	200	100	200
Hardness, Sward	D2134	30	32	22	26	30	32	22	36
Hardness, Pencil	D3363	>5H	>5H	>5H	>5H	>5H	>5H	>5H	>5H
Impact, Direct, in-lbs	D2794	70	80	100	120	70	60	80	80
Impact, Reverse, in-lbs	D2794	20	30	80	70	40	40	50	60
Crosshatch-Adhesion, % pass	D3359B	100	100	100	100	100	100	100	100
Conical Bend, % pass	D522	70	75	90	80	100	100	100	100
Yellowness Index Increase, %	E313	9	8	2	9				
Gloss Retention, 20°, %	D523	100	97	94	97	93	96	93	100
Gloss Retention, 60°, %	D523	99	99	96	99	100	100	101	100

Table 9

Physical Properties of AI-10 Enamels Applied to Cold Rolled Steel

Property	ASTM Test Method	White		Yellow		Red		Green	
Hardness, Sward	D2134	24		24		32		40	
Hardness, Pencil	D3363	>5H		>5H		>5H		>5H	
Impact, Direct, in-lbs	D2794	100		140		160		160	
Impact, Reverse, in-lbs	D2794	60		120		160		160	
Crosshatch-Adhesion, % pass	D3359B	100		100		100		100	
Conical Bend, % pass	D522	100		100		100		100	
Yellowness Index (YI)	E313	49.4		54.1					
Gloss, 20°	D523	39		72		41		48	
Gloss, 60°	D523	94		108		99		102	
Overbake, 15 min at 500°F (260°C)									
% Overbake		100	200	100	200	100	200	100	200
Hardness, Sward	D2134	26	24	24	30	28	28	26	24
Hardness, Pencil	D3363	>5H	>5H	>5H	>5H	>5H	>5H	>5H	>5H
Impact, Direct, in-lbs	D2794	60	60	120	120	100	60	120	120
Impact, Reverse, in-lbs	D2794	20	30	70	50	50	40	80	70
Crosshatch-Adhesion, % pass	D3359B	100	100	100	100	100	100	100	100
Conical Bend, % pass	D522	90	90	100	100	100	100	100	100
Yellowness Index Increase, %	E313	7	5	5	8				
Gloss Retention, 20°, %	D523	98	97	97	95	97	97	96	98
Gloss Retention, 60°, %	D523	100	99	100	99	100	100	100	100

Table 10

Salt Spray Resistance of Enamels (ASTM B-177)

		White		Yellow		Red		Green	
Substrate		**CRS**	**B37**	**CRS**	**B37**	**CRS**	**B37**	**CRS**	**B37**
Test Length, hours		**96**	**240**	**96**	**240**	**96**	**240**	**96**	**240**
Property	**Units**								
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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