Chemical Resistance for Ambient Cure Epoxy Formulations

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Epoxy formulations are frequently chosen over other systems when chemical resistance is an important attribute. The resistance of the cured epoxy system will depend on the curing agent, resin, diluent, and additives chosen. Formulators usually need to develop products where attributes in addition to chemical resistance are important, so understanding the trade off and choices involved is critical.

Evonik offers numerous products to help epoxy formulators achieve the desired results. This bulletin reviews choices in both epoxy curing agents and resins, and includes recommendations to provide specific chemical resistance while addressing the influence on other key attributes. Some application areas where this information and these products will be most useful are tank linings, flooring, secondary containment, maintenance coatings, marine coatings, mortars, and grouts.

The format includes summary sections on curing agent and resin selection, and the appendices include detailed data for the curing agent and resin combinations evaluated.

CURING AGENT SELECTION

The selection of a curing agent to be used in a chemically resistant epoxy formulation can be difficult and time consuming. Amine curing agents for chemically resistant epoxy systems can be separated into three basic categories:

- Aliphatic amine curing agents
- Cycloaliphatic amine curing agents
- Aromatic amine curing agents

Historically, aromatic amine curing agents, specifically those based on methylene-dianiline (MDA), were used in epoxy formulations to achieve excellent resistance to solvents, mineral acids and organic acids. However, regulation of aromatic amines, such as MDA, has prompted formulators to consider alternative curing agents.

Cycloaliphatic amine-cured systems can offer handling, resistance to aqueous solutions, resistance to solvents, and resistance to mineral acids comparable to aromatic amine-cured systems. Therefore, cycloaliphatic amine curing agents are now commonly used in chemically resistant epoxy systems.

Key Factors
In selecting an epoxy curing agent for a chemically resistant formulation, a number of factors must be taken into consideration, including:

- Classes of chemicals to which resistance is required
- Degree of resistance required (i.e., impervious versus minimum penetration)
- Duration of resistance required
- Processing and application requirements
- Appearance, color and weatherability

AMINE CURING AGENTS FOR CHEMICALLY RESISTANT SYSTEMS

Evonik offers a range of modified cycloaliphatic amines and modified aliphatic amines for use as curing agents in ambient cure epoxy formulations. Curing agents designed specifically for use in ambient cure chemically resistant systems are:

- Ancamine® 2280
- Ancamine® 2422
- Ancamine® 2423
- Ancamine® 1618
- Ancamine® 2143
- Ancamine® 2286
- Ancamine® 2432
- Ancamine® 1693

Each of these curing agents offers distinct handling or performance advantages over the others. In some cases, additional performance advantages can be obtained by modifying or blending the curing agents. For example, a cycloaliphatic amine can be modified with 10% to 30% by weight of a modified aliphatic amine, such as Ancamine 2432 curing agent, for faster cure and improved solvent resistance.

Ancamine 2280 curing agent is the standard for chemically resistant epoxy formulations; it imparts very good resistance to a wide range of acids, solvents and alcohols. However, an Ancamine 2280 cured system may not offer sufficient resistance to specific chemicals for specialty applications. Ancamine 2432 curing agent offers the highest overall chemical resistance. Figure 1 illustrates how other curing agents can be chosen as alternatives to Ancamine 2280 to impart improved resistance to specific chemicals.

In applications requiring better solvent resistance, Ancamine 2432 or an 8:2 blend of Ancamine 2280 with an aliphatic amine (such as Ancamine 2432, 1608, or 1638) can give improved performance compared to Ancamine 2280 curing agent alone.

For organic acid (such as lactic and acetic acid), Ancamine 2423 and Ancamine 2432 curing agents give better resistance than Ancamine 2280. Improved resistance to alcohols can be obtained with Ancamine 2432 or Ancamine 1693 curing agent.

For improved MEK (methyl ethyl ketone) resistance, Ancamine 2432 or Ancamine 1693 are recommended. In ambient cure systems exposed to chemicals at elevated temperatures, Ancamine 2280 can be modified with Ancamine 2432 curing agent for improved resistance. For the best resistance to chemicals at elevated temperatures with an ambient cure system, we recommend Ancamine 2422 curing agent with multifunctional epoxy novolac resins. Refer to the Ancamine 2422 technical data sheet for specific performance data and formulating guidelines.

For the best resistance to chlorinated solvents (such as methylene chloride), Ancamine 2422 curing agent with multifunctional epoxy novolac resins is recommended. The Ancamine 2422 systems also have good resistance to other very aggressive reagents such as 30% nitric acid and phenol. Refer to the Ancamine 2422 technical data sheet for specific performance data and formulating guidelines.

Appendix A shows detailed immersion test data for the curing agents with various epoxy resins in a wide range of chemicals.

FIGURE 1: CURING AGENT SELECTION FOR BEST CHEMICAL RESISTANCE IN AMBIENT CURE FORMULATIONS

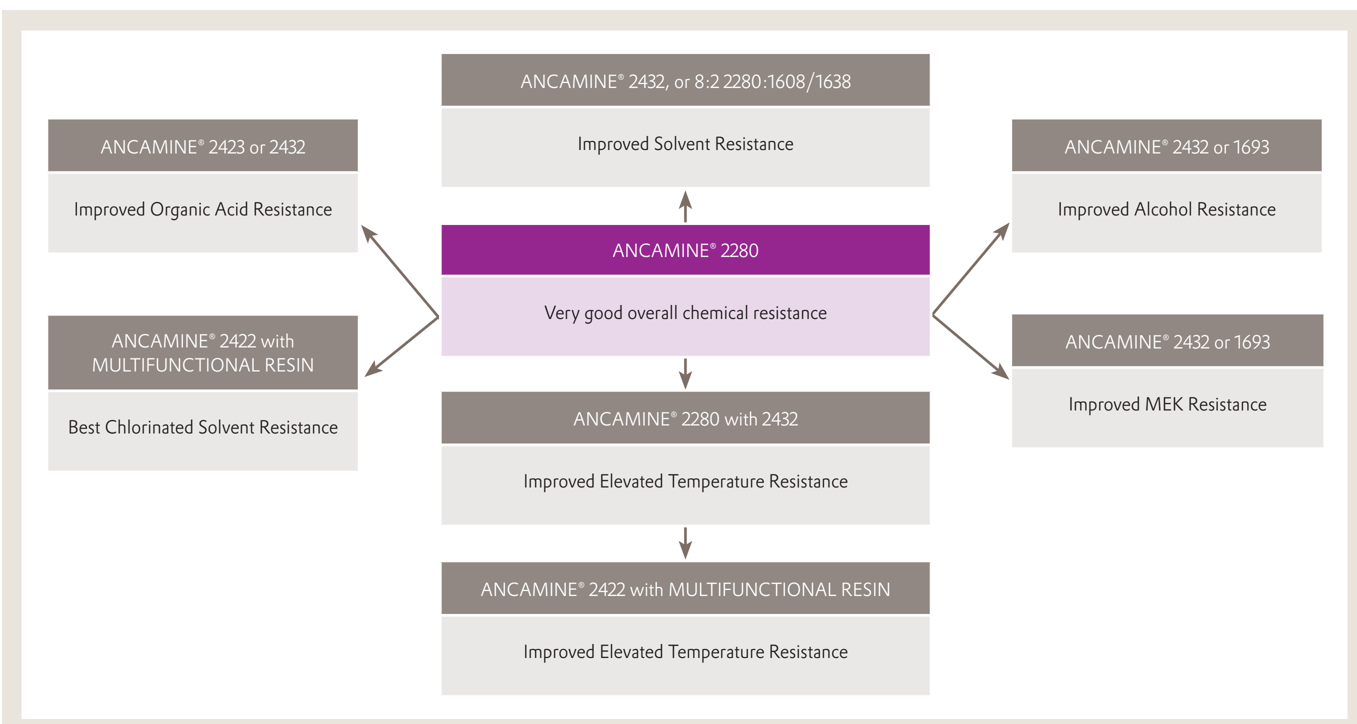


TABLE 1: HANDLING OF CURING AGENTS WITH BISPHENOL-A BASED (EEW=190) EPOXY RESIN

Curing Agent	Curing Agent Viscosity[1] (cP)	Mixed Viscosity[1] (cP)	Gel Time[2], min. (150 g mass)	Thin Film Set Time,[3] tack free (h)	60° Film Gloss[4]
Ancamine 2280	450	3,300	50	6.0	105
Ancamine 2432	300	2,100	27	2.0	109
Ancamine 2143	600	1,600	42	7.0	103
Ancamine 1618	400	2,400	50	5.5	118
Ancamine 2423	1,200	4,300	17	3.5	120
Ancamine 1693	100	1,700	52	9.0	18
Ancamine 2286	60	1,700	40	6.0	79

Note: All data at 77°F (25°C). Please see last page for footnotes.

CHEMICAL RESISTANCE IN CONJUNCTION WITH OTHER ATTRIBUTES

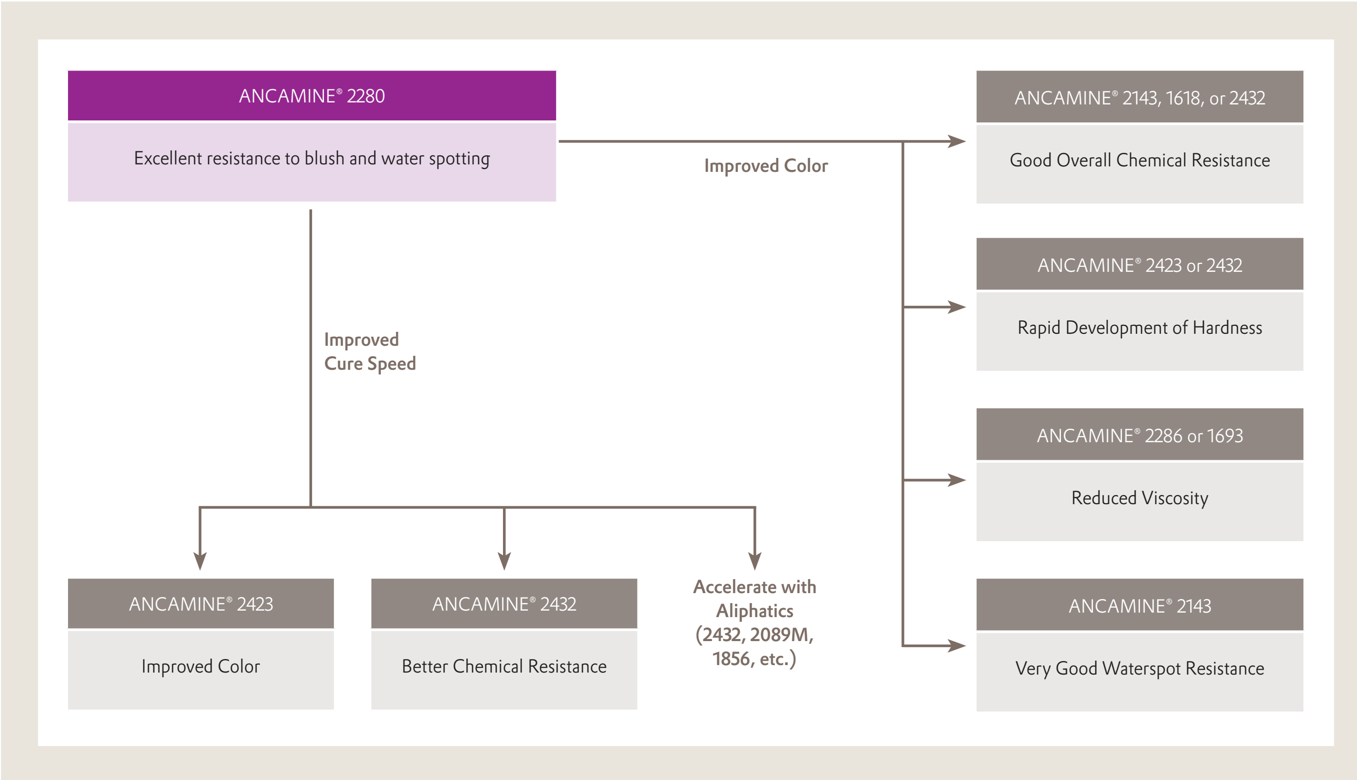
In many applications, an epoxy system must have good chemical resistance in addition to other attributes such as waterspot resistance, low color, rapid development of hardness, or low temperature cure. Table 1 shows the handling and reactivity characteristics of the curing agents formulated with standard bisphenol-A based (DGEBA) liquid epoxy resin. Data describing handling of the curing agents with alternative epoxy resins are shown in Appendix B.

Ancamine 2280 offers the best resistance to amine blush and waterspotting; it also gives very good through cure at low temperatures. The selection chart shown in Figure 2 offers guidelines in choosing a chemically resistant curing agent when specific improvements in performance relative to Ancamine 2280 are required.

For improved cure speed, curing agents can be accelerated with modified aliphatic amines (such as Ancamine 2432, 2089M, 1856, 2205, 1608, or 1638) while maintaining good chemical resistance. Ancamine 2432 should be used as the accelerator for maximum chemical resistance. Appendix C provides additional data on acceleration and hardness development.

All of the curing agents shown in Figure 2 provide good chemical resistance. However, selecting a curing agent for improved properties can result in lower resistance to certain chemicals compared with Ancamine 2280. Resistance to acids and alcohols may be lower with Ancamine 2143, 1618, or 2286 than with Ancamine 2280. Ancamine 2423 curing agent may show lower solvent and alcohol resistance than Ancamine 2280. In some applications, the reduction in chemical resistance can be minimized with proper epoxy resin selection (see "Epoxy Resin Selection," page 4, and data in Appendix A). Ancamine 2432 curing agent offers comparable or better resistance to most chemicals than Ancamine 2280.

FIGURE 2: CHEMICALLY RESISTANT CURING AGENT SELECTION: ADDITIONAL PERFORMANCE CHARACTERISTICS



EPOXY RESIN SELECTION

Once the curing agent has been selected, the next step in formulating a chemically resistant epoxy system is to select the epoxy resin that best meets both handling and performance requirements. The most commonly used epoxy resins are diglycidyl ether of bisphenol-A (DGEBA) liquid epoxy resins. Bisphenol-A based epoxy resins are available in a wide range of molecular weights. The standard bisphenol-A epoxy resin is a moderate viscosity liquid with an epoxide equivalent weight of approximately 190 and a functionality of ~2. When cured, bisphenol-A epoxy resins exhibit resistance to a wide range of chemicals.

In specialty applications, the bisphenol-A epoxy resins may not offer sufficient resistance to solvents or to concentrated mineral acids. In these applications, either diglycidyl ether of bisphenol-F (DGEBF) liquid epoxy resin or a blend of bisphenol-F epoxy resin and a multifunctional novolac epoxy resin can be used. Difunctional bisphenol-F epoxy resin is typically a low viscosity liquid with an epoxide equivalent weight of approximately 172. Multifunctional novolac epoxy resins are typically high viscosity epoxy resins that can be difficult to use without modification in epoxy formulations. However, mixing a typical multifunctional novolac epoxy resin (EEW~176) with a low viscosity bisphenol-F epoxy resin (EEW~172) can result in an epoxy resin equivalent in viscosity to standard bisphenol-A epoxy resin.

Finally, using a cresyl glycidyl ether (CGE-Epodil® 742) diluted bisphenol-A epoxy resin improves handling and film appearance compared to unmodified bisphenol-A epoxy resins while limiting the detrimental effect monofunctional diluents can have on chemical resistance.

Thus, bisphenol-A, bisphenol-F, multifunctional novolac, and CGE diluted epoxy resins can all be used in formulating chemically resistant systems. Identifying specific handling and performance requirements will help to determine which epoxy resin is best suited for a given application. Figure 3 offers guidelines for choosing the right resin. Detailed data describing the chemical resistance of the amine-cured formulations with alternative epoxy resins are included in Appendix A, and data describing formulation handling with alternative epoxy resins are described in Appendix B.

FIGURE 3: EPOXY RESIN SELECTION

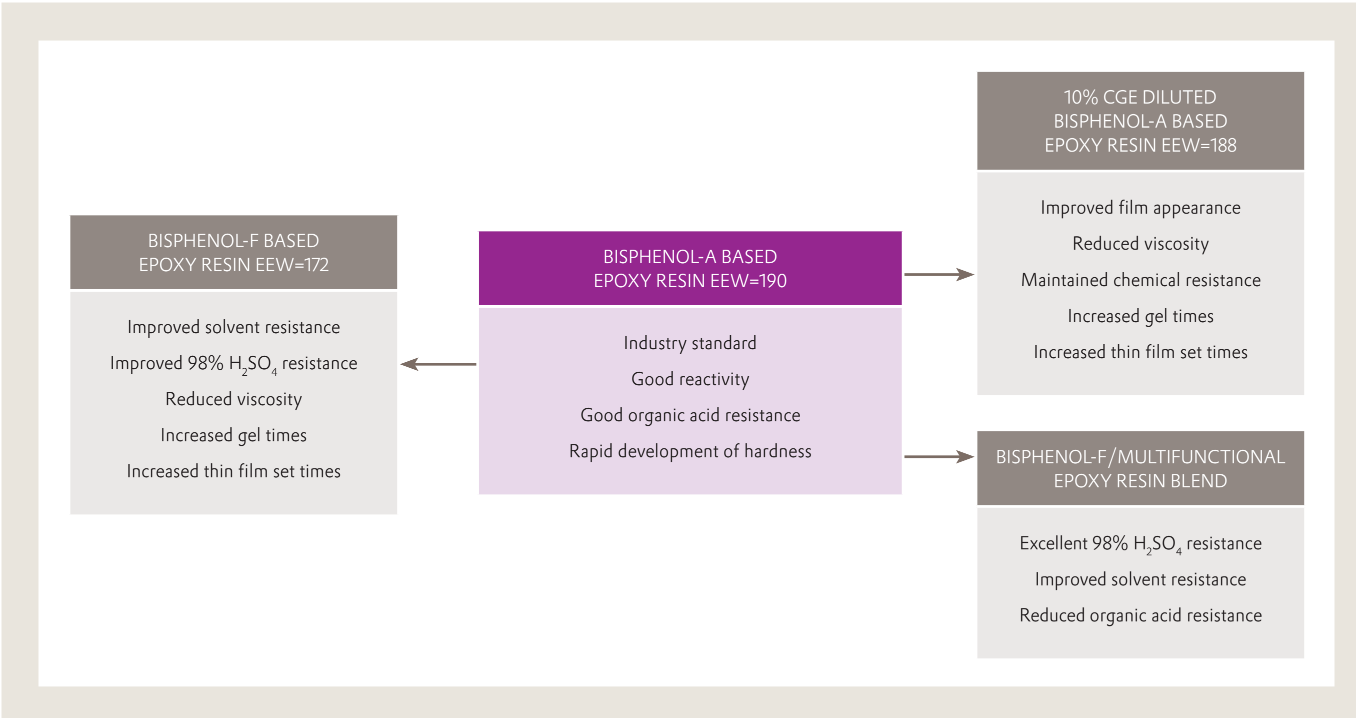


TABLE 2: CHEMICAL RESISTANCE FOR AMBIENT CURED FORMULATIONS WITH BISPHENOL-A BASED (EEW=190) EPOXY RESIN

Reagent	% Weight Change as a Function of Time									
	Ancamine 2280		Ancamine 2432		Ancamine 2143		Ancamine 1618		Ancamine 2423	
	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days
Deionized Water	0.52	1.55	0.33	1.11	0.41	1.39	0.49	1.50	0.31	1.12
Methanol	**9.38**	7.16	**6.38**	9.55	10.20	8.07	7.93	-2.41	D@3	D@3
Ethanol	**2.41**	6.92	**1.55**	4.68	2.95	7.96	3.98	10.28	6.57	D@14
Toluene	0.05	2.26	**0.17**	0.99	0.53	2.79	0.40	2.86	1.32	19.20
Xylene	0.02	0.20	0.25	0.69	0.01	0.17	0.04	0.19	0.08	1.52
Butyl Cellosolve	**0.56**	2.41	**0.31**	1.18	**0.79**	3.15	1.65	5.31	4.12	13.78
Methyl Ethyl Ketone (MEK)	17.17	D@28	**9.35**	11.19	21.48	D@5	D@3	D@3	D@1	D@1
10% Lactic Acid	**0.76**	2.99	1.10	3.24	3.08	9.52	1.81	5.42	**0.50**	1.70
10% Acetic Acid	1.70	5.64	**1.23**	3.85	5.29	14.85	2.92	8.23	**0.90**	2.85
70% Sulfuric Acid	0.01	0.36	0.10	0.13	0.20	0.37	0.08	0.14	0.04	0.11
98% Sulfuric Acid	D@1	D@1	NT	NT	D@1	D@1	D@1	D@1	D@1	D@1
50% Sodium Hydroxide	-0.05	-0.09	0.04	0.09	0.04	0.00	-0.01	-0.04	-0.04	-0.02
10% Sodium Hypochlorite	0.49	1.16	0.27	0.93	0.42	1.08	0.51	1.36	0.11	0.78
1,1,1 Trichloroethane	-0.02	0.64	0.18	0.43	**0.02**	0.20	**0.02**	-0.02	0.59	5.74

Note: Samples cured for 7 days at 77°F (25°C) before testing. Tested in accordance with ASTM D543-84.

APPENDIX A: CHEMICAL RESISTANCE FOR AMBIENT CURE EPOXY FORMULATIONS: IMMERSION DATA

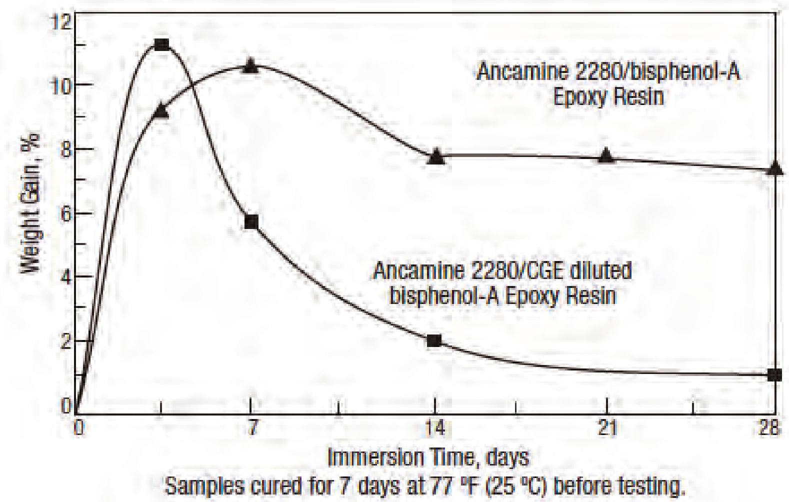
Chemical immersion studies, in accordance with ASTM D543, were conducted using formulations cured 7 days at 77°F (25°C). One inch by three inch (1″ x 3″) samples of 1/8″ thick castings were prepared and fully immersed in the reagents. Three samples of each formulation were immersed in each reagent. Chemical resistance is reported as the average percentage weight change as a function of time for 77°F (25°C) immersion.

For comparative chemical resistance immersion data to be useful, both the mechanism of chemical attack (swelling, sample degradation, etc.) and the weight change of the samples as a function of time must be considered. For example, consider Ancamine 2280 cured formulations with bisphenol-A epoxy resin and CGE diluted bisphenol-A epoxy resin immersed in methanol. Weight change as a function of time is shown in Figure 4 for both of these formulations. Simply comparing the 28 day immersion data, the Ancamine 2280 cured CGE diluted bisphenol-A epoxy resin may appear more resistant to methanol than Ancamine 2280 cured bisphenol-A epoxy resin. However, the CGE diluted bisphenol-A epoxy resin formulation actually exhibits a higher maximum weight gain followed by sample degradation in the form of weight loss. In addition, the CGE diluted bisphenol-A epoxy resin formulation swells much more rapidly than the bisphenol-A epoxy resin formulation. Thus, in cases involving aggressive chemical attack, examining both the short term and long term immersion data gives a better picture of comparative chemical resistance. When comparing data for formulations immersed in reagents such as methanol, MEK, and 98% sulfuric acid, weight gain as a function of time must be examined to more fully understand the resistance exhibited by the formulation and the type of chemical attack that occurs. In compiling the immersion data, we have included 3-day and 28-day weight change data for each formulation. Tables 2 through 5 detail the 3-day and 28- day chemical resistance results of various Ancamine curing agents, with each resin, immersed in key reagents. Table 6 includes the chemical resistance results for aliphatic amine-modified Ancamine 2280 and 2143 with bisphenol-A epoxy resin, EEW=190.

To simplify interpretation of the data, 3-day results for the best recommendations with the most aggressive reagents for each resin are listed in bold. All of the curing agents give excellent resistance to water, 70% sulfuric acid, 50% sodium hydroxide, and 10% sodium hypochlorite.

Ancamine 2422 curing agent formulated with multifunctional epoxy novolac resins offers the best resistance to very aggressive reagents. Please refer to the Ancamine 2422 data sheet for immersion test results with these formulations.

FIGURE 4: WEIGHT CHANGE AS A FUNCTION OF TIME



Ancamine 1693		Ancamine 2286	
3 days	28 days	3 days	28 days
0.53	1.59	0.52	1.51
8.46	8.21	11.74	5.07
1.97	5.57	3.76	10.35
1.37	—	0.44	2.12
0.11	1.67	0.04	0.18
0.98	3.61	2.02	5.86
15.62	11.88	D@3	D@3
0.65	2.38	2.20	6.55
1.68	5.62	3.32	9.27
0.06	-0.05	0.11	0.05
D@1	D@1	D@1	D@1
0.01	-0.04	0.64	0.54
0.54	1.26	0.47	1.22
3.02	15.91	0.02	0.23

NT= not tested. D@X – Destroyed at X days.

TABLE 3: CHEMICAL RESISTANCE FOR AMBIENT CURED FORMULATIONS WITH BISPHENOL-F BASED (EEW=172) EPOXY RESIN

Reagent	% Weight Change as a Function of Time									
	Ancamine 2280		Ancamine 2432		Ancamine 2143		Ancamine 1618		Ancamine 2423	
	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days
Deionized Water	0.68	1.73	0.43	1.30	0.35	1.39	0.58	1.74	0.35	1.30
Methanol	8.85	1.91	**6.79**	4.15	**9.00**	6.44	13.01	D@5	14.26	D@7
Ethanol	**1.97**	6.02	**1.26**	3.47	2.16	6.91	3.61	9.58	18.48	D@7
Toluene	**0.00**	0.72	**0.12**	0.37	0.05	1.82	0.05	0.78	0.02	3.17
Xylene	0.02	0.02	NT	NT	-0.01	0.32	0.11	0.09	NT	NT
Butyl Cellosolve	0.30	1.08	NT	NT	0.33	1.46	1.03	3.62	NT	NT
Methyl Ethyl Ketone (MEK)	D@3	D@3	**7.29**	7.87	**15.34**	9.70	16.63	D@5	D@1	D@1
10% Lactic Acid	**0.92**	3.35	NT	NT	2.92	7.03	1.51	4.80	**0.99**	3.20
10% Acetic Acid	2.29	6.77	**1.36**	3.71	5.05	14.13	2.29	6.95	**1.68**	5.31
70% Sulfuric Acid	0.10	0.18	NT	NT	—	0.17	0.11	0.45	NT	NT
98% Sulfuric Acid	**1.17**	-1.42	**0.62**	-0.01	1.57	—	0.77	-9.32	4.63	-15.57
50% Sodium Hydroxide	0.01	-0.02	NT	NT	-0.09	-0.15	-0.01	-0.01	NT	NT
10% Sodium Hypochlorite	0.57	1.24	NT	NT	0.29	0.94	0.54	1.48	NT	NT
1,1,1 Trichloroethane	0.04	0.36	NT	NT	0.02	0.36	0.02	0.29	NT	NT

Note: Samples cured for 7 days at 77°F (25°C) before testing. Tested in accordance with ASTM D543-84.

TABLE 4: CHEMICAL RESISTANCE FOR AMBIENT CURED FORMULATIONS WITH BISPHENOL-F/NOVOLAC RESIN BLEND*

Reagent	% Weight Change as a Function of Time									
	Ancamine 2280		Ancamine 2432		Ancamine 2143		Ancamine 1618		Ancamine 2423	
	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days
Deionized Water	0.55	1.61	0.48	1.43	0.48	1.36	0.59	1.68	0.36	1.33
Methanol	**8.94**	8.76	**6.82**	7.07	9.05	10.50	11.88	1.26	D@3	D@3
Ethanol	**1.92**	5.19	**1.24**	3.45	2.09	6.10	2.98	8.58	17.02	D@7
Toluene	**0.05**	0.56	**0.15**	0.36	5.07	5.63	4.99	0.68	0.13	4.35
Xylene	0.00	0.09	NT	NT	0.01	0.24	-0.03	0.05	NT	NT
Butyl Cellosolve	0.25	0.97	NT	NT	0.32	1.24	0.75	2.80	NT	NT
Methyl Ethyl Ketone (MEK)	15.70	D@5	**6.40**	6.74	**12.75**	9.00	**18.25**	13.20	D@1	D@1
10% Lactic Acid	**1.06**	3.35	NT	NT	3.31	9.56	1.75	5.09	**0.87**	2.78
10% Acetic Acid	**2.25**	6.64	**1.57**	4.19	5.88	16.57	2.83	7.68	**1.46**	4.55
70% Sulfuric Acid	0.03	0.08	NT	NT	0.08	0.30	0.22	0.35	NT	NT
98% Sulfuric Acid	**0.46**	-1.63	**0.72**	0.45	0.67	-3.32	0.36	-6.10	7.51	-24.29
50% Sodium Hydroxide	-0.01	-0.04	NT	NT	-0.01	-0.01	-0.04	-0.05	NT	NT
10% Sodium Hypochlorite	0.55	1.24	NT	NT	0.44	1.17	0.51	1.31	NT	NT
1,1,1 Trichloroethane	0.07	0.35	NT	NT	0.04	0.22	0.05	0.34	NT	NT

*60% by weight bisphenol-F based epoxy resin, EEW=172, and 40% by weight epoxy novolac resin, EEW=176.
Note: Samples cured for 7 days at 77 °F (25 °C) before testing. Tested in accordance with ASTM D543-84.

Ancamine 1693		Ancamine 2286	
3 days	28 days	3 days	28 days
0.55	1.62	0.48	1.63
7.29	7.28	12.26	D@5
1.42	4.25	3.37	9.22
0.13	1.98	**0.07**	0.37
-0.03	0.10	0.04	0.09
0.28	0.98	1.05	3.30
14.30	5.33	19.28	D@5
0.84	2.94	2.84	8.05
1.92	6.58	3.85	10.77
0.03	-4.32	0.17	0.44
1.86	-3.20	1.53	-9.75
-0.04	-0.12	0.03	0.02
0.46	1.14	0.50	1.27
0.01	0.20	-0.01	0.12

NT= not tested. D@X – Destroyed at X days.

Ancamine 1693		Ancamine 2286	
3 days	28 days	3 days	28 days
0.62	1.71	0.53	1.69
8.25	9.69	11.97	2.50
1.62	4.59	3.03	8.70
0.06	1.32	**0.07**	0.61
0.02	0.05	-0.01	0.09
0.35	1.11	0.84	2.92
14.63	4.54	20.00	11.75
1.12	3.46	3.24	8.70
2.50	7.51	4.50	12.69
0.04	0.11	0.18	0.65
0.65	0.27	0.58	-4.46
-0.11	-0.25	-0.02	-0.04
0.43	0.94	0.56	1.48
0.05	1.07	0.04	0.24

NT = not tested. D@X – Destroyed at X days.

TABLE 5: CHEMICAL RESISTANCE FOR AMBIENT CURED FORMULATIONS WITH 10% CGE DILUTED BISPHENOL-A BASED EPOXY RESIN, EEW=188

Reagent	% Weight Change as a Function of Time									
	Ancamine 2280		Ancamine 2143		Ancamine 1618		Ancamine 1693		Ancamine 2286	
	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days
Deionized Water	0.57	1.55	0.43	1.32	0.53	1.53	0.47	1.39	0.45	1.51
Methanol	11.22	1.11	10.85	2.50	12.90	2.52	9.09	6.25	14.29	5.90
Ethanol	3.11	7.38	3.14	8.94	4.26	10.01	2.25	5.81	4.62	12.08
Toluene	0.23	3.24	0.44	3.81	0.46	5.64	2.62	22.15	0.29	2.75
Xylene	0.02	0.12	0.04	0.27	0.04	0.58	0.40	2.87	0.03	0.19
Butyl Cellosolve	0.99	3.17	1.07	4.30	1.97	7.74	1.37	4.48	2.36	8.92
Methyl Ethyl Ketone (MEK)	16.17	D@5	21.38	14.97	D@1	D@1	16.12	11.45	D@1	D@1
10% Lactic Acid	0.97	3.03	2.43	7.40	0.92	3.04	0.72	2.39	1.87	6.01
10% Acetic Acid	2.14	6.30	4.31	12.46	1.95	5.95	1.69	5.25	2.90	8.68
70% Sulfuric Acid	0.06	0.13	0.05	0.09	0.02	0.10	-0.05	-0.17	0.16	0.16
98% Sulfuric Acid	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1
50% Sodium Hydroxide	-0.02	-0.09	0.04	-0.05	-0.03	-0.09	-0.21	-0.33	0.00	-0.03
10% Sodium Hypochlorite	0.59	1.24	0.40	1.19	0.51	1.33	0.48	1.23	0.39	1.25
1,1,1 Trichloroethane	0.03	0.24	0.03	0.27	0.05	0.32	0.01	0.40	0.03	0.47

Note: Samples cured for 7 days at 77 °F (25 °C) before testing. Tested in accordance with ASTM D543-84.
NT= not tested. D@X – Destroyed at X days.

TABLE 6: CHEMICAL RESISTANCE FOR ALIPHATIC AMINE MODIFIED FORMULATIONS WITH BISPHENOL-A EPOXY RESIN, EEW=190

Reagent	% Weight Change as a Function of Time											
	8:2 2280:1608		8:2 2280:1638		8:2 2280:TETA		9:1 2280:TETA		8:2 2143:TETA		9:1 2143:TETA	
	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days	3 days	28 days
Deionized Water	0.44	1.29	0.40	1.25	0.36	1.20	0.47	1.26	0.32	1.16	0.32	1.08
Methanol	8.55	10.83	7.91	10.11	7.44	12.07	8.36	14.15	7.21	14.06	7.95	16.54
Methyl Ethyl Ketone (MEK)	D@1	D@1	25.69	D@7	D@3	D@3	D@1	D@1	25.91	17.54	D@1	D@1
10% Acetic Acid	2.21	5.90	2.67	6.76	4.16	10.52	1.54	5.13	10.73	25.84	2.95	9.51
98% Sulfuric Acid	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1	D@1

Note: Samples cured for 7 days at 77°F (25°C) before testing. Tested in accordance with ASTM D543-84.
NT= not tested. D@X – Destroyed at X days.

APPENDIX B: HANDLING OF FORMULATIONS WITH ALTERNATIVE EPOXY RESINS AND HANDLING OF ALIPHATIC AMINE MODIFIED FORMULATIONS

Handling and appearance of some of the curing agents in stoichiometric formulations with alternative epoxy resins were characterized. Brookfield viscosity of the curing agent, Brookfield viscosity of the formulation 4 minutes after mixing, gel time for 150 g mass, thin film set time for 3 mil films on glass, and 60° film gloss of 10 mil films on cold rolled steel panels cured 7 days at 77°F (25°C)/50% relative humidity were measured. Results are shown in Tables 7 to 9. Table 10 shows handling characteristics of formulations with aliphatic amine modified curing agents.

TABLE 7: HANDLING OF CURING AGENTS WITH BISPHENOL-F BASED EPOXY RESIN, EEW=172

Curing Agent	Curing Agent Viscosity (cP)[1]	Mixed Viscosity (cP)[1]	150 g mass Gel Time (min)[2]	Thin Film Set Time,[3] tack free (h)	60° Film Gloss[4]
Ancamine 2280	450	1,640	63	7.5	125
Ancamine 2143	600	1,450	59	6.5	113
Ancamine 1618	400	1,960	58	7.0	119
Ancamine 1693	100	864	63	9.5	16
Ancamine 2286	100	652	42	6.5	74

Note: All data at 77°F (25°C). Please see last page for footnotes.

TABLE 8: HANDLING OF CURING AGENTS WITH BISPHENOL-F/MULTIFUNCTIONAL EPOXY RESIN BLEND*

Curing Agent	Curing Agent Viscosity (cP)[1]	Mixed Viscosity (cP)[1]	Gel Time (min)[2] 150 g mass	Thin Film Set Time,[3] tack free (h)	60° Film Gloss[4]
Ancamine 2280	450	1,350	32	6.5	143
Ancamine 2143	600	2,340	41	5.0	141
Ancamine 1618	400	3,488	61	5.5	124
Ancamine 1693	100	1,330	57	8.5	17
Ancamine 2286	100	1,224	42	6.2	140

*60% bisphenol-F epoxy resin, EEW=172, and 40% epoxy novolac resin, EEW=176.
Note: All data at 77°F (25°C). Please see last page for footnotes.

TABLE 9: HANDLING OF CURING AGENTS WITH 10% CGE DILUTED BISPHENOL-A BASED EPOXY RESIN, EEW=188

Curing Agent	Curing Agent Viscosity (cP)[1]	Mixed Viscosity (cP)[1]	Gel Time (min)[2] 150 g mass	Thin Film Set Time,[3] tack free (h)	60° Film Gloss[4]
Ancamine 2280	450	2,084	69	7.0	131
Ancamine 2143	600	910	74	6.0	137
Ancamine 1618	400	1,880	63	6.0	132
Ancamine 1693	100	730	77	9.0	128
Ancamine 2286	100	780	53	6.0	124

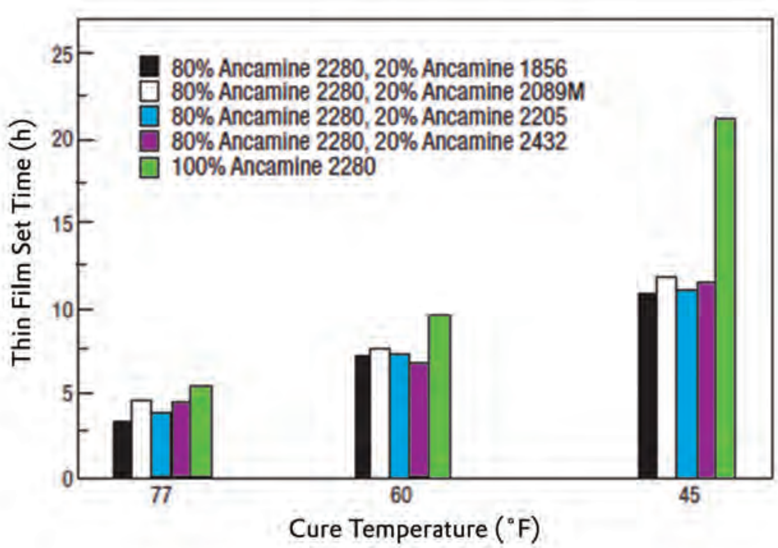
Note: All data at 77°F (25°C). Please see last page for footnotes.

TABLE 10: HANDLING OF ALIPHATIC AMINE MODIFIED CYCLOALIPHATIC CURING AGENTS WITH BISPHENOL-A BASED EPOXY RESIN, EEW=190

Curing Agent	Curing Agent Viscosity (cP)[1]	Mixed Viscosity (cP)[1]	Gel Time (min)[2] 150 g mass	Thin Film Set Time,[3] tack free (h)	60° Film Gloss[4]
8:2 Ancamine 2280: Ancamine 2432	NT	2,200	37	4.5	110
8:2 Ancamine 2280: Ancamine 1608	1,240	4,740	42	5.0	107
8:2 Ancamine 2280: Ancamine 1638	480	4,140	29	5.5	87
8:2 Ancamine 2280: TETA	276	3,390	42	6.0	87
9:1 Ancamine 2280: TETA	470	6,940	62	8.0	111
8:2 Ancamine 2143: Ancamine 2432	NT	2,500	40	4.5	110
8:2 Ancamine 2143: TETA	332	4,720	48	5.5	114
9:1 Ancamine 2143: TETA	688	7,580	66	8.0	123
8:2 Ancamine 1618: Ancamine 2432	NT	2,200	35	4.6	109

Note: All data at 77°F (25°C). Please see last page for footnotes.

FIGURE 5: CURE SPEEDS OF ACCELERATED ANCAMINE 2280 SYSTEMS



APPENDIX C: CURE SPEED FOR CHEMICALLY RESISTANT EPOXY FORMULATIONS

Accelerated Curing Agents

Some applications requiring chemical resistance, such as flooring or secondary containment, may also require rapid cure speed so that the application area can be quickly returned to service. To obtain faster cure, the curing agents can be accelerated with modified aliphatic amines such as Ancamine 2432, 2089M, 1856, 2205, 1608, or 1638 curing agents. Figure 5 shows the effect of selected curing agents used as accelerators with Ancamine 2280. The figure shows that at 20% addition levels, the modified aliphatic amines can significantly improve cure speed, especially at low temperatures.

Ancamine 2432 should be used as the accelerator for maximum chemical resistance. Table 11 shows the effect of accelerating Ancamine 2280, 2143, and 1618 curing agents with 20% Ancamine 2432. Formulations accelerated with 2432 have reduced cure times while maintaining good working life (gel time) and high gloss in the cured film.

TABLE 11: PERFORMANCE OF FORMULATIONS ACCELERATED WITH ANCAMINE 2432

	100% 2280	20% 2432/ 80% 2280	100% 2143	20% 2432/ 80% 2143	100% 1618	20% 2432/ 80% 1618
77°F (25°C) TFST (h)[3]	6.0	4.5	7.0	4.5	5.5	4.6
40°F (4°C) TFST (h)[3]	29	15.3	21	13.8	21	14.5
77°F (25°C) Gel Time (min.)[2]	55	37	45	40	50	35
60° Gloss (7 days at 77°F)[4]	105	110	103	110	118	109

Note: Curing agent blends formulated with standard bisphenol-A (DGEBA, EEW=190) resin.

Hardness Development

Although gel time and thin film set time define well the development of cure, they may not accurately predict development of hardness. Therefore, development of König pendulum hardness has been characterized for the epoxy formulations as a function of 77°F (25°C)/50% relative humidity cure time for 10 mil coatings on cold rolled steel panels. Figure 6 shows the results.

The data show that Ancamine 2280 and 1693 cured formulations develop hardness more slowly than the other curing agent formulations. The data also show that Ancamine 2423, 2143, 1618, and 2286 curing agents impart similar hardness development at ambient temperatures. At low temperatures, however, hardness development is faster with Ancamine 2423 curing agent.

Data in Figure 7 demonstrate the effect of formulating with alternative resins on the development of coating hardness. Formulating with bisphenol-F resin or 10% CGE diluted bisphenol-A epoxy resin reduces the rate of hardness development relative to Bis-A based resin.

FIGURE 6: 7 DAY DEVELOPMENT OF PENDULUM HARDNESS

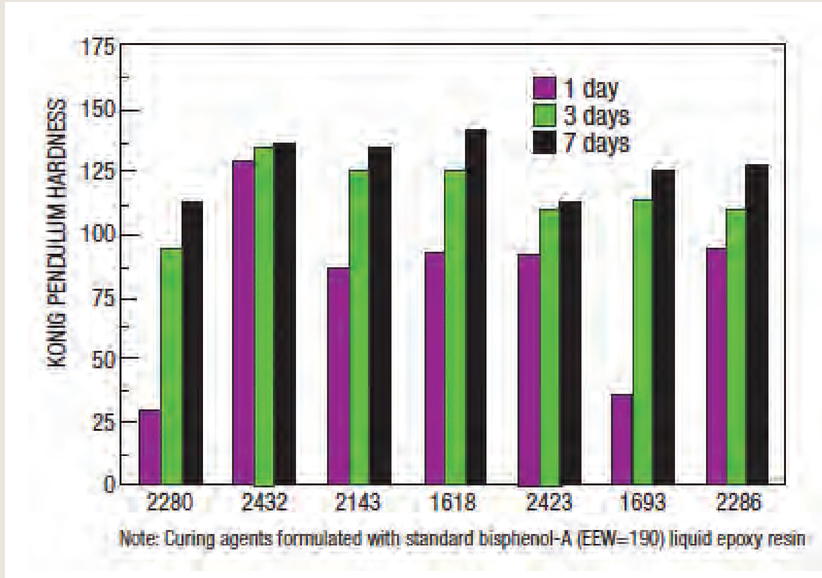
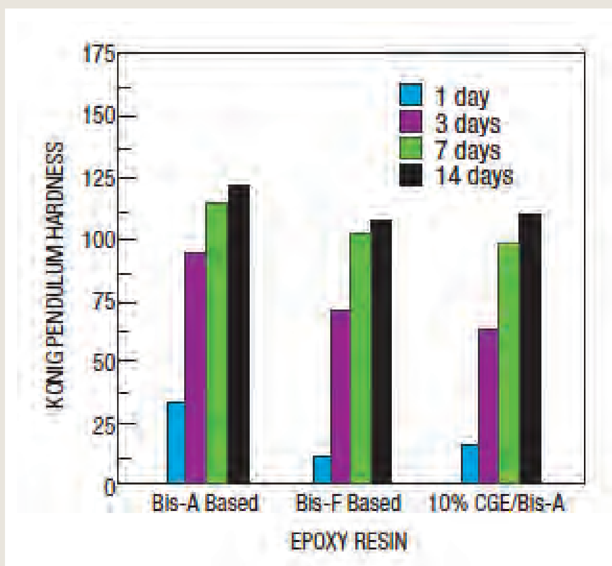


FIGURE 7: 14 DAY DEVELOPMENT OF PENDULUM HARDNESS FOR ANCAMINE 2280-CURED EPOXY RESINS



Footnotes:
(1) ASTM D-445-83, Brookfield
(2) Techne GT-4 Gelation Timer
(3) BK Drying Recorder
(4) ASTM D 523-85

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