EPON® Resin Structural Reference Manual

EPON® Resins – EPI-CURE® Curing Agents – HELOXY® Modifiers

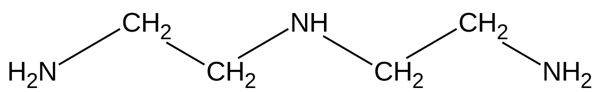
Appendix 1

EPON® Resin – Curing Agent Systems

Table of Contents

Diethylenetriamine (EPI-CURE® Curing Agent 3223) and Triethylenetetramine (EPI-CURE Curing Agent 3234)

Diethylenetriamine (DETA), available as EPI-CURE® Curing Agent 3223, and *triethylenetetramine (TETA)*, available as EPI-CURE Curing Agent 3234, are two liquid polyamine curing agents widely used with EPON® resins for fast cures or where room temperature cures are required. These materials are restricted, however, to small casting applications, since considerable exotherm develops and the pot life of the catalyzed resin is quite short. While these amines provide polymers having good properties at room temperature, better strengths at 180°F or higher may be obtained with aromatic-amine curing agents.



Application

The recommended concentration ranges of these amines for use with EPON Resins 830, 8280, 828, 826, 8201, 8132, 815C and 813 are as follows:

Amine	Concentration, phr
EPI-CURE Curing Agent 3223 (DETA)	12
EPI-CURE Curing Agent 3234 (TETA)	14

Initial Mix Viscosity with EPON Resin 828 @ 25°C, Pa-s (poise)	1.5-2.0 (15-20)
Pot life @ 23°C, min., 1 liter (quart) mass	20-35

Typical cure schedules for EPON Resin-EPI-CURE Curing Agent 3223 or 3234 systems are four days at room temperature (25°C) or one hour at 100°C. It should be recognized, however, that each EPON resin system could be cured using a variety of cure cycles depending upon fabrication and performance requirements. In all cases, the proper cure cycle must be selected on the basis of the application needs.

Specific Heat	
°C	Cal/g°C
10	0.31
25	0.39
100	0.48
150	0.62

Density of Casting (EPON Resin 828/EPI-CURE Curing Agent 3223 (DETA)) 1.19

Resin Properties

In general, these two curing agents are considered interchangeable in regard to chemical behavior and the properties of cured, EPON Resin 828 obtained. Somewhat poorer overall properties are obtained when EPON Resins 8201, 815C, 813 or 8132 are cured with these polyamines because of the reactive diluent present. The lower vapor pressure often makes TETA more attractive for casting applications.

Table 24
Effect of DETA (EPI-CURE® Curing Agent 3223) Concentration on the Heat Deflection Temperature of EPON® Resin 828 Castings

(Cure Cycle: 3 hours at 25°C + 1 hour at 200°C)

DETA Concentration (phr)	Heat Deflection Temperature (°C)
8	95
9	105
10	114
11	119
12	124
13	117
14	112

Table 25
Effect of Post Cure on Heat Deflection Temperature of EPON® Resin 828-12 PHR DETA (EPI-CURE® Curing Agent 3223) Castings

(Specimens allowed to gel at room temperature prior to post cure)

Post Cure		Heat Deflection Temperature
Hours	°C	(°C)
2	100	115
4	100	118
12	100	122
24	100	122
4	150	121
8	150	124
24	150	123

Table 26

Effect of Concentration and Post Cure on the Heat Deflection Temperature on EPON® Resin 828-TETA (EPI-CURE® Curing Agent 3234) Castings

(Specimens allowed to gel at room temperature prior to post cure)

TETA Concentration (phr)	Post Cure Hours	Post Cure °C	Heat Deflection Temperature (°C)
10	1	200	98
11	1	200	103
12	1	200	109
13	1	200	115
14	1	200	123
15	1	200	123
16	1	200	119
14	4	100	119
14	8	100	120
14	12	100	122
14	24	100	124

Table 27

Typical Properties of Filled and Unfilled EPON® Resin 815C-TETA (EPI-CURE® Curing Agent 3234) Castings

(Cure Cycle: 20 hours at 25°C plus 24 hours at 65°C)[1]

EPON® RESIN 815C—WITH 10 PHR TETA (EPI-CURE® Curing Agent 3234)

Filler[2] Concentration phr	Viscosity at 25°C (Without Curing Agent) Pa • s (poise)	Heat Deflection Temperature (°C)	Compressive Properties Strength 0.2% Offset MPa (psi)	Compressive Properties Modulus MPa (psi)	Notched Izod Impact Strength J/m (ft-lb/in)
None	0.76 (7.6)	80	83 (12,000)	3500 (500,000)	26 (0.5)
100	1.7 (17)	82	90 (13,000)	4700 (680,000)	21 (0.4)
200	4.3 (43)	85	96 (14,000)	6200 (900,000)	21 (0.4)
400	75 (750)	87	110 (16,000)	8400 (1,220,000)	26 (0.5)

[1] This curing cycle was used to insure complete cure, and is not necessarily practical for commercial cast operations.

[2] The filler used was iron oxide (grade MD – 101, Alcan Aluminum Corp)

Table 28

Effect of Post Cure on the Tensile Properties of EPON® Resin 828-12 PHR DETA (EPI-CURE® Curing Agent 3223) Castings

(Cure Cycle: Room temperature gel followed by 2 hours at 100°C)

	Strength			Elongation	
Test Temperature (°C)	Ultimate MPa (psi)	0.2% Offset MPa (psi)	Modulus MPa (psi)	0.2% Offset (%)	Ultimate (%)
100	32 (4,600)	22 (3,200)	1,800 (260,000)	1.4	9.0
50	60 (8,700)	32 (4,700)	2,500 (360,000)	1.5	6.0
25	75 (10,900)	37 (5,300)	2,800 (410,000)	1.5	6.3
0	76 (11,000)	40 (5,800)	3,200 (470,000)	1.4	4.0
-25	85 (12,300)	45 (6,500)	3,200 (470,000)	1.6	4.0

(Cure Cycle: Room Temperature gel followed by 1 hour at 200°C)

100	23 (3,400)	16 (2,300)	1,300 (190,000)	1.3	6.4
50	59 (8,600)	30 (4,300)	2,500 (360,000)	1.3	7.0
25	68 (9,800)	37 (5,300)	3,000 (430,000)	1.4	6.0
0	74 (10,700)	36 (5,200)	3,300 (480,000)	1.5	4.0
-25	68 (9,800)	43 (6,200)	3,700 (540,000)	1.3	2.6

Table 29

Effect of Room Temperature Cure Time on Tensile Properties of EPON® Resin 828-12 PHR DETA (EPI-CURE® Curing Agent 3223) Castings

		Strength			Elongation	
Cure	Test Temperature (°C)	Ultimate MPa (psi)	0.2% Offset MPa (psi)	Modulus MPa (psi)	0.2% Offset (%)	Ultimate (%)
3days	25	28 (4,100)	-	3,700 (540,000)	-	0.70
7 days	25	40 (5,800)	-	3,100 (450,000)	-	1.4
14days	24	65 (9,500)	51(7,400)	3,900 (560,000)	1.5	2.4
30 days	25	71 (10,300)	56 (8,200)	3,500 (510,000)	1.8	2.7
60 days	25	70 (10,200)	55 (8,000)	3,400 (490;000)	1.8	3.2
90 days	50	37 (5,400)	32(4,700)	2,500 (360,000)	1.5	7.0
90 days	-25	79(11,500)	67(9,700)	3,700 (530,000)	2.0	2.6

Table 30
Tensile Properties of EPON® Resin 828-DETA (EPI-CURE® Curing Agent 3223) Castings at Various Test Temperatures

(Cure Cycle: Room temperature gel followed by 4 hours at 100°C)

		Strength			Elongation	
Test Temperature (°C)	PHR DETA	Ultimate MPa (psi)	0.2% Offset MPa (psi)	Modulus MPa (psi)	0.2% Offset (%)	Ultimate (%)
100[1]	8					
50	8	68 (9,800)	42 (6,100)	2,800 (400,000)	1.7	6.5
25	8	78 (11,300)	57 (8,300)	3,400 (490,000)	1.8	3.7
0	8	63 (9,200)	-	3,800 (550,000)	-	1.8
-25	8	81(11,700)	79 (11,400)	3,800 (550,000)	2.4	2.4
100	10	19 (2,700)	08 (1,200)	1,200 (175,000)	0.80	24.0
50	10	59 (8,600)	45 (6,600)	3,000 (430,000)	1.7	3.6
25	10	79 (11,400)	49 (7,100)	3,000 (435,000)	1.8	5.7
0	10	78 (11,300)	48 (6,900)	3,700 (530,000)	1.5	3.2
-25	10	79 (11,400)	62 (9,000)	3,400 (490,000)	2.0	2.8
100	12	25 (3,700)	17 (2,400)	1,500 (220,000)	1.3	18.2
50	12	62 (9,000)	38 (5,500)	2,300 (340,000)	1.9	7.3
25	12	69 (10,000)	42 (6,100)	2,600 (380,000)	1.8	5.3
0	12	75 (10,900)	41 (6,000)	3,300 (480,000)	1.4	3.9
-25	12	95 (13,800)	58 (8,400)	2,900 (420,000)	2.2	4.9
100	14	23 (3,300)	11 (1,600)	1,000 150,000)	1.2	27.7
50	14	60 (8,700)	37 (5,400)	2,300 (330,000)	1.8	7.3
25	14	68 (9,900)	41 (5,900)	2,500 (370,000)	1.7	5.8
0	14	74 (10,700)	43 (6,200)	3,100 (450,000)	1.5	4.0
-25	14	96 (14,000)	56 (8,200)	3,000 (430,000)	2.1	5.4

[1] Too soft to test. Heat deflection temperature of cured polymer is below test temperature.

Epoxy-Amine Adducts (EPON Curing Agent® U)

EPON Curing Agent® U is a modified fast-curing, liquid amine suitable for casting formulations based on EPON® Resins 830, 828, 8280, 826, 8201, 815C, 813, or 8132 in which rapid, room-temperature cures are desirable. This curing agent is supplied as an amber-colored liquid having a viscosity of about 10 Pa•s (100 poise) at room temperature. It has been modified to provide several advantages over conventional aliphatic polyamines, such as EPI-CURE® Curing Agent 3223 (diethylenetriamine - DETA). Advantages for EPON Curing Agent U are:

1. Its lower vapor pressure minimizes the odor problems associated with unmodified polyamines.
2. The material provides a more convenient curing agent-resin ratio for easier measuring and weighing.
3. Where extremely fast cures are desirable, this curing agent gives better results than the unmodified polyamines.

However, EPON Curing Agent U (EPI-CURE Curing Agent U) has been discontinued and is no longer available. From the EPI-CURE® product line, there are three different curing agent compounds that are comparable to the discontinued product EPI-CURE Curing Agent U. These three products are EPI-CURE Curing Agents 3282, 3290 and 3295. When looking at the neat curing agent properties, you can see that the viscosity of all three alternatives is lower in viscosity than EPI-CURE Curing Agent U. The neat viscosity of the curing agent factored in with the mix ratio affects the initial viscosity of the resin / curing agent blend. Even though EPI-CURE 3282 is about half the viscosity of EPI-CURE Curing Agent U, the lower mix ratio (20 phr vs. 25 phr) produces an initial viscosity about 10% greater than the EPI-CURE Curing Agent U. However, EPI-CURE Curing Agents 3290 and 3295 have neat viscosities significantly less that EPI-CURE Curing Agent U and produce lower initial viscosities when used at the same 25 phr mix ratio. This could be an advantage, especially in filled systems, as fewer processing problems normally occur than switching to a system with a higher initial viscosity. If a lower initial viscosity is a problem for you, then it would be more desirable to select the curing agent that produces an initial viscosity closest to EPI-CURE Curing Agent U - that would be EPI-CURE Curing Agent 3282.

All three of the alternatives are lower in color. Where color is important, the lower the color the better.

Two of the three alternatives have the same Amine Hydrogen Equivalent Weight or AHEW. This value determines the mix ratio. For operations utilizing automated metered mixing/dispensing equipment or similar processes that may be difficult to accommodate change, it would be most desirable to have the same mix ratio. Both EPI-CURE Curing Agent 3290 and 3295 have the same AHEW, and therefore require the same mix ratio with EPON Resin 828 as does EPI-CURE Curing Agent U. As previously discussed the mix ratio for EPI-CURE Curing Agent 3282 is different from EPI-CURE Curing Agent® U and accommodating the change could pose some problems.

Gel time or pot life should be a major factor when considering alternative curing agents. EPI-CURE® Curing Agent 3282 is about twice as fast as EPI-CURE Curing Agent U. This is a significant difference and could be a major problem or benefit - it all depends on the application. If you need the same pot life, EPI-CURE Curing Agent 3290 or 3295 would be a better choice as they have approximately the same degree of reactivity as EPI-CURE Curing Agent U.

The cured-state physical properties of all systems are discussed in the next few paragraphs. Physical properties are determined using specimens cured 24 hours at 25°C followed by 2 hours at 100°C to insure complete cure. All three alternative curing agents produce higher Heat Deflection Temperature (HDT) values than EPI-CURE Curing Agent U.

Tensile strength, elongation, flexural strength, and flexural modulus for resins cured with EPI-CURE Curing Agent 3282 and EPI-CURE Curing Agent U are about the same - exceptionally high. A high tensile strength (>12 ksi) combined with a tensile elongation under 8%, and a flexural modulus over 500 ksi is considered a rather rigid or brittle polymer matrix.   Although the tensile strengths of resin cured with EPI-CURE Curing Agent 3290 and 3295 are less by comparison, they are still over 10 ksi and considered very strong. The exceptionally high tensile elongation (10%) and modest flexural modulus for EPI-CURE Curing Agent 3290 are indicators for good toughness characteristics. If toughness is important or could be a benefit in your application, then EPI-CURE Curing Agent 3290 may be the best choice.

The Shore D Hardness for all three alternatives is nearly identical.

Chemical resistance has been determined using the weight gain or loss of a 1 inch by 3 inch coupon, after immersion for 24 hours at 25°C. Again, all three alternatives perform comparable to EPI-CURE Curing Agent U. EPI-CURE Curing Agent 3295 seems to be susceptible to 5% Acetic Acid.

EPI-CURE Curing Agent 3282 appears to provide the best match for cured physical properties and performance. But, it requires a different mix ratio and has only half the pot life.

EPI-CURE Curing Agent 3295, has the same mix ratio, a much lower initial viscosity, the lowest but still strong tensile strength, highest flexural modulus and HDT, and the poorest resistance to 5% Acetic Acid. This system is best where increased heat resistance would be of benefit and toughness is not a concern. EPI-CURE Curing Agent 3295 can only be purchased in Batch Lots of 9,200 lbs.

EPI-CURE Curing Agent 3290 appears to offer the best overall property match to EPI-CURE Curing Agent U. It has the same mix ratio, slightly lower system viscosity, same reactivity, higher HDT, slightly lower physical properties that are offset by better toughness characteristics, and comparable chemical resistance properties.

It is highly recommended that the end-user fully evaluate the appropriateness of an alternative for EPI-CURE Curing Agent® U in the actual intended end-use application prior to making a permanent switch.

Table 31
Property Comparison of Alternatives for EPI-CURE® Curing Agent U

Curing Agent Physical Properties	EPI-CURE® 3282 Curing Agent	EPI-CURE U Curing Agent	EPI-CURE 3290 Curing Agent	EPI-CURE 3295 Curing Agent
Amine Value	761-809	950-1050	990-1020	881-961
AHEW[1]	38	48	48	45
Viscosity at 25°C, Pa-s (P)	3.9 (39)	10 (100)	0.4 (4)	0.2 (2)
Color, Gardner max	6	8	4	3
COMPOSITION (parts by weight)	**A**	**B**	**C**	**D**
EPON® Resin 828	100	100	100	100
EPI-CURE 3282 Curing Agent	20	-	-	-
EPI-CURE U Curing Agent	-	25	-	-
EPI-CURE 3290 Curing Agent	-	-	25	-
EPI-CURE 3295 Curing Agent	-	-	-	25
Handling Properties at 25°C				
Initial Viscosity, Pa-s (P)	8.8 (88)	8.0 (80)	5.4 (54)	2.6 (26)
Pot Life, 100 gram mass, mins.	12	24	23	26
Cured State Properties				
Heat Deflection Temp., °C	97	87	98	107
Tensile Strength, MPa (psi)	87 (12,600)	86 (12,500)	74 (10,700)	70 (10,100)
Tensile Elongation at break, %	4.9	5.1	10.0	4.0
Flexural Strength, MPa (psi)	150 (21,800)	140 (20,300)	117 (16,900)	125 (18,200)
Initial Flexural Modulus, MPa (Msi)	3,590 (0.52)	3,520 (0.51)	3,030 (0.44)	4,000 (0.58)
Hardness, Shore D	87	87	88	86
Tensile Shear @ 25°C, MPa (psi)	7.5 (1087)	9.2 (1333)	-	-
Chemical Resistance				
Water	0.14	0.14	0.19	0.17
5% Acetic Acid	0.15	0.13	1.10	0.39
5% Sodium Hydroxide	0.14	0.13	0.17	-
50% Xylene/50% Isopropanol	-0.1	-0.02	-0.03	0.01

[1] Not a Sales Specification - Amine Value, Viscosity and Color are the only Sales Specifications on these products.

Propylene Oxide-Amine Adduct (EPI-CURE® Curing Agent 3290)

This is a modified polyamine product with a low viscosity and rapid cure rate with liquid EPON® resins at room temperature. It has the important advantage of being very low in odor and volatility in comparison to other polyamine curing agents.

Application

This curing agent is a pale yellow liquid having a viscosity of 3.5 to 4.5 poise at 25°C. The pot life is 20-35 minutes at 25°C with most liquid EPON resins. For optimum strength and chemical resistance properties, the recommended concentration is 25 phr. However, the amount of curing agent may be varied from 20 to 30 phr to give catalyzed mixtures having somewhat longer pot lives or shorter cure times. With 25 phr of curing agent, full and apparently equal cures are obtained after 4 days at room temperature or two hours at 100°C.

Resin Properties

EPON resins cured with this curing agent give castings of somewhat lower strength than common aliphatic polyamine curing agents. Generally, it may be used in any application where EPON Curing Agent® U (see previous section), EPI-CURE® Curing Agent 3223 (DETA) or EPI-CURE Curing Agent 3234 (TETA) has been found suitable if the fabricator is willing to make a sacrifice in strength (of the order of 10-20%) and HDT to gain greater ease in handling.

It has been found that post curing casting results in only marginal improvement in tensile strength, compressive strength, or heat deflection temperature.

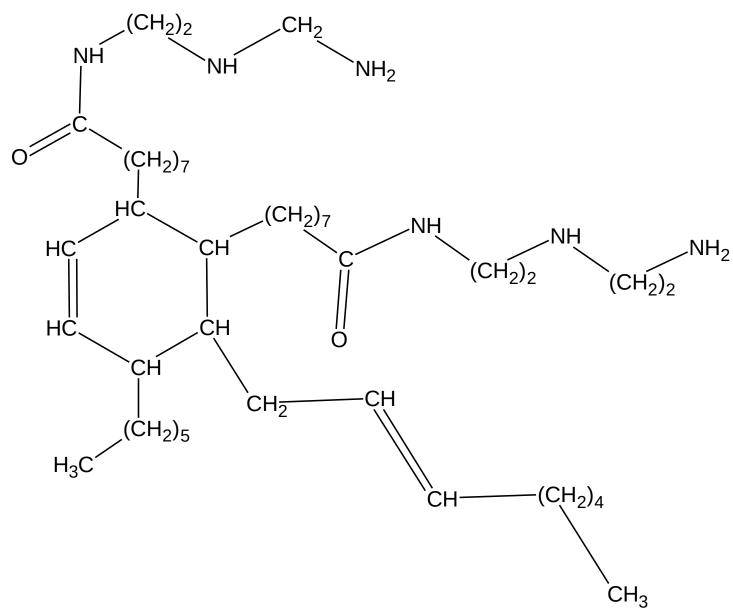
Table 32
Properties of EPON® Resin systems cured with EPI-CURE® Curing Agent 3290

Composition (parts by weight)	A	B	C	D
EPON® Resin 828	100			
EPON Resin 813		100		
EPON Resin 815C			100	
EPON Resin 8132				100
EPI-CURE® Curing Agent 3290	25	25	25	23
Handling properties at 25°C				
Initial viscosity, Pa-s (P)	5.4 (54)	0.88 (8.8)	0.8 (8.0)	0.8 (8.0)
Pot life, 100 gram mass, min.	23	27	31	33
Cured state properties[1]				
Heat deflection temperature, °C	98	55	59	50
Tensile strength, MPa (psi)	74 (10,700)	69 (10,000)	55 (7,900)	61 (8,800)
Tensile elongation at break, %	10.0	6.7	9.6	9.6
Flexural strength, MPa (psi)	117 (17,000)	133 (19,300)	115 (16,700)	98 (14,200)
Initial flexural modulus, MPa (Msi)	3,000 (0.44)	3,900 (0.57)	3,300 (0.48)	2,900 (0.42)
Hardness, Shore D	88	86	84	82
Chemical resistance[2]				
Water	0.19	0.15	0.24	0.23
5% acetic acid	1.10	4.24	4.66	3.68
5% sodium hydroxide	0.17	0.12	0.27	0.20
50% xylene/50% isopropanol	-0.03	2.48	0.41	2.23

[1] Determined on 1/8-inch thick test specimens cured 24 hrs at 25°C followed by 2 hrs at 100°C.
[2] Percent weight gain after immersion for 24 hrs at 25°C.

Polyamide Curing Agents - EPI-CURE® Curing Agents 3115, 3125, and 3140

EPI-CURE® Curing Agents 3115, 3125, and 3140 are condensation products of polyamines and dibasic acids produced by the polymerization of unsaturated fatty acids. These materials may be used where a combination of long pot life and room temperature cure is required, or where thermal shock resistance is required. These amines promote the adhesion of the epoxy system to glass, metal and many other kinds of substrates, and are excellent for many applications requiring performance temperature no higher than 80°C.



Application

Polyamides are resins in their own right. Molecular weights are higher than for EPON® Resin 828 and odor and volatility are rather low. Relative to other amines, large amounts are used for curing EPON resins, and the weight ratios of the two components are not as critical.

Typical cure schedules for EPON Resin – EPI-CURE Curing Agent 3100 Series curing agent systems are four days at room temperature (25°C) or one hour at 100°C. In all cases, the proper cure cycle must be selected on the basis of the application requirements.

The concentration of curing agents to be used for polyamide-cured EPON resin systems is dependent to a large degree upon the properties desired of the cured system. Listed below are suggested curing agent concentrations to be used with several resins for maximum hardness. These concentrations will also provide the greatest degree of chemical resistance and the best electrical properties. Increasing the concentration of curing agent will result in more flexible, less chemically resistant systems. However, it also improves the capability for room temperature cure without the need for a heat cure.

Polyamide-cured EPON® resin systems also exhibit very little shrinkage during cure and are only slightly exothermic. The cured resin has good RT (but not elevated temperature) properties. These features, combined with the low odor and low volatility of the curing agents, are important advantages of polyamide curing systems in casting and potting applications.

Concentrations of Polyamide Required For Maximum HDT and Hardness[1]

Composition	Curing Agent Concentration, phr	Barcol Hardness	Heat Deflection Temperature, °C
EPON® Resin 828/EPI-CURE® Curing Agent 3140	33	70	110
EPON Resin 8201/EPI-CURE Curing Agent 3140	33	69	110
EPON Resin 815C/EPI-CURE Curing Agent 3140	43	65	108
EPON Resin 828/EPI-CURE Curing Agent 3125	43	70	89
EPON Resin 8201/EPI-CURE Curing Agent 3125	53	68	86
EPON Resin 815C/EPI-CURE Curing Agent 3125	60	67	61
EPON Resin 815C/EPI-CURE Curing Agent 3115	65	55	42
EPON Resin 828/EPI-CURE Curing Agent 3125	67	-	83

[1] Heat Cures at 150°C.

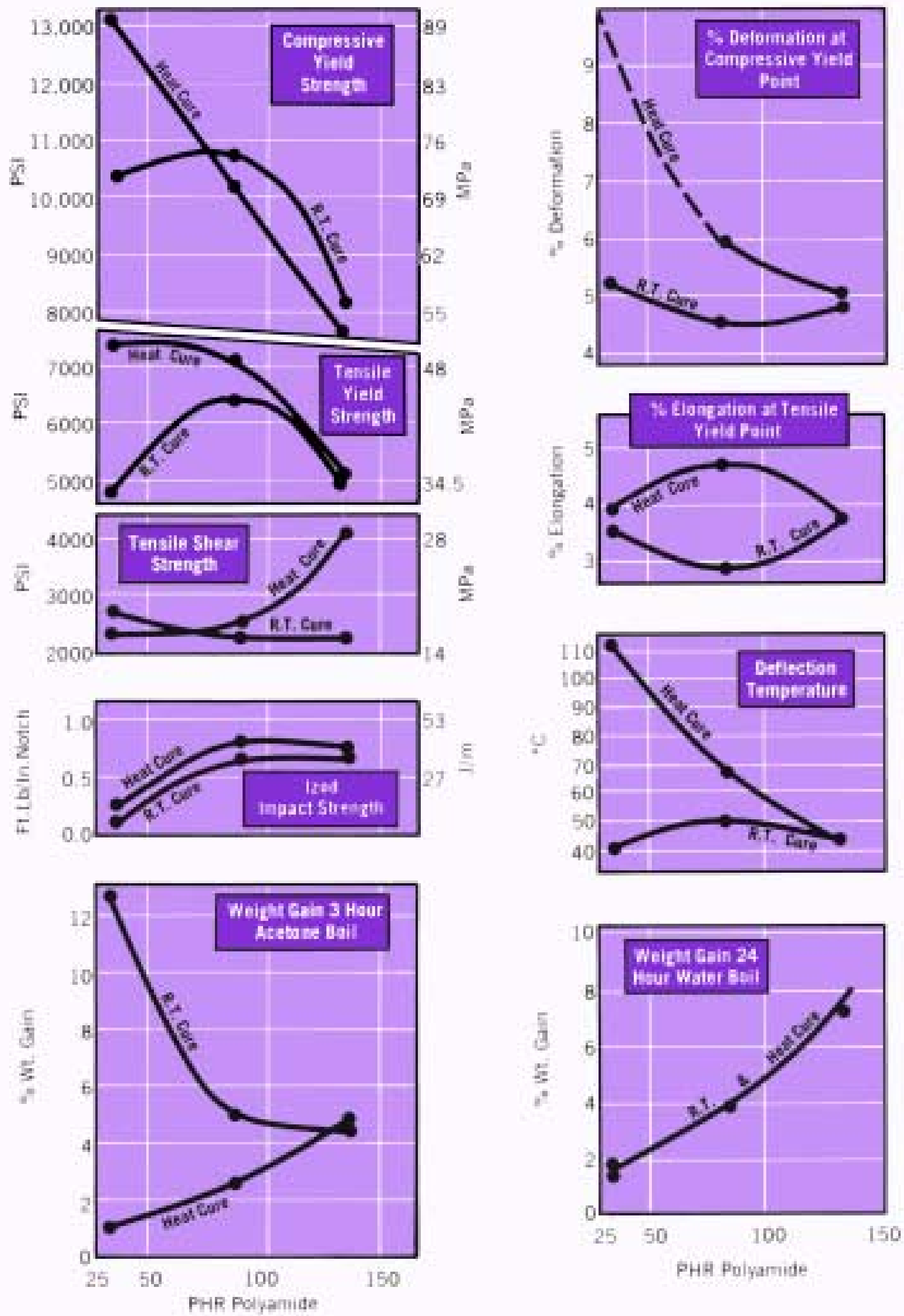


Fig. 34 – Properties of EPON® Resin 828/EPI-CURE® Curing Agent 3140 Polyamide Castings vs. Concentration of Polyamide.

Table 33

Linear Shrinkage, Exotherm Characteristics, and Other Properties of EPON® Resin Systems Cured with EPI-CURE® 3100 Series Curing Agents

System	Curing Agent Concentration, phr	Useable Pot Life (min)[1)]	Temp. at Gel (°C)	Maximum Exotherm Temp.	Linear Shrinkage (mm/mm)[2]
EPON® Resin 828/EPI-CURE® Curing Agent 3140	33[3]	75	110	215	0.0197
EPON Resin 815C/EPI-CURE Curing Agent 3125	66[3]	60	85	180	0.014
EPON Resin 815C/EPI-CURE Curing Agent 3115	100[4]	110	60	60	0.0156

[1] 045 liter (one-half pint) volume.
[2] After one hour post cure at 150°C, in/in = mm/mm.
[3] Dielectric strength, 25°C,= 430
[4] Dielectric strength, 25°C,= 470

Typical Properties EPI-CURE® 3100 Series Curing Agents

EPI-CURE® Curing Agent	3125	3140
Viscosity, Pa • s (poise)		
25°C	33 (330)	14 (140)
40°C	1.0 (10)	0.4 (4)
Density, 25°C	0.97	0.97
Amine Number, mg KOH/g	345	375
Color, Gardner	9	9

Unfilled Casting Properties[1] with EPON® Resin 828

Polyamide Concentration, phr	100	82
Pot Life 23°C, 100 gram mass, hrs	1.7	2.2
Initial Mix Viscosity, 25°C, Pa-s (poise)	36 (360)	11.8 (118)
Deflection Temperature, °C	59	68
Tensile Properties, 23°C (RT cure)		
Strength at Break, MPa (psi)	44 (6400)	51 (7400)
Elongation at Break, %	5.1	4.8
Modulus, MPa (psi)	1900 (270,000)	2100 (310,000)
Compressive Properties		
Strength at Yield, MPa (psi)	63 (9,100)	72 (10,400)
Deformation at Yield, %	5.2	5.8
Modulus, MPa (psi)	2100 (310,000)	2300 (330,000)
Tensile Shear Strength [2)], 23°C, MPa (psi)		
RT Cure [3)]	8.3 (1200)	17 (2400)
Heat Cure	17 (2400)	17 (2400)
Izod Impact Strength, J/m (ft-lb/in) of notch	53 (1.0)	53 (1.0)
24 Hour Water Boil, %w gain		

RT Cure	3.7	3.8
Heat Cure	3.9	3.8
3 Hour Acetone Boil, %w gain		
RT Cure	5.2	4.4
Heat Cure	3.6	2.5
Density of Casting	–	1.10

Specific Heat	
°C	Cal./g°C
10	0.05
25	0.44
100	0.62

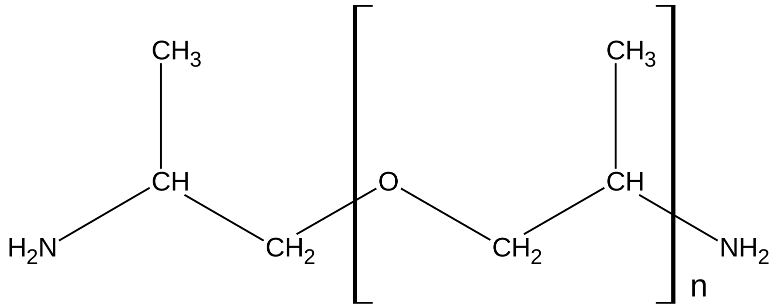
[1] Cure, hours/°C=24/25+2/150

[2] Acid etched aluminum substrate

[3] RT Cure=7 days at 23-25°C with testing on the 7th day

Polyoxypropylene Diamines (JEFFAMINE® D-230 AND D-400)[1]

JEFFAMINE® D-230 and D-400 (polyoxypropylene diamines) have the following idealized structure:



The product number designates molecular weight, i.e., JEFFAMINE D-230 has a molecular weight of 230. In addition, a 2000 molecular weight product (greater toughness) is available (JEFFAMINE D-2000), as well as a triamine type (greater HDT) designated JEFFAMINE T-403 (data not shown).

Blends of JEFFAMINE D-230 and D-400 with EPON® Resins have low viscosities, long usable pot life, and pale color. The cured polymers are exceptionally clear and glossy allowing for an excellent display of encapsulated components and making excellent decoupage coatings. The cured polymers also have exceptional flexibility, toughness, and high Izod impact strengths. Using EPI-CURE® Curing Agent 3200 (aminoethylpiperazine - AEP) as part of the curing system can further increase impact strengths.

JEFFAMINE D-230 and D-400 can be cured at room temperature or heat cured. Usually accelerators are added to speed room temperature cures; typically nonylphenol, phenol, or ACCELERATOR 399.

[1] Huntsman Chemical Company.

Table 34
Unfilled Casting Properties for EPON® Resin 828/JEFFAMINE® D-230[1] and EPON Resin 828/JEFFAMINE D-400[1] Systems

System	1	2	3	4
EPON® Resin 828	100	100	100	100
JEFFAMINE® D-230, phr	35			22
JEFFAMINE D-400, phr		57	77	
EPI-CURE® Curing Agent 3200 (AEP), phr				11
Catalyzed Resin Viscosity, 25°C, Pa • s (poise)	0.8 (8.0)	0.5 (5.0)	0.35 (3.5)	0.66 (6.6)
Pot Life, 400 g, 25°C h	5.5	20	-	0.42
Pot Life, 400 g plus 6 phr phenol, 25°C, h	1.0	3.9	-	-
Gel Time on a Gel Plate, 150°C, min	2 .3	3.9	4.5	0.52
Cure Cycle, h/°C	2/100	2/55+2/100	2/55+2/100	2/55+2/100
HDT, °C	74[2)]	31	-	65
Izod Impact Strength, 23°C, J/m (ft-lb/in.) notch	56(1.05)	53 (1.0)	636 (12)	80 (1.5)
Tensile Strength, MPa (psi)[3)]				
-40°C at break		85 (12,300)	89 (12,900)	-
23°C maximum	67 (9,700)	28 (4,000)	29(4,200)	67 (9,700)[4]
at break	51 (7,400)	17 (2,400)	21 (3,100)	48 (6,900)[4]
37°C at break		0.72 (105)		
Tensile Elongation, %[3)]				
-40°C at break		3.7	4.7	-
23°C maximum	4.0	3.3	5.0	4.1[4]
at break	7. 1	58	90	13.2[4]
37°C at break		11.2	-	-
Flexural Strength, 23°C, MPa (psi)	116 (16,800)	77 (11,200)	-	-
Flexural Modulus, 23°C MPa (psi)	3100 (450,000)	2800 (406,000)	-	-
Tensile Shear Strength, 23°C, MPa (psi)	13 (1,900)	-	23 (3,400)	67 (9,700)
24 Hour Water Boil, %w Gain	3. 0	2.3	disintegrated	4.1
3 Hour Acetone Boil, %w Gain	8.5	29	disintegrated	10
Dielectric Constant, 23°C, 1 kHz	3.8	3.7		3.7
Dissipation Factor, 23°C, 1 kHz	0.015	0.013		0.015
Density of Casting	1.16	1.13		

[1] Supplier-Huntsman Chemical Co.

[2] Post cure at 150°C

[3] Testing rates: -40°C -0.05 in/min.; 23°C and 37°C -20 in/min.

[4] Testing rate: 0.05 in/min.

Mercaptans (CAPCURE® 3-800)[2]

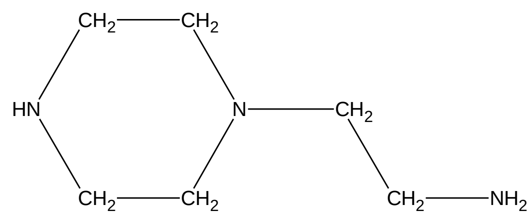
Mercaptan curing agents provide a means for simple, fast cures of EPON® Resin systems. They gel in as little as 4 minutes, provide handling strength in 6 minutes, and provide nearly full working strength in 2-4 hours. Concentrations for curing EPON resins are not critical because they cure catalytically. Metering is simple because concentrations for curing are large. Mercaptans have slight odor, but their fast cures, ability to cure at temperatures below 25°C (77°F), and ease of handling far outweigh this problem. As a result, they are widely used in room temperature cure adhesives such as for highway traffic buttons, industrial adhesives and coatings, and adhesives for home use.

Typical Properties for Neat 3-800 Curing Agent	
Viscosity, Pa•s (poise)	15 (150)
Density	1.15
Color	1
Typical Composition for 4-Minute Gel	
EPON resin 828	100
Capcure 3-800	100
EPI-CURE® Curing Agent 3253 or Capcure 30[1]	10
Tensile Properties (Cure at 25°C)	
Tensile Shear Strength, 4h, MPa (psi) on aluminum	19 (2800)
[1] Henkel Corporation Capcure DH-30 is an equivalent	

[2] Henkel Corporation

N-Aminoethylpiperazine (EPI-CURE® Curing Agent 3200)

EPI-CURE® Curing Agent 3200 (n-Aminoethylpiperazine – AEP) is a clear, high boiling, liquid trifunctional amine exhibiting handling and curing characteristics which compare favorably to EPI-CURE Curing Agent 3223 (DETA) and EPI-CURE Curing Agent 3234 (TETA). In addition, EPI-CURE Curing Agent 3200 (AEP) yields cured EPON® resin polymers with significantly better impact properties than has been attainable with other commonly used room temperature curing agents. Its molecular structure and some typical properties are as follows:



Aminoethylpiperazine, wt%	98.
Molecular weight	129.20
Specific Gravity, 20/20°C	0.984
Refractive Index at 20°C	1.499

Application

The optimum concentration of EPI-CURE Curing Agent 3200 (AEP) for curing EPON Resin 828 is in the 20 phr range. Full post cures give maximum HDTs of 110°C.

Laboratory tests have shown EPI-CURE Curing Agent 3200 (AEP) demonstrates cure behavior in large masses comparable to EPI-CURE Curing Agent 3223 (DETA). For example, one quart of an EPON Resin 828/EPI-CURE Curing Agent 3200 (AEP) mixture exhibits a pot life of approximately 20 to 30 minutes at room temperature. True room temperature cures on EPON resin 828-EPI-CURE Curing Agent 3200 (AEP) castings have not been obtained in thin sections, i.e., less than 3.2 mm (0.125 in.) thickness. However, satisfactory properties can be obtained with ambient temperature cures by adding small concentrations of phenolic materials, such as METHYLON® 75108[3]or bisphenol-A as accelerators.

Resin Properties

Cured castings based on EPON Resin 828 and EPI-CURE Curing Agent 3200 (AEP) show high strength plus improved impact strengths, which are advantages for cast plastic tool applications.

[3] Occidental Chemical Company phenolic resin.

Table 35

Effect of Concentration and Post Cure on the Heat Deflection Temperature of EPON® Resin 828-EPI-CURE® Curing Agent 3200 (AEP) Castings

AEP Concentration PHR	Cure Cycle Gel + Post (h/°C)	Heat Deflection Temperature, °C
16	RT + 1 /200	103
18	RT + 1 /200	104
20	RT + 1 /200	110
22	RT + 1 /200	109
22	RT + 1 /100	107
20	RT + 6/150	110
22	See footnote 1	101
22	See footnote 2	91
24	168/25	84
24	RT + 2/150	100

[1] EPON® Resin 828 maintained at 50°C, AEP added and mixed thoroughly; catalyzed resin poured into HDT molds maintained at the same temperature. System allowed to gel then tested.

[2] Catalyzed resin maintained at 50°C, then added to cold HDT molds. After gelation, system was tested.

Table 36

Notched Izod Impact Strength of EPON® Resin 828- EPI-CURE® Curing Agent 3200 (AEP) Castings

AEP Concentration PHR	Cure Cycle Gel + Post (h/°C)	Izod Impact Strength	
		J/m	(ft-lb/in)
20	RT + 2 hours at 150°C.	45	(0.85)
22	See footnote 1	65	(1.2)
24	168/25	105	(2.0)
24	RT + 2 hours at 150°C.	80	(1.5)

[1] Catalyzed resin maintained at 50°C (120°F), then added to cold impact mold. After gelation, system was tested.

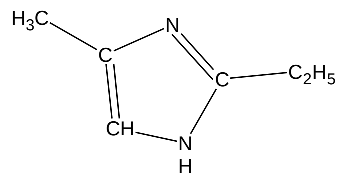
Table 37
Other Typical Properties of Unfilled
EPON® Resin 828-20 phr EPI-CURE® Curing Agent 3200 (AEP) Castings

Property	
Compressive Strength[1)], MPa (psi)	
0.2% Offset	60 (8700)
Yield	95 (13,800)
Compressive Modulus, MPa (psi)	2600 (380,000)
Compressive Deformation	
0.2% Offset	3.5
Yield	10.5
Tensile Strength, MPa (psi)	
0.2% Offset	35 (5000)
Break	66 (9600)
Tensile Modulus, MPa (psi)	2800 (400,000)
Tensile Elongation, %	
0.2% Offset	1.4
Break	8.8
3 Hour Acetone Boil, %wt Gain	1.5
24 Hour Water Boil, %wt Gain	1.8
Density of Casting	1.17

[1] Cure Cycle: RT + 2 hours at 150°C

2-Ethyl-4-Methyl Imidazole (EMI-24)[4]

Typical Properties



Color, (Gardner)	13-16
Viscosity, Pas (poise) at 25°C (Brookfield)	4-8 (40-80)
Water Content, %wt maximum	0.3
Initial Mix Viscosity, 25°C, Pas (poise) (EPON® Resin 825/EMI-24-100/10)	0.8 (8)
Pot Life 23°C, 1 liter (quart), hours (EPON Resin 828/EMI-24-100/4)	20

Recommended Use

EMI-24 may be used as the sole curing agent in epoxy resin systems at levels of between 2 and 10 phr, or it may be used at lower levels of concentration (1 phr) as a catalyst or accelerator for dicyandiamide, acid and anhydride curing agents. Being a good nucleophile, it behaves similarly to tertiary amines. Its long pot life provides usefulness in many casting and fabricating applications. Its high adhesion to many substrates provides wide usefulness in adhesives. Its ability to cure adequately at both low temperatures (60°C) and very rapidly at high temperatures (177°C) provide unusually wide versatility of cure.

Properties of EPON Resin/EMI-24 Systems

1. EMI-24 as sole curing agent.

Castings show less tensile elongation and higher modulus than many amine systems. Hence, where modified properties are desired, it may be used as a co-curing agent in systems.

[4] 2-Ethyl 4-Methyl Imidazole is available from Air Products and Chemicals, Inc.

Table 38
Typical Properties of EPON® Resin 828-EMI-24 Castings

Concentration of Curing Agent	10 phr:	4 phr	4 phr[1]
Cure Schedule	8 hrs at 60°C	8 hrs at 60°C	4 hrs at 60°C & 2 hrs at 150°C
Ultimate Tensile Strength, MPa (psi)			
25°C	67 (9,700)	59 (8,500)	39 (5,700)
100°C	35 (5110.0)	29 (4,200)	—
Tensile Elongation at Break, %			
25°C	2.3	1.8	1.8
100°C	10.3	7.2	—
Tensile Modulus MPa (psi)			
25°C	3500 (510,000)	3700 (540,000)	3700 (540,000)
100°C	1000 (150,000)	900 (130,000)	—
Flexural Strength, MPa (psi)			
25°C	145 (21,000)	137 (19,900)	—
Flexural Modulus, MPa (psi)			
25°C	3700 (540,000)	3900 (563,000)	—
Heat Deflection Temperature, °C	110	85	160
24 Hour Water Boil, % wt Gain	—	—	0.2
3 Hour Acetone Boil, % wt Gain	—	—	1.0
Density	—	—	1.180

	Specific Heat		
	°C	Cal./g°C	
	0	0.32	
	25	0.37	
	100	0.42	
	150	0.50	

[1] See also Fig.10

EMI-24 Used as an Accelerator

Properties of castings prepared from EPON® Resin 826/NADIC methyl anhydride/EMI-24 and EPON Resin 826/hexahydrophthalic anhydride/EMI-24 systems are summarized below. Data obtained using a control system based on EPON Resin 826/NADIC methyl anhydride/EPI-CURE® Curing Agent 3253 (DMP-30) are included for purposes of comparison.

The systems accelerated with EMI-24 provide higher heat deflection temperatures and improved retention of mechanical properties at elevated service temperatures, while requiring lower curing temperature schedules than the control.

Table 39
Use of EMI-24 as an Accelerator for EPON® Resin 826 – Anhydride Systems

Resin System	System A	System B	Control
EPON® Resin 826	100	100	100
NMA (NADIC Methyl Anhydride)	90	-	90
HHPA (Hexahydrophthalic Anhydride)	-	84	-
EMI-24	1	2	-
EPI-CURE® Curing Agent 3253 (DMP-30)	-	-	1
Cure Cycle, h/°C	2/80 + 4/135	2/90 + 4/150	2/125+2/200+2/245
Tensile Strength, M Pa (psi)			
25°C	52 (7,600)	72 (10,500)	69 (10,000)
100°C	63 (9,200)	52 (7,500)	54 (7,900)
150°C	17 (2,400)	-	55 (800)
Tensile Elongation at Break, %			
25°C	1.8	3.5	2.6
100°C	7.3	5.5	5.5
150°C	47.0	-	29.0
Tensile Modulus MPa (psi)			
25°C	3200 (460,000)	2600 (383,000)	2400 (350,000)
100°C	1300 (190,100)	1390 (202,000)	1700 (250,000)
150°C	620 (90,000)	-	340 (50,000)
Heat Deflection Temperature, °C	149	146	131

Handling Characteristics of EPON® Resin/EMI-24Systems

Figure 35 illustrates the viscosity/time relationships of EPON® Resin/EMI-24 systems. The low initial viscosities and the low rates of change of viscosity with time indicate that these systems will prove attractive to adhesive, casting and filament winding applications. A useful pot life in excess of 5-6 hours at normal room temperatures, 21°C-33°C (70°F-90°F), may be expected.

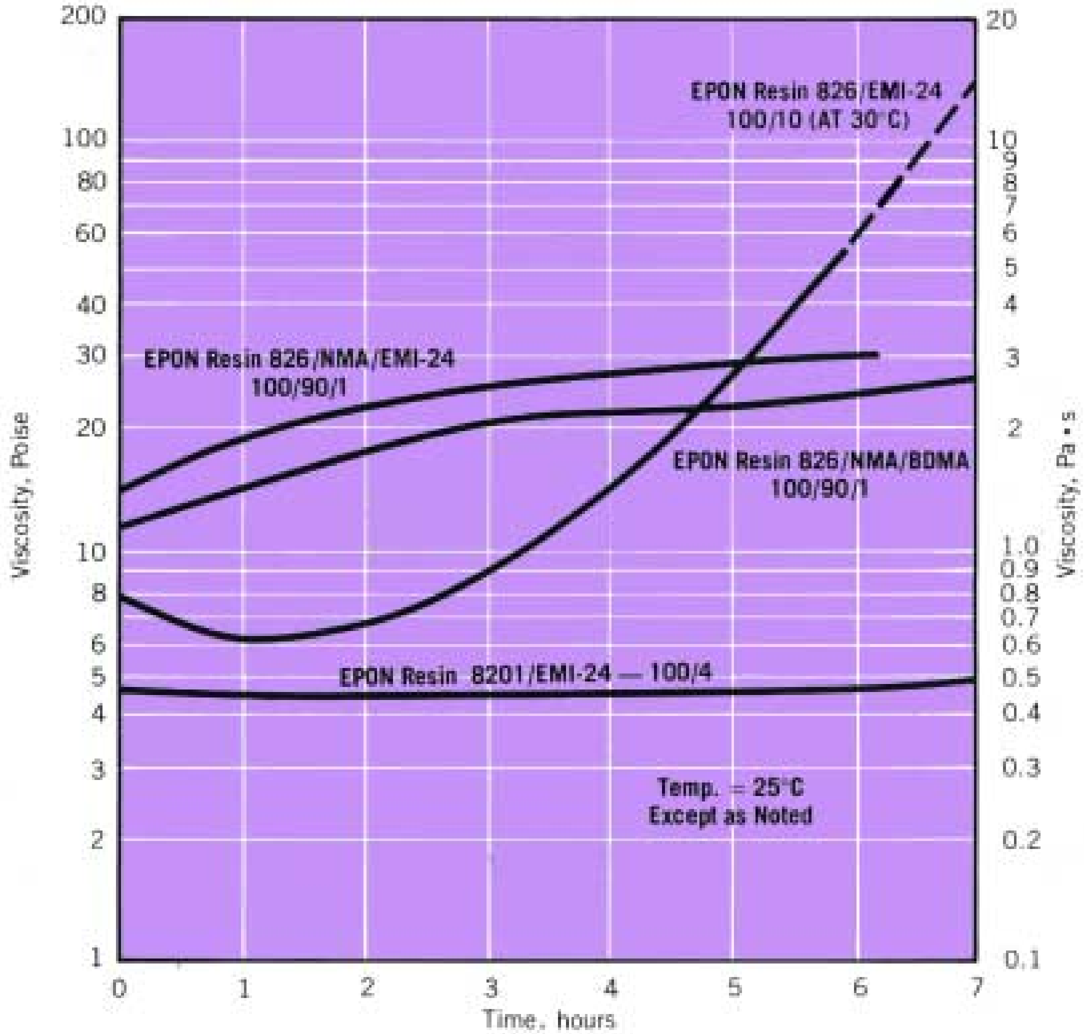


Fig.35 - Viscosity vs Time of EPON® Resin 826/EPON Resin 8201/Anhydride/EMI-24 Systems (0.45 Litre Volume).

Tertiary Amine Salt (ANCAMINE® K61B[5])

ANCAMINE® K61B is a liquid tertiary amine salt that provides good electrical and physical properties with EPON® Resin 828. ANCAMINE K61B is widely used in formulations for potting and encapsulation.

Application

The recommended concentration of ANCAMINE K61B for most electrical applications is in the 10.5 to 13.5 phr range. At these catalyst concentration levels, a blend of EPON Resin 828 and ANCAMINE K61B exhibits a useful pot life for a volume of 0.5 liter (1 pint) of approximately 2 hours at room temperature and an initial viscosity at 25°C of 14.2 (142) Pa•s (poise).

The cure cycle chosen in any electrical application will, of course, depend on the mass of the resin present, the mass of the embedment, the amount and choice of filler, and other factors that influence the extent to which the exothermic reaction will raise the temperature of the system. It has been fairly well established that a minimum temperature of between 110°C and 120°C is needed at some time during the cure if optimum properties, both electrical and physical, are to be obtained.

Resin Properties

While the EPON Resin 828-ANCAMINE K61B system is not remarkable for heat deflection temperature (ca 90°C), it has good heat stability as is evident from the data shown in the table below. Other typical physical data are summarized in the following tables and figures. Additional electrical data are in the section on electrical properties.

Table 40

Table 40 -Effect of Heat Aging at 150°C on Properties of an EPON® Resin 828/ANCAMINE® K61B System

Aging Time Days	Dielectric Constant		Dissipation Factor		Flex. Str. Ultimate MPa (psi)	Comp. Str. Ultimate MPa (psi)	Heat Deflection Temperature °C
	1 kHz	1 MHz	1 kHz	1 MHz			
0	3.81	3.60	.004	.026	129(18,700)	119 (17,200)	80
7	3.80	3.51	.007	.031	95(13,800)	81 (11,700)	78
14	3.83	3.51	.007	.032	113(16,400)	83 (12,000)	78
21	3.82	3.51	.007	.032	112(16,200)	109 (15,800)	77
28	3.86	3.48	.006	.031	114(16,600)	103 (14,900)	76

[1] Castings were cured with 10.5 phr ANCAMINE K61B for 3 hours at 60°C. Test specimens were aged in air at 150°C.

[5] Available from Air Products and Chemicals, Inc.

Table 41
Physical Properties of EPON® Resin 828 Cured with ANCAMINE® K61B

(Cure Cycle: 3 Hours at 75°C)

Flexural Strength, MPa (psi)	127 (18,500)
Flexural Modulus, MPa (psi)	3450 (500,000)
Compressive Strength, MPa (psi)	98 (14,200)
Compressive Modulus, MPa (psi)	3450 (500,000)
% Deformation, Ultimate	4.2
Tensile Strength, MPa (psi)	
0.2% Offset	76 (11,100)
Break	59 (8,500)
Tensile Modulus, MPa (psi)	3450 (500,000)
Tensile Elongation at Break, %	4.7
Barcol Hardness	25
Heat Deflection Temperature, °C	67
Density	1.166[1]
[1] Post cure = 3 hours at 150°C	

Table 42
Tensile Strength vs Temperature for EPON® Resin 828-ANCAMINE® K61B Castings

Temperature, °C	Strength		Modulus Modulus MPa (psi)	Elongation Break, %
	Break, MPa (psi)	0.2% Offset MPa (psi)		
-40	82 (11,900)	64 (9,300)	3500 (510,000)	2.8
-26	82 (11,900)	61 (8,800)	3450 (500,000)	3.1
+25	76 (11,100)	59 (8,500)	3400 (490,000)	4.7
+40	57 (8,300)	41 (5,900)	2800 (400,000)	9.8
+60	32 (4,700)	17 (2,500)	2000 (290,000)	16.1
+75	18 (2,600)	5.6 (820)	400 (60,600)	28.5

Table 43
Effect of Concentration and Post Cure on the Heat Deflection Temperature of EPON® Resin 828-ANCAMINE® K61B Castings

(Specimen gelled for 3 hours at 64°C prior to post cure of 1 hour at 130°C)

Curing Agent Concentration (PHR)	Heat Deflection Temperature (°C)
6	66
8	77
9	78
10	80
11	80
12	79
13	79
14	79
15	76

Table 44

Effect of Concentration and Additional Post Cure on the Heat Deflection Temperatures of EPON® Resin 828- ANCAMINE® K61B Castings

(Specimens gelled for 3 hours at 65°C prior to post cure)

Curing Agent Concentration (PHR)	Post-Cure (h/ °C)	Heat Deflection Temperature (°C)
6	1 /130 + 2/200	92
8	1 /130 + 2/200	96
10	1 /130 + 2/200	90
12	1 /130 + 2/200	87
14	1 /130 + 2/200	83
6	1 /130 + 4/200	90
8	1 /130 + 4/200	94
10	1 /130 + 4/200	91
12	1 /130 + 4/200	86
14	1 /130 + 4/200	85

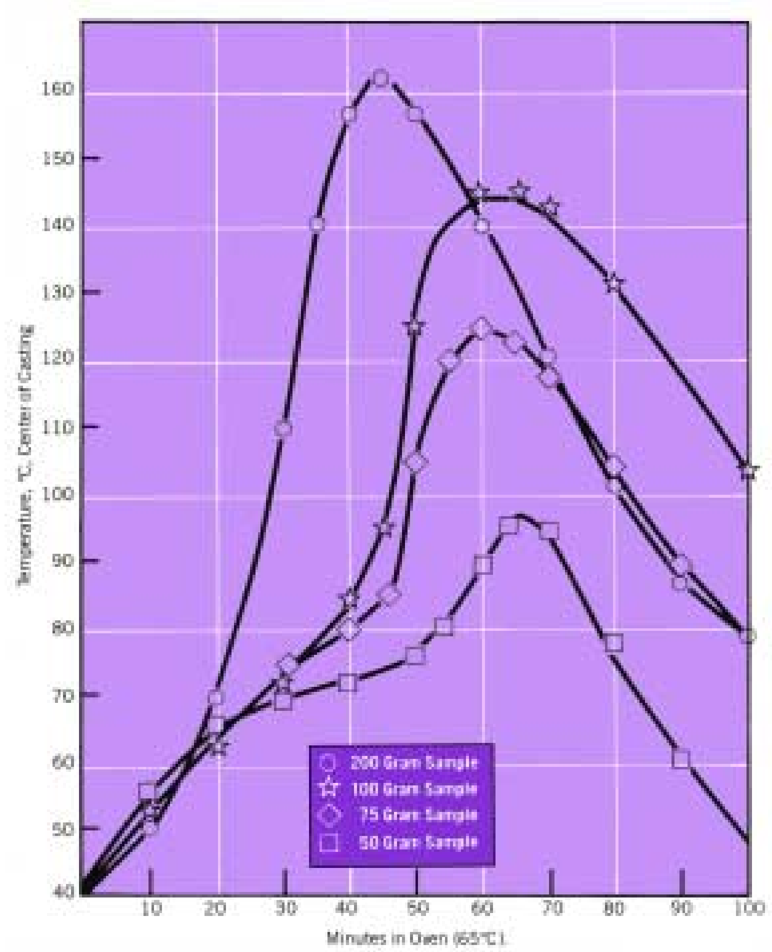
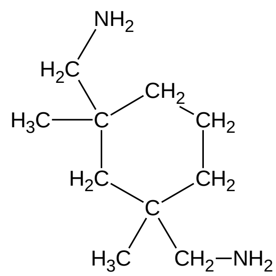
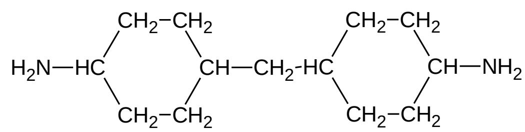


Fig. 36 - Exotherm Profiles of Various Size Castings of EPON® Resin 828 with 10.5 PHR ANCAMINE® K61B

Isophorone Diamine (EPI-CURE® Curing Agent 3300) and Bis (p-Aminocyclohexyl Methane (PACM-20)[6]

Isophorone diamine (EPI-CURE® Curing Agent 3300 - IPDA) and bis (p-amino cyclohexyl) methane (PACM-20) have the following structural formulas:





EPI-CURE® Curing Agent 3300
Isophorone Diamine (IPDA)
M.W. - 170
Eq. Wt. - 42.45
phr for EPON® Resin 828 - 23
Viscosity, 25°C, Pa-s (poise)
0.015 (0.15)

bis (p-aminocyclohexyl) methane (PACM-20)
M.W. - 210
Eq. Wt. - 52.2
phr for EPON® Resin 828 - 28
Viscosity, 25°C, Pa-s (poise)
0.006 (0.06)

Both of these curing agents give polymers with EPON® Resin 828 comparable to those cured with aromatic amines. Pot life is between that for aromatic amines and the ethylene amines (EPI-CURE® Curing Agent 3223 - DETA).

The advantages are:

1. Low viscosity
2. Pale color
3. Non-staining
4. Longer pot life than ethylene amines.

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[6] Available from Air Products and Chemicals, Inc.

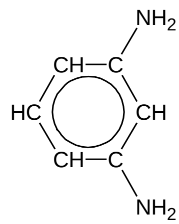
Table 45

IPDA (EPI-CURE® Curing Agent 3300) and PACM-20 (Bis (p-aminocyclohexyl) methane) as Curing Agents for EPON® Resin 828

Concentration	Isophorone diamine		Bis (p-aminocyclohexyl) methane	
Pot Life, 1 liter (quart), 23.C, h	1		1.6	
Initial Mix Viscosity, 25°C, Pa • s (poise)	1.6 (16)		2.6 (26)	
Gel Time at 177°C, sec	32		24	
Heat Deflection Temperature	phr	°C	phr	°C
	19	103	26	130
	21	128	27	142
	23	146	28	148
	25	141	29	149
			30	144
Tensile Properties, 23°C[1)]				
Strength at break, MPa (psi)	83 (12,100)		70 (10,100)	
Elongation at break, %	6.8		6.2	
Modulus, MPa (psi)	2500 (360,000)		2500 (360,000)	
Compressive Properties, 23°C				
Strength at yield, MPa (psi)	121 (17,500)		113 (16,400)	
Deformation at yield, %	9.3		8.0	
Modulus, MPa (psi)	2500 (360,000)		2400 (342,000)	
Flexural Strength, 23°C				
Strength at break, MPA (psi)	110 (16,000)		143 (20,800)	
Modulus, MPa (psi)	2800 (410,000)		3300 (480,000)	
Izod Impact Strength, 23°C J/m (ft lb./in) notch	32 (0.6)		69 (1.3)	
24 hour water boil, %w gain	0.5		0.8	
3 hour acetone boil, %w gain	0.5		1.15	
Density			1.17	

[1] Cure, h/°C – 24/25 + 3/150

Meta-phenylene diamine[7]



When combined with EPON® Resins, meta-phenylene diamine (MPDA) imparts excellent chemical resistance to the cured system as well as good retention of physical and electrical properties at temperatures up to 150°C (300°F).

This solid curing agent offers a further advantage in the curing process of going through a "B" stage, a partially advanced cure stage in which the liquid resin is converted to a solid but soluble and fusible thermoplastic form. This B-stage resin formation makes possible handling like a thermoplastic for specialized casting, molding or laminating techniques.

Application

The recommended concentration of MPDA with EPON resins is 14 phr. Concentrations of 12-13 phr have been observed to be somewhat superior in some applications (e.g., electrical encapsulation). For best results in castings, the EPON resin and curing agent should be well mixed. The following mixing procedure is suggested as being the most convenient and suitable:

Casting Mixture

EPON Resin 828	100 parts (w)
MPDA	14.0 ± 0.5 parts (w)

Mixing Procedure

1. Heat 15 parts (weight) of EPON Resin 828 to 65°C (150°F).

2. Mix well with 14 parts (weight) of molten MPDA at 65°C (150°F).

3. Blend thoroughly with 85 parts (weight) of EPON Resin 828 at room temperature.

As is the case with all casting resins, optimum curing conditions for this system are dependent on the size of the mass, the rate of development of exothermic heat and the ability of the system to dissipate or absorb reaction heat.

[7] Available from DuPont Specialty Chemicals.

In general, direct oven curing schedules for EPON® Resin 828 with MPDA can be satisfactorily worked out at temperatures anywhere from 65°C -150°C. An initial cure temperature of about 80°C is preferable for most castings (with the temperature depending to some extent on the mass of material to be cured) followed by post-curing at higher temperatures.

Curing is generally carried on for two hours. However, where small castings are being made and where it is desirable to use the shortest cure possible, test cures at various oven temperatures are suggested to find the maximum temperature that can be used without causing run-away polymerization of the resin.

It is often preferable in preparing large castings to cure the resin in two stages. These stages are commonly referred to as "B-staging" and "curing", respectively. Stage curing of a casting is usually desirable where the quantity of resin involved is so large that development of excessive exothermic heat will occur if curing is carried out directly in an oven. In stage curing, the following procedure is used:

1. Pour heated, mixed resin into mold that has been preheated to ensure good wetting out.

2. "B-stage" by allowing to stand at room temperature until a solid gel is formed (1-24 hours).

3. Cure at 80-90°C for 30 minutes after the resin has reached this temperature.

4. Post cure (optional). Where maximum chemical resistance or high temperature strength is required, post curing the casting at 150°C for 1 to 2 hours is necessary. This can be accomplished after removal of the casting from the mold, if required.

The pot life of catalyzed resin depends on the size of the batch and the initial temperature. However, MPDA shows considerably longer pot life than most amine systems. Room temperature pot life is in the range of 7 hours in 4-liter (one-gallon) batches when the described mixing procedure is used. At a working temperature of 65°C, a batch of this size would have a pot life of approximately 40-60 minutes.

Table 46
Typical Properties of the EPON® Resin 828-MPDA System

Curing Agent	MPDA
Amount of Curing Agent per Hundred Parts Resin	14
Cure Schedule	
Initial Cure	2 hours at 80°C
Post Cure	2 hours at 150°C
Heat Deflection Temperature, °C (°F)	150 (302°F)
Coefficient of Linear Thermal Expansion, per °C	0.000048
Flexural Modulus, MPa (psi)	
25°C	2800 (400,000)
125°C	1900 (270,000)
175°C	700 (100,000)
Compressive Strength, 0.2% Offset, M Pa (psi)	72 (10,500)
Tensile Strength at Break, MPa (psi)	
23°C	85 (12,400)
100°C	45 (6,600)
150°C	85 (12,400)
Tensile Modulus, M Pa (psi)	
23°C	3300 (480,000)
100°C	2200 (320,000)
Tensile Elongation at Break, %	
23°C	5.1
100°C	7.2
150°C	34
Izod Impact Strength, J/m (ft-lb./in) of notch	31 (0.6)
Density	1.213

ANCAMINE® Z [8]

ANCAMINE® Z is used in casting applications where excellent chemical resistance, high heat deflection temperature, and good electrical properties under conditions of high moisture are desired. A liquid, aromatic-amine eutectic of approximately 2 Pa-s (20 poise) viscosity, this curing agent may be blended readily with the liquid EPON® resins at room temperature to provide extended pot life over MPDA and other solid aromatic amines.

ANCAMINE Z is quite stable, samples having shown no change in curing characteristics after storage of two years at 25°C. At room temperature ANCAMINE Z is essentially a super-cooled liquid and as such may occasionally crystallize. Material which has crystallized, however, can easily be reconstituted by heating at 50°C. Reconstitution has not been found to affect the curing properties or stability of ANCAMINE Z.

This curing agent offers a method for obtaining the excellent properties afforded by the aromatic-amine curing agents in castings applications without the inconvenience of hot melt operations. In making filled castings, e.g., for plastic tooling or electrical use, ANCAMINE Z-catalyzed resin mixtures exhibit longer pot lives than mixtures employing solid, aromatic-amine curing agents. This is because the mass of filled resin does not have to be preheated, as would be the case if a solid aromatic amine were used. In tooling applications, ANCAMINE Z has the added advantage of offering a means for controlled cure of large masses of heavily filled resin. Although such controlled cures are also possible through use of slow-acting tertiary amines and aliphatic polyamines, the products obtained do not have the strength at elevated temperatures of ANCAMINE Z systems.

Application

The optimum concentration of ANCAMINE Z for most casing applications is 20 phr. Heat is normally required during the curing process. The optimum curing cycles for castings based on this EPON Resin system will vary considerably with the application.

Small castings can be cured satisfactorily in two hours at 80°C (175°F), followed by a post cure of two hours at 150°C (300°F). Large castings, however, should be allowed to gel at room temperature before heating. If the casting is sufficiently large, it may not require oven curing since the heat evolved during cure may be sufficient to provide complete curing of the casting. Where optimum heat deflection temperature is less important than high mechanical strengths, e.g., in plastic tooling, a satisfactory cure cycle is 12 hours heating at 65°C (150°F). This has the added advantage of affording very low shrinkage during the cure of the part.

In some applications, it may be desirable to allow samples of the catalyzed resin to harden at room temperature before further curing, resulting in the formation of a "B-stage" or partially cured (thermoplastic) resin. If this "B-stage" resin is heated rapidly to a temperature of about 80°C (175°F), it will melt and remain fluid for a

[8] Available from Air Products and Chemicals, Inc.

short period of time prior to transition to the final cured condition. This fluid stage can be eliminated, if desired, by heating the "B-stage" material at 60°C. for 2-3 hours and subsequently increasing the temperature slowly to the final post cure temperature of 150°C (300°F). The advantage of step-wise cure, through the "B-stage" as previously described, is that exothermic heating can be more easily controlled in this manner.

Resin Properties

The properties of catalyzed resin mixtures and castings are summarized below. These tables are based on laboratory data obtained with EPON® Resin 828. Somewhat poorer overall properties are obtained with EPON Resins 8201, 813, 815C or 8132. For example, these resins show lower HDT values. Typical comparative HDT values for castings based on EPON Resin 828, EPON Resin 8201, and EPON Resin 815C, all cured with ANCAMINE® Z (at curing agent concentration of 20 phr) are 145°C, 138°C and 105°C, respectively.

Efficient curing with ANCAMINE Z can be obtained over a wide range time-temperature relations without significant differences appearing in final properties. As can be seen, the final properties as measured by heat deflection temperature (HDT) are the same throughout the 125-200°C curing range when all specimens have been fully cured although the curing rate increases as curing temperature is raised. Expressed in another fashion, it may be said that a cured resin specimen having a deflection temperature of 145°C can be obtained after post cures of four hours at 125°C, two hours at 150°C or one hour at 200°C.

Table 47
Typical Properties of the EPON® Resin 828-ANCAMINE® Z System[1]

Properties of Catalyzed Resin Mixture (Before Cure)

Viscosity at 25°C (77°F) Pa •s (poise)	8-9 (80-90)
Pot Life 4 liters (1 gal) at 45°C (115°F)	about 3 hr
Pot Life 1 liter (1qt) at 25°C (77°F)	about 8 hr

Properties of Castings Cured for 24 Hours at 80°C (175°F) and Post Cured for 2 Hours at 150°C (300°F)

Density	1.20
Hardness, Rockwell M	105-110
Coefficient of Linear Thermal Expansion, per °C (- 50°C to +50°C)	0.000051
Impact Strength, Notched Izod, J/m (ft-lb./in) of notch	26.5 (0.5)
Heat Deflection Temperature, °C; (°F)	145 (293)
24h Water-Boil %wt gain	0.7
After 24-hour re-dry at 110 °C %wt gain	0.06
3h Acetone Boil, %wt gain	0.6
[1] 20 phr of curing agent used in all cases.	

Table 48
Typical Strength Properties of EPON® Resin 828-ANCAMINE® Z Castings[1]

Test Temperature, °C (°F)	Strength: Ultimate MPa (psi)	Strength: 0.2% Offset MPa (psi)	Modulus MPa (psi)	Elongation: 0.2 % Offset	Elongation: Ultimate
Compressive Properties					
25 (77)	131 (19,000)	72 (10,500)	3200 (460,000)	2.6	8.7
50 (122)	103 (15,000)	60 (10,000)	2800 (410,000)	3.2	7.4
75 (167)	86 (12,500)	59 (8,500)	2500 (360,000)	3.1	7.4
Tensile Properties					
25 (77)	90 (18,000)	55 (8,000)	2500 (360,000)	2.2	4.8
50 (122)	72 (10,500)	52 (7,500)	2400 (350,000)	2.2	4.2
75 (167)	62 (9,000)	45 (6,500)	2200 (320,000)	2.3	4.5
100 (212)	45 (6,500)	34 (5,000)	2100 (310,000)	1.8	5.5

[1] Unfilled castings, incorporation of 20 phr of curing agent and cured for one hour at 90° (194°F) plus 2 hours at 175°C (347°F)

Table 49
Effect of ANCAMINE® Z Concentration on the Heat Deflection Temperature of EPON® Resin 828 Castings

(Cure Cycle: 2 Hours at 80°C plus 1 Hour at 200°C)

Curing Agent Concentration (PHR)	Heat Deflection Temperature (°C)
18	142
19	147
20	149
21	147
22	141
23	137

Table 50
Effect of Post Cure on the Heat Deflection Temperature of EPON® Resin 828-20 phr ANCAMINE® Z Castings

(Cure Cycle: 2 Hours at 80°C Prior to Post Cure)

Post Cure		
Hours	°C	Heat Deflection Temperature (°C)
5	100	120
8	100	122
12	100	124
24	100	127
1	150	142
2	150	147
3	150	148
5	150	152
8	150	152
12	150	156
24	150	156
2	200	146
4	200	147
8	200	148
24	200	144

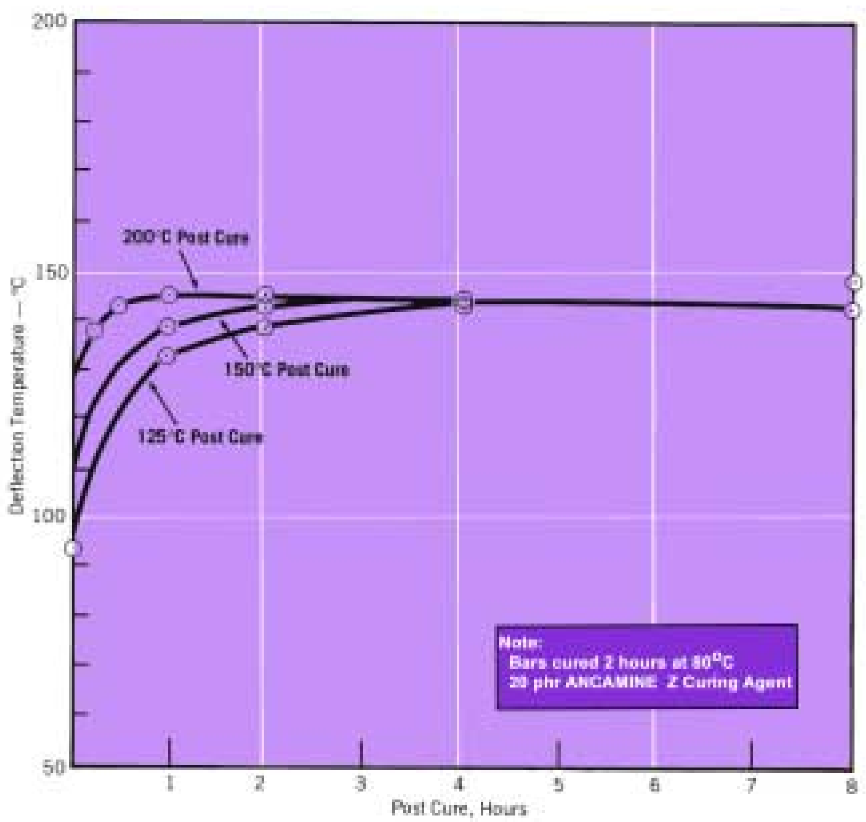


Fig. 37 - Effect of Post Cure Temperature and Time on Heat Deflection Temperature of EPON® Resin 828/ANCAMINE® Z Castings

ANCAMINE® Y[9]

ANCAMINE® Y is a liquid aromatic amine, which, when used with EPON® Resins, yields systems having increased pot lives, high heat deflection temperatures, and excellent physical properties. ANCAMINE Y has a viscosity of about 15 to 20 poise at 25°C (77°F) and is easily incorporated into EPON Resins 813, 8132, 815C, 8201, 826, 8280, 828, and 830 at ambient temperatures. For most applications the optimum concentration of ANCAMINE Y is 25 phr.

ANCAMINE Y is relatively stable at room temperature, but can crystallize after long periods of time or at lower than ambient temperatures. However, material which has crystallized, can be reconstituted by heating at 65°C (150°F) with stirring until the crystals have dissolved.

Recommended Uses

The excellent properties obtained with ANCAMINE Y cured systems suggest its use in casting, laminating, filament winding and tooling applications. End uses which require good solvent and chemical resistance, high heat resistance, and high strengths with curing temperatures up to 150°C (300°F) are especially suited to ANCAMINE Y formulations. ANCAMINE Y will also find use in applications that require the formation at room temperature of a "B-stage" or partially cured (thermoplastic) resin system.

Table 51

Typical Properties for EPON® Resin 828 - ANCAMINE® Y Systems

Properties of the Catalyzed Resin (Before Cure)	
Viscosity Pa • s (poise)	
25°C (77°F)	4.2 (42)
65°C (150°F)	0.15 (1.5)
Pot Life, 4 liters (1 gal), 45°C (115°F), h	4.0
Pot Life, 1 liter (1 qt), 25°C (77°F), h	22.0
Gel Time on a Gel Plate, 177°C (350°F), m	3.3

[9] Available from Air Products and Chemicals, Inc.

Table 52

Selected Properties of Unfilled Castings for EPON® Resin 828 - ANCAMINE® Y Systems

Cured for 2 Hours at 80°C (175°F) and Post Cured 3 Hours at 150°C (300°F)		
Density	1.190	
Hardness, Rockwell	110	
Coefficient of Thermal Expansion, per °C	0.000052	
Impact Strength, 23°C, J/m (ft-Ib/in)of notch		
Izod	26.5 (0.5)	
Charpy	53 (1.0)	
HDT, °C	161	
24 h Water Boil, %wt gain	1.4	
3 h Acetone Boil, %wt gain	0.8	
Specific heat	°C	Cal/g°C
	10	0.34
	25	0.39
	100	0.44
	150	0.50

Table 53

Strength, HDT and Tg Properties of EPON® Resin 828-ANCAMINE® Y Castings

Test Temperature °C (°F)	Strength at Break MPa (psi)	Modulus MPa (psi)	Elongation Deformation at Break %
Tensile Test Values			
23 (73)	83 (12,100)	2800(400,000)	6.3
149 (300)	7 (1,000)	1000 (146,000)	3.3
Compressive Test Values			
23 (73)	127 (18,500)		10.7
Flexural Test Values			
23 (73)	108 (15,700)	2700 (390,000)	
121 (250)	51 (7,400)	1800 (261,000)	
149 (300)	1 (140)	34 (5,000)	

Effect of Curing Agent Y Concentration on HDT of EPON® Resin 826 Castings		Effect of Cure on HDT of EPON Resin 826-25 phr Y Castings	
Phr	HDT,°C	h/°C	HDT,°C
22	142	2/80 + 1/150	155
23	154	2/80 + 2/150	161
24	160	2/80 + 6/150	165
25	162		
26	160		

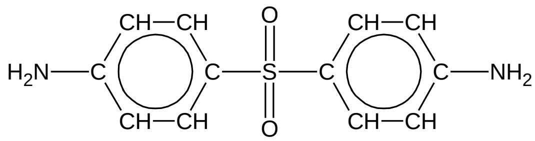
Effect of Resin Type on HDT's and T_g's of Casting Cured with ANCAMINE® Y			
Resin[1]	HDT	Tg[2]	Tg[3]
EPON Resin 828/ANCAMINE Y – 100/25	153	158	160
EPON Resin 828/HELOXY® Modifier 71/ Y – 50/50/18	53	78	86
EPON Resin 828/EPON Resin 1031/Y – 50/50/23	166	178	181
EPON Resin 1031/Y – 100/22	200	210	215

[1] Cure, h/°C, 2/80 + 1/150

[2] Tg by Differential Scanning Calorimeter (DSC)

[3] Tg by DSC rerun on the same sample

4, 4' Diaminodiphenylsulfone[10]



4, 4'-Diaminodiphenylsulfone (DADS) blends with EPON® Resin 828 are particularly useful in casting applications for use at elevated temperatures (120-150°C.) Among the amine curing agents for EPON Resins, DADS yields thermoset polymers having the best overall properties for high-temperature applications. It is suggested for use with EPON Resin 828 since this resin gives the best structural properties at elevated temperatures attainable with liquid EPON Resins.

Application

Two properties of the EPON Resin 828-DADS system that should be considered by the user are:

1. The resin-curing agent blend is quite viscous at ambient temperatures. Because of this, heated resin is used in all casting applications.

2. "B-staging" of castings can be carried out in a manner similar to resin blends containing ANCAMINE® Y or Z, meta-phenylene diamine, or methylene dianiline.

The EPON Resin 828-DADS system cures slowly even at elevated temperatures. For this reason, the addition of 1 phr of BF_3-monoethylamine, an effective accelerator for the resin-amine reaction, is suggested to shorten the cure time. Through use of this accelerator, resin systems easily adaptable to commercial curing equipment have been developed. For example, a 40-gram mass of EPON Resin 828 and DADS incorporating this accelerator showed a pot life at 65°C of 2-3 hours, gelled in one hour at 120°C and showed properties indicating full cure after being heated for an additional 1-2 hours at 200°C. Only slight diminution of final properties results when the BF3-monoethylamine catalyst is present at a concentration of 1 phr.

The following procedure is suggested for preparing castings incorporating EPON Resin 828, DADS and the BF_3-monoethylamine accelerator:

1. Heat 100 parts by weight of EPON Resin 828 to 130°C (270°F).

2. Add 20-30 parts by weight of DADS slowly, maintaining temperature and stir until dissolved. (Approximately 10 minutes will be required.)

3. Remove heat source and allow solution to cool to 100°C (212°F.)

4. Add one part by weight of BF_3-monoethylamine and blend thoroughly.

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[10] Available from R.S.A. Corporation.

5. Pour into mold. (Note: due to the extremely high viscosity of the catalyzed mixture at room temperature, it is recommended that a temperature of 65°C-95°C be maintained to facilitate pouring. The catalyzed material has a pot life of approximately one-hour at this temperature in liter (quart) quantities.

Various cure schedules can be used to obtain optimum high-temperature properties for small castings made by this procedure. Complete cure can be obtained by heating for extended periods at temperatures as low as 125°C. However, much shorter cure times may be used if curing can be carried out at higher temperatures. Present data indicate castings should be first allowed to gel in an oven at 125°C. This usually requires about one hour. Continued heating of the casting at this temperature for 7 days will promote ample cure and produce maximum elevated temperature properties. However, castings of similar strength at elevated temperatures can be obtained within 1 to 2 hours after gelation if curing temperatures of approximately 200°C are used.

Resin Properties

Laboratory evaluations have demonstrated that for many high-temperature applications cured polymers based upon EPON® Resin 828/DADS and EPON Resin 828/BF_3-monoethylamine are of approximately equal utility. For these applications, if low curing temperature and/or "B-staging" are desirable, the EPON Resin 828/DADS system would normally be the preferred resin-curing agent combination. The EPON Resin 828/DADS system is recommended for electrical castings in severe service and other applications requiring excellent elevated temperature strength. To illustrate this property of the system, the deflection temperature of EPON Resin 828/DADS castings (post cured) is compared below with those of several other EPON Resin casting formulations. The improvement in elevated temperature strength of a casting based on the EPON Resin 828/DADS/BF_3-monoethylamine system as cure is continued at various temperatures is also illustrated.

Table 54

Typical Deflection Temperatures of EPON® Resin 828 - DADS Castings

		Cure cycle				
		Cure		Post Cure		
Curing Agent	Concentration PHR	h	Temp. (°C)	h	Temp. (°C)	Heat Deflection Temperature
Diaminodiphenylsulfone (DDS) plus BF_3 monoethylamine (1 phr)	30	5	125	1	200	175°C
BF_3 monoethylamine	3	4	120	4	200	173°C
ANCAMINE® Z Curing Agent	20	2	80	1	200	146°C
Metaphenylenediamine (MPDA)	14	2	80	1	200	152°C
EPI-CURE® Curing Agent 3223 (DETA)	12	3	25	1	200	124°C
ANCAMINE® Y Curing Agent	26	2	80	3	150	162°C

Table 55

Effect of DADS Concentration on the Heat Deflection Temperature of EPON® Resin 828- DADS Castings[1]

(Specimens gelled for 2 hours at 125°C prior to post cure for 2 hours at 200°C.)

DADS Concentration (PHR)	Heat Deflection Temperature (°C)
10	157
14	160
18	176
20	175
22	173
24	172
26	175
28	175
30	175
32	172
34	170
36	169
38	166

[1] 1 phr of BF_3-monoethylamine used as an accelerator in all cases.

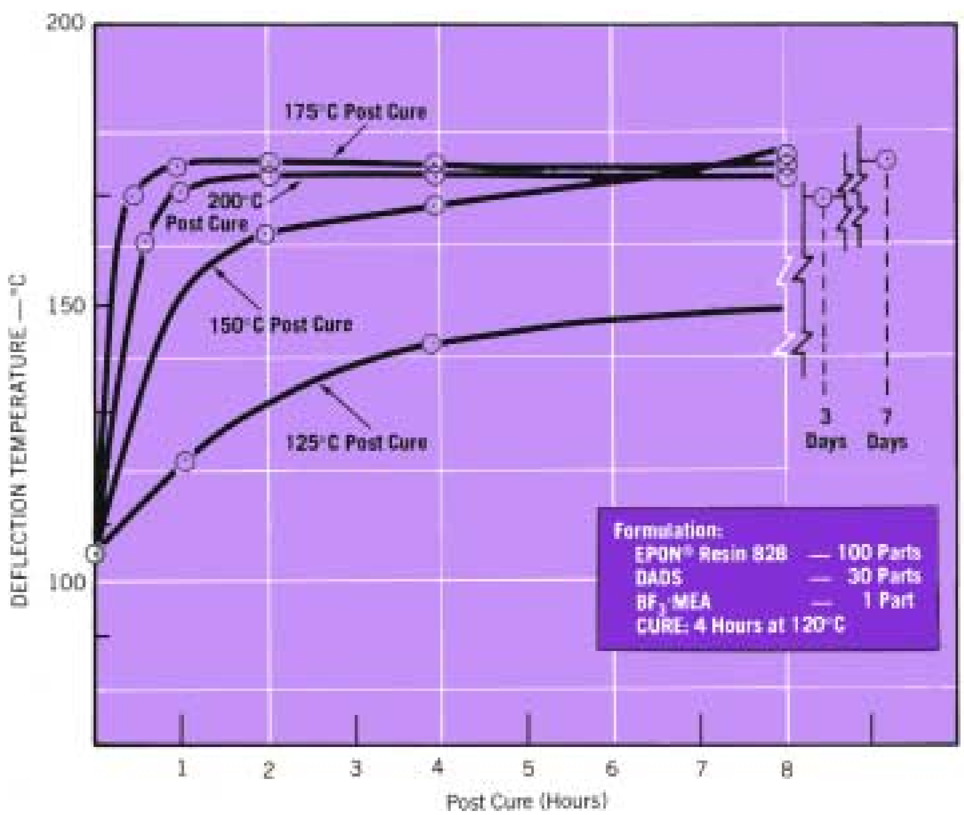
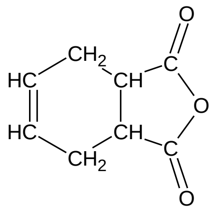


Fig. 38 - Effect of Post Cure Temperature and Time on Heat Deflection Temperature of EPON® Resin 828-DADS Castings

Acid Anhydride Systems[11]



The acid anhydrides as a class are used less often than the amine curing agents but they have several large volume uses. They represent a group of EPON® resin-curing agent materials that are economical, provide very long pot life, have excellent electrical properties and have the best heat stability at temperatures above 150°C.

Relatively large amounts of anhydrides are needed for curing EPON resins. This provides low viscosity mixtures that are easily blended either by automatic metering and mixing equipment or by hand. Because they are slow curing, resin-anhydride blends have comparatively long useful pot lives (several days to weeks) and they have low heat exotherms when cured. Accelerators are usually added to resin/anhydride blends to shorten cure times and obtain optimum properties. Tertiary amines, such as benzyldimethylamine, are the most common accelerators, but there are many other types (see section on Additive Selection). The acid anhydrides are hygroscopic materials and should not be allowed to remain exposed to the atmosphere for extended periods.

There are currently a number of anhydrides on the market, which appear to offer excellent possibilities as co-reactants with EPON resins. Three anhydrides, which have received commercial attention on the basis of ease of handling, are methyl tetrahydrophthalic anhydride (MTHPA), NADIC Methyl Anhydride (NMA) and hexahydrophthalic anhydride (HHPA). Both NMA and MTHPA are liquids of low viscosity, while HHPA is a solid that readily dissolves in EPON Resin 828 at 40°C. Chlorinated compounds such as chlorendic anhydride[12] (CA) appear attractive in specific electrical applications where flame resistance is a major consideration. It contains approximately 57% chlorine by weight. It is a high melting (ca. 250°C) solid that dissolves in EPON Resins at 100-120°C. At this temperature, it is not considered practical to use this anhydride alone since the limited pot life (about ½ hour) does not permit sufficient time for necessary handling procedures. However, the pot life may be extended by replacement of part of the CA with hexahydrophthalic or other low melting anhydride. Such a eutectic co-anhydride mixture has a lower melting point and working temperature. It must contain a minimum of 80% by weight of CA, however, in order to impart flame resistance properties.

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[11] Suppliers include Lonza Fine Chemicals and Specialties, Lindau Chemicals Inc., Buffalo Color Corporation, and Air Products and Chemicals, Inc. among others.
[12] Available from Velsicol Chemical Corp.

Dianhydrides are not usually thought of as common curing agents for EPON® resins because their high melting points and low solubility in resins, many solvents, and other anhydrides do not permit sufficient time for handling procedures. However, dispersions of powdered anhydride in resins can readily be cured in such applications as powder coatings and many kinds of molding compounds. These systems achieve extremely high HDT's (in the 200-260°C range) after very short cure times, such as 1-5 minutes at about 200°C. Typical dianhydrides are benzophenone-tetracarboxylic dianhydride[13] (BTDA), pyromellitic dianhydride[14] (PMDA), and trimellitic anhydride[14] (TMA - not a dianhydride).

Table 56

Summary of Anhydride Curing Agents with EPON® Resin 828

Anhydride	Physical State	Recommended Optimum Concentration Range (phr)[1]	Approximate Pot Life at Temperature of Use
Dodecenyl succinic anhydride (DSA)	Liquid	120-150	10d/25°C; 1-2 h/90°C
Chlorendic anhydride (CA)	Solid	100-117	20-30 m / 150°C
Hexahydrophthalic anhydride (HHPA)	Solid	75-85	1 d/25°; 1-2 h/100 °C
NADIC Methyl anhydride (NMA)	Liquid	80-90	5-6 d/25°C;1-2 h/120°C
Phthalic anhydride (PA)	Solid	75	I h/120°C
Succinic anhydride (SA)	Solid	ca50	1-2 h/120°C
Tetrahydrophthalic anhydride (THPA)	Solid	75-80	1-2 h/100°C
Methyl tetrahydrophthalic anhydride (MTHPA)	Liquid	75-85	1-2 h/100°C

[1] When amine accelerators are employed in catalytic amounts of 0.1 to 1%.

Table 57

Pot Lives of Typical EPON® Resin 828-Anhydride Combinations

Anhydride	phr	BDMA phr	Orig. Viscosity Pa•s (poise) °C	Time to Reach[1] 100 Pa•s (1000 poise)
NMA	90	1	1.8(18) 27	5-6d
DSA	134	1	1.5 (15) 26	10d
HHPA	80	1	0.1215 (2) 40	1d
CA/HHPA	80/20	-	0.07 (0.7) 90	2.5 to 3 h
MTHPA	80	1	0.7 (7) 26	5-6d
	80	1	0.04 (0.4) 80	

[1] System allowed to cool to room temperature after viscosity measurement was made.

[13] Available from Daicel Chemical Industries, Ltd. among others.
[14] Available from Lonza Fine Chemicals and Specialties among others.

Table 58

Heat Deflection Temperature of EPON® Resin 828-Anhydride Combinations

Anhydride, phr		Accelerator, phr		Gel Schedule	Heat Deflection Temperature °C			Density
					Cure 1	Cure 2	Cure 3	Cure 1
DSA	134	BDMA	1.0	4 h/90°C	57	69	74	-
CA	117	None	-	-	170	186	197	-
HHPA	78	BDMA	1.0	3 h/90°C	128	130	132	1.21
NMA	90	BDMA	1.0	3 h/120°C	112	128	144	1.21
PA	75	BDMA	0.1	3 h/120°C	146	147	153	-
SA	50	BDMA	0.5	2 h/120°C	98	102	98	-
THPA	76	BDMA	0.5	2 h /100°C	122	125	-	-
MTHPA	80	BDMA	1.0	1 h/100°C	124	130	-	1.21
NMA	90	EMI-24	0.5	2 h /100°C	-	170	-	1.21

[1] The same concentrations, gel, and post cure schedules were employed to obtain the data presented in the following tables. The post cures are identified as follows:

Cure 1-4 hours at 150°C
Cure 2-24 hours at 150°C
Cure 3 - 200 hours at 150°C

Table 59

Water and Acetone Resistance of EPON® Resin 828-Anhydride Combinations

Anhyride[1]	% Gain in Weight After 24-Hour Water Boil			% Gain in Weight After 3-Hour Acetone Boil		
	Cure 1	Cure 2	Cure 3	Cure 1	Cure 2	Cure 3
Dodecenyl Succinic Anhydride	0.92	0.76	0.71	10.1	8.5	8.1
HET Anhydride	0.58	0.52	0.48	1.2	0.90	0.85
Hexahydrophthalic Anhydride	0.45	0.45	0.46	1.3	1.3	1.2
NADIC Methyl Anhydride	0.98	0.67	0.67	3.2	1.9	0.9
Phthalic Anhydride	0.50	0.51	0.73	3.0	2.3	3.5
Succinic Anhydride	1.3	1.3	1.5	2.9	2.4	2.4
Tetrahydrophthalic Anhydride	0.60	0.81	-	1.5	1.6	-
Methyl Tetrahydrophthalic Anhydride	0.85	-	-	1.1	-	-

[1] See footnote Table 58

Table 60

Tensile Properties of EPON® Resin 828 Anhydride Combinations

		Cure 1			Cure 2			Cure 3		
		Tensile			Tensile			Tensile		
Anhydride[1]	Test Temp.	Strength MPa (psi)	Modulus Mpa (psi)	Elongation (%)	Strength MPa (psi)	Modulus MPa (psi)	Elongation (%)	Strength MPa (psi)	Modulus MPa (psi)	Elongation (%)
Dodecenyl Succinic Anhydride	-25°C	42 (6,000)	3400 (500,000)	1.4	45 (6,600)	2800 (400,000)	1.9	62(9,000)	2800 (400,000)	3.8
	23°C	49 (7,100)	2400 (350,000)	3.5	51(7,400)	2800 (400,000)	4.5	45(6,600)	2100 (300,000)	4.7
NADIC Methyl Anhydride	-25°C	64 (9,300)	3400 (500,000)	1.9	61(8,800)	4100 (600,000)	1.8	46 (6,700)	3400 (500,000)	1.5
	23°C	80(11,600)	3400 (500,000)	3.0	72 (10,500)	3400 (500,000)	2.7	83 (12,100)	2800 (400,000)	4.5
	100°C	27 (3,900)	1700 (250,000)	19.0	46 (6,700)	1400 (200,000)	7.2	52 (7,600)	2100 (300,000)	5.5
Hexahydrophthalic Anhydride	-25°C	85(12,300)	2800 (400,000)	4.0	82 (11, 900)	2800 (400,000)	3.5	67 (9,700)	2800 (400,000)	2.6
	23°C	77(11,200)	2800 (400,000)	7.0	72 (10,500)	2800 (400,000)	5.6	76(11,100)	2800 (400,000)	6.4
	100°C	36 (5,200)	2100 (300,000)	12.0	37 (5,300)	2100 (300,000)	11.1	39 (5,600)	2100 (300,000)	10.6
Chlorendic Anhydride	-25°C	55 (8,000)	3400 (500,000)	1.8	45 (6,500)	3400 (500,000)	1.5	43 (6,300)	2800 (400,000)	1.5
	23°C	68 (9,800)	2800 (400,000)	2.6	47 (6,800)	2800 (400,000)	1.8	59 (8,600)	2800 (400,000)	2.5
	100°C	57 (8,300)	2100 (300,000)	3.7	(8,200)	2800 (400,000)	2.7	54 (7,900)	2100 (300,000)	2.6
Phthalic Anhydride	-25°C	56 (8,100)	3400 (500,000)	1.8	77(11,200)	3400 (500,000)	2.7	-	-	-
	23°C	79(11,500)	2800 (400,000)	4.1	56(13,600)	2800 (400,000)	5.7	93(13,500)	2800 (400,000)	6.0
	100°C	42 (5,100)	2100 (300,000)	10.6	51(7,400)	2100 (300,000)	8.3	61(8,800)	2100 (300,000)	5.8
Succinic Anhydride	23°C	63 (9,100)	2800 (400,000)	6.3	63 (9,100)	2800 (400,000)	7.6	62 (9,000)	2800 (400,000)	8.0
Tetrahydrophthalic Anhydride	23°C	74(10,700)	2800 (400,000)	4.5	-	-	-	-	-	-
	100°C	34 (5,000)	2100 (300,000)	10.0						
Methyl Tetrahydrophthalic Anhydride[2]	23°C	83(12,100)	3000 (440,000)	6.7	-	-	-	-	-	-

1 See footnote Table 58

2 Specific heats

°C	Cal/g °C
10	0.30
25	0.33
100	0.34
150	0.44

Table 61

Heat Deflection Temperatures of EPON® Resins Cured with CA and CA/Hexahydrophthalic Anhydride Systems

Resin	Gel Schedule	Anhydride	Concentration (phr)	Post Cure	Heat Deflection Temperature °C
EPON® Resin 828	-	CA	117	24 h/180°C.	205
EPON Resin 820	2 h/120°C.	CA	117	24 h/180°C.	198
EPON Resin 815C	2 h/120°C.	CA	117	24 h/180°C.	174
EPON Resin 828	2 h/120°C.	CA/HHPA	70/30[1)]	24 h/180°C.	159
EPON Resin 828	2 h/120°C.	CA/HHPA	80/20[1)]	24 h/180°C.	175
EPON Resin 828/ CARDURA® E-10 Glycidyl Ester (90/10)	2 h/120°C.	CA	115	16 h/180°C.	175

[1] Mixture concentrations given in percent weight.

Table 62

Tensile Strength of Silica-Filled EPON® Resin 828-Anhydride Systems[1]

Room Temperature Tensile Properties

Anhydride	Filler Parts 100 Mix [2,4]	Cure Schedule h/°C[3]	Strength MPa (psi)	Modulus MPa (psi)	Elongation %
Dodecenyl Succinic Anhydride	43	1/130 + 24/150	53 (7,700)	3,400 (500,000)	3.4
	85	1/130 + 24/150	55 (8,000)	4,800 (700,000)	2.9
	128	1/130 + 24/150	59 (8,500)	5,500 (800,000)	2.2
	213	1/130 + 24/150	61 (8,800)	8,300 (1,200,000)	1.1
NADIC Methyl Anhydride	52	1/140 + 24/150	67 (9,700)	5,500 (800,000)	1.3
	105	1/140 + 24/150	72 (10,400)	7,600(1,100,000)	1.0
	157	1/140 + 24/150	69 (10,000)	10,300 (1,500,000)	0.8
	209	1/140 + 24/150	65 (9,400)	12,400 (1,800,000)	0.6
CA/HHPA	50	1/120 + 24/150	65 (9,400)	5,500 (800,000)	1.3
	100	1/120 + 24/150	78 (11,300)	8,300 (1,200,000)	1.1
	150	1/120 + 24/150	54 (7,800)	10,300 (1,500,000)	0.6
MTHPA	222	4/190 + 16/120	69 (10,000)	-	1.0

[1] Based on formulations of 100 parts EPON® Resin 828/134 phr Dodecenyl Succinic/1 phr BDMA.
100 parts EPON Resin 828/90 phr NADIC Methyl Anhydride/1 phr BDMA.
100 parts EPON Resin 828/60 % CA - 40% HHPA/0.5 phr BDMA
100 parts EPON Resin 828/80 phr MTHPA/1 phr BDMA

[2] Whittaker, Clarke and Daniels Company, Silica 219 added to resin at 100°C.

[3] The same gel and post cure schedules were employed to obtain the data shown in the following tables.

[4] Parts per 100 parts resin plus anhydride

Table 63

Room Temperature Flexural Strength of EPON® Resin 828-Anhydride Systems

		Flexural Properties	
Anhydride	Filler Parts/100 Mix	Ultimate MPa (psi)	Modulus MPa (psi)
Dodecenyl Succinic Anhydride	43	88(12,800)	2800(400,000)
	85	96 (13,900)	4100(600,000)
	128	104 (15,100)	4800(700,000)
	213	96 (14,000)	6900(1,000,000
NADIC Methyl Anhydride	52	117 (17,000)	4800(700,000)
	105	132 (19,100)	6900(,1000,000)
	157	119 (17,300)	9000(1,300,000)
	209	120 (17,400)	1,1000(1,600,000)
CA/HHPA	50	116 (16,800)	4800 (700,000)
	100	117 (17,000)	6900 (1,000,000)
	150	119 (17,300)	8300 (1,200,000)
MTHPA	222	98 (14,200)	13,200(900,000)

Table 64

Room Temperature Compressive Properties of Silica-Filled EPON® Resin 828-Anhydride Systems

		Strength			Deformation	
Anhydride	Filler Parts/100 Mix	Maximum MPa (psi)	0.2% Offset MPa (psi)	Modulus MPa (psi)	0.2% Offset %	Maximum %
Dodecenyl	43	77 (11,200)	62 (9,000)	2800 (0.4)	2.8	5.2
Succinic	85	85 (12,400)	65 (9,500)	3400 (0.5)	2.2	4.9
Anhydride	128	99 (14,300)	68 (9,900)	4100 (0.6)	1.8	6.0
	213	154 (22,300)	81 (11,800)	6200 (0.9)	1.5	17.7
NADIC Methyl	52	133 (19,300)	104 (15,100)	3400 (0.5)	3.3	6.6
Anhydride	105	161 (23,400)	125 (18,200)	4800 (0.7)	2.9	6.1
	157	209 (30,300)	135 (19,600)	6200 (0.9)	2.4	12.0
	209	240 (34,800)	158 (22,900)	7600 (1.1)	2.3	9.8
CA/HHPA	50	150 (21,800)	111 (16,100)	4100(0.6)	2.9	6.1
	100	185 (26,800)	130 (18,800)	6200(0.9)	2.3	7.8
	150	174 (25,200)	125 (18,100)	6200(0.9)	2.4	6.9
MTHPA	222	179 (26,000)	-	-	-	-

BF_3 Monoethylamine[15]

BF_3-monoethylamine is a boron trifluoride based curing agent that can be classified as a Lewis acid.

Application

The recommended concentration of BF_3-MEA with EPON® Resin 828 is 3 phr for most applications. Larger amounts may be used if greater reactivity is required; and smaller amounts will effect cure if high enough temperatures are used.

Curves showing viscosity versus time at various temperatures for EPON Resin 828 containing 3 phr of BF_3-MEA are shown below. Several samples of catalyzed resin have shown storage life in excess of 6 months and, while considerable increase in viscosity was noted after this interval, the materials could still be used upon warming. Long pot life can be expected even at the elevated temperatures that might be chosen for application of the resin.

As indicated below, little cure occurs at room temperature. At higher temperatures, formulations of EPON Resin 828 containing 3 phr of the complex showed the following activity:

Size of Batch	Temperature	Time to Gel	Time to Cure[1]
3 g	232°C (450°F)	1 m	2 m
25 g	107°C (225°F)	30 m	1 h
25 g	100°C (212°F)	3 h	4 h

[1] Time to reach Barcol Hardness greater than 30.

Upon curing, unfilled EPON Resin 828 catalyzed with BF_3-MEA often wrinkles or 'alligators' at surfaces in contact with air. The causes of this effect have not been fully clarified. A thickness of about 6 mm (0.25 in) can be cured in approximately one hour at 110°C-120°C. Use of higher cure temperatures often results in development of a very high exotherm and a darkened polymer. Castings obtained at higher temperatures also have inferior resistance to chemicals.

[15] Suppliers include Leepoxy Company and Air Products and Chemicals, Inc. among others.

Table 65

Effect of BF_3-Monoethylamine Concentration and Post Cure on Heat Deflection Temperature of EPON® Resin 828-Castings

BF_3-MEA Concentration [2] phr	Post Cure[1] h/200 °C	Heat Deflection Temp. °C
1	1	50
2	1	120
3	1	174
4	1	175
5	1	168
6	1	166
1	4	65
2	4	140
3	4	170
4	4	165
5	4	161
6	4	162

[1] Initial cure=3 hours at 120°C

[2] BF_3-MEA is available from Leepoxy Company and Air Products and Chemicals, Inc.

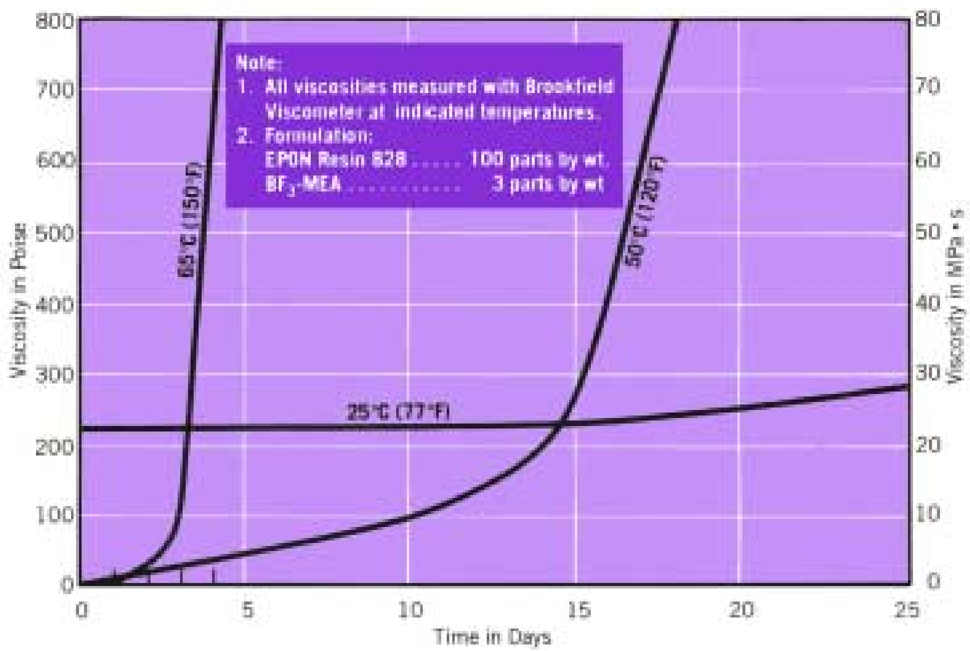


Fig. 39 - Pot Life at Various Temperatures of EPON® Resin 828 Catalyzed with BF_3-MEA.

Table 66
Effect of Post Cure on Heat Deflection Temperature of EPON® Resin 828/3 PHR BF_3- Monoethylamine Castings

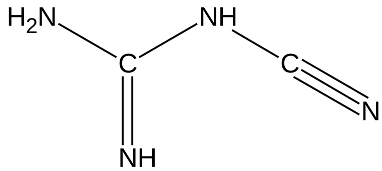
Cure		Heat Deflection Temperature
hours	°C	°C
4	120	64
8	120	78
12	120	90
24	120	99
48	120	109
Post Cure (Specimens gelled for 3 hours @ 120°C prior to post cure)		
4	150	129[1)]
8	150	137
12	150	140
24	150	159
48	150	184
1	200	174
4	200	170
8	200	165

[1] Density of Casting = 1.195

Table 67
Tensile Properties of EPON® Resin 828/3 PHR BF_3-MEA Castings at Various Test Temperatures

(Cure cycle 3 hours @ 120°C followed by 1 hour @ 200°C)					
Temperature	Strength		Modulus	Elongation	
°C	0.2% Offset MPa (psi)	Break MPa (psi)	MPa (psi)	0.2% Offset (%)	Break (%)
100	45 (6,500)	29 (4,200)	1900 (271,000)	1.7	4.1
25	60 (8,700)	43 (6,200)	2700 (390,000)	1.8	3.0
-25	41 (6,000)	44 (6,400)	3400 (490,000)	1.5	1.4

Dicyandiamide[16]



Dicyandiamide (DICY) is widely used with EPON® Resins where long shelf life, up to one year, is required prior to curing. Significantly longer shelf lives can be obtained by storage under refrigeration until use.

Cure with dicyandiamide is believed to be both catalytic and via amine hydrogens, since recommended single package concentrations for curing are significantly below stoichiometric amounts.

Stability is thought to be because of insolubility in EPON Resins. For this reason, dicyandiamide must be powdered, then blended or milled into resin systems; or it must be dissolved in water or suitable solvents such as DMF, then added to EPON Resins followed by removal of the water or solvent to form a solvent-free resin/curing agent system or prepreg.

Cures with DICY are relatively slow. Hence, the addition of 0.2-1%wt benzyldimethylamine (BDMA) or other accelerator (see section on Accelerators) is common to reduce cure times or cure temperatures.

DICY can also be a co-curing agent and accelerator for amines and may be dissolved in many amines, such as EPI-CURE® Curing Agent 3223 (DETA). However, while such cures are effective, the solvent resistance of this type of system is usually reduced.

A unique feature of DICY is its water solubility. This is attractive when used as a curing agent for water dispersions of EPON resin systems (EPI-REZ® Resins and Curing Agents) for adhesives and laminate cures.

Application	Recommended Concentration[1]
Resin	phr
EPON® Resin 828	6
EPON Resin 1001, 1120, 2002	4

[1] Accelerator concentration 0.2-1 phr BDMA or other accelerator. Stability of up to one year is common for solvent-free catalyzed resin systems.

[16] Available from SKW Trostberg AG among others.

Table 68

Tensile Shear Strengths for an EPON® Resin 828/ DICY Adhesive for Bonding Aluminum Sheet

Test Temperature	Tensile Shear Strength, psi[1]
-57 (-70)	3100
25 (77)	3100
82 (180)	3700
121 (250)	2200
149 (300)	1200

[1] Cure=1 ½ h at 174°C (345°F)

Table 69

Flexural Strengths and Tg's for EPON® Resin 1123-A-80/DICY FR-4 Electrical Laminate[1-2]

Flexural Strength, MPa (psi)	
25°C (77°F)	469 (68,000)
T_g°C (°F) by DSC	135 (275)
T_g°C °C by DMA	145 (293)
% Resin	40

[1] Cure = one hour at 177°C (350°F)

[2] Solid brominated resin sold as a solution in acetone

Table 70

Film Properties EPON® Resin 2002/ Accelerated DICY Powder Coating

Bake Schedule M/°C (°F)	15/177 (350)
Reverse Impact Resistance, Gardner, in-lb	pass 160
Flexibility, Zuhr Conical Mandrel	pass 1/8"
Pencil Hardness	pass F
Cross Hatch Adhesion, 1/8 inch Squares	pass
Solvent Resistance	
MIBK,	pass 2
MEK, min	pass 8
Gloss, 60°, %	100
T_g°C (°F)[3]	103 (217)

[1] Accelerated dicyandiamide, pigmented coating. The powder was applied via electrostatic spray on cold rolled steel panels.
Film thickness 2.0-2.2 mils.

[2] An alternate cure is 5-7 minutes at 204°C (400°F).

[3] T_g for unpigmented coating.