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PROPERTIES OF EPOXY RESINS USED IN WET FILAMENT WINDING

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ABSTRACT

Data on the properties of epoxy resin systems studied at Lawrence Livermore Laboratory have been collected and are presented in tabular form.

INTRODUCTION

In the past few years, the LLL fiber composites group has studied numerous epoxy resin systems for wet filament winding applications. These results have been thoroughly reported but unfortunately, the information is scattered throughout the literature. Thus for this paper, we have compiled extensive data on the properties of the investigated systems, including references to the reports and articles in which the information was originally reported.

Here we present appendices of the epoxy resin systems investigated, the chemical nature of the resins and curing agents, as well as data sheets for each system. Included in the data sheets are the composition of the system (resin, diluent, and curing agent); the cure schedule; tensile, compressive, and shear data; viscosity, gel time, and exotherm; density, shrinkage, and water absorption; the glass transition temperature; and thermal properties.

DISCUSSION OF RESIN SYSTEMS

Data are reported for epoxy resin systems that have been fully characterized for both mechanical and physical properties (Systems 1-4) and for resin systems that have only been compared on the basis of tensile strength and water absorption and are otherwise incompletely characterized. The original publications from which these data are drawn should be consulted for results and properties that are not reported in this paper.

All resin systems discussed meet the processing requirements of low viscosity (less than 1.0 Pa·s) and long pot life (gel times generally greater than 30 hours). Resin Systems 2 and 5, cured with Jeffamine T-403, are room or low temperature curable systems whereas all other systems require elevated temperatures of 120°C or greater to achieve a complete cure. System 1 has the highest tensile strength of all systems studied and was used by Garrett AiResearch Corporation to construct a flywheel with the highest energy density (30 Wh/lb) of all such flywheels built to date.

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We have also included data on 15 flexible epoxy resins ranging in properties from nearly rigid to very soft and flexible. The utility of these systems has yet to be determined and precise tests of the relative strengths and weaknesses of composite specimens constructed from these resins are needed.

ACKNOWLEDGEMENTS

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APPENDIX 1. EPOXY RESINS AND REACTIVE DILUENTS

Resins

DGEBA Diglycidyl ether of bisphenol A; the standard epoxy resin.

DER 332 Pure liquid low viscosity DGEBA resin; mostly $n=0$; Dow Chemical Company.

Epon 826 Liquid low viscosity DGEBA resin; mostly $n=0$; Shell Chemical Company.

XD 7818 A low viscosity resin, essentially the diglycidyl ether of bisphenol F. The structure contains several isomers that lower the melting point and prevent crystallization during storage; Dow Chemical Company. See structure in XD 75 75.02.

XD 7575.02 XD 7818 into which is reacted 10% by weight of a carboxy-terminated acrylonitrile-butadiene copolymer (CTBN); Dow Chemical Company.

XD 7818

CTBN

ERE 1359 Resorcinol diglycidyl ether with low viscosity of 0.5 Pa·s at 25°C; Ciba-Geigy.

Epon 871 Aliphatic polyepoxide diglycidyl ester of linoleic dimer acid with a low viscosity of 0.4 to 0.9 Pa•s; Shell Chemical Company.

Araldite 508 Mixture of Araldite 6010 (DGEBA) and epoxidized polyol; from Ciba-Geigy.

DER 732 and 736 Polyglycol diepoxides. DER 736 has a lower n and hence, a shorter chain length than does DER 732; Dow Chemical Company.

DER 741 Polyglycol epoxide related to DER 732 and DER 736 but having a higher viscosity; Dow Chemical Company.

Lekutherm X-80 Diglycidyl ester of a special bisphenol in which the aromatic rings are linked through a long aliphatic chain. Infrared spectra show that these links contain ester groups; Bayer.

ERL 2256 Mixture of regular DGEBA, 63% ERL 2774, and reactive diluent bis (2,3-epoxy cyclopentyl) ether, 37% ERLA 0400; Union Carbide Corporation.

ERL 2258 Mixture of 50% ERL 2774 and 50% ERLA 0400, having a lower viscosity than ERL 2256; Union Carbide Corporation.

Epi-Rez 505 A low viscosity polyepoxide resin that imparts flexibility; Celanese Chemical Company. It is reported to be the triglycidyl ether of hydrogenated castor oil.

Diluents

ERLA 0400 Liquid isomer of bis (2,3-epoxy cyclopentyl) ether;
from Union Carbide Corporation.

ERL 4206 Vinyl cyclohexene dioxide; from Union Carbide Corporation or
or Ciba-Geigy.

CIBA RD-4

XD 7114 Diluent of diglycidyl ether of neopentyl glycol from Dow Chemical
Company. It is a mixture of 7 components as determined by GPC;
major peak 50%, minor peak 25%, 5 other peaks of less than 5%.

BDE Butanediol diglycidyl ether.

RD-2 Diluent of crude diglycidyl ether of 1, 4-butanediol; Ciba-Geigy.

APPENDIX 2. CURING AGENTS

MDA Methylene dianiline.

MPDA Meta phenylene diamine.

DAP 2,6 diaminopyridene.

Jeffamine T-403 Polyether triamine of low viscosity (0.08 Pa·s at 25°C) that provides good flexibility and toughness to cured epoxies; Jefferson Chemical Company. Gas chromatography analysis of 7 components, each of greater than 7% plus 8 other components of less than 7%. Its idealized structure is:

$$x + y + z \approx 5.3$$

T-403 Acrylonitrile Jeffamine T-403 reacted with acrylonitrile to replace all the primary amine hydrogens.

Tonox 60-40 Aromatic amine curing agent; a viscous liquid mixture of 60% crude methylene dianiline and 40% meta phenylene diamine; Uniroyal.

Tonox LC Aromatic amine curing agent made by reacting formaldehyde with aniline plus another aromatic amine. It contains methylene dianiline with other similar products that break up the crystallinity and lower the melting point. It is a viscous liquid that reacts more slowly than Tonox 60-40; Uniroyal.

ZZL 0820 Mixture of methylene dianiline and meta phenylene diamine reacted with a small amount of DGEBA resin to lower the melting point; Union Carbide Corporation.

Epi-Cure 855 Aliphatic amide-amine curing agent.

B-3 Amine curing agent consisting of one-third meta phenylene diamine, one-third methylene dianiline, and one-third isopropyl meta phenylene diamine; Hysol Corporation.

XU-205 Liquid aromatic amine curing agent similar to MDA consisting of a mixture of 60%

and 40% methylene dianiline as determined by NMR analysis; Ciba-Geigy.

ATBN (1300 x16) Amine terminated butadiene acrylonitrile polymer that may be represented structurally as

where $x = 5$, $y = 1$, and $m = 10$.

ATBN is a high viscosity material [200,000 cps at 27°C

(200 Pa·s)] used to toughen and flexibilize epoxy resins..

ATBN (Lot 42-82) A modified ATBN of lower viscosity and acrylonitrile content; B. F. Goodrich Chemical Company.

APPENDIX 3. EPOXY RESIN SYSTEMS

System No.	Epoxy Resin Components	Page
1.	XD 7818/XD 7575.02/ERL 4206/Tonox 60-40	9
2.	DER 332/Jeffamine T-403	10
3.	XD 7818/XD 7114/Tonox 60-40/DAP	11
4.	Epon 826/RD-2/Tonox 60-40	12
5.	XD 7818/Jeffamine T-403	13
6.	XD 7818/ERL 4206/Tonox 60-40	14
7.	XD 7818/XD 7114/Tonox 60-40	15
8.	XD 7818/XD 7575.02/XD 7114/Tonox 60-40	16
9.	XD 7818/XD 7114/Tonox LC	17
10.	XD 7818/ERL 4206/Tonox 60-40/DAP	18
11.	XD 7818/XD 7575.02/XD 7114/Tonox 60-40/DAP	19
12.	XD 7818/XD 7575.02/ERL 4206/Tonox 60-40/DAP	20
13.	ERL 2256/Tonox 60-40	21
14.	ERL 2258/ZZL 0820	22
15.	ERE 1359/RD-2/DAP	23
16.	XD 7818/XD 7114/Epon 871/Tonox 60-40 (a and b)	24, 25
17.	XD 7818/XD 7114/Araldite 508/Tonox 60-40 (a and b)	26, 27
18.	XD 7818/DER 741/XD 7114/Tonox 60-40 (a and b)	28, 29
19.	XD 7818/XD 7114/Epi-Rez 505/Tonox 60-40 (a and b)	30, 31
20.	XD 7818/DER 732/Tonox 60-40 (a and b)	32, 33
21.	Lekutherm X-80/XD 7114/Tonox 60-40	34
22.	XD 7818/XD 7114/ATBN/Tonox 60-40	35
23.	XD 7114/ATBN/Tonox 60-40	36
24.	XD 7818/XD 7114/Jeffamine T-403/T-403 Acrylonitrile	37
25.	XD 7818/XD 7114/T-403 Acrylonitrile	38

APPENDIX 4. PROPERTIES OF EPOXY RESIN SYSTEMS

CURED EPOXY RESIN DATA SHEET: SYSTEM 1

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	XD 7818	50	Uncured	
	XD 7575.02	50	Cured	1.223
Diluent	ERL 4206	30	Shrinkage, % volume	
Curing agents	Tonox 60-40	38	After gelation	4.69
			After cure	5.32
Cure schedule, °C/h			Water absorption after	
60/5.5 + 120/3			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa		128	1.23	
Stress at failure, MPa			Glass transition	
Strain at maximum, %		5.40	temperature by TMA, °C	
Strain at failure, %			105-125	
Modulus, GPa		4.12	Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa		134	1820 kPa (264 psi), °C	
Strain at maximum			110	
strength, %		5.68	Thermal coefficient at	
Modulus, GPa		3.51	linear expansion at	
Shear properties			213 to 408 K, °C ⁻¹	
Stress at failure, MPa		84	4.79x10 ⁻⁵	
Modulus, GPa		2.18	Specific heat	
Viscosity at 25°C, Pa·s			(ASTM-C-351-61), K	
Time to reach 2.0 Pa·s, h			at K	
Gel time for 30 g at			at K	
25°C, h			Heat capacity, J/kg·K	
Exotherm of 500 g from			at 313 K	
25°C, °C			at 373 K	
			at 433 K	
			Thermal conductivity, W/m·K	
			at K	
			at K	
			at K	

Source: L. Penn, B. Morra, and E.T. Mones, "A Rubberized-Epoxy System for Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78167 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 2

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	DER 332 100	Uncured	
		Cured	1.16*
Diluent		Shrinkage, % volume	
Curing agents	Jeffamine T-403 36	After gelation	4.4 *
		After cure	4.4 *
Cure schedule, °C/h 60/16		Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	73	(ASTM-D-570-63), % gain	0.75*†
Stress at failure, MPa	65	Glass transition	
Strain at maximum, %	3.6	temperature by TMA, °C	
Strain at failure, %	4.9	Heat distortion	
Modulus, GPa	3.24	temperature at	
Compressive properties		1820 kPa (264 psi), °C	
Maximum strength, MPa	88	Thermal coefficient at	
Strain at maximum		linear expansion at	
strength, %	3.7	298 to 374 K, °C ⁻¹	
Modulus, GPa	3.48	Specific heat	
Shear properties		(ASTM-C-351-61), J/kg·K	
Stress at failure, MPa	61	at K	1.75*
Modulus, GPa	1.27	at K	
Viscosity at 25°C, Pa·s 0.8		Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h		at K	
Gel time for 30 g at		at K	
25°C, h		at K	
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C		at 298 K	0.133 *
		at 318 K	0.174 *
		at 336 K	0.210 *

* Cured at 60°C/24 h + 77°C/24 h.

† After 2 h in boiling water.

Source: T. T. Chiao and R. L. Moore, "A Room-Temperature-Curable Epoxy for Advanced Fiber Composites," presented at the 29th Annual Technical Conference, Reinforced Plastics/Composites Institute, Society of Plastics Industry, Inc., Section 16B (1974).

CURED EPOXY RESIN DATA SHEET: SYSTEM 3

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u>	<u>100</u>	Uncured	<u>1.17</u>
			Cured	
Diluent	<u>XD 7114</u>	<u>30</u>	Shrinkage, % volume	
Curing agents	<u>Tonox 60-40</u>	<u>13.2</u>	After gelation	<u>5.4</u>
	<u>DAP</u>	<u>13.2</u>	After cure	<u>5.4</u>
Cure schedule, °C/h			Water absorption after	
<u>90/4.5 + 120/4</u>			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa	<u>101</u>		<u>1.65*</u>	
Stress at failure, MPa			Glass transition	
Strain at maximum, %	<u>6.3</u>		temperature by TMA, °C	
Strain at failure, %			<u>100-107</u>	
Modulus, GPa	<u>3.12</u>		Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa	<u>119</u>		1820 kPa (264 psi), °C	
Strain at maximum			<u>107</u>	
strength, %	<u>5.5</u>		Thermal coefficient at	
Modulus, GPa	<u>3.83</u>		linear expansion at	
Shear properties			298 to 374 K, °C ⁻¹	
Stress at failure, MPa	<u>27.3</u>		<u>5.0x10⁻⁵</u>	
Modulus, GPa	<u>1.38</u>		Specific heat	
Viscosity at 25°C, Pa•s			(ASTM-C-351-61),	
Time to reach 2.0 Pa•s, h			at K	
Gel time for 30 g at			at K	
25°C, h			Heat capacity, J/kg•K	
Exotherm of 500 g from			at 313 K	
25°C, °C			at 353 K	
			at 393 K	
			Thermal conductivity, W/m•K	
			at K	
			at K	
			at K	

* 3.5% after 24 h in boiling water.

Source: L. Penn and T.T. Chiao, "A long Pot-Life Epoxy System for Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76918 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 4

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	Epon 826	100	Uncured	1.15
			Cured	1.21
Diluent	RD-2	25	Shrinkage, % volume	
Curing agents	Tonox 60-40	28.5	After gelation	3.7
			After cure	5.4
Cure schedule, °C/h			Water absorption after	
60/3 + 120/2			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa		90	0.93	
Stress at failure, MPa		89	Glass transition	
Strain at maximum, %		7.8	temperature by TMA, °C	
Strain at failure, %		8.9	126-133	
Modulus, GPa		2.68	Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa		111	1820 kPa (264 psi), °C	
Strain at maximum			121	
strength, %		8.0	Thermal coefficient at	
Modulus, GPa		2.9	linear expansion at	
Shear properties			298 to 374 K, °C ⁻¹	
Stress at failure, MPa		52	6.81x10 ⁻⁵	
Modulus, GPa			Specific heat	
Viscosity at 25°C, Pa·s		1.20	(ASTM-C-351-61),	
Time to reach 2.0 Pa·s, h		6	at 363 K	
Gel time for 30 g at			1.54x10 ³	
25°C, h		23	at 424 K	
Exotherm of 500 g from			1.71x10 ³	
25°C, °C			Heat capacity, J/kg·K	
			at 363 K	
			1.38x10 ⁵	
			at 424 K	
			2.58x10 ⁵	
			at K	
			Thermal conductivity, W/m·K	
			at 325 K	
			0.243	
			at 356 K	
			0.244	
			at 389 K	
			0.256	

Source: T.T. Chiao, E.S. Jessup, and H.A. Newey, "An Epoxy System for Filament Winding," SAMPE Quarterly, 6(1), (1974).

CURED EPOXY RESIN DATA SHEET: SYSTEM 5

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	<u>XD 7818 100</u>	Uncured	<u>1.116</u>
		Cured	
Diluent		Shrinkage, % volume	
Curing agents	<u>Jeffamine T-403 49</u>	After gelation	
		After cure	
Cure schedule, °C/h		Water absorption after	
<u>60/11 or 100/3</u>		6 h in boiling water	
Tensile properties		(ASTM-D-570-63), % gain	
Stress at maximum, MPa	<u>75</u>		<u>1.15</u>
Stress at failure, MPa		Glass transition	
Strain at maximum, %	<u>4.3</u>	temperature by TMA, °C	
Strain at failure, %		Heat distortion	
Modulus, GPa	<u>2.90</u>	temperature at	
Compressive properties		1820 kPa (264 psi), °C	
Maximum strength, MPa			<u>67</u>
Strain at maximum strength, %		Thermal coefficient at	
Modulus, GPa		linear expansion at	
Shear properties		298 to 374 K, °C ⁻¹	
Stress at failure, MPa		Specific heat	
Modulus, GPa		(ASTM-C-351-61),	
Viscosity at 25°C, Pa·s		at K	
Time to reach 2.0 Pa·s, h		at K	
Gel time for 30 g at		Heat capacity, J/kg·K	
25°C, h	<u>13.3</u>	at K	
Exotherm of 500 g from		at K	
25°C, °C	<u>5</u>	Thermal conductivity, W/m·K	
		at K	
		at K	
		at K	

Source: T.T. Chiao, E.S. Jessup, and H.A. Newey, "A Moderate-Temperature-Curable Epoxy For Advanced Composites," SAMPE Quarterly, 6(3), (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 6

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	XD 7818	100	Uncured	
			Cured	
Diluent	ERL 4206	30	Shrinkage, % volume	
Curing agents	Tonox 60-40	39.7	After gelation	
			After cure	
Cure schedule, °C/h		60/4 + 120/3	Water absorption after	
Tensile properties			6 h in boiling water	
Stress at maximum, MPa		117	(ASTM-D-570-63), % gain	1.1
Stress at failure, MPa			Glass transition	
Strain at maximum, %		6.1	temperature by TMA, °C	
Strain at failure, %			Heat distortion	
Modulus, GPa		3.42	temperature at	
Compressive properties			1820 kPa (264 psi), °C	
Maximum strength, MPa			Thermal coefficient at	
Strain at maximum			linear expansion at	
strength, %			298 to 374 K, °C ⁻¹	
Modulus, GPa			Specific heat	
Shear properties			(ASTM-C-351-61),	
Stress at failure, MPa			at K	
Modulus, GPa			at K	
Viscosity at 25°C, Pa·s		0.9	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h			at K	
Gel time for 30 g at			at K	
25°C, h		30	at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C			at K	
			at K	
			at K	

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 7

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u> <u>100</u>	Uncured	<u> </u>
		Cured	<u> </u>
Diluent	<u>XD 7114</u> <u>30</u>	Shrinkage, % volume	
Curing agents	<u>Tonox 60-40</u> <u>31.5</u>	After gelation	<u> </u>
		After cure	<u> </u>
Cure schedule, °C/h	<u>60/4 + 120/3</u>	Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	<u>95</u>	(ASTM-D-570-63), % gain	<u>1.95</u>
Stress at failure, MPa	<u> </u>	Glass transition	
Strain at maximum, %	<u>6.5</u>	temperature by TMA, °C	<u> </u>
Strain at failure, %	<u> </u>	Heat distortion	
Modulus, GPa	<u>2.94</u>	temperature at	
Compressive properties		1820 kPa (264 psi), °C	<u>100</u>
Maximum strength, MPa	<u> </u>	Thermal coefficient at	
Strain at maximum		linear expansion at	
strength, %	<u> </u>	298 to 374 K, °C ⁻¹	<u> </u>
Modulus, GPa	<u> </u>	Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa	<u> </u>	at K	<u> </u>
Modulus, GPa	<u> </u>	at K	<u> </u>
Viscosity at 25°C, Pa·s	<u>0.8</u>	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h	<u> </u>	at K	<u> </u>
Gel time for 30 g at		at K	<u> </u>
25°C, h	<u>26</u>	at K	<u> </u>
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C	<u> </u>	at K	<u> </u>
		at K	<u> </u>
		at K	<u> </u>

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 8

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u>	<u>50</u>	Uncured	<u> </u>
	<u>XD 7575.02</u>	<u>50</u>	Cured	<u> </u>
Diluent	<u>XD 7114</u>	<u>45</u>	Shrinkage, % volume	
Curing agents	<u>Tonox 60-40</u>	<u>33.7</u>	After gelation	<u> </u>
			After cure	<u> </u>
Cure schedule, °C/h			Water absorption after	
<u>60/4.5 + 120/3</u>			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	<u>1.4</u>
Stress at maximum, MPa	<u>88</u>		Glass transition	
Stress at failure, MPa	<u> </u>		temperature by TMA, °C	<u> </u>
Strain at maximum, %	<u>6.1</u>		Heat distortion	
Strain at failure, %	<u> </u>		temperature at	
Modulus, GPa	<u>2.96</u>		1820 kPa (264 psi), °C	<u> </u>
Compressive properties			Thermal coefficient at	
Maximum strength, MPa	<u> </u>		linear expansion at	
Strain at maximum	<u> </u>		298 to 374 K, °C ⁻¹	<u> </u>
strength, %	<u> </u>		Specific heat	
Modulus, GPa	<u> </u>		(ASTM-C-351-61),	
Shear properties			at K	<u> </u>
Stress at failure, MPa	<u> </u>		at K	<u> </u>
Modulus, GPa	<u> </u>		Heat capacity, J/kg·K	
Viscosity at 25°C, Pa·s	<u>0.8</u>		at K	<u> </u>
Time to reach 2.0 Pa·s, h	<u> </u>		at K	<u> </u>
Gel time for 30 g at			at K	<u> </u>
25°C, h	<u>30</u>		at K	<u> </u>
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C	<u> </u>		at K	<u> </u>
			at K	<u> </u>
			at K	<u> </u>

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 9

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	XD 7818 100	Uncured	
		Cured	
Diluent	XD 7114 45	Shrinkage, % volume	
Curing agents	Tonox LC 50.3	After gelation	
		After cure	
Cure schedule, °C/h	60/5 + 120/3	Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	90	(ASTM-D-570-63), % gain	1.4
Stress at failure, MPa		Glass transition	
Strain at maximum, %	5.3	temperature by TMA, °C	
Strain at failure, %		Heat distortion	
Modulus, GPa	3.06	temperature at	
Compressive properties		1820 kPa (264 psi), °C	
Maximum strength, MPa		Thermal coefficient at	
Strain at maximum		linear expansion at	
strength, %		298 to 374 K, °C ⁻¹	
Modulus, GPa		Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa		at K	
Modulus, GPa		at K	
Viscosity at 25°C, Pa·s	0.85	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h		at K	
Gel time for 30 g at		at K	
25°C, h	57	at K	
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C		at K	
		at K	
		at K	

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 10

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u>	<u>100</u>	Uncured	<u> </u>
			Cured	<u> </u>
Diluent	<u>ERL 4206</u>	<u>20</u>	Shrinkage, % volume	
Curing agents	<u>Tonox 60-40</u>	<u>14.4</u>	After gelation	<u> </u>
	<u>DAP</u>	<u>14.4</u>	After cure	<u> </u>
Cure schedule, °C/h			Water absorption after	
<u>80/5 + 120/3</u>			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	<u>1.5</u>
Stress at maximum, MPa	<u>103</u>		Glass transition	
Stress at failure, MPa	<u> </u>		temperature by TMA, °C	<u> </u>
Strain at maximum, %	<u>3.1</u>		Heat distortion	
Strain at failure, %	<u> </u>		temperature at	
Modulus, GPa	<u>3.92</u>		1820 kPa (264 psi), °C	<u> </u>
Compressive properties			Thermal coefficient at	
Maximum strength, MPa	<u> </u>		linear expansion at	
Strain at maximum	<u> </u>		298 to 374 K, °C ⁻¹	<u> </u>
strength, %	<u> </u>		Specific heat	
Modulus, GPa	<u> </u>		(ASTM-C-351-61),	
Shear properties			at K	<u> </u>
Stress at failure, MPa	<u> </u>		at K	<u> </u>
Modulus, GPa	<u> </u>		Heat capacity, J/kg·K	
Viscosity at 25°C, Pa·s	<u>0.8</u>		at K	<u> </u>
Time to reach 2.0 Pa·s, h	<u> </u>		at K	<u> </u>
Gel time for 30 g at			at K	<u> </u>
25°C, h	<u>95</u>		at K	<u> </u>
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C	<u> </u>		at K	<u> </u>
			at K	<u> </u>
			at K	<u> </u>

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 11

Epoxy components, parts by weight

Resins	<u>XD 7818</u>	<u>50</u>
	<u>XD 7575.02</u>	<u>50</u>
Diluent	<u>XD 7114</u>	<u>45</u>
Curing	<u>Tonox 60-40</u>	<u>14.1</u>
agents	<u>DAP</u>	<u>14.1</u>

Cure schedule, °C/h 80/5 + 120/3

Tensile properties

Stress at maximum, MPa	<u>93</u>
Stress at failure, MPa	<u></u>
Strain at maximum, %	<u>5.3</u>
Strain at failure, %	<u></u>
Modulus, GPa	<u>3.2</u>

Compressive properties

Maximum strength, MPa	<u></u>
Strain at maximum	<u></u>
strength, %	<u></u>
Modulus, GPa	<u></u>

Shear properties

Stress at failure, MPa	<u></u>
Modulus, GPa	<u></u>

Viscosity at 25°C, Pa·s 0.85

Time to reach 2.0 Pa·s, h

Gel time for 30 g at
25°C, h 90

Exotherm of 500 g from
25°C, °C

Density at 25°C, Mg/m³

Uncured

Cured

Shrinkage, % volume

After gelation

After cure

Water absorption after

6 h in boiling water

(ASTM-D-570-63), % gain 2.2

Glass transition

temperature by TMA, °C

Heat distortion

temperature at

1820 kPa (264 psi), °C

Thermal coefficient at

linear expansion at

298 to 374 K, °C⁻¹

Specific heat

(ASTM-C-351-61),

at K

at K

Heat capacity, J/kg·K

at K

at K

at K

Thermal conductivity, W/m·K

at K

at K

at K

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 12

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u> <u>50</u>	Uncured	<u> </u>
	<u>XD 7575.02</u> <u>50</u>	Cured	<u> </u>
Diluent	<u>ERL 4206</u> <u>30</u>	Shrinkage, % volume	
Curing agents	<u>Tonox 60-40</u> <u>15.9</u>	After gelation	<u> </u>
	<u>DAP</u> <u>15.9</u>	After cure	<u> </u>
Cure schedule, °C/h	<u>80/5 + 120/3</u>	Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	<u>103</u>	(ASTM-D-570-63), % gain	<u>1.14</u>
Stress at failure, MPa	<u> </u>	Glass transition	
Strain at maximum, %	<u>3.6</u>	temperature by TMA, °C	<u> </u>
Strain at failure, %	<u> </u>	Heat distortion	
Modulus, GPa	<u>3.8</u>	temperature at	
Compressive properties		1820 kPa (264 psi), °C	<u> </u>
Maximum strength, MPa	<u> </u>	Thermal coefficient at	
Strain at maximum	<u> </u>	linear expansion at	
strength, %	<u> </u>	298 to 374 K, °C ⁻¹	<u> </u>
Modulus, GPa	<u> </u>	Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa	<u> </u>	at K	<u> </u>
Modulus, GPa	<u> </u>	at K	<u> </u>
Viscosity at 25°C, Pa·s	<u>0.8</u>	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h	<u> </u>	at K	<u> </u>
Gel time for 30 g at		at K	<u> </u>
25°C, h	<u>109</u>	at K	<u> </u>
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C	<u> </u>	at K	<u> </u>
		at K	<u> </u>
		at K	<u> </u>

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 13

Epoxy components, parts by weight	Density at 25°C, Mg/m ³
Resins <u>ERL 2256</u> <u>100</u>	Uncured _____
_____	Cured _____
Diluent _____	Shrinkage, % volume
Curing <u>Tonox 60-40</u> <u>29.5</u>	After gelation _____
agents _____	After cure _____
Cure schedule, °C/h <u>50/16 + 95/2</u>	Water absorption after
Tensile properties	6 h in boiling water
Stress at maximum, MPa <u>108</u>	(ASTM-D-570-63), % gain <u>1.45</u>
Stress at failure, MPa _____	Glass transition
Strain at maximum, % <u>7.1</u>	temperature by TMA, °C _____
Strain at failure, % _____	Heat distortion
Modulus, GPa <u>3.46</u>	temperature at
Compressive properties	1820 kPa (264 psi), °C _____
Maximum strength, MPa _____	Thermal coefficient at
Strain at maximum	linear expansion at
strength, % _____	298 to 374 K, °C ⁻¹ _____
Modulus, GPa _____	Specific heat
Shear properties	(ASTM-C-351-61),
Stress at failure, MPa _____	at K _____
Modulus, GPa _____	at K _____
Viscosity at 25°C, Pa•s <u>1.59</u>	Heat capacity, J/kg•K
Time to reach 2.0 Pa•s, h _____	at K _____
Gel time for 30 g at	at K _____
25°C, h <u>41</u>	at K _____
Exotherm of 500 g from	Thermal conductivity, W/m•K
25°C, °C _____	at K _____
_____	at K _____
	at K _____

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 14

Epoxy components, parts by weight

Resins   ERL 2258   100

Diluent

Curing   ZZL 0820   31

agents

Cure schedule, °C/h   60/16 + 160/3

Tensile properties

Stress at maximum, MPa   107

Stress at failure, MPa

Strain at maximum, %   5.2

Strain at failure, %

Modulus, GPa   3.74

Compressive properties

Maximum strength, MPa

Strain at maximum

strength, %

Modulus, GPa

Shear properties

Stress at failure, MPa

Modulus, GPa

Viscosity at 25°C, Pa·s   1.4

Time to reach 2.0 Pa·s, h

Gel time for 30 g at

25°C, h   30

Exotherm of 500 g from

25°C, °C

Density at 25°C, Mg/m³

Uncured

Cured

Shrinkage, % volume

After gelation

After cure

Water absorption after

6 h in boiling water

(ASTM-D-570-63), % gain   1.78

Glass transition

temperature by TMA, °C

Heat distortion

temperature at

1820 kPa (264 psi), °C

Thermal coefficient at

linear expansion at

298 to 374 K, °C⁻¹

Specific heat

(ASTM-C-351-61),

at K

at K

Heat capacity, J/kg·K

at K

at K

at K

Thermal conductivity, W/m·K

at K

at K

at K

Source: T.T. Chiao, E.S. Jessup, and L. Penn, "Screening of Epoxy Systems for High Performance Filament Winding Applications," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76836 (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 15

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	ERE 1359 100	Uncured	
		Cured	
Diluent	RD-2 12.5	Shrinkage, % volume	
Curing agents	DAP 23.9	After gelation	
		After cure	
Cure schedule, °C/h		Water absorption after	
80/12 + 100/2 + 125/2 + 150/4		6 h in boiling water	
Tensile properties		(ASTM-D-570-63), % gain	
Stress at maximum, MPa	126	Glass transition	
Stress at failure, MPa		temperature by TMA, °C	
Strain at maximum, %	6.8	Heat distortion	
Strain at failure, %		temperature at	
Modulus, GPa	3.93	1820 kPa (264 psi), °C	
Compressive properties		Thermal coefficient at	
Maximum strength, MPa		linear expansion at	
Strain at maximum strength, %		298 to 374 K, °C ⁻¹	
Modulus, GPa		Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa		at K	
Modulus, GPa		at K	
Viscosity at 25°C, Pa·s		Heat capacity, J/kg·K	
0.8		at K	
Time to reach 2.0 Pa·s, h		at K	
Gel time for 30 g at		at K	
25°C, h		Thermal conductivity, W/m·K	
156		at K	
Exotherm of 500 g from		at K	
25°C, °C		at K	
		at K	

Source: T.T. Chiao, E.S. Jessup, and M.A. Hamstad, "Performance of Filament-Wound Vessels from an Organic Fiber in Several Epoxy Matrices," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-76913. (1975).

CURED EPOXY RESIN DATA SHEET: SYSTEM 16a

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	XD 7818	30	Uncured	_____
	Epon 871	50	Cured	_____
Diluent	XD 7114	20	Shrinkage, % volume	
Curing agents	Tonox 60-40	16.4	After gelation	_____
			After cure	_____
Cure schedule, °C/h			Water absorption after	
70/3 + 130/5			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa	36.9		2.4	
Stress at failure, MPa	33.4		Glass transition	
Strain at maximum, %	6.0		temperature by TMA, °C	
Strain at failure, %	41		66	
Modulus, GPa	1.45		Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa	_____		1820 kPa (264 psi), °C	
Strain at maximum	_____		Thermal coefficient at	
strength, %	_____		linear expansion at	
Modulus, GPa	_____		298 to 374 K, °C ⁻¹	
Shear properties			Specific heat	
Stress at failure, MPa	_____		(ASTM-C-351-61),	
Modulus, GPa	_____		at K	
Viscosity at 25°C, Pa·s			at K	
Time to reach 2.0 Pa·s, h			Heat capacity, J/kg·K	
Gel time for 30 g at			at K	
25°C, h	29.2		at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C	_____		at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 16b

Epoxy components, parts by weight

Resins	XD 7818	20
	Epon 871	70
Diluent	XD 7114	10
Curing agents	Tonox 60-40	13.3

Cure schedule, °C/h 70/3 + 130/5

Tensile properties

Stress at maximum, MPa	<u>21.2</u>
Stress at failure, MPa	<u>21.2</u>
Strain at maximum, %	<u>64</u>
Strain at failure, %	<u>64</u>
Modulus, GPa	<u>0.36</u>

Compressive properties

Maximum strength, MPa	<u> </u>
Strain at maximum strength, %	<u> </u>
Modulus, GPa	<u> </u>

Shear properties

Stress at failure, MPa	<u> </u>
Modulus, GPa	<u> </u>

Viscosity at 25°C, Pa·s 0.69

Time to reach 2.0 Pa·s, h

Gel time for 30 g at 25°C, h 31.5

Exotherm of 500 g from 25°C, °C

Density at 25°C, Mg/m³

Uncured

Cured

Shrinkage, % volume

After gelation

After cure

Water absorption after

6 h in boiling water (ASTM-D-570-63), % gain 2.6

Glass transition

temperature by TMA, °C 56

Heat distortion

temperature at 1820 kPa (264 psi), °C

Thermal coefficient at

linear expansion at 298 to 374 K, °C⁻¹

Specific heat

(ASTM-C-351-61),

at K

at K

Heat capacity, J/kg·K

at K

at K

at K

Thermal conductivity, W/m·K

at K

at K

at K

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 17a

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	XD 7818	15	Uncured	
	Araldite 508	50	Cured	
Diluent	XD 7114	35	Shrinkage, % volume	
Curing agents	Tonox 60-40	16.9	After gelation	
			After cure	
Cure schedule, °C/h		70/3 + 130/5	Water absorption after	
Tensile properties			6 h in boiling water	
Stress at maximum, MPa		59.8	(ASTM-D-570-63), % gain	3.7
Stress at failure, MPa		50	Glass transition	
Strain at maximum, %		3.8	temperature by TMA, °C	54
Strain at failure, %		6.0	Heat distortion	
Modulus, GPa		2.76	temperature at	
Compressive properties			1820 kPa (264 psi), °C	
Maximum strength, MPa			Thermal coefficient at	
Strain at maximum			linear expansion at	
strength, %			298 to 374 K, 1/°C	
Modulus, GPa			Specific heat	
Shear properties			(ASTM-C-351-61),	
Stress at failure, MPa			at K	
Modulus, GPa			at K	
Viscosity at 25°C, Pa·s			0.87	
Time to reach 2.0 Pa·s, h				
Gel time for 30 g at				
25°C, h		41.1	Heat capacity, J/kg·K	
Exotherm of 500 g from			at K	
25°C, °C			at K	
			at K	
			Thermal conductivity, W/m·K	
			at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 17b

Epoxy components, parts by weight

Resins   Araldite 508   70

Diluent   XD 7114   30

Curing   Tonox 60-40   14

agents   _____

Cure schedule, °C/h   70/3 + 130/5

Tensile properties

Stress at maximum, MPa   11.0

Stress at failure, MPa   11.0

Strain at maximum, %   100

Strain at failure, %   100

Modulus, GPa   0.1

Compressive properties

Maximum strength, MPa   _____

Strain at maximum

strength, %   _____

Modulus, GPa   _____

Shear properties

Stress at failure, MPa   _____

Modulus, GPa   _____

Viscosity at 25°C, Pa·s   1.05

Time to reach 2.0 Pa·s, h   _____

Gel time for 30 g at

25°C, h   41.4

Exotherm of 500 g from

25°C, °C   _____

Density at 25°C, Mg/m³

Uncured   _____

Cured   _____

Shrinkage, % volume

After gelation   _____

After cure   _____

Water absorption after

6 h in boiling water

(ASTM-D-570-63), % gain   4.2

Glass transition

temperature by TMA, °C   32

Heat distortion

temperature at

1820 kPa (264 psi), °C   _____

Thermal coefficient at

linear expansion at

298 to 374 K, °C⁻¹   _____

Specific heat

(ASTM-C-351-61),

at K   _____

at K   _____

Heat capacity, J/kg·K

at K   _____

at K   _____

at K   _____

Thermal conductivity, W/m·K

at K   _____

at K   _____

at K   _____

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 18a

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	XD 7818 15	Uncured	
	DER 741 50	Cured	
Diluent	XD 7114 35	Shrinkage, % volume	
Curing agents	Tonox 60-40 17.4	After gelation	
		After cure	
Cure schedule, °C/h	70/3 + 130/5	Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	61.4	(ASTM-D-570-63), % gain	3.7
Stress at failure, MPa	53	Glass transition	
Strain at maximum, %	3.8	temperature by TMA, °C	55
Strain at failure, %	6.0	Heat distortion	
Modulus, GPa	2.87	temperature at	
Compressive properties		1820 kPa (264 psi), °C	
Maximum strength, MPa		Thermal coefficient at	
Strain at maximum		linear expansion at	
strength, %		298 to 374 K, °C ⁻¹	
Modulus, GPa		Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa		at K	
Modulus, GPa		at K	
Viscosity at 25°C, Pa·s	0.86	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h		at K	
Gel time for 30 g at		at K	
25°C, h	45.6	at K	
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C		at K	
		at K	
		at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 18b

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	DER 741	70	Uncured	_____
	DER 741	70	Cured	_____
Diluent	XD 7114	30	Shrinkage, % volume	
Curing agents	Tonox 60-40	14.7	After gelation	_____
			After cure	_____
Cure schedule, °C/h			Water absorption after	
70/3 + 130/5			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa	11.5		4.2	
Stress at failure, MPa	11.5		Glass transition	
Strain at maximum, %	100 +		temperature by TMA, °C	
Strain at failure, %	100 +		32	
Modulus, GPa	0.16		Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa			1820 kPa (264 psi), °C	
Strain at maximum			Thermal coefficient at	
strength, %			linear expansion at	
Modulus, GPa			298 to 374 K, °C ⁻¹	
Shear properties			Specific heat	
Stress at failure, MPa			(ASTM-C-351-61),	
Modulus, GPa			at K	
Viscosity at 25°C, Pa·s			at K	
Time to reach 2.0 Pa·s, h			Heat capacity, J/kg·K	
Gel time for 30 g at			at K	
25°C, h	47.2		at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C			at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 19a

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	XD 7818	40	Uncured	
	Epi-Rez 505	50	Cured	
Diluent	XD 7114	10	Shrinkage, % volume	
Curing agents	Tonox 60-40	14.9	After gelation	
			After cure	
Cure schedule, °C/h			Water absorption after	
70/3 + 130/5			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa	21.0		2.3	
Stress at failure, MPa	21.0		Glass transition	
Strain at maximum, %	39.0		temperature by TMA, °C	
Strain at failure, %	39.0		64	
Modulus, GPa	0.55		Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa			1820 kPa (264 psi), °C	
Strain at maximum			Thermal coefficient at	
strength, %			linear expansion at	
Modulus, GPa			298 to 374 K, °C ⁻¹	
Shear properties			Specific heat	
Stress at failure, MPa			(ASTM-C-351-61),	
Modulus, GPa			at K	
Viscosity at 25°C, Pa·s			at K	
Time to reach 2.0 Pa·s, h			Heat capacity, J/kg·K	
Gel time for 30 g at			at K	
25°C, h	21.4		at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C			at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 19b

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	XD 7818	20	Uncured	
	Epi-Rez 505	70	Cured	
Diluent	XD 7114 505	10	Shrinkage, % volume	
Curing agents	Tonox 60-40	11.5	After gelation	
			After cure	
Cure schedule, °C/h	70/3 + 130/5		Water absorption after	
Tensile properties			6 h in boiling water	
Stress at maximum, MPa	1.5		(ASTM-D-570-63), % gain	2.4
Stress at failure, MPa	1.5		Glass transition	
Strain at maximum, %	48.4		temperature by TMA, °C	11
Strain at failure, %	48.4		Heat distortion	
Modulus, GPa	0.005		temperature at	
Compressive properties			1820 kPa (264 psi), °C	
Maximum strength, MPa			Thermal coefficient at	
Strain at maximum			linear expansion at	
strength, %			298 to 374 K, °C ⁻¹	
Modulus, GPa			Specific heat	
Shear properties			(ASTM-C-351-61),	
Stress at failure, MPa			at K	
Modulus, GPa			at K	
Viscosity at 25°C, Pa·s	0.48		Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h			at K	
Gel time for 30 g at			at K	
25°C, h	33.5		at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C			at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 20a

Epoxy components, parts by weight

Resins	XD 7818	50
	DER 732	50
Diluent		
Curing agents	Tonox 60-40	17.3

Cure schedule, °C/h 70/3 + 130/5

Tensile properties

Stress at maximum, MPa	<u>54.8</u>
Stress at failure, MPa	<u>40.8</u>
Strain at maximum, %	<u>4.2</u>
Strain at failure, %	<u>14.8</u>
Modulus, GPa	<u>2.47</u>

Compressive properties

Maximum strength, MPa	
Strain at maximum strength, %	
Modulus, GPa	

Shear properties

Stress at failure, MPa	
Modulus, GPa	

Viscosity at 25°C, Pa·s 0.61

Time to reach 2.0 Pa·s, h

Gel time for 30 g at 25°C, h 82.3

Exotherm of 500 g from 25°C, °C

Density at 25°C, Mg/m³

Uncured	
Cured	

Shrinkage, % volume

After gelation	
After cure	

Water absorption after

6 h in boiling water (ASTM-D-570-63), % gain	<u>3.4</u>

Glass transition

temperature by TMA, °C	<u>59</u>

Heat distortion

temperature at 1820 kPa (264 psi), °C	

Thermal coefficient at

linear expansion at 298 to 374 K, °C ⁻¹	

Specific heat

(ASTM-C-351-61),	
at K	
at K	

Heat capacity, J/kg·K

at K	
at K	
at K	

Thermal conductivity, W/m·K

at K	
at K	
at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 20b

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u> <u>30</u>	Uncured	<u> </u>
	<u>DER 732</u> <u>70</u>	Cured	<u> </u>
Diluent	<u> </u>	Shrinkage, % volume	
Curing agents	<u>Tonox 60-40</u> <u>15</u>	After gelation	<u> </u>
	<u> </u>	After cure	<u> </u>
Cure schedule, °C/h	<u>70/3 + 130/5</u>	Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	<u>6.6</u>	(ASTM-D-570-63), % gain	<u>4.5</u>
Stress at failure, MPa	<u>6.6</u>	Glass transition	
Strain at maximum, %	<u>69.1</u>	temperature by TMA, °C	<u>22</u>
Strain at failure, %	<u>69.1</u>	Heat distortion	
Modulus, GPa	<u>0.09</u>	temperature at	
Compressive properties		1820 kPa (264 psi), °C	<u> </u>
Maximum strength, MPa	<u> </u>	Thermal coefficient at	
Strain at maximum	<u> </u>	linear expansion at	
strength, %	<u> </u>	298 to 374 K, °C ⁻¹	<u> </u>
Modulus, GPa	<u> </u>	Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa	<u> </u>	at K	<u> </u>
Modulus, GPa	<u> </u>	at K	<u> </u>
Viscosity at 25°C, Pa·s	<u>0.32</u>	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h	<u> </u>	at K	<u> </u>
Gel time for 30 g at		at K	<u> </u>
25°C, h	<u>134.4</u>	at K	<u> </u>
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C	<u> </u>	at K	<u> </u>
		at K	<u> </u>
		at K	<u> </u>

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 21

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins	Lekutherm X-80	60	Uncured	
			Cured	
Diluent	XD 7114	40	Shrinkage, % volume	
Curing agents	Tonox 60-40	17.7	After gelation	
			After cure	
Cure schedule, °C/h			Water absorption after	
70/3 + 130/5			6 h in boiling water	
Tensile properties			(ASTM-D-570-63), % gain	
Stress at maximum, MPa	73.8		4.9	
Stress at failure, MPa	68.0		Glass transition	
Strain at maximum, %	4.0		temperature by TMA, °C	
Strain at failure, %	5.2		55	
Modulus, GPa	3.1		Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa			1820 kPa (264 psi), °C	
Strain at maximum			Thermal coefficient at	
strength, %			linear expansion at	
Modulus, GPa			298 to 374 K, °C ⁻¹	
Shear properties			Specific heat	
Stress at failure, MPa			(ASTM-C-351-61),	
Modulus, GPa			at K	
Viscosity at, 25°C, Pa·s			at K	
Time to reach 2.0 Pa·s, h			Heat capacity, J/kg·K	
Gel time for 30 g at			at K	
25°C, h			at K	
47.0			at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C			at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 22

Epoxy components, parts by weight		Density at 25°C, Mg/m ³	
Resins	<u>XD 7818</u> <u>30</u>	Uncured	<u> </u>
		Cured	<u> </u>
Diluent	<u>XD 7114</u> <u>70</u>	Shrinkage, % volume	
Curing agents	<u>ATBN</u> <u>15</u>	After gelation	<u> </u>
	<u>Tonox 60-40</u> <u>23.8</u>	After cure	<u> </u>
Cure schedule, °C/h	<u>70/3 + 130/5</u>	Water absorption after	
Tensile properties		6 h in boiling water	
Stress at maximum, MPa	<u>67.8</u>	(ASTM-D-570-63), % gain	<u>3.2</u>
Stress at failure, MPa	<u>58.0</u>	Glass transition	
Strain at maximum, %	<u>4.1</u>	temperature by TMA, °C	<u>75</u>
Strain at failure, %	<u>8.0</u>	Heat distortion	
Modulus, GPa	<u>2.62</u>	temperature at	
Compressive properties		1820 kPa (264 psi), °C	<u> </u>
Maximum strength, MPa	<u> </u>	Thermal coefficient at	
Strain at maximum	<u> </u>	linear expansion at	
strength, %	<u> </u>	298 to 374 K, °C ⁻¹	<u> </u>
Modulus, GPa	<u> </u>	Specific heat	
Shear properties		(ASTM-C-351-61),	
Stress at failure, MPa	<u> </u>	at K	<u> </u>
Modulus, GPa	<u> </u>	at K	<u> </u>
Viscosity at 25°C, Pa·s	<u>0.74</u>	Heat capacity, J/kg·K	
Time to reach 2.0 Pa·s, h	<u> </u>	at K	<u> </u>
Gel time for 30 g at		at K	<u> </u>
25°C, h	<u>33.8</u>	at K	<u> </u>
Exotherm of 500 g from		Thermal conductivity, W/m·K	
25°C, °C	<u> </u>	at K	<u> </u>
		at K	<u> </u>
		at K	<u> </u>

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 23

Epoxy components, parts by weight			Density at 25°C, Mg/m ³	
Resins			Uncured	
			Cured	
Diluent	XD 7114	80	Shrinkage, % volume	
Curing	ATBN	20	After gelation	
agents	Tonox 60-40	19.2	After cure	
Cure schedule, °C/h	70/3 + 130/5		Water absorption after	
Tensile properties			6 h in boiling water	
Stress at maximum, MPa	44.9		(ASTM-D-570-63), % gain	4.7
Stress at failure, MPa	31.0		Glass transition	
Strain at maximum, %	4.5		temperature by TMA, °C	
Strain at failure, %	9.0		50	
Modulus, GPa	1.77		Heat distortion	
Compressive properties			temperature at	
Maximum strength, MPa			1820 kPa (264 psi), °C	
Strain at maximum			Thermal coefficient at	
strength, %			linear expansion at	
Modulus, GPa			298 to 374 K, °C ⁻¹	
Shear properties			Specific heat	
Stress at failure, MPa			(ASTM-C-351-61),	
Modulus, GPa			at K	
Viscosity at 25°C, Pa·s			at K	
Time to reach 2.0 Pa·s, h			Heat capacity, J/kg·K	
Gel time for 30 g at			at K	
25°C, h			at K	
Exotherm of 500 g from			Thermal conductivity, W/m·K	
25°C, °C			at K	
			at K	
			at K	

Source: J. A. Rinde, E. T. Mones, and H. A. Newey, "Comparison of Flexible Epoxy Resins for Wet Filament Winding," Lawrence Livermore Laboratory, Livermore, Rept. UCRL-78278 (1976).

CURED EPOXY RESIN DATA SHEET: SYSTEM 24

Epoxy components, parts by weight

Resins   XD 7818   100

Diluent   XD 7114   10

Curing   Jeffamine T-403   26.2

agents   T-403 Acrylonitrile   52.5

Cure schedule, °C/h   90/3 + 120/2

Tensile properties

Stress at maximum, MPa   52.9

Stress at failure, MPa   31.0

Strain at maximum, %   4.1

Strain at failure, %   15.9

Modulus, GPa   2.3

Compressive properties

Maximum strength, MPa   _____

Strain at maximum

strength, %   _____

Modulus, GPa   _____

Shear properties

Stress at failure, MPa   _____

Modulus, GPa   _____

Viscosity at 25°C, Pa·s   0.74

Time to reach 2.0 Pa·s, h   7.1

Gel time for 30 g at

25°C, h   27.8

Exotherm of 500 g from

25°C, °C   _____

Density at 25°C, Mg/m³

Uncured   _____

Cured   1.16

Shrinkage, % volume

After gelation   _____

After cure   _____

Water absorption after

6 h in boiling water

(ASTM-D-570-63), % gain   2.4

Glass transition

temperature by TMA, °C   41

Heat distortion

temperature at

1820 kPa (264 psi), °C   _____

Thermal coefficient at

linear expansion at

298 to 374 K, °C⁻¹   _____

Specific heat

(ASTM-C-351-61),

at K   _____

at K   _____

Heat capacity, J/kg·K

at K   _____

at K   _____

at K   _____

Thermal conductivity, W/m·K

at K   _____

at K   _____

at K   _____

CURED EPOXY RESIN DATA SHEET: SYSTEM 25

Epoxy components, parts by weight

Resins	<u>XD 7818</u>	<u>100</u>
Diluent	<u>XD 7114</u>	<u>10</u>
Curing agents	<u>T-403 Acrylonitrile</u>	<u>105</u>
	<u>T-403 Acrylonitrile</u>	<u>105</u>

Cure schedule, °C/h 120/3 + 160/2

Tensile properties

Stress at maximum, MPa	<u>13.1</u>
Stress at failure, MPa	<u>13.1</u>
Strain at maximum, %	<u>100 +</u>
Strain at failure, %	<u>100 +</u>
Modulus, GPa	<u>0.08</u>

Compressive properties

Maximum strength, MPa	<u> </u>
Strain at maximum strength, %	<u> </u>
Modulus, GPa	<u> </u>

Shear properties

Stress at failure, MPa	<u> </u>
Modulus, GPa	<u> </u>

Viscosity at 25°C, Pa·s 0.77

Time to reach 2.0 Pa·s, h 18.0

Gel time for 30 g at 25°C, h 103

Exotherm of 500 g from 25°C, °C

Density at 25°C, Mg/m³

Uncured	<u> </u>
Cured	<u>1.15</u>

Shrinkage, % volume

After gelation	<u> </u>
After cure	<u> </u>

Water absorption after

6 h in boiling water (ASTM-D-570-63), % gain	<u>1.99</u>

Glass transition

temperature by TMA, °C	<u>27</u>

Heat distortion

temperature at 1820 kPa (264 psi), °C	<u> </u>

Thermal coefficient at

linear expansion at 298 to 374 K, °C ⁻¹	<u> </u>

Specific heat

(ASTM-C-351-61),	
at K	<u> </u>
at K	<u> </u>

Heat capacity, J/kg·K

at K	<u> </u>
at K	<u> </u>
at K	<u> </u>

Thermal conductivity, W/m·K

at K	<u> </u>
at K	<u> </u>
at K	<u> </u>

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