EXIDE TECHNOLOGIES

Global Leader
in Stored Electrical Energy

Exide Technologies
2700 S. Indiana Street
Vernon, CA 90058
Phone 323.262.1101
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May 2, 2013

Mr. Rizgar Ghazi
Branch Chief
Office of Permitting
Department of Toxic Substances Control
8800 Cal Center Drive
Sacramento, CA 95826-3200

RE: Information Requested by DTSC
Exide Technologies Inc. Vernon, California
EPA ID No. CAD 097854541

Dear Mr. Ghazi:

Pursuant to the Department's request for a "written summary of the proposed fixes for the storm sewer system and the reduction of risk", please see attached. As discussed, we would like to come in and meet with you immediately to discuss this information and the ability to resume operations.

Again, by providing this information, we do not waive any legal rights or agree with the allegations or factual assertions in the Order and Accusation. Exide continues to reserve all of its legal rights and defenses and evaluate its available legal and administrative rights.

Respectfully submitted,
EXIDE TECHNOLOGIES, INC.

John Hogarth
Plant Manager

Attachments

cc: Edward Nieto -- DTSC
Joe Preuth – Exide Technologies
Fred Ganster – Exide Technologies
Ed Mopas – Exide Technologies
Dr. Barry Wallerstein, AQMD
Mohsen Nazemi, AQMD
Leonard Grossberg, City of Vernon
Wendy Liu, Regional Water Quality Control Board
Jerrick Torres, City of Vernon

Air

ENVIRON

MEMORANDUM

TO: Exide Technologies

FROM: Russell S. Kemp, PE
Principal

DATE: May 2, 2013

RE: Assessment of Effectiveness of Blast Furnace Isolation Door
Vernon, California, Facility

As requested, we have conducted an evaluation of the effectiveness of the blast furnace charge chute isolation door installed at the Exide Technologies facility in Vernon, California, in terms of reducing emissions from the Hard Lead Ventilation System stack and reducing overall calculated facility risk. Based upon the details and analysis provided below, we conclude that the isolation door has been effective in its intended purpose and has resulted in reducing the overall calculated facility risks to below the Action Risk Levels specified in South Coast Air Quality Management District (AQMD) Rule 1402, which implements the AB2588 air toxics program. This conclusion is based upon preliminary engineering test data collected on April 9, 10, 18, and 19, 2013 subsequent to the installation of an isolation door on the blast furnace charge chute. These test data have been shared with the AQMD and are subject to confirmation through further detailed emission testing specified in the air permit for the installation of the isolation door issued on March 28, 2013. It is our opinion that these confirmatory official tests will confirm the findings and conclusions presented in this memorandum.

Background

On March 1, 2013, AQMD issued its approval of the AB2588 Health Risk Assessment (HRA) prepared by ENVIRON International Corporation (ENVIRON) and submitted in January 2013. That HRA was prepared in accordance with protocols approved by AQMD with DTSC in a consultative role and is based upon emissions data collected in testing conducted in 2010 and 2012. As summarized in the AQMD letter of March 1, 2013 the calculated health risks exceeded the Public Notice thresholds and Action Risk Levels in AQMD Rule 1402 which implements AB2588.

The primary driver of risk in this HRA was the impact of arsenic emitted from the facility's Hard Lead Ventilation System stack. This ventilation system is comprised of ductwork serving a number of hoods intended to collect metal-bearing dust at points of potential worker exposure around the facility's blast furnace and the refining kettles associated with that furnace. The air collected at these hoods is filtered in a baghouse to remove metals prior to discharge to the atmosphere. Through evaluations performed in 2011 and 2012 it was determined that blast furnace process exhaust was making its way into some of the hooding around the furnace charge chute rather than being confined to its intended path through the furnace afterburner, blast furnace baghouse, and wet scrubber. Operational improvements implemented in 2012 were successful in reducing arsenic emissions from the Hard Lead Ventilation System stack by approximately 70% from that measured in 2010. The HRA submitted in January 2013 and approved on March 1, 2013 was based upon the average of the 2010 and 2012 test results for this stack.

In order to more reliably preclude the entry of blast furnace process exhaust into the Hard Lead Ventilation System, Exide designed an isolation door system for the charge chute which would provide a more direct and positive barrier for containing the process exhaust gases in the furnace as desired. The AQMD approved a permit application for the installation of this isolation door on an expedited basis on March 28, 2013 and the installation of the door was completed on April 4, 2013.

Testing

ENVIRON developed a testing program for the evaluation of the effectiveness of the isolation door which was shared with AQMD. Emissions testing on the Hard Lead Ventilation System stack commenced on April 9, 2013 with ENVIRON personnel in attendance for all testing. As testing progressed over subsequent days, AQMD personnel observed some of the tests and splits of the physical samples collected by Almega were delivered to the AQMD's laboratory. Preliminary results from the testing were transmitted to AQMD by Almega simultaneously with delivery to ENVIRON and Exide.

Three 2-hour duration tests were conducted on April 9, 2013. At this stage, the isolation door was newly installed and still in a "debugging" mode of operation. Notably, the mechanism experienced jams resulting in leakage, especially during the third run. A single 4-hour duration test was conducted on April 10, 2013. Operation of the door was more steady during this run.

Subsequent to the testing on April 9 and 10, the facility made further improvements to the door mechanism. Four-hour tests on the Hard Lead Ventilation System exhaust were conducted on April 18 and 19. During the testing on the 18th, arsenic was added directly to one of the refining kettles served by the Hard Lead Ventilation System to assess the potential for that activity to affect emissions.

The preliminary results from these four days of testing are presented in **Table 1**. In that Table we also present, for reference, the prior results for arsenic, benzene, and 1,3-butadiene from this stack from 2010 and 2012 which formed the basis of the approved January 2013 HRA. We also compare the emission results obtained since installation of the isolation door with these prior data. As noted above, the reduction in arsenic emissions achieved by operational adjustments between 2010 and 2012 was 70%. The recent data indicate a further reduction beyond the 2012 improvement on the order of 98%. Comparable levels of improvement are also seen in the emissions of benzene and 1,3-butadiene, both of which would be associated with furnace process gases, further demonstrating the effectiveness of the isolation door in minimizing the escape of process gases into the Hard Lead Ventilation System.

Risk

To evaluate the impact of these emissions improvements on calculated risk, we substituted these new emission data for arsenic, benzene, and 1,3-butadiene from the Hard Lead Ventilation System stack into the same HRA protocol and calculation approach as used in the HRA approved on March 1, 2013. That is, we reassessed facility-wide risk including all the other stacks and pollutant data just as they were in the January 2013 HRA with the only adjustment being these alternate emission data from the Hard Lead Ventilation System stack. Results of these analyses are also presented in **Table 1**.

Based upon the April 10, 2013 emission data, highlighted in pink in Table 1, calculated risks are all below the Rule 1402 Action Risk Levels. Residential and sensitive receptor (e.g., schools) cancer risks are all less than 5 in a million. The maximum worker cancer risk is only slightly above 10 in a million.

As stated above, improvements were made to the isolation door system between the testing conducted on April 10 and April 18. The testing conducted on April 18 also had the diagnostic purpose of assessing the potential remaining influence from the addition of arsenic into a refining kettle to adjust alloy specification – an activity typically performed on only a handful of kettle batches each week. Arsenic emissions from the Hard Lead Ventilation System stack were, indeed, higher on April 18 than on the 10th or 19th, but still 98% less than the arsenic emission rate used in the January 2013 HRA. In addition, the 1,3-butadiene emission rates on the 18th and 19th were a factor of ten lower than those measured on April 10, indicating that the door function was improved between the 10th and 18th. Arsenic emissions on the 19th were also substantially lower than those seen during the first week of testing on the 9th and 10th.

A second set of risk calculations was run using the average rates from April 18th and 19th as inputs. This combination is believed to be a conservative projection of the emissions that would be expected during the official testing series which will involve three 8-hour tests. These risk calculations, again simply substituting in data in Table 1 for the Hard Lead Ventilation System stack with all other inputs as they were in the approved January 2013 HRA, indicate essentially the same results as the scenario from the April 10 data. That is, any elevation in arsenic emissions resulting from the occasional addition of arsenic to a refining kettle for alloy adjustment was offset by the further reductions in 1,3-butadiene emissions achieved by the improvements to the isolation door mechanism after April 10.

Results of the Hard Lead Ventilation System stack testing reflect that only one receptor has a calculated cancer risk above 10 in a million and that is the same receptor that had a calculated cancer risk of 156 in a million in the January 2013 HRA.

Most significantly, all these calculated risks based on preliminary emissions testing since the installation of the isolation door meet the risk reduction Action Risk Levels specified in AQMD Rule 1402 of 25 in-a-million cancer risk, hazard index of 3, and cancer burden of 0.5 by a wide margin. It is our opinion that based on these preliminary results, no further risk reduction will be necessary to satisfy Rule 1402.

Summary and Next Steps

It is our understanding that AQMD is reviewing these preliminary test data. In addition, as noted above, the air permit issued on March 28, 2013 calls for triplicate emissions tests conducted simultaneously on the Hard Lead Ventilation System stack and the Neptune Scrubber stack (through which the blast furnace process gases exhaust) to be conducted before August 2, 2013. Given the breadth of the preliminary engineering testing conducted thus far, we believe that the emissions to be measured during these pending tests will be less than the average rates from April 18th and 19th. That is, it is our expectation that the pending official permit-required testing will confirm the analysis contained herein, likely with emissions and risks below those presented.

Table 1 **Comparison of Hard Lead System Test Data**

Green = ND value entered at detection limit

INITIAL THREE RUNS, 09 April 2013

	2008 lb/hr	2010 lb/hr	2012 lb/hr	%Reduction 2012 v. 2010	2010-2012 avg. used in HRA	4/9/13 Run 1	4/9/13 Run 2	4/9/13 Run 3	4/9/2013 Average	4/9/2013 avg %Reduction from 2010	4/9/2013 avg %Reduction from 2012	4/9/2013 avg %Reduction from HRA
Arsenic	8.50E-04	0.0759	0.0210	72%	0.0486	0.00032	0.00063	0.0031	0.00136	98.2%	93.6%	97.2%
Benzene		1.41	0.531	62%	0.97	0.011	0.0185	0.045	0.02483	98.2%	95.3%	97.4%
1,3-Butadiene		0.345	0.15	57%	0.248	0.0012	0.0017	0.013	0.00530	98.5%	96.5%	97.9%

DETINNING TREATMENT, 10 April 2013

	2008 lb/hr	2010 lb/hr	2012 lb/hr	%Reduction 2012 v. 2010	2010-2012 avg. used in HRA	OUTLET 4/10/2013 lb/hr	4/10/2013 %Reduction from 2010	4/10/2013 %Reduction from 2012	4/10/2013 %Reduction from HRA
Arsenic	8.50E-04	0.0759	0.0210	72%	0.0486	4.00E-04	99.5%	98.1%	99.2%
Benzene		1.41	0.531	62%	0.97	0.045	96.8%	91.5%	95.4%
1,3-Butadiene		0.345	0.15	57%	0.248	0.019	94.5%	87.3%	92.3%

Substituted in for Hard Lead stack with all other inputs same as January 2013 HRA

Purple font indicates value above Notification Threshold
Red font indicates value above Risk Reduction Action Level

MEIW max Worker Cancer Risk	1.07E-05	at receptor 1005
MEIW max Worker Chronic Hazard Index	1.23	at receptor 1005
Acute Hazard Index Max Worker	0.438	at receptor 80
MEIR max Resident Cancer Risk	3.48E-06	at receptor 1016
MEIR max Resident Chronic Hazard Index	0.128	at receptor 1016
Max School Cancer Risk	2.59E-06	Salazar Park Head Start
Max School Chronic Hazard Index	0.1	Salazar Park Head Start
Cancer Burden	0.315	

ARSENIC ADDITION IN REFINERY, 18 April 2013

	2008 lb/hr	2010 lb/hr	2012 lb/hr	%Reduction 2012 v. 2010	2010-2012 avg. used in HRA	OUTLET 4/18/2013 lb/hr	4/18/2013 %Reduction from 2010	4/18/2013 %Reduction from 2012	4/18/2013 %Reduction from HRA
Arsenic	8.50E-04	0.0759	0.0210	72%	0.0486	1.16E-03	98.5%	94.5%	97.6%
Benzene		1.41	0.531	62%	0.97	0.0385	97.3%	92.7%	96.0%
1,3-Butadiene		0.345	0.15	57%	0.248	0.0017	99.5%	98.9%	99.3%

TYPICAL OPERATIONS, 19 April 2013

	2008 lb/hr	2010 lb/hr	2012 lb/hr	%Reduction 2012 v. 2010	2010-2012 avg. used in HRA	OUTLET 4/19/2013 lb/hr	4/19/2013 %Reduction from 2010	4/19/2013 %Reduction from 2012	4/19/2013 %Reduction from HRA
Arsenic	8.50E-04	0.0759	0.0210	72%	0.0486	2.10E-04	99.7%	99.0%	99.6%
Benzene		1.41	0.531	62%	0.97	0.0073	99.5%	98.6%	99.2%
1,3-Butadiene		0.345	0.15	57%	0.248	0.0012	99.7%	99.2%	99.5%

Average of results from 18 and 19 April

	2008 lb/hr	2010 lb/hr	2012 lb/hr	%Reduction 2012 v. 2010	2010-2012 avg. used in HRA	OUTLET 18 & 19 avg lb/hr	4/19/2013 %Reduction from 2010	4/19/2013 %Reduction from 2012	4/19/2013 %Reduction from HRA
Arsenic	8.50E-04	0.0759	0.0210	72%	0.0486	6.85E-04	99.1%	96.7%	98.6%
Benzene		1.41	0.531	62%	0.97	0.0229	98.4%	95.7%	97.6%
1,3-Butadiene		0.345	0.15	57%	0.248	0.00145	99.6%	99.0%	99.4%

Substituted in for Hard Lead stack with all other inputs same as January 2013 HRA

Average of 4/18 and 4/19	
Arsenic	6.85E-04
	lb/hr
Benzene	2.29E-02
1,3-Butadiene	1.45E-03

Purple font indicates value above Notification Threshold
Red font indicates value above Risk Reduction Action Level

MEIW max Worker Cancer Risk	1.11E-05	at receptor 1005
MEIW max Worker Chronic Hazard Index	1.59	at receptor 1005
Acute Hazard Index Max Worker	0.438	at receptor 80
MEIR max Resident Cancer Risk	3.50E-06	at receptor 1016
MEIR max Resident Chronic Hazard Index	0.144	at receptor 1016
Max School Cancer Risk	2.44E-06	Salazar Park Head Start
Max School Chronic Hazard Index	0.106	Salazar Park Head Start
Cancer Burden	0.322	

Storm Water

PROPOSED TEMPORARY STORMWATER MANAGEMENT PLAN
EXIDE TECHNOLOGIES
VERNON, CALIFORNIA

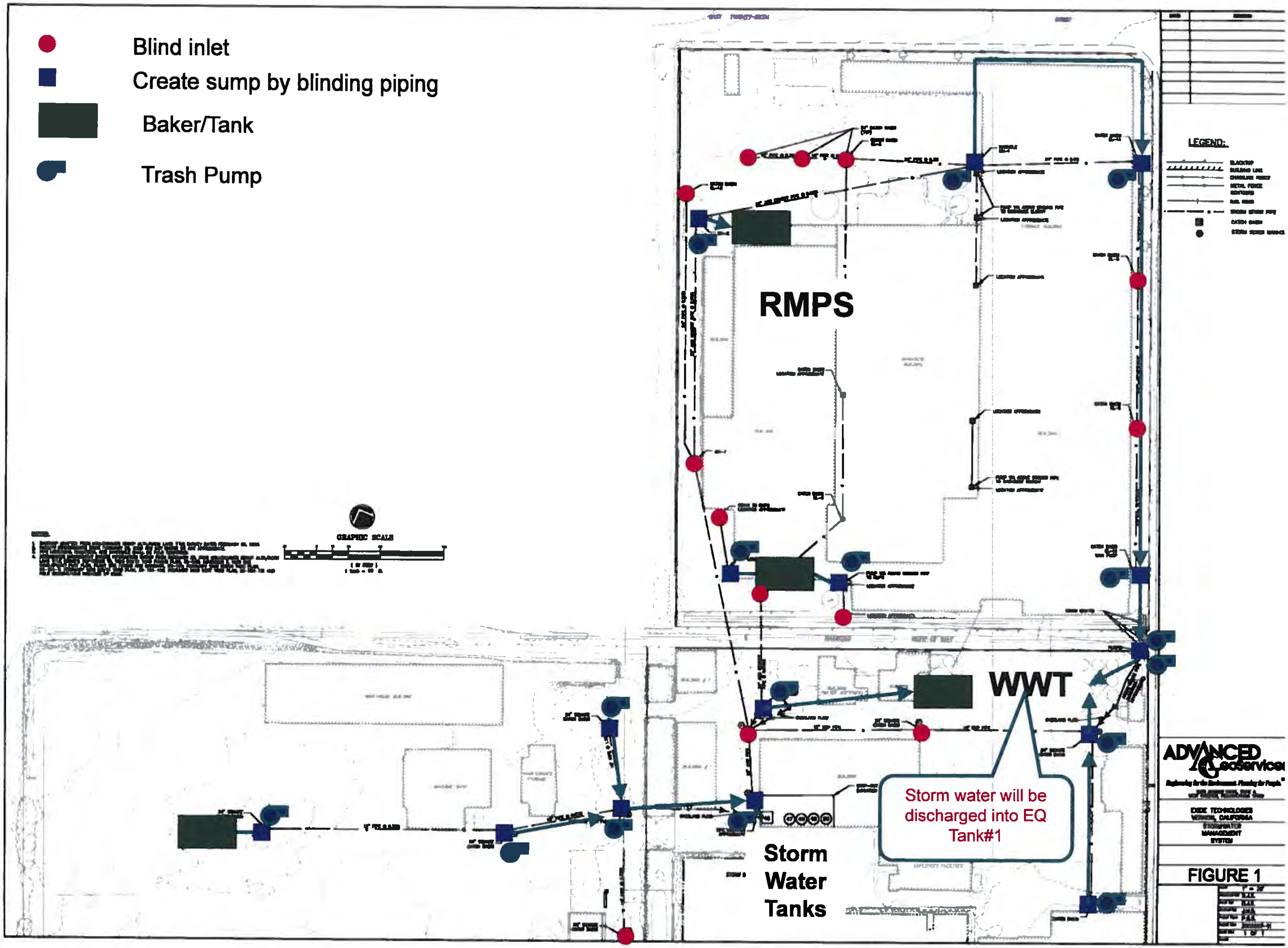
In response to DTSC's Order and Accusation, Exide Technologies proposes to implement measures to temporarily manage stormwater at the facility above-grade and not within the existing stormwater piping system. These measures will also manage wash-down water from housekeeping activities conducted pursuant to AQMD requirements. The proposed measures are depicted on the attached figure and are described below. Installation is anticipated to take approximately 9 calendar days from DTSC approval.

Thirteen (13) inlets will be blinded by installing a steel plate over the inlet grate. The steel plate will be welded into place, and the seams will be sealed with sealant. Specifications for the sealant are attached. Fifteen (15) inlets will be converted to sumps which collect stormwater runoff and create a point for pumping. These inlets will be converted to sumps by blinding the below-grade inlet and outlet piping by installing a circular plug (HDPE, metal or plywood) into the cross-section of the pipe. The plug will be sealed into place with an epoxy-type sealant. The epoxy-type sealant at the inlet blinds and pipe plugs will create a water tight seal.

Stormwater and wash down water in the areas of blinded inlets will accumulate on the ground surface, and then flow on the ground surface to the nearest sump. Each sump will have a pump which will transfer the water out of the sump. The pump will be existing pumps at the facility, or a similar pump provided by a vendor. Specifications for the vendor-supplied pump are attached.The pumps will be manually primed by facility personnel that are available 24-hours per day. It is expected that the existing pumps at the Railroad Sump on the east side of the facility will continue to be used. The pumps may be upgraded to self-priming centrifugal pumps if warranted based on operating considerations or duration the temporary measures remain in-place. If needed to manage higher intensity stormwater flows, a second pump can be added to a sump.

The water accumulating in the sumps will be transferred temporarily to one of four (4) 20,000 gallon frac tanks (a.k.a. Baker Tank), to a nearby stormwater sump, or directly to Unit 46 (Pump Sump) at the Drop Out System or Unit 52 (Equalization Tank No. 1) at the Wastewater Treatment Plant. Ultimately all water will be processed through the WWTP and then discharged to the sanitary sewer under the facility's Industrial Discharge Permit. The inlet piping to Unit 46 will be blinded so that Unit 46 functions as a sump for water entering the Drop Out System. The water will be transferred through above-grade hose resting on the ground surface. The hose will be double-contained. A tanker truck will be mobilized as needed to empty the 20,000 gallon frac tanks during and after storm events and move the water to the Drop Out System or Wastewater Treatment Plant. The tanker truck can be mobilized with one day's notice.

Weather forecasts will be monitored daily to determine if storm events are predicted. The tanker truck will be scheduled accordingly. In the event that a large storm is forecasted, additional pumps and temporary 20,000 gallon tanks can be mobilized within a few days.



Blind inlet
Create sump by blinding piping
Baker/Tank
Trash Pump
RMPS
WWT
Storm water will be discharged into EQ Tank#1
Storm Water Tanks
LEGEND:
GRAPHIC SCALE
ADVANCED GeoServices
FIGURE 1

PRODUCT DATA SHEET

June, 2009

4" PA4A60-4045D PRIME-ASSISTED PUMP

GENERAL INFORMATION

This pump is fitted with a compressor / ejector priming system to create a vacuum on the inlet to the pump. This allows the pump to automatically prime and reprime.

PERFORMANCE DATA

» **Flow (min/max):**	-	60 gpm / 925 gpm
» **Minimum Shutoff Head:**	-	87 feet (38 psi)[1] @ 1550 rpm
» **Maximum Shutoff Head:**	-	152 feet (66 psi)[1] @ 2100 rpm
» **Speed (min/max):**	-	1550 rpm / 2100 rpm
» **Maximum Suction Lift:**	-	25 feet [6] (@350 gpm and 2100 RPM)
» **Maximum Casing Press:**	-	99 psi
» **Maximum Temperature:**	-	160°F
» **Maximum Solids Size:**	-	3" spherical diameter

PUMP SPECIFICATIONS

» **Impeller:**	-	9-3/4"; two vanes, open
» **Bearing Lubrication:**	-	SAE No. 30 oil
» **Vacuum System:**	-	Piston compressor, 20 cfm, with venturi eductor
» **Mechanical Seal Lubrication:**	-	Oil lubricated

PHYSICAL SPECIFICATIONS

» **Suction Size:**	-	4" ASA Flange
» **Discharge Size:**	-	4" ASA Flange
» **Total Weight:**	-	3802 lbs.[2]
» **Overall Height:**	-	7'-7" (To top of lifting bail)
» **Overall Width:**	-	5'-11"
» **Overall Length:**	-	10'-2" (Trailer length)

MATERIAL SPECIFICATIONS

» **Pump Casing:**	-	Gray Iron No. 30
» **Shaft Sleeve:**	-	17-4 PH S.S.
» **Wearplates:**	-	Carbon steel No. 1018
» **Mechanical Seal Faces:**	-	Silicon carbide/ Silicon carbide
» **Pump Shaft:**	-	Alloy steel No. 4140
» **O-rings:**	-	Buna-N
» **Impeller:**	-	Ductile iron No. 65-45-12
» **Check Valve Body:**	-	Gray Iron No. 30
» **Check Valve Flapper:**	-	Buna-N Flapper

ENGINE SPECIFICATIONS

» **Engine Make/Model:**	-	John Deere 4045D
» **Max. Continuous BHP:**	-	72 @ 2500 RPM[5]
» **Crankcase Oil:**	-	9 quarts of SAE 10W40 [3]
» **Safety Shutdowns:**	-	High water temperature & low oil pressure
» **Fuel Capacity/Type:**	-	61 gallons of No. 2 diesel
» **Fuel Consumption:**	-	2.1 gal/hr @ 2100 rpm
» **Run Time:**	-	29 hours + [4]
» **Coolant:**	-	4 gal. 50/50 water/antifreeze
» **Number of Cylinders:**	-	Four
» **Fuel Filter:**	-	RE600021
» **Oil Filter:**	-	RE59754
» **Engine Air Filter:**	-	AT44377

Notes:

(1) Based on 1.0 specific gravity
(2) Includes weight of trailer, pump and engine
(3) Midrange compromise. See John Deere manual.
(4) At 2100 RPM. Run time increases with reduced speed and decreases with higher speed.
(5) **WARNING** – this is the rated speed for the ENGINE ONLY. The rated speed of the pump is only 2100 RPM.
(6) Depends on flowrate and pump speed. See pump curve.

BAKERCORP™

3020 Old Ranch Parkway • Suite 220 • Seal Beach, CA • 562-430-6262

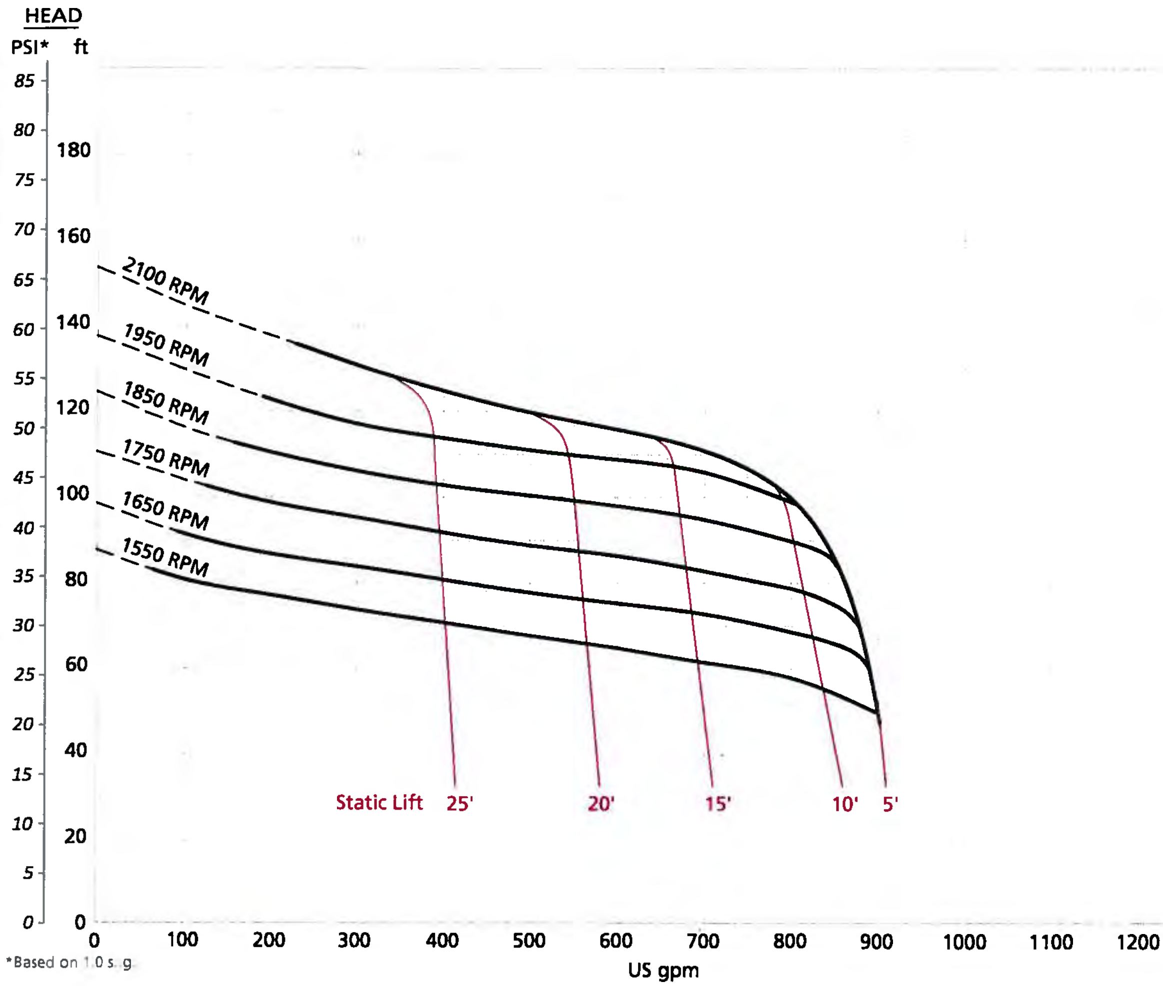
PRIME-ASSISTED PUMP CURVE

June, 2009

4" PA4A60-4045D PRIME-ASSISTED PUMP

GENERAL INFORMATION

This pump is fitted with a compressor / ejector priming system to create a vacuum on the inlet to the pump. This allows the pump to automatically prime and reprime.

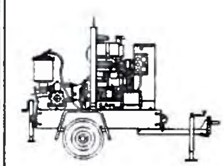


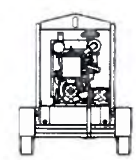
PUMP

MODEL	PA4A60-4045D
CURVENO.	PA4A-4045D-1
SUCTION	4-inch
DISCHARGE	4-inch
MAXSOLID	3-inch
IMP. DIA.	9.75 inches
SPEED	Various
MIN SPEED	1400 RPM

ENGINE

MAKE	John Deere
MODEL	4045D
RATING	72 hp @ 2500





BAKERCORP

3020 Old Ranch Parkway • Suite 220 • Seal Beach, CA • 562-430-6262

TECHNICAL DATA

QUESTMARK 8120

ACID RESISTANT EPOXY MORTAR PATCH KIT/RESURFACER

PRODUCT DESCRIPTION:
8120 is a three component 100% solids epoxy mortar designed for applications where splash and spills of dilute acids and chemicals occur.

RECOMMENDED FOR:
Recommended for heavy traffic areas, chemical troughs, curbs, tanks, and chemical spill areas.

NOT RECOMMENDED FOR:
Immersion applications for all acids and chemicals

SOLIDS BY WEIGHT:
100%

VOLATILE ORGANIC CONTENT:
zero pounds per gallon

STANDARD COLORS:
Light gray, red, dark gray, and natural

RECOMMENDED THICKNESS:
1/8" to 1/4"

COVERAGE PER UNIT:
18.7 sq. ft. @ 1/4" and 37.4 sq. ft. @ 1/8"

PACKAGING	CUBIC FEET
1/4 unit	.095 (approx)
unit	.39 (approx)
bulk unit	1.85 (approx)

*UNIT= 6.80# part A, 2.65# part B, 44# aggregate
BULK= 34.0# part A, 13.25# part B, 200# aggregate
(all weights approximate)

MIX RATIO:
*UNIT= 0.73 gallons part A to 0.31 gallons part B plus 44# aggregate
(weight and volumes approximate)

SHELF LIFE:
2 years in unopened containers

ABRASION RESISTANCE:
excellent

VISCOSITY:
Part A= 950-1,250 cps, Part B= 200-275 cps

DOT CLASSIFICATIONS:
Part A&C "not regulated"
Part B "CORROSIVE LIQUID N.O.S., 8, UN1760,PGIII"

FLEXURAL STRENGTH:
12,100 psi @ ASTM D790

COMPRESSIVE STRENGTH:
10,375 psi @ ASTM D695

TENSILE STRENGTH:
7,875 psi @ ASTM D638

ULTIMATE ELONGATION:
6.59%

IMPACT RESISTANCE:
Excellent

HEAT DEFLECTION TEMP.:
144.5 degrees F @ ASTM D648

WEATHERING:
Good (chalks)

CURE SCHEDULE: (70° F)
pot life – (.39 cu. ft. mix) ....30-40 minutes
recoat or topcoat.. 6-7hours
light foot traffic..12-14 hours
full cure (heavy traffic)... ....2-7 days

APPLICATION TEMPERATURE:
50-90 degrees F

CHEMICAL RESISTANCE:

REAGENT	RATING
xylene	C
1,1,1 trichloroethane	C
MEK	A
methanol	A
ethyl alcohol	B
skydrol	B
10% sodium hydroxide	D
50% sodium hydroxide	D
10% sulfuric acid	C
70% sulfuric acid	A
10% HC1 (aq)	C
5% acetic acid	B

Rating key: A - not recommended, B - 2 hour term splash spill, C - 8 hour term splash spill, D - 72 hour immersion, E - long term immersion. NOTE: extensive chemical resistance information is available through your sales representative.

PRIMER:
None required

TOPCOAT:
None required. For increased performance and reduced porosity, topcoat with 3094 and 3095

LIMITATIONS:
*Color stability may be affected by environmental conditions such as high humidity or chemical exposure.
*Product is not UV color stable and may discolor if exposed to lighting such as sodium vapor lights.
*Colors may vary from batch to batch due to variations in the silica filler.
*Mortar colors are not from our standard color chart.
*Substrate temperature must be 5°F above dew point.
*For chemical exposure areas, we recommend a suitable topcoat to reduce porosity and chemical migration.
*All new concrete must be cured for at least 30 days prior to application.
*See reverse side for application instructions.
*Test data based on neat resin.
*Physical properties are typical values and not specifications.
*See reverse side for limitations of our liability and warranty.

TECHNICAL DATA

QUESTMARK 8253

ACID/CHEMICAL RESISTANT COLORED NOVOLAC EPOXY SEAL

PRODUCT DESCRIPTION:
8253 is a two component colored high solids novolac epoxy coating designed for application where splash and spills of acids, chemicals, and solvents occur.

RECOMMENDED FOR:
Recommended for a high build topcoat for traffic areas, chemical troughs and curbs as well as tanks and chemical spill areas for cement masonry or brick.

SOLIDS BY WEIGHT:
96% (+/- 1%)

SOLIDS BY VOLUME:
94% (+/- 1%)

VOLATILE ORGANIC CONTENT:
0.40# per gallon (mixed)

STANDARD COLORS:
Light gray, medium gray, and tile red

RECOMMENDED FILM THICKNESS:
16-18 mils

COVERAGE PER GALLON:
90-100 square feet per gallon @ 16-18 mils

PACKAGING INFORMATION
3 gallon kit (volume approximate)
15 gallon kits (volume approximate)

MIX RATIO:
10.15 pounds (1 gallon) part A to 4.2 pounds (.50 gallons) part B (volumes approx.)

SHELF LIFE:
1 year in unopened containers

FINISH CHARACTERISTICS;
Gloss (>40 at 60 degrees @ Erichsen glossmeter)

FLEXURAL STRENGTH:
9,610 psi @ ASTM D790- 1/2"X1/2" bars span 4"

COMPRESSIVE STRENGTH:
9,900 psi @ ASTM D695

TENSILE STRENGTH:
6,680 psi @ ASTM D638

ADHESION:
425 psi @ elcometer (concrete failure, no delamination)

ULTIMATE ELONGATION:
4.7%

HARDNESS:
Shore D = 88

GARDNER VARIABLE IMPACTOR:
50 inch pounds direct – passed

ABRASION RESISTANCE:
Taber abraser CS-17 calibrase wheel with 1000 gram total load and 500 cycles= 20 mg loss

VISCOSITY:
Mixed = 2200-2700 cps (typical)

DOT CLASSIFICATIONS:
Part A "not regulated"
Part B "CORROSIVE LIQUID N.O.S., 8, UN1760, PGIII"

HEAT DEFLECTION TEMP.:
115.5 degrees F, ASTM D648

CURE SCHEDULE: (70° F)
pot life – (1 1/2 gallon volume) ....25-35 minutes
tack free (dry to touch) ....5-7 hours
recoat or topcoat....................................5-10 hours
light foot traffic....................................10-18 hours
full cure (heavy traffic)... ....2-7 days

APPLICATION TEMPERATURE:
60-95 degrees F with relative humidity below 90%

CHEMICAL RESISTANCE:

REAGENT	RATING
xylene	D
1,1,1 trichloroethane	C
MEK	C
methanol	C
ethyl alcohol	C
skydrol	C
10% sodium hydroxide	E
50% sodium hydroxide	E
10% sulfuric acid	E
70% sulfuric acid	C
10% HC1 (aq)	D
5% acetic acid	D

Rating key: A - not recommended, B - 2 hour term splash spill, C - 8 hour term splash spill, D - 72 hour immersion, E - long term immersion. NOTE: extensive chemical resistance information is available through your sales representative.

PRIMER:
Recommended 8257

TOPCOAT:
None recommended

LIMITATIONS:
*Color stability or gloss may be affected by environmental conditions such as high humidity, low temperature or chemical exposure.
*Colors may vary from batch to batch. Therefore, use only product from the same batch for an entire job.
*Apply a suitable primer before using this product
*This product is not UV color stable and exposure to lighting such as sodium vapor lights may cause discolorations.
*Mixtures of chemicals and applications with exposures to chemicals at elevated temperatures should be thoroughly evaluated before applying coating. A test patch is recommended.
*Product can develop surface irregularities in leveling in combination to some chemical contamination or substrate compositions.
*Substrate temperature must be 5°F above dew point.
*For best results, apply with a 1/4" nap roller.
*All new concrete must be cured for at least 30 days prior to application.
*See reverse side for application instructions.
*Physical properties are typical values and not specifications.
*See reverse side for limitation of our liability and warranty.

TECHNICAL DATA

QUESTMARK 8257

CHEMICAL RESISTANT NOVOLAC COLORED EPOXY PRIMER

PRODUCT DESCRIPTION:
8257 is a two component novolac epoxy primer in colors. 8257 offers high solids, good substrate penetration and low odor. This primer reduces air release generation from the substrate when applying higher solids novolac topcoats. This will result in fewer surface imperfections in high build and self leveling type coating.

RECOMMENDED FOR:
Recommended for priming concrete and cement substrates prior to applying other novolac topcoats. This product can withstand exposure to many chemicals.

SOLIDS BY WEIGHT:
Mixed= 85% (+/- 2%)

SOLIDS BY VOLUME:
Mixed= 80% (+/- 2%)

VOLATILE ORGANIC CONTENT:
Part A= 1.7 pounds per gallon
Part B= 1.25 pounds per gallon

STANDARD COLORS:
Light gray, medium gray, and tile red

RECOMMENDED FILM THICKNESS:
5-6 mils per coat wet thickness (yields 4-5 mils dry)

COVERAGE PER GALLON:
267 to 320 square feet @ 5-6 mils wet thickness

PACKAGING INFORMATION:
3 gallon and 15 gallon kits (volume approx),
3 gal kit= 2 gallons part A (9.95#/gal) and 1 gallon part B (8.3#/gal)

MIX RATIO:
9.95# part A (1 gallon) to 4.15# (1/2 gallon) part B (volumes are approximate)

SHELF LIFE:
1 year in unopened containers

FINISH CHARACTERISTICS:
Satin gloss (>20 at 60 degrees @ Erichsen glossmeter)

FLEXIBILITY:
No cracks on a 1/8" mandrel

IMPACT RESISTANCE:
Gardner Impact, direct= 50 in. lb. (passed)

ABRASION RESISTANCE:
Taber abrasor CS-17 calibrase wheel with 1000 gram total load and 500 cycles= 26.1 mg loss

ADHESION:
375 psi @ elcometer (concrete failure, no delamination)

VISCOSITY:
Mixed= 250-500 cps (typical)

DOT CLASSIFICATIONS:
Part A "FLAMMABLE LIQUID N.O.S., 3, UN1993 PGIII"
Part B "FLAMMABLE LIQUID N.O.S., 3, UN1993 PGIII"

CURE SCHEDULE: (70° F)
pot life – (1 1/2 gallon volume)....................1-3 hours
tack free (dry to touch)....................4-7 hours
recoat or topcoat....................7-10 hours
light foot traffic....................12-24 hours
full cure (heavy traffic)....................2-7 days

APPLICATION TEMPERATURE:
60-90 degrees F with relative humidity below 90%

CHEMICAL RESISTANCE:

REAGENT	RATING
acetic acid 5%	D
xylene	D
toluene	D
1,1,1 trichloroethane	C
mek	C
methyl alcohol	C
gasoline	D
10% sodium hydroxide	E
50% sodium hydroxide	E
10% sulfuric acid	E
10% hydrochloric acid	E
20% nitric acid	C
ethylene glycol	E

Rating key: A - not recommended, B - 2 hour term splash spill, C - 8 hour term splash spill, D - 72 hour immersion, E - long term immersion. NOTE: extensive chemical resistance information is available through your sales representative.

PRIMER:
None required

TOPCOAT:
Many novolac products are suitable such as our 8253 or our 8253SL product line.

LIMITATIONS:
*Colors may be affected by high humidity, low temperatures or chemical exposure.
*For best results use a 3/8" nap roller.
*Slab on grade requires moisture barrier.
*Substrate temperature must be 5°F above dew point.
*All new concrete must be cured for at least 30 days.
*Physical properties are typical values and not specifications.
*This product should be topcoated with a suitable novolac epoxy topcoat.
*Colors may vary from batch to batch.
*See reverse side for application instructions.
*See reverse side for limitations of our liability and warranty.

Dow Plastics

DOW EPOXY NOVOLAC RESINS [redacted]

HIGH-TEMPERATURE, HIGH-PERFORMANCE
EPOXY RESINS

TABLE OF CONTENTS

DOW

EPOXY NOVOLAC RESINS

INTRODUCTION

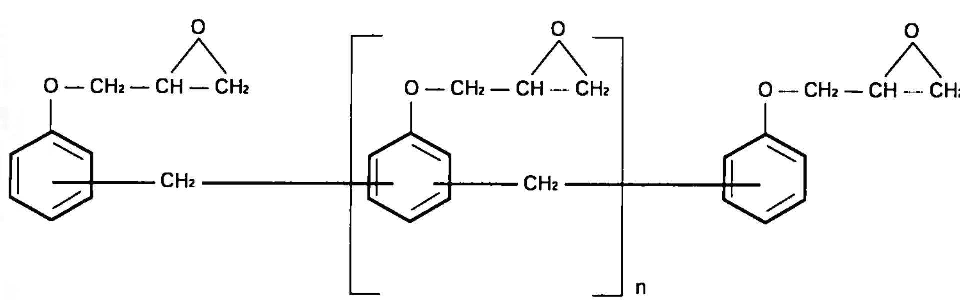
D.E.N.* epoxy novolac resins are thermosetting plastic materials that provide good strength and chemical resistance at high temperatures. Because of this, these products offer formulators and fabricators excellent value as an alternative to bisphenol-A based epoxies and phenolic resins.

Figure 1 illustrates how D.E.R.* 354 epoxy resin and D.E.N. 431, D.E.N. 438* and D.E.N. 439 resins combine the reactivity and versatility of an epoxy resin with the thermal stability of a phenol-formaldehyde based backbone. This unique structure results in multi-epoxy functionality and additional reactive sites, producing tightly crosslinked systems that offer the following advantages over bisphenol-A type resins:

- Improved resistance to acids, bases and solvents
- Retention of mechanical properties at high temperatures and under wet conditions
- Minimal shrinkage
- Acceptance of a wide range of modifiers, fillers and pigments
- Improved high temperature adhesive properties

Note: Although D.E.R. 354 is a bisphenol-F based resin, it is generally grouped with the D.E.N. resins due its highly similar molecular structure and performance in cured systems.

Figure 1 – Molecular Structure of D.E.R. 354, D.E.N. 431, D.E.N. 438 and D.E.N. 439 Resins



n = Number of repeating units

Average value for n:
D.E.R. 354 = 0.2
D.E.N. 431 = 0.7
D.E.N. 438 = 1.6
D.E.N. 439 = 1.8

* Trademark of The Dow Chemical Company.

APPLICATIONS

The thermal stability of DOW Epoxy Novolac resins allows their application as adhesives, structural and electrical laminates, coatings and castings in elevated temperature service.

For example, ease of processing – coupled with resistance to heat of friction – makes epoxy novolac adhesives ideal for use as binders in abrasives for grinding and polishing products. The liquid forms of D.E.R. 354 and D.E.N. 431 resins and the semi-solid form of D.E.N. 438 resin facilitate the preparation of pliable pre-pregs for vacuum bag lamination. In electrical laminates, the use of epoxy novolacs improves resistance to hot solder, as well as providing elevated temperature service. (Electrical grade laminates have been made using mica, glass flake and glass fiber reinforcement.) Plus, coatings formulated with epoxy novolacs provide excellent chemical resistance associated with an increased crosslink density when used in a solvent or waterborne formulation.

In addition, the high viscosity of D.E.N. 439 resin (semi-solid state at room temperature) offers a means of obtaining good drape and limited tack, once the solvent has been removed from the pre-impregnated web. Pre-pregs made with little or no "B" stage advancement provide good flow properties for press lamination. The inherently heat-resistant epoxy novolac resins can also be used to improve halogenated resins or hardeners in applications such as structural laminates for the aerospace and electronic circuit board industries. And epoxy novolacs can be combined with carbon, glass and Kevlar[1] fibers to create many types of engineering composites.

Electrical varnishes, encapsulants, semiconductors and general molding powders are other applications where common operating temperatures suggest the use of epoxy novolac resins.

Filament wound pipe and storage tanks, liners for pumps and other chemical process equipment and corrosion-resistant coatings are typical applications that take advantage of the chemical-resistant properties of DOW Epoxy Novolac resins.

[1] Trademark of E.I. du Pont de Nemours & Company.

TYPICAL PROPERTIES

Table 1 lists typical properties of several DOW Epoxy Novolac resins.

VISCOSITY

The high viscosity of D.E.N. 438 and D.E.N. 439 resins at room temperature require reduction for some applications. This can be accomplished in a number of ways. For pre-preg applications, these resins are offered in solvent solutions of methyl ethyl

Table 1 – Typical Properties of Selected D.E.N. Resins[1]

Property	D.E.R. 354LV[2]	D.E.R. 354	D.E.N. 431	D.E.N. 438	D.E.N. 438-MK75	D.E.N. 438-EK85	D.E.N. 438-A85	D.E.N. 439	D.E.N. 439-EK85
Epoxide Equivalent Weight (EEW)[3]	160-170	158-175	172-179	176-181	176-181	176-181	176-181	191-210	191-210
Viscosity at 77°F (25°C), cP	2,000-3,000	3,000-5,500	—	—	200-600	600-1,600	500-1,200	—	4,000-10,000
Viscosity at 125°F (52°C), cP	—	—	1,100-1,700	22,500-50,000	—	—	—	15,000-35,000[4]	—
Specific Gravity at 25/39°F (4°C)	1.19	1.19	1.21	1.22	1.09	1.14	1.14	1.22	1.15
Mettler Softening Point, °F (°C)	—	—	—	—	—	—	—	118-136 (48-58)	—
Flash Point (Pensky-Marten Closed Cup), °F (°C)	495 (257)	495 (257)	424 (218)	424 (218)	55 (13)	16 (-9)	-4 (-20)	424 (218)	16 (-9)
Gardner Color, Max.	3	4	3	2	2	2	2	3	3
Solvent, % Weight	—	—	—	—	Methyl Isobutyl Ketone, 25±1	Methyl Ethyl Ketone, 15±1	Acetone, 15±1	—	Methyl Ethyl Ketone, 15±1
Lbs./Gallon (kg/liter)	9.9 (1.19)	9.9 (1.19)	10.1 (1.21)	10.2 (1.22)	9.2 (1.10)	9.5 (1.14)	9.5 (1.14)	10.2 (1.22)	9.6 (1.15)

[1] Typical property values, not to be construed as specifications.
[2] Low Viscosity.
[3] Determined using base resin.
[4] Measured at 160°F (71°C).

ketone (EK). D.E.N. 438 resin is also offered in acetone (A) or methyl isobutyl ketone (MK) solutions. Other special solutions can be made available for special customer requirements, if quantities justify meeting the need.

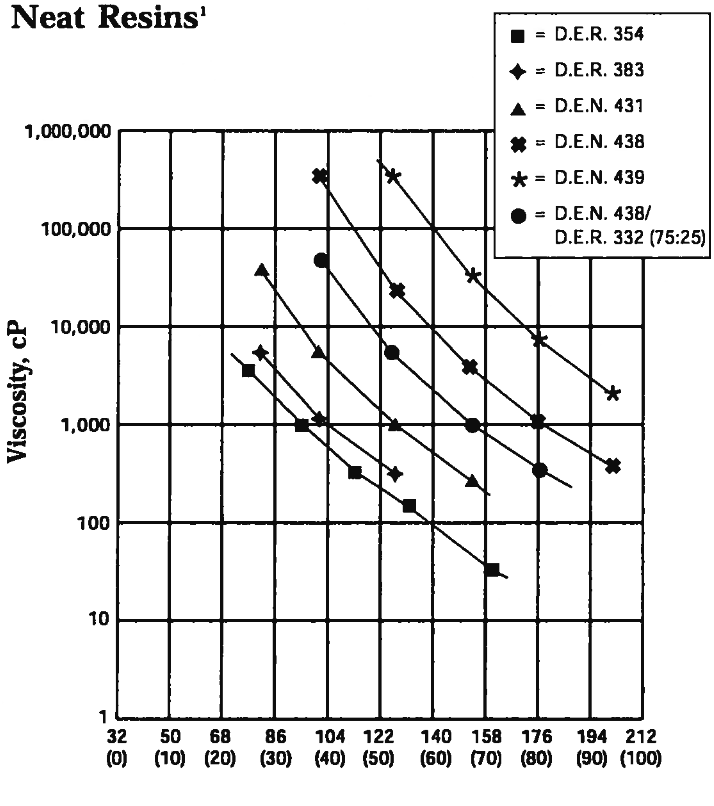
In cases where solvents cannot be tolerated, viscosity may be reduced by heating, the use of diluents, or blending with other low viscosity resins – including epoxy novolac resins, the diglycidyl ether of bisphenol-A based resins (i.e., D.E.R. 331*, D.E.R. 383 or D.E.R. 332 resin), or the diglycidyl ether of bisphenol-F based resins (i.e., D.E.R. 354).

The use of heat to lower viscosity is very satisfactory. At 176-194°F (80-90°C), the resins are fluid enough for easy mixing with most epoxy curing agents. Figure 2 illustrates the typical viscosity/temperature relationships of selected neat resins.

Figure 3 shows the substantial reductions that can be achieved by blending D.E.N. 438 resin with lower viscosity resins, as well as the near proportional increase in viscosity that occurs as the epoxy novolac resin content is increased. It should be noted, however, that blending with low viscosity resins or diluents usually results in some reduction of elevated temperature performance and chemical resistance.

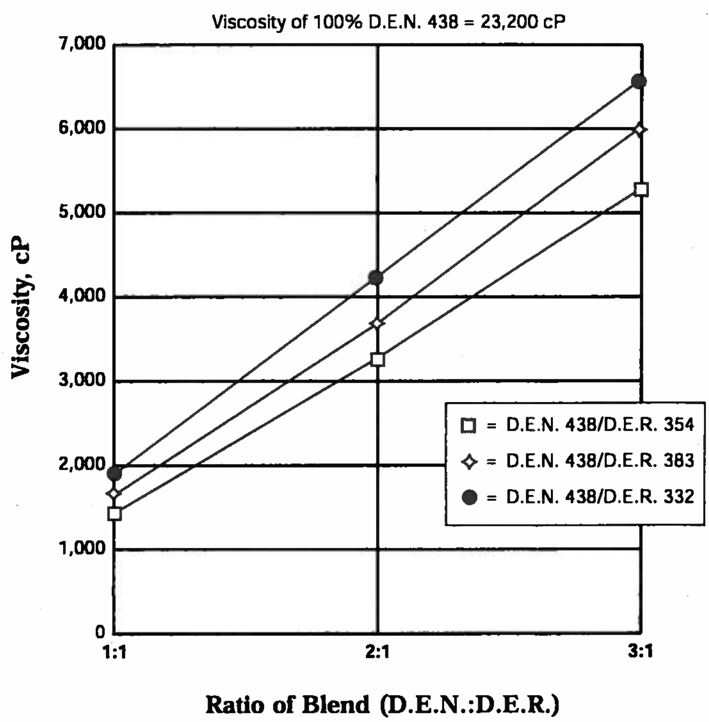
*Trademark of The Dow Chemical Company.

Figure 2 – Viscosity versus Temperature of Neat Resins[1]



[1] Laboratory test data, not to be construed as specifications.

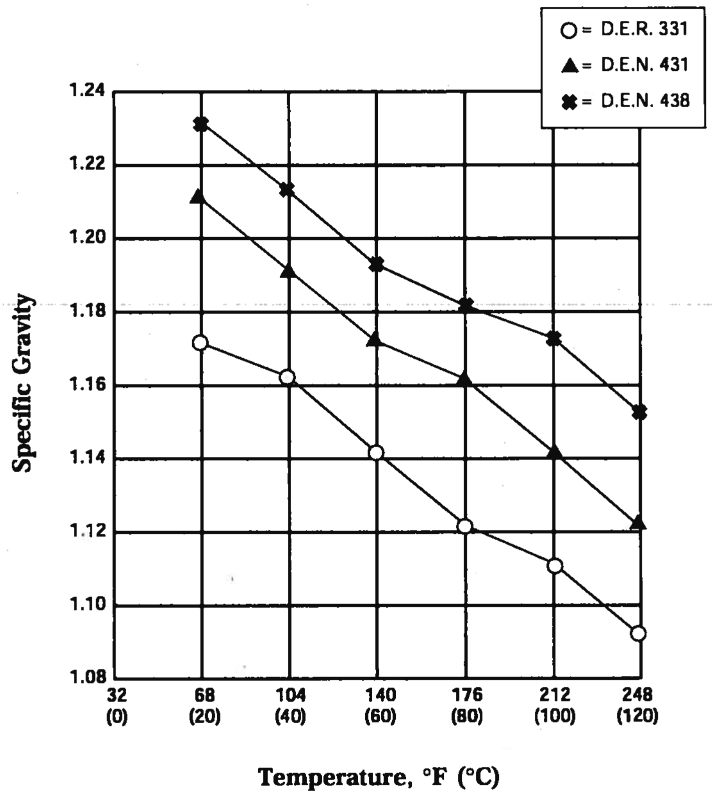
Figure 3 – Viscosity of Neat Resin Blends at 125°F (52°C)[1]



SPECIFIC GRAVITY

The volume of product used is greater at elevated temperatures due to the increase in specific gravity. The specific gravity of bisphenol-A based epoxy is lower than that of epoxy novolac resin independent of temperature. Figure 4 demonstrates the relationship between specific gravity and temperature, with a bisphenol-A based resin (D.E.R. 331) included for comparison.

Figure 4 – Specific Gravity versus Temperature[1]



[1] Laboratory test data, not to be construed as specifications.

FILLERS AND MODIFIERS

The fillers and modifiers normally used with liquid epoxy resins can also be used with epoxy novolac resins. For example, polysulfide resins have been used in the formulation of amine cured adhesives and silicone resins are frequently used to improve flow and wetting. Polyols, polyesters and phenolics are among other resins suggested for use as modifiers.

Fillers can also be used to modify specific formulation properties. In applications that require the protection of delicate encapsulated parts, the incorporation of fillers can provide additional reduction of shrinkage along with improved adhesion. Likewise, metallic fillers can be used to improve heat transfer, and soft metal fillers, such as aluminum powder, are added to improve machinability. Fibrous fillers improve mechanical strength, while graphite or molybdenum disulfide can reduce friction in bearings or seals. Abrasive pigments can be used to improve the wear resistance of surfaces.

The high viscosities of D.E.N. 438 and D.E.N. 439 resins require that they be heated to 167-212°F (75-100°C) for filler addition. However, when viscosity reducing modifiers are also being used, fillers can be added to the mix at lower resin temperatures. In any case, fillers are usually preheated to 302-392°F (150-200°C) to drive off moisture.

Curing Agents and Cure Schedules

When selecting a curing agent for use with epoxy novolac resins, the effect on cured resin properties must be considered. Modified amines, catalytic curing agents and some anhydrides provide optimum elevated temperature properties. In addition, epoxy novolacs cured with polyamide hardeners, or aliphatic polyamines and their adducts, show improvement over similar systems using bisphenol-A based epoxies. However, the elevated temperature performance is still limited by the performance of the curing agent itself.

Table 2 – Cure Schedules of Common Curing Agents (Used with Neat Resins)

Curing Agent	Initial Gel Time, Hours	Temperature °F (°C)	Post Cure Time, Hours	Temperature °F (°C)	Comments
Methyl Tetrahydrophthalic Anhydride (MTHPA)	2	185 (85)	2 +2	302 (150) 392 (200)	Catalyzed with 1.0 phr of 1- (2-hydroxy-propyl) imidazole. Epoxy novolac resins heated to 140°F (60°C) before addition of curing agent. Molds preheated to 122°F (50°C).
Dicyandiamide (Dicy)	2	356 (180)	2	392 (200)	Testing for thermal properties only. Test samples made in small aluminum pans. Hardener dissolved by first warming resin/hardener blend on hot plate at 410°F (210°C). 5.0 phr mix ratio of Dicy.
Nadic Methyl Anhydride (NMA)	2	185 (85)	2 +2	302 (150) 446 (230)	Catalyzed with 1.0 phr of 1- (2-hydroxy-propyl) imidazole or 1.5 phr benzyl-dimethylamine (BDMA) as accelerator.
Diethyltoluene-Diamine (DETDA)	2	248 (120)	2 +2	347 (175) 437 (225)	Epoxy novolac resins heated to 176°F (80°C) before addition of curing agent. Molds preheated to 122°F (50°C).
Diamino Diphenyl Sulfone (DDS)	3	351 (177)	2	482 (250)	Resin, curing agent and molds heated to 302°F (150°C) before blending.
Boron Trifluoride Monoethylamine (BF_3 • MEA)	4	212 (100)	16	302 (150)	Resin preheated to 176-212°F (80-100°C) to dissolve catalyst. Molds preheated to 212°F (100°C).
Diaminocyclohexane (DACH)	1	176 (80)	2	350 (177)	Molds preheated to 122°F (50°C).

Other factors to be considered when selecting a curing agent include the pot life and viscosity desired for the application. If heat is used to reduce viscosity, then polyamides and aliphatic polyamines and their adducts will react extremely fast, resulting in too short a pot life to permit batch mixing. Such systems may, however, be adapted to production operations by using automatic metering and dispensing equipment.

Modified amines, latent catalytic curing agents and most anhydrides offer sufficient pot life at modestly elevated temperatures to allow batch mixing. The liquid anhydrides, such as Nadic Methyl Anhydride (NMA) and Methyl Tetrahydrophthalic Anhydride (MTHPA) are particularly useful because they reduce the viscosity of the solution as well as providing excellent elevated temperature performance in the cured system.

Table 2 lists cure schedules for some of the more common curing agents, along with comments on formulating procedures. Curing agents and cure schedules were selected to allow comparison with other Dow epoxy resin data, not because they are optimum for use with epoxy novolac resins.

Figures 5 through 10 show the relationship between viscosity and cure time for selected epoxy resins cured with Methyl Tetrahydrophthalic Anhydride (MTHPA), Dicyandiamide (Dicy), Diethyltoluene-Diamine (DETDA) and Diamino Diphenyl Sulfone (DDS).

Figure 5 – Viscosity versus Time at 185°F (85°C) for Resins Cured with MTHPA[1]

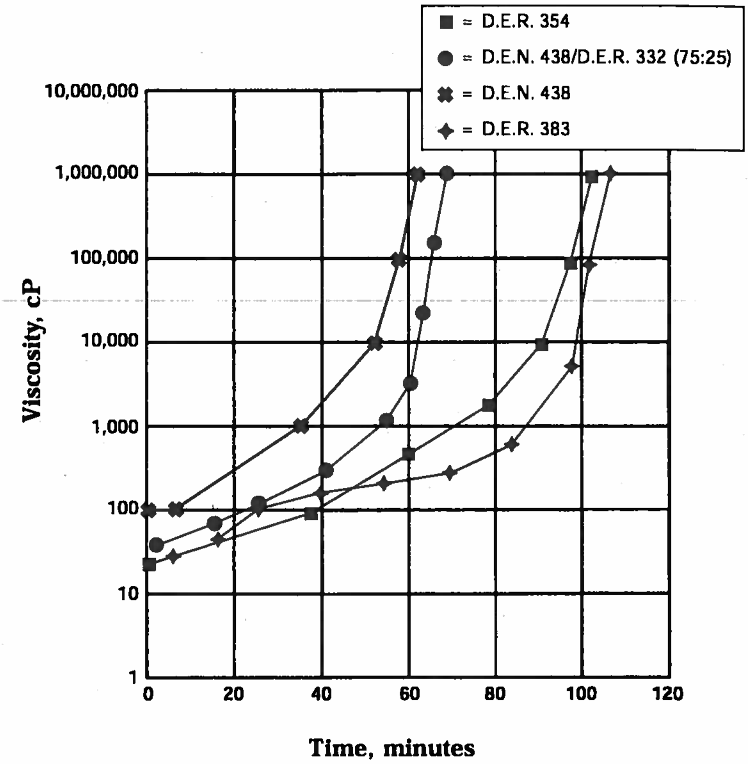
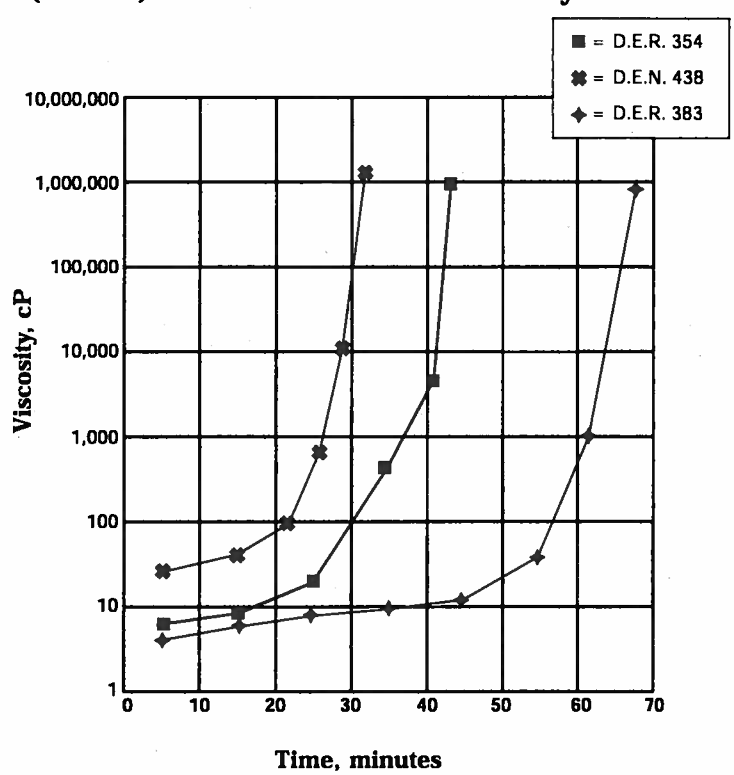


Figure 6 – Viscosity versus Time at 320°F (160°C) for Resins Cured with Dicy[1]



[1] Laboratory test data, not to be construed as specifications.

A general discussion of the curing mechanisms and polymer formations obtained with various curing agents can be found in the Dow publication "Formulating with DOW Epoxy Resin" (Form No. 296-00346). In addition, this publication includes formulating guidelines; procedures for determining equivalent weights and calculating stoichiometric ratios; and information on the types of epoxy products available, along with suitable applications and the reasons behind successful system performance.

Figure 7 – Viscosity versus Time at 250°F (121°C) for Resins Cured with DETDA[1]

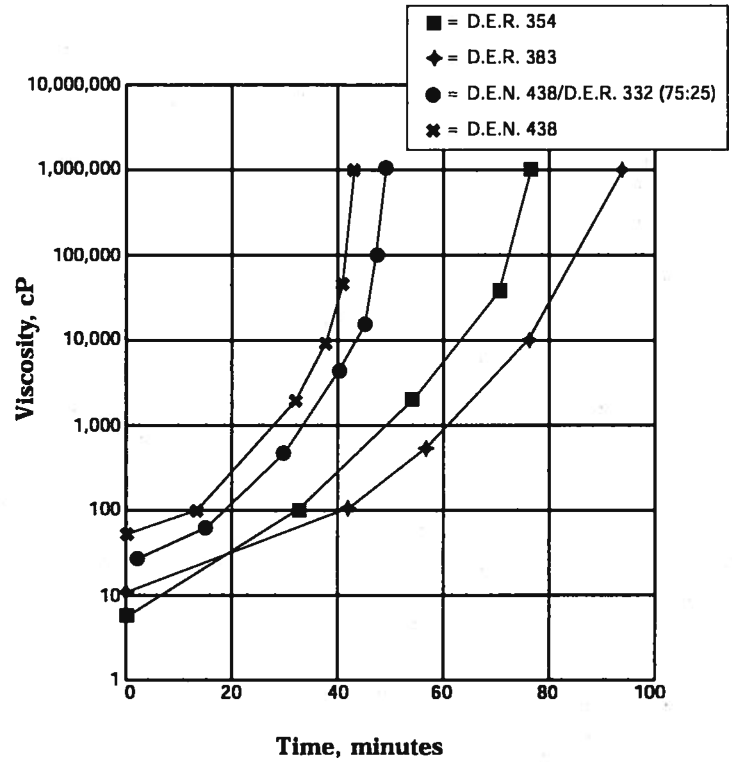
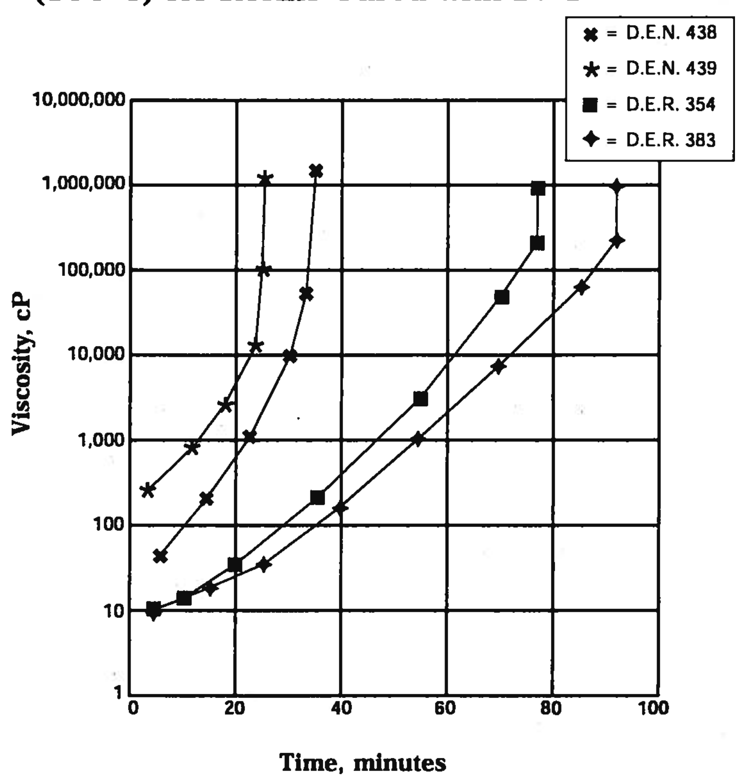


Figure 8 – Viscosity versus Time at 302°F (150°C) for Resins Cured with DDS[1]



[1] Laboratory test data, not to be construed as specifications.

Cured Resin Performance Data

TEST METHODS

This section provides performance data for a wide range of properties in cured DOW Epoxy Novolac resin systems. Due to the large volume of data involved, all test methods used have been listed in Table 3. Unless otherwise noted, all testing was performed according to the ASTM standard test methods indicated. In cases where an ASTM method was not used, a brief description of the procedure is given. Test samples were cured according to the schedules shown in Table 2 (page 8).

Table 3 – Test Methods

Property	Test Method	Comments
Rheology of neat resins and formulations	—	Cup and Bob Rheometer. 12g samples.
Cure Kinetics (Δ H, onset temperature, maximum exotherm temperature)	ASTM D 3418	Differential Scanning Calorimeter (DSC).
Glass Transition Temperature (Tg)	ASTM D 3418	Differential Scanning Calorimeter (DSC). Wet testing performed on samples after two-week water boil.
Thermal Degradation	—	2" diameter x 1/8" T round coupons exposed to air convection oven at specified temperature.
Coefficient of Linear Thermal Expansion (CLTE)	ASTM E 831	Thermomechanical Analyzer (TMA). 1/8" thick samples.
Storage (E') and Loss (E") Modulus, tan delta	ASTM D 4065	Dynamic Mechanical Analyzer (DMA). 1/8" thick samples. Wet testing performed on samples after two-week water boil.
Flexural Strength, Modulus, Strain	ASTM D 790	1/2" W x 1/8" T x 3" L samples, 2" span.
Tensile Strength, Modulus, % Elongation	ASTM D 638	3/4" W x 1/8" T x 8 1/2" L samples, routed to 1/2" neck width.
Liquid Density	ASTM D 1475	Density Cup.
Solid Density	ASTM D 792	Cured Castings – Liquid displacement method.
Water Absorption	—	1" W x 1/8" D x 3" L samples, two-week water boil.
Thermogravimetric Analysis	ASTM D 3850	Thermal Gravimetric Analyzer (TGA).
Dielectric Constant and Dissipation Factor	ASTM D 150	3" x 3" samples.

THERMAL PROPERTIES

With Glass Transition Temperatures (Tg) ranging from 259-491°F (126-255°C), DOW Epoxy Novolac resins offer excellent heat resistance in cured systems. Table 4 lists the representative glass transition temperatures for various resin/curing agent formulations, with data for D.E.R. 383 (a liquid bisphenol-A based epoxy resin) provided for comparison. In addition, Figure 9 graphically illustrates the wide range of glass transition temperatures available.

Generally speaking, the higher the functionality of an epoxy resin formulation, the higher the crosslink density of the cured product. In turn, crosslink density and several other factors (i.e., cure schedule, catalyst concentration and type, curing agent type, and stoichiometric ratio of curing agent and resin) help determine the glass transition temperature of a particular formulation. The higher glass transition temperatures obtained with epoxy novolacs suggest the maintenance of cured product integrity at elevated temperatures. Long-term thermal performance is also dictated by environmental exposure. Therefore, environmental conditioning should be used to determine the long-term thermal performance of a cured product.

Table 4 – Representative Glass Transition Temperatures (Tg) of Formulated Resin Systems[1]

Resin	Curing Agent	Tg, °F (°C)
D.E.R. 354	MTHPA	264 (129)
	Dicy	259 (126)
	NMA	315 (157)
	DETDA	273 (134)
	DDS	351 (177)
	DACH	270 (132)
D.E.N. 431	MTHPA	300 (149)
	Dicy	327 (164)
	NMA	361 (183)
	DETDA	360 (182)
	DDS	414 (212)
	BF_3•MEA	361 (183)
D.E.N. 438	MTHPA	300 (149)
	Dicy	374 (190)
	NMA	417 (214)
	DETDA	428 (220)
	DDS	491 (255)
	BF_3•MEA	365 (185)
D.E.N. 439	MTHPA	298 (148)
	Dicy	383 (195)
	NMA	432 (222)
	DETDA	410 (210)
	DDS	450 (232)
D.E.R. 383	MTHPA	298 (148)
	Dicy	316 (158)
	NMA	354 (179)
	DETDA	360 (182)
	DDS	428 (220)
	BF_3•MEA	342 (172)

[1] Laboratory test data, not to be construed as specifications.

Figure 9 – Comparative Glass Transition Temperatures (Tg) of Formulated Resin Systems[1]

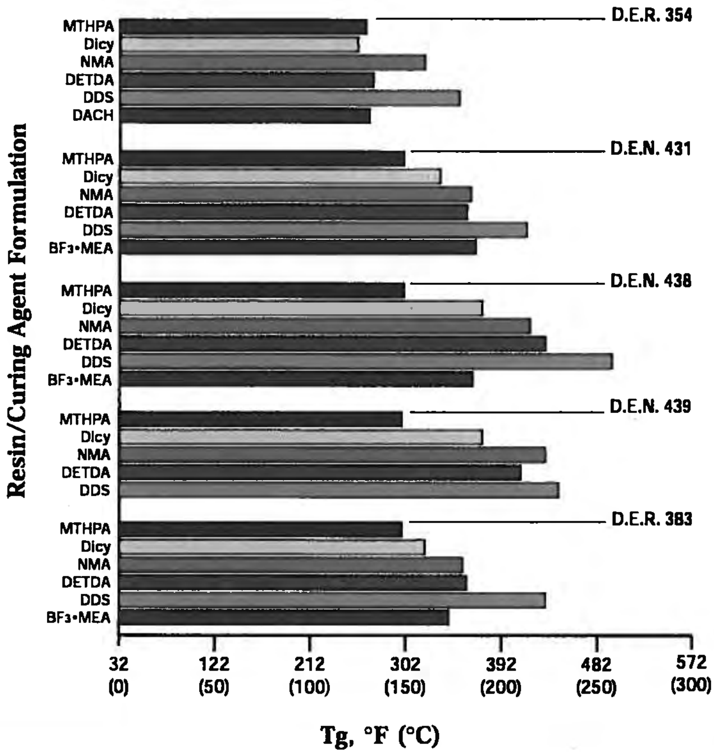


Table 5 lists percent weight loss under isothermal conditions and heat distortion temperature for various DOW Epoxy Novolac resins and bisphenol-A based D.E.R. 331 resin after standard cures. The data suggest that the D.E.N. resins are better suited to withstand elevated service temperatures over long periods of time.

Table 5 – Typical Thermal Degradation (Percent Weight Loss) and Heat Distortion Temperatures[1]

Resin	D.E.N. 431	D.E.N. 438	D.E.N. 439	D.E.R. 331	D.E.N. 438	D.E.R. 331	D.E.N. 438	D.E.N. 439	D.E.R. 331
Curing Agent	NMA[2]	NMA[2]	NMA[2]	NMA[2]	DDS	DDS	BF_3•MEA	BF_3•MEA	BF_3•MEA
% Weight Loss									
Temperature									
320°F (160°C)									
100 Hours	0.21	0.05	0.32	0.12	—	—	0.11	0.42	0.36
200 Hours	0.00	0.00	0.34	0.07	—	—	0.08	0.26	0.48
300 Hours	0.00	0.01	0.61	0.10	—	—	0.10	0.26	0.71
500 Hours	0.00	0.00	1.04	0.10	—	—	0.05	0.26	0.86
410°F (210°C)									
100 Hours	0.67	0.63	0.35	0.66	—	—	1.73	1.23	2.60
200 Hours	1.04	1.07	0.39	1.10	—	—	2.97	2.55	4.00
300 Hours	1.30	1.46	0.60	1.50	—	—	3.82	3.25	4.90
500 Hours	1.55	2.07	1.20	1.80	—	—	5.02	3.95	5.50
500°F (260°C)									
100 Hours	—	5.20	4.80	5.60	—	—	11.30	10.50	19.60
200 Hours	—	9.20	9.00	10.20	—	—	13.15	12.40	D
Heat Distortion Temp., °F (°C)	324 (162)	378 (192)	356 (180)	313 (156)	496 (258)	387 (197)	473 (245)	493 (256)	334 (168)

1 Laboratory test data, not to be construed as specifications.
2 Plus 1.5 Parts BDMA.
D=Decomposed

PHYSICAL PROPERTIES

Tables 6 through 10 indicate typical physical properties of cured epoxy novolac resin systems formulated with DOW Epoxy Novolac resins and selected curing agents. Data from samples of bisphenol-A based D.E.R. 383, cured with the same curing agents, has also been provided for comparison.

Table 6 – Typical Physical Properties of Resin Systems Cured with MTHPA/Imidazole[1]

Resin	D.E.R. 354	D.E.N. 431	D.E.N. 438	D.E.N. 438/ D.E.R. 332 (75:25)	D.E.N. 439	D.E.R. 383
Epoxide Equivalent Weight (EEW) Range	158-175	172-179	176-181	175-180	191-210	176-185
Curing Agent/Catalyst	MTHPA/ Imidazole	MTHPA/ Imidazole	MTHPA/ Imidazole	MTHPA/ Imidazole	MTHPA/ Imidazole	MTHPA/ Imidazole
Mix Ratio of Curing Agent: Catalyst, phr	85:1	85:1	85:1	85:1	85:1	85:1
Cure Schedule, hours at °F (°C)	2/185 (85)	2/185 (85)	2/185 (85)	2/185 (85)	2/185 (85)	2/185 (85)
	2/302 (150)	2/302 (150)	2/302 (150)	2/302 (150)	2/302 (150)	3/302 (150)
	2/392 (200)	2/392 (200)	2/392 (200)	2/392 (200)	2/392 (200)	—
Glass Transition Temp. (Tg), °F (°C)	284 (140)	300 (149)	300 (149)	300 (149)	298 (148)	298 (148)
Coefficient of Linear Thermal Expansion (CLTE), ppm/°F (ppm/°C)	126 (70)	124 (69)	124 (66)	131 (73)	126 (70)	126 (70)
Dynamic Mechanical Analysis (DMA)						
E' onset, °F (°C)	259 (126)	293 (145)	320 (160)	—	282 (139)	300 (149)
E" onset, °F (°C)	270 (132)	302 (150)	340 (171)	—	298 (148)	311 (155)
Tan delta, °F (°C)	282 (139)	313 (156)	351 (177)	327 (164)	316 (158)	318 (159)
Water Absorption, two-week water boil, %	1.63	1.43	1.49	1.40	2.37	1.45
Flexural Strength, ksi (MPa)	18.6 (128)	21.0 (145)	20.0 (138)	20.2 (139)	21.0 (145)	18.5 (128)
Flexural Modulus, ksi (MPa)	481 (3,316)	502 (3,461)	509 (3,509)	520 (3,585)	565 (3,896)	474 (3,268)
Flexural Strain at Yield, %	6.0	6.6	6.7	6.1	6.3	6.7
Cured Density, g/ml	1.225	1.225	1.224	—	1.225	1.190

1 Typical property values, not to be construed as specifications.

Table 7 – Typical Physical Properties of Resin Systems Cured with NMA/Imidazole[1]

Resin	D.E.R. 354	D.E.N. 431	D.E.N. 438	D.E.N. 439	D.E.R. 383
Epoxide Equivalent Weight (EEW) Range	158-175	172-179	176-181	191-210	176-185
Curing Agent/Catalyst	NMA/ Imidazole	NMA/ Imidazole	NMA/ Imidazole	NMA/ Imidazole	NMA/ Imidazole
Mix Ratio of Curing Agent: Catalyst, phr	85:1	85:1	85:1	85:1	85:1
Cure Schedule, hours at °F (°C)	2/185 (85)	2/185 (85)	2/185 (85)	2/185 (85)	2/185 (85)
	2/302 (150)	2/302 (150)	2/302 (150)	2/302 (150)	2/302 (150)
	2/446 (230)	2/446 (230)	2/446 (230)	2/446 (230)	2/446 (230)
Glass Transition Temp. (Tg), °F (°C)	315 (157)	361 (183)	417 (214)	432 (222)	354 (179)

Table 8 – Typical Physical Properties of Resin Systems Cured with DETDA[1]

Resin	D.E.R. 354	D.E.N. 431	D.E.N. 438	D.E.N. 438/ D.E.R. 332 (75:25)	D.E.N. 439	D.E.R. 383
Epoxide Equivalent Weight (EEW) Range	158-175	172-179	176-181	175-180	191-210	176-185
Curing Agent	DETDA	DETDA	DETDA	DETDA	DETDA	DETDA
Mix Ratio of Curing Agent, phr	27.4	26.6	26.3	25.3	23.3	26.0
Cure Schedule, hours at °F (°C)	2/248 (120)	2/248 (120)	2/248 (120)	2/248 (120)	2/248 (120)	2/248 (120)
	2/350 (177)	2/350 (177)	2/350 (177)	2/350 (177)	2/350 (177)	2/350 (177)
	—	2/437 (225)	2/437 (225)	2/437 (225)	2/437 (225)	—
Glass Transition Temp. (Tg), °F (°C)	273 (134)	360 (182)	428 (220)	421 (216)	410 (210)	360 (182)
Coefficient of Linear Thermal Expansion (CLTE), ppm/°F (ppm/°C)	137 (76)	131 (73)	124 (69)	149 (83)	131 (73)	133 (74)
Dynamic Mechanical Analysis (DMA)						
E' onset, °F (°C)	280 (138)	351 (177)	417 (214)	—	406 (208)	360 (182)
E" onset, °F (°C)	297 (147)	365 (185)	451 (233)	—	433 (223)	374 (190)
Tan delta, °F (°C)	311 (155)	379 (193)	477 (247)	484 (251)	239 (239)	387 (197)
Water Absorption, two-week water boil, %	2.40	2.24	2.47	2.10	2.44	2.35
Flexural Strength, ksi (MPa)	15.9 (110)	15.6 (108)	16.0 (110)	13.0 (90)	16.6 (114)	15.7 (108)
Flexural Modulus, ksi (MPa)	438 (3,020)	431 (2,972)	444 (3,061)	420 (2,896)	451 (3,110)	383 (2,641)
Flexural Strain at Yield, %	6.8	7.1	6.1	4.1	6.9	6.9
Cured Density, g/ml	1.172	1.199	1.210	—	1.198	1.140

[1] Typical property values, not to be construed as specifications.

Table 9 – Typical Physical Properties of Resin Systems Cured with DDS[1]

Resin	D.E.N. 431	D.E.N. 438	D.E.N. 439
Epoxide Equivalent Weight (EEW) Range	172-179	176-181	191-210
Curing Agent	DDS	DDS	DDS
Mix Ratio of Curing Agent, phr	35.5	35.5	31.5
Cure Schedule, hours at °F (°C)	3/350 (177)	3/350 (177)	3/350 (177)
	2/482 (250)	2/482 (250)	2/482 (250)
Glass Transition Temp. (Tg), °F (°C)	414 (212)	491 (255)	450 (232)
Coefficient of Linear Thermal Expansion (CLTE), ppm/°F (ppm/°C)	—	124 (69)	140 (78)
Dynamic Mechanical Analysis (DMA)			
E' onset, °F (°C)	361 (183)	433 (223)	—
E" onset, °F (°C)	390 (199)	455 (235)	—
Tan delta, °F (°C)	432 (222)	523 (273)	527 (275)
Water Absorption, two-week water boil, %	3.40	4.10	—
Flexural Strength, ksi (MPa)	20.6 (142)	19.6 (135)	17.9 (123)
Flexural Modulus, ksi (MPa)	470 (3,241)	480 (3,310)	490 (3,378)
Flexural Strain at Yield, %	7.1	7.0	7.0

[1] Typical property values, not to be construed as specifications.

Table 10 – Typical Physical Properties of Resin Systems Cured with DACH[1]

Resin	D.E.R. 354	D.E.R. 332/ D.E.R. 354 (75:25)	D.E.R. 383
Epoxide Equivalent Weight (EEW) Range	158-175	168-176	176-185
Curing Agent	DACH	DACH	DACH
Mix Ratio of Curing Agent, phr	17.6	17.2	17.2
Cure Schedule, hours at °F (°C)	1/176 (80)	1/176 (80)	1/176 (80)
	2/350 (177)	2/350 (177)	2/350 (177)
Glass Transition Temp. (Tg), °F (°C)	270 (132)	356 (180)	352 (178)
Coefficient of Linear Thermal Expansion (CLTE), ppm/°F (ppm/°C)	128 (71)	133 (74)	119 (66)
Dynamic Mechanical Analysis (DMA)			
E' onset, °F (°C)	262 (128)	360 (182)	342 (172)
E'' onset, °F (°C)	275 (135)	369 (187)	369 (187)
Tan delta, °F (°C)	297 (147)	379 (193)	378 (192)
Water Absorption, two-week water boil, %	1.83	2.04	1.93
Flexural Strength, ksi (MPa)	18.7 (129)	17.3 (119)	17.7 (122)
Flexural Modulus, ksi (MPa)	494 (3,406)	436 (3,006)	420 (2,896)
Flexural Strain at Yield, %	7.1	7.1	7.7
Cured Density, g/ml	1.193	1.142	1.172

[1] Typical property values, not to be construed as specifications.

ELECTRICAL PROPERTIES

Table 11 lists typical electrical properties of cured epoxy novolac resin systems formulated with DOW Epoxy Novolac resins and appropriate curing agents.

CHEMICAL RESISTANCE

Tables 12 and 13 show the results of chemical resistance testing conducted on various cured formulations of both DOW Epoxy Novolac resins and bisphenol-A based D.E.R. 331 liquid epoxy resins. Test specimens (3" x 1" x 0.125") were submerged in acids, bases and organic solvents for 120 days at 73°F (23°C) ± 2. The specimens were weighed at intervals of 7, 28 and 120 days with any changes in weight recorded.

The high functionality of D.E.N. 438 resin results in a cured system with a highly crosslinked three-dimensional structure that is resistant to chemical and solvent attack. With a few exceptions, epoxy novolacs show similar chemical resistance results to bisphenol-A based resins in aqueous solutions. In addition, epoxy novolacs are generally superior in resistance to organic solvents.

Catalytic cures, which promote the epoxy-to-epoxy reaction and its resultant stable ether linkage, typically provide the best all around chemical and solvent resistance. If conditions of cure, formulation or performance dictate the use of other curing agents, the preferred alternatives are anhydrides for acid conditions and amines for alkaline exposure.

Table 11 – Typical Electrical Properties of Cured Resin Systems[1]

Resin	D.E.R. 354	D.E.N. 431	D.E.N. 438	D.E.N. 439	D.E.R. 354	D.E.N. 431	D.E.N. 438	D.E.N. 439	D.E.N. 431	D.E.N. 438
Curing Agent	MTHPA	MTHPA	MTHPA	MTHPA	DETDA	DETDA	DETDA	DETDA	DDS	DDS
Dielectric Constant										
Frequency, Hz										
1.00E+03	3.37	3.40	3.45	3.46	4.38	4.38	4.50	4.50	4.50	4.86
1.00E+04	3.34	3.36	3.40	3.42	4.29	4.27	4.38	4.40	4.36	4.68
5.00E+04	3.30	3.32	3.35	3.36	4.17	4.13	4.23	4.25	4.23	4.51
1.00E+05	3.29	3.30	3.34	3.35	4.12	4.08	4.17	4.20	4.18	4.44
Dissipation Factor										
Frequency, Hz										
1.00E+03	0.0052	0.0064	0.0076	0.0076	0.0093	0.0120	0.0128	0.0114	0.0167	0.0207
1.00E+04	0.0092	0.0109	0.0125	0.0129	0.0221	0.0261	0.0272	0.0254	0.0259	0.0310
5.00E+04	0.0135	0.0155	0.0172	0.0176	0.0323	0.0350	0.0361	0.0348	0.0289	0.0365
1.00E+05	0.0154	0.0171	0.0189	0.0193	0.0349	0.0369	0.0380	0.0369	0.0289	0.0370

[1] Typical properties; not to be construed as specifications.

Table 12 – Typical Chemical and Solvent Resistance of Resin Systems Cured with NMA[1]

Resin	D.E.N. 431			D.E.N. 438			D.E.N. 439			D.E.R. 331		
Curing Agent	NMA			NMA			NMA			NMA		
	% Weight Change			% Weight Change			% Weight Change			% Weight Change		
Days	7	28	120	7	28	120	7	28	120	7	28	120
Sulfuric Acid, 30%	0.32	0.52	0.80	0.44	0.68	0.77	0.33	0.62	0.80	0.33	0.83	0.55
Hydrochloric Acid, 36%	—	—	—	0.24	0.60	1.50	0.26	0.49	1.09	0.32	0.56	1.36
Nitric Acid, 40%	—	—	—	0.59	1.37	3.11	0.38	1.00	2.05	0.40	1.10	1.70
Ammonium Hydroxide, 28%	—	—	—	0.77	1.31	1.92	0.72	1.46	2.40	0.67	1.24	1.84
Acetic Acid, 25%	—	—	—	0.57	0.93	1.12	0.58	0.91	1.28	0.46	0.73	0.90
Acetone	1.10	3.77	9.00	0.24	1.15	5.07	0.17	0.66	3.43	4.80	13.00	22.30
Toluene	—	—	—	0.07	0.14	0.32	0.00	0.02	0.28	0.06	0.09	0.28
Sodium Hydroxide, 10%	—	—	—	0.42	0.64	0.64	0.45	0.82	1.13	0.37	0.51	0.50
JP4 Fuel	0.02	0.04	0.14	0.00	0.01	0.12	0.01	0.04	0.15	0.02	0.02	0.16
Distilled Water	0.44	0.79	1.15	0.55	0.97	1.13	0.52	0.96	1.38	0.52	0.82	0.87

Table 13 – Typical Chemical and Solvent Resistance of Resin Systems Cured with $BF_3 \cdot MEA$[1]

Resin	D.E.N. 438			D.E.N. 439			D.E.R. 331		
Curing Agent	$BF_3 \cdot MEA$			$BF_3 \cdot MEA$			$BF_3 \cdot MEA$		
	% Weight Change			% Weight Change			% Weight Change		
Days	7	28	120	7	28	120	7	28	120
Sulfuric Acid, 30%	0.40	0.91	1.58	0.40	0.82	1.53	0.40	1.10	1.20
Hydrochloric Acid, 36%	0.15	0.45	1.07	—	—	—	0.26	0.49	1.17
Nitric Acid, 40%	0.12	1.01	2.22	—	—	—	0.45	1.20	1.50
Ammonium Hydroxide, 28%	0.64	1.35	2.57	—	—	—	0.57	1.22	2.17
Acetic Acid, 25%	0.63	1.32	2.10	—	—	—	0.53	1.03	1.65
Acetone	-0.04	0.00	0.20	0.05	0.14	0.64	0.43	1.20	3.20
Toluene	0.10	0.20	0.62	—	—	—	0.09	0.17	0.26
Sodium Hydroxide, 10%	0.53	1.13	1.93	—	—	—	0.50	0.94	1.46
JP4 Fuel	0.02	0.05	0.26	0.03	0.08	0.31	0.02	0.06	0.23
Distilled Water	0.60	1.43	2.24	0.57	1.18	2.25	0.62	1.20	1.80

[1] Laboratory test data, not to be construed as specifications.

MECHANICAL PROPERTIES AT ELEVATED TEMPERATURES AND WHEN WET

Epoxy novolac resins retain good overall mechanical properties at elevated temperatures and when wet. Figure 10 shows flexural strengths ranging from room temperature to the glass transition temperature for selected resin systems. Figures 11 through 13 illustrate flexural modulus, tensile strength and tensile modulus performance under both wet and dry conditions at room and elevated temperatures.

Figure 10 – Flexural Strength at Elevated Temperatures[1]

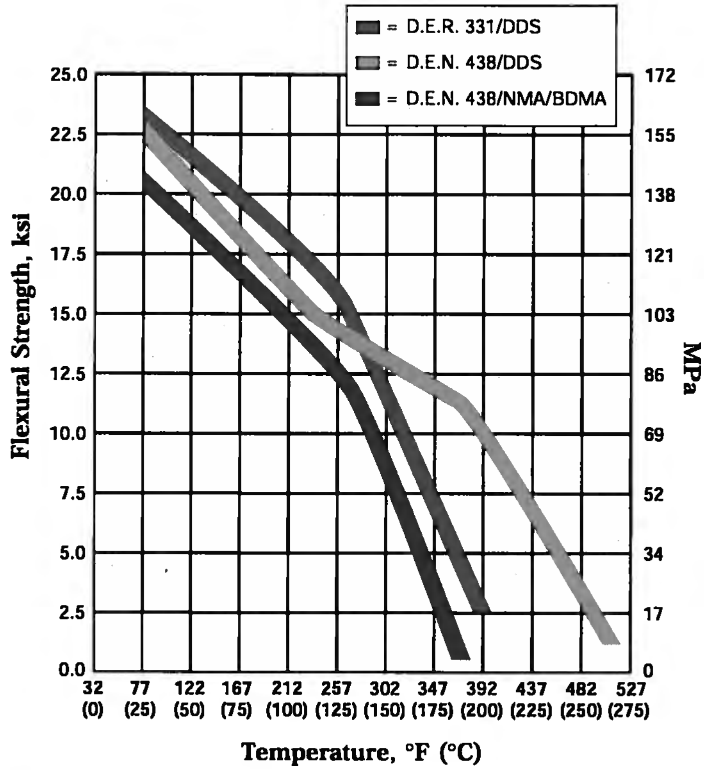
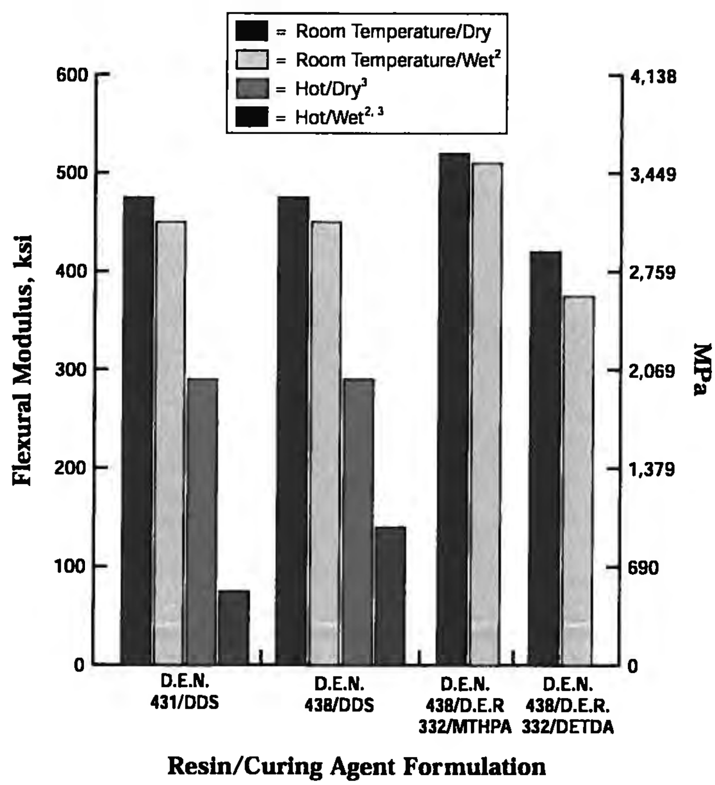
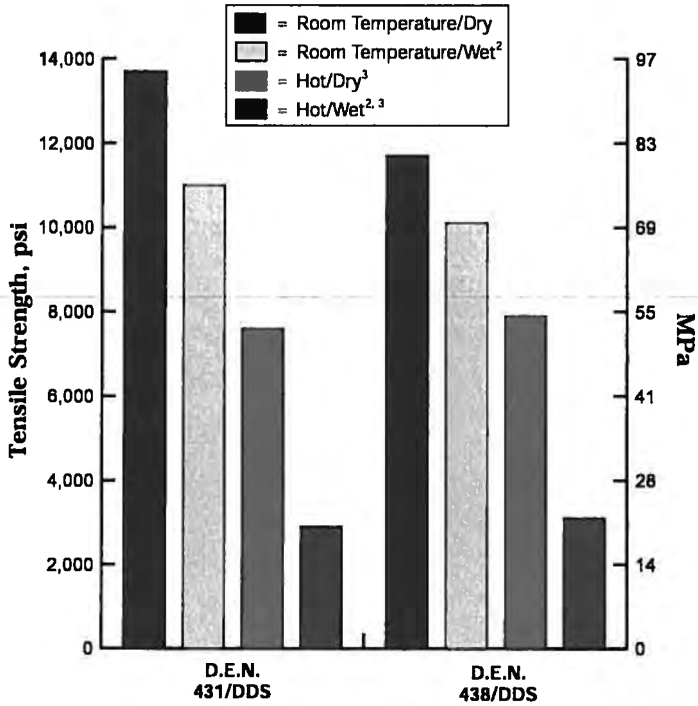


Figure 11 – Flexural Modulus Under Various Temperature/Moisture Conditions[1]



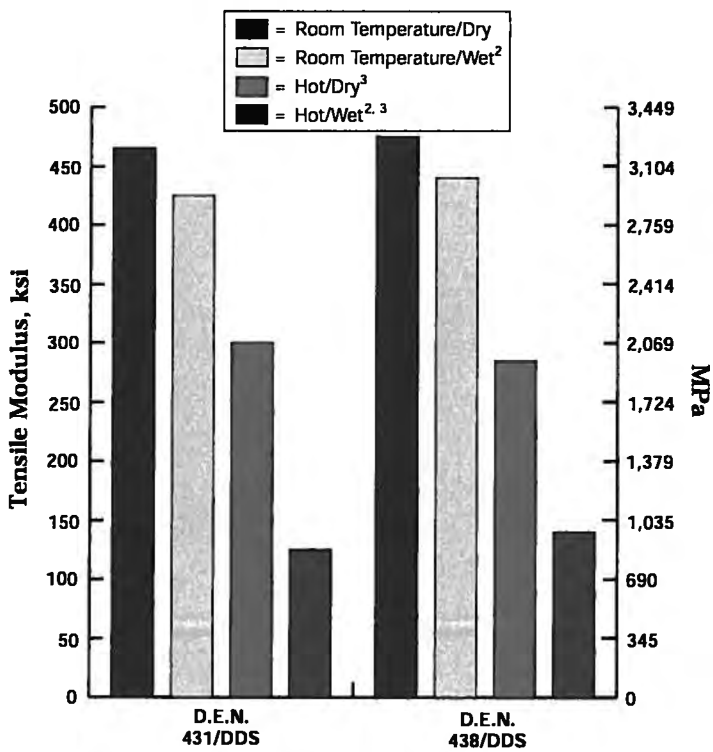
[1] Laboratory test data, not to be construed as specifications.
[2] Wet = Two-week water boil.
[3] Hot = 300°F (149°C).

Figure 12 – Tensile Strength Under Various Temperature/Moisture Conditions[1]



Resin/Curing Agent Formulation

Figure 13 – Tensile Modulus Under Various Temperature/Moisture Conditions[1]



Resin/Curing Agent Formulation

[1] Laboratory test data, not to be construed as specifications.
[2] Wet = Two-week water boil.
[3] Hot = 300°F (149°C).

ACCELERATED MOISTURE RESISTANCE

Table 14 shows the effects of exposure to high temperature and pressure on coupons formulated from D.E.N. 438 and D.E.R. 331 resins cured with various curing agents. The test specimens were subjected to 250°F (121°C) and 15 psi (0.103 MPa) for 500 hours in a steam generating autoclave.

In virtually all cases, the D.E.N. 438 epoxy novolac resin maintained higher post-test values for flexural strength, flexural modulus and glass transition temperature. For example, in coupons cured with BF_3•MEA, D.E.N. 438 resin retained nearly 90 percent of its pre-test flexural strength, while the bisphenol-A based D.E.R. 331 resin retained only 18 percent due to some stress cracking in the samples. The one exception was the flexural strength of coupons cured with DDS.

Table 14 – Moisture Resistance, 500 Hours Exposure at 250°F (121°C) and 15 psi (0.103 MPa)[1]

Resin	D.E.N. 438	D.E.R. 331	D.E.N. 438	D.E.R. 331	D.E.N. 438	D.E.R. 331
Curing Agent	NMA[2]	NMA[2]	DDS	DDS	BF_3• MEA	BF_3• MEA
% Weight Increase @ 500 Hours	2.21	3.68	4.19	4.34	3.37	2.70
Flexural Strength, ksi (MPa)						
Pre-exposure	20.7 (143)	23.1 (159)	21.2 (146)	23.4 (161)	16.4 (113)	18.1 (125)
Post-exposure	13.7 (95)	16.9 (48)[3]	13.5 (93)	16.4 (113)	14.5 (100)	3.3 (23)[3]
% Retention	66	30	64	70	88	18
Flexural Modulus, ksi (MPa)						
Pre-exposure	542 (3,738)	504 (3,476)	549 (3,786)	493 (3,400)	559 (3,855)	490 (3,380)
Post-exposure	491 (3,386)	477 (3,290)[3]	461 (3,179)	437 (3,014)	506 (3,490)	405 (2,793)[3]
% Retention	91	95	84	89	90	83
Glass Transition Temp. (Tg), via DSC						
Pre-exposure, °F (°C)	383 (195)	316 (158)	417 (214)	340 (171)	415 (213)	327 (164)
Post-exposure, °F (°C)	322 (161)	226 (108)	318 (159)	277 (136)	318 (159)	261 (127)
% Retention	82	68	74	80	75	77

1 Laboratory test data, not to be construed as specifications.
2 Plus 1.5 parts BDMA.
3 Sample exhibited some cracking.

Safety, Hazards and Handling Considerations

For Environmental, Health, Safety and Handling Considerations of Dow Products, consult the technical brochures "Storage and Handling of DOW Epoxy Resins" (Form No. 296-00312) and "Storage and Handling of DOW Epoxy Curing Agents" (Form No. 296-01331), as well as the respective product Material Safety Data Sheets (MSDS). For Dow and non-Dow products always request, read and understand safety, health, environmental and handling information before handling any of these materials. Safety information on solvents, diluents, modifiers, curing agents and other additives for epoxy formulations are equally important. Contact your suppliers for information on these materials along with specific safe handling recommendations.

For more information on DOW Epoxy Novolac resins, contact your Dow sales representative, or call 1-800-441-4369 or 1-517-832-1426. In Mexico, call 95-800-441-4369.

ABBREVIATION INDEX

A – Acetone

BDMA – Benzyldimethylamine

BF_3 • MEA – Boron Trifluoride • Monoethylamine

DACH – Diaminocyclohexane

DDS – Diamino Diphenyl Sulfone

DETDA – Diethyltoluene-Diamine

DSC – Differential Scanning Calorimeter

EEW – Epoxide Equivalent Weight

EK – Methyl Ethyl Ketone

HDT – Heat Distortion Temperature

MK – Methyl Isobutyl Ketone

MTHPA – Methyl Tetrahydrophthalic Anhydride

NMA – Nadic Methyl Anhydride

phr – Parts Per Hundred Parts Resin

PMCC – Pensky-Marten Closed Cup

TGA – Thermogravimetric Analysis

TMA – Thermomechanical Analysis

Tg – Glass Transition Temperature

PRODUCT STEWARDSHIP

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