

CNSL Based Epoxy Diluents and Modifiers

Cardolite Corporation
July 2020



Contents

1. CNSL (Cashew Nutshell Liquid)

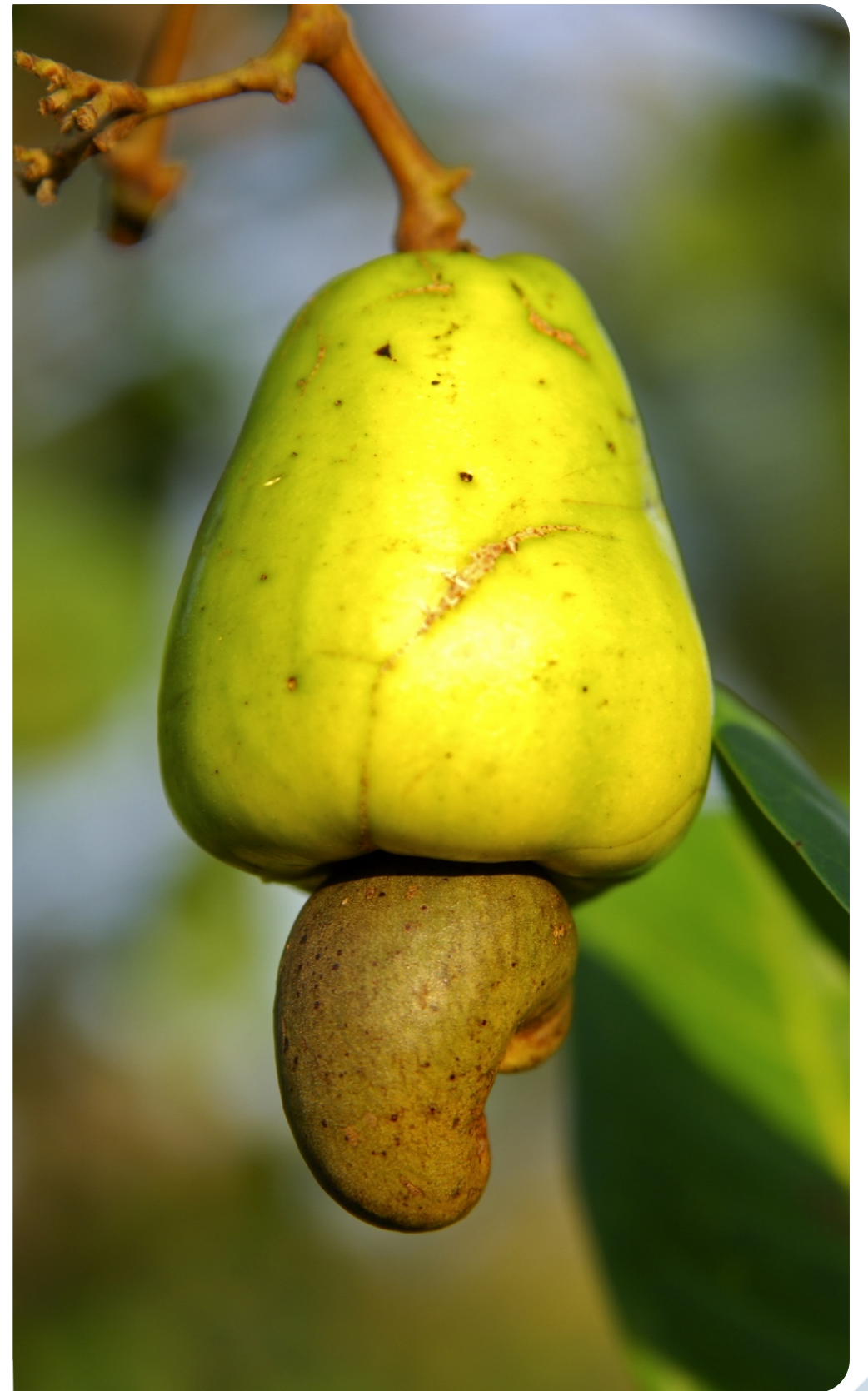
Technology

2. Epoxy diluents

- NC-513/UL-513/LITE 513E
- Cardanols
- Hydrocarbons

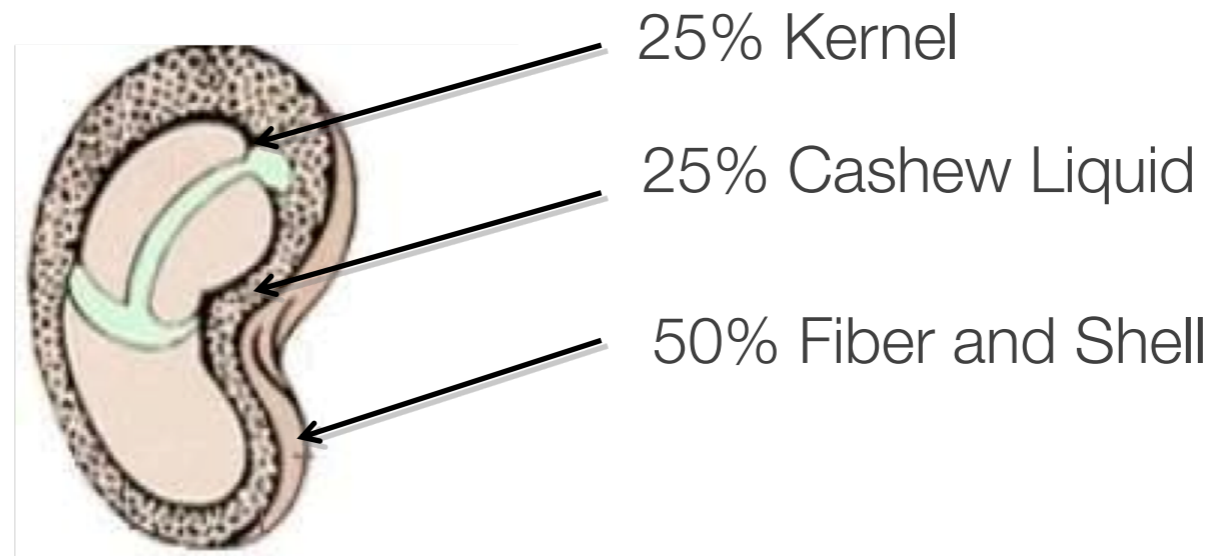
3. Epoxy modifiers

- NC-514/NC-514S/GX-2551
- NC-547

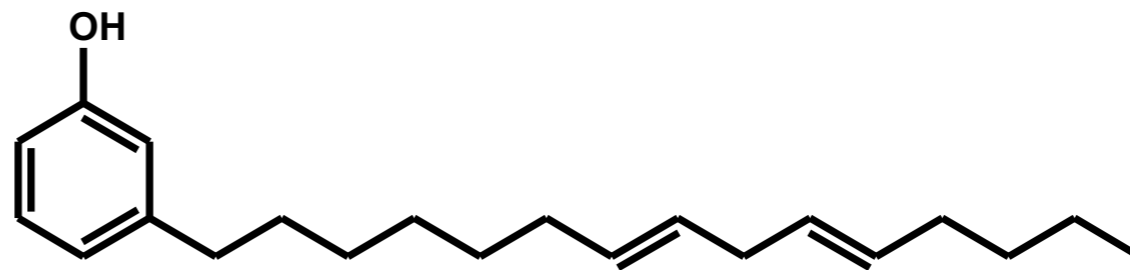


Cashew Liquid Technology

- CNSL is approximately 25% of the cashew fruit by weight.



- The primary component of CNSL is cardanol, a natural phenolic compound with a long unsaturated fatty side chain.



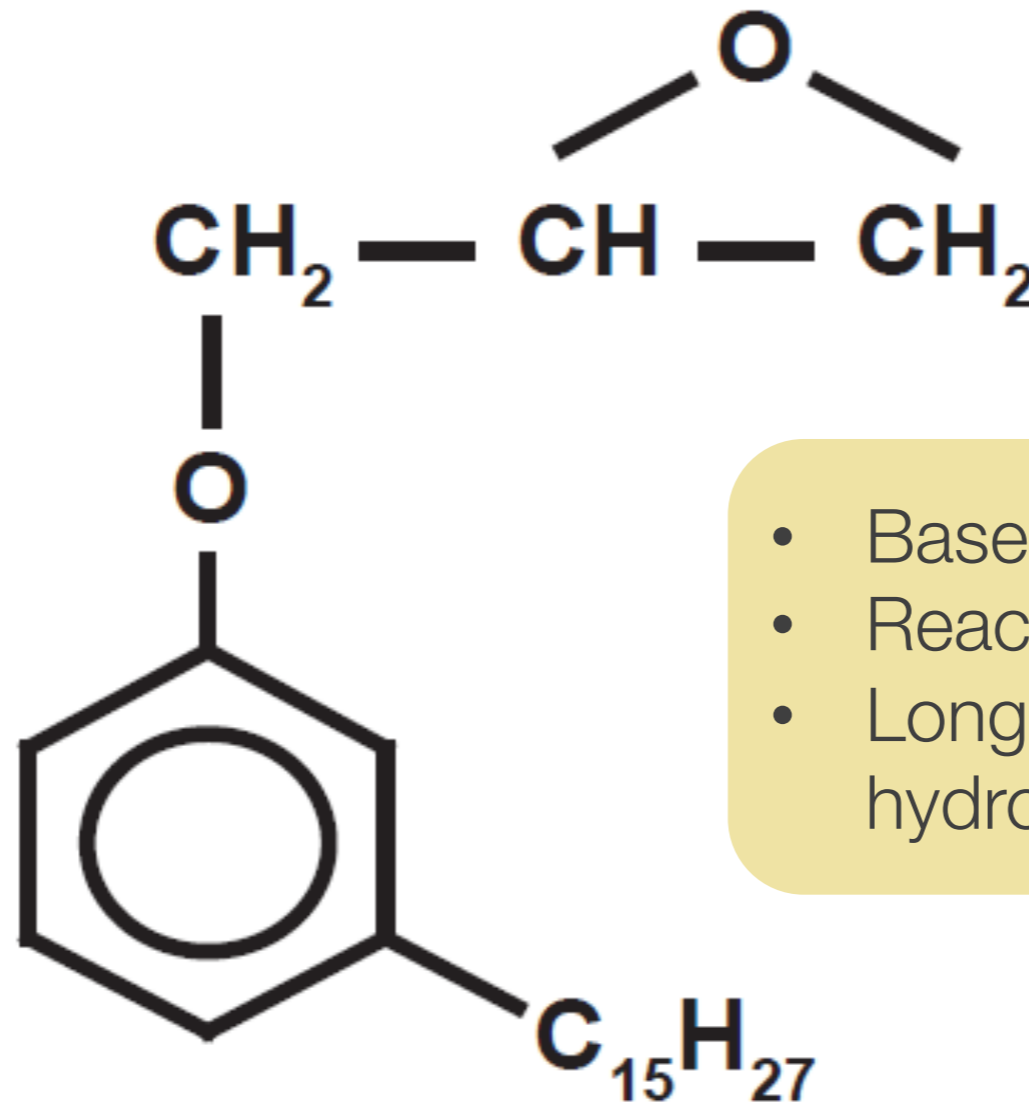
Cardolite

CNSL Epoxy Diluents: NC-513 Grade



Cardolite

NC-513
Ultra LITE 513
LITE 513E



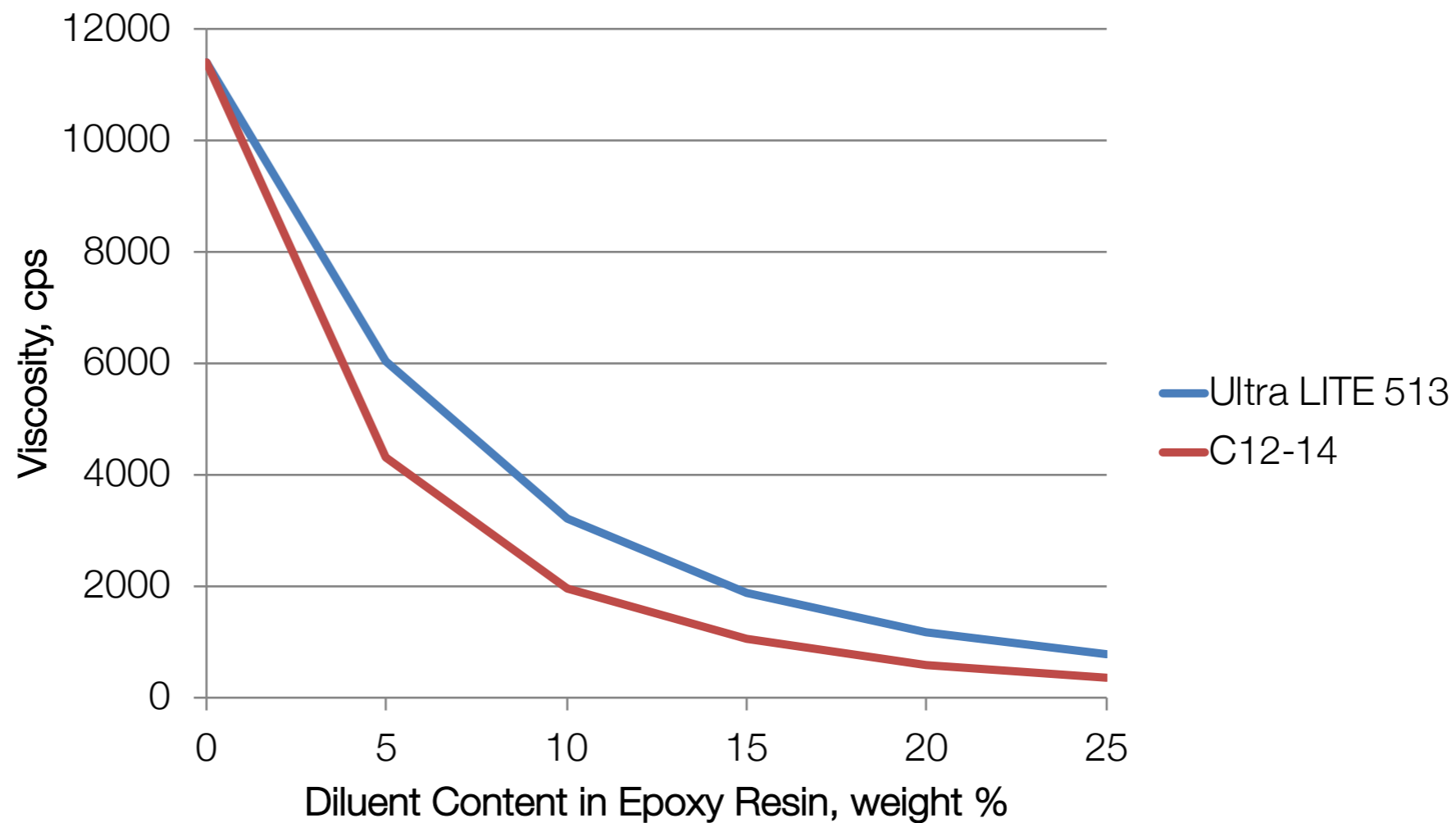
- Based on renewable CNSL
- Reactive
- Long aliphatic chain provides hydrophobicity and flexibility

Product Family Structure

Product	NC-513	LITE 513E	Ultra LITE 513
Color (Gardner)	11	4	1
Viscosity at 25°C (cps)	40-70	20-40	20-35
EEW(g/eq)	425-575	360-410	350-425
Total chloride (%)	≤2	≤0.1	≤0.5

- Ultra LITE 513 has much lower viscosity than NC-513 and Gardner color 1
- LITE 513E has low total chloride and halogen content, ≤1000ppm

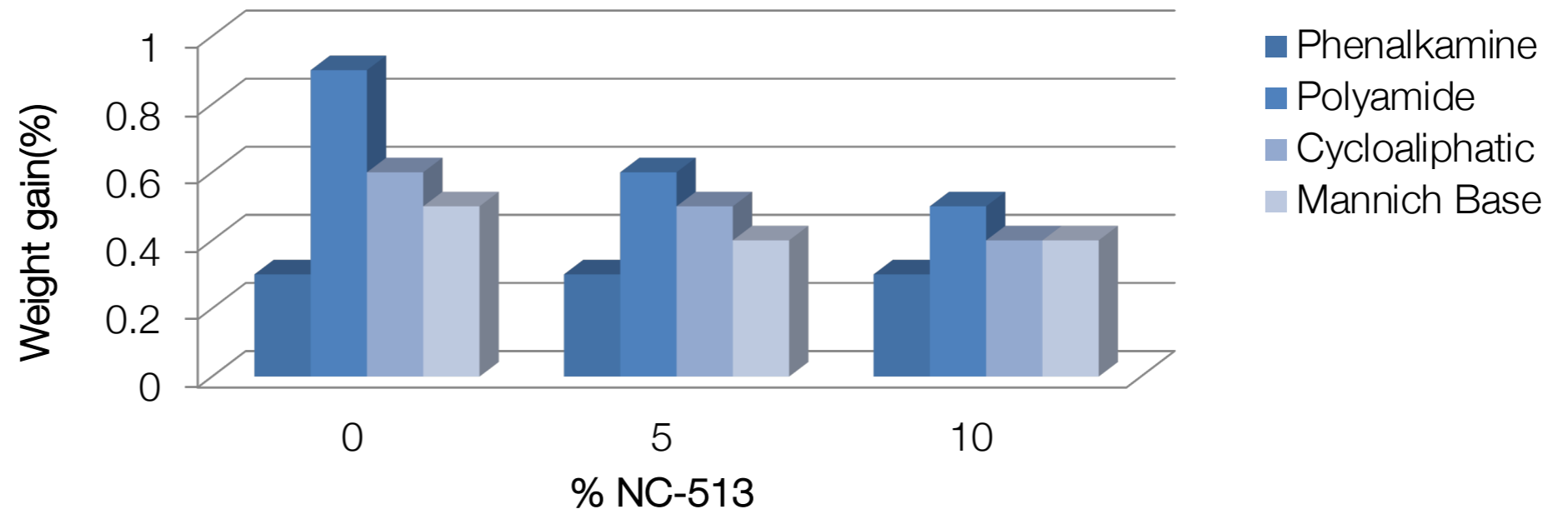
NC-513 Grade



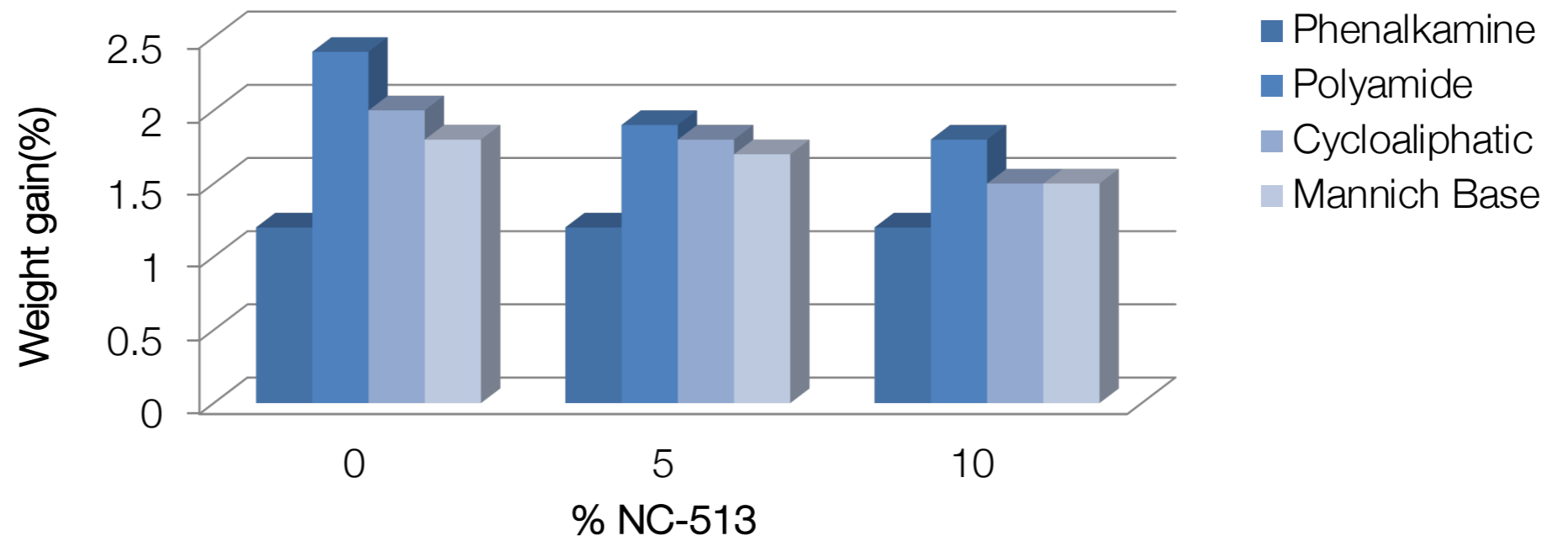
Ultra LITE 513 shows good dilution effect, close to C₁₂-C₁₄ glycidyl ether type diluents at use levels > 10%.

Dilution Curve

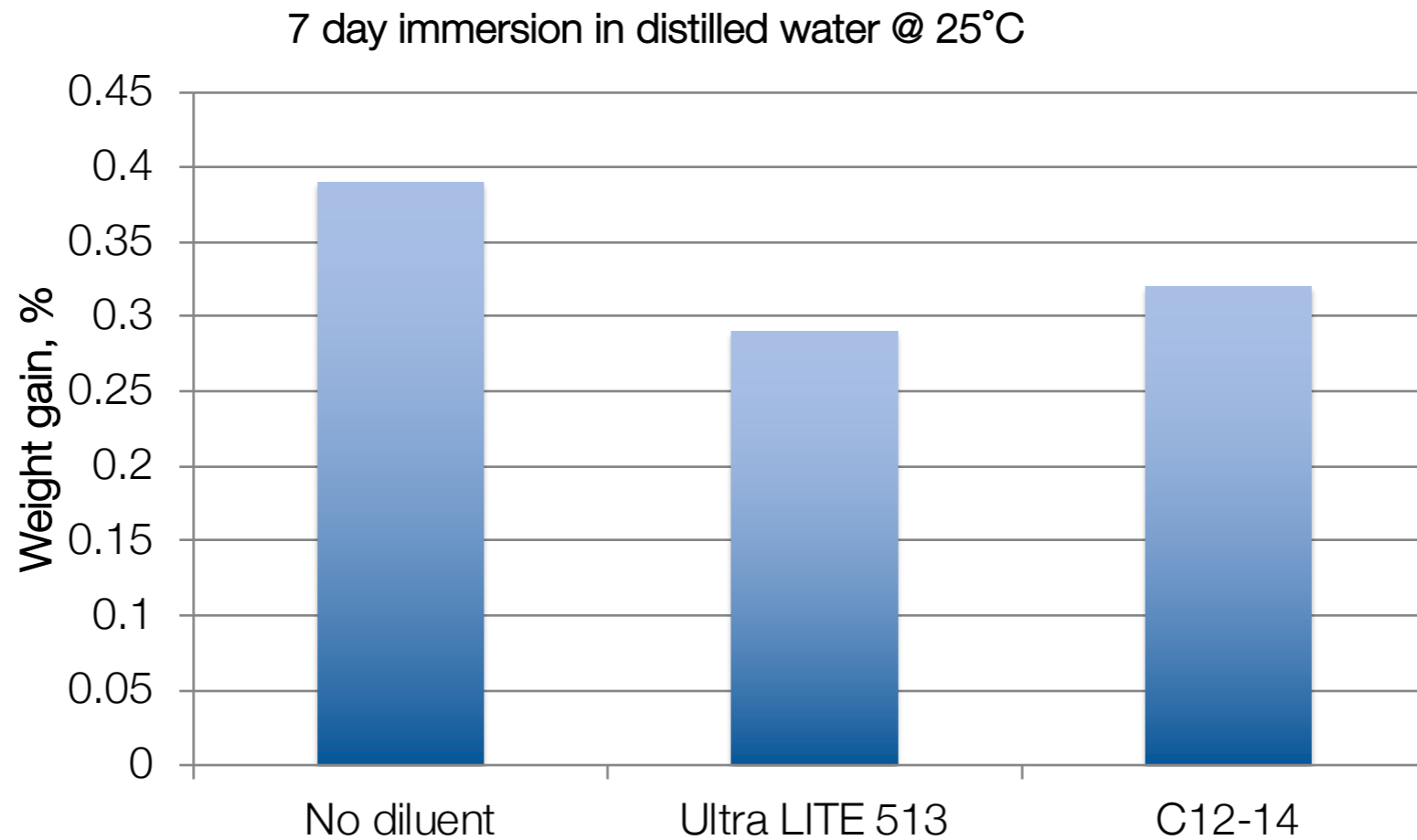
25°C water resistance



65°C water resistance



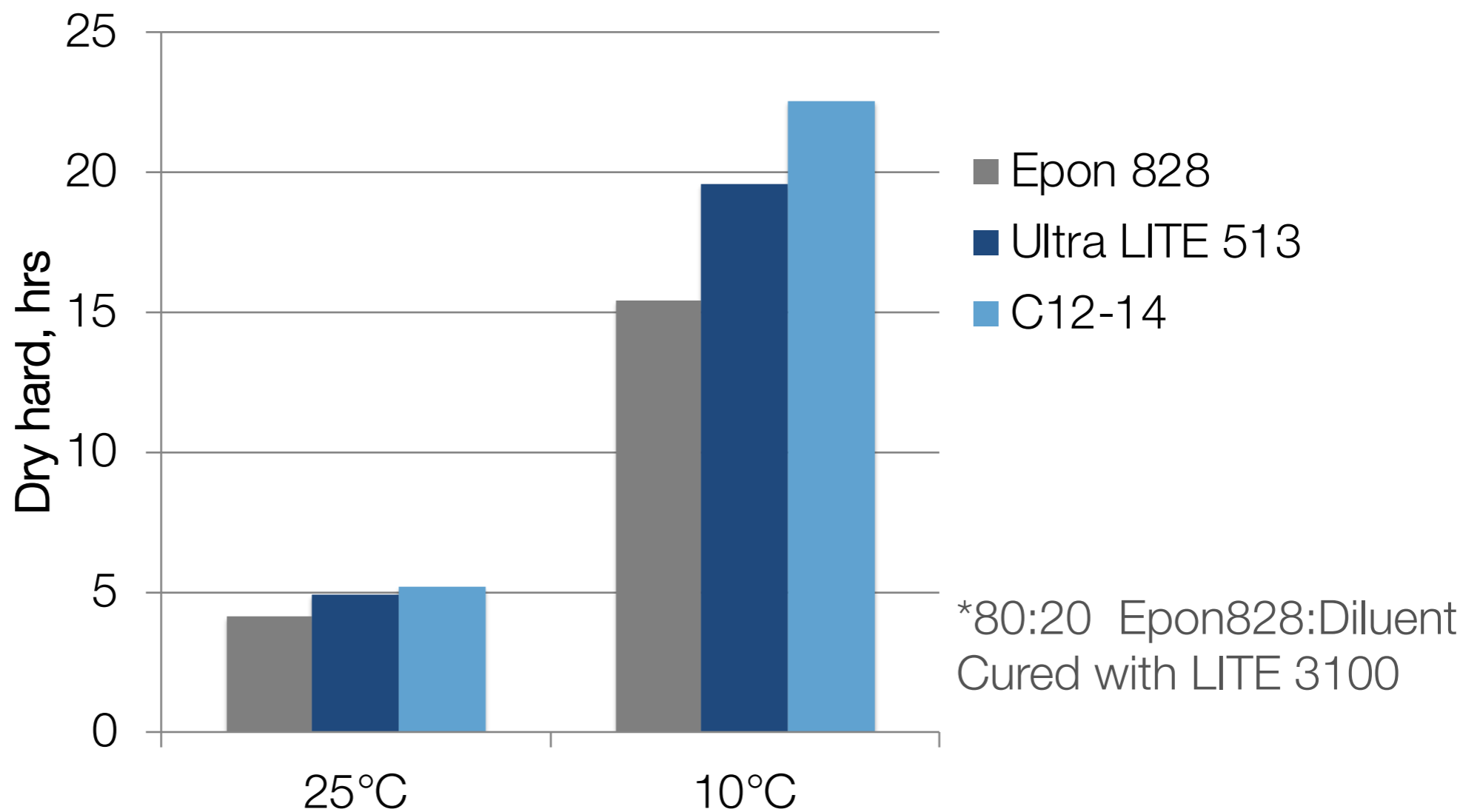
Improved Water Resistance



- Ultra LITE 513 can improve water resistance of epoxy systems.
- Ultra LITE 513 shows better performance than C₁₂-C₁₄ glycidyl ether type diluent.

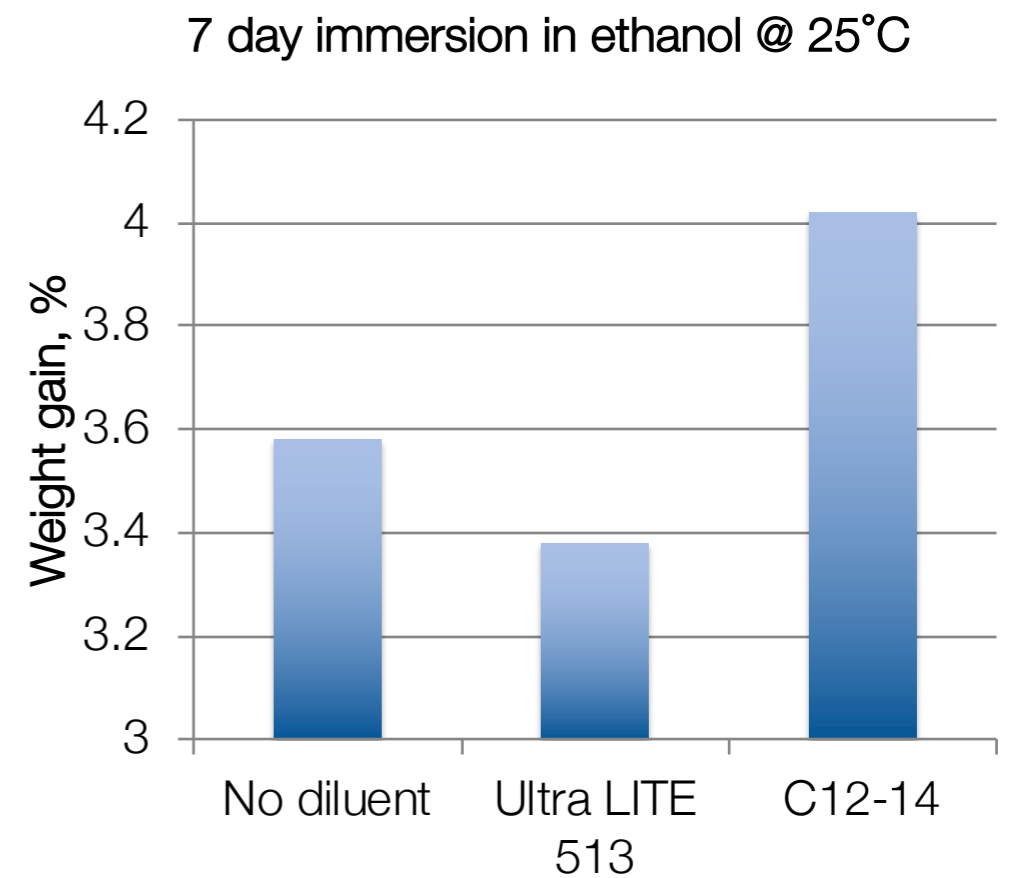
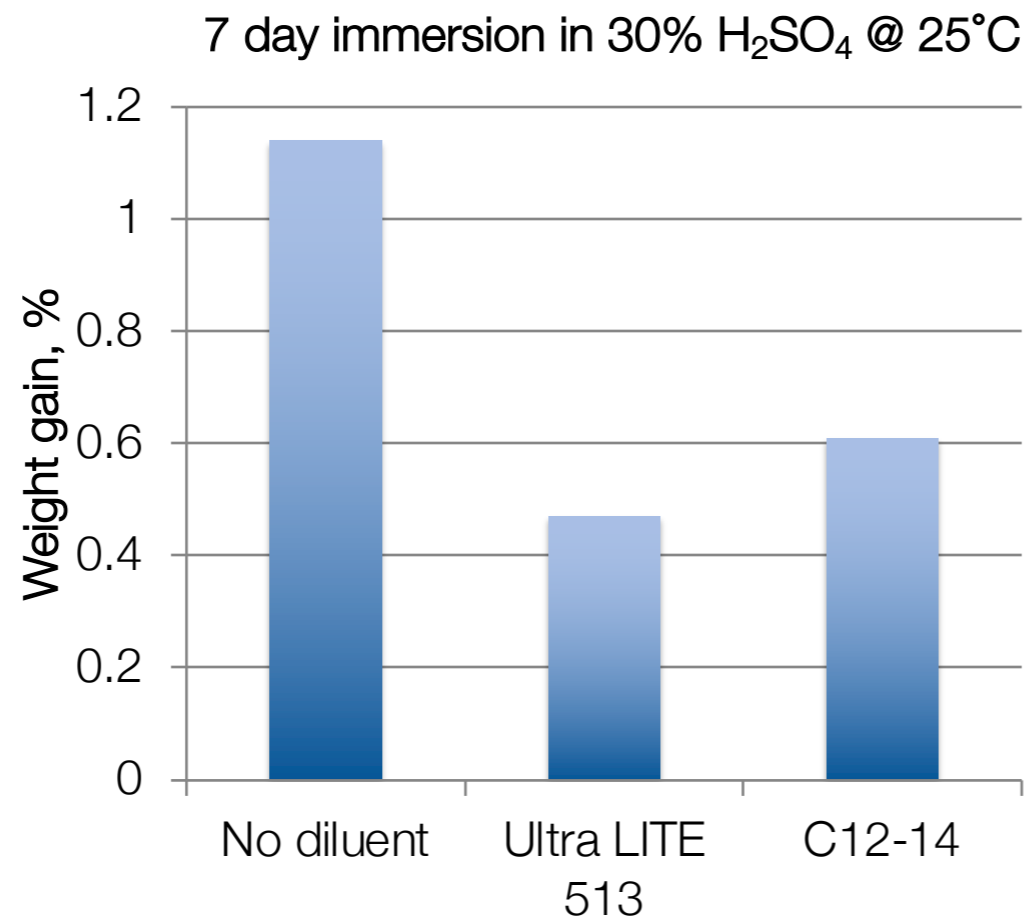
*80:20 Epon828:Diluent
Cured with LITE 3100

Water Resistance



Ultra LITE 513 shows faster cure time than C₁₂-C₁₄ glycidyl ether type diluent at room and low temperatures.

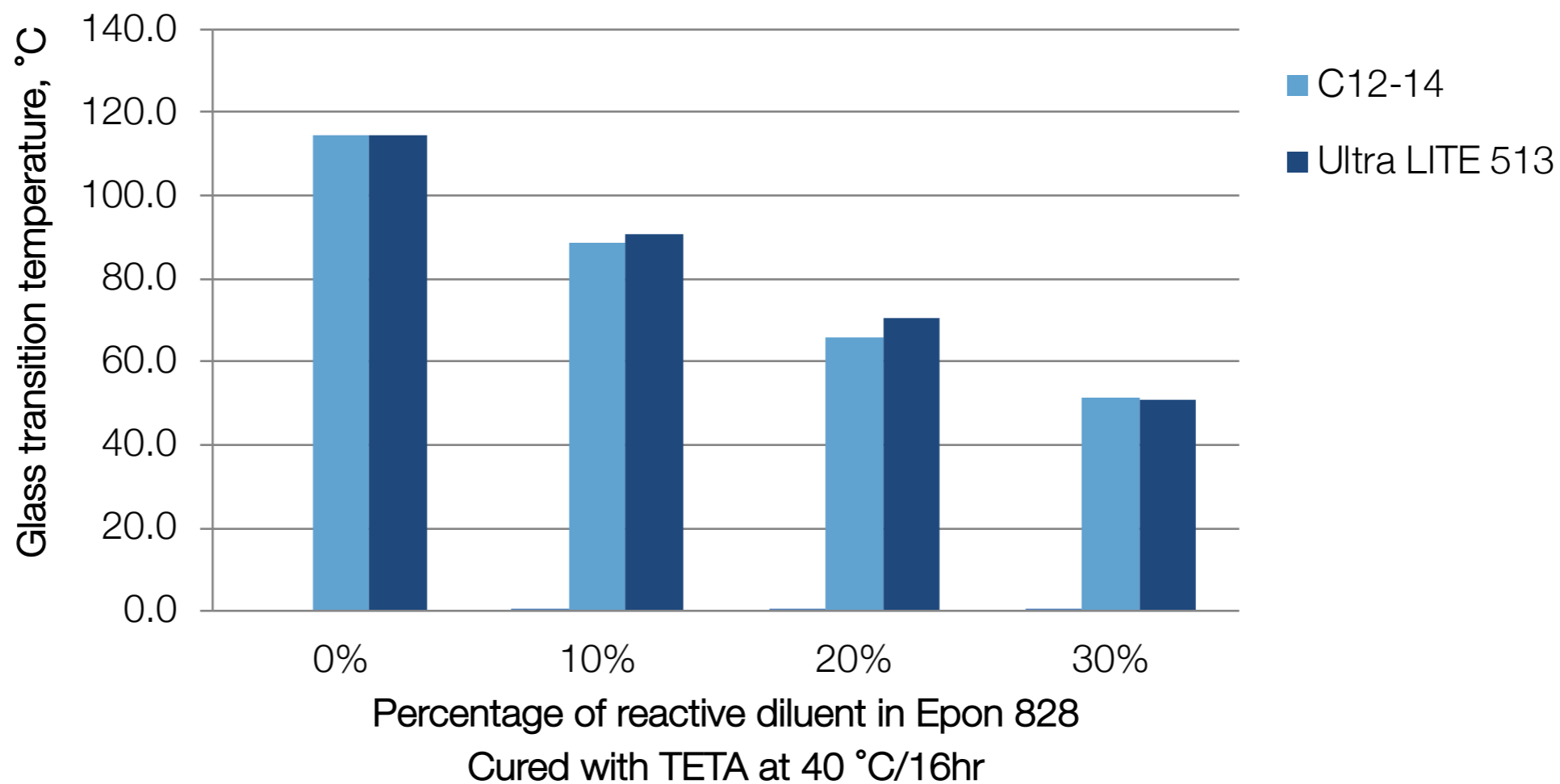
Cure time



- Ultra LITE 513 can improve sulfuric acid and ethanol resistance of epoxy systems.
- Ultra LITE 513 shows better performance than C₁₂-C₁₄ glycidyl ether type diluent.

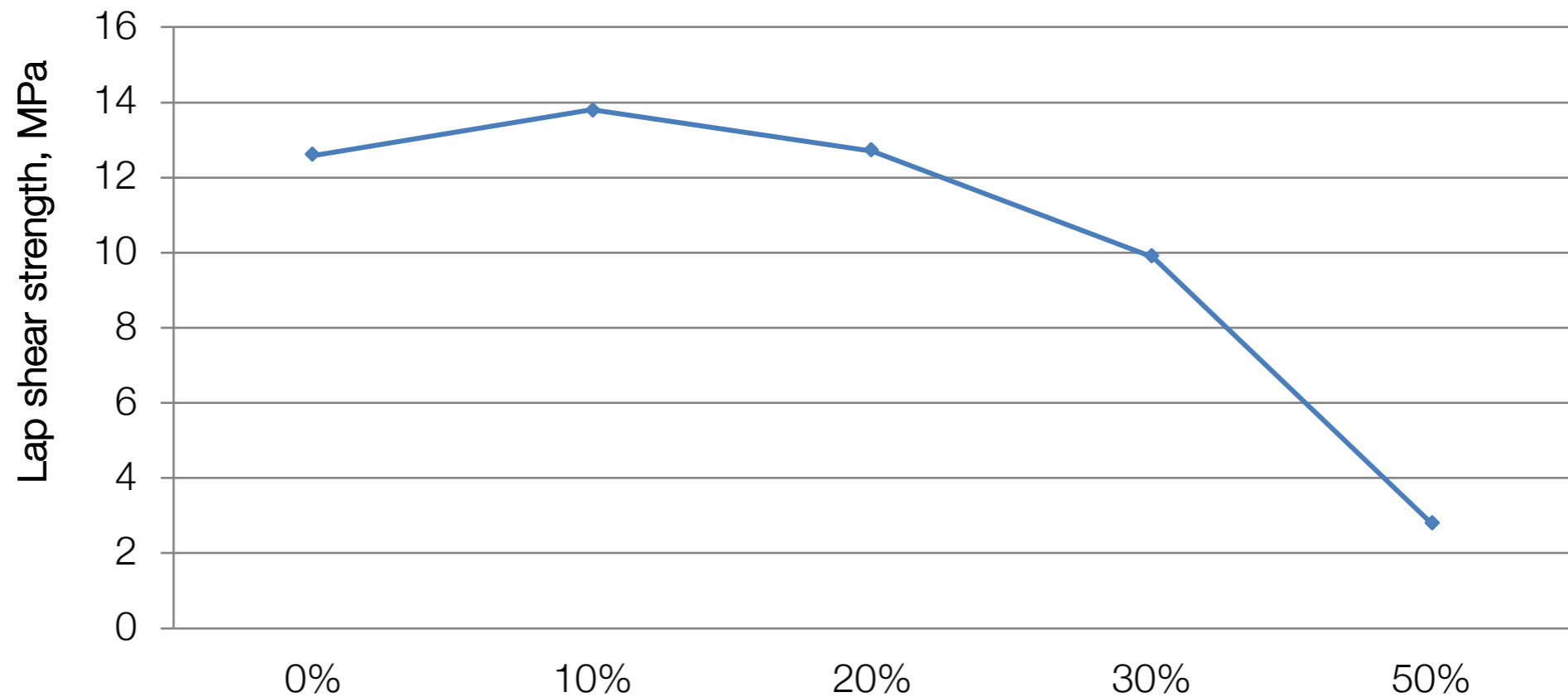
*80:20 Epon828:Diluent
Cured with LITE 3100

Chemical Resistance



Ultra LITE 513 shows slightly less Tg reduction vs. C₁₂-C₁₄ epoxy

Glass Transition Temperature Comparison

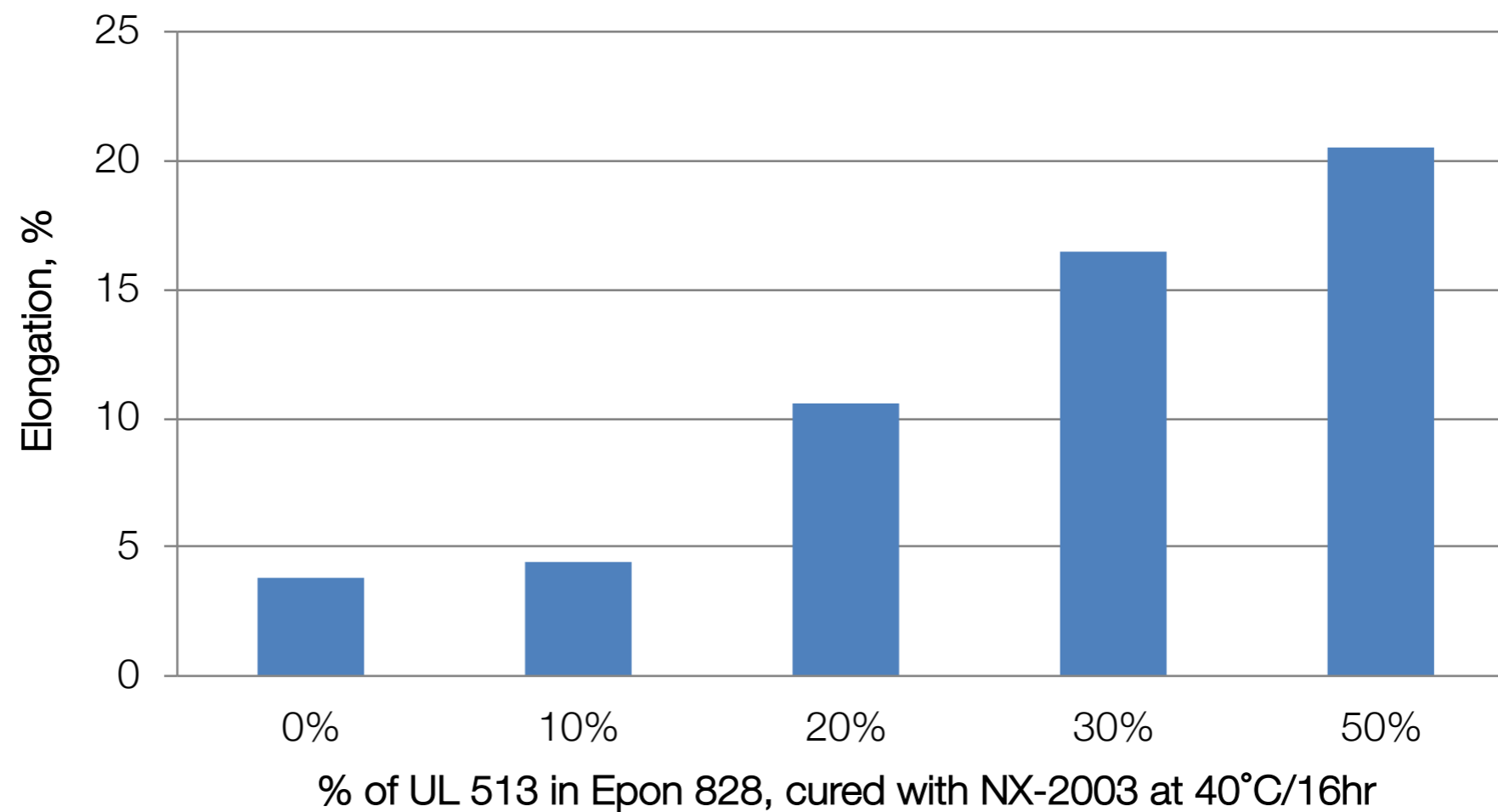


% of UL 513 blended in Epon 828, cured with NX-2003 at 40°C/16hr

*Lap shear substrate: non-abraded carbon steel

- Addition of Ultra LITE 513 to liquid epoxy helps to increase bond strength
- Maximum use-level of Ultra LITE 513 is 20% for improvement on bond strength

Lap Shear Strength: Ultra LITE 513

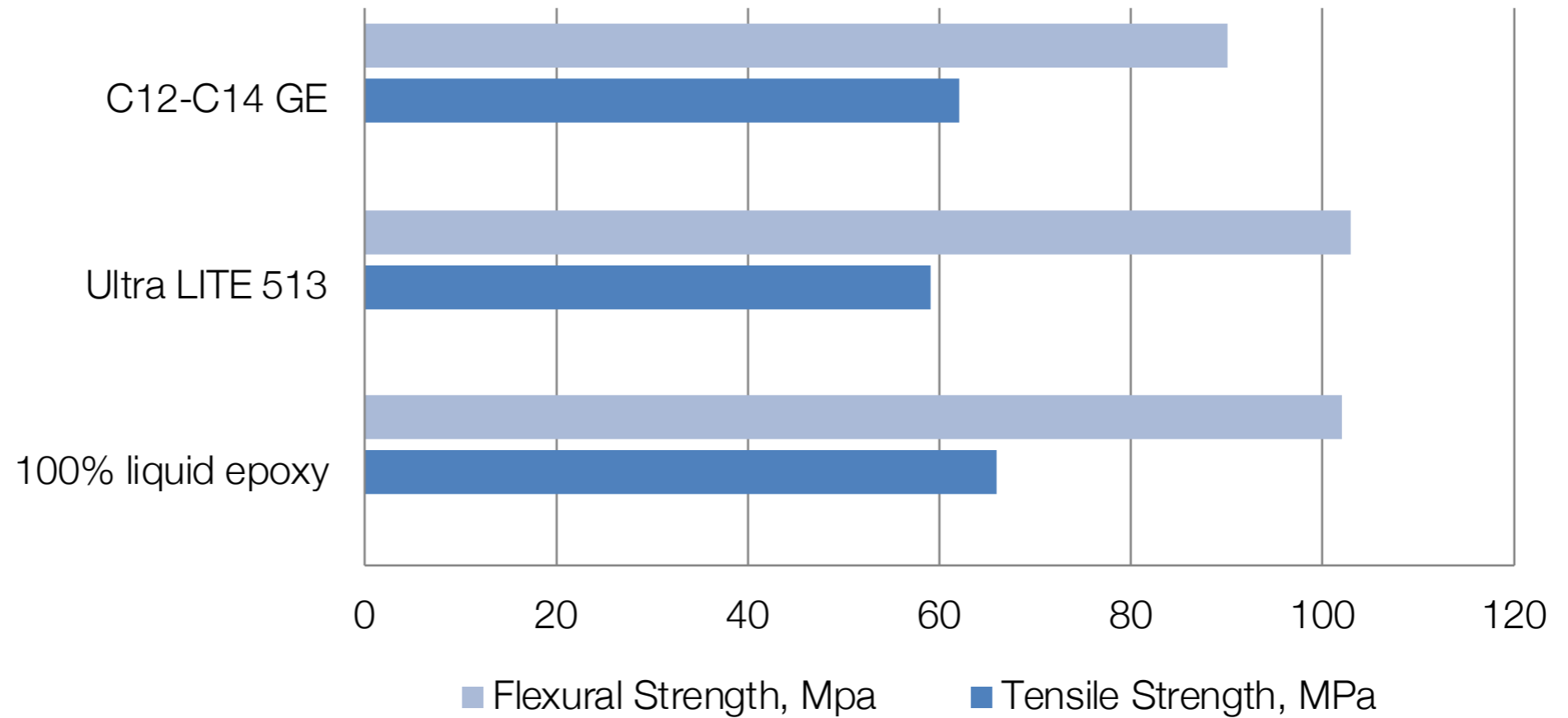


Addition of Ultra LITE 513 to liquid epoxy improves flexibility

Elongation: Ultra LITE 513



Impact of 5% diluent on mechanical properties of liquid epoxy (EEW=190) system cured with polyetheramine



Addition of Ultra LITE 513 shows excellent flexural strength

Mechanical Strength



NC-513/Ultra LITE 513/ LITE 513E

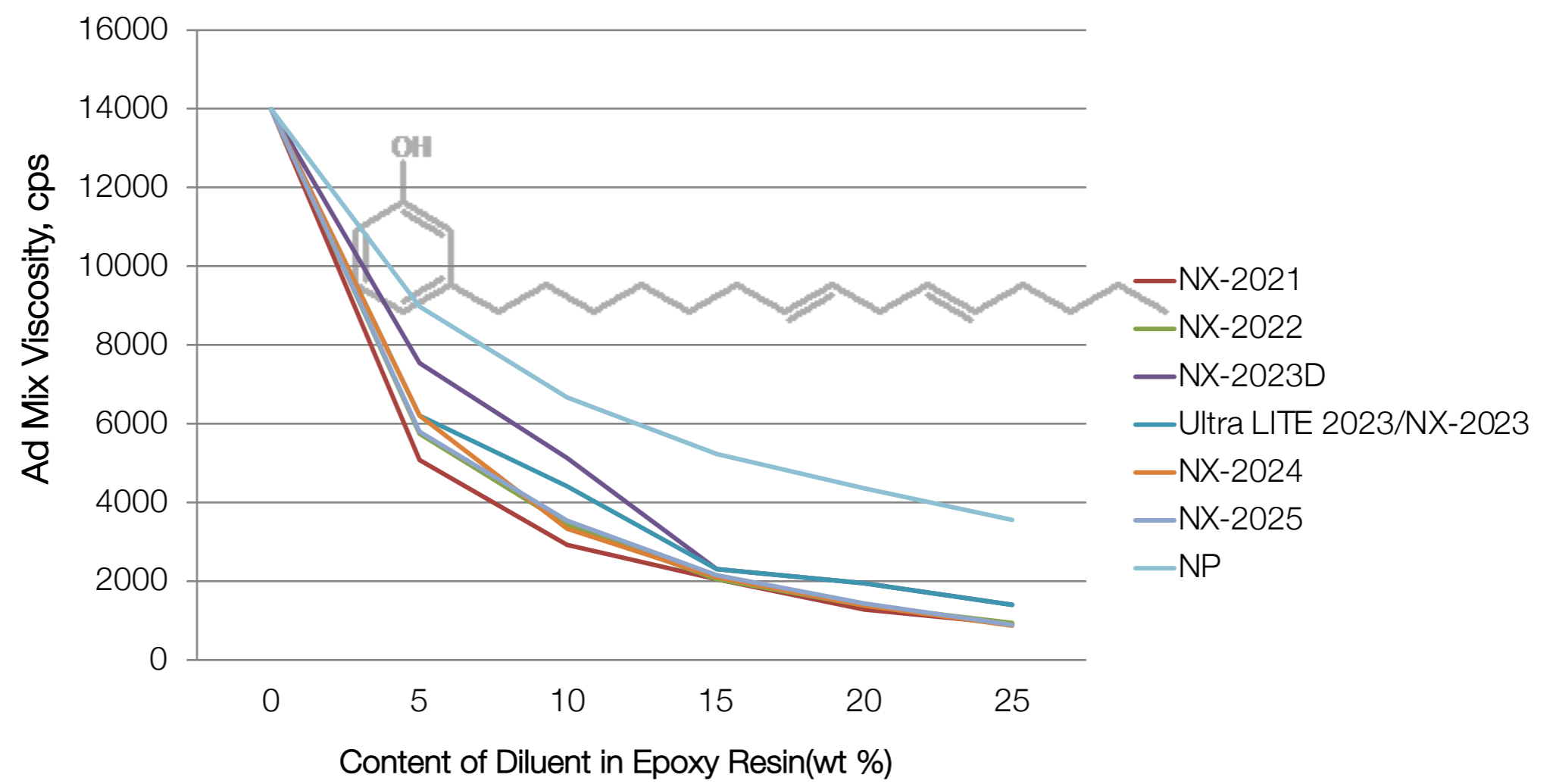
- High bio-content
- Excellent water resistance and chemical resistance
- Better cure speed than C₁₂-C₁₄ glycidyl ether
- Better mechanical properties and Tg than C₁₂-C₁₄ glycidyl ether
- Improve flexibility
- Improve bond strength
- LITE 513E is for electronics/electrical applications

Cardanols



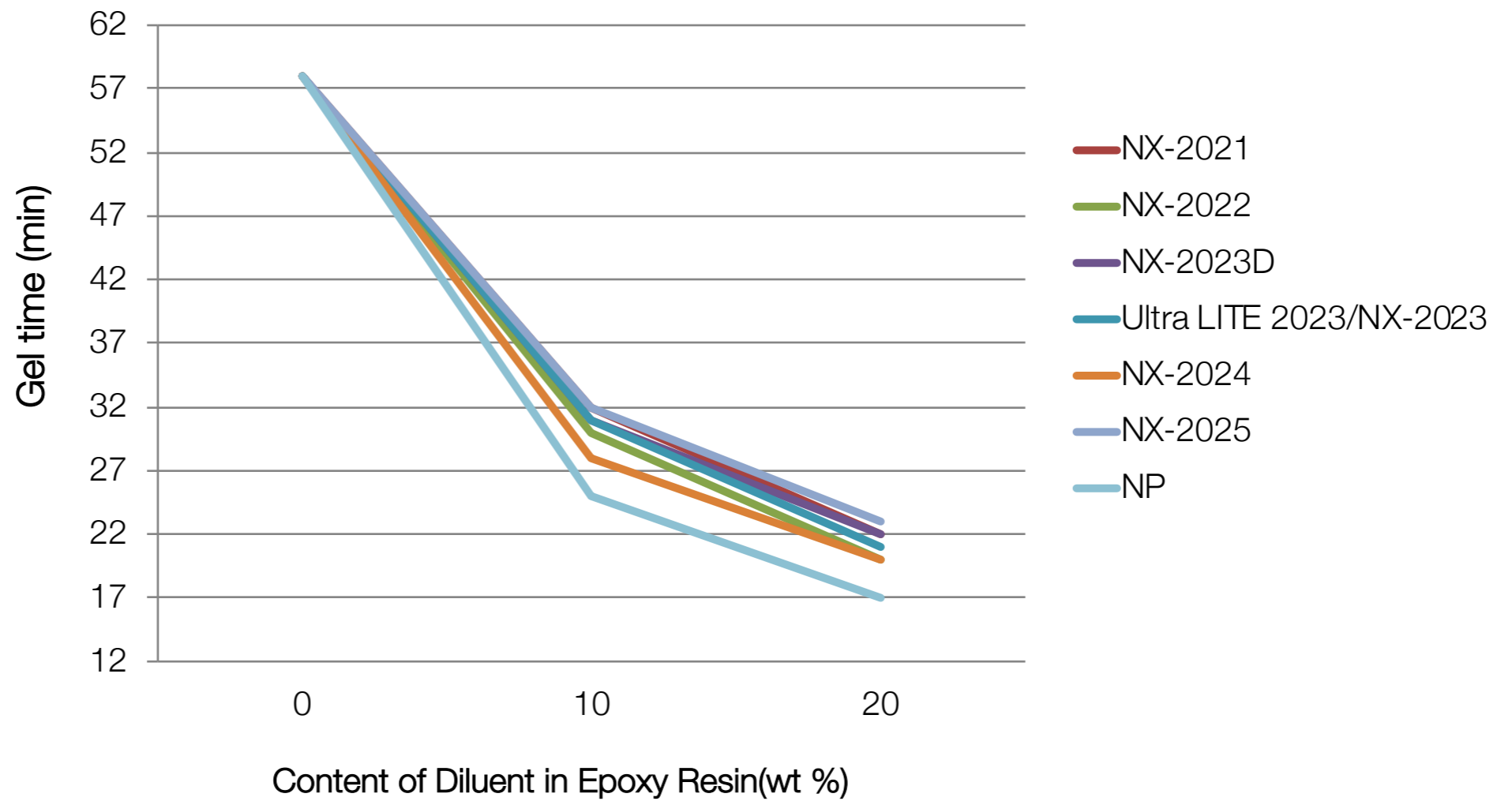
Material	Viscosity, cps @25°C	Typical Color(Gardner)	Label	Type
Nonyl phenol	~1,200	~1	Health hazard	
NX-2021	45 - 75	12	nontoxic	Standard cardanol
NX-2022	40 - 60	8	nontoxic	High purity cardanol
NX-2023D	80 - 140	10	nontoxic	Dark, wet color stable cardanol
NX-2023	40 - 100	5	nontoxic	Light, wet color stable cardanol
Ultra LITE 2023	40 - 100	≤ 1	nontoxic	Ultra light, wet color stable cardanol
NX-2024	45 - 60	≤ 9	nontoxic	Low odor, std purity cardanol
NX-2025	≤ 60	≤ 5	nontoxic	Low odor, high purity cardanol
NX-2026	≤ 60	≤ 2	nontoxic	Light color, Low odor, high purity cardanol

Cardanol Grades vs. Nonyl phenol



Cardanol grades show much higher dilution power than Nonyl phenol.

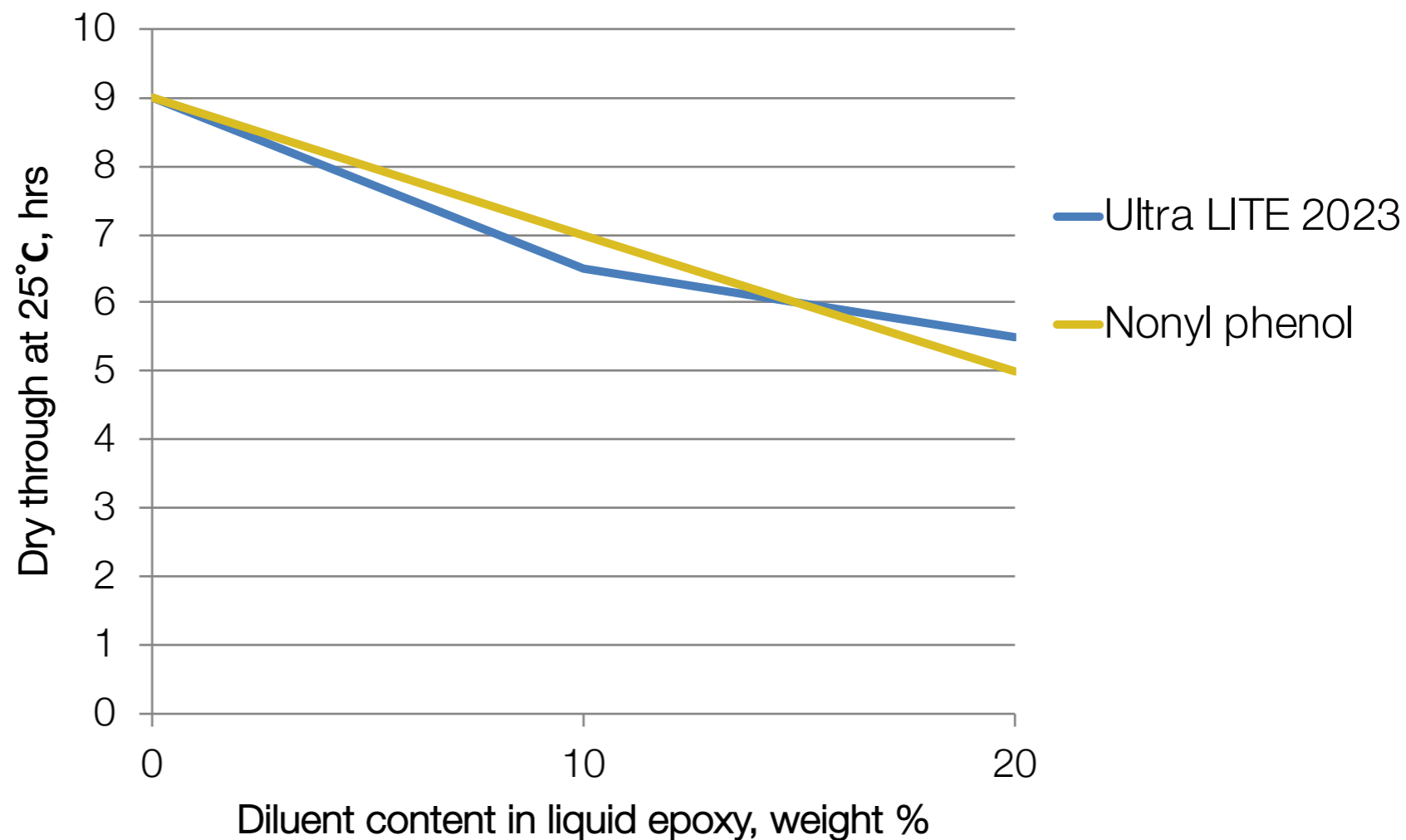
Dilution Power



*Cured with Cardolite NX-2003

Cardanol grades do not reduce gel time as much as Nonyl phenol

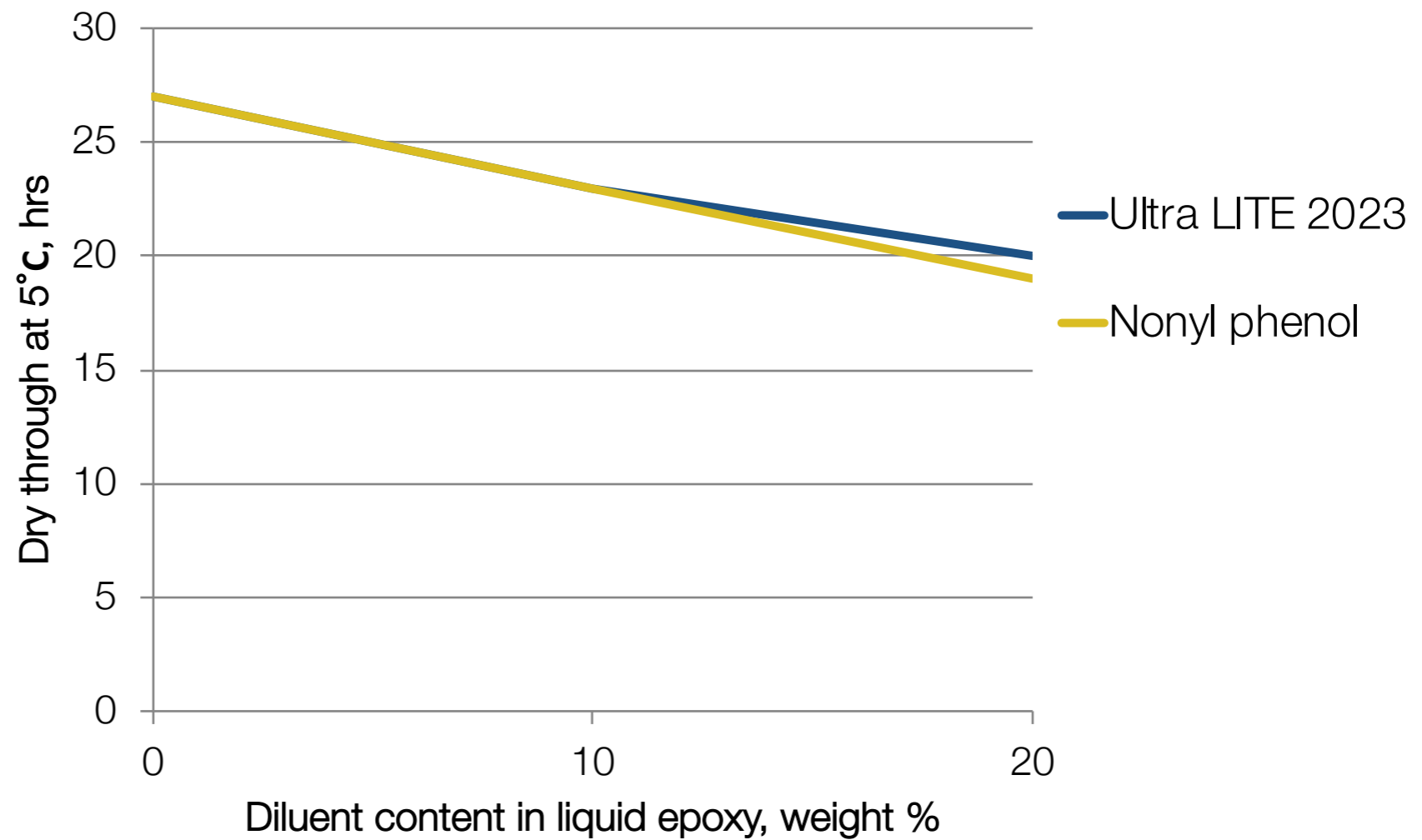
Acceleration Effect



- Ultra LITE 2023 can be used as an accelerator.
- Ultra LITE 2023 provides similar acceleration to nonyl phenol at 25°C

**Cured with Cardolite NX-2003

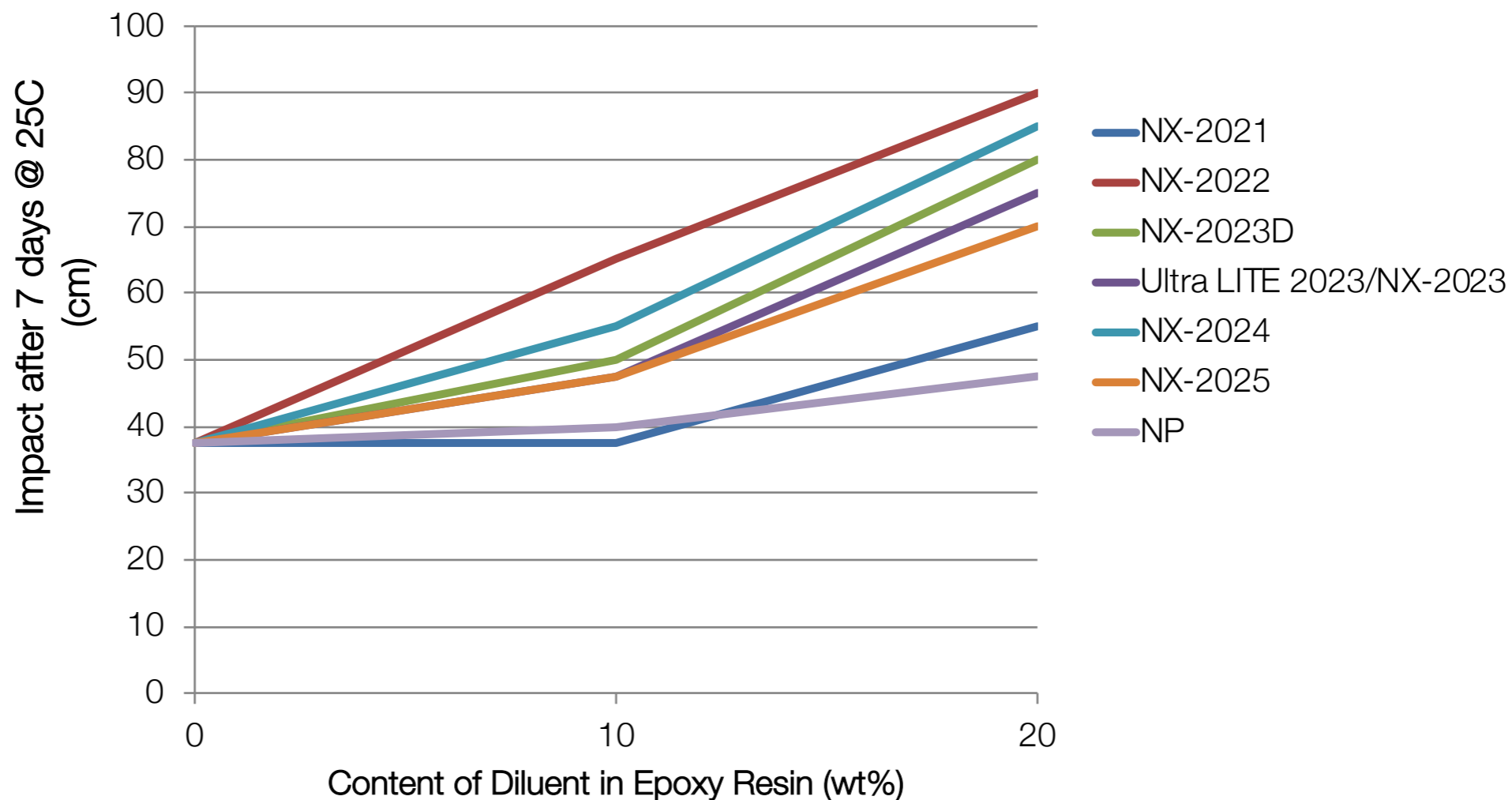
Acceleration Effect at 25°C



- Ultra LITE 2023 can be used as an accelerator at low temperatures
- Ultra LITE 2023 provides similar acceleration to nonyl phenol at 5°C

**Cured with Cardolite NX-2003

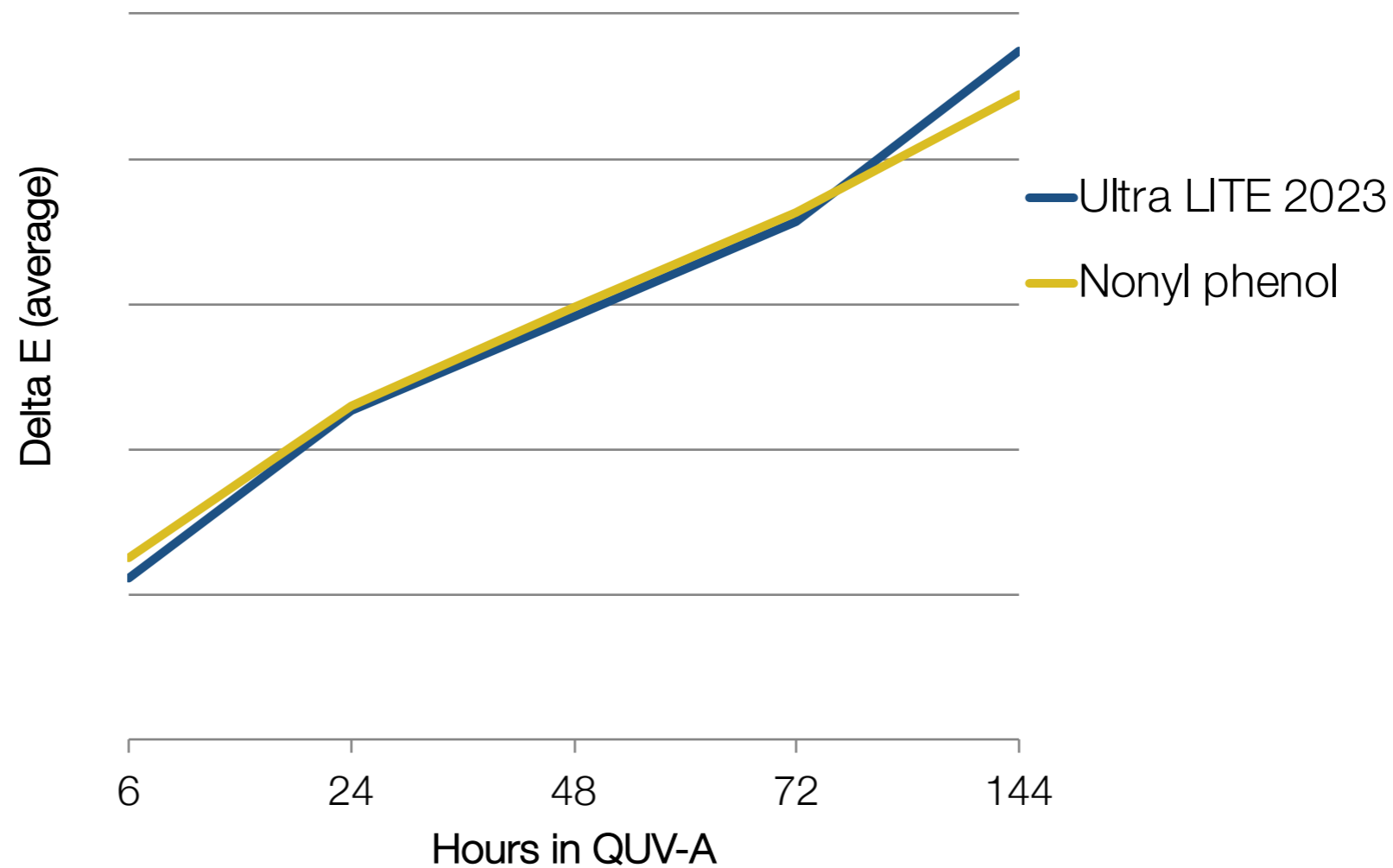
Acceleration Effect at 5°C



*Cured with Cardolite NX-2003

Cardanol grades improve impact resistance of epoxy systems due to long aliphatic side chain. Improvement is more significant than for Nonyl phenol.

Impact Resistance



Ultra LITE 2023 shows similar yellowing to nonyl phenol

**Average delta E based on cure with different phenalkamines

Color Retention

Samples	Lap shear strength Mpa (Steel)	Tensile strength Mpa	Tensile modulus Mpa	Elongation at break/%	Flexual strength Mpa	Flexual modulus Mpa	Compressive strength Mpa	Compressive modulus Mpa	Tg/°C
Epon828/TETA =100/12.8	6.98	65.63	2917.5	3.43	123.4	2999.8	104.8	1682.1	120.9
Epon828/NP/TETA =80/20/10.23	13.32	75.49	3144.6	3.66	123.4	3303.8	101.3	1815.1	83.4
Epon828/NX-2026/TETA =80/20/10.23	16.53	54.69	2433.9	5.29	98.6	2595.5	76.4	1566.6	72.5

Test method: Epoxy was blend with 20% of NP or Cardanol and cured with TETA
Cure condition: 25°C/16-24h+100°C/2h cured

- Cardanol, NX-2026, showed increased flexibility compared to Nonyl Phenol
- Addition of Cardanol improves bond strength
- Nonyl Phenol shows less impact on mechanical properties than Cardanol

Mechanical Properties

	Moisture absorption(wt%)			
Samples	0day	1day	3day	7day
NX-2025	0.01	0.1	0.18	0.26
Nonyl Phenol	0.44	0.5	0.51	0.55

Test conditions: Samples(50g in the glass container) are stored under the hood with the cap opened for the given time. Sampling for moisture content at 0day, 1day, 3day, 7day exposure.

Test equipment: Karl-Fisher measurement.

Cardanol, NX-2025, showed better water resistance than nonyl phenol

Water Resistance



Cardanols

- Non-toxic alternative for NP
- Lower viscosity than NP
- Accelerator in Epoxy systems
- Low color is available: Ultra LITE 2023, NX-2026
- Improve flexibility
- Good compatibility
- Excellent water resistance

CNSL Hydrocarbons



Cardolite



LITE 2100(R) Hydrocarbon

CNSL modified hydrocarbon resins are renewable epoxy modifiers that provide excellent:

- Dilution power
- Hardness development
- Flexibility and wetting properties (long aliphatic chain)
- Adhesion (even to unprepared surfaces)
- System compatibility
- Cost benefit!

Properties	LITE 2100	LITE 2100R
Color (Gardner)	≤ 4	≤ 4
Viscosity (cps)	450 - 750	500 - 1,000
Volatile Content (%)	≤ 1	≤ 1
Recommended use level* (% resin)	≤ 30	≤ 30

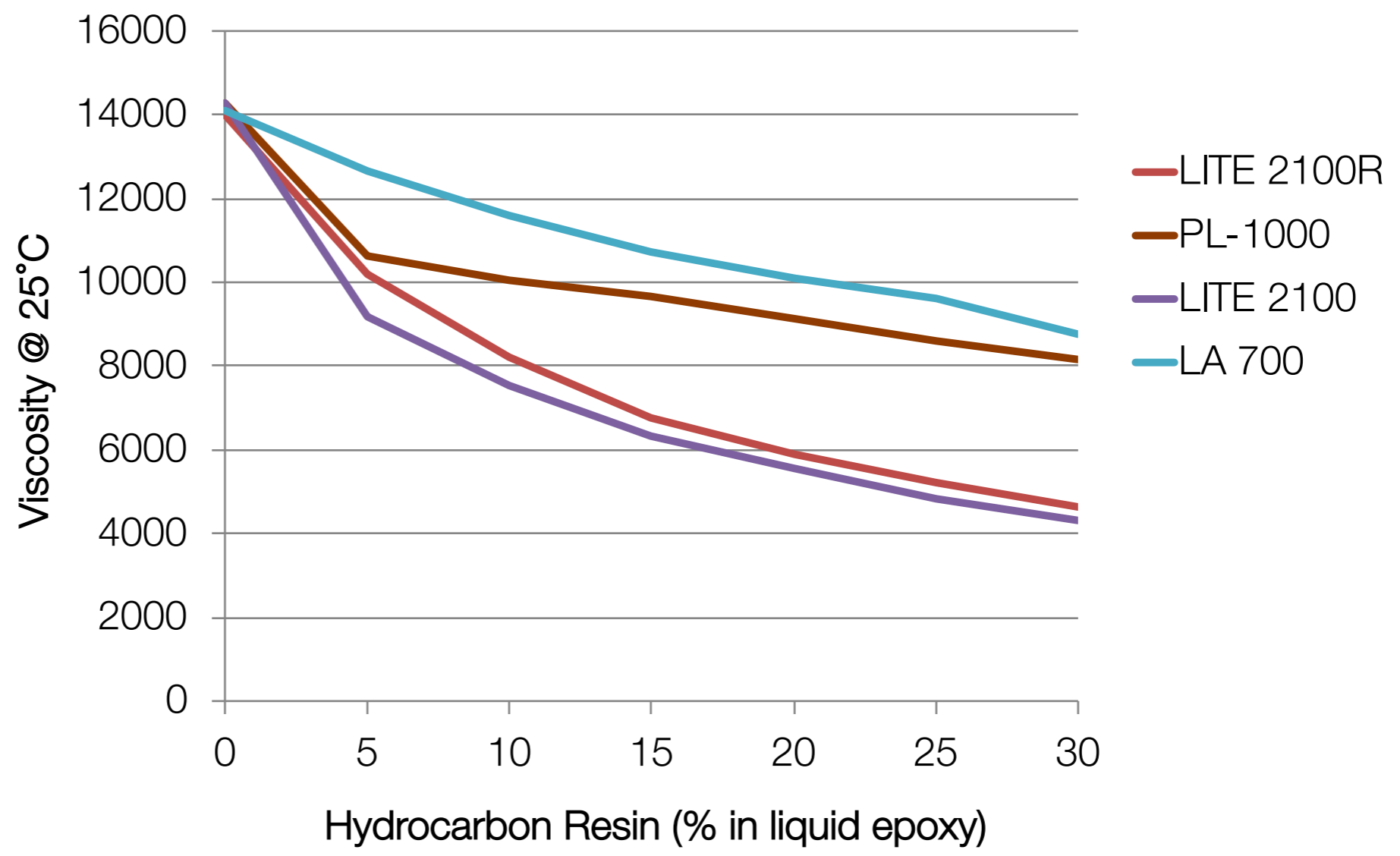
*Optimum use level varies with application

*It can be used in part A or part B

*LITE 2100R is the REACH Version



Typical Properties



LITE 2100R and LITE 2100 show better dilution power with liquid epoxy than other hydrocarbon resins

Dilution Curve



Test formulations, 25°C/16-24h+100°C/2h cured	Lap shear strength Mpa (Steel)	Tensile strength Mpa	Tensile modulus Mpa	Elongation at break/%	Flexural strength Mpa	Flexural modulus Mpa	Tg/°C
Epon828:TETA=100:12.8	14.0	74.7	2881.8	4.6	129.5	2768.0	118.4
Epon828:LITE2100:TETA=80:20:10.23	23.9	63.0	2764.1	4.7	109.6	2680.2	91.8
Epon828:LITE2100R:TETA=80:20:10.23	23.1	64.1	2834.6	5.1	109.6	2784.6	91.1
Epon828:PL1000S:TETA=80:20:10.23	16.4	78.1	3584.4	4.0	136.7	3559.3	86.1
Epon828:LA700:TETA=80:20:10.23	17.8	69.2	3506.3	3.8	134.8	3570.8	85.2

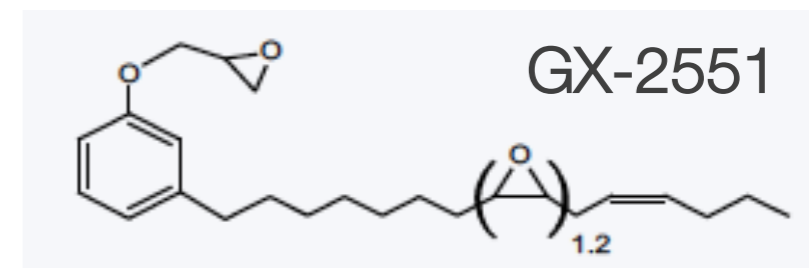
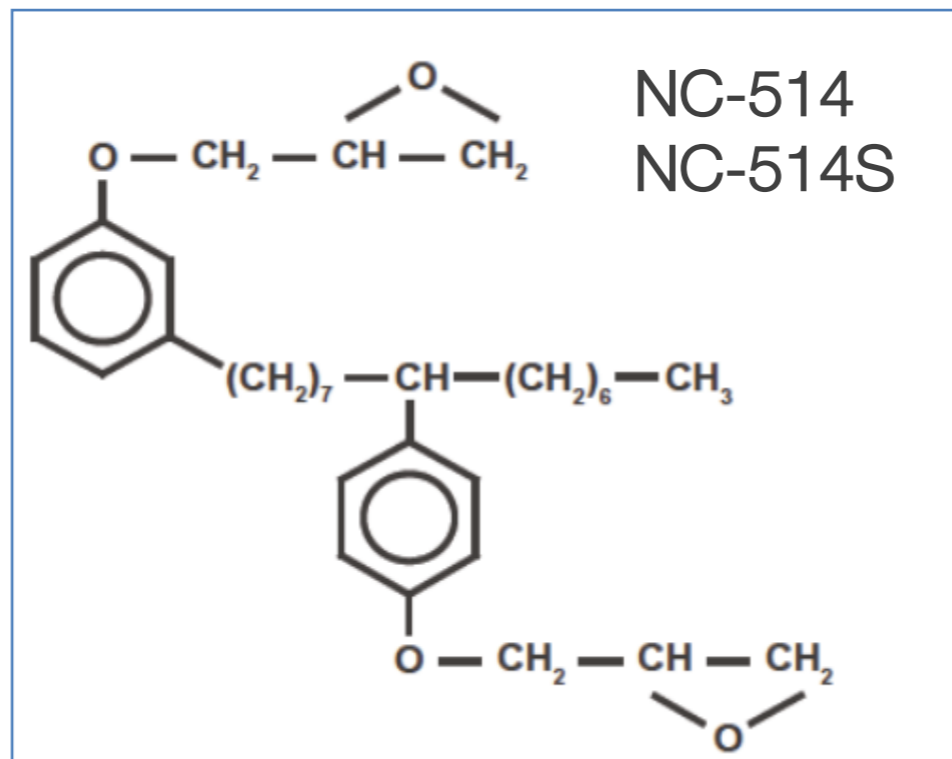
- LITE 2100R and LITE 2100 improve bond strength and flexibility
- LITE 2100R and LITE 2100 show slightly higher Tg than other hydrocarbons
- Mechanical strengths of LITE 2100R and LITE 2100 are lower than other hydrocarbons

Physical Properties

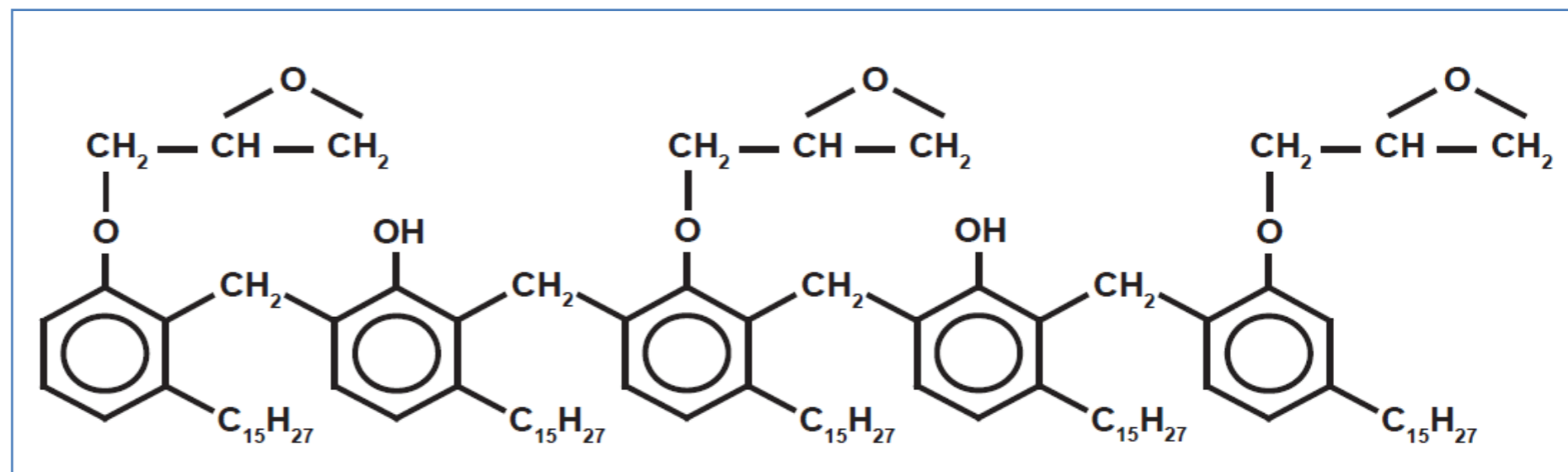
CNSL Based Epoxy Modifiers



Cardolite



NC-547



CNSL based Epoxy Functional Modifiers

CNSL Epoxy Modifiers

Items	NC-514	NC-514S	GX-2551*	NC-547
Color, Gardner	17	17	4	18
Viscosity at 25°C, cps	25000	<3000	<110	30000
EEW, g/eq	490	370	182	800
Hydrolizable Chlorine, %	<2%	<0.5%	<0.1%	<2.5%
Functionality (Avg)	2	2	2	3

* GX-2551 has only TSCA registered, no other registration for other regions



Cardolite

Benefits of CNSL Epoxy Modifiers

- High Bio-content
- Increased water resistance
- Surface tolerance (moisture, oil and etc.) upon bonding
- Increased bond strength
- Increased flexibility and toughness



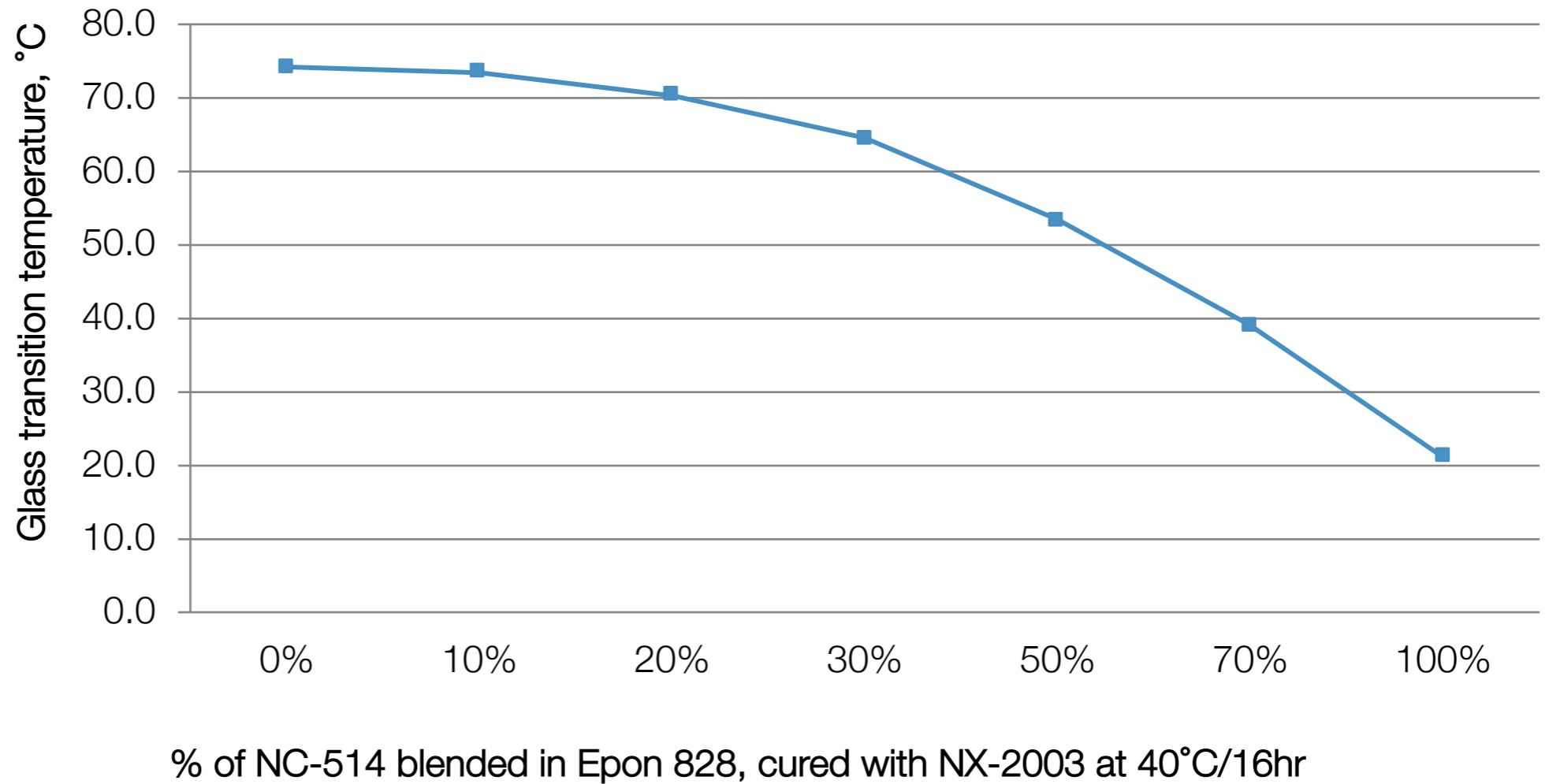
Cardolite

Formulations	Tensile strength at max, MPa	Elongation at break(%)	Tg, °C	Comments
Epon 828:TETA=100:12.79	65	3.0	120	High strength and brittle
NC-547:TETA=100:3.04	1.5	15.3	-10	Low strength, soft and low Tg
Epon 828:NC-547:TETA=50:50:7.91	21.2	4.8	96.6	Mid strength and maintain high Tg
NC-514:TETA=100:4.96	7.8	53	17.4	Reasonable strength and flexibility with low Tg
Epon 828:NC-514:TETA=70:30:10.44	67	4	86	High strength and reasonable Tg

* Cured at elevated temperature

2K Epoxy Cure Properties

Glass Transition Temperature: NC-514

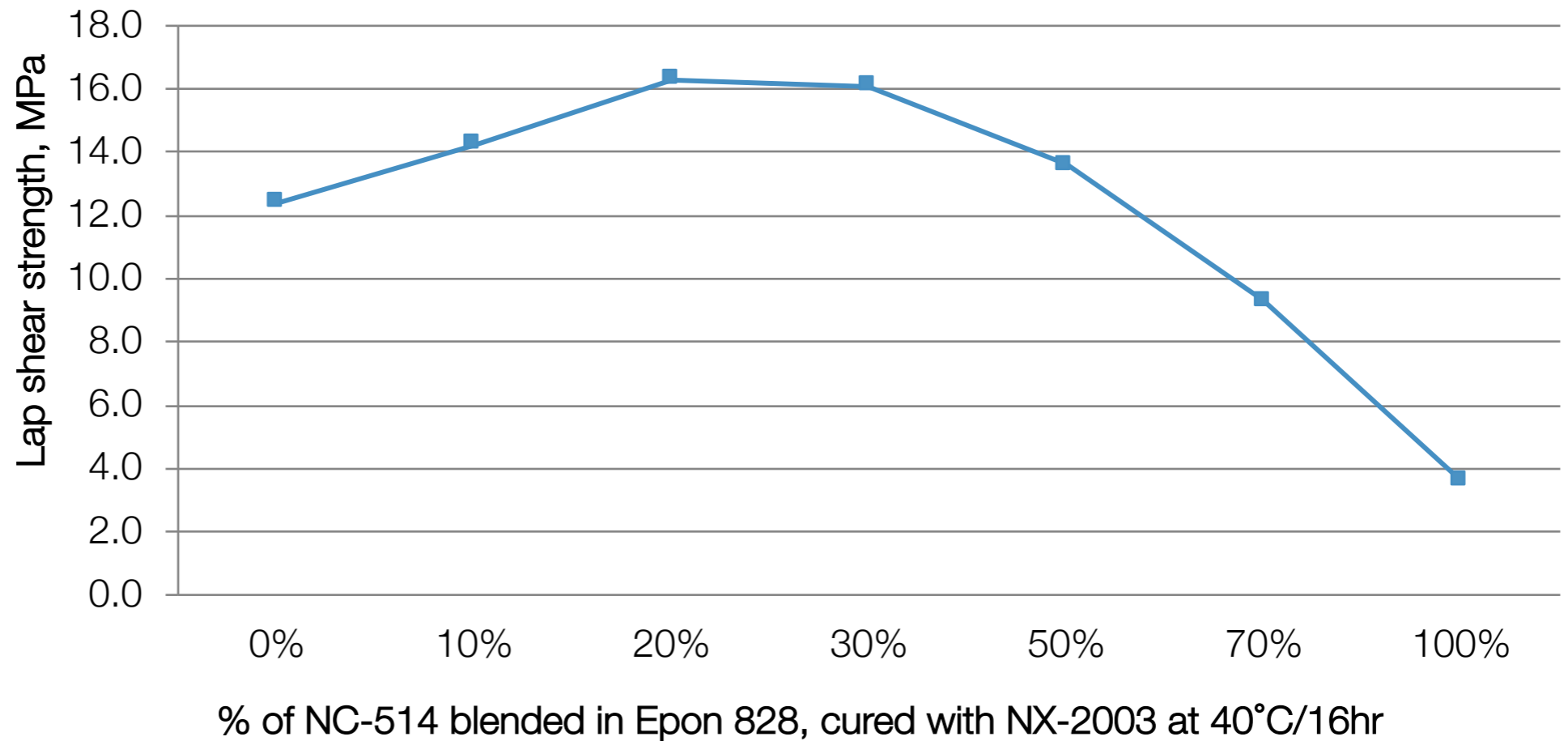


- Addition of NC-514 lowers T_g
- Up to 20% uselevel of NC-514 can be used to maintain T_g



Cardolite

Lap Shear Strength: NC-514



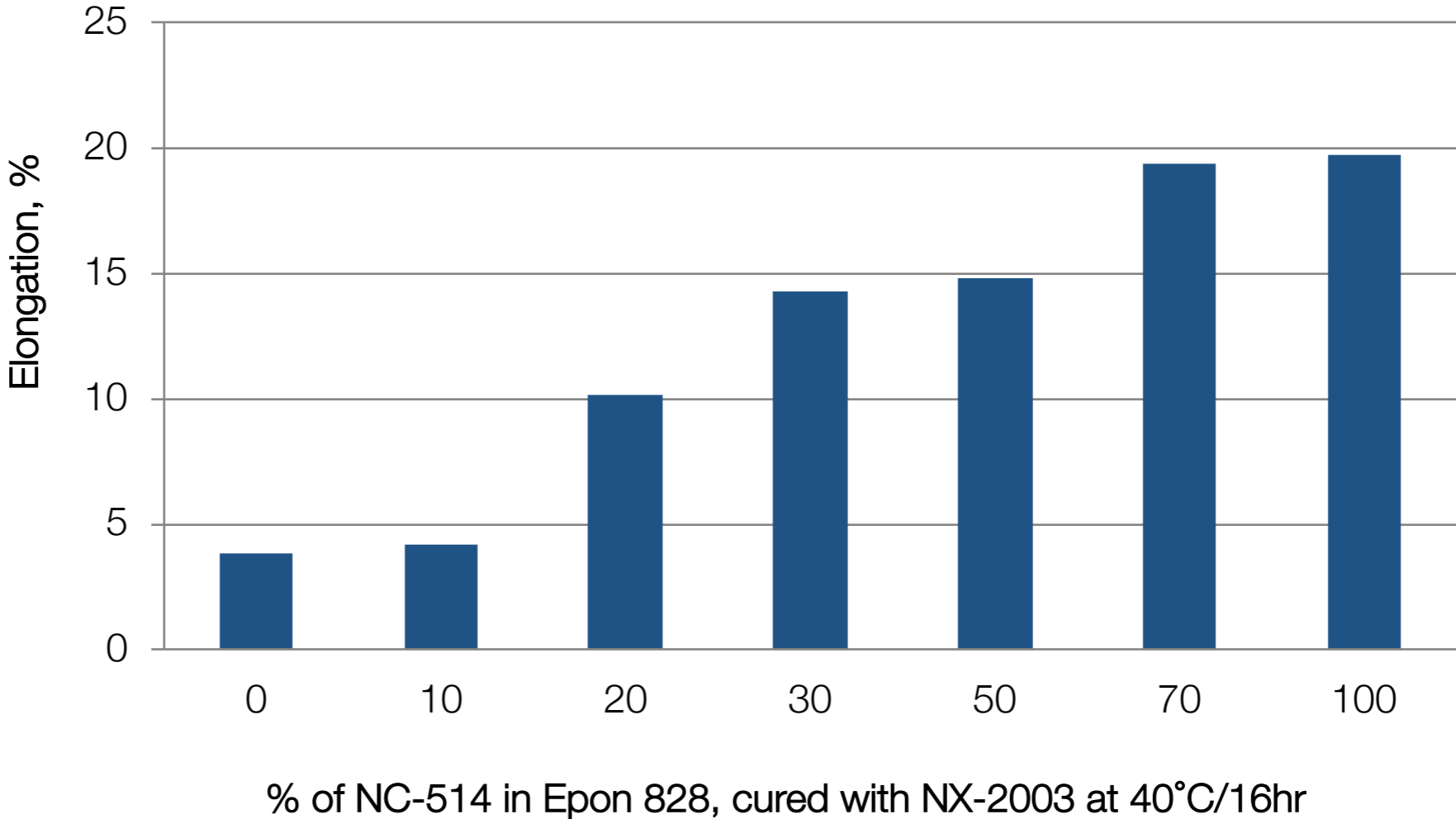
Substrate: non-abraded carbon steel

- Addition of NC-514 enhances adhesion strength.
- Up to 50% of NC-514 can be used for adhesion improvement



Cardolite

Elongation: NC-514



Use of NC-514 improves flexibility in epoxy system

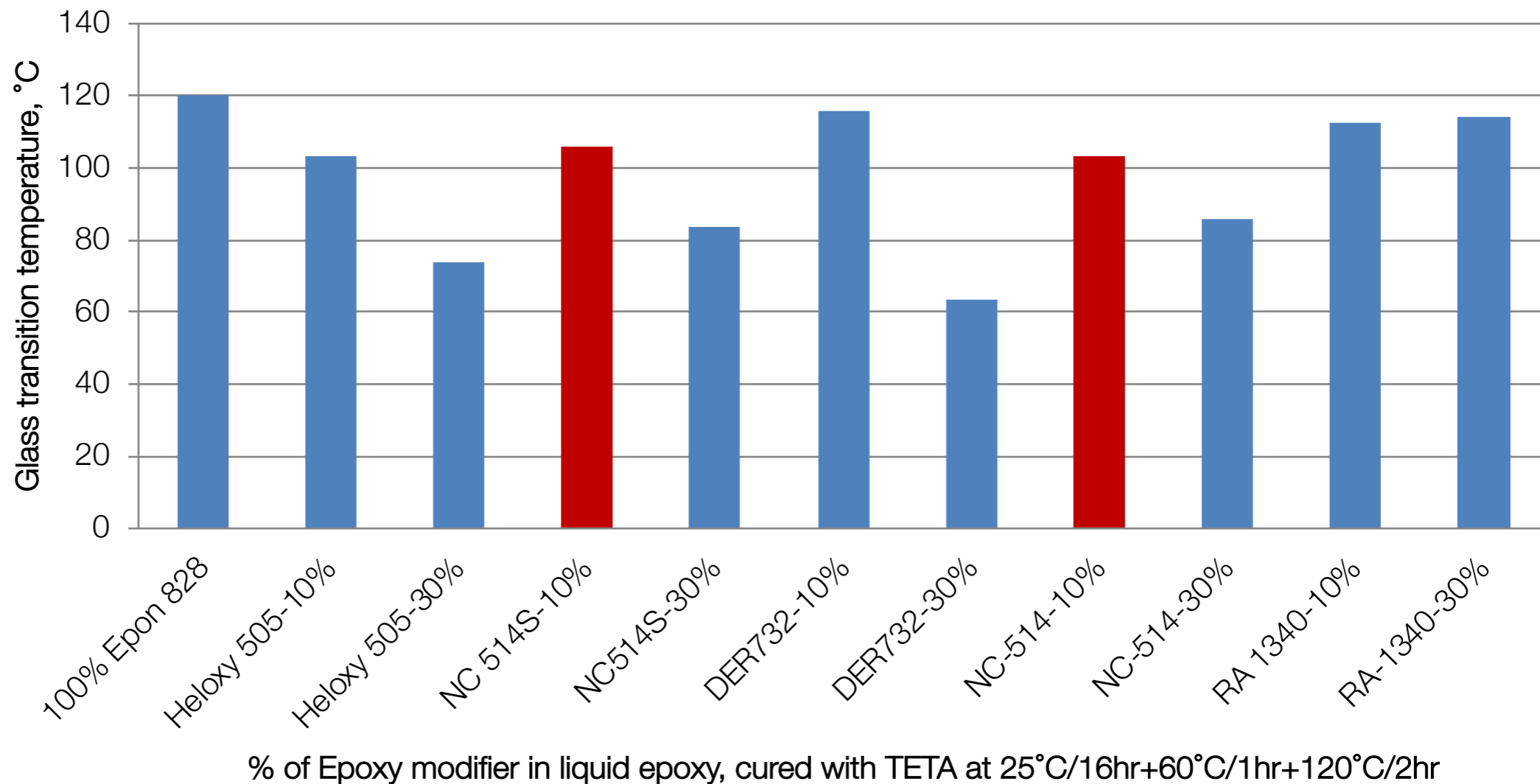


Cardolite

- RA 1340: Diglycidyl ether of Bisphenol A modified with a CTBN elastomer
 - Often shows compatibility issues in epoxy systems
 - Viscosity of 450,000 cps at 25°C
- Heloxy 505: Castor oil triglycidyl ether
- DER 732: Polyglycol diglycidyl ether

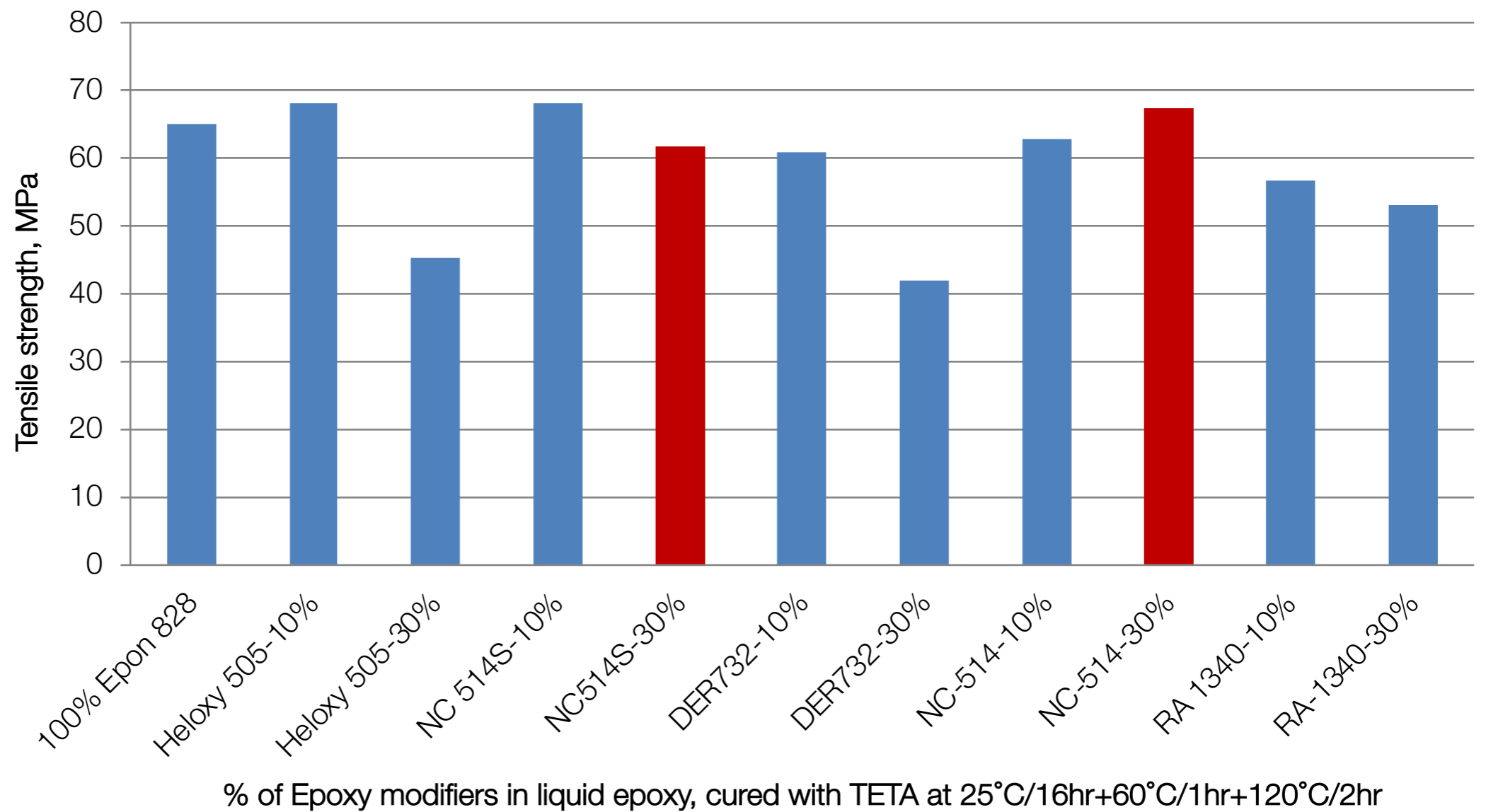
- **NC-514/NC-514S: Di-functional CNSL Epoxy modifier**

Comparison Study: 2K Epoxy



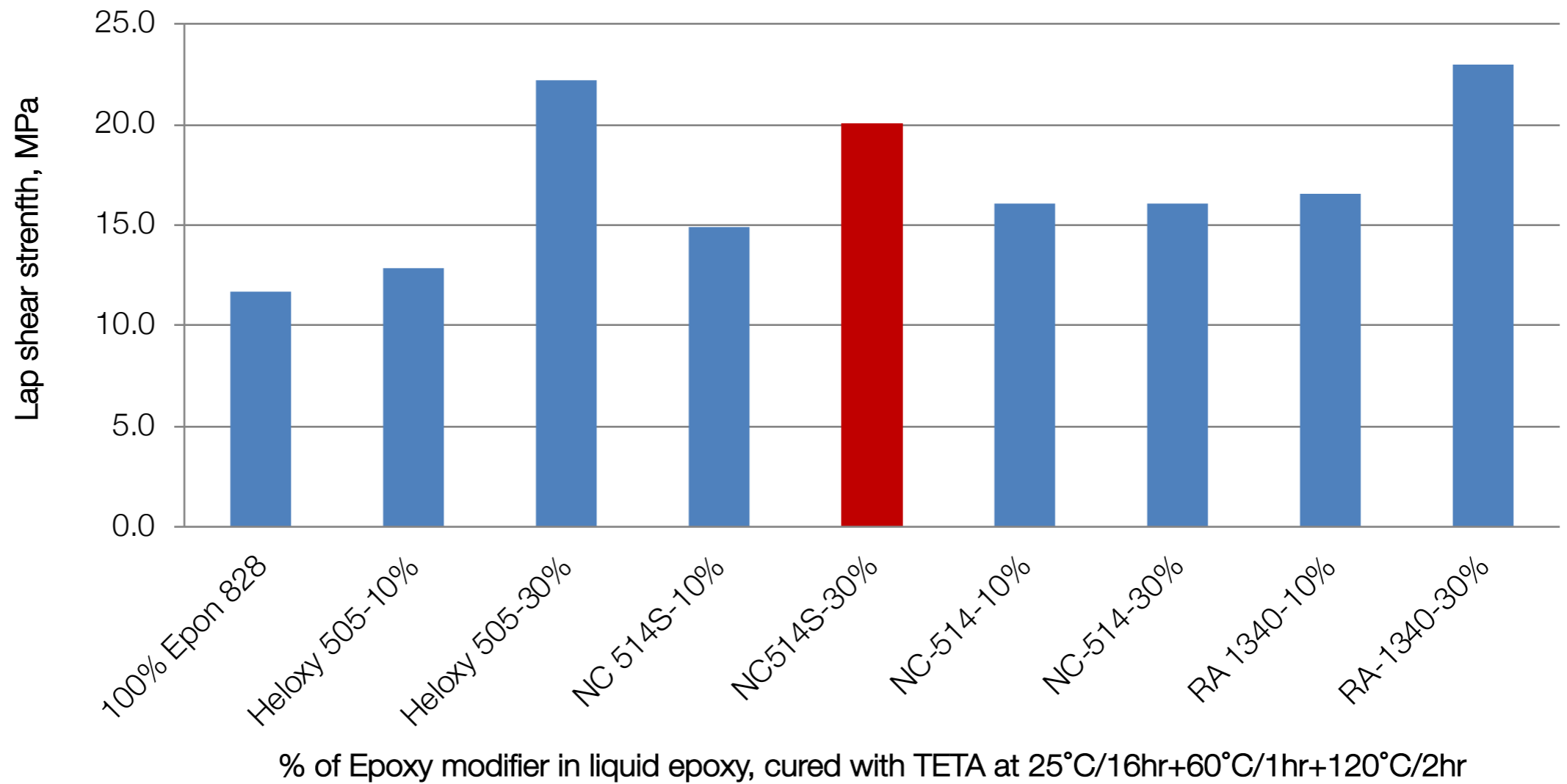
CNSL Epoxy Modifiers show minor reduction on Tg at use-level of 10%, similar to those of RA1340

Effect of Epoxy Modifier: Tg



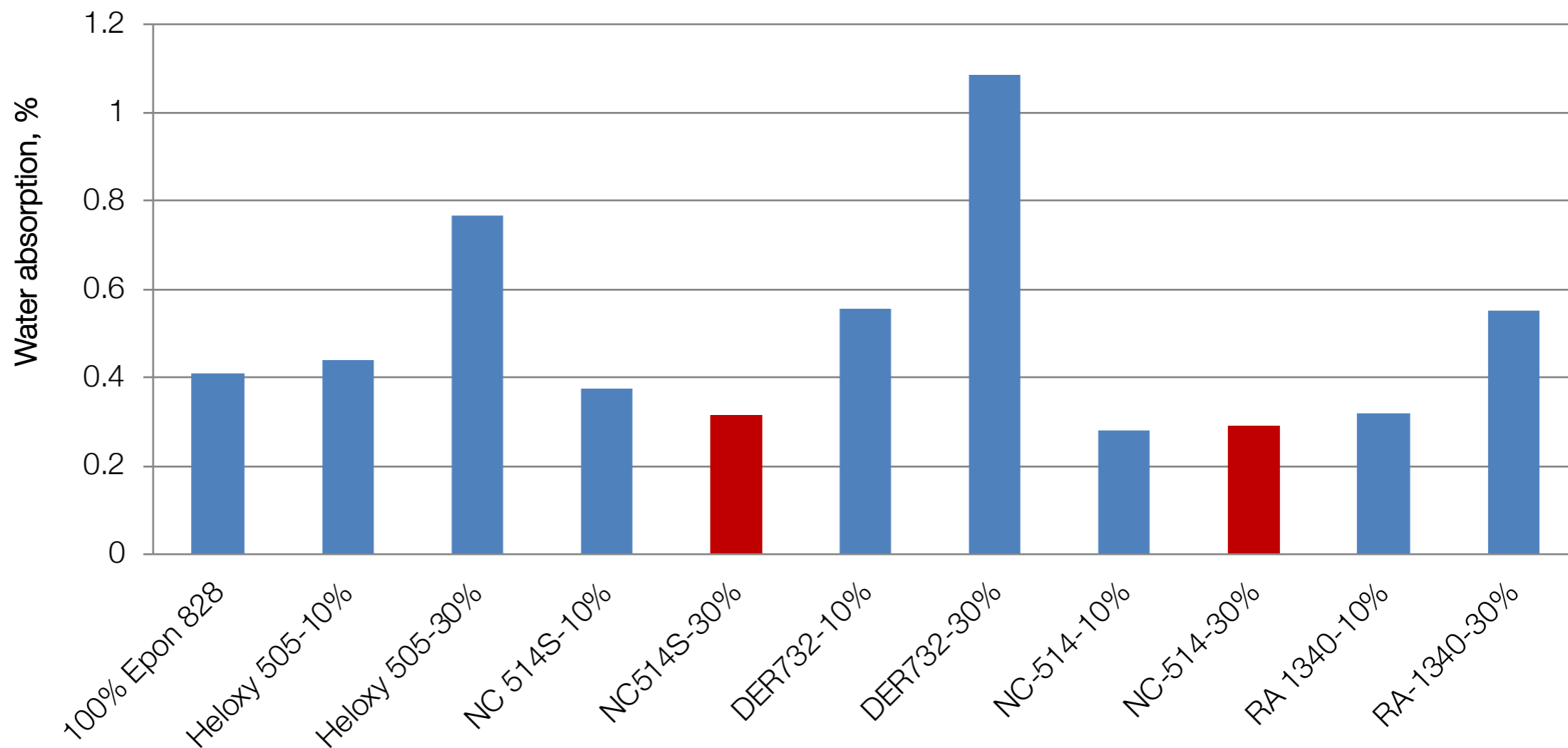
CNSL epoxy modifiers exhibits better tensile strength at 30% use-level than other references

Effect of Epoxy Modifier: Tensile Strength



- Use of epoxy modifiers exhibits improvement of bond strength
- 30% use-level provides significant improvement on bond strength

Effect of Epoxy Modifier: Bond Strength



% of Epoxy modifier in liquid epoxy, cured with TETA at 25°C/16hr+60°C/1hr+120°C/2hr

NC-514 and NC-514S provide significant improvement on water resistance, better than RA1340

Effect of Epoxy Modifier: Water Resistance

1k Epoxy formulation	Lap shear strength on Al, MPa	Tg, °C	Tensile strength at max, MPa	Tensile modulus, MPa	Elongation at break, %	Cure condition	Mixed viscosity, cps
NPEL128:GX-2551 :DDA5 : U-52M =80 : 20 : 7 : 2.6	23.71	97.1	51.08	3062	1.93	120°C/1 hr+150 °C/2hr	2950
NPEL128:NC-514S :DDA5 : U-52M =80 : 20 : 7 : 2.6	21.24	106	65.50	3062	2.42		9000

- GX-2551 and NC-514S can offer low viscosity 1k epoxy system
- Offer excellent adhesion on Aluminum substrate
- Use of GX-2551 and NC-514S can increase flexibility

1K Epoxy Study for GX-2551 vs NC-514S



Benefits of CNSL Modifiers

- NC-514/NC-514S
 - Excellent bond strength
 - Improved hydrophobicity
 - Increased flexibility
- GX-2551
 - Low viscosity
 - Improved flexibility
- NC-547
 - Low Tg
 - Improved flexibility