Cardolite

COMPOSITES

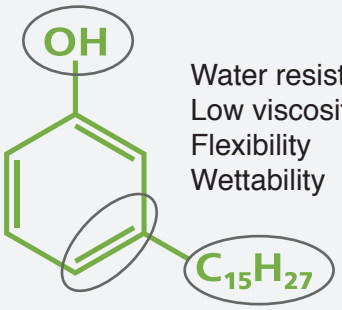
PRODUCT OVERVIEW

Cardolite Corporation is a privately held manufacturer of the world's largest variety of products derived from cashew nutshell liquid (CNSL). CNSL is an annually renewable resource that does not interfere with the food chain. The unique properties of CNSL are used to develop and produce a wide range of specialty curing agents, resins, and diluents for coatings, adhesives, composites and friction applications.

With 30 years of experience, Cardolite is the leader in the production and development of high quality CNSL based materials across the globe. Cardolite's manufacturing facilities in Newark, New Jersey (USA), Zhuhai, Guangdong (China), and Mangalore, Karnataka (India), have the unique capability to consistently process CNSL from any source to the desired properties.

To further advance CNSL technology, Cardolite operates state-of-the-art research facilities in the USA, China and India. By using CNSL as a primary building block, these laboratories are able to develop epoxy hardeners, modifiers and resins for composite applications with performance advantages over some traditional, petrochemical based chemistries. In addition, these facilities are equipped with application testing machines such as mechanical testers, thermal analysis DSC and TGA, dynamic mechanical analysis, impact and pull off adhesion testers, and QUV and salt spray chambers amongst others. This full test capability allows our Technical Service group to develop relevant application data that help customers accelerate time to market and assure product quality and performance.

Low temperature cure
Fast cure
Excellent adhesion



Water resistance
Low viscosity
Flexibility
Wettability

Chemical and thermal shock resistance

CNSL Technology

Cardanol is a unique natural phenolic material obtained by distilling CNSL and serves as the primary building block for Cardolite products. The molecule is composed of an aromatic ring with an OH group and a long aliphatic side chain, which bring valuable intrinsic benefits to composite materials. The aromatic ring provides a strong chemical resistant backbone while the OH group gives high bond strength and good reactivity for fast and low temperature cure. The side chain provides excellent water resistance, good flexibility, low viscosity, and extended pot life.

Cardolite Products

Cardolite offers a variety of **epoxy amine curing agents, epoxy modifiers and epoxy resins** based on CNSL technology for use in the design of a wide range of composite formulations.

The Mannich reaction of CNSL, formaldehyde and certain amines is called a **phenalkamine**. Phenalkamines are epoxy curing agents that offer unique benefits to composite manufacturers such as a wide range of pot life and curing cycles, great chemical properties, excellent water resistance and very good fiber wetting and adhesion for a variety of synthetic and natural fibers. **Cardolite curing agents are ideal for two-component epoxy composites.**

Cardolite **CNSL based novolac resins** are used as curing agents for epoxy resins in high temperature curing systems, such as pultrusion, hot-molding and pre-preg. They offer the unique advantages of very high bio-content, long pot life, and fast reaction at the target curing temperature. **CNSL based novolac resins are suitable for one- or two-component epoxy systems.**

Cardolite also offers **reactive epoxy diluents** that can be used to reach the target formulation viscosity. Such diluents are reactive epoxy monomers that do not affect the stability and reactivity of the system while lowering viscosity and having little impact on Tg and mechanical properties. **CNSL based reactive diluents are recommended for two-component epoxy systems.**

Cardolite continues to invest heavily in research, technical support, manufacturing and market development to meet the ongoing needs of the composites industry with innovative, natural, renewable CNSL based products.

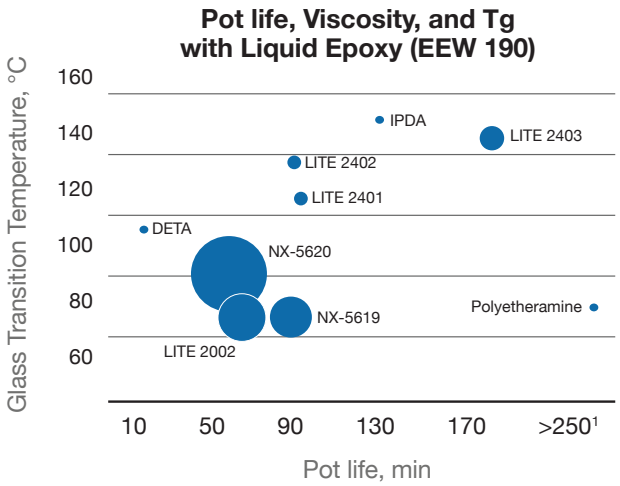
Epoxy Curing Agents
Phenalkamines

Formulation Friendly

Cardolite phenalkamines' portfolio includes a broad selection of curing agents that cover a wide range of viscosity and pot life requirements suitable for the majority of composite production processes.

Good workability and formulation latitude, good reactivity at low and medium temperatures, excellent wetting of synthetic and natural fibers, medium and high glass transition temperatures, and non-critical mix ratios are inherent characteristics of phenalkamines.

Whether your goal is saving time and energy during processing, achieving high performance, or maximizing bio-content, phenalkamines are the choice hardener, offering unique advantages in combination with standard or bio-based epoxies, epoxy novolacs and epoxy modifiers.



(Diameter of the spheres represents viscosity of the hardener)

[1]Not to scale

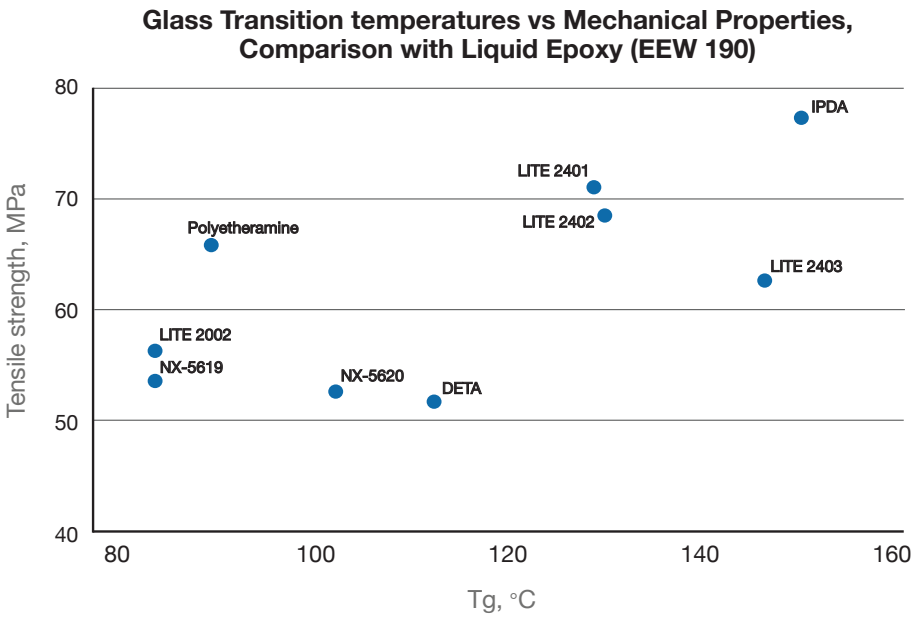
Phenalkamine Curing Agent Property Selection Chart

Product	Tg[1] (°C)	AHEW[2] (g/eq.)	Pot life[3] 25°C (min)	Use level[4] (phr)	Viscosity[5] 25°C (cps)	Color[6] (Gardner)	Key advantages
LITE 2002	86	104	65	50	495	10	Room temperature cure, high bio-content, chemical resistance
NX-5619	86	104	90	50	425	8	Room temperature cure, high bio-content, chemical resistance
NX-5620	102	82	63	40	830	13	Room temperature cure, high bio-content, chemical resistance
LITE 2401	126	61	90	32	90	5	Low viscosity, light color, better mechanical properties, chemical resistance
LITE 2402	130	56	85	30	105	11	Comparable to LITE 2401 with higher Tg
LITE 2403	120[a]/145[b]	58	170	31	230	5	High Tg, long pot life

[1]Formulated with liquid epoxy resin (EEW 190). Cure schedule: hardening at RT + post cure 2hrs at 120°C (LITE 2403 hardened at 80°C and post-cured at 120/140°C).

Tg: ASTM 3418-99, Tg measured on second scan from 20°C to 200°C at 20°C/min

[a]Cure schedule: 10hrs at 80°C + 2hrs at 120°C [b]Cure schedule: 10hrs at 80°C + 6hrs at 140°C



	Tensile Strength[7] (MPa)	Tensile Modulus[7] (MPa)	Elongation[7] (%)	Flexural Strength[8] (MPa)	Flexural Modulus[8] (MPa)	Processes
	60	2696	4.2	84	2506	Wet lay-up, vacuum bagging, RTM, VARTM, infusion
	55	2743	2.6	84	2506	Wet lay-up, vacuum bagging, RTM, VARTM, infusion
	58	2917	3.9	89	2515	Vacuum bagging, RTM, VARTM, infusion
	70	2902	3.2	105	2673	Wet lay-up, lamination, vacuum bagging, RTM, VARTM, infusion
	68	2670	4.1	112	2825	Wet lay-up, RTM, VARTM
	63	2568	4.4	97	2508	RTM, VARTM

[2]Theoretical based on total product weight [3]Formulated with liquid epoxy resin (EEW 190), determined upon viscosity increase up to 10,000 cps

[4]With liquid epoxy resin (EEW 190) [5]ASTM D2196 [6]ASTM D1544

[7]Tensile properties: ASTM D638-10 [8]Flexural properties: ISO 178

Epoxy Curing Agents
Phenalkamines

Phenalkamine Process-defining Parameters

Product	25°C		40°C		Suggested Cure Schedule[1]
	Pot life (min)	Mix Viscosity (cPs)	Pot life (min)	Mix Viscosity (cPs)	
LITE 2002	65	2,717	36	770	**Curing:** 4-8hrs at RT **Post-curing:** 2hrs at 100°C
NX-5619	90	2,824	45	750	
NX-5620	63	4,542	24	980	
LITE 2401	90	2,583	44	635	**Curing:** 4-8hrs at RT[2] **1st post cure:** 2-4hrs @ 60-80°C **2nd post cure:** 2hrs at 120°C (optional)
LITE 2402	85	2,320	44	650	
LITE 2403	170	5,157	120	1,278	**Curing:** 16hrs at 60°C or 10hrs at 80°C **Post-curing:** 2hrs at 120°C or 6hrs at 140°C[3]

[1]The parameters were measured in a formulation with liquid epoxy resin (EEW 188, viscosity at 25°C 10,000-14,000 cps). This cure schedule is recommended to fully develop mechanical, thermal and chemical resistance properties. Cure schedule can be adapted based on process needs.

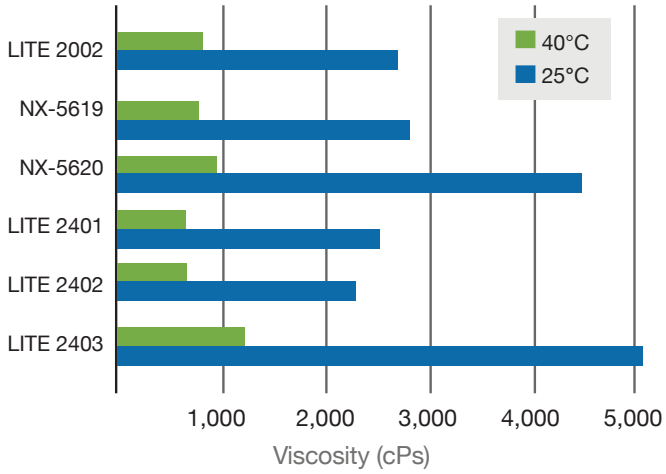
[2]LITE 2401 and LITE 2402: Demolding is possible after 1st post cure.

[3]Post-cure at 140°C will yield maximum material performance.

Phenalkamine Properties

Phenalkamines provide a universal solution for customers who need to meet stringent process and performance requirements along with satisfying the global mega trend move to bio-based materials in composite applications. Phenalkamines offer a good balance of high strength and toughness with good mechanical and thermal properties. Combined with a broad range of pot life and workable viscosity, phenalkamines can be easily formulated in the majority of composite production processes.

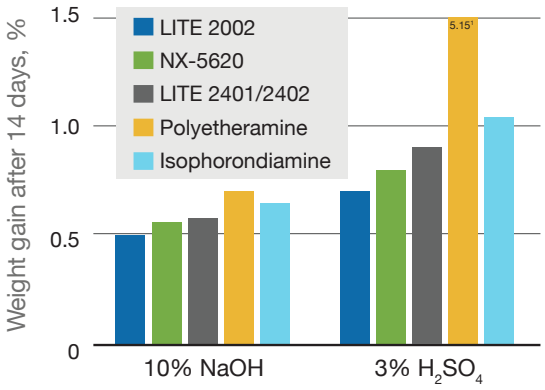
Formulation Viscosity of Phenalkamines with Liquid Epoxy (EEW 190) at 25°C and 40°C



Excellent Chemical and Water Resistance

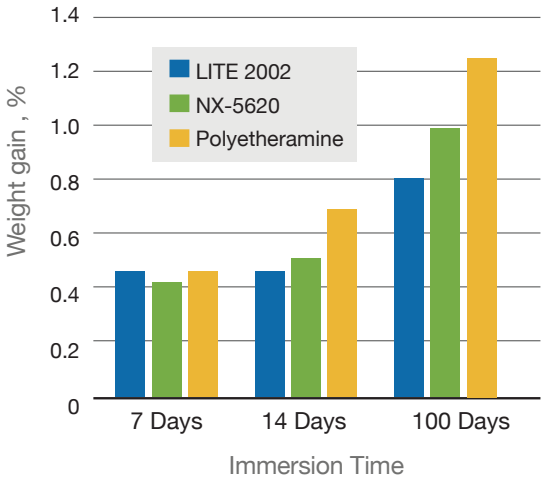
Cardolite curing agents are very hydrophobic due to the long aliphatic side chain of the cardanol, which provides excellent water resistance compared to other amine curing agents commonly used in the composites industry. As a result, phenalkamines absorb much less water than competitive technologies and in addition, their aromatic structure imparts significant resistance to acid and alkali attack.

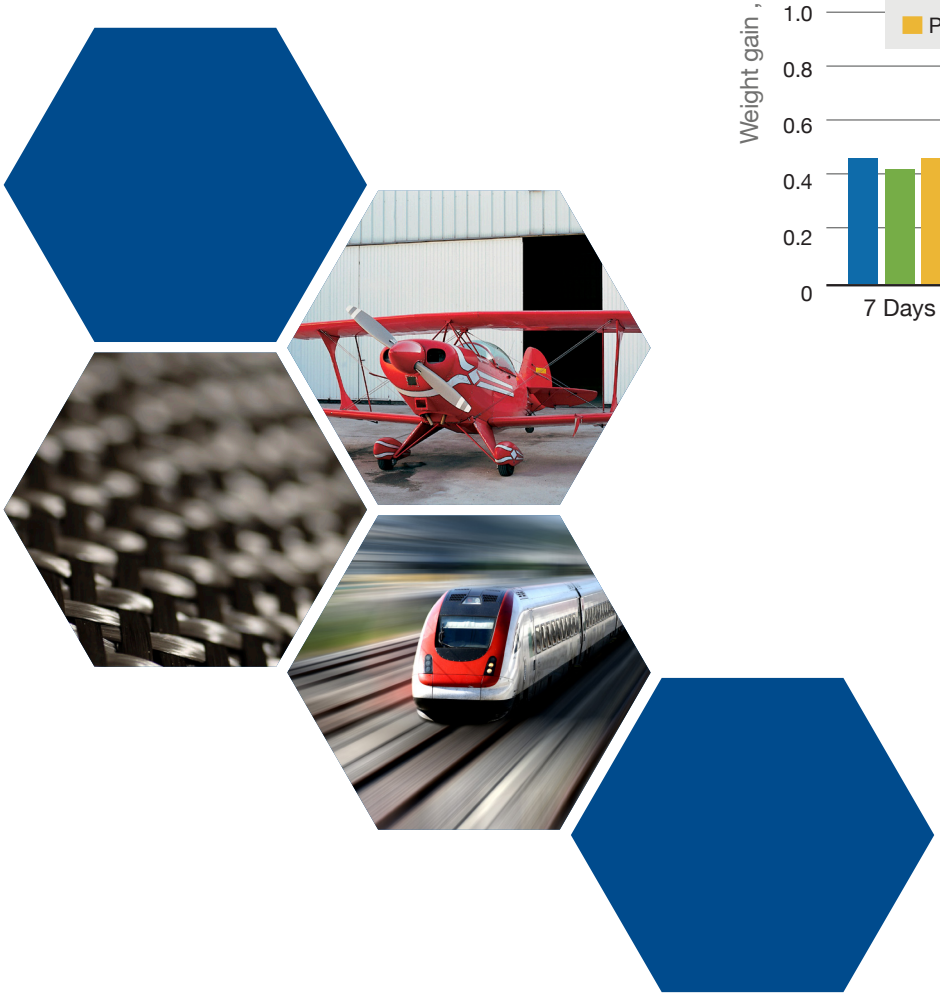
Phenalkamines Chemical Resistance at 25°C with Liquid Epoxy (EEW 190)



†Represents the outlier weight gain (%) of polyetheramine

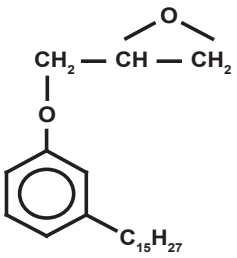
Phenalkamines Water Resistance at 25°C with Liquid Epoxy (EEW 190)





Epoxy Diluents and Modifiers

Cardolite NC-513/Ultra LITE 513

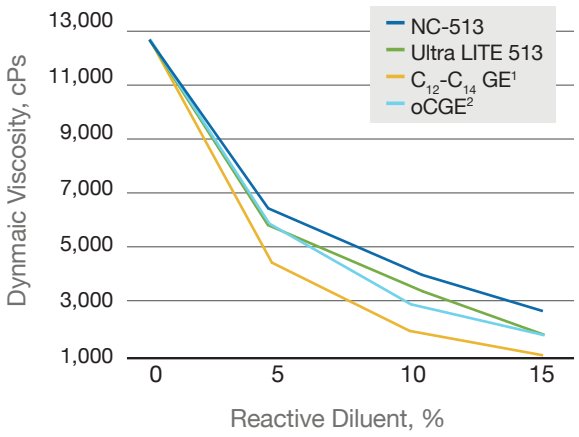


Ultra LITE 513 and NC-513 are low viscosity, monofunctional epoxy reactive diluents that can be used to increase flexibility, impact and water resistance. These reactive diluents are ideal for formulating low emission and low odor solvent-free systems. Their good reactivity means that these diluents react completely into the epoxy network, which can increase the bond strength. Ultra LITE 513 is a lower viscosity, higher purity, and lighter color version of NC-513. Both grades have a similar chemical make-up and have favorable labeling. They are excellent replacements for toxic and environmentally unfriendly glycidyl ether based diluents.

Excellent Chemical and Water Resistance

Cardolite epoxy monomers are very hydrophobic due to the long aliphatic side chain of the cardanol, which provides excellent water resistance. Cardanol derivatives absorb much less water than competitive technologies and in addition, their aromatic structure imparts significant resistance to acid and alkali attack.

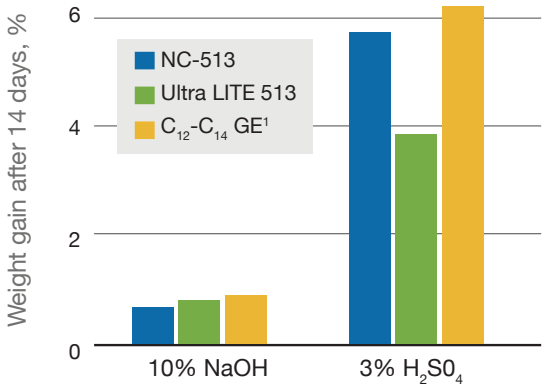
NC-513 and Ultra LITE 513 Dilution Curve (25°C with Liquid Epoxy Resin, EEW 190)



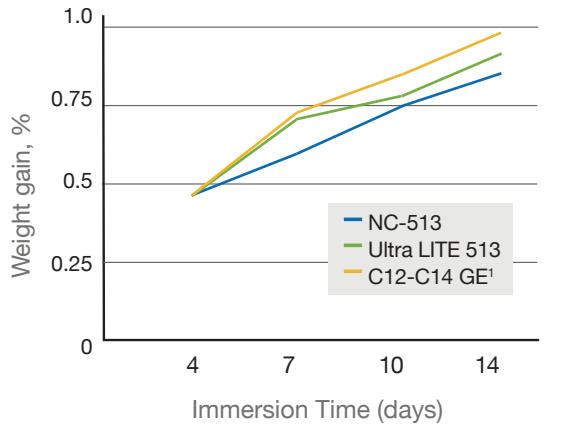
[1]C_{12}-C_{14} Glycidyl Ether

[2]Ortho-Cresyl Glycidyl Ether

Comparative Chemical Resistance of Reactive Diluents at 25°C (10% use level)



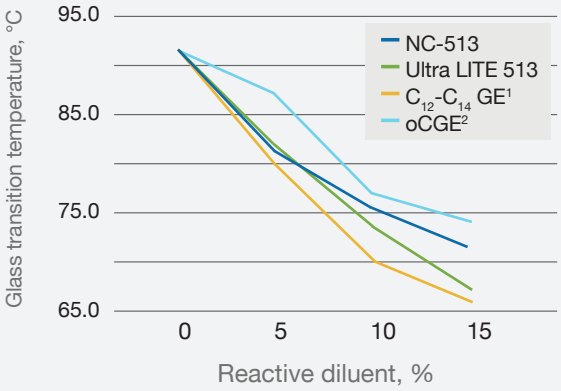
Comparative Water Resistance of Reactive Diluents at 25°C (10% use level)



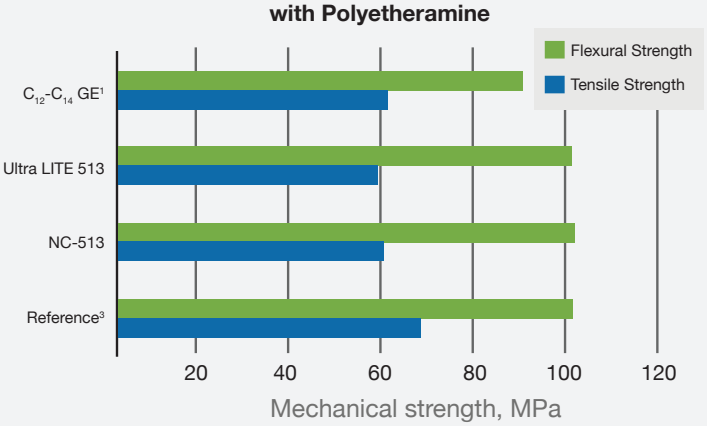
Low Impact on Tg and Mechanical Strength

Cardolite epoxy diluents fully react with the epoxy-amine formulation and therefore, their impact on Tg is comparable to other industry standards such as C_{12}-C_{14} monofunctional glycidyl ethers and ortho-cresyl glycidyl ethers. The versatility of NC-513 and Ultra LITE 513 allows users to formulate high bio-content systems with phenalkamine hardeners without sacrificing performance and workability.

Impact of Diluent on Tg of Liquid Epoxy (EEW 190) System Cured with Polyetheramine



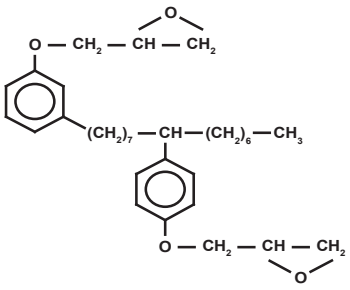
Impact of 5% Diluent on Mechanical Properties of Liquid Epoxy (EEW 190) System with Polyetheramine



[1]C_{12}-C_{14} Glycidyl Ether [2]Ortho-Cresyl Glycidyl Ether [3]100% Liquid Epoxy

Cardolite NC-514S

Cardolite NC-514S is a low viscosity flexible difunctional glycidyl ether epoxy resin. The chain of 8 carbons separating the aromatic groups allows this resin to be used in conjunction with traditional epoxy resins or as a sole resin to increase flexibility, abrasion resistance, and water and chemical resistance without adversely affecting other properties.



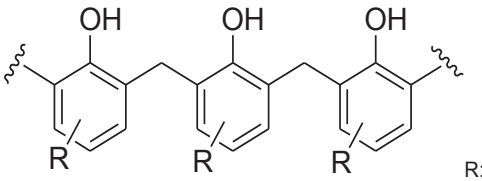
Epoxy Diluents & Modifiers Property Selection Chart

Product	EEW[1] (g/eq.)	Hydrolyzable chlorine (%)[2]	Viscosity at 25°C (cps)[3]	Color (Gardner)[4]	Product Description	Application
NC-513	425 - 575	≤ 2	50	11	Monofunctional epoxy	Diluent for epoxy systems
Ultra LITE 513	≤ 450	≤ 0.5	24	1	Light color monofunctional epoxy	Diluent for epoxy systems
NC-514S	320-420	≤ 0.5	2,000	12	Difunctional epoxy	Modifier for epoxy systems

[1]ASTM D1652 [2]ASTM D1726 [3]ASTM D2196 [4]ASTM D1544

Novolac Resins for Epoxy Crosslinking

CNSL-based novolac resins belong to a family of phenolic resins that can be used as epoxy crosslinkers or additives to phenolic resins in solvent-based and solvent-free systems for prepregs and resin films.



R: $C_{15}H_{31-2n}$

This class of solvent-free novolacs is based on CNSL, a naturally occurring structure with both aromatic and alkyl content.

The CNSL-novolacs are characterized by high functionality and high equivalent weight with good moisture and chemical resistance. They provide improved fiber wetting and interlaminar adhesion in addition to lower density compared with solid latent hardeners.

CNSL Novolac Resins Property Selection Chart

Product	Hydroxyl group equivalent weight (g/eq.)[1]	Pot life[2] 25°C (min)	Use level (phr)	Viscosity 25°C[3] (cPs)	Color[4] (Gardner)	Bio-content[5] (%)	Processes
NX-4001	316	2 days[a] >12 weeks[b]	5-25	100,000 at 40°C	≤ 18	95	Hot melt pre-pregs and films for coatings
NX-4004	316	2 days[a] 12 weeks[b]	5-33	5,500	≤ 18	95	Epoxy crosslinker for RTM, prepreg, lamination, pultrusion
NX-4005	316	2 days[a] 12 weeks[b]	5-33	968	≤ 18	95	Epoxy crosslinker for RTM, infusion, prepreg, lamination, pultrusion

[1]Calculated based on average structure [a]With 2-ethyl,4-methylimidazole (3.6 phr) [b]With latent catalyst

[2]Time to double initial viscosity [3]ASTM D2196 [4]ASTM D1544 [5]Calculated

Compatible with:

- Epoxy Resins
- Phenol-based systems
- Solvent-free formulations
- Solventborne formulations

Notes	Tensile Strength[6] (MPa)	Tensile Modulus[6] (MPa)	Elongation[6] (%)	Flexural Strength[7] (MPa)	Flexural Modulus[7] (MPa)	Tg[8] (°C)
20 phr NX-4001 + 2 phr blocked imidazole	50	2456	3.4	82	2987	124[c]
14 phr NX-4001 + 2 phr blocked imidazole	37	2790	2.3	-	-	127[c]
8 phr NX-4001 + 2 phr blocked imidazole	34	2969	2.6	-	-	144[c]
5 phr NX-4001 + 2phr blocked imidazole	33	3489	2.2	-	-	146[c]
33 phr NX-4004 + 2 phr 2,4 EMI	-	-	-	-	-	91
25 phr NX-4004 + 5 phr blocked Lewis acid	48	2377	3.8	76	2040	97
25 phr NX-4004 + 2 phr 2,4 EMI	52	1880	2.6	78	2103	103
17 phr NX-4004 + 2 phr 2,4 EMI	-	-	-	-	-	123
33 phr NX-4005 + 2,4 EMI	-	-	-	-	-	87
25 phr NX-4005 + 5 phr blocked Lewis acid	56	2338	6.5	76	2050	100
14 phr NX-4005 + 2 phr blocked imidazole	-	-	-	-	-	107
25 phr NX-4005 + 2 phr 2,4 EMI	49	2261	2.5	73	1850	118
17 phr NX-4005 + 2phr 2,4 EMI	-	-	-	-	-	120
11 phr NX-4005 + 5 phr blocked Lewis acid	35	2389	1.6	96	2474	122
8 phr NX-4005 + 2 phr blocked imidazole	-	-	-	-	-	126

[6-8]Formulated with liquid epoxy resin (EEW=188) [c]With 65% Solid Epoxy Resin (EEW=550) and 35% Liquid Epoxy Resin (EEW=188)

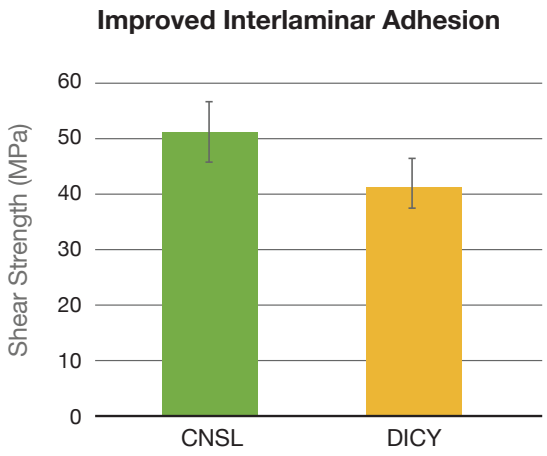
[6]Tensile properties: ASTM D638-10 [7]Flexural properties: ISO 178 [8]Tg: ASTM 3418-99, Tg measured on second scan from 20°C to 200°C at 20°C/min

Novolac Resins for Epoxy Crosslinking

Improved Interlaminar Adhesion

The unique chemical structure of CNSL-based novolacs improves fiber wetting and adhesion, resulting in a significant increase in interlaminar adhesion.

Apparent interlaminar shear strength was determined on cured prepreg samples using ASTM 2344M-00 short beam flexural test. The test shows that CNSL-based novolac, used at 20 phr in an epoxy system, improves interlaminar shear strength by 22% compared with a dicyandiamide cured system.

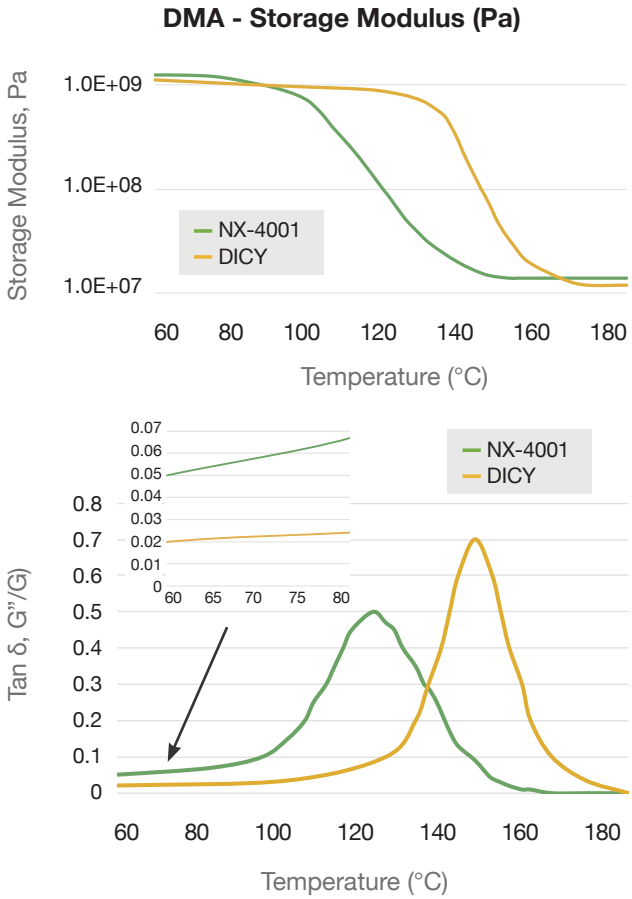


Increased Vibration Damping

DMA analysis performed on comparative prepregs with dicyandiamide or NX-4001 (20% by weight) as epoxy crosslinker shows that the initial energy dissipation, tan δ, of the material is higher for the NX-4001 based prepreg, therefore indicating a higher dampening capacity. This is confirmed by additional resonance tests that show 37% improvement in vibration dampening at various frequencies (Data courtesy of SHD Composite Materials Ltd.).

Smooth Thermal Transition

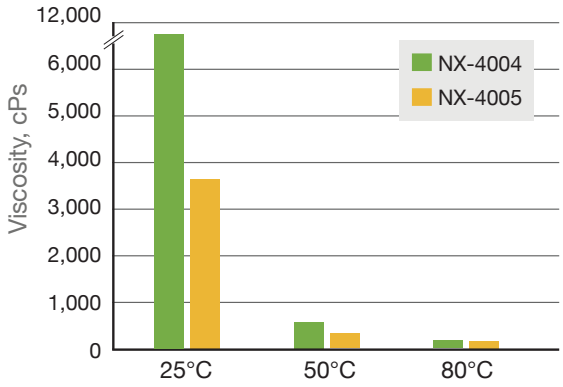
Both Storage Modulus slope and tan δ width suggest a smoother glass transition for the NX-4001 prepreg.



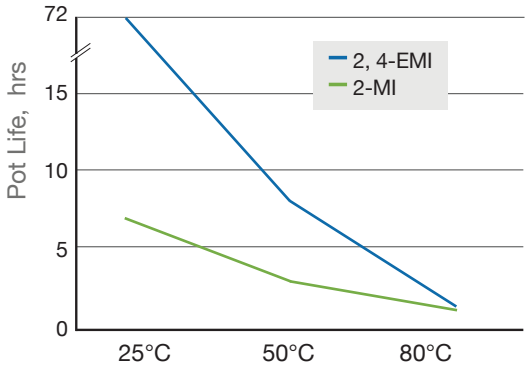
Catalyst Selection

The reaction between CNSL based novolacs and epoxy resins can be accelerated by a number of imidazole-type materials, Lewis acids and urones. Among the suggested accelerators are 2-ethyl,4-methylimidazole, 2-methylimidazole, blocked imidazole and boron trifluoride complex. The choice of the catalyst determines the pot life of the formulation and the cure time at different temperatures. It will also affect mechanical properties and final Tg. All of these novolac resins have a similar reaction kinetics and can be used in conjunction with solid or liquid epoxy resin, epoxy novolacs, and standard phenolic resins in solvent-based or solvent-free systems.

Formulation Viscosity and Temperature

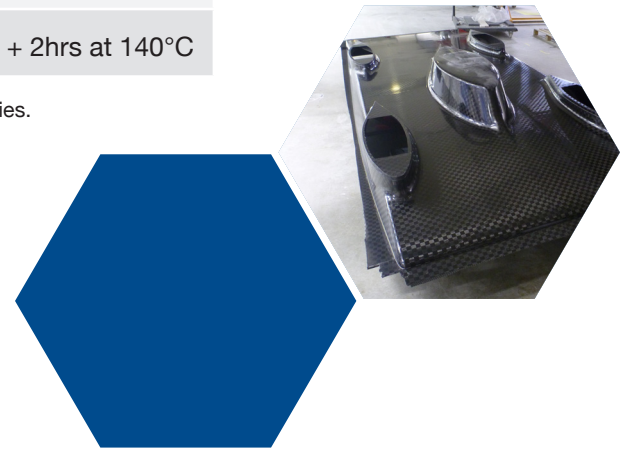


Pot life of Novolac Resins with Liquid Epoxy (EEW 190) and Imidazoles



Suggested Cure Schedule		
Accelerator	**Use Range (phr)**	**Cure Schedule**
Substituted imidazole	1.5-3	1hr at 100°C + 1hr at 120°C*
Blocked Imidazole	1-3	1hr at 120°C + 1hr at 140°C*
Blocked Lewis acid	3-7	2hrs at 120°C + 2hrs at 140°C
Urea-based	1-3	2hrs at 120°C + 2hrs at 140°C

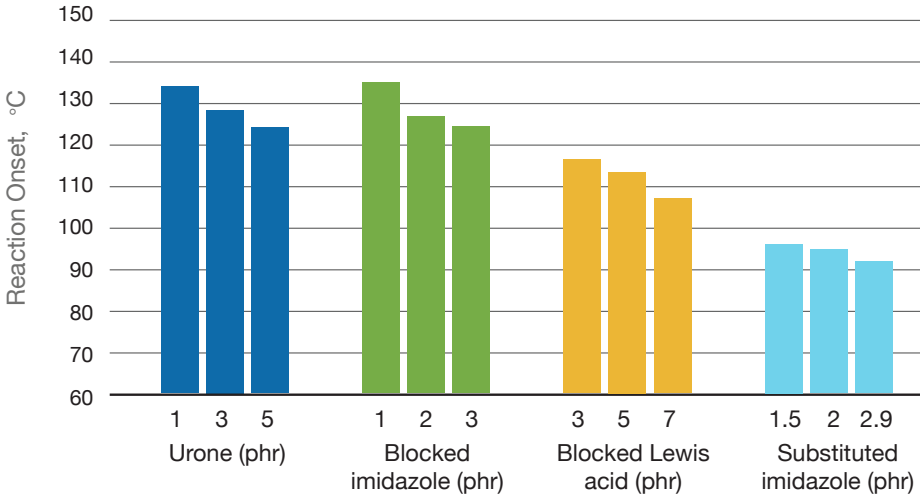
*Post cure can be used to obtain the highest Tg and mechanical properties.

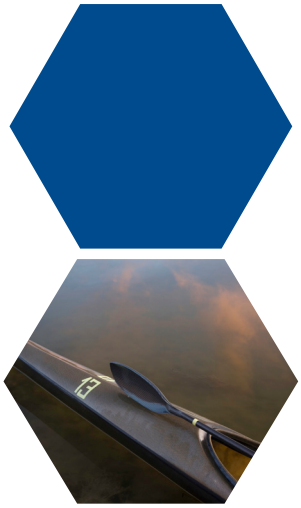


Novolac Resins for Epoxy Crosslinking

Reaction Onset

Reaction onset is dependent on the type and amount of accelerator used.

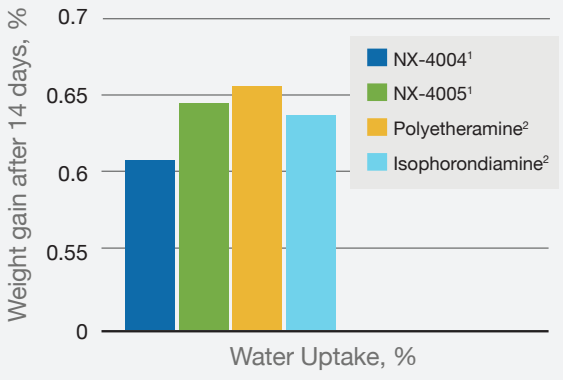




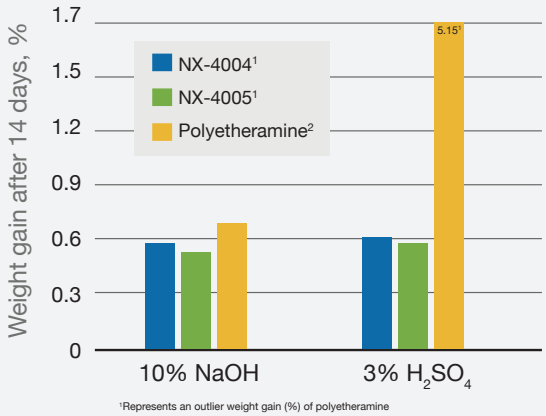
Excellent Chemical and Water Resistance

CNSL-based novolacs are very hydrophobic due to the long aliphatic side chain of the cardanol, which provides excellent water and chemical resistance, coupled with high bio-based content and a wide formulation latitude.

Water Resistance of CNSL Novolac Resin with Liquid Epoxy (EEW 190)



Chemical Resistance of CNSL Novolac Resin with Liquid Epoxy (EEW 190)



[1]Represents an outlier weight gain (%) of polyetheramine

[1]Formulation with 80% liquid epoxy resin (EEW 188), 20% CNSL based novolac resin, 2.9 phr of 2-ethyl,4-methylimidazole.

[2]Formulation with liquid epoxy resin (EEW 188)

Composite Applications

Composite Selection Chart

Process	Suggested Products	Application Industry	End Products
Hand Lay-up	LITE 2002 NX-5619 NX-5620 LITE 2401 LITE 2402 NC-513 UL 513	Marine	Boat hulls, panels
		Sport & leisure	Canoes, kayaks
		Automotive & transportation	Components: seating and panels
		Construction & housing	Small tanks, shower trays, etc.
		Other	Repair kits for composite parts
RTM	LITE 2002 NX-5619 NX-5620 LITE 2401 LITE 2402 LITE 2403 NX-4004 NX-4005 NC-513 UL 513	Sport & leisure	Boards and skis, paddles, helmets, protective apparel, suitcases
		Automotive & transportation	Truck chassis and cabins, leaf spring bars, doors and seating, engine bay components
		Wind energy	Wind turbine engine housing and other components
		Other	Auxiliary tanks for fish farming, small wastewater or sewage units, etc.
Vacuum Processes	LITE 2002 NX-5619 NX-5620 LITE 2401 LITE 2402 LITE 2403 NC-513 UL 513	Marine	Boats (construction and repairing)
		Wind energy	Wind blades
		Sport & leisure	Surfboards, canoes and kayaks, tennis rackets
Pultrusion	NX-4004 NX-4005	Construction & building	Reinforced profiles for buildings, facades, bridges, rebars for reinforced concrete, window/door frame elements
		Sport & leisure	Arrows, fishing rods
Prepreg	NX-4001 NX-4004 NX-4005	Automotive & transportation	Car body, semistructural panels
		Sport & leisure	Golf shaft, fishing rods
		Wind energy	Wind blades

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