QUALITY LASTS.

Handbook

for **Adiprene® LF** MDI Prepolymers
cured with **Duracure®** Blocked Curatives

Adiprene® LF
Low Free Prepolymers

Duracure®
Blocked Curatives

QUALITY WORKS.

LANXESS
Energizing Chemistry

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INTRODUCTION

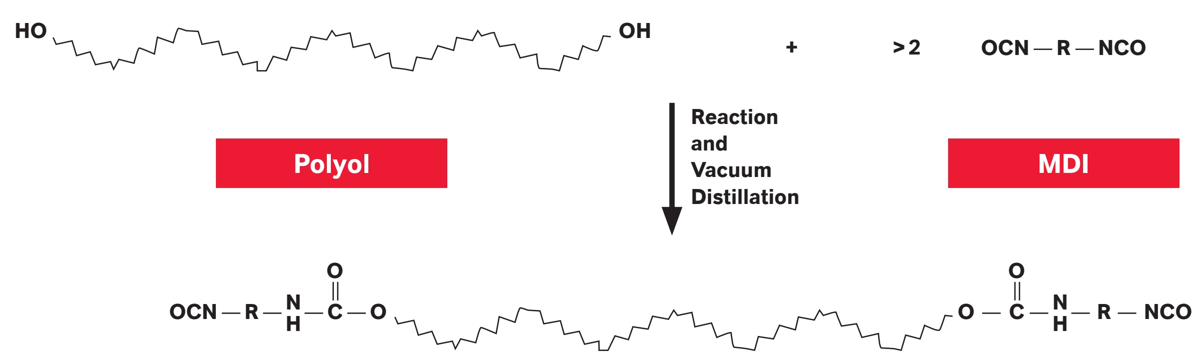
Adiprene® LF MDI urethane prepolymers cured with Duracure® blocked curatives result in novel two-component high performance urethane systems that offer a unique combination of processing, performance and value in use advantages versus other two-component urethane systems currently available in the market. These systems are based on low-free MDI prepolymer and a blocked amine curative compound.

These systems offer some unique processing and productivity improvements, including extremely long pot life and a quick demold time (thickness dependent). This enables them to be used to cast very large (in the order of tons) or very intricate parts. The resulting elastomers have excellent physical and engineering properties, including high cut and tear resistance, high flex fatigue resistance, low temperature flexibility, excellent dynamics and high temperature properties.

CHEMISTRY

Adiprene® LF MDI prepolymers are prepared by the reaction of Methylene Diisocyanate (MDI) with polymeric diols. After the initial reaction the prepolymer is passed through a vacuum distillation unit to reduce the amount of free MDI. Most prepolymer grades contain free monomer level of less than 1%, while certain grades, such as Adiprene® C930, contain as much as 3% free monomer. In comparison, conventional MDI prepolymers typically contain 10% – 20% free monomer. The formation of Adiprene® LF MDI prepolymer is shown in Figure 1.1. Adiprene® LF MDI prepolymers can be chain extended with Duracure® blocked curative to achieve the best combination of properties and processing. Although other curatives such as MBOCA, MCDEA, Vibracure® 2107, and Butanediol can also be used, the Duracure® blocked curatives provide unique performance characteristics as a result of similar structure of the Isocyanate and the curative that forms the hard segment. (Figure 1.2)

Figure 1.1: Formation of Adiprene® LF MDI Prepolymer



This symmetric structure leads to a urethane with excellent phase segregation leading to a high performance elastomer.

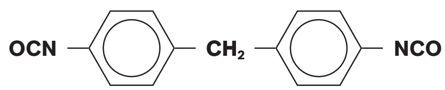
Duracure blocked curatives are blocked amines formed by the reaction of Tris (4, 4'-diaminodephenyl methane) with Sodium Chloride (NaCl). The particles of this coordination complex are dispersed in a plasticizer. The structure of salt complex of Tris (4, 4'-diaminodephenyl methane) is shown in Figure 1.3. Use of this curative requires special precautions and adherence to applicable regulations.

The salt complex is heat activated. Unlike other curatives that start reacting as soon as they are added to the prepolymer, Duracure® blocked curatives remain inactive as long as the temperature of the mixture is below the activation temperature.

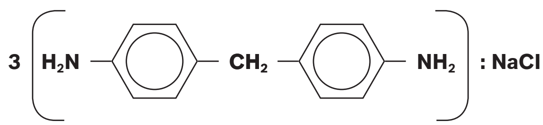
When the activation temperature is reached, the complex disassociates to release the amine which reacts rapidly with the prepolymer to form the urethane.

In comparison to conventional urethane systems, which typically have a pot life of minutes, the Adiprene® LF MDI with Duracure® blocked curatives system can have a pot life of several hours or longer. In many cases (mix held at lower temperatures such as 50–70°C) the pot life is in the order of 24–48 hours. The chain extension reaction is rapid once the deblocking temperature is reached and maintained.

Figure 1.2: Similar structure of MDI and Duracure® blocked curative

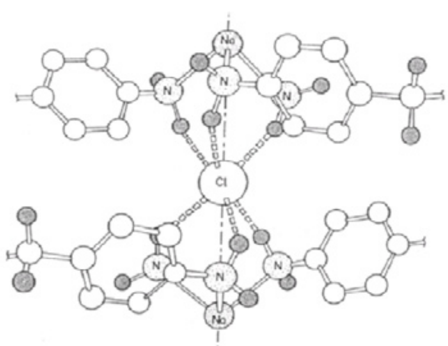


4,4'-Diphenylmethane Diisocyanate (MDI)



Tis(4,4'-diaminodiphenlmethane)-NaCl (TDDM)

Figure 1.3: Structure of salt complex of Tris (4,4'-Diaminodiphenyl Methane)



Safety and Handling

Your attention is directed to the Safety Data Sheets for this product.

This product contains the compound tris(4,4'-diaminodiphenylmethane)sodium chloride, a compound formed from 4,4'-diaminodiphenylmethane (otherwise known as 4,4'-methylene dianiline, or 4,4'-MDA).

On heating or on exposure to water, this compound can dissociate to form 4,4'-MDA. In mixtures with heated Adiprene® LF MDI prepolymers, such 4,4'-MDA quickly reacts with the surrounding isocyanate groups and is consumed during the curing cycle provided the components are well mixed in the intended ratio.

Because it liberates MDA, Duracure blocked curatives are suitable only for well controlled industrial use with proper training and protective equipment. While it is a liquid curative and therefore does not have dust exposure potential, proper protective equipment that eliminates potential for skin contact is required. In the USA, its use is regulated by OSHA under the regulation 29CFR 1910.1050. This places a number of additional restrictions and requirements on those using this curative. For further explanation of the OSHA requirements, please see OSHA document 3135 (https://www.osha.gov/Publications/OSHA3135/osha3135.html) or contact Chemtura for more information.

DURACURE blocked curatives should be protected from elevated temperatures or water before being mixed into Adiprene® LF MDI prepolymers, since this can generate higher levels of free 4,4' MDA. The substance 4,4-MDA is considered to be a potential human carcinogen. It has been shown to produce cirrhosis of the liver and kidney damage in rats and dogs in experimental studies. It is known to have caused hepatitis in industrial workers in the 1970s.

Comparison of Adiprene® LF MDI cured with Duracure® Blocked Curatives to conventional Urethane Systems

These unique urethane systems provide unique processing and performance advantages in comparison to other conventional two component systems. The processing of these systems is significantly simplified in comparison to conventional two component systems (Table 1.1). These advantages include easy 4-step processing, virtually unlimited pot life, quick demold time, better ratio control, reduced exposure to Isocyanate monomers, the ability to use a hand batch process, and large scale batch processing using a day tank or a meter-mix machine.

Table 1.1: Processing steps of Adiprene® LF MDI Prepolymers cured with Duracure® Blocked Curatives compared to traditional two component Urethanes

Adiprene® LF MDI with Duracure® blocked curatives	Typical two-component system
■ Heat activated curing. Mix stable at 50-70˚C for prolonged period. ■ No curative melting. ■ No curative dust issues. Easy handling at room temperature. ■ Quick mold fill is not required. ■ Better ratio control. ■ Quick demold time (10-20 minutes) ■ Easy 4 step processing. Can use batch process in a day tank or a conventional two component machine.	■ Cure reaction begins as soon as curative is added. ■ MBOCA has to be melted at 110˚C. ■ Dust issues with MBOCA. ■ Quick mold fill is required to prevent gel formation. ■ Much more difficult to control ratio (especially in Butanediol (BD) cured systems) ■ Much longer demold time (30-60 min)

Table 1.2: A comparison of Curative Characteristics

Urethane systems	Adiprene® LF MDI with Duracure® blocked curatives	MDI Prepolymer Butanediol (BD)	TDI Prepolymer MBOCA	TDI Prepolymer MCDEA
Physical state of curative (at 30°C)	Liquid	Liquid	Solid	Solid
Pot life (minutes)	300-1500	3-10	3-10	2-4
Demold (minutes)	5-30	20-60	20-40	10-30

Types of Adiprene® LF MDI prepolymers

Adiprene® LF MDI prepolymers are classified into three product families: polyethers, polyesters and polycaprolactones. The list below shows the existing grades of Adiprene® LF MDI prepolymers that can be cured with Duracure blocked curatives.

Adiprene® LF MDI / Polyesters:

1) Adiprene® S930* – 93A Ester
2) Adiprene® LFM S350X – 90A Ester
3) Adiprene® LFM S265X – 85A Ester
4) Adiprene® LFM S223X – 80A Ester
5) Adiprene® LFM S183X – 70A Ester

Adiprene® LF MDI / PTMEG Polyethers:

1) Adiprene® LFM E615X – 53D
2) Adiprene® LFM E500X – 95A
3) Adiprene® LFM E320X – 90A

Adiprene® LF MDI / Polycaprolactones:

1) Adiprene® LFM C700X – 60D
2) Adiprene® C950* – 95A
3) Adiprene® C930* – 93A
4) Adiprene® LFM C350X – 90A

Other urethane prepolymers are occasionally used with Duracure blocked curatives depending on the need (lower/higher hardness, cost etc).

They are as follows:

1) Vibrathane® 6060 – 60A polycaprolactone
2) Adiprene® LFG 740D – 65D polyether
3) Adiprene® LF 830 & Adiprene® LF 800 – 80-83A PTMEG ether

* These products contain >1% free MDI.

PROCESSING

Systems made from Adiprene® LF MDI with Duracure® blocked curatives have unique processing characteristics. These systems are very versatile and can be processed in several different ways. Processing becomes quite easy once fully learned and properly set up. It is however, different from processing other urethane materials and has several nuances. There are three common ways in which Adiprene® LF MDI prepolymers are processed while Open Casting. These techniques are outlined in detail below. Additionally several other processes (other than Open Casting) are listed and outlined briefly.

Initial Preparation before Processing

There are several steps that need careful attention before casting these systems into molds.

Prepolymer Preheating

Adiprene LF MDI prepolymers are solid at room temperature. Devices such as melting ovens, thermostatically controlled warming blankets, or drum heaters can be used for pre-heating these prepolymers. Band heaters are generally not recommended as they promote localized hot spots. Approximate preheat times in a 70 °C (158 °F) oven are:

5 gallon pail	16 – 24 hours
55 gallon drum	36 – 48 hours

Resins exposed to temperatures lower than 24 °C during shipment and/or storage may require longer meltdown times. Do not loosen the bung to relieve pressure while melting. This will lead to moisture contamination and gel formation.

Adiprene® LF MDI prepolymers may undergo some separation during storage. Therefore it is critical that they are rolled prior to use to ensure homogeneity. Alternatively, if charging full containers to a mix tank, mixing can be accomplished in the tank itself. If it is possible to roll the drums while melting it not only lowers melting time but also improves homogeneity. To ensure
homogeneity and thorough melting it is recommended that a clean metal rod is inserted into the container to check for sediments/solids at the bottom. Rolling the drum for approximately 15 – 30 minutes after melting is generally enough to ensure homogeneity. All Adiprene® LF MDI prepolymers when molten and homogenized are free of striations and solids.

The NCO content of Adiprene® LF MDI prepolymers decreases with time (as all urethane prepolymers) on exposure to heat. Prolonged heat exposure will result in lower than expected final hardness and physical properties of the cured elastomer and longer de-mold times. Maximum recommended heating times as a function of temperature are shown below.

Maximum Heating Times as a Function of Temperature

Temperature	Time
60°C (140°F)	2 Weeks
70°C (158°F)	3 Days
82°C (180°F)	36 Hours
93°C (200°F)	12 Hours
100°C (212°F)	8 Hours

Heat history is cumulative over all heating cycles and must be added to determine total effect.

PROCESSING

Curative Preparation

Duracure® blocked curatives are dispersions of micron sized curative particles (blocked amine complex) in plasticizer. These curatives are liquid at room temperature and the particles tend to settle over time. Thus homogenization of the curative is critical to achieve good properties in the final urethane. Care should be taken to store and process Duracure® blocked curatives at room temperature. Since the curative is heat activated, storing or using the material at temperatures higher than 40°C (104°F) is not recommended. The ideal storage temperature is <30°C (<86°F). Required rolling times at 30°C (86°F) at 20–50 rpm are:

5 gallon pail	6 - 12 hours
55 gallon drum	18- 24 hours

To ensure homogeneity and thorough melting it is recommended that a clean metal rod is inserted into the container to check for sediments/solids at the bottom. When the rod is removed from the container if solids are seen on the rod then it indicates incomplete rolling. Continue rolling until all solids are dispersed. Drum tumblers can also be used but they are a more expensive option than a roller but can disperse material faster. Other options to disperse Duracure® blocked curatives include using a paint shaker or using a drill with a mixing blade attached. Using a paint shaker and drill mixer, these curatives can be dispersed in 20–30 minutes. Both options are viable only if using smaller containers such as 5 gallon pails. A drum roller or drum tumbler is necessary when using drums to ensure adequate mixing takes place.

Duracure® Activator Q1

is a curative catalyst that is used to lower the deblock temperature of Duracure® blocked curatives to 100–115°C (212–240°F) depending on the loading of Duracure® Activator Q1. Even though Activator Q1 lowers the deblock temperature of the curatives, it does not adversely affect the stability/pot life of the mixture at 50–70°C (122–168°F). Typical loading of Duracure® Activator Q1 is 1–2 parts per hundred by weight of prepolymer.

As a liquid (at room temperature) with reasonable viscosity (approximately 500–700 cps), Duracure® Activator Q1 is suitable for use with both hand batch and machine processing.

Duracure® Activator Q1 can be mixed with Adiprene® LF MDI prepolymers or added to the mixture of prepolymer and curative, but should not be added directly to Duracure® blocked curative as it unblocks the curative. Once added to the prepolymer or the prepolymer-curative mixture, the catalyst remains active for 4–6 hours. The catalytic activity wears off after 4–6 hours. Duracure® Activator Q1 is available in three different packages, 1 gallon cans, 5 gallon pails and 55 gallon drums.

Mold and Oven preparation

Molds used in processing of Adiprene® LF MDI prepolymers with Duracure® blocked curatives can be made from metals such as Aluminium or Steel. Materials such as Polyurethanes, Silicone, Epoxy and Wood are not recommended for use with these systems because of their low heat transfer. Uncatalyzed systems require a minimum mold temperature of 127°C (260°F) however a lower mold temperature such as 100–115°C (212–240°F) can be used with the addition of Duracure® Activator Q1. In order to maximize physical properties, molding temperatures of 127–140°C (260–284°F) are recommended. Care should be taken to measure the mold temperature with a contact thermocouple to ensure that the mold is at the right temperature. It is important to note that the oven needs to set a 5–20°C higher than the required mold temperature to compensate for heat loss.

Shrinkage

While designing the mold the coefficient of expansion of the mold material must be balanced against the shrinkage of the cast polyurethane. The shrinkage of polyurethane is predominantly a function of the molding temperature and the exotherm of the cure reaction. Conventional urethane materials such as TDI prepolymers cured with MOCA or MDI prepolymers cured with Diols are cured at 100˚C (212˚F). The shrinkage of conventional polyurethanes is typically 1-2%. Since these Adiprene LF MDI prepolymers are cured between 127-140˚C (260-284˚F), the shrinkage is higher. Typical shrinkage rate of these systems is 1.5-3%.

Pigments

Pigment selection is very important for these systems. Pigments that use polar plasticizers (such as Benzoflex) or polyols as carriers have a tendency to reduce pot life of the system as they accelerate deblocking of the curative. It is recommended that pigments based on Diisodecyl Phthalate (DIDP), Diisononyl Phthalate (DINP), Dioctyl Adipate (DOA) or Dioctyl Phthalate (DOP) plasticizers be used with these systems. Additionally, any pigment or other ingredient to be used in a these formulations for the first time should be tested for pot life stability before a long stable pot life is relied upon.

Color Stability Additive

Unpigmented systems cure to a pale yellow/off-white color. However when exposed to hot air the surface of the urethane that is exposed to air discolors to a medium to dark brown color. This may lead to inconsistencies in appearance although it does not affect performance. This cosmetic issue can be mitigated by simply using dark pigments, but in cases where that is not possible it is recommended that a color stabilizing additive be used. Weston PDDP is a phosphite antioxidant that can be used as a color stabilizer for Adiprene® LF MDI prepolymers. Weston PDDP at 0.3 % by weight of prepolymer is adequate in maintaining good color stability.

Degassing Aid

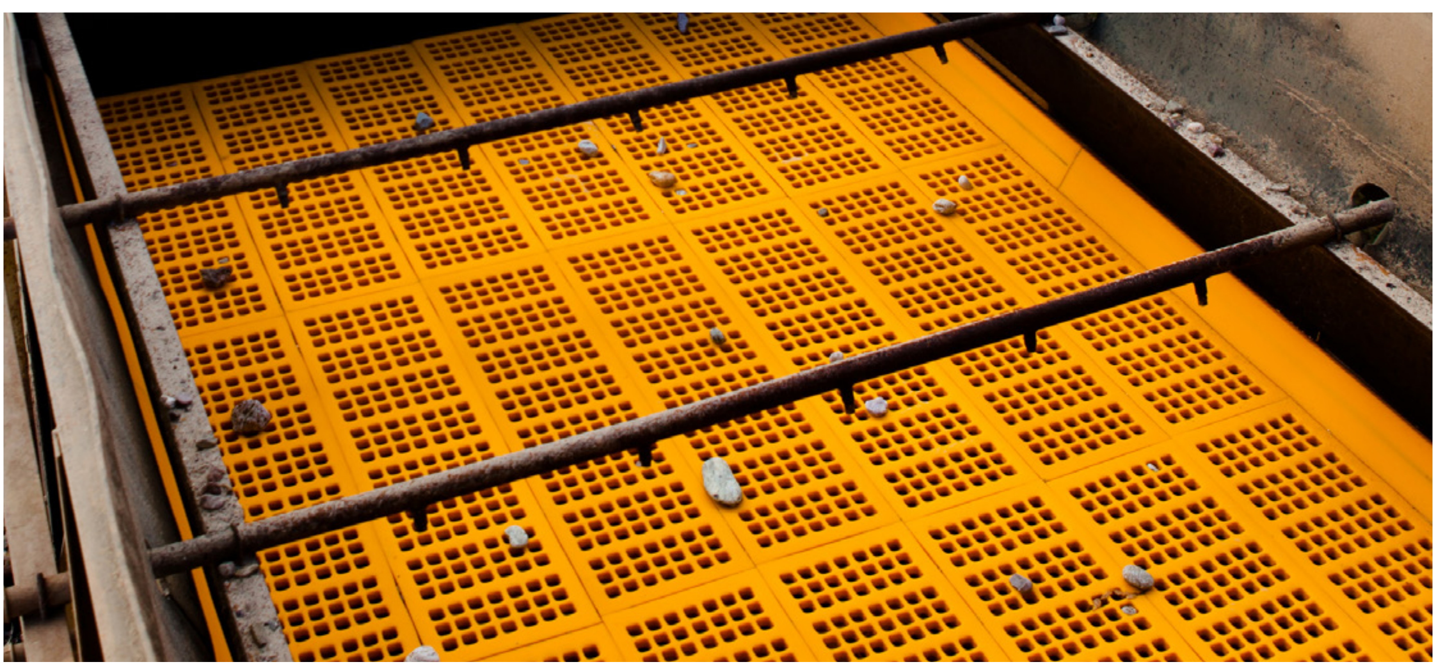
Certain Adiprene® LF MDI prepolymers, such as Adiprene® LFM S265X, are very viscous, and degassing them without any degassing aid is extremely difficult. BYK® A560 is a degassing aid which works extremely well in degassing the mixture these systems. Typical loading is 0.1 – 0.25 % by weight of prepolymer.

Other Additives

Specific formulation additives (fillers, plasticizers etc) should be tested to check for stability of the mix before use. It is important to use non polar additives if long pot life is desired. It is highly recommended that small batches be prepared with specific additives to understand effect of additives before starting large scale production.

Care should be taken to reseal all open containers of both Adiprene® LF MDI prepolymers and Duracure® blocked curatives under a nitrogen blanket. These products have moisture sensitivity that is similar to other urethane prepolymers.

Please refer to Adiprene® LF MDI prepolymers, Duracure® blocked curatives, Duracure® Activator Q1, Weston PDDP, and BYK® A560 technical datasheets and MSDS for more information.



Processing Conditions

Processing conditions for different Adiprene LF MDI prepolymers varies depending on the polyol backbone and the hardness. Table 2.1 shows the ideal process conditions which are useful in most applications.

Process Techniques

The three commonly used processing techniques for Open Casting these systems include

- Hand Casting/Drill Mix process
- Batch Tank Process and
- Multi Component Mix Machine.

Hand Casting/Drill Mix Process

Once the initial preparation of prepolymer and curative system is complete (outlined above), the system can be mixed using a spatula or a mixing blade such as the Hanson blades or Jiffy mix blade. When you pour out the desired amount of Adiprene LF MDI prepolymer, fill the head space of the drum with nitrogen.

Table 2.1: Process conditions for various Adiprene® LF MDI Prepolymers

Adiprene® LF MDI Prepolymers	LF MDI Ethers	LF MDI Esters Low Hardness	LF MDI Esters	LF MDI Polycaprolactone	
	LFM E320X LFM E500X LFM E615X	LFM S183X LFM S223X LFM S265X	LFM S350X S930 LFM SE478X	LFM C350X	C930 LFM C700X
Duracure® Temperature, °C			20–25		
Prepolymer Temperature, °C	50	75	75	50	70
Blend Storage Temperature, °C	50	70	70	50	70
Pot Life @ Storage Temperature	>24 hours	4 hours	>24 hours	>24 hours	>24 hours
Minimum Mold (Curing) Temperature, °C	120	110	127	115	127
Mold Temperature (Curing) with Duracure® Activator Q1 (1 phr), °C	115	Activator not needed	115	Activator not needed	115
Post Cure Temperature, °C			140		

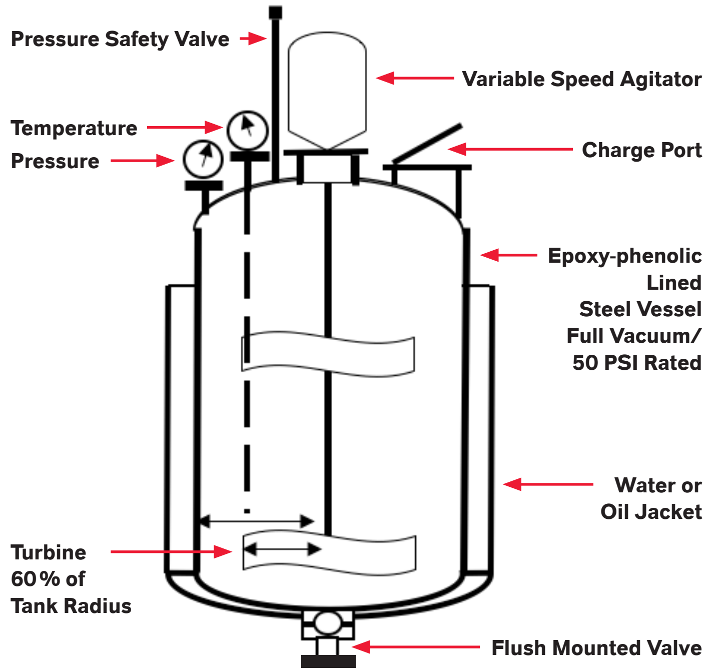
Re-tighten bung. Add pigments (DIDP or DOA based) and degassing agent (BYK A560 – 0.1wt% prepolymer). Calculate the amount of Duracure blocked curative for the prepolymer by using the equivalent weight (EW) on the drum/COA or a midpoint of 250. Pour out curative into a separate container. If using a mixing vessel with limited head space, degas the curative until foam head breaks and bubbling subsides to a slow rate. Ideal vacuum is 29 inch Hg (982 mbar) at sea level. Cap head space of the drum with nitrogen and retighten the drum bung. Adjust Adiprene® LF MDI prepolymer to the mixing temperature indicated in the table and degas the material (Vacuum at 29 in Hg). The above noted prepolymer mixing temperatures are recommended if the mix (prepolymer + curative) will be held for several hours. Add the curative to the prepolymer under agitation/stirring. Mix to uniform consistency (approx 1-2 min).

It is important to add Duracure® blocked curative to the prepolymer while mixing. Failure to do so will result in parts with irreversible white specs in the cured urethane, particularly when elevated prepolymer temperatures are used. Scrape sides and bottom while mixing. Avoid whipping high levels of air into the mix to ensure easy degassing. Degas mix until foam head breaks and bubbles subside. (Vacuum at 29 in Hg). Mix is stable for several hours in mixed state (at 50–70°C under nitrogen). Care should be taken to ensure that the mix is under nitrogen in storage. Constant Agitation/Rolling of the mix is recommended. Pour mix into a hot mold (mold to be heated to 120–140°C). Demold time is controlled by the thickness of the urethane. For best results post cure the urethane after demold for 16–24 hours at 120–140°C.

Batch Tank Process

Systems made with Adiprene® LF MDI cured with Duracure® blocked curatives can be readily mixed and held in a well-designed tank. It is highly recommended to utilize a jacketed tank (water or oil) to prevent any localized hot spots that could cause premature deblocking of the curative. Tanks should be flushed with Diisononyl Phthalate (DINP) or other compatible plasticizer before and after use of the tank to ensure that no contaminants are present that could deblock the mixture. The mix preparation procedure is similar to that described in the hand batch process. A high degree of mixing with low air entrapment will decrease the time required for mixing and degassing. A large motor and turbine agitator will meet most of the mixing requirements. The prepolymer and curative system should be continuously stirred and maintained under a nitrogen blanket or vacuum. The batch tank offers several advantages including limiting the number of prepolymer curative mix produced per day, good ratio control, product to product consistency, simple operation, low capital and operating costs.

Figure 2.1. Batch tank used in preparation of Adiprene® LF MDI Prepolymers Cured With Duracure® Blocked Curatives



Due to the difficulties related to the removal of cured urethane from a tank, it is recommended that any residual material be flushed from the tank within 24 hrs. The holding time may be extended once stability studies are completed for specific formulations. Furthermore, it is important to check the impact of all additives on blend stability before adding to a mixing tank.

Multicomponent Mix Machine

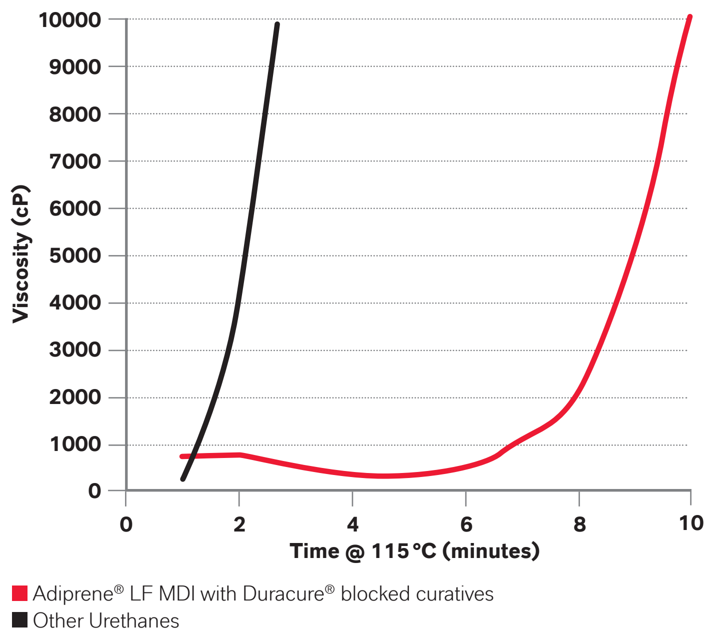
A multicomponent mix machine used for processing other urethanes can be used for Adiprene® LF MDI prepolymers. Several processing conditions can be changed (if long pot life is not needed, which is usually the case on a machine) to improve the productivity. Traditional curatives such as MBOCA and 1, 4 Butanediol are much lower viscosity than Duracure® blocked curatives. Thus, for machines with smaller curative pumps and lines, larger lines may need to be installed to ensure effective dispensing of Duracure® blocked curatives. Tanks should be flushed with Diisononyl Phthalate (DINP) or other non-polar plasticizers before and after use of the tank. Trace amounts of diols and other amines in the curative lines can deblock the curative and plug the lines.

The prepolymer and curative should be degassed prior to mixing. Suggested temperatures for machine mixing are 70-95 °C (158 to 203 °F) for the Adiprene® LF MDI prepolymer and 20–50 °C (68 to 122 °F) for Duracure® blocked curatives. The recommended mix head temperature is 70–95 °C (158 to 203 °F). This will lead to a process with pot life of 10–20 minutes. This lowers the viscosity of the mix and also hastens demold time. As noted earlier, the chemical stability of Duracure® blocked curatives decreases substantially above 50 °C (122 °F), so it should not be processed above that temperature.

Recommended cure profile

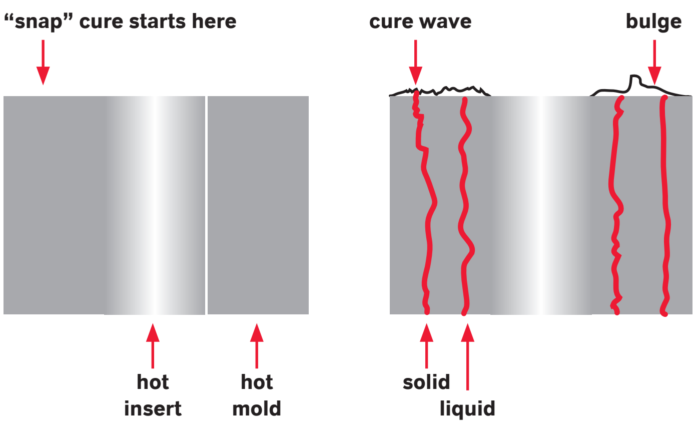
These systems have a unique cure profile. The viscosity of other urethane systems constantly raise in viscosity once the curative is mixed in as the reaction between the prepolymer and curative starts instantly. Since Duracure blocked curative is heat activated an increase in mix viscosity is not seen. As the prepolymer and curative mix is poured into the hot mold, the viscosity of the mix initially decreases as the temperature of the mix increases. This allows for easier filling of the mold, especially if the mold is very intricate. As the temperature of the mix rises and the mix approaches the deblocking temperature the viscosity rises sharply to result in a complete cure of the part. This is shown in figure 2.2

Figure 2.2: Cure profile of Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives compared to other urethanes



These systems are also very unique in the way they solidify in the mold. Once the prepolymer and curative mix is poured into the hot mold and the temperature of the mix reaches the deblocking temperature, the mix closest to the insert and molds start curing. Thus, cracking or weakness at the bond line is reduced. The exotherm produced by the un-blocking and curing at the heated surfaces pushes initiates a deblocking waves that travels through thick parts. Thus the polyurethane formed by Duracure blocked curatives last at the center. This may lead to bulges at the surface near the center of the part as the liquid is pushed upwards due to the cure wave. It is also possible to see certain eruptions on the surface of the part. This is perfectly normal and if undesired can be mitigated by using Duracure Activator Q1, a closed mold or covering the open mold with a hot plate. This quick, “snap” cure also means quicker demold time with higher durometers at de-mold. These systems, unlike other urethanes, are very near full durometer when demolded.

Figure 2.3: Cure profile of Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives



Post curing of urethanes formed by this reaction is critical to achieve excellent high performance properties. Typical post cure cycle is between 127–140 °C for 16–24 hours. Higher post cure temperature will yield even better high performance properties.

Other Molding / Processing Techniques

Although not as common as open casting other molding techniques may be used for special applications. They include:

Liquid Injection Molding (LIM)

These systems lend themselves very well for using LIM to produce defect free parts. The urethane mix can be fed to the LIM machine either through a two component machine or the day tank. The day tank process is best suited for this as a large batch can be produced followed by feeding the LIM machine either through pressure or through gear pumps. Due to the snap cure characteristics of Duracure® blocked curatives, it is possible to inject the low viscosity liquid into a hot mold and get high productivity. Complex parts can be produced with relative ease using this process.

Centrifugal/Spin Casting

is used to produce parts with fine detail relatively free from air. It is also convenient to cast bubble free sheet stock using centrifugal casting. The mold is attached to a horizontal spinning disk which rotates at a speed of 5–30 m/s. The mold is designed to add the polyurethane mixture at the center of the disk. Air vents are required to prevent air entrapment on the horizontal surfaces. The centrifugal forces move the denser polyurethane to the circumference of the mold and the air moves to the center. With conventional materials the mold does not have to be heated during the casting process. However since these systems are heat activated the mold has to be heated continuously while spinning. It is important to have the mold balanced and securely locked in place before the spinning process is started. It is also important to have safety guards capable of retaining the mold if it comes loose from the equipment.

Vacuum Casting

is another method to produce parts that are relatively bubble free. The low viscosity of these systems (since the viscosity is not rising constantly) lends itself well to the process. The mixing can be done under vacuum and the molds filled from the bottom by drawing the material under vacuum. Since these systems have extremely long pot life, the material can be stored in a day tank and mold filled using vacuum to draw the material out of the tank. This greatly reduces bubble formation.

Curing large parts

The size of part can be a limitation with several polyurethane formulations due to limited pot life. Typical two component hot cast systems have pot life in the range of 1–20 minutes depending on the hardness (% NCO) and chemistry. With systems made from Adiprene LF MDI cured with Duracure blocked curatives, the pot life is independent of the hardness of the part and is solely depending on the processing temperature. Thus, it is possible to control the mold temperature between 50–70°C while filling the mold and slowly ramping the temperature to deblocking temperature of the mixture (127–140°C). Parts as large as 4 metric tons (approximately 9000 lbs) have been cast using these systems.

A slow ramp study was done to understand the suitability of systems for such a process. The experiment was performed on Adiprene LF MDI prepolymers cured with Duracure blocked curatives to determine if a slow temperature ramp profile has an effect on the curing capabilities of the materials. Parts were stored at their recommended storage temperatures and times prior to the start of the slow ramp.

Table 2.2: Slow ramp study of various systems made with Adiprene® LF MDI prepolymers and Duracure® blocked curatives

Material	Storage	Ramp Rate	Notes
Adiprene® C930	16hrs @ 70°C	10°F every 20 min	Cured ok
Adiprene® S930	24hrs @ 70°C	10°F every 10 min	Cured ok
Adiprene® LFM S350X	16hrs @ 70°C	10°F every 20 min	Cured ok
Adiprene® LFM S265X	4 hrs @ 70°C	10°F every 20 min	Cured Soft on bottom
Adiprene® LFM S223X	4 hrs @ 70°C	10°F every 20 min	Cured Soft on bottom
Adiprene® LFM S183X	4 hrs @ 70°C	10°F every 20 min	Cured Soft on bottom
Adiprene® LFM E500X	16 hrs @ 50°C	10°F every 20 min	Cured ok
Adiprene® LFM E320X	16 hrs @ 50°C	10°F every 20 min	Cured ok

It was found that initially Adiprene® S930 did not cure properly with a 10°F ramp every 20 minutes. The rate was increased to 10°F every 10 minutes at which point the part cured properly. While the soft esters (S850, S800, and S700) are stable at 70°C for approx 4 – 6 hrs, they did not cure properly with the slow ramp up. The bottom cured up with varying hardness (all softer than it should have been) and the sides were close to hardness.

It is recommended that the Adiprene S930 have a more aggressive ramp up compared to the other materials. It is also recommended that Adiprene® LFM S265X, S223X, and S183X not be used in a slow ramp/cold mold.

Bonding

The below procedure is currently used in our internal laboratories. Other methods can also be used. Bonding agents other than Chemlok 218, 219 and 213 may be used but it is important to note that the molding process for these systems requires higher temperatures and thus the bonding agent should be able to withstand temperatures in the range of 127 – 140°C. For more information about bonding to metal please contact your bonding agent supplier.

1. Clean/scrub bonding surface thoroughly (we currently use Triton X-100 in water).
   Note: Once surface is cleaned, do not touch/contaminate surface
2. Let surface dry
3. Grit blast (we currently use Aluminium Oxide 30 Grit).
4. Immediately and thoroughly clean off grit agent (we currently flush the part surface with clean Toluene)
5. Allow to dry
6. Immediately Apply 1st coat of Chemlok 218 (we currently use 2:1 ratio of Chemlok 218:MEK)
7. Allow to dry
8. Immediately Apply 2nd coat of Chemlok 218 (we currently use 2:1 ratio of Chemlok 218:MEK)
9. Allow to dry
   Note: Final Chemlok thickness should be between 0.5-1.5 mil thick
10. Immediately Protect surface so no contamination occurs
11. Prebake the metal with bonding agent at 250°F (metal surface temperature) for approximately 2 hours before casting.

Finishing

Polyurethane formed by the reaction of Adiprene LF MDI prepolymers and Duracure blocked curatives yield very tough elastomers. Many standard urethane finishing processes can be used with these systems, however the one process that cannot be used is dry grinding. Since the final elastomer is extremely tough (discussed in detail in Chapter 3), the elastomer has a tendency to overheat and melt when dry grinding is used. It is recommended that a sharp cutting tool be used while machining these elastomers. They are machined relatively easily if a sharp cutting tool is used. Use of coolants while cutting is recommended to ensure that heat build up does not occur during finishing.

Processing Issues and Troubleshooting

These systems are easy to process and handle, however the processing is unique to the system. There are several differences between these and other urethane formulations (as discussed in previous sections). Thus, troubleshooting processing problems is also somewhat different.

Troubleshooting Guide

Problem Description	Probable Cause	Solution
1) Final part low in durometer compared to TDS 2) Part easily tears	Incomplete mixing of prepolymer	Roll prepolymer pail.
	Aging of prepolymer	Ensure prepolymer has not been heated more than what is recommended in the TDS.
	Moisture contamination	Ensure prepolymer container was sealed while melting and always capped with nitrogen in use.
	Incomplete dispersion of curative	Roll curative pail as per recommendation. Check for solids at the bottom before use.
	Mold temperature is low	Curing temperature was very low. Ensure mold is at recommended temperature.
	Blend storage Time too long or at wrong temperature	Excessive storage time could lead to low durometer with Adiprene LFM S265X, S223X, and S183X
Short Pot Life	Heated curative	Ensure curative was not heated in the oven. Always store Duracure blocked curatives at room temperature (<30°C). If Duracure blocked curatives were heated, discard the product.
Short Pot Life	Mixing machine will cause shear heating which may raise the temperature above the deblock temperature.	Lower RPM's of mixing machine or adjust prepolymer and curative temperature so shear heating does not spike the temperature above deblock.
Cheesy appearance/feel. Material liquid for prolonged period even after exposure to heat.	Initial mold temperature is inadequate for deblocking	Ensure mold temperature is at the recommended temperature before material is poured.
Major color differences within the same product extracted from the same mold / same post cure cycle	Oxidation of the amine due to air exposure. Different levels of air exposure causes discoloration.	Use dark pigments such as black, blue, green etc or use Weston PDDP color stabilizer to prevent oxidation
Parts are domed on the surface (no flat surface). Eruptions are present Top surface is cracked	Material cures last at the center (described in section 2.4) causing doming, eruption and cracking	Use Duracure Activator Q1 to accelerate green strength build up to prevent doming. To prevent eruptions and cracking of surface cover the open surface with a metal plate that is at mold temperature (127°C-140°C).
Bubbles in the final part (Hand/Batch mix)	Air entrapment	Ensure adequate degassing before pouring the part. Pour along the wall of the mold or insert to prevent splashing.

Problem Description	Probable Cause	Solution
Uneven vertical surfaces and cracking along vertical and horizontal faces of the part	Typically seen in Adiprene LFM E500X, E615X and C700X. These materials are more prone to cracking (higher % NCO materials) and shrinkage.	Cure with 1-2 parts Duracure Activator Q1 along with high mold temperature (do not use slow ramps or lower mold temperature). Always cover the open surface of the mold with a heated metal plate to prevent material loss and shrinkage along the vertical face of the part (Please see appendix for further information).
Micro bubbles in final part (Batch Tank mix)	Air entrapment. Leaving the agitator on after applying nitrogen pressure will result in nitrogen entrapment causing micro bubbles in cured part.	Ensure that agitation system is off when mix is pressurized using nitrogen.
Bubbles in the final part (Machine Mix)	Air entrapment. If the mix head is run at high speed and a higher viscosity material is used then mix head may not be full.	Ensure Mix head is running full. Reduce mix head speed. Increase pump speed. Increase back pressure in mix head.
Striations in the cured part	Incomplete mixing	Mix thoroughly. If batch mixing ensure agitator diameter is at least 60% that of diameter of tank. While hand mixing ensure walls are scraped and figure 8 mixing is used for complete mixing.
Flow marks	Material curing while being poured into the mold	Increase fill rate of the mold or use a slow ramp to cure.
White specs seen in the cured part	Curative added to the prepolymer without _agitation	Ensure curative is always added while the prepolymer is agitated.
Skin formation when surface is torched	Premature deblocking of mixture	Since Duracure blocked curatives are heat activated the high temperature of a torch deblocks the surface leading to skin. This step is not required to release air in the system. With adequate degassing and proper pouring this step is eliminated
Fumes while curing from the part	Duracure blocked curatives are dispersions of curative particles in Dioctyl Adipate (DOA). At high temperatures (>130°C) fumes of DOA are liberated.	Ensure adequate ventilation of the oven.
Parts are off ratio when machine mixed	Duracure blocked curatives are more viscous than standard curatives such as MOCA or BD. The curative lines are too small.	Check if bigger lines can be installed. Increase temperature of curative lines to 50°C (122°F). Note: Do not raise temperature >50°C
Mold leakage	Section 2.4 describes the cure profile of these blocked systems. The viscosity of the system drops before increasing leading to leakage	Ensure mold are well sealed (does not have to be airtight). Seal using a high temperature silicone sealant.
Gel particles in prepolymer	If unopened container inform sales or customer service. If opened and re-sealed nitrogen was not used.	Always cap all open containers of prepolymer and curative with nitrogen to prevent moisture contamination.
Solid chunks at the bottom of curative pail	Insufficient rolling	Continue to roll until chunks disappear and a uniform dispersion is obtained

PROPERTIES

There are a number of factors that influence the final property of polyurethanes. The most important of these are:

- Type of Polyol and Molecular Weight
- Type of Isocyanate
- Type of Curative
- Curative Ratio/Stoichiometry
- Processing conditions

Systems made with Adiprene® LF MDI and Duracure® blocked curatives provide some unique properties due to the superior hard segment and phase segregation. As discussed in prior chapters this is due to the similar structure of prepolymer and curative. By processing these systems under the right conditions an excellent high performance system can be obtained. Chapter 3 discusses performance of these systems under various test conditions.

Physical Properties of Prepolymer and cured Elastomer

For all physical properties, please refer to the relevant technical data sheets for Adiprene® LF MDI cured with Duracure® blocked curatives. These systems are characterized by long pot life. They are also characterized by high tear values and low compression set indicating excellent phase segregation. They also have high abrasion resistance and are known to perform very well in applications requiring dry sliding abrasion resistance. Another interesting feature of the polyester-based versions of these systems is the high Bashore rebound. Esters are usually characterized by low rebound in comparison with ether based urethanes because of decreased phase segregation due to hydrogen bonding of ester linkages (with other urethane systems polyesters have bashore rebound in the range of 25–35%). The superior MDI-Amine-MDI hard segment offers improved phase segregation leading to improved properties.

Properties of Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives compared with other urethane systems

Table 3.2 compares physical properties of Adiprene® LF MDI esters with TDI esters. Adiprene® LFM S223X has better engineering properties. Along with long pot life, these systems offer better tear, elongation, compression set and bashore rebound all indicative of a superior hard segment. Table 3.3 compares Adiprene LF MDI ethers with TDI and MDI ethers and a similar behaviour is observed.

Table 3.2: Comparison of Adiprene® lf MDI esters with TDI esters

Property	Adiprene® LFM S223X / Duracure C3 80A / Ester	TDI Ester MOCA 80A
Pot Life (70°C)	4 hour	<20 minutes
Post Cure (°C/Hrs)	140 / 16	100 / 16
Hardness, Shore A	80	80
100% Modulus, psi	482	600
300% Modulus, psi	716	1050
Tensile Strength, psi	4590	6700
Elongation at Break, %	600	660
Tear, Split, pli	105	120
Tear, Trouser, pli	319	250
Bashore Rebound, %	56	31
Comp. Set, Method B (22 hrs. @ 70°C), %	27	29

Table 3.3: Comparison of Adiprene® LF MDI ethers with TDI and MDI ethers

Property	Adiprene® LFM E500X / Duracure® C3 95A / Ether	TDI Ester MOCA 95A	MDI Ether / BD 95A
Pot Life (50°C)	Several hrs	<20 min	<20 min
Post Cure (°C)	140	100	100
Hardness, Shore A	95A	95A	95A
100% Modulus, psi	1841	1800	1345
Tensile Strength, psi	6300	5000	5460
Elongation at Break, %	450	400	460
Tear, Split, pli	180	150	155
Tear, Trouser, pli	330	230	-
Bashore Rebound, %	56	40	60
Comp. Set, Method B (22 hrs. @ 70°C), %	32	40	30

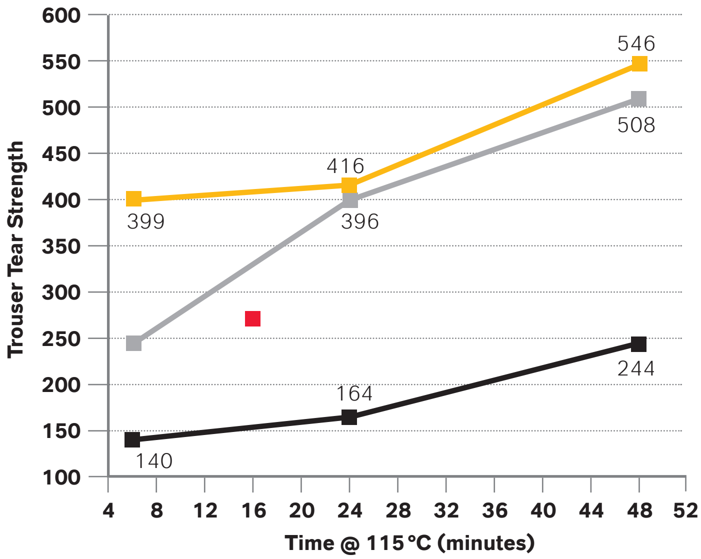
Effect of Curative Ratio / Stoichiometry on Properties

The curative mixing ratio has a number of different influences on properties of final elastomer. The curative weight is calculated using the %NCO or the percentage of reactive NCO groups available. If 100% of the NCO/isocyanate groups are reacted then the stoichiometry (also called % theory or ratio) is 100%. The best balance of properties is achieved when 95% of the isocyanate groups are reacted with the remaining 5% crosslinking through biuret or allophanate linkages.

Effect of Post cure time on Properties

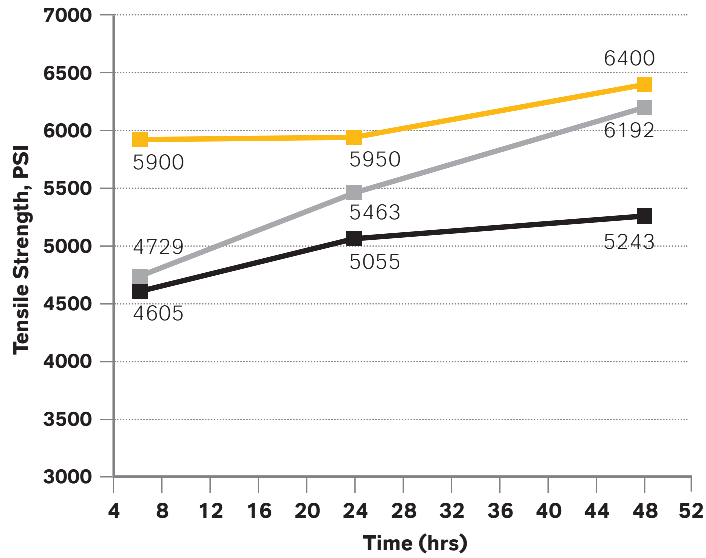
Like all urethane systems, Adiprene® LF MDI prepolymer systems have to be post cured to achieve maximum properties. Conventional urethane systems (TDI/MOCA or MDI/Diol) are cured typically at 100°C for 16–24 hours followed by room temperature conditioning for 1–2 weeks before put into service. These blocked systems are typically post cured between 127°C–140°C for 16-24 hours. However the effect of time on properties is pronounced and this is shown in Figure 3.5. Data shown is for a 90A LF MDI / ester. When cured at 120°C, the LF MDI has lower properties than the control 90A TDI / ester system. Even after 48 hour post cure the tear properties are not better than the 90A ester. When post cured at 140°C, LF MDI tear properties are significantly better. After 6 hours of post cure the tear strength is approximately similar to that of the TDI / ester system. After 24 hours, LF MDI systems have approximate tear strength of approximately 1.5 times that of TDI / ester system. This can be further improved by post curing for 48 hours. The effect of temperature and time is more pronounced when LF MDI systems are post cured at 150°C. Excellent properties can be obtained after just 6 hours of post cure at 150°C. A similar effect can be seen with tensile strength as well.

Figure 3.5: Effect of temperature and post cure time on tear strength of Adiprene® LFM S350X



■ 90A LF TDI Ester/MOCA 100°C for 16 hrs
■ 120 °C ■ 140 °C ■ 150 °C

Figure 3.5: Effect of temperature and post cure time on tensile strength of Adiprene® LFM S350X



■ 120 °C ■ 140 °C ■ 150 °C

Curing thick cross sections of Elastomers made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

Due to their long pot life, these systems are frequently the material of choice for curing large parts (in the order of several hundred to thousand pounds) and parts with thick cross sections. The properties of a material may vary across the cross section due to either incomplete curing or the exotherm (material will be hotter in the center than the surface). It is critical for the material to have uniform properties across the cross section for best performance. The parts cast were cylinders (50 lbs) with diameter and height of several inches. The cylinders were post cured overnight at 127°C. The parts were then skived and properties were measured from samples from center and outside. These systems cure very uniformly across the cross section (Table 3.4) making it the ideal system for use in large parts.

Table 3.4: Properties of various systems showing uniform cure across thick cross sections

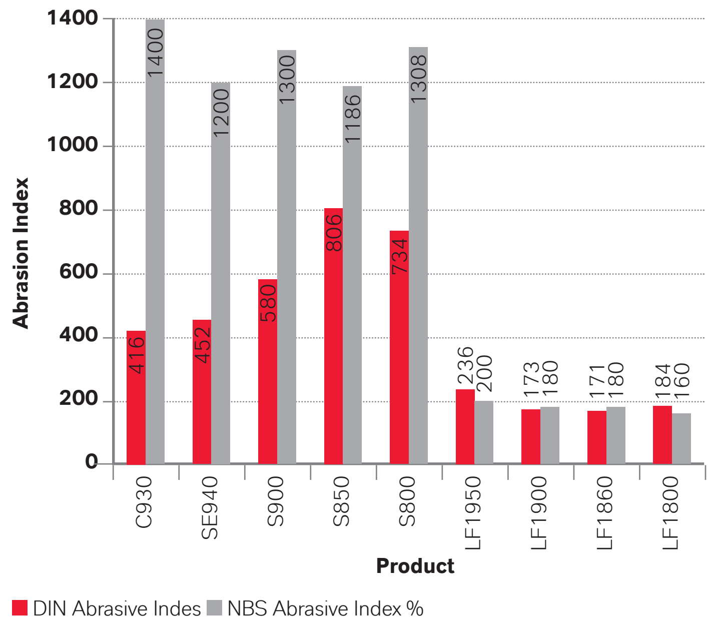
	Adiprene LFM E320X		Adiprene C930		Adiprene LFM S350X		Adiprene S930	
Physical Property	Center	Outside	Center	Outside	Center	Outside	Center	Outside
Shore A	89A		93A		89A		92A	
100% Modulus (psi)	1152	1129	1364	1423	1013	1026	1464	1370
300% Modulus (psi)	1698	1636	1847	1 934	1617	1581	2150	1982
Elongation (%)	477	473	515	538	422	431	477	490
Tensile (psi)	3443	3117	4700	5582	2727	2347	4175	4255
Trouser Tear (pli)	55.1	51.5	305	234	154	113	178	150

Abrasion resistance of Systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

One of the most important properties that these systems offer is excellent abrasion resistance. Lab and field tests have indicated that they perform very well in environments that require sliding abrasion (for example: scraping blades).

These systems have significantly better abrasion resistance than other urethane systems available in the market. Because they also have excellent high temperature resistance they can be used in extremely aggressive environments. Figure 3.7 shows the abrasion resistance of various Adiprene® LF MDI / ester systems in comparison to TDI / ester systems. LF MDI systems outperform TDI systems by a factor of three to eight times. For abrasion data on Adiprene® LF MDI / polyether based systems, please refer to the relevant technical data sheets.

Figure 3.7: Abrasion Properties of systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives compared to TDI systems

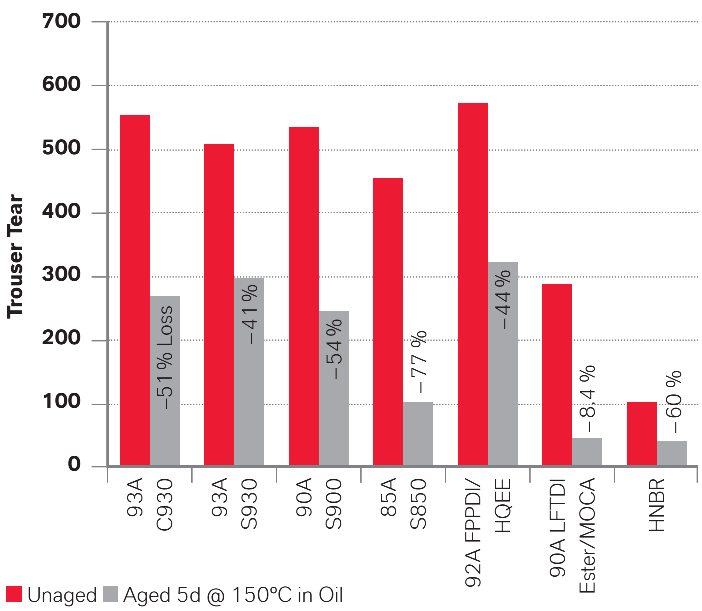


Duracure Products – 16hr 140°C Post Cure

Oil resistance of Systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

These systems offer a unique combination of easy processing and high performance. The unique processing characteristics help customers pour defect free complex shapes such as those required in the oil industry. They also offer high tear properties and excellent abrasion resistance. For application requiring oil exposure, it is critical that along with these properties the urethane system has excellent oil resistance. Lab testing was conducted at 150°C by immersing samples in IRM 903 oil (heavy hydro treated naphthenic distillates) and then measuring physical properties. IRM 903 oil is a standard material used in material specification tests often used to understand the compatibility of a material with oils and greases. Typically ester, polycaprolactone or polycarbonate-based prepolymers are used in applications requiring resistance to oil and greases. Figure 3.8 compares standard materials used in the oil industry such as TDI ester and HNBR rubber, Adiprene® LF PPDI, and Adiprene LF MDI systems. Only tear strength is shown here but all physical properties follow a similar pattern (see appendix for more information). At similar hardness, for example, a 92A LF PPDI system compared with Adiprene® S930, the Adiprene S930 performs equally to or slightly better than LF PPDI. Previously PPDI was known to be the best performing system under extreme conditions, but Adiprene® LF MDI cured with Duracure blocked curatives provides similar performance at a reasonable cost.

Figure 3.8: High Temperature Oil Resistance of systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

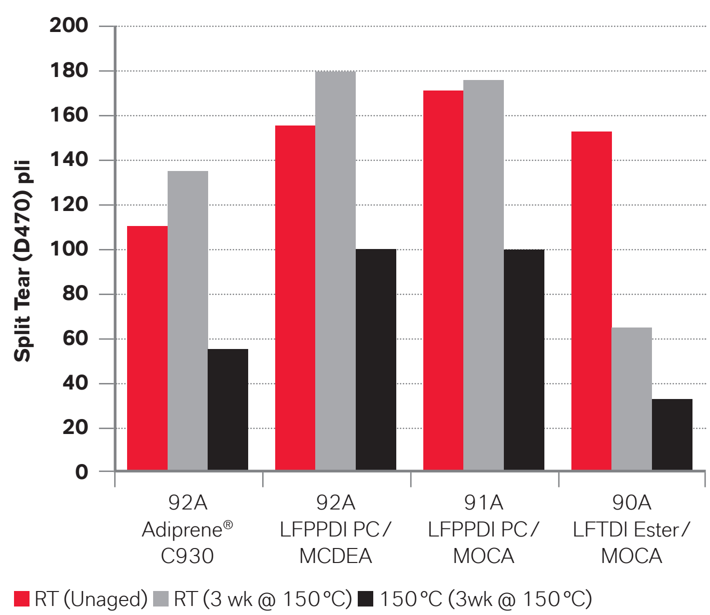


At similar hardness standard TDI ester prepolymers cured with MOCA (90A) compared with Adiprene LF MDI (90A) show significant difference. The LF MDI systems retain properties to a large extent after 5 day aging. The 90A TDI / Ester / MOCA system loses most of its properties after aging at 150°C for 5 days.

High Temperature Properties of Systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

One of the weaknesses of urethanes systems such as TDI/MOCA and MDI/Diol is high temperature resistance. Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives provide excellent high temperature resistance due to a superior quality hard segment. Figure 3.9 shows the tear properties of these LF MDI systems compared with PPDI systems and TDI systems. The LF MDI systems show similar properties as other high temperature systems and significantly improved properties in comparison to conventional urethane systems such as TDI / MOCA.

Figure 3.9: Tear properties of systems made from Adiprene® LF MDI compared with PPDI and TDI systems



Dynamic Properties of Systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

Polyurethane elastomers like all elastomers have a combination of elastic and viscous properties. Storage modulus (G') is indicative of the elastic component of the material whereas Loss modulus (G") is indicative of the viscous component. Tangent delta (commonly known as tan delta) is the ratio of loss modulus to storage modulus and indicates if the material is more viscous or more elastic at a particular temperature, load and strain.

In roller coaster wheels, skate wheels, forklift wheels and rolls dynamic properties play a very important part in part performance. Materials that retain their storage modulus over a wide temperature range, and have low tangent delta value (dissipate less heat) perform well in the applications mentioned above.

Figures 3.10-3.15 compare dynamic properties of ethers, esters and caprolactone based LF MDI urethanes with standard materials such as TDI/MOCA and MDI/Diol. All systems made with Adiprene LF MDI maintain the storage modulus (indicating temperature retention) over the range of temperatures. Several standard materials (especially MDI/Butanediol cured materials) lose modulus as the temperature increases. Thus such a material may function very well at ambient temperature but as the temperature rises the modulus decreases which may lead to failures.

The tangent delta of systems made with Adiprene® LF MDI is also significantly better when compared to TDI/MOCA or MDI/Diol systems. This indicates lower heat build-up as the wheels or rolls are under load which leads to better performance and longer life. Due to the combination of storage modulus retention and low tangent delta over a wide temperature range, these systems provide excellent performance under dynamic loads.

Figure 3.10: Storage modulus of systems made from Adiprene® LF MDI / ester compared with TDI / ester

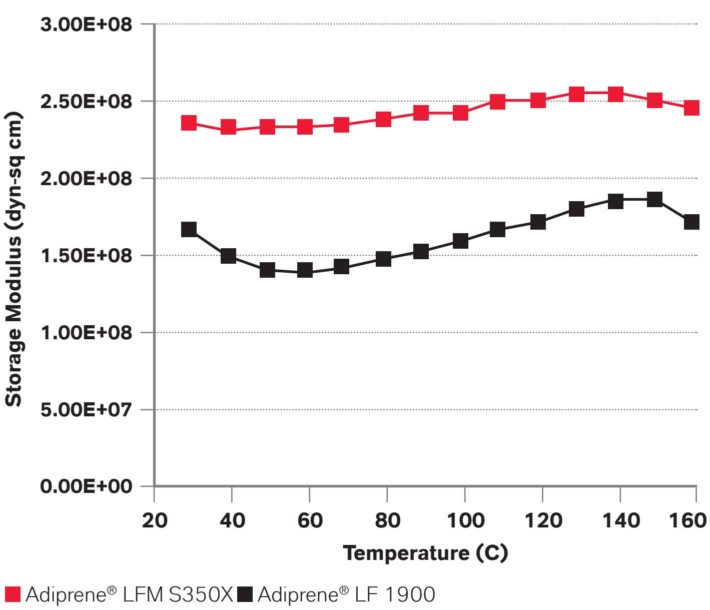


Figure 3.10: Tan delta modulus of systems made from Adiprene® LF MDI / ester compared with TDI / ester

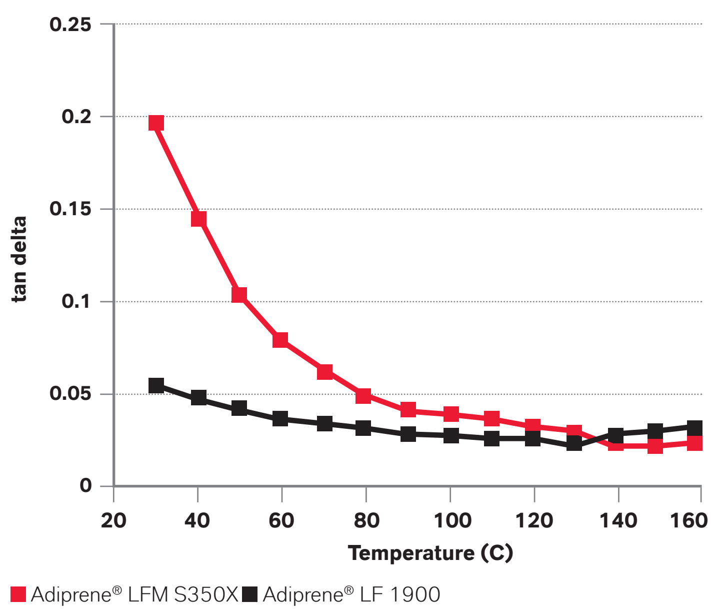
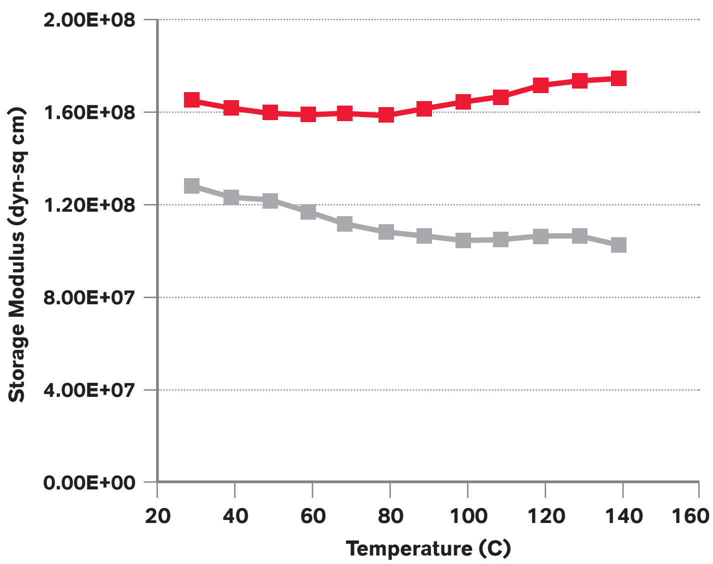
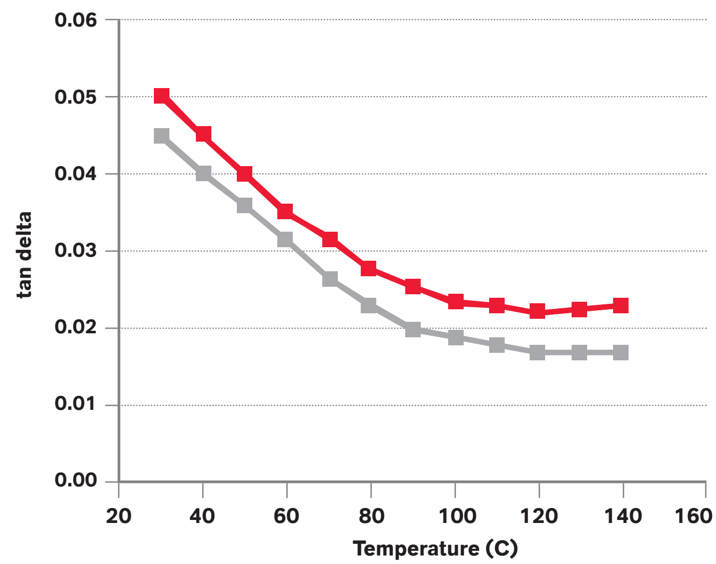


Figure 3.12: Storage modulus of systems made from Adiprene® LF MDI / ether compared with MDI / ether



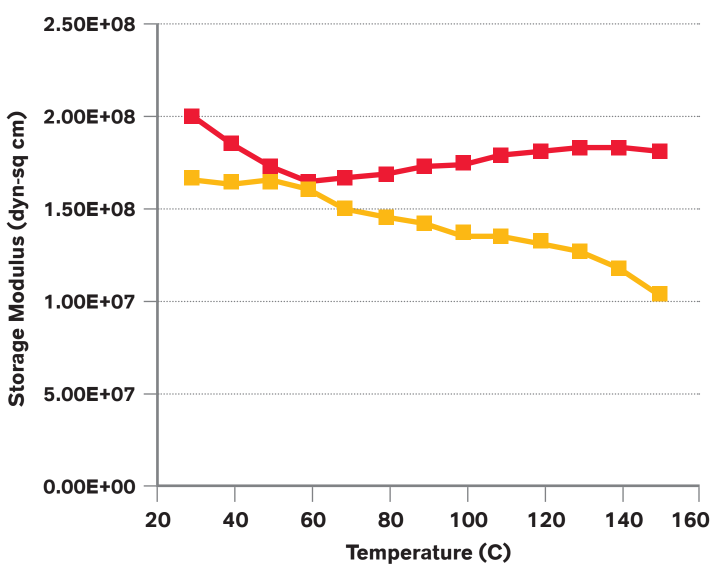
Adiprene® LFM E320X Vibrathane® B821

Figure 3.13: Tan delta of systems made from Adiprene® LF MDI / ether compared with MDI / ether



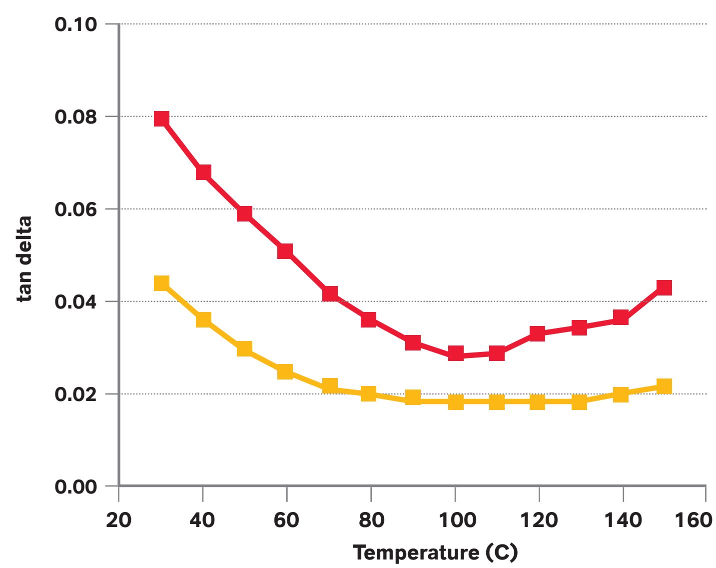
Adiprene® LFM E320X Vibrathane® B821

Figure 3.14: Storage modulus of systems made from Adiprene® LF MDI / PCL compared with MDI / PCL



Adiprene® LFM C350X MDI / PCL / BD 90A

Figure 3.15: Tan delta of systems made from Adiprene® LF MDI / PCL compared with MDI / PCL



Adiprene® LFM C350X MDI / PCL / BD 90A

Flex Fatigue of Systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

Fatigue resistance is a very important property in several applications such as flip flow screens, roller coaster ride wheels, couplers, belts etc. Flex fatigue resistance is measured as the crack growth response of a material to cyclic deformation or stress. Under repeatedly applied loads cracks can develop at stress concentration (stress riser) points which propagate over time leading to failure of the part. Flex fatigue can be measured using several different methods. One such method is Texus Flex Fatigue.

In this method coupons of cast urethane are punched to create a small defect (0.08 inches wide). The samples are mounted on a rotary wheel and different strains are applied on the coupon (11%, 18%, 35% and 45%). The rotary wheel is then spun at high speed and the cut growth is measured at different intervals. The test is stopped when the sample fails or when the cut is 0.5 inches wide (whichever happens first). The number of cycles is measured and flex fatigue resistance is calculated.

Systems made from Adiprene® LF MDI prepolymers were compared with LF TDI systems, conventional MDI systems and LF PPDI systems at different strains to understand the performance under cyclic loads. Table 3.5, 3.6, and 3.7 shows that the LF MDI systems out-perform other systems currently available.

Table 3.5: Flex fatigue comparison of a 95A Adiprene® LF MDI / ether with other 95A ether systems

		Cycles to Failure			
Material	**% Theory**	**11%**	**18%**	**35%**	**45%**
Adiprene® LFM E500X	100%	128,00	50,000	25,000	8,300
Adiprene® LF950/MOCA	100%	1,500	1,400	800	550
Vibrathane® B836/BD	100%	12,000	14,250	8,300	3,750

Table 3.6: Flex fatigue comparison of an 85A Adiprene® LF MDI / ester with 85A TDI ester systems.

		Cycles to Failure	
Material	**% Theory**	**35%**	**45%**
Adiprene® LFM S350X	95%	780,000	480,000
Adiprene® LF 1860	95%	1100	<500
PST 85A	95%	2000	<500

Table 3.7: Flex fatigue comparison of a 60D Adiprene® LF MDI system with 60D TDI system.

		Cycles to Failure			
Material	**% Theory**	**11%**	**18%**	**35%**	**45%**
Adiprene® LFM C700X	100%	110,000	31,000	4,000	2,200
Adiprene® LF600D/MOCA	95%	500	500	100	100

Glass Transition of Systems made from Adiprene® LF MDI based Systems

Glass Transition Temperature (Tg) data of Adiprene LF MDI based systems are listed in Table 3.9, along with comparison to TDI based counterparts. This table provides a general guidance of selection of the materials for low temperature performance. An elastomer with lower Tg suggests that it remains elastic at lower temperature, therefore provides a better performance at low temperature.

In general, LF MDI Ether type elastomers have Tg in the range of -70°C, which is lower than LF MDI Ester and Caprolactone based systems, which have Tg in the range of -50°C.

In Table 3.8, glass transition temperature of LF MDI based systems are compared to that of TDI prepolymers cured with MOCA. They demonstrate the lower Tg than TDI based materials, suggesting a better performance at low temperature (for example: applications such as Snow Wheels, Sprockets, Snow Plow Blades, Pigs, Salt Spinners etc).

Table 3.8: Glass transition temperature comparison of a 95A Adiprene® LF MDI / ether with other 95A ether systems

	LF MDI Ether		TDI Ether		LF MDI Ester					TDI Ester		LF MDI PCL	
Adiprene® LFM	**E320X**	**E500X**	**LF900A**	**LF950A**	**S183X**	**S223X**	**S265X**	**S350X**	**S930**	**LF1800A**	**LF1900A**	**C350X**	**C930**
Curative	C3	C3	MOCA	MOCA	C3	C3	C3	C3	C3	MOCA	MOCA	C3	C3
Hardness	90A	95A	90A	95A	70A	80A	85A	90A	93A	80A	90A	90A	93A
Tg, °C	-72	-76	-67	-47	-54	-56	-60	-57	-58	-38	-23	-57	-57

Effect of salt water immersion on Adiprene® LF MDI Systems

Adiprene® LF MDI based systems cured with Duracure® blocked curatives are amine-cured systems, which are unique due to the presence of NaCl (common salt) which remains in the cured urethane. Since NaCl is hydrophilic (affinity to water) the cured urethane has a tendency to absorb more water than MDI/Diols or TDI/MOCA system. Therefore 11 week study was run to understand the behaviour of these systems when exposed to salt water. Cured urethane sheets were immersed in salt water of density 1.02 at 50°C and aged for 11 weeks. Physical properties were tested before and after aging to understand the effect of salt water exposure. Table 3.9 shows the property comparison of Adiprene® LFM E615X with Vibrathane® B836 (MDI/Diol) and Vibrathane® B601 (TDI/MOCA).

Table 3.9: Salt water aging (11 weeks @ 50°C) of Adiprene® LF MDI and other Urethane systems

Material	B836 Unaged	B836 Aged	% Change	B601 Unaged	B601 Aged	% Change	E615X Unaged	E615X Aged	% Change
Peak Stress (PSI)	3825	3143	-18%	6165	3185	-37%	6139	4701	-23%
Elongation (%)	392	395	1%	318	328	3%	552	574	4%
300% Modulus (PSI)	2470	2119	-14%	5374	3185	-41%	2547	2012	-21%
Trouser Tear (PLI)	75	72	-4%	160	155	-3%	442	524	19%

Adiprene® LFM E615X property retention is between that of an MDI/DIOL and TDI/MOCA. In the long run, these LF MDI systems are expected to perform as well as a traditional Amine cured system such as TDI/MOCA.

Volume resistivity of systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

Volume resistivity is a measure of how strongly a material opposes the flow of electric current. A low resistivity indicates a material that readily allows the flow of electrical current. Urethanes are well known to be good insulators and can build up static charge. Frequently, additives such as Antistatic agents and conductive fillers may need to be added to improve the conductivity (reduce the resistivity) of the system. Build-up of static charge may be an issue in several applications such as scraping blades (fire hazard due to static charge in underground mines), belts used in ATM machines (static charge prevents dispensing of bills) etc. Adiprene LFM prepolymers cured with Duracure blocked curatives are inherently lower resistivity than most other urethane systems, due to the presence of salt.

Table 3.10: Volume resistivity of various Urethane systems

Material	Volume Resistivity (ohm-cm)
Adiprene® LFM C350X	3.93 x 1010
Adiprene® LF900	8.93 x 1011
Adiprene® L100	5.9 x 1011

Cast urethane systems find applications in a wide range of industries. In many demanding applications, they provide significant benefits – performance and processing – over metals, plastics, ceramics and other elastomers. They are tough, abrasion resistant, have excellent load bearing properties, chemically resistant and provide excellent cut & tear resistance. This makes polyurethanes the first choice material in many applications. As discussed in Chapter 3, systems made with Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives provide superior performance and outperform other hot cast urethane systems. Chapter 4 provides an overview of various market segments and applications in which LF MDI systems have successfully outperformed other hot cast urethanes and other elastomers.

Markets

Systems made with Adiprene and Vibrathane urethane prepolymers are currently being used successfully in many market segments and applications. The applications range from very high tech dynamic applications to standard sheet stock. Table 4.1 shows the various market segments and an assortment of applications in which these systems are used.

Table 4.1. Market segments and applications for systems made with Adiprene® and Vibrathane® urethane prepolymers

Market Segment	Application Examples
General Industrial	Sheet Stock, Rods, Tubes
Electronics	Polishing Pads
Mining	Scraper blades, Chute liners, Screens, Pipe liners, Impellers, Hydrocyclones
Oil and Gas	Pipeline pigs. Blow out preventers, Discs and Cups, Seals
Rolls	Steel Mill rolls, Dryer Rollers
Paper	Rolls, Die Cutting Pads (cardboard cutting)
Office Machines	Drive belts, Rolls
Marine	Buoys, Marine Bumpers
Printing	Printing and Coating rolls, Squeegees
Construction	Binder, Nail gun bumpers
Agriculture	Cotton Doffers (cotton picking discs), Grain Handling equipment.
Recreation Wheels	In Line Skate Wheels, Roller Coaster Wheels, Skateboard Wheels
Tires and Wheels	Fork Lift Tires
Sporting Goods	Bungee Cords, Skateboard Bushings
Transportation	Bumpers, Bushings, Track Pads
Offshore	Bend stiffeners, Bend restrictors

Market Segments for Systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

These systems can be used in almost all applications in which other urethane systems are traditionally used to improve the performance at high temperature, superior abrasion resistance, high cut and tear, excellent dynamics and demonstrated longer field life. Due to their superior properties, they can also be used in several other applications in which other urethanes have not succeeded (for example: High temperature application as a HNBR replacement). Table 4.2 the various market segments and applications in which these systems have been successfully used and have outlasted other hot cast urethanes.

Please note that it is extremely critical to understand the complete requirements of an application before selecting a material. The section below attempts to provide a generic overview of different applications

Table 4.2.: Market segments and applications for systems made from Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives

Market Segment	Adiprene LF MDI Grades	Application Examples
Mining	LFM S265X LFM E500X	High Temperature Scraping blades, Flip Flow screens, Impellers
Tire and Wheels	C930 LFM E500X	Fork Lift tires (standard and high temp/high load), Bogey wheels
Transportation	LFM S265X	Automotive Bumpers, Bushings
Oil and Gas	LFM S265X	Pipeline Pigs, Riser Protector, Pipe Transport Rollers
Rolls	C930	Steel Mill Rolls, Laundry Dryer Roller
Seals	C930	Rolls, Die Cutting Pads (cardboard cutting)
LFM C700X	High Temperature Seals, Geothermal Seals	Drive belts, Rolls
Belting	LFM E500X LFM S350X	Power Transmission Belts (Link Belts)
Sporting goods	LFM E500X	Skateboard Bushings
Textile	C930	Cam Rollers
Paper	LFM S265X	Die Cutting Pads
Glass	C930	Chopping Cots (glass fiber chopping)
Agriculture	LFM S265X	Weed Whacking Blades, Cotton Doffers, Chute Liners

Mining

LF MDI based systems can be used in aggressive environments such as aggregate handling. Field results indicate that they have been successfully used in high temperature scraping blades, Flip flow screens and Impellers. They can also be used in mining screens, liners for metals in aggregate handling, rolls and conveyor belts used in the mining industry. Though each application is different some of the common features required by products used in these applications are excellent abrasion resistance, toughness, cut and tear resistance and in some cases chemical resistance.

These systems provide excellent tear, abrasion, high temperature resistance, toughness and have performed exceedingly well in several mining applications. Some examples of success include:

- **Flip Flow Screens:**
  Adiprene® LFM S265X out-performed other high performance materials. These are fine screens which sift material through flexing action. This is particularly useful in handling fine or sticky materials which cause blinding of the screens. Urethanes systems used widely in this application have superior flex fatigue, abrasion resistance and good cut and tear properties. The incumbent screens last 6 months in the field, whereas screens made from Adiprene® LFM S265X have lasted >8 months.

- **High Temperature Scraping Blades:**
  These systems have found a unique niche in high temperature scraping (belt cleaning) blades. The combination of high abrasion resistance, high tear strength and high temperature properties enables them to be used in this high performance application. In one such extreme application mining was conveyed on the belt at 160°C (320°F). The scraping blade previously used was an MDI ester which was failing due to high heat. The customer's expectation was for a material that would last 3 weeks at 160°C (320°F). The LF MDI based systems lasted for 4 weeks at 160°C (320°F)

Tires and Wheels

These systems are ideal for use in several tire and wheel applications due to excellent hysteresis properties, toughness, cut and tear, low tendency to flat spot and wear resistance. The most popular LF MDI system used is Adiprene® C930 although other systems such as Adiprene® LFM E500X, E320X, E615X, S930 and C350X can all be used. Selection of tire and wheel material is dependent on load and speed conditions along with environmental conditions. Our technical team can assist with the design and selection through the use of the in house computer tire model. Using this model our technical team is able to determine if the loads and speeds involved in the application would cause blowout failure (due to internal heat build-up), fatigue failure or bond loss. The required inputs for the computer tire model are tire dimensions (Outside Diameter, Outside Diameter at sidewall, Inside Diameter, Width), load, speed and operating temperature.

LF MDI based systems have been used in forklift tires with good success. They have been tested alongside several high performance urethane systems such as PPDI/Esters, PPDI/PCL and NDI/Ester materials. Adiprene® LF MDI based systems have either outperformed or have performed equally as several high performance materials known to the marketplace.

A unique tire and wheel application with Adiprene® LFM E500X was for Bogey wheels. A customer had previously tried several different urethane materials without much success. Most wheels failed after a few hours of operation. The application presented a significant challenge as the loads were extremely high (10,000 lbs/wheel) and the design window was very small. By working with the end user and molder our technical team was able to successfully design a wheel with Adiprene® LFM E500X. The wheel has been in operation for several months without failure issues.

Oil and Gas:

Adiprene® LF MDI Esters and Caprolactones (S-series and C-series) can be used in most applications involving exposure to oil such as seals, blow out preventers, pipeline pigs, discs and cups. The high temperature properties of these systems combined with excellent toughness, low compression set, oil resistance and abrasion resistance make it a good choice for applications involving oil exposure. Property comparison of Adiprene® LF MDI based systems with other systems such as LFPPDI/PC and TDI/Ester (refer to Chapter 3, section 3.7) has shown that LF MDI Esters and PCL systems perform similarly to LF PPDI and are significantly superior to TDI/Ester systems.

Adiprene® LFM S350X, S265X, S223X and S183X have been used in the field to make pipeline pigs, discs and cups and all the materials have performed exceptionally well in the field. One such example was for a high temperature pipeline pig. Customer was interested in a material that could withstand 150°C (300°F) in an oil environment for 5 days. Internal testing with IRM 903 oil indicated that Adiprene® LFM S350X could be a possible solution. The pig made from Adiprene® LFM S350X was tested alongside pigs made from a conventional ester based system. At the end of the field test, the pig made from Adiprene® LFM S350X showed very little wear and tear whereas the competitive Ester-based pig had disintegrated.

Rolls:

Rolls used in steel mills, dryer rolls or coating rolls have very similar property requirements as tires and wheels. Although some properties differ most rolls are expected to have good abrasion resistance, cut and tear, low set and toughness. Depending on the type of roll chemical resistance to solvents, inks, water may also be required. Adiprene LF MDI based systems make excellent roll materials and have been successfully used in steel mill rolls, coating rolls and laundry dryer rolls.

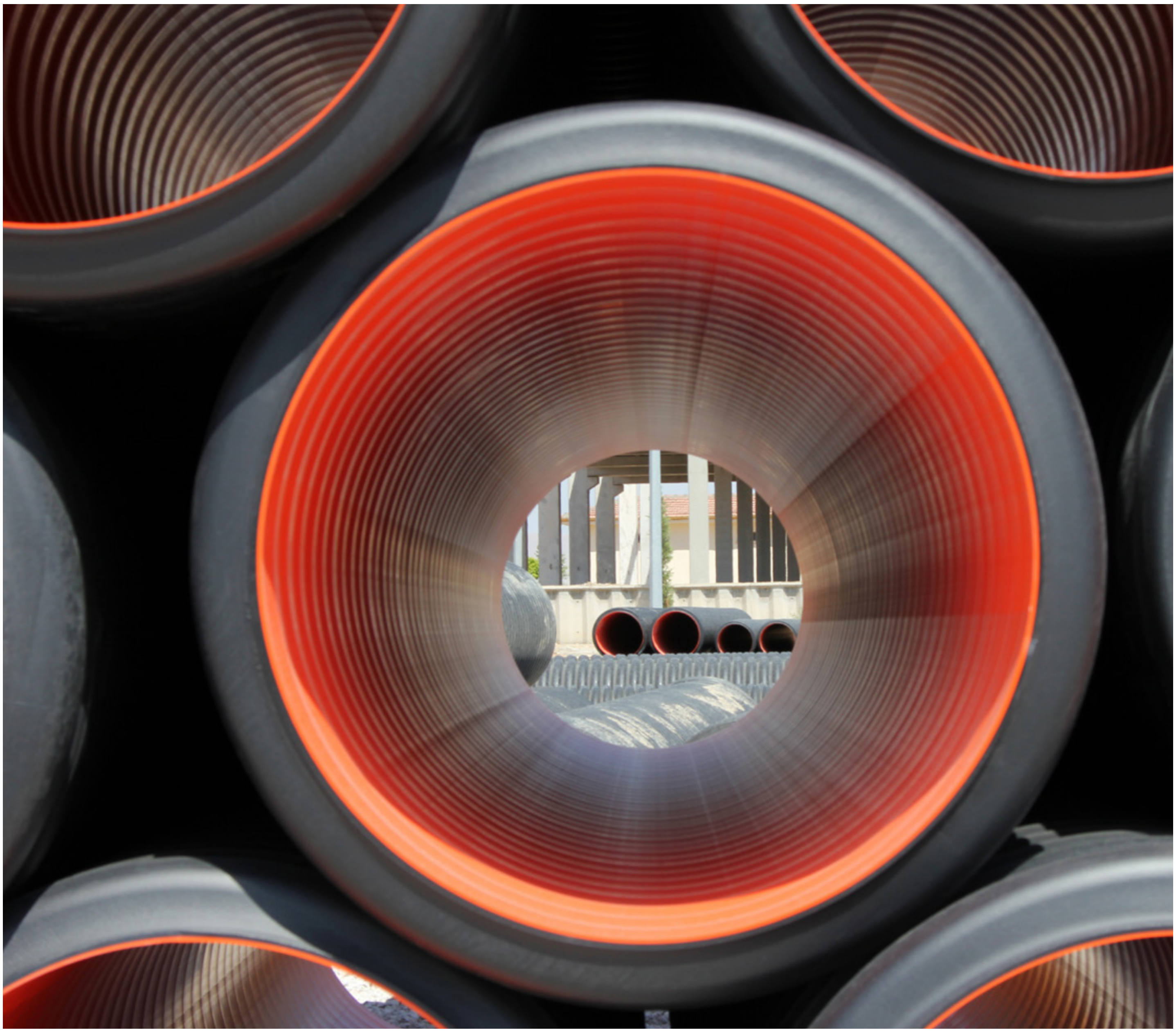
Laundry dryer rollers are an application that requires high temperature resistance. Typically high temperature resistant rubbers such as NBR or HNBR are used as most urethanes cannot handle continuous use temperature of 150°C. Adiprene C930 was successfully used in this application and the rollers thus produced performed well for several months (significantly longer than rubber rolls).

Glass

Polyurethanes are used in the fiber glass chopping industry. Chopping cots/wheels/back up rolls are used as the chopping surface. In a typical fiber glass chopping process bundles of glass fibers are passed between a knife and the chopping cot. The fibers are oscillated on the cot surface for better heat dissipation. The high speed cutting knife chops the glass at regular intervals. This results in wear of the chopping cot. After a certain numbers of cycles the cot surface is machined to a predetermined diameter and the process is repeated. Due to the aggressive nature of the operation the urethane can fail due to chunking, heat build up, inconsistent wear life etc. Thus it is critical to have a urethane which has excellent wear resistance, low hysteresis and good cut and tear resistance. Adiprene® LF MDI based systems have been used in several different fiber glass chopping operation with much success.

CONCLUSIONS

Systems made with Adiprene® LF MDI prepolymers cured with Duracure® blocked curatives are novel high performance, easy processing hot cast urethane elastomers. They provide superior performance in a wide variety of applications along with several other advantages that include extremely long pot life, very quick demold time, versatile processing, no curative melting or dusting, low/minimal capital investment for processing equipment, the ability to cast extremely large or intricate parts and lower exposure to isocyanates. Furthermore, the technology can reduce costs due to ease of automation, reduced worker training time and reduced scrap. Adiprene® LF MDI based systems are available in a wide range of hardness and with different backbones.



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