SUPERLINK® CROSS-LINKABLE ROTOMOULDING RESINS

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Ingenia Polymers In Rotomoulding

- Ingenia is a global supplier to the rotomolding industry with a track record of developing innovative products

- Superlink® cross-linkable polyethylenes exemplify this commitment to excellence in rotomoulding.




SUPERLINK® XLPE

- Traditional linear materials do not meet the requirements of high performance applications including fuel and hydraulic oil tanks:
  - High impact and/or low temperature impact
  - Improved ESCR
  - Improved temperature resistance
- Ingenia Superlink® XLPE can meet these requirements either as a single layer rotomoulded product or as part of a multilayer solution for applications requiring low fuel permeation.

Property Comparison

Resin Type	Superlink® XLPE	Typical LLDPE/HDPE
Density	0.943	0.932-0.942
Impact resistance (ARM test, -40 ° C) (ft-lbs)	>180	80-160
Brittle failure (%)	0	85%-100%
Tensile elongation (%)	800	865-1000
Flexural Modulus (psi)	110,000	88-110,000
ESCR (hrs)	>1000	20-400 typical
HDT (°C) ASTM D648 at 66psi	67	49-57
Chemical Resistance	Excellent	Fair
Moldability	Excellent	Good

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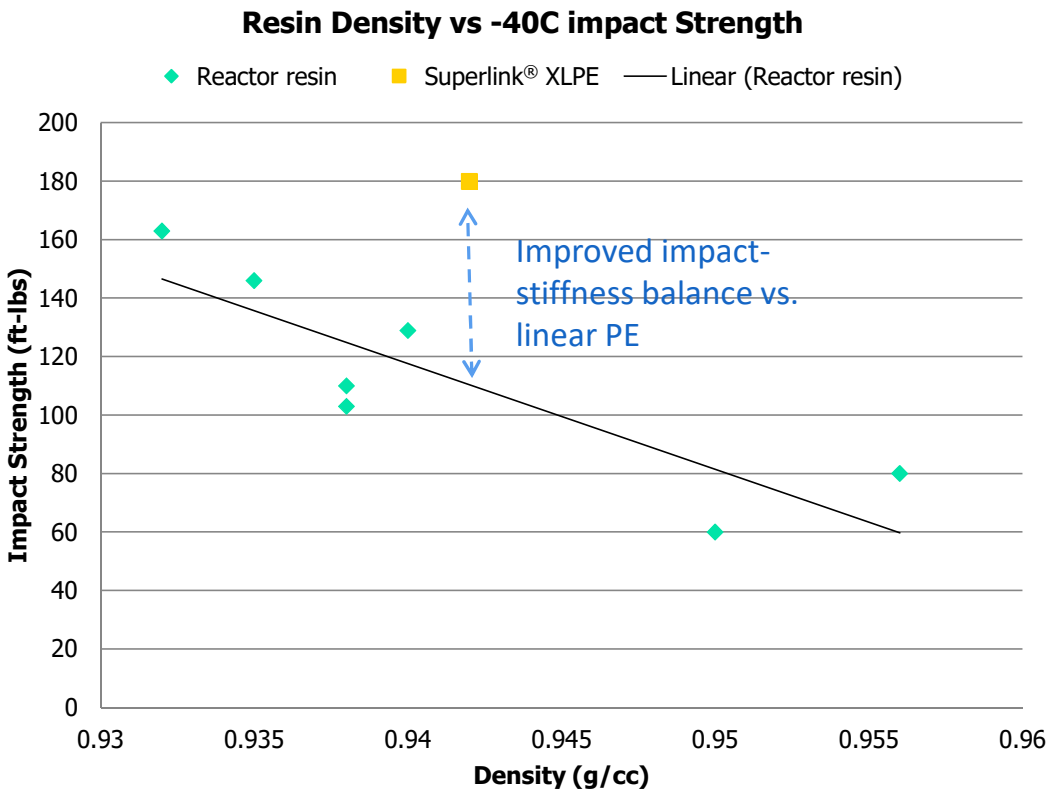
Impact Strength vs Density

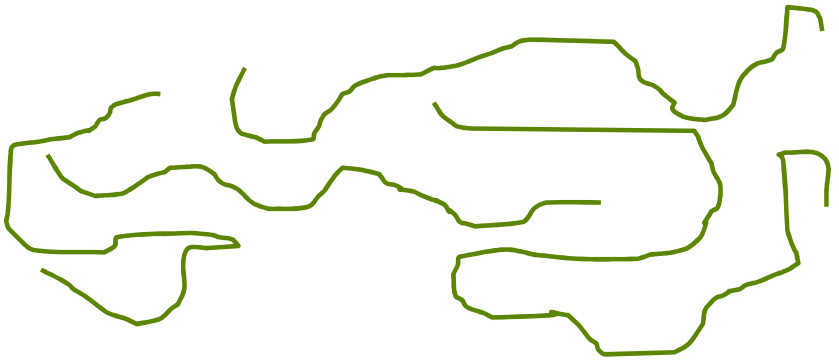
- Linear PE resins show a negative correlation between impact strength and increasing density
- Superlink® XLPE shows highly improved impact strength relative to density as compared to linear PE

- Besides improvements in impact strength, crosslink resins offer improvements in several properties…

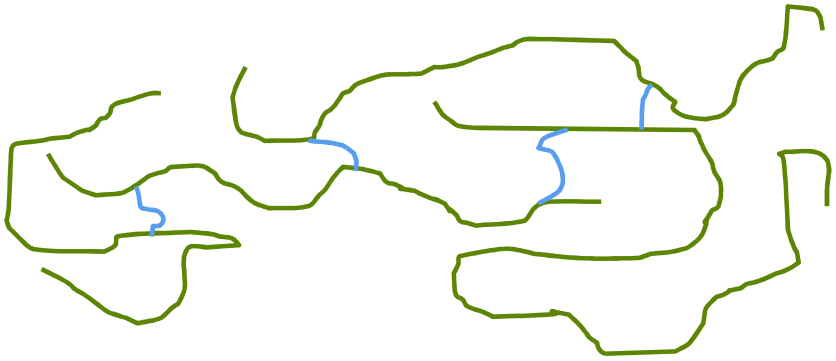


What is Crosslinking?

- Crosslinking is a chemical reaction
- It is initiated by heat or temperature
- Rate is time and temperature dependent.
- It changes the composition of PE from a collection of linear thermoplastic polymer chain to a thermoset network chain structure



Schematic representation of linear PE molecules



Schematic representation of XLPE molecules

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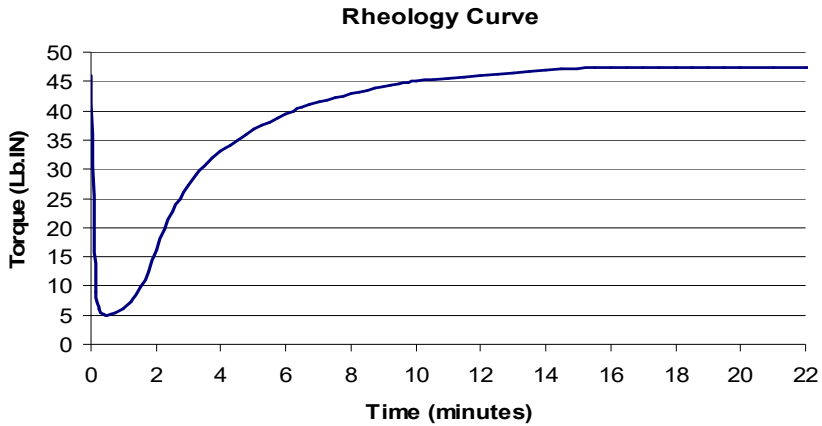
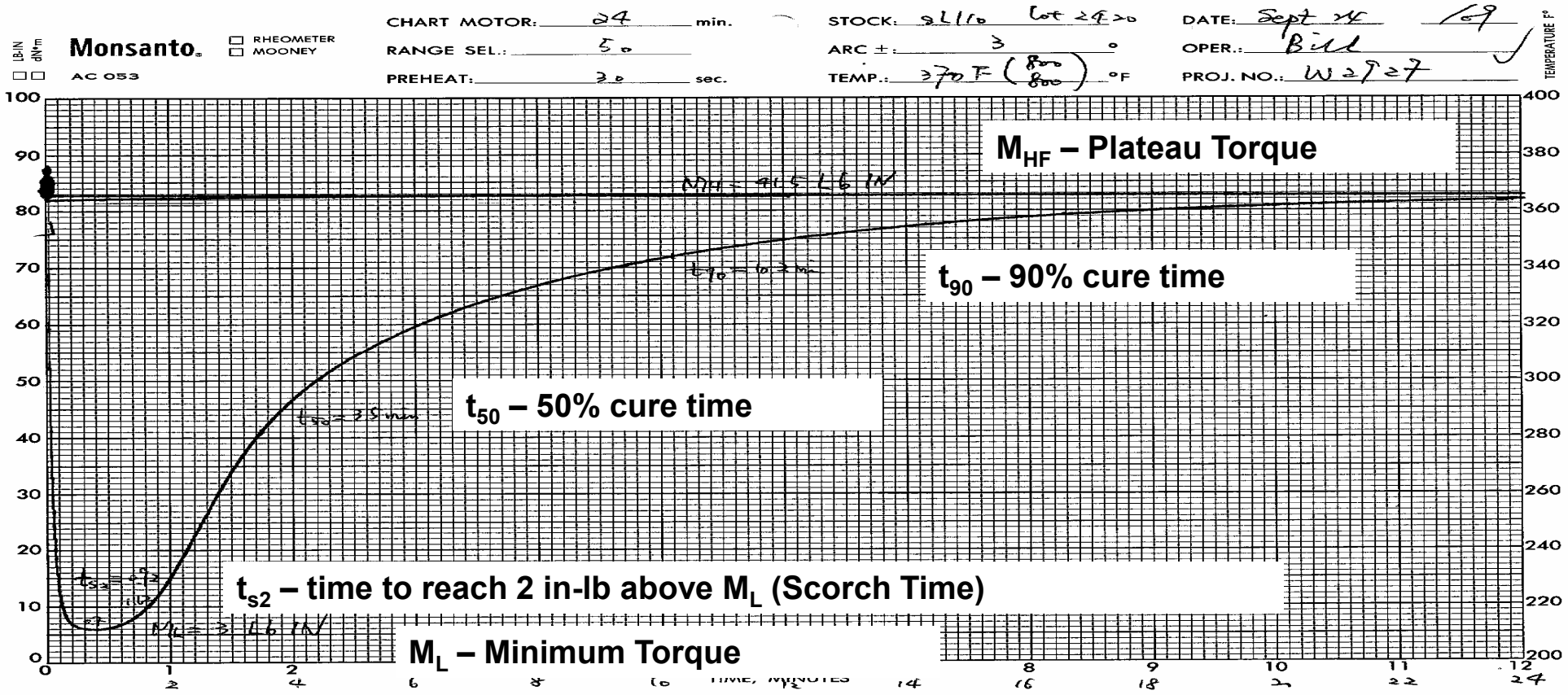
Measuring Crosslinking

- Crosslinking of Superlink® resins is initiated by decomposition of peroxide
- A torque rheometer can measure crosslinking characteristics
  - Viscosity and torque will increase as crosslinking proceeds
  - The time to reach a percentage (50 or 90%) of maximum torque is indicative of the rate of cross-linking. Shorter times = higher rates



Measuring Crosslinking via Torque Rheometer



Rotomolding Process and Crosslinking

- Linear PE
  - Loading of powder
  - Heating of mold and powder
  - Fusion of resin
  - Cooling
  - Removal of part
- Cross-linkable PE
  - Loading of powder
  - Heating of mold and powder
  - Fusion of resin
  - Chemical crosslinking
  - Cooling
  - Removal of part

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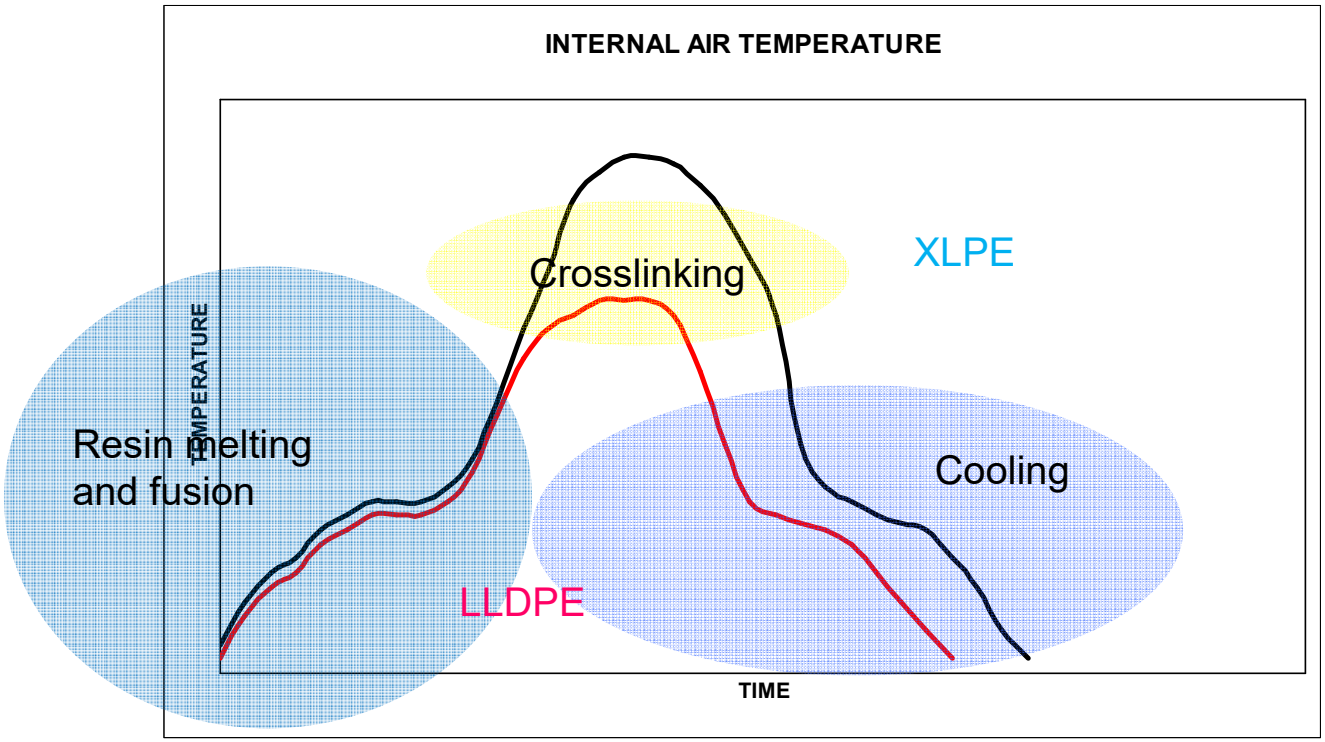
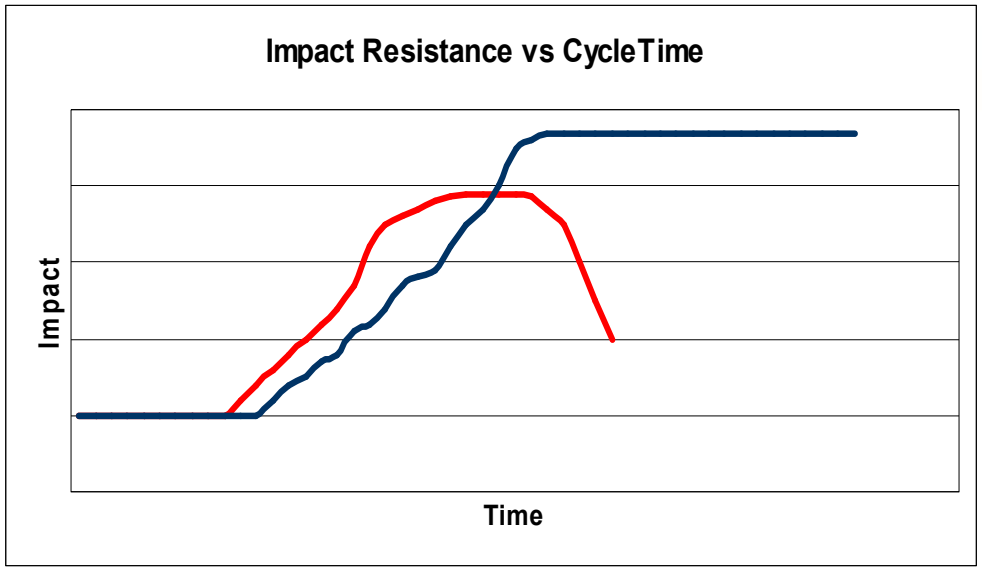
Rotomolding process and Crosslinking



- XLPE requires a higher peak internal air temperature (PIAT) as compared to linear PEs during rotomolding

Impact properties vs. cycle time



- Linear PEs are known to degrade if the rotomoulding cycle is extended. The resin 'overcooks', and undergoes thermal and oxidative degradation. Impact properties are severely negatively affected
- However XLPEs maintain their impact properties if the rotomoulding cycle is extended beyond the full gel point.

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Peroxide decomposition and crosslinking process

Gel test apparatus

- Measuring gel content of finished product confirms complete crosslinking
- The gel content is measured by dissolving the PE in recirculating hot xylene. Linear PEs will completely dissolve. XLPE will have a content of undissolvable 'gel'
- A typical gel content of 70-84% indicates full cross-linking and fully developed physical properties.
  - Increased toughness
  - Increased stress crack resistance
  - Increased notch crack resistance
  - Increased abrasion resistance

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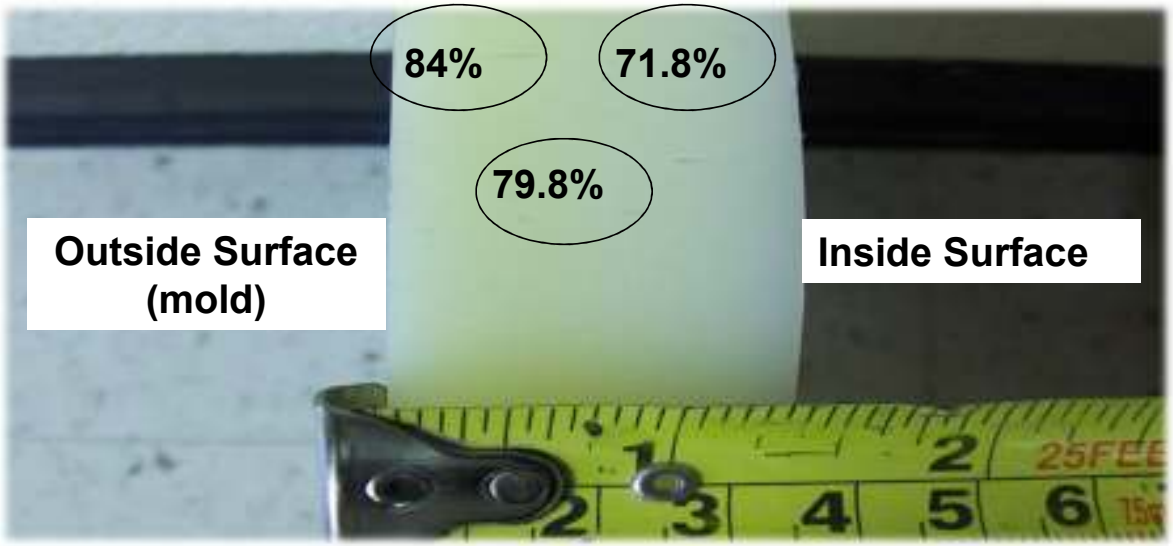
GEL Analysis



- Due to the nature of the rotomoulding process – where heat is applied from the outside – the part thickness has a gradient in heat history and corresponding gel level. → the gel content will be higher on the outside wall.

Property Comparison

- Superlink® has been tested extensively and has a proven track record of 20+ years
- Superlink® XLPE outperforms linear materials
- Superlink® has also been evaluated against industry competitive XLPEs and demonstrates superior processability and properties
- Differences between XLPE resins can be attributed to differences in:
  - Base resin
  - Crosslinking system (peroxide type, concentration and use of co-additives)
  - Antioxidant system
  - UV additives
  - Pigments

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Comparison of Industry XLPEs

- Ingenia regularly benchmarks its Superlink® XLPE versus industry competitors

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Property Comparison

Resin Type	SL110NA	Competitive 1	SL110CA
Lot#	113218 (Natural)	Natural	112376 (Black)
Density	0.942	0.941	0.942
Impact resistance (ARM test, -40 ° C, ¼“) (ft-lbs)	183	181	186
Tensile Strength at Yield (psi)	2921	2806	2935
Tensile Strength at Break (psi)	899	904	860
Flexural Modulus (psi)	113,000	101,200	111,800
ESCR (hrs) 100% Igepal 10% Igepal	 >1000 >1000	 >1000* >1000*	 >1000 >1000
HDT (°F) ASTM D648 at 66 psi 264 psi	 152 104	 141* 98*	

*from datasheet. All other properties measured

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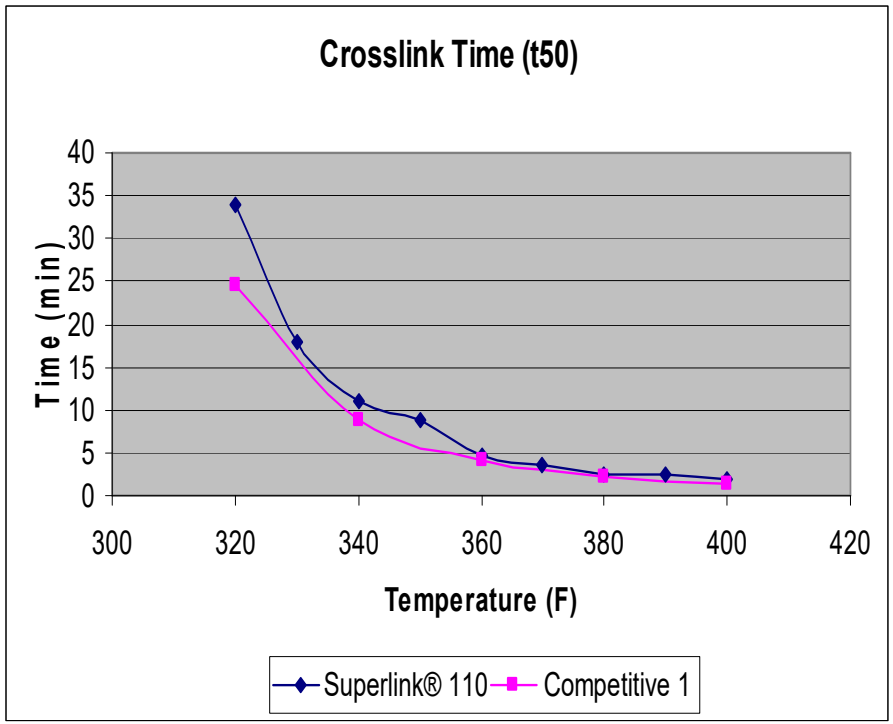
Comparison of Industry XLPEs



- Rheological studies show that Ingenia Superlink® has a longer crosslinking time (t50 and t90) at lower temperatures and a similar crosslinking time at higher temperatures to competitive XLPE
- A lower reactivity at low temperatures allows Superlink® to fully fill the mold, fill out detail, and fully fuse without entrapped air bubbles, before crosslinking
- A higher reactivity at higher temperatures allows Superlink® to fully crosslink without extended heating cycles

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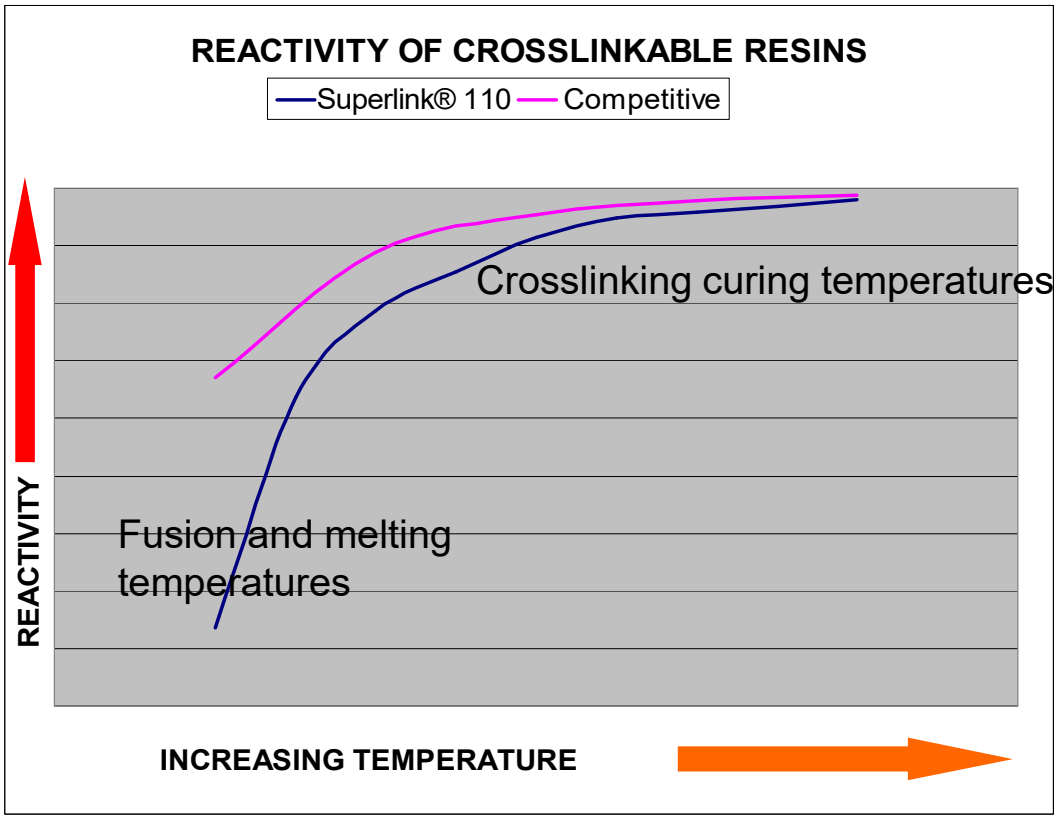
Comparison of Industry XLPEs



- Crosslinking time is inversely proportional to reactivity.
- Superlink® is less reactive at lower temperatures and has increased reactivity at higher temperatures
- This provides good moldability
  - Good fill and detail
  - Complete melting and fusion prior to crosslinking
  - Efficient molding times

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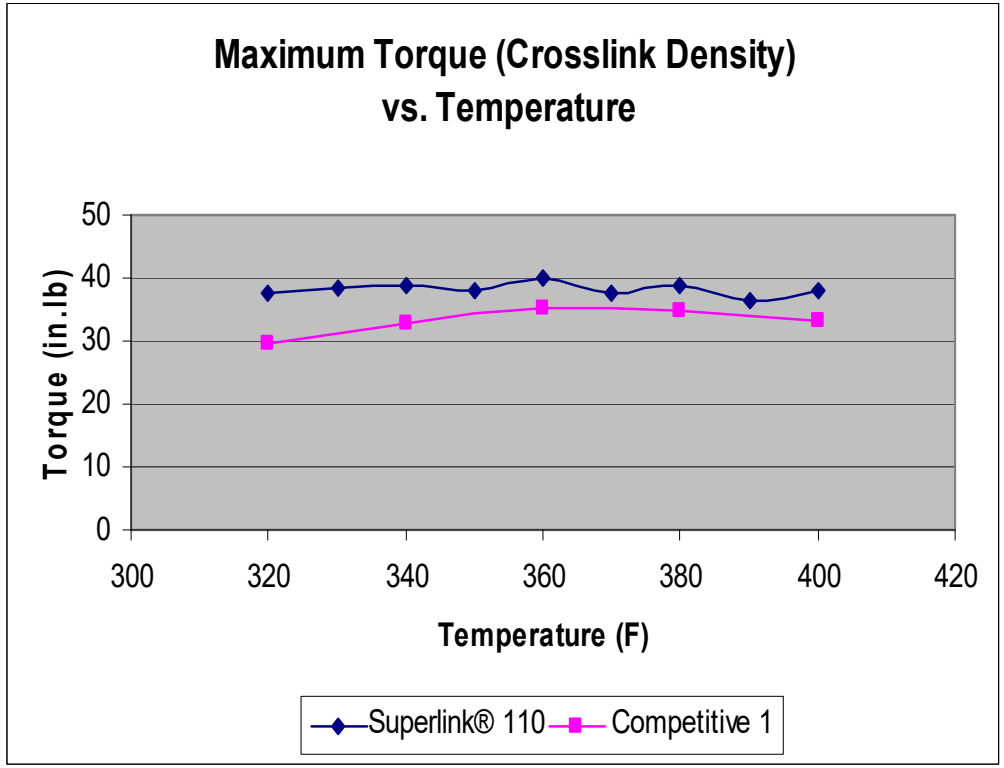
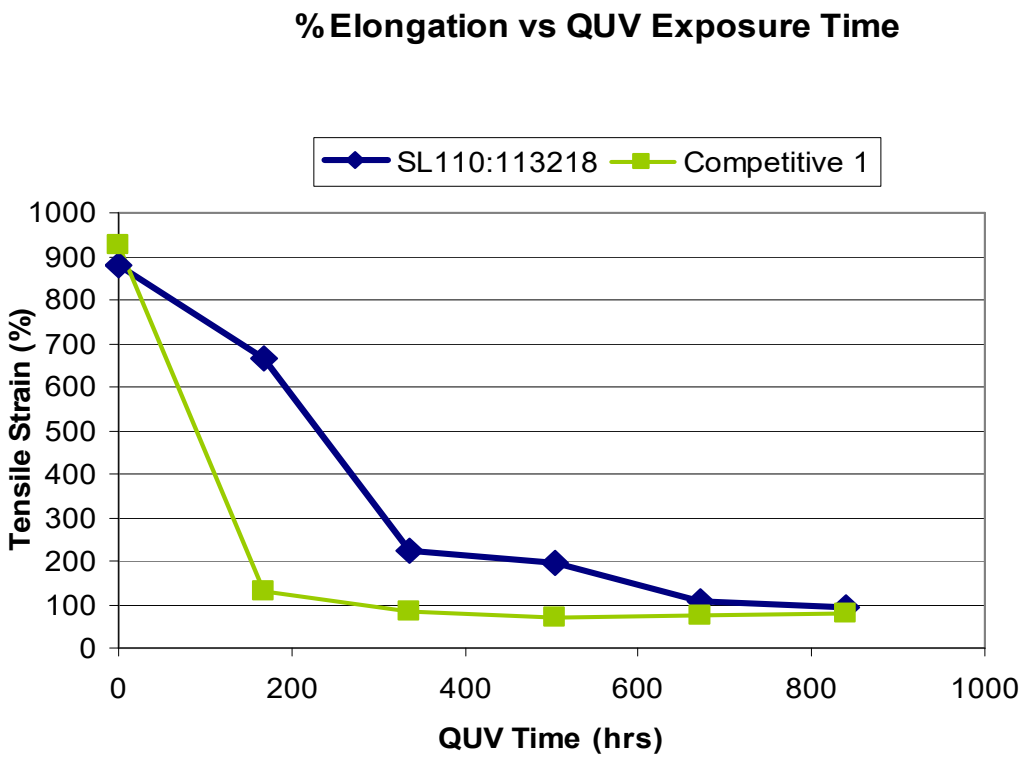
Comparison of Industry XLPEs



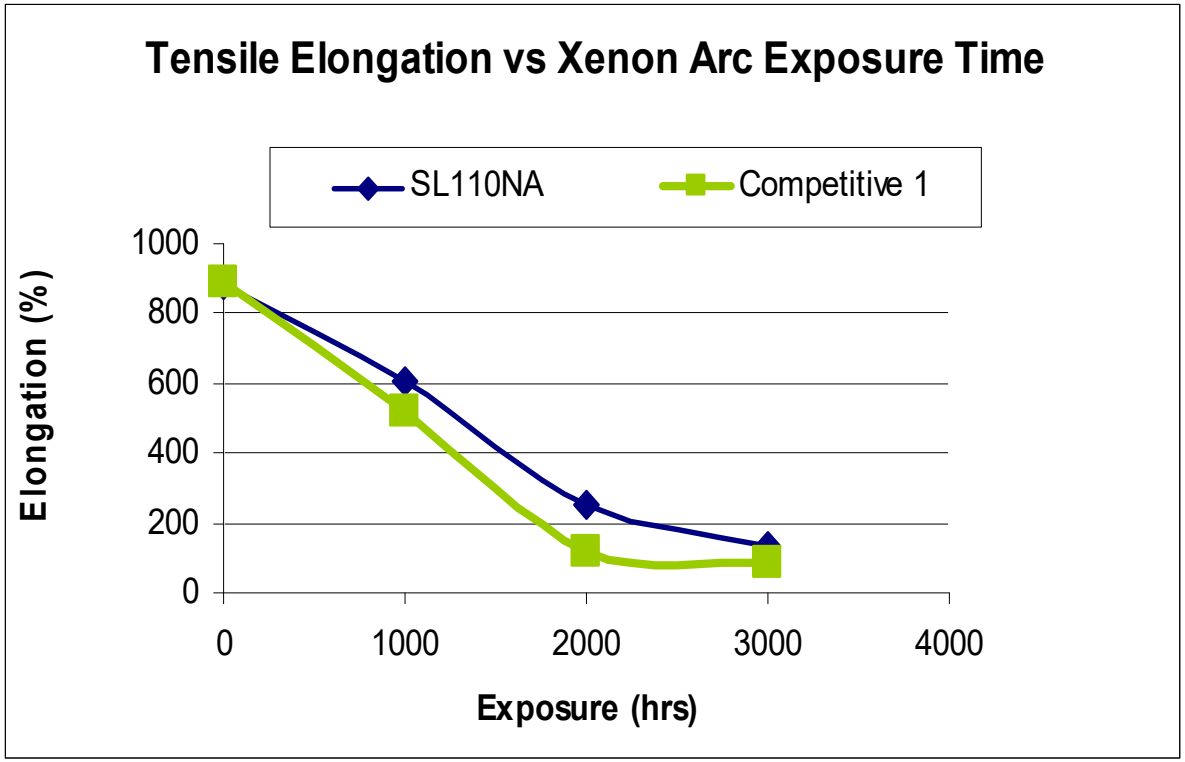
- Rheological studies show that Superlink® has a higher maximum torque than industry competitive XLPE
- Maximum torque is an indication of crosslink density and gel content

Comparison of Industry XLPEs



- Ingenia has carried out extensive long term testing of Superlink® and competitive XLPE
- Ingenia Superlink® has superior QUV resistance to industry competitive XLPE
  - All XLPEs have comparatively low UV resistance compared to well stabilized linear resins.

Comparison of Industry XLPEs



- The UV performance of Superlink® was confirmed by Xenon Arc Weatherometer, which is considered more representative to real world conditions than QUV

Comparison of Industry XLPEs

- Materials have also been evaluated for resistance to thermal aging

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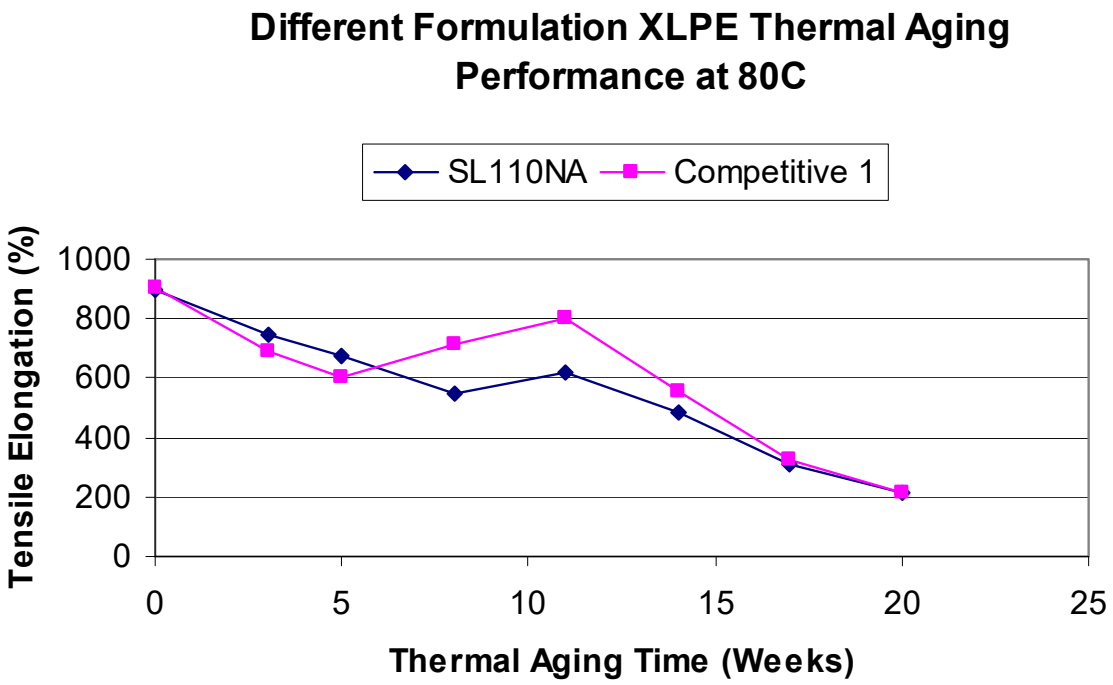
Comparison of Industry XLPEs



- Superlink® shows equivalent performance to industry competitive XLPE in thermal aging tests

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Long Term Testing of Superlink®

- HYDROSTATIC PRESSURE TESTING (ASTM D1998/D2837)
- LTHS: LONG TERM HYDROSTATIC STRENGTH
  - Samples are exposed to pressurized high temperature water for an extended period of time
  - Property that resists stress in the hoop direction generally due to hydrostatic forces in applications such as pipe, pressure vessels or upright storage tanks
  - LTHS improves as MW increases (this is why pipe is extruded from high to very high MW resins)
  - Roto XLPE is generally 30% higher LTHS vs LLDPE of similar density
  - Critical for large tanks (i.e. wall thickness/material usage, process window for thick walled parts)

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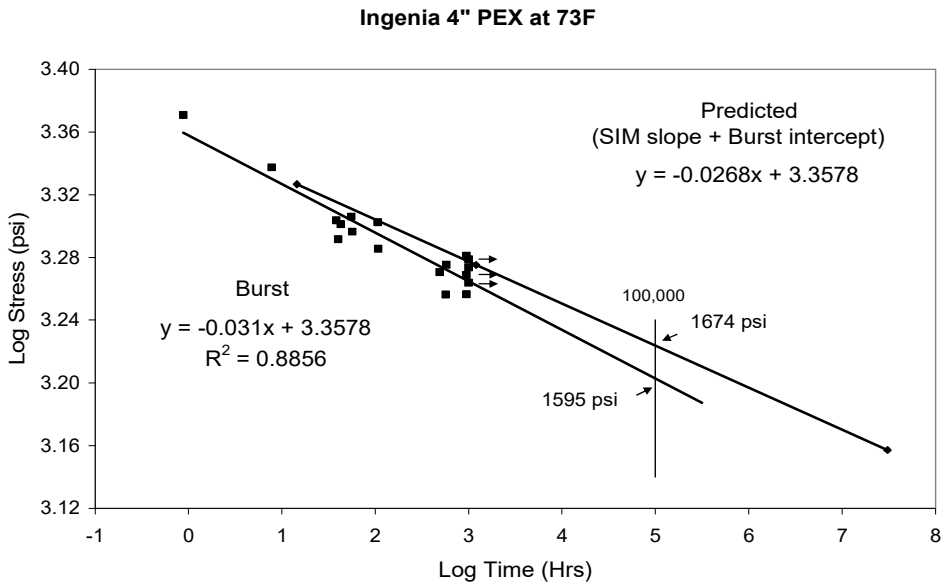
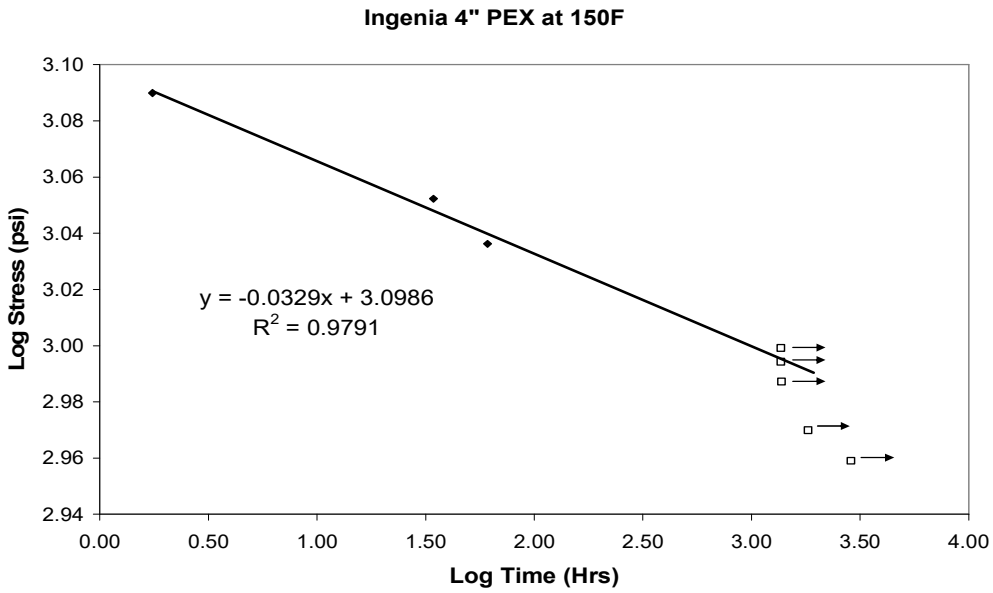
Long Term Hydrostatic Testing

- Preparation of samples for LTHS
- Samples are tested until failure

Long Term Hydrostatic Testing

- Testing at different pressure and temperature allows extrapolation to extended times at lower temperatures





WHAT DOES ALL OF THIS MEAN TO THE MOLDERS?

- Superlink® offers improved properties over linear materials for high performance applications including large chemical tanks and fuel tanks
- Performance has been demonstrated in extensive laboratory and field testing and supported by industry certifications:
  - UNECE-R34 TUV certificate for wheel vehicle part application;
  - UL94 HB burning test certificate,
  - Open fire resistance testing certificate per ABYC H24 specification for marine fuel tank application (provided on request)
- Processability and performance are improved versus industry competitive XLPE. Molders observations
  - Lower scrap rate
  - Faster cycle time
  - Fewer defects and rejects (Pinholes, Voids, Blemishes)

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XLPE applications

- Fuel tanks for gasoline and diesel
  - (single layer or part of a multilayer solution depending on local fuel permeability requirements)
- Large chemical tanks
- Road barriers
- Waste bin covers
- Go-cart bodies
- High impact doors

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XLPE Grades

SL110 Series: High performance XLPE resin with wide processing window.

SL120 Series: ‘Low odor’ product

SL114 Series: High flow, high productivity grade for molding challenging product design at very high oven temperatures, short oven times with moderated gel content.

SL230 series: High adhesion grade for bonding to metal. Used for lining metal tanks in order to provide excellent chemical resistance.

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Processing Guidelines for SUPERLINK®

- Oven temperature ~510F—600F (265C to 315C)
- PIAT target: SL110 series----195C to 210C
  SL120 series----195C to 205C
  SL114 series----205C to 215C
  SL230 series----195C to 210C
- We suggest the use of AXEL WB 4606 mold release for all Superlink® resins
- 2” vent opening.
- Cycle time: ~18 to 28 minutes depending on part thickness and design, mold specifics and oven temperature.

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Benefits of Superlink®

- Greatly improved stiffness - toughness balance as compared with LLDPE and HDPE:
- Improved temperature resistance
- Improved abrasion resistance
- Improved stress crack resistance
  - propagation failure

- Superlink® was developed to meet the demanding requirements for applications requiring outstanding durability, improved abrasion and scratch resistance and improved ESCR.

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