Silox®, Silcat®, Silquest®
Silanes and XL-PEarl®
Liquid Silanes for
Crosslinking

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Silane Crosslinking of Polyolefins

Polyethylene has been crosslinked for many years by a number of proven methods. The initial goal was to extend the maximum service temperature. However, this technology can help deliver many important advantages to non-crosslinked polymers like polyethylene and PVC:

- Typically improves Temperature Resistance (e.g., Long-Term Service Temperature (XLPE = 90°C) and Short-Time Peak Temperature (XLPE up to 250°C))
- Can help increase Aging Resistance
- Can reduce drip phenomena when burning
- Can reduce deformation under load, improved creep, and for pipe, improved stress rupture performance (Environmental Stress)
- Typically improves chemical resistance (e.g., against solvents)
- Can help increase abrasion resistance
- Memory effect (e.g., for shrink tubing, shrink film and stretch wrap)
- Typically improves Flexural Modulus and Low Temperature Impact Strength
Silane Crosslinking Technologies for Polyethylene

Momentive Performance Materials supply silane chemicals to four well-established methods that employ silanes in crosslinking polyethylene:

- Silcat® Silane Crosslinking Chemicals: for the One-Step Process, originally commercialized as Monosil® [1]
- Silox® Silane Grafting Chemicals: for the Two-Step Process, originally commercialized as Sioplas® [2]
- Silquest® Silanes: for copolymerization in reactor
- XL-PEarl® Liquid Crosslinking Chemicals

Concepts of Crosslinking

- Process which forms bonds between polymer chains
- Creates 3-dimensional macro-molecular crosslinked structure
- Material changes from thermoplastic compound to an elastomer (thermoset)
- Network translates into better hot-set or permanent set properties than peroxide crosslinking
- Unlike radiation or peroxide crosslinking, silane systems need a curing cycle immersed in hot water or exposed to steam

Silane Crosslinking Technology

Utilizing Silane crosslinking is a flexible and economical process. Silane crosslinked polyolefins are linked through an Si-O-Si moiety rather than a C-C bond.

Peroxides/Radiation

Direct carbon bond provides a rigid structure

Silane technology (Silquest Silanes, Silox Silane, Silcat Silane, XL-PEarl Liquids)

Siloxane bonds providing enhanced chemical resistance and mechanical flexibility

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Moisture Curing

- Curing involves providing moisture and heat to the grafted polymer
- Organotin compounds (catalyst) accelerate cure
- Rate of curing:
  - Proportional to temperature and the quantity of moisture
  - Inversely proportional to thickness
- Curing Options
  1. Sun bath: Expose to open air for 7 to 14 days (ambient curing)
     - depends on weather and humidity
     - slow and may require 15 days or longer
  2. Steam bath: Place in steam room for 4 or more hours
     - may be used for cables or pipes in huge coils
  3. Water bath: Immerse at 80 ~ 95°C for 4 or more hours
     - may be used for all products

Silane Crosslinking One-Step Process - Monosiil

- Monosiil is a one-step process
- Polyethylene, silane, peroxide, catalyst and other compatibles additives are added in a continuous extrusion step
- The one-step process combines the raw materials, accomplishes the grafting reaction and continuously forms a finished part such as a wire and cable insulation or a PEX pipe
- The technically sophisticated extrusion system employs an extruder with a long barrier screw (L/D = 30) and an injection system for the liquid silane blend
- As in all silane crosslinking methods, the finished part is moisture-cured

Advantages

- Can be cost effective on larger scale
- Single step - high speed
- May be lowest variable cost
- Wide formulation latitude
- Custom formulation flexibility
- No additional heat history

Disadvantages

- Extruder modification/purchase required
- Care in handling of chemicals

Silcat* Silanes Selection Chart for One-Step Process - Monosiil

<table>
<thead>
<tr>
<th>Stabilized Polyethylene Resins</th>
<th>Non-Stabilized Polyethylene Resins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cables</td>
<td>Cables</td>
</tr>
<tr>
<td>LLDPE/LDPE/MDPE/HDPE</td>
<td>LLDPE/LDPE/MDPE</td>
</tr>
<tr>
<td>Silcat R silane</td>
<td>Silcat VS-735/1 silane 10 days @ 150°C</td>
</tr>
<tr>
<td>Silcat RHE silane</td>
<td></td>
</tr>
<tr>
<td>Silcat RHS silane</td>
<td></td>
</tr>
<tr>
<td>Pipes (HDPE)</td>
<td>HFFR**/Semiconductive Compounds and Foams</td>
</tr>
<tr>
<td>XL-PEarl 60 Liquid</td>
<td>XL-PEarl 70M Liquid</td>
</tr>
<tr>
<td>Silcat VS 758-0 silane</td>
<td></td>
</tr>
</tbody>
</table>

*(1) Maillefer SA and BICC Ltd.

*Silcat is a trademark of Momentive Performance Materials Inc.
Silane Crosslinking Two-Step Process - Sioplas

Separates the process into two steps
Silane and peroxide are added in the first step for grafting
Grafting is usually done on a twin screw extruder, pelletized and isolated as the Silane Grafted Polymer (Sioplas compound)
End-user buys Sioplas compound and Tin catalyst to add to extrude into cable or pipe (the second step) on a conventional single screw extruder L/D = 24
Antioxidant or stabilizer, metal deactivator, processing aid and color master batch may be added

Advantages

- Can be lowest investment as existing extruders can be used
- Very high speed and output
- Silane Grafted Polymer is more stable over time than any silane soaking processes
- System generally requires less technical expertise and has fewer problems

Disadvantages

- Higher cost for Sioplas compounds
- Need to mix catalyst prior to production (requiring second compounding step)
- Additional heat history in polymer
- Silane Grafted Polymer has a more stable shelf life over time

(2) Midland Silicons (Dow Corning)

*Silox is a trademark of Momentive Performance Materials Inc.
Silox* and Silquest* Silanes Selection Chart for Two-Step Process - Sioplas(2)

- **General Use**
  - PEX Pipes (for water, gas & fuel transportation)
  - Wire & Cable (low & medium voltage)
  - HDPE

- **LLDPE/LDPE/MDPE/HDPE**
  - Silquest A-171* silane
    - Vinyltrimethoxysilane (need peroxide)
  - Silox*23 silane
    - Formulated system for cables
  - Silox 23 silane
    - Formulated system for PEX pipes
  - Silox VS-604 silane
    - System with processing additive - need peroxide
  - Silox VS-604 silane
    - Stabilized system for copper cables

- **PEX Pipes (for water, gas & fuel transportation)**
  - Silox 23 silane
    - Formulated system for PEX pipes
  - PEarlstab* Y-15760
    - Chlorine Resistant Catalyst & Antioxidant Masterbatch for PEX pipes

(a) Aging test on Copper wire.
Note: Test data. Actual results may vary.

(2) Midland Silicones (Dow Corning)

*Silox, Silquest, Silquest A-171 and PEarlstab are trademarks of Momentive Performance Materials Inc.
**XL-PEarl** Crosslinking Chemicals and **PEarlstab** grades:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>XL-PEarl 31 Liquid</td>
<td>Crosslinking system to be used with LLDPE, MDPE and HDPE resins for cables insulation. Must be used in combination with resins that contains stabilizers or with a suitable antioxidant masterbatch.</td>
</tr>
<tr>
<td>XL-PEarl 35 Liquid</td>
<td>The product is designed for crosslinking high density polyethylene (HDPE) for manufacturing PEX pipes.</td>
</tr>
<tr>
<td>PEarlstab Y-15760 Masterbatch</td>
<td>It is a multi-component chlorine resistant antioxidant and catalyst masterbatch.</td>
</tr>
<tr>
<td>XL-PEarl 60 Liquid</td>
<td>The product is designed for crosslinking medium and high density polyethylene (HDPE) for manufacturing PEX pipes. Additional stabilizer package might be required.</td>
</tr>
<tr>
<td>XL-PEarl 70M Liquid</td>
<td>Crosslinking system for Halogen-Free Flame Retardant cable compounds, semiconductive cable compounds and polyethylene foams.</td>
</tr>
</tbody>
</table>

*XL-PEarl and PEarlstab are trademarks of Momentive Performance Materials Inc.*
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