Silquest® Silanes
Selector and Handling Guide
SILQUEST* silanes products and potential applications

Product Description
Silquest silanes are versatile products that react with a wide variety of organic and inorganic materials. Their unique ability as coupling agents, crosslinking agents, and surface modifiers has been proven in an ever-increasing number of applications, ranging from fuel-saving silica tires, adhesives to coatings to fiberglass reinforced composites. The benefits that Silquest silanes may impart to these end-use applications are highlighted on page 2.

Application Guidelines
The choice of a Silquest silane is specific to resin type and application. We recommend that you contact the nearest Momentive Performance Materials sales office for assistance before selecting a silane for your end-use application. The following selection guide is provided to help you select a Silquest silane for various polymer (resin) systems. It should be considered merely a starting point. The selection of the preferred silane for a specific end-use application will require specific experimentation.

Potential Applications

<table>
<thead>
<tr>
<th>Potential Applications</th>
<th>Typical Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesives</td>
<td>Moisture-initiated crosslinking of resins, improved wet adhesion, primerless adhesion to many materials, improved chemical resistance, weatherability and durability</td>
</tr>
<tr>
<td>Coatings / Inks</td>
<td>Moisture-initiated crosslinking of resins, improved adhesion, chemical and corrosion resistance, weatherability, pigment dispersion and scrub resistance</td>
</tr>
<tr>
<td>Fiber Reinforced Composites and Glass Insulation</td>
<td>Coupling of resins with fibers for improved resiliency of insulation batts, better wet strength retention and electrical properties of FRP composites, and improved fiber strand integrity, protection and handling</td>
</tr>
<tr>
<td>Filler Treatment</td>
<td>Improved coupling of resins with fillers, better filler dispersion and processing ease in thermoset and thermoplastic resins</td>
</tr>
<tr>
<td>Polymer Modification</td>
<td>Moisture-cure crosslinking for improved environmental and chemical resistance</td>
</tr>
<tr>
<td>Rubber and Elastomers</td>
<td>Coupling of resins with minerals for improved composite strength, toughness, abrasion resistance, rolling resistance, wet electrical properties and rheology control, fewer mixing steps and better silica dispersion</td>
</tr>
<tr>
<td>Sealants</td>
<td>Moisture-initiated crosslinking of resins, improved adhesion, chemical resistance, filler dispersion and weatherability</td>
</tr>
<tr>
<td>Thermoplastics</td>
<td>Moisture-cureable crosslinked polyethylene for wire &amp; cable and polyethylene crosslinked (PEX) pipe, mineral and pigment treatment for dispersibility and coupling of resins with fillers in high performance-thermoplastics</td>
</tr>
<tr>
<td>Tires</td>
<td>Coupling silica in tire compounds to improve the rolling resistance, traction and wear. New generation silanes may facilitate higher efficiency tire manufacturing while enhancing tire performance.</td>
</tr>
</tbody>
</table>

Silanes make performance possible, and here is why.

The following pages outline how silanes work, and how they are added to systems.

How they work
Silanes have four main functions:

- **Crosslinking**
  Once attached to a polymer backbone, silanes can link polymer molecules together via the formation of siloxane bonds, creating a three-dimensional network. This “crosslinking” is activated by ambient moisture and can take place at ambient temperature. Silanes can provide improved thermal stability, creep resistance, hardness and chemical resistance to coatings, adhesives and sealants.

- **Adhesion Promotion**
  Silanes can provide improved substrate adhesion in adhesives, sealants and coatings, especially under hot and humid conditions. Silanes are commonly used to improve adhesion to glass and metals, but they can also be beneficial with difficult substrates like polyamide, SMC, acrylics, PVC and others.

- **Coupling**
  Silanes can couple inorganic pigments and fillers to organic resins. Coupling typically improves the moisture and chemical resistance of the coating or adhesive.

- **Dispersion**
  Silanes can aid in the dispersion of inorganic pigments and fillers in coatings and sealants. This can lead to lower viscosity in the formulated product and can improve the hiding power of a coating.

Chemistry
Organofunctional silanes are bi-functional molecules in that they usually have two types of reactivity built into their structures - organic and inorganic. Figure 1 shows the common elements of a typical organofunctional silane.

![Figure 1: Anatomy of a Typical Organofunctional Silane](image)

Reactions at the Organic End of a Silane
The organic end (Y) is designed for reactivity with an organic resin. Reactive organic groups that are available include primary and substituted amino, epoxy, methacryl, vinyl, mercapto, urea and isocyanate. The organic group is selected either to react with or co-polymerize into a resin or to take part in the cure reaction of the resin system.

**Linking Group in the Center of a Silane**
Between the organic group and the silicon atom is a linking group, commonly, a “trimethylene chain.” The silicon-carbon bond of the linking group is stable to most environmental conditions. The inorganic end of the molecule reacts through the hydrolyzable groups attached to silicon (X). The hydrolyzable groups are usually alkoxyl groups such as methoxy, ethoxy or isopropoxy. Each hydrolyzes at a different rate and releases a different alcohol upon reaction with ambient moisture. In some cases only two hydrolyzable groups are present, although a three-group configuration is more convenient synthetically and usually gives more moisture-resistant bonds. Most coupling agents have only one silicon atom, but some silanes are available with multiple silicones.
Introducing Silanes into Polymer-based Systems

There are basically three ways to use a silane in a polymer matrix:

- **polymer modification**
- **integral blending**
- **filter and surface pre-treatment**

The optimum method is governed by the benefits sought, variables of the chemistry, nature of the application and cost. Like any moisture-reactive system, silane reaction rates depend on availability of water, the moisture diffusion rate, pH, catalysts and the system’s overall hydrophobicity.

- **Polymer Modification**

The organic functionality of silanes can be used to silylate polymers by grafting, endcapping or co-polymerization. This can be accomplished with most polymers: acrylics, polyesters, epoxies, urethanes, polyureas, etc.

Silated copolymers offer coupling or crosslinking reactions through the graft silanized group, without requiring high temperature cure. The result is a moisture-cured, self-crosslinking system generally curable at room temperature. Coupling and crosslinking typically give significant improvements in polymer properties including:

- **Durability**
- **Water and chemical resistance**
- **Higher tensile strength and elongation**
- **Tear and crack resistance**
- **Toughness and abrasion resistance**
- **Thermal stability**
- **Creep resistance**

- **Integral Blending**

Integral blending is often the easiest method for using silanes because it avoids a separate polymer modification or surface pre-treatment step. Sililated silanes can be mixed with the polymer component of most systems or formulations by any convenient method. For good dispersion of the small amounts usually involved, it is advisable to prepare a pre-dispersion containing a high silane concentration to aid the bulk of the polymer. In solvent-containing systems, the silane can be pre-dispersed in a small amount of the solvent. In latex systems, it can be added to the coalescing solvent.

The chosen silane should have reactivity with the resin; there is enough variety in silane functionalities to make this possible. Figure 4 shows the adhesion obtained between an epoxy paint and aluminum metal using a mercaptosilane and an amino silane. Generally, the biggest increase in adhesion is achieved after exposure to moisture or humidity.

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**Table 1: Typical Silane Primer Recipe**

<table>
<thead>
<tr>
<th>Parts by Weight</th>
<th>Ingredient</th>
<th>Act.</th>
<th>% Silquest A-189 silane</th>
<th>% Silquest A-1125 silane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silane</td>
<td>Act.</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>40</td>
<td>Alcohol</td>
<td>50</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>5</td>
<td>Distilled water</td>
<td>40</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>4</td>
<td>Water</td>
<td>5</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Product formulations are included as illustrative examples only. Momentive makes no representation or warranty as to any such formulations, including, without limitation, concerning the efficacy or safety of any product manufactured using such formulations.

Primers offer excellent technology for improving adhesion in coatings. They do require extra steps, labor and care that rule them out of many applications. Even if a primer is not used for the final version of a product, it is worthwhile to experiment with primers to observe the possible benefits.
**SILQUEST® silanes products and potential applications**

### Reactive Resins

**Silquest Silanes**

<table>
<thead>
<tr>
<th>Resin System</th>
<th>Aqueous Non-Aqueous</th>
</tr>
</thead>
</table>

### Thermoplastic Resins

**Silquest Silanes**

<table>
<thead>
<tr>
<th>Thermoplastic Resins</th>
<th>Silquest Silanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyolefin</td>
<td>A-151NE, A-171</td>
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</table>

### Elastomers

**Silquest Silanes**

<table>
<thead>
<tr>
<th>Elastomers</th>
<th>Silquest Silanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butyl</td>
<td>A-174VE, A-189</td>
</tr>
<tr>
<td>Neoprene</td>
<td>A-189, A-Link 599</td>
</tr>
<tr>
<td>Nitrile</td>
<td>A-187, A-189</td>
</tr>
<tr>
<td>Silicone</td>
<td>A-171, A-174NT</td>
</tr>
</tbody>
</table>

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**Silane Selection Decision Tree for Coatings Adhesives and Sealants**

**Resin System**

- **Waterbased?**
  - Yes
  - No

**Thermoset Resins**

- **ACRYLIC**
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-1100* silane
  - Silquest A-174NT silane
  - Silquest A-1000* silane
  - Silquest A-189 silane
  - Silquest A-1524 silane
  - Silquest A-1170 silane

- **PUR**
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane

- **EPOXY**
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane

- **SILICONE**
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane

- **POLY**
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane
  - Silquest A-174NT silane

**One Pack**

- **FILLED**
  - Silquest A-1120 silane
  - Silquest A-1120 silane
  - Silquest A-1120 silane
  - Silquest A-1120 silane

- **CLEAR**
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane

**Two Pack**

- **FILLED**
  - Silquest A-1120 silane
  - Silquest A-1120 silane
  - Silquest A-1120 silane
  - Silquest A-1120 silane

- **CLEAR**
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
  - Silquest A-187* silane
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### Chemical Structures and Typical Physical Properties

<table>
<thead>
<tr>
<th>SILANES ESTERS</th>
<th>Chemical Name</th>
<th>Formula</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-137</td>
<td>Octyltriethoxysilane</td>
<td>C_{8}H_{17}Si(OCH_{2}CH_{3})_{3}</td>
<td>276.6</td>
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<tr>
<td>A-162</td>
<td>Methyltriethoxysilane</td>
<td>CH_{3}Si(OCH_{2}CH_{3})_{3}</td>
<td>178.3</td>
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<tr>
<td>A-1230</td>
<td>Proprietary nonionic slane dispersing agent</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>A-189</td>
<td>gamma-Mercaptopropyltrimethoxysilane</td>
<td>HSCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>196.4</td>
</tr>
<tr>
<td>A-1891</td>
<td>gamma-Mercaptopropyltriethoxysilane</td>
<td>HSCH_{2}CH_{2}CH_{2}Si(OCH_{2}CH_{3})_{3}</td>
<td>238.4</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>SILANES</th>
<th>Chemical Name</th>
<th>Formula</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl</td>
<td>RC-1</td>
<td>Coupling agent - proprietary</td>
<td>—</td>
</tr>
<tr>
<td>A-151NT</td>
<td>Vinyltrimethoxysilane</td>
<td>CH_{2}=CHSi(OCH_{3})_{3}</td>
<td>148.2</td>
</tr>
<tr>
<td>A-1524</td>
<td>gamma-Ureidopropyltrimethoxysilane</td>
<td>H_{2}NCNHCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>222.4</td>
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<table>
<thead>
<tr>
<th>VINYL</th>
<th>Chemical Name</th>
<th>Formula</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1100*</td>
<td>gamma-Aminopropyltrimethoxysilane</td>
<td>H_{2}NCH_{2}CH_{2}CH_{2}Si(OCH_{2}CH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1102</td>
<td>gamma-Aminopropyltriethoxysilane</td>
<td>H_{2}NCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1106</td>
<td>gamma-Aminopropyltriethoxysilane</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1110</td>
<td>gamma-Aminopropyltrimethoxysilane</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1116</td>
<td>gamma-Aminopropyltrimethoxysilane</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1120</td>
<td>N-beta-(Aminooethyl)-gamma-aminopropyltrimethoxysilane</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}NHCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1130</td>
<td>Triaminofunctional silane</td>
<td>H_{2}NCH_{2}CH_{2}NHCH_{2}CH_{2}NHCH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>265.4</td>
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<tr>
<td>A-1170</td>
<td>Barcylanino-silane</td>
<td>CH_{2}=CHNHCH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
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<tr>
<td>A-1230</td>
<td>Proprietary nonionic silane dispersing agent</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>A-1387</td>
<td>Polyazamide silane</td>
<td>—</td>
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<tr>
<td>Y-9668</td>
<td>N-Phenyl-gamma-aminopropyltrimethoxysilane</td>
<td>NH_{2}CH_{2}CH_{2}CH_{2}NHCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
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<tr>
<td>A-Link 15</td>
<td>N-ethyl-3-triethoxysilyl-propanamine</td>
<td>CH_{2}=CH(OC_{2}H_{5})_{3}</td>
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<td>A-172NT</td>
<td>Vinyltris-[2-methoxyethoxy]silane</td>
<td>CH_{2}=CHSi(OCH_{2}CH_{2}OCH_{3})_{3}</td>
<td>280.4</td>
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<td>A-174NT</td>
<td>gamma-Methacryloxypropyltrimethoxysilane</td>
<td>CH_{2}=CHCO_{2}CH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>236.1</td>
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<table>
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<th>Chemical Name</th>
<th>Formula</th>
<th>Molecular Weight</th>
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<tr>
<td>A-187</td>
<td>gamma-Glycidoxypropyltrimethoxysilane</td>
<td>CH_{2}CHCH_{2}OCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>236.1</td>
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<td>A-1871</td>
<td>gamma-Glycidoxypropyltrimethoxysilane</td>
<td>CH_{2}CHCH_{2}OCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
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<thead>
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<th>EPOXY</th>
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<tr>
<td>A-186</td>
<td>beta-[(4-Epoxy)cyclohexyloxy]trimethoxysilane</td>
<td>CH_{2}=C(CH_{3})CO_{2}CH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
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<td>Vinyltrimethoxysilane</td>
<td>CH_{2}=CHSi(OCH_{3})_{3}</td>
<td>148.2</td>
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<tr>
<td>A-187</td>
<td>gamma-Glycidoxypropyltriethoxysilane</td>
<td>CH_{2}CHCH_{2}OCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>236.1</td>
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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>A-189</td>
<td>gamma-Mercaptocyclohexyloxytrimethoxysilane</td>
<td>HSCH_{2}CH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>196.4</td>
</tr>
<tr>
<td>A-1891</td>
<td>gamma-Mercaptocyclohexyloxytrimethoxysilane</td>
<td>HSCH_{2}CH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>238.4</td>
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<td>A-Link 599</td>
<td>3-octanoyloxy-1-propyltrimethoxysilane</td>
<td>CH_{3}(CH_{2})<em>{7}CO</em>{2}CH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
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<th>Formula</th>
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<td>gamma-Aminoxypropyltrimethoxysilane</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
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<tr>
<td>A-1100</td>
<td>gamma-Aminoxypropyltrimethoxysilane (Technical Grade)</td>
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<td>221.4</td>
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<td>A-1101</td>
<td>gamma-Aminoxypropylsiloxane (aqueous solution)</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
</tr>
<tr>
<td>A-1110</td>
<td>N-beta-(Aminooethyl)-gamma-aminopropyltrimethoxysilane</td>
<td>(CH_{3})<em>{2}NHCH</em>{2}CH_{2}NHCH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>221.4</td>
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<tr>
<td>A-1120</td>
<td>N-ethyl-3-triethoxysilyl-propanamine</td>
<td>CH_{2}=CH(OC_{2}H_{5})_{3}</td>
<td>222.1</td>
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<tr>
<td>A-1218</td>
<td>Barcylanino-silane</td>
<td>CH_{2}=CHNHCH_{2}CH_{2}Si(OCH_{3})_{3}</td>
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<th>UREIDO</th>
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<tbody>
<tr>
<td>A-1260</td>
<td>gamma-Ureidoxypropylsilane (50% in methanol)</td>
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<td>196.4</td>
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</tbody>
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<table>
<thead>
<tr>
<th>ISOYCYANATE</th>
<th>Chemical Name</th>
<th>Formula</th>
<th>Molecular Weight</th>
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<tbody>
<tr>
<td>A-1524</td>
<td>gamma-Ureidoxypropyltrimethoxysilane</td>
<td>H_{2}NCNHCH_{2}CH_{2}CH_{2}Si(OCH_{3})_{3}</td>
<td>222.4</td>
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<tr>
<td>A-Link 55</td>
<td>gamma-Isoacyanatopropyltrimethoxysilane</td>
<td>O=C=NHCH_{2}CH_{2}CH_{2Si(OCH_{3})_{3}}</td>
<td>247.3</td>
</tr>
<tr>
<td>A-Link 35</td>
<td>gamma-Isoacyanatopropyltrimethoxysilane</td>
<td>O=C=NHCH_{2}CH_{2}CH_{2Si(OCH_{3})_{3}}</td>
<td>206.2</td>
</tr>
</tbody>
</table>

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### Chemical Structures and Typical Physical Properties

<table>
<thead>
<tr>
<th>Silquest</th>
<th>Chemical Name</th>
<th>Formula</th>
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</table>

<table>
<thead>
<tr>
<th>Molecular</th>
<th>Weight</th>
</tr>
</thead>
</table>

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Tips For Success With Silanes

General Tips

- For good dispersion of silanes in solvents or polymer-based formulations, the unhydrolyzed silane should be dispersed as well as possible. Intensive agitation and adding solvent are two useful recommendations in case of difficulties. As a rule, pH should be controlled prior to adding silanes, and adjusted as necessary throughout the process.

- As the hydrolysis reaction takes place in the presence of water, no silane condensation is expected in dry, tight containers.

- Ambient humidity is often sufficient for silanes to fully hydrolyze and therefore to activate silanes for subsequent condensation.

- It can take time for complete hydrolysis to occur. To ensure a reaction, silanes cannot be left to react with moisture one hour prior to use, if needed.

Tips for Water-Based Systems

- Some silanes are not water-soluble. However, once hydrolyzed, most of these become water-soluble.

- For most silanes, high concentrations in solutions are not necessarily chemical equivalents and, as such, may pose different safety issues and hazards.

- For good dispersion of silanes in solvents or polymer-based formulations, the unhydrolyzed silane should be dispersed as well as possible. Intensive agitation and adding solvent are two useful recommendations in case of difficulties. As a rule, pH should be controlled prior to adding silanes, and adjusted as necessary throughout the process.

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**Guidelines for Handling Silanes (continued)**

**The Alkoxy Silane Group:** Hydrolysis/Condensation and Liberation of Alcohol

Organofunctional alkoxy silanes, by nature, react with water (hydrolyze) from humid air, moisture, or from water contamination within process chemicals or equipment. Hydrolysis and condensation are necessary for organofunctional silanes to work effectively. However, premature hydrolysis that occurs as a result of careless handling or moisture contamination will reduce product quality, possibly resulting in reduced downstream performance. Therefore, it is important to keep silanes free from moisture contamination throughout storage.

Amino-functional alkoxysilanes are readily soluble in water and hydrolyze very rapidly with noticeable heat generation (exotherm) and the liberation of alcohol. Other silanes hydrolyze more slowly depending upon the organic functionality, the specific alkoxysilane group attached to silicon, the product's solubility in water, and the pH of the water. Upon hydrolysis, the alkoxyl groups of all alkoxysilanes (most typically in the form of "methoxy" (-OCH3) or "ethoxy" (-OCH2CH3) are liberated as the corresponding alcohol (methanol or ethanol, respectively). The amount of alcohol liberated upon hydrolysis can be as high as 70% by weight of the initial silane charge. During hydrolysis, the resulting silane is converted to a silanol (-Si-OH) group. The formation of silanol is key to the function of silanes, because silanols and hydroxylated substrates to form siloxanes and silicate-like structures (-Si-O-Si- or –Si-O-[metal atom]). This reaction is referred to as the "condensation" of silanols. The liberation of alcohol from alkoxysilane hydrolysis has an impact on flammability, personnel exposure, and environmental issues:

a) **Flammability:** The flammability of the resulting silane mixture will increase following hydrolysis according to the amount of water present. In the simplest case, the flash point of a silanol (-Si-OH) group. The formation of silanol is key to the function of silanes, because silanols and hydroxylated substrates to form siloxanes and silicate-like structures (-Si-O-Si- or –Si-O-[metal atom]). This reaction is referred to as the "condensation" of silanols. The liberation of alcohol from alkoxysilane hydrolysis has an impact on flammability, personnel exposure, and environmental issues:

b) **Personnel Exposure:** For methoxy-silane hydrolysis, by-product methanol is toxic and can be absorbed through the skin. In addition, the OSHA and ACGIH occupational exposure limit for methanol by inhalation is 200 ppm TWA. For ethoxy-silanes, ethanol is liberated upon hydrolysis. Although ethanol is significantly less toxic than methanol, the MSDS carries the associated warnings appropriate for ethanol exposure. For either methoxy or ethoxy silane esters, additional effects would be observed based on the specific organofunctionality of each silane product.

c) **Environmental:** Since up to 70% by weight of the silane charge is converted to alcohol (depending on the silane structure and hydrolysis conditions), the environmental release and handling requirements must be taken into consideration.

**The Alkoxy Silane Group:** Adventitious Moisture

A nuisance in handling some alkoxysilanes is the undesirable formation of silanol, or build-up of solids due to premature hydrolysis and condensation of the product. Silane hydrolyzate may appear crystalline or gummi depending upon the original silane and hydrolysis conditions. The solids are actually condensed, crosslinked amorphous polymers of the silane. A typical problem in handling laboratory quantities of alkoxysilanes is the opening of sealed bottles if the caps appear "frozen". Leather gloves and extra precautions are recommended when opening glass containers of organofunctional silanes. Silane hydrolyzate is avoidable or can be minimized with the proper use of a dry nitrogen purge, desiccants, and solvent flushing of equipment and lines.

Hydrolysis and condensation reactions and kinetics for organofunctional silanes have been studied in depth by F. D. Osterholtz and E. R. Pohl,(1) of Momentive Performance Materials. The potential exists for self-heating reactions of vinyl silanes, especially at elevated temperatures and if peroxides or other free radical initiators are present. The primary examples of vinyl silanes are Silquest A-151NT and Silquest A-171* silanes. Follow the precautions specified in the MSDS.

**The Organofunctional Group:** Vinyl Silane Reactivity

The potential exists for self-heating reactions of vinyl silanes, especially at elevated temperatures and if peroxides or other free radical initiators are present. The primary examples of vinyl silanes are Silquest A-151NT and Silquest A-171* silanes. Follow the precautions specified in the MSDS.

**Guidelines for Handling Silanes (continued)**

**The Alkoxy Silane Group:** Avoiding Hydrolyzate Formation

a) **Use of Desiccants:** To avoid premature hydrolysis of silanes during storage and use, desiccants can be utilized. Various disposable desiccating units are currently available from independent distributors and chemical supply companies.

b) **Use of an Inert Gas (e.g., dry nitrogen):** The use of dry nitrogen to blanket the headspaces of silane containers with nitrogen or any other gas; the container could rupture. Nitrogen gas can be dangerous due to the displacement of oxygen in the work area, which can potentially cause asphyxiation. In any operating area where nitrogen is used, adequate ventilation must be ensured. The atmosphere of the work area should be checked periodically to be certain adequate oxygen is present. Be aware of potential "confined spaces" and use proper testing and entry procedures, if applicable.

c) **Solvent Flushing Techniques:** Hydrolyzate build-up can be a particular problem at equipment nozzles and valves, and in transfer lines, pipes and tubing. Lines, valves and nozzles should be dry and pre-purged with nitrogen before introducing silanes. The appropriate solvent should be used to flush equipment after shutting down a processing line or operation. Selection of solvent is important. It should be non-reactive, free from water contamination, and compatible with the specific process.

**The Organofunctional Group:** Reactivity

The organofunctional portion of the silane molecule is designed to react/interact with an organic phase, for example, in polymeric resins or with polymerizable organic media. The proper silane is matched with the organic/polymeric medium to maximize the compatibility and effectiveness for optimum coupling and product performance. The reactivity of silanes at the organofunctional end varies among silanes. Therefore, refer to the MSDS, Section 10 ("Stability and Reactivity") for warnings of incompleteness and specific conditions to avoid.

**The Organofunctional Group:** Polymerization

An organofunctional silane may be susceptible to polymerization and may require extra care during temporary and longer term storage. The polymerization potential is described within the MSDS (Section 10). Examples are products containing methacrylate, epoxy, and vinyl functionality.

In order to prevent unwanted polymerization, certain contaminants must be avoided with methacryloxy-silanes (e.g., Silquest A-171* and Silquest Y-9886 silanes). Peroxides and other free radical initiators, oxidants, reducing agents, and transition metal salts or their oxides (even rust) should be avoided. Avoid direct exposure to UV light and excessive heat.

Follow storage and handling procedures as dictated in standard vinyl ester and acrylate/methacrylate ester product safety brochures. Do not attempt to remove polymerization inhibitors or treat these products with adsorption media that could lower the concentration of contained inhibitors.

**Silquest** silanes products and potential applications
and that intentional hydrolysis be properly controlled to avoid contamination of the epoxysilanes with water be avoided,

Note: It is imperative, therefore, that unintentional the rate of continued reactions.

polyglycol ethers are produced via the epoxy functional group

Polysiloxanes are produced by hydrolysis and condensation exceptible to base catalyzed ring opening. Polymerization can more prone to acid catalyzed ring opening; Silquest A-187, contaminants such as acids and bases, amines, and ionic group. Epoxy ring opening can occur when exposed to certain conditions of catalyzed partial hydrolysis. Hydrolysis can occur at both the silyl ester group as well as the epoxy group. Epoxy ring opening can occur when exposed to silanols and is a necessary step in promoting the chemical bonding of the silane to inorganic substrates. Most silanes will liberate either methanol or ethanol during the intentional silane coupling process in which inorganic fillers are bonded to a polymeric resin. The potential, therefore, exists for flam-

silanes products and potential applications

The Organofunctional Group: Amino Silane Reactivity

Silquest A-1102®, Silquest A-1102, Silquest A-1110, Silquest A-1120, Silquest A-1130, Silquest A-1170 silanes are common exceptions of aminofunctional silanes. Aminosilanes are unique in that the rate of hydrolysis is independent on the adjustment of the water used in the aqueous preforms. Therefore, aminosilanes are readily soluble in water and the subsequent hydrolysis occurs almost instantaneously. When hydrolysis occurs with these silanes, heat may be noticeable and the alcohol by-product is rapidly generated (methanol or ethanol, depending upon whether the silane contains methoxy- or ethoxy- substituents on the silicon atom).

Note: Certain weight ratios of silane and water can lead to the generation of enough heat that the mixture may boil, thereby liberating the reactants under pressure. This is a common occurrence when using silanes that have low SADT (spontaneous ignition temperature). Due to the inherent affinity of amino-functional silanes with water, extra care should be taken to ensure that moisture contamination does not occur within original containers and temporary storage tanks prior to their intended use. Unintentional water contamination can lead to gels or solids which can cause plugging of equipment and lines. Therefore, nitrogen blanketing and purging of equipment and containers is strongly encouraged for eliminating equipment fouling and for maintaining the integrity of these silanes.

Flammability Considerations: Special Blending and Mixing Operations

Blenders, mixers, and compounding operations may present varying inherent hazards when introducing silanes. In addition to the mechanical hazards associated with mixing units, there are recommended precautionary steps to avoid flammable atmospheres during or following the mixing of silanes with other chemicals, solvents, polymers, mineral fillers, or inorganic substrates.

Operations personnel should be aware of the inherent generation of free alcohol when organofunctional silanes are exposed to water or moisture. Hydrolysis is an inherent characteristic of silanes, and in most applications is intended for the optimum performance of the silane. As noted earlier, hydrolysis occurs when alkoxysilanes react with free water. The water may be 1) a separate ingredient within the mixture, or 2) atmospheric moisture, or 3) present on the surface of the inorganic filler, such as clay, calcium carbonate, silica, etc. This reaction involves the conversion of alkoxysilanes to silanols and is a necessary step in promoting the chemical bonding of the silane to inorganic substrates. Most silanes will liberate either methanol or ethanol during the intentional silane coupling process in which inorganic fillers are bonded to a polymeric resin. The potential, therefore, exists for flam-

Guidelines for Handling Silanes (continued)

To minimize flammability potential during transfer, mixing, compounding, and blending operations, all equipment and tanks should be purged and drained. Grounds should be periodically tested for electrical continuity. Purge and blanket all mixing, compounding, blending, and storage units and vessels with an inert gas, such as dry nitrogen, to reduce the oxygen concentration to a safe level prior to the addition of silane. The inert blanketing should be maintained throughout the entire operation and storage. As described earlier, inerting also helps to maintain a moisture-free atmosphere, and this helps to ensure the integrity of the product against premature hydrolysis. This is especially true with aminofunctional silanes that hydrolyze rapidly in the presence of moist air.

Note: An exception to the purging/inert blanketing requirement is the (methylacylate functional silane group, including Silquest A-174™ silane, and Silquest V-9936 silane or any other silane with a long chain alkyl group (see MSDS for compositional information). The inhibitors in these silanes require the presence of oxygen to help retard premature polymerization. Therefore, these silanes should be maintained with a head space of dry 3% oxygen, rather than pure nitrogen.

Guidelines for Handling Silanes (continued)

To minimize oxidation: In addition to reducing flammability concerns, inert blanketing also helps to reduce air oxidation that can lead to color formation, especially with the aminosilanes (Silquest A-1102® silane, Silquest A-1120 silane, Silquest A-1130 silane and Silquest A-1170 silane). In order to maintain the quality and original integrity of the aminosilanes, purge the headspace of all partial drums with nitrogen. Do not transfer unused silane back into the original drum. Do not use silane drums as mixing containers. Dispose of all empty drums properly, utilizing an environmentally responsible drum disposal company or reclaimer.

Volatile Organic Compounds (VOCs)

It is difficult to determine the volatile organic compound value for silanes using ASTM method D2392 (EPHA Method A24), due to the propensity of the alkoxysilane to hydrolyze during the test procedure. Once hydrolysis takes place, a loss of alcohol results, which affects the gravimetric determination of low boiling materials.

Personal Protective Equipment

The minimum recommended personal protective equipment (PPE) is outlined in the applicable MSDS. Be particularly sensitive to the potential for eye and skin contact. The correct glove must be worn if contact is likely. Safety goggles/ monogoggles are mandatory when working with silanes. For inhalation concerns, use adequate ventilation, including local exhaust hoods, to minimize the need for respirators and full-face supplied-air systems (required for high vapor concen-

Toxicity of Organofunctional Silanes

Refer to the MSDS and Toxicology Summary for each product for a review of the toxicity testing that has been conducted to date.

Fire Safety (Storage) Considerations

Refer to the Appendix for fire safety considerations, particularly if assessing design for the storage of silanes.

Materials of Construction (MOC)

The recommended material of construction for silanes in general have exceptionally good solvating properties. For elastomers, silicones are recommended. For applications that require greater elasticity and flexibility, other elastomers may suffice; however, compatibility varies from one silane to another. Silanes in general have exceptionally good solvating properties. For this reason, many elastomers are not suitable for use with silanes.
Guidelines for Handling Silanes (continued)

Maintaining the Integrity of Partial Drums of Silanes

The purging of drum headspaces with dry nitrogen is critical to maintaining the quality integrity of alkoxysilanes. The exception to nitrogen purging is Silquest A-174®, Silquest Y-9936 or any other (meth)acryloxy functional silane (see discussion earlier).

If piped nitrogen is not available, a simple rack of exchangeable nitrogen cylinders can be arranged into a regulated manifold delivery system. As a secondary approach, desiccated air lines can be used to purge the headspaces of silanes provided the silanes have a flash point greater than 150°F.

Environmental Considerations

(Including Disposal)

Clean-Up Procedures

Equipment and transfer line clean-ups are necessary to avoid hydrolytically build-up and to reduce the potential for plugging. Due to the hydrolytically instability of most alkoxysilanes, solvent flushing at ambient temperature is recommended following silane contact, especially if inert purging is not possible. The solvent(s) selected for clean-up should be non-reactive, free of water contamination, and compatible with the rest of the process chemistry. The appropriate fire safety precautions should be taken if flammable solvents are selected. For assistance in selecting the appropriate solvent for your purposes, contact your Momentive Performance Materials Technical Service group.

Spills

For spills, refer to the MSDS. Contain spills by barricading the area and use temporary diking. If possible, to avoid run-off to sewers and waterways. Be certain that clean-up or emergency personnel use the proper protective equipment as specified in the MSDS. Be aware of potential ignition sources. Remember that organofunctional silane esters readily generate explosive mixtures with water, or when mixed with water generates toxic gases, vapors, or fumes, or releases over 500 ppm of sulfides/cyanides.

If the silane has been blended or reacted with another material, additional waste codes may apply. If you have questions on the regulatory status of your waste, consult your state or province environmental authorities.

Disposal Issues

The proper disposal method for waste silane or silane mixtures may vary depending upon the state or province. Definitions of “hazardous waste” vary. Waste disposal firms have different capabilities and permits that may influence the mode of disposal.

Be certain that the clean-up and containment procedures for the waste are safe and appropriate. For emergency assistance, contact CHEMTREC or emergency phone numbers provided in the MSDS.

Consult local, municipal and state regulatory agencies for proper classification of the waste(s). Under the federal RCRA rules (40CFR 261), the following characteristic properties are indicative of hazardous wastes:

D001: Flash point less than 140°F (PMCC)
D002: pH <2 or >12.5, or corrodes steel at >0.25 in. per year.
D003: Reacts violently with water, forms potentially explosive mixtures with water, or when mixed with water generates toxic gases, vapors, or fumes, or releases over 500 ppm of sulfides/cyanides.

If the silane has been blended or reacted with another material, additional waste codes may apply. If you have questions on the regulatory status of your waste, consult your state or province environmental authorities.

Empty Containers

Under RCRA, empty containers are defined as having all contents removed by common means (pumping, pouring, etc.) and not containing more than one inch of residue in the bottom of the container or liner. For containers equal to, or less than, 110 gallons, no more than 3.3 wt.% of the total container capacity can remain. For containers greater than 110 gallons, no more than 0.3 wt.% of the container can remain.

Disposal of Empty Containers

Empty containers must be disposed of or reclaimed only by reputable facilities. Momentive Performance Materials recommends that contractors be audited for approval. Due to the exposure and reactivity potential of residual silanes, “empty” containers should never be given to the public, or sold for reuse by the public or by non-reputable firms.
Appendix (continued):

- General layout of operating or storage areas / access and egress (NFPA-30 restrictions)
- Storage [general guidance: NFPA-231 (231C covers rack storage)] based on physical properties of the materials
- Minimum aisle space; separation between storage containers and portable tanks
- Minimum distance between storage and use areas
- Temperature of equipment in vicinity
- Vehicular traffic limitations
- Explosion proof equipment requirements
- Spark producing devices or open flame in area
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- Grounding and inerting (purging) practices (also see Spark producing devices or open flame in area
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- Explosion proof equipment requirements
- Spark producing devices or open flame in area

B. Equipment Design/Classification

- Electrical classification
- Equipment electrical rating
- Equipment supplier’s recommendations
- Engineering controls

C. Raw Material Characteristics:

- Physical Properties, Reactivity, etc.
- Flash point of organosilicone/silane
- Boiling point of organosilicone/silane
- Reactivity of organosilicone/silane
- Keeping equipment and raw materials dry
- Maximum volume of material
- Delivery rate of material
- Open vs. closed transfer operations (hard-piped vs. temporary connections)
- Materials of construction and compatibility of equipment
- Transfer equipment, reaction/treatment equipment, and storage equipment

D. Corporate Health, Safety & Environmental Policy / Procedures (e.g., for design criteria)

- Corporate manual/standards
- Fire Safety Group/Skills Center availability within organization
- Standard Operating Procedures
- General Process Operation
- Emergency Procedures
- Life Critical Procedures
- Hazardous Work Procedures
- Confined Space Entry
- Use of Ignition Sources in Classified Areas
- Breathing or Cutting of Lines or Opening Equipment
- Facilities and Operational Change
- Review Procedures
- Grounding and Inerting Procedures
- Vessel to Vessel Transfer Procedures
- Flammable Liquid Dispensing Procedures
- Administrative Controls

- Safety Review Process
- Process Hazard Analysis
- Risk Assessments
- Internal Audits
- Safe Operating Envelope for the Process
- Personnel Safety

- Personnel Training
- Personal Electrical Safety: 29CFR1910, Subpart S (coincides with NFPA-70)

E. Local/State Codes:

- OSHA and NFPA requirements (Note: not all states are subject to NFPA requirements)
- Local laws and regulations
- State laws and regulations
- Fire Marshall requirements

F. Insurance Carrier Requirements

- Consultation prior to design
- Liability perspective
- Review of hazards with local fire companies
- On-site fire brigade availability SMT April 2000

Patent Status

Nothing contained herein shall be construed to imply the nonexistence of any relevant patents or to constitute the permission, inducement or recommendation to practice any invention covered by any patent, without authority from the owner of the patent.

Product Safety, Handling and Storage

Customers considering the use of this product should review the latest Material Safety Data Sheet and label for product safety information, handling instructions, personal protective equipment if necessary, and any special storage conditions required. Material Safety Data Sheets are available at www.momentive.com or, upon request, from any Momentive Performance Materials representative. Use of other materials in conjunction with Momentive Performance Materials products may require additional precautions. Please review and follow the safety information provided by the manufacturer of such other materials.

Limitations

Customers must evaluate Momentive Performance Materials products and make their own determination as to fitness of use in their particular applications.

Emergency Service

Momentive Performance Materials maintains an around-the-clock emergency service for its products. The American Chemistry Council (CHEMTREC) and CareChem24 International also maintain an around-the-clock emergency service for all chemical products:

<table>
<thead>
<tr>
<th>Location</th>
<th>Momentive Performance Materials Products</th>
<th>All Chemical Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainland U.S.</td>
<td>518.233.2500</td>
<td>CHEMTREC: 800.424.9300</td>
</tr>
<tr>
<td>Alaska, Hawaii</td>
<td>518.233.2500</td>
<td>CHEMTREC: 800.424.9300</td>
</tr>
<tr>
<td>Canada</td>
<td>518.233.2500</td>
<td>CHEMTREC: 800.424.9300</td>
</tr>
<tr>
<td>Europe</td>
<td>+518.233.2500 (Albanian, Czech, Danish, Dutch, English, Finnish, French, German, Greek, Hungarian, Italian, Lithuanian, Norwegian, Polish, Portuguese, Romanian, Russian, Serbian-Croatian, Slovak, Spanish, Swedish, Turkish, Ukrainian)</td>
<td>+44.0208.762.8322 (UK)</td>
</tr>
<tr>
<td>Middle East</td>
<td>+518.233.2500</td>
<td>+961.3.467.287 (Lebanon)</td>
</tr>
<tr>
<td>Middle East, Israel</td>
<td>+518.233.2500</td>
<td>+44.0208.762.8322 (UK)</td>
</tr>
<tr>
<td>Latin America, Asia/Pacific</td>
<td>+518.233.2500</td>
<td>CHEMTREC: +1-703.527.3887 (collect)</td>
</tr>
<tr>
<td>All sea</td>
<td>Radio U.S. Coast Guard, which can directly contact Momentive Performance Materials at 518.233.2500 or CHEMTREC at 800.424.9300.</td>
<td></td>
</tr>
</tbody>
</table>

*Silquest is a trademark of Momentive Performance Materials Inc.

Page 18 of 20
CUSTOMER SERVICE CENTERS

North America    E cs-na.silicones@momentive.com
• Specialty Fluids  T +1.800.523.5862  F +1.304.746.1654
• UA, Silanes and Specialty Coatings  T +1.800.334.4674  F +1.304.746.1623
• RTVs and Elastomers  T +1.800.332.3390  F +1.304.746.1623
• Consumer Sealants & Construction  T +1.877.943.7325  F +1.304.746.1654
• Sealants and Adhesives

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