Silanes for Coatings and Adhesives
Topics:

- Chemistry of Silanes
- Silanes for Coatings
  - Primer
  - Polymerization
  - Post Addition
- Silanes for Adhesives and Sealants
- Factors of Silane Reaction
Silane Structure

FG = Functional Group (Organog Type)
e.g. -Vinyl, -Glycidoxy (Epoxy),
-Amino, -Methacryloxy, -Ayl ,etc.

OR = Alkoxy, Acetoxy, Oxime
e.g. - Methoxy (-OCH₃),
-Ethoxy (-OCH₂CH₃), etc.
How Silanes Work

Silanes are 2 step Reaction Chemical which most of them are monomer. When store under inert gas (N₂), Silanes will be non-reactive monomer in form of FG-Si-OR which -R or Akyl is non-reactive group.

However, Silanes can be hydrolyzed by moisture which -Si-OR will be changed to -Si- OH called “Silanol” group and be ready to react or bond to the substrates or the fillers. The change of -Si-OR to -Si-OH is called “Hydrolysis” which is the 1st step of silane reaction.

\[
\text{RO} \quad \text{Si} \quad \text{OR} \quad \xrightarrow{\text{H₂O}^*} \quad \text{HO} \quad \text{Si} \quad \text{OH} + 3\text{ROH}
\]

1st Step Reaction-Hydrolysis

* H₂O can come from atmosphere/air.
How Silanes Work

2nd step of the reaction is “Condensation”. After Hydrolysis, Silane contains “Silanol” group or Si-OH which is very reactive and ready to bond to substrates or fillers. This bonding step is called “Condensation” which is function of adhesion promoter to the substrates or coupling/dispersing agent to the fillers.

* e.g. Application of Glass Fiber Surface Treatment
**Benefits of Silanes in Each Function**

1. **Graft or Interact**
   - Crosslinker
     - Resins/Plastics
   - Silanes
     - Hydrolysis + Condensation

2. **Hydrolysis + Condensation**
   - Adhesion Promoter
     - Resins/Plastics
   - Coupling/Dispersing Agent
     - Fillers or Glass Fibers
Benefits of Silanes in Each Function

- Create net work structure in Polymer
- Increase strength and hardness
- Longer service life of product
- Higher temperature resistance
- Higher scrub/scratch resistance

- Enhance adhesion performance btw resins and substrates
- Improve corrosion resistance and prevent corrosion’s spreading from crack line.

- Link btw resins and fillers, stay together as one system
- Optimize strength of composites
- Able to add higher filler loading
- Improve filler’s dispersion in resins
Silanes for Coatings
Benefits of Silanes in Paints and Coatings

- Increase Adhesion Performance to Substrate
- Increase Crosslinking Density of Resin which affected to
  - Increase hardness
  - Increase mar resistance*
  - Improve solvent, acid, alkaline resistance
  - Improve water resistance
  - Increase abrasion resistance or scrub resistance
- Change Resin Properties
  - Thermoplastics to near Thermosets
- Disperse Pigments/Fillers
  - Improve consistency of viscosity and able to have lower viscosity
  - Benefit to lower loading of pigments in the formulation
- Bind Pigments/Fillers
  - Act as coupling agent to pigments/fillers to improve scrub ability

* The mar resistance is surface coating’s ability to withstand scratching and scuffing actions which tend to mar (change) the surface appearance of coating.
Typical Ingredients of Organic Coating

- **Resins** - Be also called binder, usually major non-volatile component, made up of a polymer

- **Solvents** - Dissolve the resin, soften the coating, allow good flow, viscosity control, drying behavior, and reduce cost

- **Surfactants** - Stabilize resin particles in WB coatings

- **Pigments/Fillers** - Provide color, opacity, special effect and cheapen coating

- **Thickeners** - Control and adjust viscosity

- **Stabilizers** - Provide longer service term e.g. Hindered Amine Light Stabilizers (HALS)

- **Neutralizers** - Adjust pH e.g. volatile amines

- **Additives** - Silane is one of coating additives for adhesion promoter, crosslinker, and coupling agent. Other additives e.g. Flow, Slip, Anti-Foam, etc.
Application in Paints and Coatings

**Primer**
- 2-5% Silanil919
- 4-5% DI Water
- Solvent (Alcohol/Toluene)
- Cold Blend

**Polymerization**
- Monomers to produce Resin
- Silanes
  - e.g. Silanil276,250
  - (0.5-2% in WB, Up to 10% in SB)

**Post Addition**
- Resin + Silane
  - (e.g. Silanil919,258 at 0.2-2% wt.of Resin Solid)
- Induction time at least overnight
- Other Additives/ Fillers added
  + Mill-base added

**Paint**
- Silane as Crosslinker, Coupling Agent, Adhesion Promoter
Application: Primer
Typical Formulation of Primer

- Dissolve 2-6 % wt. silane in a compatible volatile solvent (or mixture of solvents).
- Amino silanes e.g. Silanil 919, 138 and 176 are recommended.
- Alcohols are most commonly used, for water compatibility.
- Water at equal part of silane may be added to pre-hydrolyze silane if water is compatible with the solvent.
- Apply to grease-free surface by wiping, spraying, brushing, or dipping.
- Film thickness < 0.1 mil.
- Leave the surface dry to remove solvent around 15-30 mins. Apply the top coat within 24 hrs to protect surface from contamination.

<table>
<thead>
<tr>
<th>Components</th>
</tr>
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<tbody>
<tr>
<td>Amino silanes 2-6%</td>
</tr>
<tr>
<td>+ Mixed Solution:</td>
</tr>
<tr>
<td>Alcohol e.g. IPA</td>
</tr>
<tr>
<td>Distilled water</td>
</tr>
<tr>
<td>Toluene</td>
</tr>
<tr>
<td>n-Butanol</td>
</tr>
<tr>
<td>Butyl Cellosolve</td>
</tr>
</tbody>
</table>
Application: Polymerization
Silanil 276, 780 and 250 are widely used to modify polymer structure especially in surface coating resin for both of WB and SB such as Acrylic Latex which is commonly added in polymerization step.

Silane as Crosslinker in Emulsion Polymerization:

Typical Monomers for Acrylic Latex

- Methacrylic Acid
- Methyl Methacrylate
- Vinyl Silane

Emulsion Polymerization

Silane Modified Structure e.g. \( R \) is -CH3
Silanes for Polymer Modification (Continue)

Silane as Crosslinker in Emulsion Polymerization:

Silane Modified Structure

\[ \text{H}_2\text{O} \rightarrow \text{Silane Modified Structure after Hydrolysis} \]

Silane as Crosslinker or called “Silylated Acrylic”
Silane Dosage in Polymerization

In Soventborne Resin: recommended silane dosage at 0.4-10.0% on total monomer wt.

In Waterborne Resin: recommended silane dosage at 0.1-2.0% on total monomer wt.

pH is recommended close to neutral or $\leq 8.5$ pH for stability purpose.

For emulsion polymerization, it is recommended to add silane in the pre-emulsion stage.

In case of none pre-emulsion stage, it is recommended to add silane into the monomixture at the remaining of 10-15% monomers feeding time.
Typical Formula of Silylated Acrylic

Monomers:
- BA 20-30 Mole %
- MMA 65-75 Mole %
- MAA 2-3 Mole %
- Silane 1-3 Mole%

Typical Emulsion Recipe
Water 40-50 %
Monomers 40-50 %
Surfactants 2-5 %
Initiator 0.3-0.5 %
Others Additives

General Specification of Emulsion
- Tg 40-80
- Acid Value 10-50
- Solids 40-50%
Effect of Glass Transition (Tg) on Latex Properties

<table>
<thead>
<tr>
<th>Latex properties</th>
<th>Low Tg</th>
<th>High Tg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying speed</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Gloss</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Resolubility</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Solvent tolerance</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Adhesion</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Film formation</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Flexibility</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Water resistance</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Pigment dispersion</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

* Silanes could increase the Tg value in Acrylic Latex.*
Application: Post Addition
Silanes for Post Addition

Post addition is the process to add chemicals or additives into polymer (resin) after the polymer is formed or after polymerization. Silanes in Post addition show 2 mechanisms: 1) Grafting in part of functional group of silanes and 2) Hydrolysis and condensation in part of -OR which is changed to -ROH (Silanol Group).

A. Resins/Plastics → (1) Grafting or Interaction → B. Substrates

(2) Hydrolysis + Condensation

A. Resins/Plastics

FG

Silanes

RO

OR

OR

Si

OR

FG

Hydrolysis

Condensation

Si

OH

OH
Manufacturing Process of Paint

Part 1 - Accurate measurement of ingredient

Part 2 - Mill-base preparation and pigment dispersion

Part 3 - Let-down
In a separate, larger, vat the rest of the paint (resin, solvent, additives and also “Silanes”) is combined and mixed. This is called the let-down. When the let-down and the mill-base are completed, the mill-base is added with stirring to the let-down. At this stage, if required by the formulation, any final additions are made and added in.

Part 4 - Finished product and in process laboratory testing

Part 5 - Canning
Application Guide Line for Post Addition

First step
Silane + Resin

Second step
Addition of Solvent or Water + Other Additives
e.g. Matting Agent, Wetting Agent, Wax, Pigments, Ammonia, etc.

Guide Line for Post Addition: Silane Grafting on Resin

• Blend silane directly into resin. (without other additives or pigments)
• Prefer pH near to neutral or pH of resin should be < 8.5 before adding silane. (for water-based resin)
• Induction time is needed after adding silane into resin. pH may be increased during induction time comparing to resin without silane. Proper induction time is able to study by pH evolution curve VS time.
• The induction time is at the onset point which pH is started to increase dramatically. Typical induction time is 5-48 hrs.
  High shear agitation is able to accelerate the induction time
• It is recommended to add additives and fillers after the induction period.
• If pH adjustment is required for final coating, it is recommended to adjust pH after the induction period.
• Aging test at high temperature (for product stability study) have to be done after induction period.
Silane Dosage in Post Addition

Epoxy and amino silanes e.g. Silanil 258, Silanil 289, Silanil 919, and Silanil 176 are popular to be used for “Post Addition”.

The effective silane dosage is varied up to type of polymers, “It is recommended at 0.2-2 %wt of silane based on resin solid content.”

However, ladder test is recommended with various silane dosages to study the optimum point which may show different results in each polymer.
## Recommendation in Paints and Coatings

### By Functional Group Matching

<table>
<thead>
<tr>
<th>Acrylic</th>
<th>PU 1K</th>
<th>PU 2K</th>
<th>Epoxy</th>
<th>Alkyd</th>
<th>Polyamide</th>
<th>Phenolic</th>
<th>PBT</th>
<th>Polyester</th>
<th>PUD</th>
<th>Silicone</th>
<th>Melamine</th>
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<tbody>
<tr>
<td>Silanil 250</td>
<td>Silanil 258</td>
<td>Silanil 258</td>
<td>Silanil 258</td>
<td>Silanil 176</td>
<td>Silanil 176</td>
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<td>Silanil 250</td>
<td>Silanil 258</td>
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<tr>
<td>Silanil 258</td>
<td>Silanil 260</td>
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<td>Silanil 919</td>
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<td>Silanil 250</td>
<td>Silanil 258</td>
<td>Silanil 176</td>
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<tr>
<td>Silanil 289</td>
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<td>Silanil 919</td>
<td>Silanil 919</td>
<td>Silanil 176</td>
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<td>Silanil 250</td>
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<td>Silanil 919</td>
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<td>Silanil 919</td>
<td>Silanil 919</td>
<td>Silanil 176</td>
<td>Silanil 176</td>
<td>Silanil 258</td>
<td>Silanil 250</td>
<td>Silanil 258</td>
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<td>Silanil 276</td>
<td>Silanil 250</td>
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<td>Silanil 176</td>
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<td>Silanil 258</td>
<td>Silanil 250</td>
<td>Silanil 258</td>
<td>Silanil 176</td>
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<tr>
<td>Silanil 780</td>
<td>Silanil 250</td>
<td>Silanil 919</td>
<td>Silanil 919</td>
<td>Silanil 176</td>
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<td>Silanil 250</td>
<td>Silanil 258</td>
<td>Silanil 176</td>
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</table>

### By Functions

<table>
<thead>
<tr>
<th>Crosslinker</th>
<th>Adhesion Promoter</th>
<th>Coupling Agent</th>
<th>Primer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silanil 250</td>
<td>Silanil 258</td>
<td>Silanil 919</td>
<td>Silanil 919</td>
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<tr>
<td>Silanil 276</td>
<td>Silanil 289</td>
<td>Silanil 919</td>
<td>Silanil 919</td>
</tr>
<tr>
<td>Silanil 780</td>
<td>Silanil 258</td>
<td>Silanil 258</td>
<td>Silanil 289</td>
</tr>
</tbody>
</table>

*Sequence of silane addition into formulation is affected to the function of silane.*

**Remark:** Recommendation based on testing and historical experience data.
Silanes for Adhesives and Sealants
Application in Adhesives and Sealants

Applications are in the same direction as coatings:

- Primer > as adhesion promoter
- Polymerization > as crosslinker
- Post addition > as adhesion promoter, coupling agent, or crosslinker
Typical Ingredients of Sealants

Typical Ingredients:

- Resins
- UV stabilizers
- Plasticizers
- **Moisture scavengers** > Silanil 276
- Fillers (CaCO$_3$, etc.)
- Thixotropic agents
  (Fumed silica or additives)
- Pigments/Colorants
- **Adhesion promoters*** > Silanil 176, 138, 919, 1479, etc.
- Catalysts > BRB DBTDL, BRB DBTDA, etc.
- Other additives
- May be solvents
- Also **curing agents for silicone sealants**
  > Silanil MOS, VOS, MTAS, ETAS, PTA S, etc.

* Dosage of silanes in range of 0.2-2% on resin solid wt.
## Curing (Crosslinking) Type of RTV-1

![Chemical structure of curing process](image)

<table>
<thead>
<tr>
<th>Curing Type</th>
<th>By product</th>
<th>Features</th>
</tr>
</thead>
</table>
| **Oxime**   | Methylethylketoxime | ✓ Good adhesion on plastics  
✓ Neutral cure, no acidic ador  
✓ Low corrosive to metallic substrates  
✓ Longer tack free time and cure time than acetoxy type |
| **Acetoxy** | Acetic acid | ✓ Fast cure and short tack free time  
✓ Good adhesion on any substrates  
✓ Good stability up to 300°C  
✓ Vinegar odor from by product  
✓ Corrosive to metallic substrates |
| **Alkoxy**  | Alcohols  
i.e. Methanol  
or Ethanol | ✓ Neutral cure, non-acidic odor  
✓ Non-corrosive to metallic substrates  
✓ Good adhesion (< acetoxy type)  
✓ Longer tack free time and cure time than acetoxy type  
✓ Stability up to 220°C |
# Silanes as RTV-1 Crosslinkers

<table>
<thead>
<tr>
<th>Curing Type</th>
<th>BRB Silane</th>
<th>Chemical Name</th>
<th>CAS no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxime</td>
<td>Silanil MOS</td>
<td>Methyltris(methylethylketoxime)silane</td>
<td>22984-54-9</td>
</tr>
<tr>
<td></td>
<td>Silanil VOS</td>
<td>Vinyltris(methylethylketoxime)silane</td>
<td>2224-33-1</td>
</tr>
<tr>
<td></td>
<td>Silanil POS</td>
<td>Phenyltris(methylethylketoxime)silane</td>
<td>34036-80-1</td>
</tr>
<tr>
<td>Acetoxy</td>
<td>Silanil MTAS</td>
<td>Methyl(triacetoxy)silane</td>
<td>4253-34-3</td>
</tr>
<tr>
<td></td>
<td>Silanil ETAS</td>
<td>Ethyl(triacetoxy)silane</td>
<td>17689-77-9</td>
</tr>
<tr>
<td></td>
<td>Silanil PTAS</td>
<td>Propyl(triacetoxy)silane</td>
<td>17865-07-5</td>
</tr>
<tr>
<td></td>
<td>Silanil MTAS/ETAS Blend</td>
<td>Methyl(triacetoxy)silane/ Ethyl(triacetoxy)silane</td>
<td>4253-34-3/17689-77-9</td>
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<tr>
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<td>Silanil MTAS/PTAS Blend</td>
<td>Methyl(triacetoxy)silane/ Propyl(triacetoxy)silane</td>
<td>4253-34-3/17865-07-5</td>
</tr>
<tr>
<td>Alkoxy</td>
<td>Silanil 118</td>
<td>Methyltrimethoxysilane</td>
<td>1185-55-3</td>
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<td></td>
<td>Silanil 203</td>
<td>Methyltriethoxysilane</td>
<td>2031-67-6</td>
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</table>
### Functional Group: Amino

<table>
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<tbody>
<tr>
<td>Silanil 919</td>
<td>3-aminopropyltriethoxysilane</td>
<td>919-30-2</td>
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<tr>
<td>Silanil 138</td>
<td>3-aminopropyltrimethoxysilane</td>
<td>13822-56-5</td>
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<td>Silanil 176</td>
<td>N-(2-aminoethyl)-3-aminopropyl-trimethoxysilane</td>
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</table>

**New product**

<table>
<thead>
<tr>
<th>BRB Silane</th>
<th>Chemical Name</th>
<th>CAS no.</th>
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</thead>
<tbody>
<tr>
<td><strong>Silanil 1479</strong></td>
<td>Diamino alkyl silane co-oligomer</td>
<td>-</td>
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</table>

### Functional Group: Epoxy

<table>
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<th>BRB Silane</th>
<th>Chemical Name</th>
<th>CAS no.</th>
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</thead>
<tbody>
<tr>
<td>Silanil 258</td>
<td>3-glycidoxypropyltrimethoxysilane</td>
<td>2530-83-8</td>
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<tr>
<td>Silanil 289</td>
<td>3-glycidoxypropylmethylidethoxysilane</td>
<td>2897-60-1</td>
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<tr>
<td>Silanil 260</td>
<td>3-glycidoxypropyltrimethoxysilane</td>
<td>2602-34-8</td>
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</table>

### Functional Group: Methacryloxy

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<th>Chemical Name</th>
<th>CAS no.</th>
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</thead>
<tbody>
<tr>
<td>Silanil 250</td>
<td>3-methacryloxypropyltrimethoxysilane</td>
<td>2530-85-0</td>
</tr>
</tbody>
</table>
Adhesion Promoter: Silanil 1479
Diamino Akyl Silane Co-oligomer

The benefits over regular amino silanes:
Lower VOC, less by products, resulting in lower odor during application

Less yellowing to resins

Higher hydrophobicity than diamino silane monomer, resulting in good wet adhesion

High elasticity with lower modulus of cured adhesives

Good adhesion performance between organic resins and inorganic substrates.
Product Package for RTV-1 Sealants

1. Acetoxy sealants
2. Alkoxy Sealants
3. Oxime Sealants
4. MS Polymer Sealants
1. Acetoxy sealants

A: 100% Silicone Sealant General Purpose

- BRB OH Fluid 80,000 cSt ➔ 60-80%
- BRB Silicone Oil 1,000 cSt ➔ 10 - 20%
- BRB Silanil MTAS ➔ 5 - 10%
- BRB DBTDL ➔ 0.2 -1%
- Third party fumed Silica ➔ 10%

*Optional adhesion promoters: BRB Silanil 176, Silanil 919, Silanil 138, Silanil 1479, etc.
1. Acetoxy sealants

B: Extended Silicone Sealant General Purpose

- BRB OH Fluid 80,000 cSt ➔ 40-60%
- Third party solvent plasticizer ➔ 20 - 40%
- BRB Silanil MTAS ➔ 5 - 10%
- BRB DBTDL ➔ 0.2 -1%
- Third party fumed Silica ➔ 10%

*Optional adhesion promoters: BRB Silanil 176, Silanil 919, Silanil 138, Silanil 1479, etc.*
Catalyst for Fast Cure: DBTDA
Dibutyltin diacetate (Diacetoxybutyltin)

Faster speed of catalysis performance – faster gelation, tack-free time, and cure time – than DBTDL.

Suitable for acetoxy sealants. (The mixture of DBTDA : DBTDL can be used to design cure time such as ratio of 1.9 : 2.8.)

Soluble in the common solvents i.e. toluene, xylene, benzene, acetone, ethanol, ethyl acetate, chloroform, and other petroleum ethers.

CAS# 1067-33-0
2. Alkoxy sealants

- BRB OH Fluid 20,000 cSt and 80,000 cSt
- BRB Silicone Oil 500 cSt
- Third party coated calcium carbonate
- BRB Silanil 118

*Optional adhesion promoters: BRB Silanil 176, Silanil 919, Silanil 138, Silanil 1479, etc.*
3. Oxime Sealants

Neutral Cure All Weather Purpose

• BRB OH Fluid 80,000 cSt ➔ 30 -40%
• BRB Silicone Oil 100 cSt ➔ 5-10%
• Third party coated calcium carbonate ➔ 40-50%
• BRB Silanil MOS and VOS ➔ 3-4%
• BRB DBTDL ➔ 0.2 - 1.0%

*Optional adhesion promoters: BRB Silanil 176, Silanil 919, Silanil 138, Silanil 1479, etc.
4. MS-Polymer

Crosslinker and adhesion promoter for MS-Polymer

- BRB Silanil 118

*Optional adhesion promoters: BRB Silanil 176, Silanil 919, Silanil 138, Silanil 1479, etc.
What BRB offers

1. Full range of siloxane, silanes, and tin catalyst products
2. Formulation help
3. Only raw material supplier, not competing with sealants in the market
4. Flexible supply from regional warehouse
5. Competitive prices for continuous sustainable growth
**Recommendation in Adhesives and Sealants**

*Remark: Recommendation based on testing and historical experience data.*

**By Functional Group Matching**

<table>
<thead>
<tr>
<th>Acrylic</th>
<th>Polyurethane 1K</th>
<th>Polyurethane 2K</th>
<th>Epoxy</th>
<th>Silicone</th>
<th>Polysulfide</th>
<th>MS Polymers</th>
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<tbody>
<tr>
<td>Silanil 250</td>
<td>Silanil 258</td>
<td>Silanil 258</td>
<td>Silanil 258</td>
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<td>Silanil 919</td>
<td>Silanil 919</td>
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**By Functions**

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<th>Adhesion Promoter</th>
<th>Coupling Agent</th>
<th>Moisture Scavenger</th>
<th>Primer</th>
<th>Curing Agent for RTV</th>
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<td>Silanil MOS (Oxime)</td>
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<td>Silanil 276</td>
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<td>Silanil MTAS (Acetoxy)</td>
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</table>

* Sequence of silane addition into formulation is affected to the function of silane.  

Remark: Recommendation based on testing and historical experience data.
Factors of Silane Reaction
Factors Affecting Performance of Silanes

The performance of Silane is influenced by many parameters including:

- **Silane Structure**
- **Dosage of Silane**
  - Too high dosage may affect poorer property e.g. too rigid, poor stability.
- **pH of Resin or Coating**
  - pH can catalyze rate of Hydrolysis and Condensation per next page.
- **Unknown Chemicals may catalyze Silane**
  - Mineral Acids, Alkoxide Salts, Tin Compound, Titanate Ester, Zirconium Salts, Phosphorous Compound, and Amines are catalysts for Silanes.
- **Temperature of System**
  - Molecule can be moved faster and met each other at higher temperature.

\[ \text{FG} - \text{R- SiX}_3 \]

- **FG (functional group)** matches to the resin chemistry to let silane graft well on the resin chains.
- **X group** affects to reactivity rate.
  - bulkier group gives slower reactivity.
  - Methoxy is faster than Ethoxy.
Hydrolysis Rate of Silanes

Time for hydrolysis is dependent on solution’s pH.

- Prefer pH near to neutral (pH 7) for storage stability purpose in adhesion promoter function.
- For WB, pH is not recommended at > 8.5 which may affect to shelf life of Paints&Coatings.
- -Si-OH (silanol groups) can also react each other or so-called self-crosslink which is not required.

At pH 7, condensation rate is medium in which condensation is the reaction happening after hydrolysis of silane.

During application, the environment which is contained moisture in the air and unstable pH, hydrolysis and condensation can happen and let silane react to substrate.
Hydrolysis Tips for WB and SB

**Waterborne (WB)**
- Hydrolysis is slowest around pH 7, this is good for storage purpose.
- Acid pH and alkaline pH can catalyze rate of hydrolysis.
- Bigger substituents (hydrocarbon) on silicon retard hydrolysis e.g. Ethoxy is slower hydrolysis rate than methoxy.

**Solventborne (SB)**
- Hydrolysis of the first alkoxy group is slow.
- Alcohols can retard hydrolysis rate.
- Silanetriol species are unstable and able to condense in SB.
Signs of Unexpected Hydrolysis + Condensation of Silane

Trouble signs in Resins or Coatings

- Gel formation
- Seeding
- Viscosity buildup
- White precipitate
- Loss of performance over time
  e.g. The first test shows good adhesion performance but after a few weeks, the second test shows poor adhesion on the same sample.

These signs mean silanes may self-crosslink. The worst case is entire gel.
Powerful like a major, flexible like a formulator