Silane coupling agents are silicon-based chemicals that contain **two types of reactivity**--inorganic and organic--in the same molecule. A typical general structure is Y-Si$(OR)_3$ where OR is a hydrolyzable group such as methoxy, ethoxy, or acetoxy, and XY is an organofunctional group such as amino, methacryloxy, epoxy, etc.

A silane coupling agent will act at as a **link between an inorganic substrate** (such as glass, metal, mineral) and an **organic material** (such as an organic polymer, coating, adhesive) to bond, or couple, the two dissimilar materials together. A simplified picture of the coupling mechanism is shown in the figure below.

Figure 7 : Silane coupling mechanism

Mineral fillers have become increasingly important additives and modifiers for organic polymer. The metal hydroxyl groups on the surface of minerals are usually very **hydrophobic** and very **incompatible with organic polymers**. Silanes are a natural fit to treat the surface of the mineral to make the mineral **more compatible and dispersible in the polymer**, or even make the filler into a reinforcing additive.

The silane treatment can improve processing, performance, and durability of a mineral-modifed product by:

- **Improving adhesion** between the mineral and the polymer
- Improving wet-out of the mineral by the polymer
- Improving dispersion of the mineral in the polymer
- Improving electrical properties
- Increasing mechanical properties
- Reducing viscosity of the filler/polymer mix

Silanes used as coupling agents in filler treatment are useful for many applications, some examples are HFFR wire & cable compounds, Mica filled poplypropylene and polyamide and clays in rubber.

The most destructive force in adhesion is **migration of water** to the hydrophilic surface of the inorganic reinforcement and **attack of water** at the interface to destroy the adhesive bond. A 'true' coupling agent provides a **water-resistant bond** between the inorganic and organic materials. **Silane coupling agents** have the unique chemical and physical properties to not only **enhance bond strength**, but also more importantly, **prevent de-bonding at the interface** during aging, and use, of the composite.
Figure 1 shows that **retention of flexural strength is much better with silane coupling agents** than with the chrome complex (blue line).

Using silane coupling agents leads to a significant improvement of **filler and pigment dispersion in resin** (see the figure below). This improvement results from displacement or modification of the moisture layer, giving reduced clumping of particles and improved wettability by polymer.

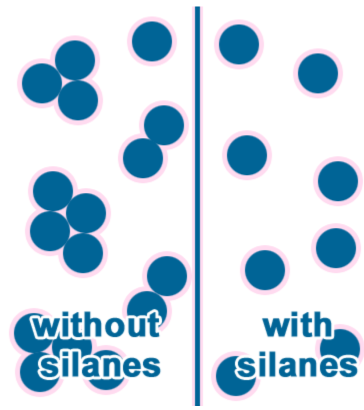


Figure 3 : Improvement of dispersion with silanes coupling agents

This improved dispersion often results in less air occlusion, giving fewer voids and reduced slurry viscosity. **Easier flow in molding** or **increased proportions of inexpensive filler**, or both, are possible

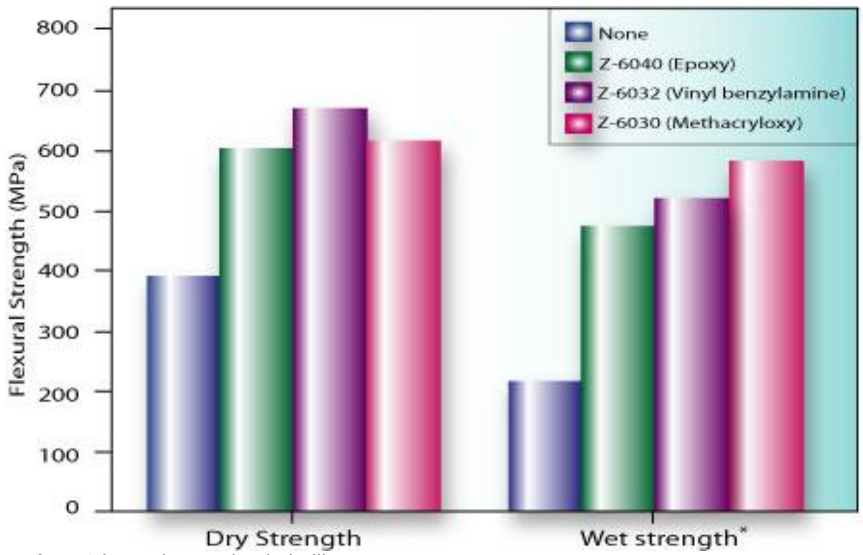
The ability of silane coupling agents to impart **improved electrical properties** is shown in the table below with an epoxy resin reinforced with quartz filler.

System	Dielectric Constant		Dissipation Factor	
	Dry	Wet*	Dry	Wet*
Unfilled resin	3.44	3.43	0.007	0.005
Quartz, no silane	3.39	14.60	0.017	0.305
Quartz, Z-6040	3.40	3.44	0.016	0.024
Quartz, Z-6020	3.46	3.47	0.013	0.023

** After 72 hours immersion in boiling water*
Table 1: Improvement of electrical properties with silanes coupling agents in quartz-reinforced epoxy resins

Without filler, the epoxy resin showed good electrical properties, dielectric constant and dissipation factor, even after aging for 72 hours in boiling water. However, once quartz filler was added, the hydrophilic surface of the quartz led to severe loss of electrical properties during the water boil test. With either Z-6040 epoxysilane or Z-6020 aminosilane, the quartz-filled composite exhibited a dramatic **retention of electrical properties**.

Mechanical properties, in particular tensile, flexural and compressive strengths, are significantly improved with the use of silanes coupling agents. The figure below shows the improvement of flexural strength of glass fiber reinforced epoxy resins obtained by using silanes-coupling agents.



** After 72 hours immersion in boiling water*

Figure 2: Improvement of flexural strength with silanes coupling agents

In composites, often a 40 percent increase in flexural strength is obtained by use of the right silane-coupling agent.

Due to the **lower viscosity** of the composite possible by (table 3) adding silane coupling agents, improved processability in compounding and injection molding is usually observed, leading to a **higher production rate**.

Silane coupling agents are a critical component of glass-reinforced thermosets.

Methacrylate functional silanes, Z-6030, were first developed for the reinforcement of polyesters. More recently, epoxy functional, Z-6040, vinyl-benzyl-amino functional silanes such as, Z-6032, have proven valuable in epoxy, polyester and other thermoset resin composites using glass reinforcements.

Most important benefits imparted to glass-reinforced thermosets coupled with silanes are:

- Increased mechanical strength of the composites
- Improved electrical properties
- Improved resistance to moisture attack at the interface

Silane coupling agents are a critical component of **glass-reinforced polymers**. The glass is very **hydrophilic** and **attracts water to the interface**. Without silane treatment on the glass surface, the bond between the glass fiber and the resin would weaken and eventually fail, making a composite essentially useless.

Silane coupling agents are used in glass treatment (fiber, bead...) for **general purpose applications**, such as automotive, marine, sporting goods, and construction, as well as for **high performance applications** in printed circuits boards and aerospace composites.

Glass materials treated with silane coupling agents can be used either in thermosets or in thermoplastics, or any other desired polymer system..

Some of the benefits imparted to glass-reinforced polymers by Dow Corning brand silanes include:

- Increased mechanical strength of the composites
- Improved electrical properties
- Improved resistance to moisture attack at the interface
- Improved wet-out of the glass fiber
- Improved fiber strand integrity, protection and handling
- Improved resistance to hot solder during fabrication
- Improved performance in cycling tests from hot to cold extremes

Silane coupling agents are often used to treat silica (both fumed and precipitated) treatment with great effectiveness in filled polymer systems.

The silane treatment can improve processing, performance, and durability of silica-modifed product by:

- **Improving adhesion** between the silica and the polymer
- Improving wet-out of the silica by the polymer
- Improving dispersion of the silica in the polymer
- Improving electrical properties
- Increasing mechanical properties

Reducing viscosity of the silica/polymer mix
Mineral fillers have become increasingly important additives and modifiers for organic polymer. The metal hydroxyl groups on the surface of minerals are usually very **hydrophobic** and very **incompatible with organic polymers**. Silanes are a natural fit to treat the surface of the mineral to make the mineral **more compatible and dispersible in the polymer**, or even make the filler into a reinforcing additive.
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Figure 1 shows that **retention of flexural strength is much better with silane coupling agents** than with the chrome complex (blue line).

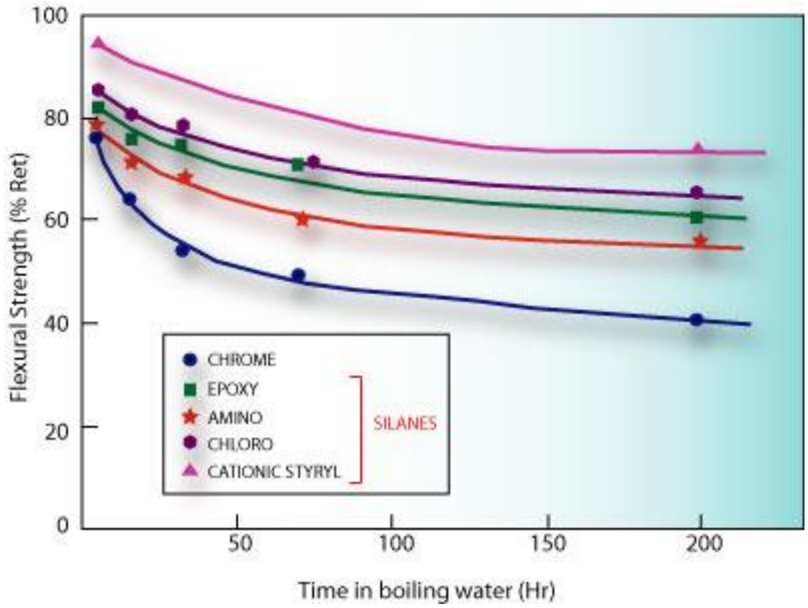

Figure 1: Retention of flexural strength in **wet environment** with the use of different coupling agents

Fillers are known to have varying degress of inhibition of the curing of thermoset resins. Using silanes can cover and seal the filler surface to prevent tag interaction of the filler with the curatives. In both polyesters and epoxies it was observed that silane treatment of fillers often overcomes cure inhibition as measured by cure exotherms (see the table below). Silanes that allowed maximum exotherms were generally the most effective coupling agents.

System	**Reduction Of Cure Exotherm ΔT (°C)**	
	Polyester	Epoxy
Untreated	- 22	- 17
Z-6040 (Epoxy)	- 20	- 8
Z-6020 (Diamine)	- 15	- 1
Z-6032 (Cationic Styryl)	- 10	0

Table 4 : Resin exotherms with silane-treated filler