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Formulating Silicone Adhesives Gels and Sealants

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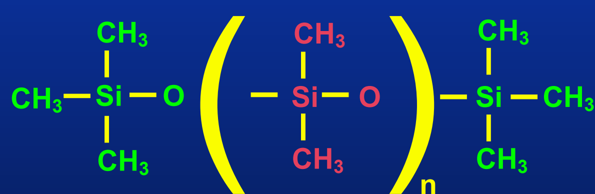
Silicone Technology is a wide and mature science spanning the gamut of materials from commodity lubricants to high performance defense coatings. This paper will give an overview of the basic technology and classes of silicone fluids. Cure types,basic formulations,applications,catalyst types and blending methods will all be discussed. United Chemical Technologies (UCT) is a major manufacturer of high quality silicones. During the discussions the catalog numbers for the corresponding UCT product will be introduced when appropriate. In many chemical reactions the reacting groups are color coded for clarity.

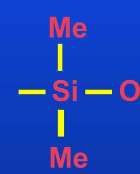
For those wanting additional detail on industrial manufacturing methods for bulk silicones, the Kirk Othmer Encyclopedia (Ref 1) is an excellent guide. More recent advances in high performance silicone materials are reviewed by Brook (Ref 2) in an excellent text.

Before we discuss basic silicone structures and curing mechanisms,it is necessary that the reader be familiar with simple silicone structural terminology and other common industrial terms. Figure 1 and Table 1 review the structural features and industrial terms commonly encountered.

Figure 1

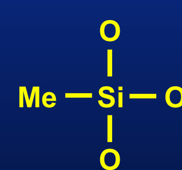
Silicones
INTRODUCTION



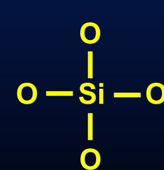


D unit

(Me_3SiO) **M unit**



T unit



Q unit

Table 1 Common Terms

Basic Terminology

Cure: **Crosslink a liquid polymer system to where it forms an elastic gel (sets up and solidifies).**

Addition Cure: **Platinum Catalyzed,**
Examples: PC072, PC075, PC085

Condensation Cure: **Tin, Zinc Catalyzed,**
Examples: PC040, PC050

Peroxide Cure: **Peroxide Catalyzed,**
Example: PC010

RTV : Room Temperature Vulcanizabe (curable) system,
Usually an addition or condensation cure resin.

The most basic class of silicones is the conventional inert polydimethylsiloxane series. They are trimethylsiloxy terminated and possess no reactive chemical functionality. These fluids find utility as plasticisers, lubricants, defoamers, in high temperature baths, and cosmetic products. Typical service temperatures are to 250° celsius. UCT offers the full line of these materials from very low to gum like viscosities. Table 2 is a compilation of this series.

Table 2

Conventional Silicone Fluids

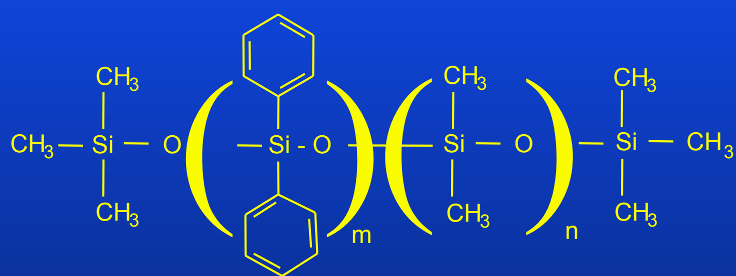
Product#	Viscosity	Specific Gravity	Refractive Index	Flash Point	Pour Point
Polydimethylsiloxanes Trimethylsiloxy Terminated CAS No. (63148-62-9)					
PS034	.65	.761	1.3750	-1°	-68°
PS035	1.0	.818	1.3825	38°	-85°
PS036	1.5	.853	1.3880	63°	-75°
PS037	2.0	.873	1.3900	79°	-80°
PS037.5	3.0	.898	1.3935	100°	-70°
PS038	5.0	.918	1.3970	135°	-65°
PS038.5	7.0	.930	1.3980	150°	-65°
PS039	1.0	.935	1.3990	163°	-65°
PS039.5	2.0	.950	1.4000	232°	-65°
PS040	5.0	.960	1.4015	285°	-65°
PS041	100	.966	1.4025	315°	-65°
PS041.2	200	.968	1.4030	315°	-60°
PS041.5	350	.970	1.4031	315°	-60°
PS042	500	.971	1.4033	315°	-55°
PS043	1,000	.971	1.4034	315°	-50°
PS044	5.000	.973	1.4035	315°	-48 °
PS045	10,000	.974	1.4035	315°	-48°
PS046	12,000	.974	1.4035	315°	-46°
PS047	30,000	.976	1.4035	315°	-43°
PS047.5	60,000	.976	1.4035	315°	-42°
PS048	100,000	.977	1.4035	321°	-41°
PS048.5	300,000	.977	1.4035	321°	-41°
PS049	600,000	.978	1.4035	321°	-41°
PS049.5	1,000,000	.978	1.4035	321°	-39°
PS050	2,500,000	.978	1.4035	321°	-38°
Branched Polydimethylsiloxane CAS No. (68037-74-1)					
PS052	50 cSt.	0.97	1.4030	279°	-85°

Polydimethylsiloxane Emulsion

PS053.5 — *30% silicone antifoam in water.*
Used to defoam biological mixtures by adding 2-50 mg/liter.

Although conventional fluids are stable thermally to 250° celsius, many high performance coating applications require higher temperature stability. Introduction of aromatic groups (phenyl rings) raises thermal stability to greater than 300° celsius. The indices of refraction and the rigidity of cured resins are also increased over conventional fluids. Figure 2 describes these materials in more detail. They are available with curable vinyl terminals at the polymer terminals and containing variable viscosities and mole percentages of phenyl groups. The most utilized UCT product line of curable aromatic silicones is the PS732-PS793 series of vinyl terminated fluids.

Figure 2 Thermal Silicones



The most commonly used high temperature silicone fluids are the phenyl containing siloxanes. The phenyl group is usually incorporated in two ways. It may be introduced as a phenylmethylsiloxane or a diphenylsiloxane. As phenyl groups replace methyl groups in a polysiloxane, several changes occur. Lubricity, oxidation resistance, thermal stability and shear resistance are enhanced. For polymethylphenyl siloxane the service temperature is -55º to 290º C.

In a closed oxygen-free system the polymethylphenylsiloxanes are stable for thousands of hours at 230ºC. The materials are used in heating baths. The tetrachlorophenyl-dimethylsiloxane copolymer is well-suited for metal to metal lubrication. They are also used as base oils for high temperature lubrication.

The phenyl group also introduces rigidity in the silicone chain. When substitution exceeds 75 mole percent the polymers are solid. Diphenylhomopolymers demonstrate liquid crystal behavior between 250ºC and 500ºC. Silanol terminated polydiphenylsiloxane is a glassy solid useful as a resin intermediate. The refractive index also increases with phenyl concentration. At 15-20 mole percent phenyl concentrations the refractive index matches that of amorphous silica and transparent compounds may be prepared.

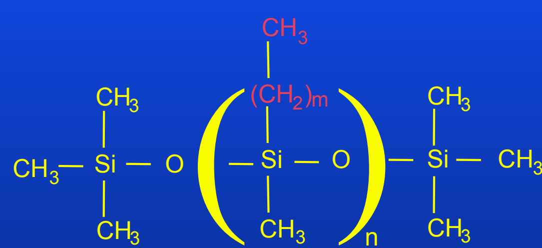
Figure 2 Thermal Silicones (Contd)

At low phenyl concentrations these fluids are dielectric coolants. They also function in place of standard dimethylfluids where extended service temperature is necessary. One special class of phenyl fluids are the dimer, trimer and tetramer fluids (see section on diffusion pump fluids). Because the introduction of a moderate concentration of phenyl groups also improves lubricity, members of the family have found utilization as lubricants for instruments and timing devices. High phenyl content fluids are also used as heat transfer media and chromatographic stationary phases. The polymethylphenylsiloxanes exhibit good radiation resistance by remaining serviceable up to 200 megarads exposure.

The compressibility of phenyl containing siloxanes is reduced in comparison to dimethyl fluids. Polymethylphenylsiloxane has a compressibility of 5.5% at 20,000 psi. Dimethyl phenylmethylsiloxane copolymer has a compressibility of 6.5% at 20,000 psi.

Silicone fluids typically show low solubility in petroleum oils. Addition of long hydrocarbon chains on the backbone increases solubility in these oils and also the lubricity. The fluids are then of utility as oil well defoamers and cosmetic lubricants. These fluids are described in detail in Figure 3. The UCT product line is shown in Table 3.

Figure 3 Polymethylalkylsiloxanes



Silicones can be modified to impart organic characteristics to their inorganic structure, which makes them more compatible with organic materials such as petroleum oils and synthetic resins.

Replacement of a methyl group with longer chain aliphatic moieties produces silicones with properties that more closely resemble hydrocarbons. When compared to polydimethylsiloxanes, methylalkylsiloxanes have greatly improved lubrication characteristics and greater compatibility with organic materials. The fluids have higher viscosity-temperature coefficients, lower compressibility and decreased oxidation stability. This last characteristic has been substantially overcome by compounding the fluids with stabilizers such as BHT or DSTDP or copolymerizing them with aromatic siloxanes as internal stabilizers.

Lubrication properties are optimized when the alkyl unit is at least eight carbons long. Polymethyloctylsiloxane is useful as a lubricant for soft metals such as aluminum, zinc and copper. It is also useful as a rubber or plastic lubricant especially when mated against steel or aluminum. Polymethyloctylsiloxane is also employed in aluminum machining operations.

With increasing length of the alkyl substituent the melting point increases. As the pour point of the alkyl modified siloxanes increases, the resemblance and compatibility with hydrocarbon oils increase. Polymethyltetradecylsiloxane has a high degree of hydrocarbon compatibility and maintains liquid behavior at room temperature. Polymethyloctadecylsiloxane is a creamy solid with a melting point just above room temperature. It is compatible with paraffin wax. It is used as a component in thread and fiber lubricant formulations and as a process aid in melt spinning. Methylalkylsiloxane reduces the surface tension of many non-aqueous solvents allowing them to act as wetting and leveling agents in coating and ink formations.

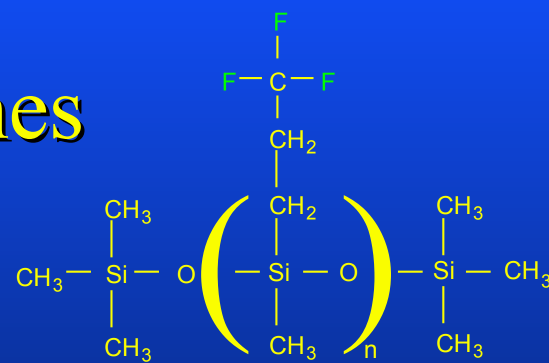
Table 3 Polymethylalkylsiloxanes

Prod#	Description [CAS#]	Visc.	SG	RI	PP	ST
PS130	Polymethyloctadecyl-siloxane [68607-75-0]	250-300	0.89	1.443	50°	39.5
PS130.5	(70%) Dimethyl (30%) Methyloctadecyl Siloxane Copolymer	250-350	0.892	1.44		
PS134	Polymethyltetradecyl-siloxane [76684-67-8]	1500-3000	0.89	1.455		
PS134.5	(70%) Dimethyl (15%) Dodecyl (15%) Tetradecyl Siloxane Terpolymer	150-200	0.916	1.43		
PS134.8	(50%) Dimethyl (25%) Dodecyl (25%) Tetradecyl Siloxane Terpolymer	150-200	0.903			
PS135	Polymethylhexadecyl-siloxane		0.88	1.451 (50)	35°	
PS136.5	(35-40%) Methyloctyl- (3-4%) Vinylmethyl (56-64%) Dimethylsiloxane Terpolymer	500-600	0.93	1.437		
PS140	Polymethyloctylsiloxane	600-1000	0.91	1.445	-50°	30.4
PS141	Propylmethyl Homopolymer Vinyldimethyl Terminated	200		1.43		

The most outstanding thermal stability and solvent resistance is imparted by the inert fluorosilicones (see description in Figure 4). Indices of refraction are considerably lower than for conventional fluids. See the UCT product catalog for more information. Curable versions of this series are UCT catalog number PS184.5, a silanol fluid, and PS185, a vinyl fluid. The curing chemistries for these classes of silicone will be described later.

Figure 4

Fluorosilicones



Many advantages of fluorocarbons and silicones are combined in fluorosilicones. Fluorination of compounds usually enhances their thermal stability. In the case of the polysiloxanes, fluorination usually begins at the gamma position of an alkyl chain. Due to the electropositive nature of silicon, fluorination at the alpha and beta positions generally results in poor thermal stability. As a consequence, commercial fluorosilicones are currently limited to trifluoropropyl substituted methyl fluids. The materials are useful from -40 to 285° C in a wide range of aggressive service environments. The fluids are excellent lubricants under extreme pressure conditions. Trifluoropropylmethylsiloxane fluids have a compressibility of 7.45% at 20,000 psi. They are not miscible with fuel or oils.

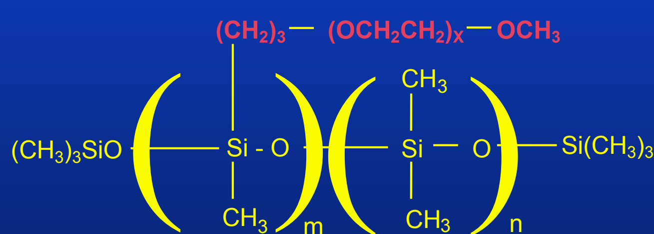
Trifluoropropylsilicone fluids have achieved a number of unique applications due to their chemical and solvent resistance, lubricity and thermal stability. They have been employed in mechanical vacuum pumps where moisture and high temperature oxygen exposure is encountered. They are used as defoamers in processes involving solvent-based wash solutions. They have been employed as grease bases when formulated with thickeners such as PTFE. Their high density has led to their use as flotation media for inertial guidance systems. Longer chain fluorinated silicone fluids demonstrate increased solvent resistance and have been employed as partitioning phases in gas chromatography. Acoustic velocities in fluorosilicones are lower than in conventional silicones, allowing sonar lens development.

Copolymers of fluoroalkylsiloxanes with dimethylsiloxanes exhibit improved boundary lubrication properties while maintaining excellent solvent and chemical resistance. They also form high performance greases when thickened with fluoropolymer powders. Such greases have been used in sealed transmissions and other extreme pressure applications. Other fluorocopolymers have been employed as lubricants for electrical contacts and precision timing devices.

Silicone fluids typically show limited water solubility and must be emulsified. To impart such solubility long chain polyethylene oxide or polyethylene oxide/polypropylene oxide chains are grafted on to the silicone backbone. Figure 5 and accompanying text describes this series. See the UCT product catalog for more information. Available materials are non curable and are typically used as surfactants or defoamers.

Figure 5 Hydrophilic Silicones

Hydrophilic silicones are non-reactive fluids that have been modified to give them slight to complete solubility in water. Their chemical description is polyalkylene oxide modified polydimethylsiloxanes. The typical structure of a hydrophilic silicone is:



Polydimethylsiloxanes prepared as copolymers with alkene oxides are widely used as surfactants. By altering the amounts of alkene oxide (hydrophile) and dimethylsiloxane (lipophile) the desired surfactant properties may be balanced. The higher the alkene oxide content the higher the hydrophilicity. Materials with ethylene oxide contents 75% and higher are freely soluble in water, as well as other commonly used organic solvents such as methanol, isopropanol, acetone, xylene, and methylene chloride. PS071 is a low molecular weight water soluble fluid that is used in lithographic and photographic plates to facilitate wetting and spreading of developers. It is also used as an anti-fogging treatment for glass and plastic optical surfaces. PS073 is used as an anti-foam in water-based coatings. PS072 is a water soluble copolymer employed as a lubricant for fibers and plastics. It also imparts anti-tack and mar resistant qualities coatings. PS071, PS072 and PS073 all have excellent long term hydrolytic stability. PS071 and PS072 provide slip in flexographic and gravure inks. PS073.5 reduces the static charge generation of fiber substrates and has been incorporated into rolling oil formulations for metal drawing and stamping. The coefficient of thermal expansion is 8 x 10°C.

The silicone fluids described to this point are non reactive, that is, they are not readily cured to solid elastomers. Table 4 summarizes many of the uses of these materials. Usually applications involve adding the liquid to a formulation as a plasticiser or stabilizer. Uses also include lubricants in machinery and high temperature bath oils.

Table 4 Silicone Fluid Selection Guide

Function	Application	Fluid Class
Performance Additive	Surfactant/Antifoam	Conventional (Low Viscosity) Hydrophilic or Fluorosilicone
	Hydrocarbon Compatibility	Organic Compatible
	Flow Control	Conventional (Low Viscosity)
	Wetting	Hydrophilic
	Radiation Resistance	Thermal
Acoustical	Sonobuoy Sound Coupling	Conventional (Low Viscosity) Fluorosilicone
Optical	Optical Coupling Fluid Anti-fog Agent	Thermal Hydrophilic
Heat Transfer	Heat Treatment Bath	Thermal
	Constant Temperature Bath	Conventional (Intermediate Viscosity) or Thermal
	Temperature Measurement Device	Conventional (Intermediate Viscosity), Thermal or Fluorosilicone
	Closed Loop Heating	Thermal
	Refrigerated Systems	Low Temperature

Silicone Fluid Selection Guide (contd)

Function	Application	Fluid Class
Working Media	Fluid Clutch	Conventional or Thermal
	Smart Fluids	Conventional or Organic Compatible
	Hydraulic Fluid	Low Temperature, Conventional or Thermal
	Brake Fluid	Conventional (Intermediate Viscosity)
	Shock Absorber	Conventional, Thermal
	General Damping	Conventional, Thermal or Fluorosilicone
	Meter Damping	Conventional
	Timing Devices	Conventional or Thermal
	Magnetic Amplifier	Thermal
	Diffusion Pump	Thermal (Oligomeric)

Silicone Fluid Selection Guide (contd)

Function	Application	Fluid Class
Lubrication	Mold Release	Conventional Organic Compatible Emulsion
	Aluminum Machining and Extruding	Organic Compatible
	Die Casting	Organic Compatible
	Ball Bearing and Gear Lubrication	Organic Compatible Thermal or Fluorosilicone
	Airborne Radar	Low Temperature
	Rubber/Plastic Contact	Conventional or Organic Compatible
	Fiber/Plastic Contact	Hydrophilic
	Metal/Plastic Contact	Organic Compatible Thermal or Fluorosilicone
	Metal/Metal Contact	Organic Compatible Thermal (Chlorophenyl)
	Grease	Conventional, Thermal or Fluorosilicone

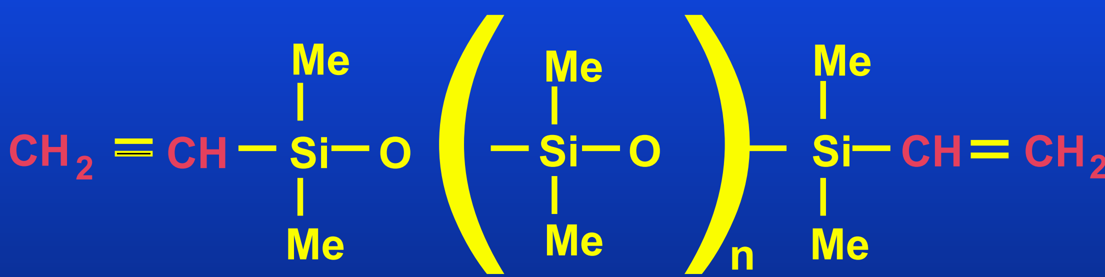
Silicone Fluid Selection Guide (contd)

Function	Application	Fluid Class
Dielectric Coolant/Fluid	Transformers, Rectifiers Capacitors	Conventional
	Magnetron	Conventional Thermal
	Dielectric Impregnation of Porous Substrate	Conventional

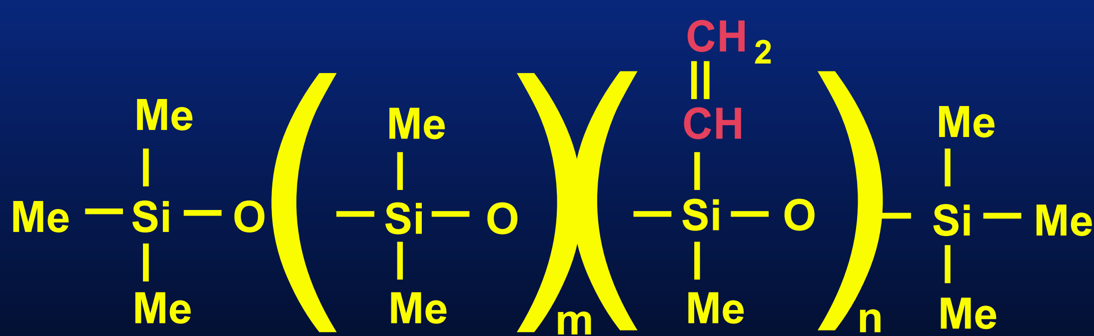
The basic feed stocks employed in homogeneous platinum catalyzed silicone resin systems are vinyl fluids, whose structural types are outlined in Figure 6, and hydrosilicones, outlined in Figure 8. Vinyl fluids are typically blended in the " base" or "part A" side while hydrosilicones are put into the "crosslinker" or "part B" side. The A side and B side convention is sometimes violated and inverted by major turn key formulation manufacturers. Technical datasheets and MSDS sheets should be reviewed for unequivocal determination of each sides identity.

United Chemical Technologies is also a major manufacturer of these silicone resins. Table 5 and Table 6 list these materials and their most common applications.

Figure 6 Vinyl Fluids



Vinyl Terminated Siloxanes



Vinyl Functional Copolymers

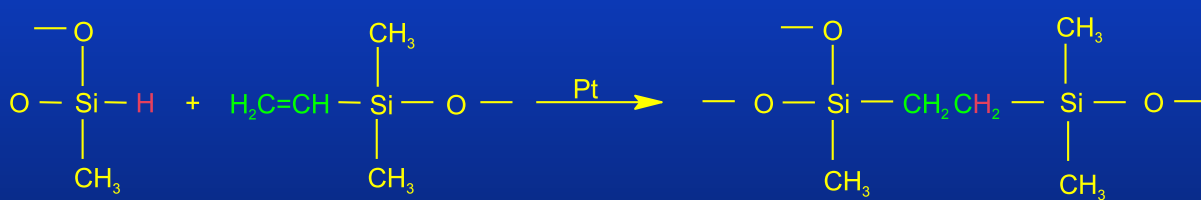
Vinyl functional silicones are commonly cured by two routes. The "addition cure" route involves adding a silicon hydride functional group to a terminal "vinyl" double bond. The catalyst is a homogeneous platinum catalyst of the Karstedt (Ref 4) type. These cures can be either at room or high temperature, depending on the activity of the catalyst. We will describe these platinum catalysts in more detail later (see Figure 15).

The second route involves cures catalyzed by a high temperature radicle induced polymerization , initiated via decomposition of an organic peroxide. Both of these routes are illustrated in Figure 7. In a later section we will discuss in detail the advantages of the platinum catalyzed route over the peroxide route for curing silicone resins.

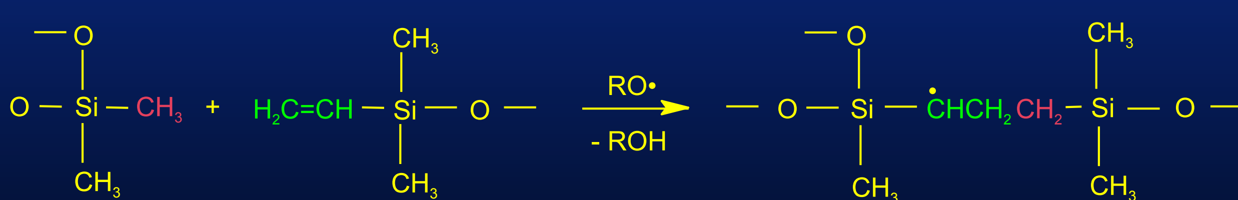
Figure 7 Cure of Vinyl Silicones

Si-CH = CH_2

VINYL FUNCTIONAL SILICONES



addition cure



peroxide activated cure

The complete product line of United Chemical Technologies vinyl silicones is listed in Table 5. PS437 through PS449.5 are di-functional at the the polymer terminals (the ends). These fluids are the base resins incorporated into the "Part A" of two part silicones employing platinum catalysis. These formulations will be described and illustrated in later sections. PS422 through PS488 are poly (>2) functional in vinyl, either in the backbone or at the terminals. These resins are additives to the di - functional fluids in Part "A" to impart greater hardness and tear strength.

"Q" resins (see Figure 1 nomenclature) are also used as additives to improve tear strength and abrasion resistance. PS496 and PS498 are representative members of this class offered by UCT.

PS437 and PS925 are efficient cure retarders for the platinum based addition cure silicone curing systems.

Table 5 Vinyl Fluids

Description (CAS #)	Viscosity	Weight % Vinyl	SG	Primary Use in RTV Addition Cure Systems
Polydimethylsiloxane, Vinyldimethyl Terminated CAS No. [68951-99-5]				
PS437	2-3	10-12	0.919	Cure moderator or as an inhibitor
PS438	4-6	7-9	0.93	
PS441	100	12-14	0.97	
PS441.2	200		0.97	Base polymer or part of
PS442	500		0.97	Polymer blend of liquid RTV
PS443	1000	0.18-0.26	0.97	systems
PS444	5000		0.97	
PS445	10,000		0.97	High strength RTV systems
PS447.6	65,000	0.03-0.07	0.97	
PS448	100,000		0.97	
PS448.5	165,000		0.97	
PS449	600,000		0.98	Main polymer for High
PS449.5	1,000,000	0.01-0.02	0.98	Consistency RTV systems
Polydimethylsiloxane, Monovinyl, Mono n-Butyldimethyl Terminated				
PS491	10,000	0.05-0.1	0.98	

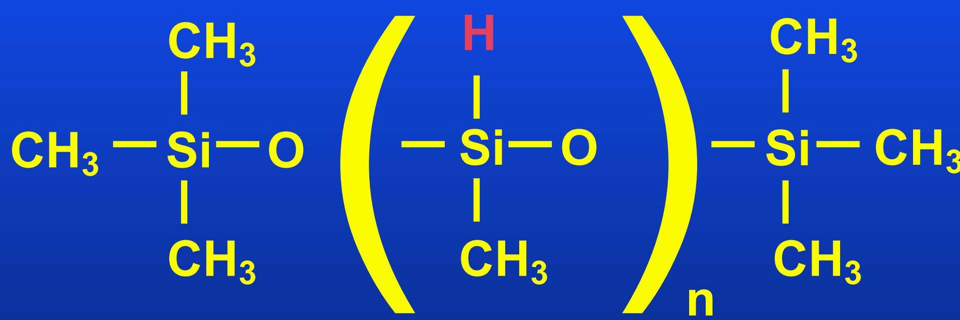
Table 5 Vinyl Fluids(CONTD)

Description (CAS #)	Viscosity	Weight % Vinyl	SG	Primary Use in RTV Addition Cure Systems
Vinyldimethyl, Dimethylsiloxane Copolymer, Trimethylsiloxy Terminated CAS No. [67762-94-1]				
PS422	250	1.0		Peroxide or Pt cure
PS424	1000	7-5		
PS426	1000	1.0		
Vinyldimethyl, Dimethylsiloxane Copolymer, Vinyl Dimethyl Terminated				
PS493	1000			
Divinylmethyl Terminated, Polydimethyl Siloxanes				
PS483	1000			
PS488	100,000			
Vinyl Q-resin Dispersion				
PS496	4000-6000		1.02	High strength RTV systems
PS498	165,000		1.02	
Vinylphenylmethyl Terminated Dimethyl Siloxanes				
PS463	1000			
T-structure Polydimethylsiloxane with vinyl at branchpoint				
PS408	50-75			
T-structure Polydimethylsiloxane with vinyl at branch terminus				
PS410	300-500		0.99	
Cyclic Vinylmethyl, Dimethyl Siloxanes CAS No. [2554-06-5]				
PS925	3-7			

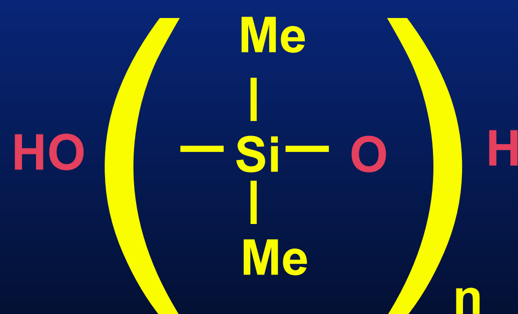
The other component of the two part RTV platinum curable silicones is a hydrosilicone crosslinker (see Structure 1 of Figure 8). This crosslinker typically contains hydrosilicone in the backbone of the polymer. Silanol fluids (see Structure 2 of Figure 8) may also be formulated with hydrosilicones and a tin or zinc catalyst. Hydrogen gas results which blows the polymer matrix on curing. These blown silicone systems are useful in cushioning materials.

The other major use of hydrosilicones is as selective reducing agents (Ref 3). Equations for these chemistries are shown in Figure 9.

Figure 8 Structure 1



Organo-Hydrosiloxane Polymers and Copolymers



Structure 2

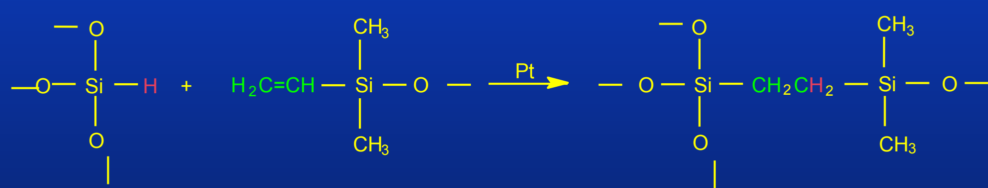
Silanol Terminated and Related Polydimethylsiloxanes

Figure 9

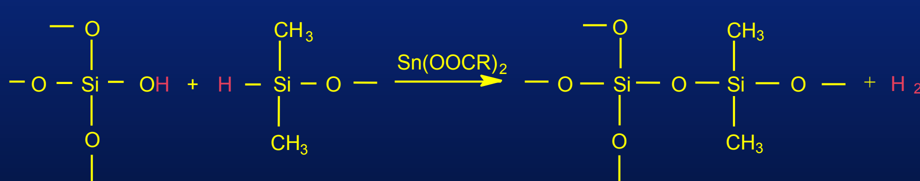
CHEMISTRY OF HYDRIDE FUNCTIONAL POLYMERS

Hydride Functional siloxanes undergo three main classes of reactivity: Hydrosilylation, dehydrogenative coupling and hydride transfer.

Hydrosilylation



Dehydrogenative Coupling



Reduction

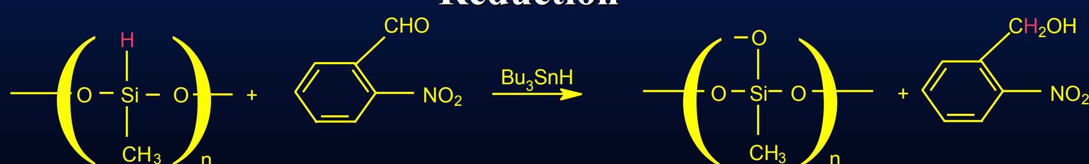


Table 6 lists the complete line of UCT hydrosilicones. PS118-PS122 are hydrosilicone homopolymers with trimethylsiloxy terminals and backbones consisting entirely of methylhydrosiloxy groups. These are very potent crosslinkers. They also are used as starting materials to graft on alkyl or other functionalities via the hydrosilylation reaction. PS122.5-PS124.5 are more moderate crosslinkers containing varying molar amounts of methyl hydrosiloxane in the backbone, the remainder being dimethylsiloxane. Specialized crosslinkers with cyano, octyl or phenyl functionality in the backbone are offered in PS124 through PS129.5.

Hydrosilicone chain extenders are use extensively to soften platinum cure formulations and impart greater elongation. They are di functional in hydride at the polymer terminals. UCT offers a complete line of these with catalog numbers PS537 through PS545.

Table 6 Hydrosilicones

Description [CAS #]	Viscosity	Wt% Methyl Hydro	Specific Gravity	Refractive Index	Flash Point	Uses
Polymethylhydrosiloxane, Trimethylsilyl Terminated CAS No. [63148-57-2]						
PS118	2-5			1.382	50°	
PS119	20		0.99	1.395	100°	
PS120	30		0.99	1.396	121°	Blowing Agent Crosslinker
PS122	85		0.99	1.397		
Methyl Hydro, Dimethylsiloxane Copolymer, Trimethylsilyl Terminated CAS No. [68037-59-2]						
PS122.5	10-15	(50-55%)	0.99	1.394	70°	
PS123	25-30	(30-35%)	0.99	1.399	125°	
PS123.5	25-35	(15-18%)	0.99	1.400		RTV Crosslinker for addition cured Pt catalyzed systems
PS123.8	7500± 2500	(0.5-1.0%)	0.97	1.404	300°	
PS124.5	250-275	(4-6%)	0.97	1.404		

Table 6 Hydrosilicones (CONTD)

Description [CAS #]	Viscosity	Wt% Methyl Hydro	Specific Gravity	Refractive Index	Flash Point	Uses
Methyl Hydro, Cyanopropylmethyl Siloxane Copolymer						
PS124	1000-3000	(3-4%)	1.07	1.446		
Methyl Hydro, Methyloctyl Siloxane Copolymer						
PS125	200-400	(40-60%)	0.93	1.435		
PS125.5	300-600	(25-30%)	0.91	1.440		
Methyl Hydro, Phenylmethyl Siloxane Copolymer, Dimethylsiloxy Terminated						
PS129.5	75-100	(45-50%)		1.500		
Polydimethylsiloxane, Hydride Terminated						
PS537	2-3		0.905	1.395		
PS542	500		0.971	1.403		
PS543	1000		0.971	1.403		
PS545	10,000		0.974	1.403		

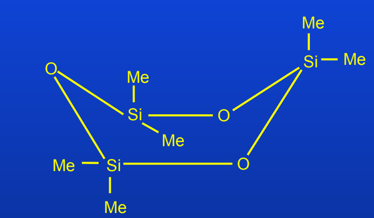
The physical properties of silicone resins are intimately related to the structure of the starting monomer units. Table 7 is a summary of these structure/property relationships. Trends commonly experienced by polymer formulators are the increased rigidity and decreased elongation on introduction of aromatic groups into the backbone of the silicone.

Table 7 Effect of Monomers on the Properties of Silicone Resin Films

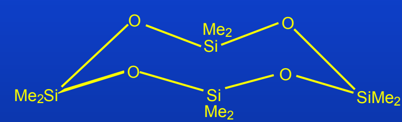
Property	CH_3SiCl_3	$C_6H_5SiCl_3$	$(CH_3)_2SiCl_2$	$(C_6H_5)_2SiCl_2$	$CH_3(C_6H_5)SiCl_2$
hardness	increase	increase	decrease	decrease	decrease
brittleness	increase	increase	decrease	decrease	decrease
stiffness	increase	increase	decrease	decrease	decrease
toughness	increase	increase	decrease	decrease	decrease
cure speed	much faster	some increase	slower	much slower	slower
tack	decrease	some decrease	increase	increase	increase

Other monomeric short chain silane end cappers, cross linkers and chain extenders are employed where the formulator desires a more rigid structure or more tightly defined stoichiometry. Figure 10 lists the most commonly available commercial products and their United Chemical Technologies catalog numbers.

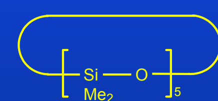
Figure 10 Typical Silicone Monomers



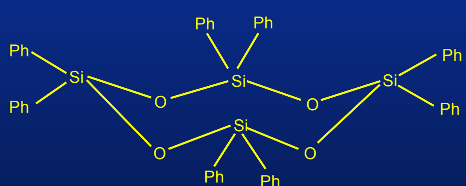
Hexamethylcyclotrisiloxane
H7260



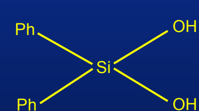
Octamethylcyclotetrasiloxane
O9810



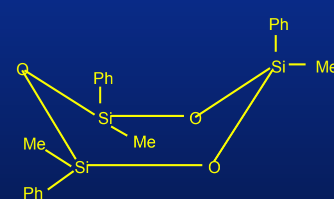
Decamethylcyclopentasiloxane
D3770



Octaphenylcyclotetrasiloxane
O9817

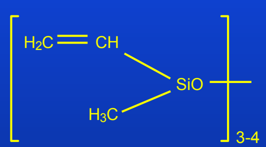


Diphenylsilanediol
D6150



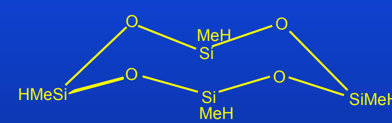
Trimethyltriphenylcyclotrisiloxane
T3800

Figure 10 (contd)

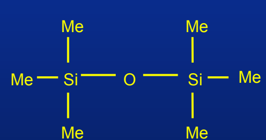


Vinylmethylcyclosiloxane
PS925

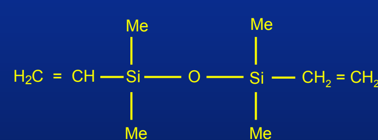
Trifluoropropylmethylcyclosiloxanes
T2844



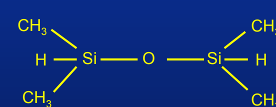
Methylhydrocyclosiloxane
T2000



Hexamethyldisiloxane
H7310



Divinyltetramethyldisiloxane
D6210



Tetramethyldisiloxane
T2030

Typical commercial silicone sealants are formulated to give high elongation, moderately hard elastomers. Table 8 is an overview of typical cured rubber physical properties for representative industrial sealants. UCT silicones are extensively used by these compounders as base resins for both one and two part systems.

The high gas permeability of silicones is quantitatively illustrated in Table 9. This property results in their extensive use in contact lens formulations (Figure 11) to allow oxygen transmission to the cornea. This property also allows small mammals to breathe in a low viscosity silicone medium.

Table 8 Cure Properties of Typical RTV Silicone Rubbers

Property	One-component general-purpose	One-component construction sealant	Two-component adhesive sealant	Two-component molding compound
hardness, Shore A durometer	30	22	50	60
tensile strength MPa	2.4	1.0	3.5	5.5
elongation	400	850	200	220
tear strength	0.80	0.35	0.52	1.75

Table 9 Permeability of Silicone Elastomers

Type	CAS Registry No.	Temperature °C	Gas	Permeability $(cm^3\text{-}cm)/(s\text{-}cm^2\text{-}kPa) \times 10^{-7}$
Dimethyl silicone	(63148-62-9)	25	CO_2	405
		25	O_2	79
		25	air	44
		30	butane	2.0
		70	butane	1.7
fluorosilicones	(63148-56-1)	26	CO_2	79
		26	O_2	13
nitrile silicones	(70775-91-6)	31	CO_2	237
		31	O_2	40

Figure 11

Hard oxygen-permeable contact lenses allow correction of a wider range of visual defects without compromising wearer comfort (courtesy R. Capozza, Syntex Ophtalmics)

The low toxicity and high gas permeability of silicones are shown in this experiment, in which snails completely immersed in 3-5-ctsk polydimethylsiloxane lived for more than 72 h (author's experiment constructed from unpublished work of R. LeVier)

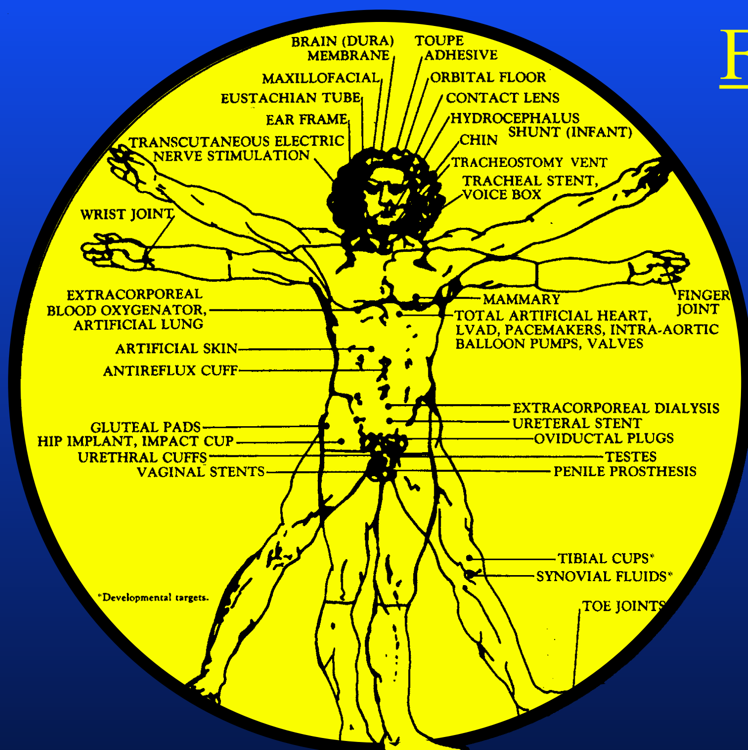
The inertness and low toxicity of silicones allows them to be used extensively in medical and prosthetic applications, as illustrated in figures 12 and 13. While UCT does not warrant silicones for medical use, its customers have qualified a wide variety of formulations in a plethora of devices. The most recent qualification is in the "Abiocor™" artificial heart device.

Figure 12

Here actor Dustin Hoffman has aged to 121 years for the film " Little Big Man."

The mask and other appliances are made of silicone and bonded by PSAs. These materials are non-sensitizing and used in a wide range of bonding applications, including surgical dressings, ileostomy and colostomy appliances, and toupes (courtesy Dow-Corning Corp.)

Figure 13



Silicone medical devices and the body:
Numerous medical devices are made from silicone-containing polymers.

Ultraviolet (UV) curable silicones are a specialized application with unique advantage but also limitations. UV curing allows a continuous curing process by passing the coated substrate through a high intensity UV light bank. If this technology is available the advantages of no premixing, humidity effect or heating are obvious. UV technology has the following limitations.

A) Need for thin coats (typically 20 micron or less).
B) Need for high power mercury arc lamp type UV device.
C) Inhibition by oxygen.
D) Need for adding photoinitiator (typically several hundred ppm).

Good photoinitiators are the "Irgacure" series of substituted acetophenones.

The UCT product line of UV curable silicones is summarized in Table 11. Among the most popular products are:

PS560. Monomethacryl functional silicone for grafting of a silicone backbone into a methacrylate cure resin.

PS583 Difunctional silicone methacrylate giving soft UV cures.

PS851 Methacrylate with functionality in backbone. Gives moderately hard (Shore A ~ 20-30) UV cures. A good photoinitiator is Irgacure 851 (2,2-dimethoxyphenylacetophenone).

PS2067 Cyclic high functionality methacrylate, gives very hard (Shore A > 50) cure with minimal elongation.

Methacrylate & Acrylate-Functional Polymers

Acryloxypropyl-functional silicones undergo UV and visible light polymerization in the presence of photoinitiators such as ethylbenzoin.

Methacryloxypropyl-functional silicones undergo the same general chemistry as the vinylsilicones, but possess several significant reactivity differences. They copolymerize readily with methacrylate monomers and undergo light activated polymerization.

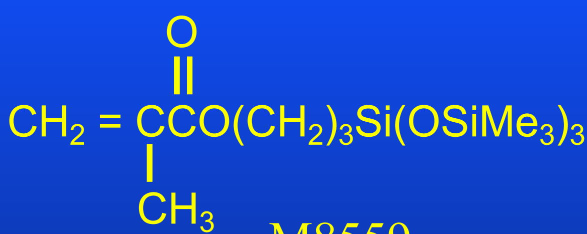
Table 10

Methacrylate & Acrylate-Functional Polymers

Product #	Description	Viscosity	Specific Gravity	Mole % Comonomer
PS560	Polydimethyl siloxane Monomethacryloxy-Propyl terminated	1000		
PS583	Polydimethyl siloxane Methacryloxypropyl-terminated	2000	1.00	
Polydimethyl Siloxane, Methacrylate & Acrylate Functional Copolymers				
PS802	(Acryloxypropyl) Methyl	80-120	0.98	15-20
PS851	(Methacryloxypropyl) Methyl	1000-2000	0.98	2-3
PS852	(Methacryloxypropyl) Methyl	10000	0.92	5
PS853	(Methacryloxypropyl) Methyl	2500	0.91	8
PS854	(Methacryloxypropyl) Methyl		0.98	16
Methacrylate Functional T-structure				
PS406	Methacryloxy Propyl	25-50	0.97	
Acrylate Homopolymers				
PS 901	Poly(Methacryloxypropylmethyl)Siloxane (Includes Cyclics)	25-125		
PS 901.5	Poly(Acryloxypropylmethyl)-Siloxane (Includes Cyclics)	100	1.10-1.12	

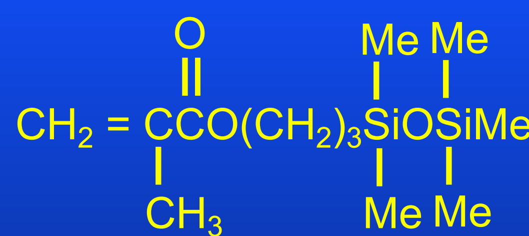
"Lens Monomers" are low molecular weight silane additives for contact lens formulations. They greatly increase the permeability of the lens to oxygen and moisture. United Chemical Technologies is a basic manufacturer of lens monomers. Figure 14 shows the most common silane lense monomers.

Figure 14 Lens Monomers



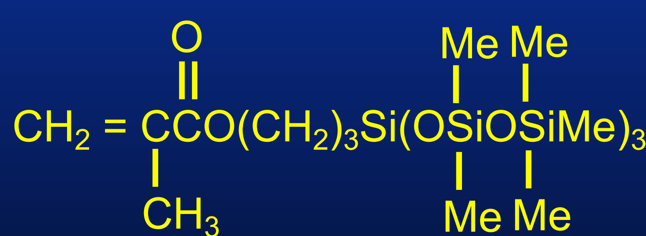
M8559

Methacryloxypropyltris (trimethylsiloxy)silane



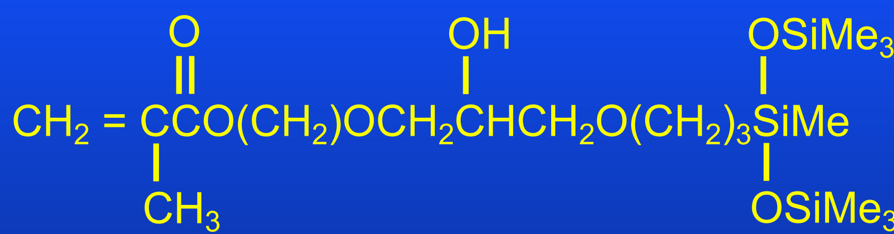
M8547

Methacryloxypropylpen-tamethyldisiloxysilane

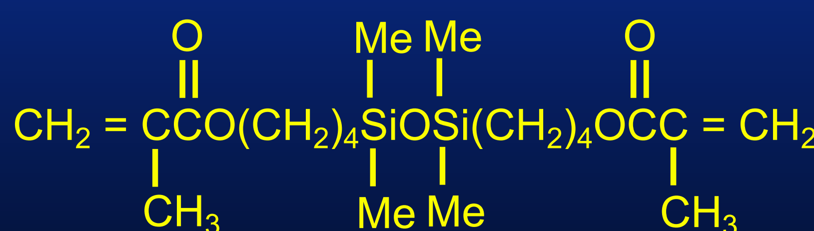


Methacryloxypropyltris(pentamethyl-disiloxanyl)silane

Figure 14 Lense Monomers (Contd)



Methylbis(trimethylsiloxy)silylpropylglycerol-methacrylate



Bis(Methacryloxybutyl)tetramethyldisiloxane

B2408.5

This article will attempt to highlight the benefits of homogeneous platinum catalysts of the Karstedt type (Ref 4) over other catalyst systems commonly used in curing polydimethylsiloxane resins. The technology is also applicable to organic synthesis where an active silyl functionality needs to be grafted onto an olefinic moiety. These platinum catalysts are described in detail in Figure 15 and Table 11 . Advantages over the older "Speiers" catalyst (chloroplatinic acid in ethanol) are summarized in Table 12.

Table 13 is a compilation of the many features and benefits offered by the United Chemical Technologies line of Homogeneous Platinum Catalysts.

Figure 15 Platinum Vinylsiloxane Catalysts

Platinum vinylsiloxane complexes have found extensive use as catalysts for promoting hydrosilylation reactions. The bond forming chemistry proceeds according to the following equation:

$$\equiv SiH + CH_2 = CHSi \xrightarrow[\text{Catalyst}]{\text{Platinum}} SiCH_2CH_2Si \equiv$$

Typical Properties

Product	Platinum[1] Content	Carrier	Cure time[2]
PC072	$\geq$ 2%	Xylene	5.0 - 8.5
PC075	$\geq$ 2%	Linear Silicone Fluid	5.0 - 10.0
PC085	$\geq$ 2%	Cyclic Silicone Fluid	10.0 - 15.0

1 Assay Test Method No. UCT0001

2 In minutes standard RTV system, Test Method No. UCT0002

Application

Applications include two part silicone compositions (RTV addition cure systems) utilized in dental impression compounds, prototype molding, sealants, and electronic coating applications. Cure time is reduced from hours to minutes in RTV systems due to the solubility of these catalysts in dimethylsiloxane polymers.

For hydrosilylation reactions or two part RTV systems, it is recommended that platinum catalysts be utilized at the 5-50 ppm range based on total formulation weight. The reactivity of PC072, PC075, and PC085 can be modified using inhibitors such as UCT's products designated D6210 and T4290 to achieve optimum reactivity characteristics. Reactivity rates are PC072 > PC075 > PC085.

Table 11 Homogeneous Platinum Catalysts

Product	Minimum Percent Platinum (1)	Carrier
PC065	10	Linear Inhibitor
PC072	2	Xylene
PC073	1	Xylene
PC074 (CLEAR)	2	Xylene
PC074.5	2	Octamethylcyclotetrasiloxane
PC075	2	Linear Silicone
PC075.3	3	Linear Silicone
PC075.5	5	Linear Silicone
PC076	1	Linear Silicone
PC085	2	Cyclic Silicone (Ashbey's Catalyst)
PC085.3	3	Cyclic Silicone
PC086	1	Cyclic Silicone
PC088.3	2.1	Octanol/Octanal (Lamoreaux's Catalyst)

1. Standard UCT atomic absorption method.

Table 12

Advantages of Platinum (0) Vinyl Siloxane Complexes PC065-PC086 Over Chloroplatinic Acid, H_2PtCl_6

1) Homogeneous.
2) Higher reactivity.
3) Reactivity is fine tuned by choice of solvent and inhibitor.
4) No corrosive HCl or chloride byproducts.
5) Colorless catalyst solutions are available.

Table 13 Features and Benefits

Features

- Consistent reactivity profile.
- High Clarity, Low Color.
- Customized platinum levels available.
- Specialized packaging available.
- Wide variety of catalyst activities for room temperature and high temperature cure profiles.
- Complete catalyst product line to serve Platinum-based, Peroxide-based, and Condensation-based Silicone cures.

Benefits

- Just in time delivery, very competitive pricing.
- Less customer problems with final cured product.
- Our platinum catalysts are more reactive and selective than chloroplatinic acid.
- Our platinum catalysts require low formulated platinum concentrations (5-30 ppm).
- Platinum catalyzed cures evolve no volatile byproducts.
- Our homogenous platinum catalysts have more consistent reactivity than heterogeneous catalysts due to irregular surface effects in the latter.

While homogeneous platinum catalyzed resins have many processing advantages over peroxide cure systems (see Table 14), United Chemical Technologies is a full service company that offers a comprehensive line of peroxide catalysts. Figure 16 describes this product line and gives starting process conditions. The peroxide catalysts are supplied as pastes in inert silicone to allow easier compounding into the formulation.

Figure 16 Peroxide Catalysts

Peroxide catalysts are primarily used for the cross linking of silicone rubber compounding.

Typical Properties

Product	Chemical Description	Carrier	Concentration
PC010	2,4-Dichloro-benzoyl peroxide	Polydimethyl siloxane	50%
PC020	Benzoyl peroxide	Polydimethyl siloxane	50%

Applications

Peroxide catalysts are best used for low vinyl containing polymers (for example - UCT's products PS255, PS264, PS268, PS286) which can be cured at elevated temperatures using peroxide. The benzoyl peroxide catalyst has less tendency to scorch than dichlorobenzoyl peroxide and is therefore favored for thin sections.

Peroxide loading is approximately 0.2-1.0% and curing is at 125-150°C.

Table 14

Advantages of Addition Cure (Platinum) Over Peroxide Cure Systems:

A) Lower curing temperatures possible.

B) No acidic byproducts
(e.g., benzoic acid from benzoyl cure).

C) No “frothing” from oxygen byproduct of cure.

D) No oxidative degradation of elastomer possible.

High molecular weight silicone gum stock is curable utilizing both peroxide and platinum based catalysts if the gum contains vinyl functionality. Table 15 lists the complete UCT product line. Of these all but PS240 contain vinyl groups and are curable with a homogeneous platinum catalyst plus hydrosilicone crosslinker.

Silicone Gums

Silicone gums are high molecular weight linear polydiorganosiloxanes that can be converted from a highly viscous plastic state into a predominantly elastic state by cross-linking. They are base stocks for most traditional silicone rubbers. The principal method of producing rubbers is to cure at elevated temperatures with peroxides. Elevated temperature cure gums usually have molecular weights ranging from 500,000 to 900,000. A variety of groups, including trifluoropropyl, cyanopropyl, phenyl, and vinyl, are used to substitute for methyl groups in order to impart specific cure, mechanical or chemical properties to silicone rubbers. Introduction of phenyl groups reduces elasticity, increases radiation resistance and useful temperature range. Phenyl groups reduce crosslinking efficiency. Trifluoropropyl groups increase solvent resistance. Introduction of low percentages of vinyl groups reduces the vulcanization temperature and imparts greater elasticity and lower compression set to rubbers. Peroxide cure gums may be trimethylsiloxy or vinyldimethylsiloxy terminated. Most gum stocks have methylvinylsiloxane chain components. The peroxides most commonly used are benzoyl peroxide and bis(dichlorobenzoyl) peroxide. Other peroxides are restricted to more specific systems. Dicumyl peroxide, for example, can be used only for vinyl containing polymers. Generally, peroxide loading is 0.2 to 1.0% and cure is at 125°-155°. Trifluoropropylmethylsiloxane compounds are often stabilized with red iron oxide.

Table 15 Silicone Gums

Product #	Description	Normal Cure System Used
PS240	**Poly (Dimethylsiloxane), gum**	Peroxide
PS255	**Poly (Dimethylsiloxane) - (0.1-0.3%) (Methylvinylsiloxane) Copolymer, Gum**	Peroxide
PS264	**Poly (Dimethylsiloxane) - (5-6%) - (Diphenyl) - (0.1- 0.3%) - (Methylvinylsiloxane) Copolymer, Gum**	Peroxide
PS268	**Poly (Dimethylsiloxane) - (15%) - (Diphenylsiloxane) (0.1-0.3%) - (Methylvinylsiloxane) Copolymer, Gum**	Peroxide
PS286	**Poly (Methyl-3,3,3-Trifluoropropyl) - (1-2%) (Methylvinylsiloxane) Copolymer, Gum**	Peroxide

Typical formulated silicone rubber systems require substantial molar excesses of hydrosilicone over vinyl fluid to achieve optimal physical properties. The desired mix ratio depends on the chain length of the vinyl terminated silicone and percent hydride in the backbone of the crosslinker. Table 16 lists theoretical mix ratios for three commercial United Chemical Technologies vinyl fluids when compounded with three hydrosilicones of varying hydride content (refer to tables 4 and 5). Ratios are computed at a 1.5/1.0 SiH/Vinyl molar ratio. Less potent crosslinkers, such as PS123.8, and higher viscosity vinyl fluids, such as PS445, give softer cures at equivalent molar ratios.

Table 16

Starting Ratios of Hydrido Siloxanes (parts) to 100 parts of Vinylsiloxanes

Vinylsiloxane	PS123.8	PS123.5	PS123.0
PS443	80.8	4.2	2.1
PS445	11.5	1.8	0.9
PS735	11.9	1.9	0.9

Formulation is based upon molar ratio of 1.5 Si-H to 1.0 vinyl.

Filled formulations may require up to 3x the amounts listed for optimal physical properties.

Experienced formulators and compounders can startup new materials research with little guidance, but for those new to silicone formulation Tables 17-18 are convenient starting points. The crosslinker, catalyst and plasticiser levels can all be varied to achieve the formulator's unique cure profile and physical properties requirements. Other general guidelines are:

a:) For two part systems, always put the platinum catalyst in the " A" (vinyl or base) side to avoid slow reaction of the catalyst with the hydrosilicone.

b:) Plasticiser and vinyl fluid can be partially mixed with the " B" (hydrosilicone) side to achieve a better mix ratio. Care must be taken to avoid metal contamination on the "B" side if this approach is taken.

c:) Avoid:
Contact with platinum catalyst poisons such as tin salts, mercaptans, PVC beakers or amino compounds.

Table 17 Starting Formulation, Molding RTV Silicone

This formulation has low modulus and durometer but is useful as a molding compound. No special procedure or apparatus is required and the procedure may be modified by varying the ratios of concentration to accelerate or retard the cure rate. Alternatively, the cure rate may be retarded by addition of T2160 inhibitor.

PS443	**(Vinyl Fluid)**	**100 parts**
SS0216	**(Filler)**	**50 parts**
PS123	**(Hydrosilicone)**	**3-4 parts**
PC075	**(Catalyst)**	**150-220 ppm**

With a spatula or tongue depressor, stir the PS443 into the SS0216. A plastic beaker or coffee cup is a convenient disposable recepticle. After producing a uniform paste, stir in the PS123. This paste is stable at room temperature if stored. For activation add the platinum solution dropwise with eyedropper or syringe and rapidly stir with spatula. Expect a 5-10 minute work life. Let cure overnight at room temperature to optimize physical properties.

Table 18 Starting RTV Formulation

PART A

PS443	(Vinyl Fluid)	82g
SS0216	(Filler)	17.85g
PC075	(Catalyst)	0.15g
TOTAL:		100g

PART B

PS443	(Vinyl Fluid)	90g
PS123	(Hydrosilicone)	10g
TOTAL:		100g

Prepare parts A and B separately. Mix 3 parts A with one part B.
Cure at ambient conditions for four hours.

Physical Properties

Shore A	20-30	Tensile Strength	3.5 Mpa (500psi)
Elongation	400-500%	Tear Strength	16N/mm(91ppi)

Simple formulating technique for small scale development work is illustrated in Figure 17. No expensive equipment is required and physical properties such as Shore A durometer hardness and elongation are easily measured. Other physical properties such as tear strength or modulus will require more sophisticated instrumentation.

Figure 17 How To Use UCT's PETRARCH® Silicones

1. WEIGHING: Weigh A and B in the recommended ratios.

2. MIXING: Use a spatula to make a homogenous mixture of A and B.

3. DEAIRING: Place the mixed silicone in a vacuum chamber (desiccator) and apply vacuum until foam collapses.

4. POURING: Pour mix into mold or form avoiding entrapment of air.

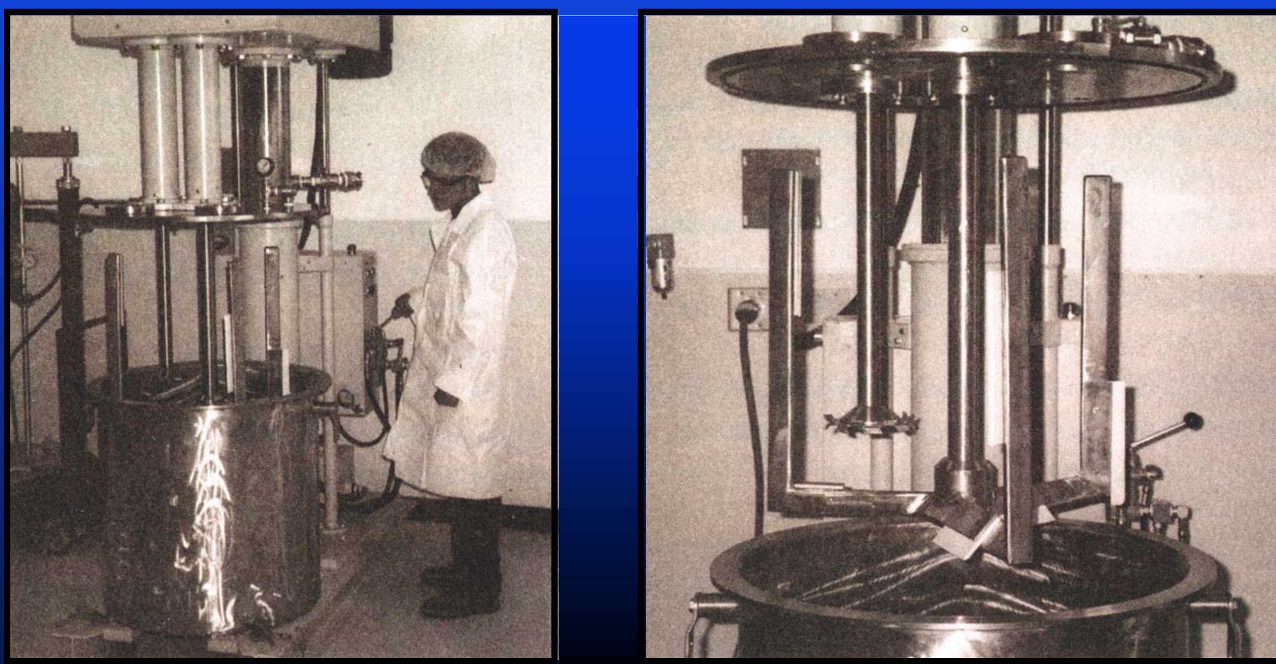
How To Use UCT's PETRARCH® Silicones (Contd)

5. CURING: Follow the recommended cure schedule

6. DEMOLDING THE FINISHED PART

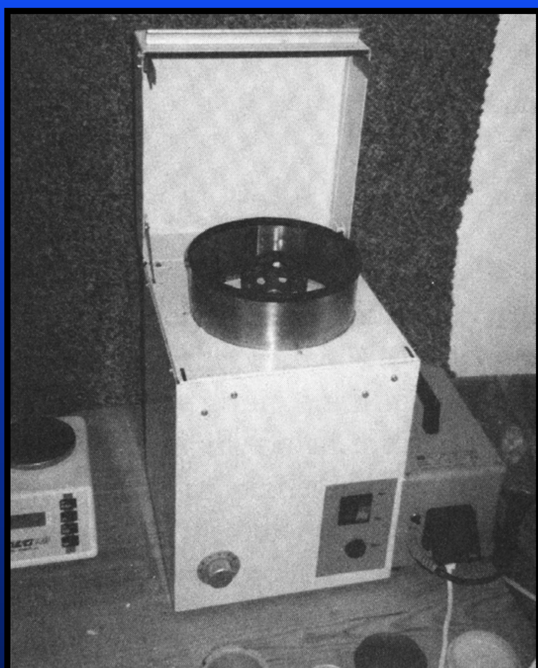
In contrast, scale up to commercial silicone resin requirements will require specialized blending equipment to achieve uniform mixing. High viscosities and filler levels necessitate such an investment. Alternatively, formulations may be sub contracted to experienced adhesives manufacturers. Figure 18 shows typical large scale equipment and Figure 19 illustrates intermediate scale equipment for scale up to kilogram level.

Figure 18 Large Scale Formulation Equipment

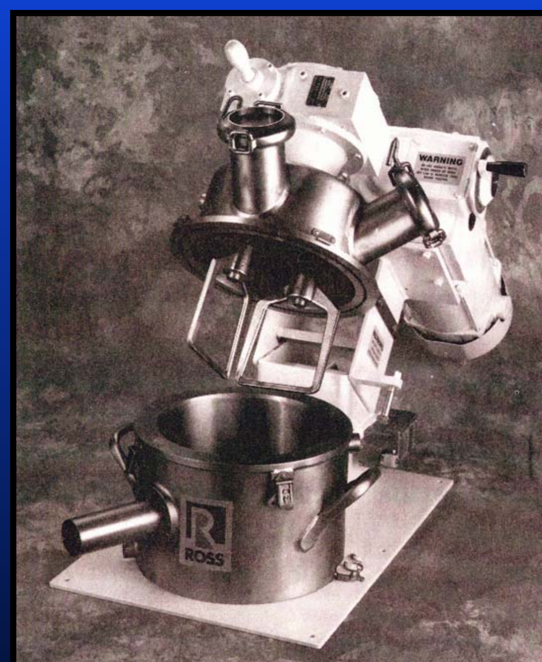


"**50 gallon high speed disperser** – produced by Applied Silicone Corp, Ventura, California"

Figure 19 Kilogram scale formulation equipment



"Hauschild Speed Mix from FlackTek Inc.,
Landrum South Carolina"



"One gallon Double Planetary Mixer"
produced by Charles Ross & Son
Company, Hauppauge, New York"

While United Chemical Technologies is a major manufacturer of the basic building blocks for silicone rubber formulations,UCT also offers “turn-key” pre blended formulations for those customers who do not want to do their own development work. Figure 20 begins an extensive discussion of formulation techniques and also describes our most popular two part kits. PEM10 is a two part RTV platinum catalyzed system that cures to a clear silicone elastomer. PEG060 is a two part RTV platinum cure system that cures to a soft silicone gel. Adjusting the crosslinker (part “B”) level up or down can make the systems harder/softer for individual specialized requirements.

Figure 20

Two Part Elastomeric Sealant Kits

Prototype and Model Making Silicones

How Modeling Silicones Work

The silicones are supplied as two part kits with “A” and “B” parts, containing at least three components:

1. Base
2. Crosslinker
3. Catalyst

The base, typically a moderate viscosity vinyl fluid, and crosslinker, typically a hydrosilicone, combine with each other to form the cured product. The catalyst, often a platinum derivative, is premixed with the base, so most kits have only two parts. They are referred to as vinyl-addition silicones.

Other materials can be added by the craftsman to modify the basic properties of the silicones. These include fillers, softening agents, pigments, dyes, additional catalyst or cure retarders. The modifiers are added to the base. After mixing these components, the crosslinker is added. All of UCT’s kits are in ready-to-use form with responses and strengths most widely desired. Only the experienced modellist should consider blending materials other than pigments and dyes, such as softening agents and fillers.

Two Part Elastomeric Sealant Kits

Mixing

It is important to obtain a homogenous mix of the silicones and to avoid entrapment of air. Mixing can be accomplished with a spoon or mixing stick. If air is entrapped as bubbles, cured rubber will contain weak areas and detail will be lost. In most systems vacuum de-airing is desirable. Some systems will de-air on standing for 5 to 20 minutes, particularly if the mix container is tapped sharply or placed on a vibrating surface. Bubbles on mold surfaces can be reduced by brushing a layer of catalyzed mix over the surface before pouring.

Work Life

All silicone systems are designed to have a work life of 30 to 90 minutes. The work life can be extended by adding a cure retarder to the initial mix. The work life can be shortened by adding catalyst or warming the mix.

Curing

Most UCT silicones will cure at room temperature in 24 hours. The cure can be accelerated by heating the silicones. At a temperature of 110°C(240°F) most will cure within two hours.

Materials to Avoid

The "A" Part, "B" Part and catalyzed mixture of A/B can be cure-inhibited by certain contaminants. Avoid contamination with amines, sulfur, chloride or tin containing compounds. These materials are found in epoxy, natural rubber, PVC and moisture cure silicones, respectively.

Two Part Elastomeric Sealant Kits

PEM-10

Description

PEM-10 silicone elastomer is supplied as a two part kit consisting of liquid base and curing agent. When the base and the curing agent are thoroughly mixed in a 10:1 weight ratio, the liquid mixture will cure in thick or thin sections to a flexible, transparent elastomer ideally suited for electrical/electrical potting and encapsulating`applications.

Uses

Equipment modules
Relays, power supplies and magnetic amplifiers
Transformers, coils and ferrite cores
Connectors
Fiber optic waveguide coatings
Encapsulation of circuit boards

Mixing

PEM-10 silicone elastomer is supplied in two parts, a lot-matched base and curing agent, mixed in a ratio of 10 parts base to one part curing agent, by weight.

For best curing results, glassware or tinned cans with glass or metal stirring implements should be used. Mix with a smooth action that will minimize the introduction of excess air.

Two Part Elastomeric Sealant Kits

PEM-10

Physical Properties

Base viscosity at 25°C, 5500 centipoise
Specific Gravity at 25°C, 1.05
Mixed Viscosity at 25°C, 3900 centipoise
Pot Life at 25°C, 2 hours
Cure Time at 25°C, 24 hours

Cured Physical Properties

Appearance, Transparent
Hardness Shore A, 40
Tensile Strength MPa (psi), 6.20 (900)
Elongation Percent, 100
Tear Strength die B kN/m (ppi), 2.6 (15)
Brittle Point Centigrade, -65
Refractive Index at 25°C, 1.430

Storage and Shelf Life

When stored in original unopened containers at or below 32°C, PEM-10 has a shelf life of 12 months from date of shipment from United Chemical Technologies, Inc.

Packaging

PEM-10 silicone elastomer, base and curing agent, is shipped in kits containing both the base and curing agent in separate containers. Each kit contains the appropriate weight of curing agent for the amount of base. Complete kits are available in 1.1, 8.8, 44 and 495-lb (0.5, 4, 20 and 225-kg) quantities, net weight.

Two Part Elastomeric Sealant Kits

PEG-60

Description

PEG-60 is a silicone gel. A silicone gel is a solid with fluid characteristics. PEG-60 maintains good cohesion, high instantaneous deformation and good resilience. It is clear with a range of firmness that varies from slow flowing to free standing. The temporarily deformable material has found application in soft tissue prosthesis and shock adsorption. It may be characterized as a viscoelastic substance of which only a small portion is crosslinked by an addition cure mechanism. Variation of base components gives a wide range of firmness.

Properties, Mixed
Viscosity, centistokes @25°C, 1000
Specific Gravity @25°C, 0.97
Penetration mm, 150-250

Processing

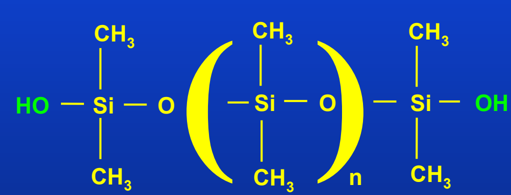
PEG-60 is a 2 part addition cure system. The system comprises an "A" and "B" which, as supplied, are mixed in a 10 to 1 ratio. After thoroughly mixing 10 parts "A" to 1 part "B", allow mix to de-air cure at 115-120°C for 30-60 minutes or at room temperature for 48 hours. If penetration of the cured gel is either too firm or too soft for the given application, the "A" part to "B" ratio can be changed:

Too firm-low penetration-change "A" to "B" ratio to 11:1, 12:1, 13:1, etc.
Too soft-high penetration-change "A" to "B" ratio to 9:1, 8:1, 7:1, etc.
At each ratio, re-cure and check penetration until desired softness is achieved.

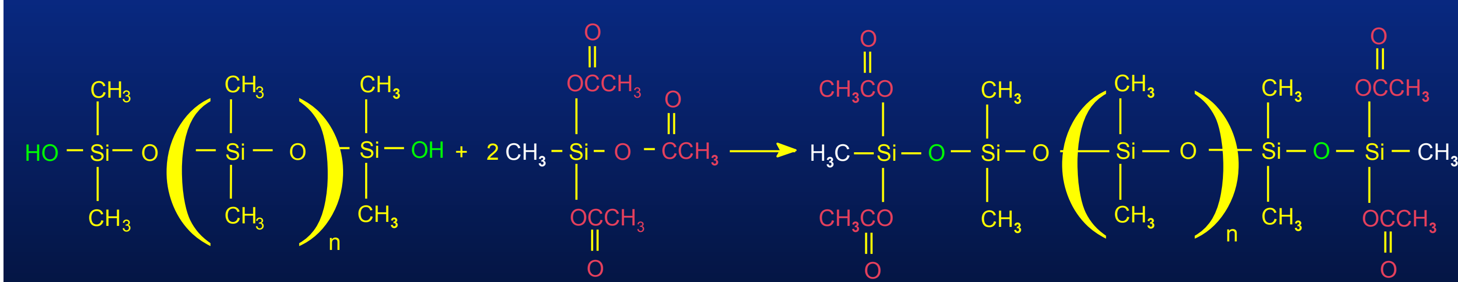
A quite old silicone curing technology involves use of silanol fluids (Figure 21) cured with a zinc or tin catalyst and a wide variety of crosslinkers such as polysilicate, oxime or acetate. Figure 21 also illustrates generation of a moisture curable tetra acetato functional silicone, by reaction of a silanol fluid with a triacetate functional silane (UCT number M8980). Table 19 lists the complete UCT line of silanol fluids. All are difunctional with the silanol groups at the polymer terminals. Table 20 lists moisture curable silicone prepolymers with acetoxy or alkoxy functionality. Materials in Table 20 are curable with zinc or tin alkanoate catalysts (see Figure 23).

Figure 21

≡Si-OH



Silanol Functional Polymers



Condensation cure

Table 19

Polydimethylsiloxanes, Silanol Terminated

Product # [CAS #]	Viscosity	Functionality Weight %	Specific Gravity	Uses
Polydimethyl Siloxanes Silanol Terminated CAS No. [7013-67-8]				
PS340	15-35	4.0-6.0	0.95	Structure control additive for Silicone rubber and cure
PS340.5	45-85	0.9-1.2	0.97	Moderator for RTV foams
PS341	100	0.8-0.9	0.97	
PS342.5	750	0.2	0.97	
PS343	1000	0.1	0.98	One & two part RTV's
PS343.5	2000	0.09	0.98	
PS343.8	3500	0.08	0.98	
PS344.5	8000	0.06	0.98	
PS345.5	18,000	0.04	0.98	
PS347.5	50,000	0.03	0.98	
PS348.7	125,000 – 175,000	0.03	0.98	
PS349.5	800,000 – 1,200,000	0.01	0.98	Silicone pressure sensitive adhesives, silicone curable solvent dispersions.

Table 20

Other Moisture Cure Prepolymers

Product # [CAS #]	Viscosity	Functionality Weight %	Specific Gravity	Uses
Polydimethylsiloxane, Dimethylacetoxy Terminated				
PS363.5 [68440-60-8]	2500-3500	0.30	0.98	
Polydimethylsiloxane, Methyldiacetoxy Terminated				
PS368.5	2500-3500	0.5-0.6	0.99	
Polydimethylsiloxane, Dimethylchloro Terminated				
PS375 [67923-13-1]	2-5	13-16	1.00	
Polydimethylsiloxane, Dimethylamino Terminated				
PS383 [67762-92-9]	2-5	13-16	0.98	
Polydimethylsiloxane, Dimethylethoxy Terminated				
PS393 [70851-25-1]	2-3	20-25	0.92	
PS395	6-11	7-13	0.94	
Polydimethylsiloxane, Dimethylmethoxy Terminated				
PS397	1000	R.I.=1.4040	0.98	

Silanol fluids are curable to elastomers by a wide variety of crosslinkers. Equations listing the most common cure pathways are listed in Figure 22. All of these cure systems result in elimination of a volatile byproduct such as acetic acid, an oxime or alcohol. These systems are thus called "condensation cures". Metallic corrosion can result from elimination of acetic acid or to a lesser extent alcohols. Oxime or enoxy cure systems are preferred if metal contact is anticipated. Due to the problems with volatile byproducts or corrosion, the homogeneous platinum catalyzed systems described earlier have replaced silanol based cure systems in many electronic, fiber optic or defense applications. The advantages of the platinum based over the condensation based cure systems are outlined in Table 21.

Figure 22

THE MOST COMMON CONDENSATION CURE SYSTEMS ARE:

Acetoxy $\equiv Si-OH + CH_3C(=O)O-Si\equiv \longrightarrow \equiv Si-O-Si\equiv + CH_3C(=O)OH$

Enoxy $\equiv Si-OH + CH_3C(=CH_2)O-Si\equiv \longrightarrow \equiv Si-O-Si\equiv + CH_3C(=O)CH_3$

Oxime $\equiv Si-OH + (C_2H_5)(H_3C)C=NO-Si\equiv \longrightarrow \equiv Si-O-Si\equiv + (C_2H_5)(H_3C)C=NOH$

Alkoxy $\equiv Si-OH + CH_3O-Si\equiv \longrightarrow \equiv Si-O-Si\equiv + CH_3OH$

Amine $\equiv Si-OH + (CH_3)_2N-Si\equiv \longrightarrow \equiv Si-O-Si\equiv + (CH_3)_2NH$

Table 21

Advantages of Addition Cure (Platinum) Over Condensation Cure (Tin, Zinc) Systems:

A) No volatile byproducts.

B) Lower catalyst concentrations (5-30 ppm vs 100-300 ppm).

C) Less moisture sensitivity

D) Smoother reaction profiles.

Typical one and two part condensation cure RTV systems are listed in Table 22 and Table 23. For one part moisture cures it is critical that all components be thoroughly dried to prevent premature gelation in a dispensing tube or "hot warehouse". Liquid components, if low viscosity, can be dried over molecular sieves. Alternatively, water can be azeotroped off with toluene. Solid fillers should be oven dried if possible. Untreated silica fillers when incorporated into one part systems, often cause viscosity buildup or gelation from active silanols on the surface. Treated fillers, such as UCT number SS0216, cap off these groups and give more stable systems.

Table 22
Condensation Cure Silanol System

PART A			PART B		
PS347.5	(Silanol)	70g	PS041	(Plasticizer)	35g
SS0216	(Filler)	28g	SS0216	(Filler)	45g
PS9120	(Crosslinker)	2g	PC055	(Catalyst)	20g
TOTAL:		100g	TOTAL:		100g

Procedure

Prepare parts A and B separately. Mix 10 parts A with one part B. Cure at ambient conditions.

Table 23

Starting One Part Moisture Cure RTV Formulation

PS347.5	(Silanol)	65.9g
PS043	(Plasticizer)	20.0g
M9220	(Oxime Crosslinker)	5.0g
A0750	(Primer)	1.0
$150 m^2/g$ Fumed Silica		8.0g
Dibutyl Tin Dilaurate (Catalyst)		0.1g
TOTAL:		**100g**

Physical Properties

Shore A	22	Tensile Strength	1.9 Mpa
Elongation	550%	100% Modulus	0.4 Mpa
Skin over	10 min	Tack Free	60 min
Scratch time	120 min	Through cure	2.0 mm (24hr)

Figure 23 describes the tin and zinc alkanoate catalysts offered by United Chemical Technologies for condensation cure systems. The catalysts are blended with low viscosity inert silicone to allow easier compounding. The "octanoate" group is actually 2-ethyl hexanoate, not a linear C8 carboxylic acid.

Tin salts are generally more reactive than zinc salts. Typical starting formulations incorporate a minimum of 500 ppm of active metal.

Figure 23

Metal Octanoates (Zinc & Tin)

and Metal Dilaurate (Tin)Catalysts

Zinc and Tin Octanoates are catalysts used independently or together in RTV formulations. RTV systems are formulated from silanol terminated polymers with a molecular weight of 26,000 to 200,000.

Typical Properties

Product	Chemical Description	Carrier	Concentration
PC040	Zinc Octanoate	Polydimethyl siloxane	50%
PC050	Tin Octanoate	Polydimethyl siloxane	50%
PC055	Dibutyl Tin Dilaurate	Polydimethyl siloxane	25%

Applications

There are several applications for UCT's metal catalysts. They may be cross-linked with small quantities of multifunctional silanes that condense with silanol groups, as in the following equation:

$$\equiv Si - OH + MeO - Si \xrightarrow{\text{Catalyst}} Si - O - Si \equiv$$

These catalysts may also be used to apply silicon elastomers on surface treatments if the surface has an - OH group. Zn and Sn catalysts also catalyze the reaction between a silanol and hydrosilane.

Application is from a dilute (0.5 - 2%) hydrocarbon or chlorinated hydrocarbon solution and cured at 110 - 150°C.

UCT also offers an extensive line of one part heat or moisture curable pre formulated systems under the Glassclad® product line. These are described in detail in Figures 24-29. Brief overviews of these coatings are given below.

PS252, a one part moisture cure silicone described in Figure 24. Cure generates a clear soft shiny hydrophobic silicone coat.

PS200 , a one part coating applied in water to glass or other active substrate to generate a highly hydrophobic deactivated surface. Technically a silane as it is C18 functional. See detailed information in Figures 25 and 26.

PS216, described in Figure 27. A one part reactive chloro silicone applied in dry alcohol or aprotic solvent. Generates a permanently bonded hydrophobic silicone surface to glass, with lower critical surface tension than PS200 coatings.

PS220,PS225 and PS233, all one part solvent applied thermally cured silicones, described in Figure 28. All generate hard abrasion resistant clear films.

PS222 and PS225, are one part neat or solvent applied silicones thermally generating thin silicon dioxide films. For detailed description see Figure 29.

PR6772, a water borne protective coating for masonry. Refer to Figure 30.

Figure 24
PS252 Glassclad® FF

Applications

PETRARCH® FF **(PS252)** is a source of filler-free silicone rubber in a tough bulk film. It exhibits high bond strength to a wide range of substrates including other silicones, silica, metals and solvent compatible plastics and fibers. In biomedical equipment, PETRARCH® FF coatings reduce physiological interaction including protein adsorption and clot initiation. In optical devices it provides a clear mechanical barrier that seals and gaskets without scratching or initiation notch failure.

Description

PETRARCH® FF **(PS252)** is a moisture-activated silicone RTV dispersed in a solution of tetrahydrofuran/dioxane. In the presence of atmospheric moisture a condensation of silicone prepolymers to a high molecular weight rubber occurs. The byproduct of the reaction is acetic acid, which imparts a vinegar-like odor. The system is designed for wet out and adhesion to polar substrates.

Figure 24 PS252 PETRARCH® FF (Contd)

Cured Properties		Uncured Properties	
Tensile Strength	>100psi	Percent	48-52%
Elongation	>150%	Viscosity	350-400 ctsks
Durometer, Shore A	>8	Specific gravity	0.97
Tear Strength	>5psi	Skin over time	30-45 min
		Cure time (10 mls)	6-8 hours
		Flash Point	0°

Application Methods

PETRARCH® FF is applied by dipping or brushing. Solvent is allowed to evaporate. Cure is at room temperature.

Caution:

Use in a well ventilated area. Flammable. Keep away from open flame.

Figure 25 PS200 Glassclad®-18 Hydrophobic Coating
® = Trademark of Sivento, Inc.

PS200 (Glassclad® -18) Imparts the Following Properties to Treated Surfaces

- Non-adherent, non-oily surfaces
- Greater scratch resistance
- Easier cleaning, improved appearance
- Reduces the number of surface polar sites

PS200 = Glassclad® 18

Uses

Applications where Glassclad® 18 has been used successfully include:

Laboratory glassware - improves drainage, reduces breakage.
Porcelain ware - provides a glide surface and reduces adhesion to other porcelain ware.
Optical fibers - provides lubricity and reduces breakage during fabrication and in operational flexing.
Clinical analysis - treatment of analytical equipment extends clotting time of blood, reduces hemolysis, reduces protein adsorption. Glassclad® 18 is not for food or drug use.
Fluorescent light bulbs - increases scratch resistance, reducing breakage, increases surface resistivity.

Figure 25 PS200, Glassclad®-18 Hydrophobic Coating (Contd)

Properties of Treated Surface
Values reported are for glass slides dipped in 1 % solution of Glassclad® 18 (PS200) and cured at 100°C.

Critical surface tension

Untreated	γ_c =78 dynes/cm
Treated (hydrophobic)	γ_c =31 dynes/cm

Surface resistivity

Untreated	1×10^{12} ohms
Treated	1.2×10^{13} ohms

Blood protein adsorption
(glass slide on glass slide)
comparative 100 hour adsorption values for whole human blood on borosilicate glass surfaces

Untreated	0.13mg/mm^2
Treated	0.01-0.02mg/mm^2

Coefficient of friction, static

Untreated	0.9-1.0
Treated	0.2-0.3

These results are not meant to suggest "in vivo" application of Glassclad® 18. Glassclad® 18 should be used only in treatment of diagnostic apparatus for clinical analysis in outside the human body application.

Figure 25 PS200, Glassclad®-18 Hydrophobic Coating (Contd)

Description

Glassclad® 18 **(PS200)** is a monomeric octadecylsilane derivative in a solution of t-butanol and diacetone alcohol that reacts with water to form a silanol-rich prepolymer and an alcohol. The silanol-rich prepolymer is able to condense with available hydroxy groups of glass or other siliceous materials to form a chemically bound alkylsilicone.

Typical Properties of Glassclad® 18 (PS200)

% active	20%
Color, Gardner scale	8
Flashpoint	10°C
Specific gravity	0.88
Solidification point	-30°C

Figure 26

PS200Application Methods

Glassclad® 18 (PS200) is most frequently used as a dilute aqueous solution containing 0.1%-1.0% of reactive silicone prepolymer. A 0.2% solution of active chemical can be easily prepared by adding one part by weight of the product as supplied to 99 parts of water while stirring. The following procedure is frequently employed.

1. Thoroughly clean objects with an alkaline detergent. Used-glass surfaces may require immersion in 2-3% sodium hydroxide. All detergent or alkali should be removed with a final rinse.

2. Prepare a 1% solution of Glassclad® 18 in water. Ordinary tap water, but not "hard water," is acceptable.

3. Immerse the glass or vitreous surface in the solution for 5-10 seconds, ensuring that all surfaces are wetted by the solution. Agitation of the solution or the part generally results in more uniform deposition. After immersion remove the part and thoroughly rinse with water to remove excess Glassclad® 18 from the surface.

4. Cure Glassclad® 18 coatings by bringing surface temperature to 100°C for 3-5 minutes. Room temperature cure may be accomplished by air drying for 24 hours if relative humidity is 65% or less.

Each liter of solution will coat approximately 80 one liter beakers or 600 15cm test tubes. It will coat approximately 250 m^2 of surface.

Stability of Glassclad® 18 and Solutions

Aqueous solutions of Glassclad® 18 are not stable indefinitely and may turn cloudy and precipitate after standing for several days. The solution stability can be optimized by adjusting the pH of the solution to 4.5-5.

PS200 = Glassclad® 18

Figure 27 Glassclad 6C®

PS216 = Glassclad® 6C

Uses

Applications where Glassclad® 6C (PS216) has been used successfully include:
Laboratory glassware - improves drainage, reduces breakage.
Fiberoptics -reduces moisture adsorption and surface fracture.
Clinical analysis - reduces protein and lipid adsorption of diagnostic glassware:
Glassclad® 6C (PS216) is not for food or drug use.
Electronic glassware - reduces surface tracking in mercury switches and optical displays.

Properties of Treated Surface

Values reported are for glass slides dipped in 1 % solution of Glassclad® 6C (PS216) and cured at 100°C.

Critical surface tension

Untreated	γ_c =78 dynes/cm
Treated (hydrophobic)	γ_c =25 dynes/cm

Description

Glassclad® 6C (PS216) is a chlorine terminated polydimethylsiloxane telomer. The chlorines react with hydroxy and silanol groups of glass or other siliceous surfaces to form a chemically bound polydimethylsiloxane "siliconized" surface.

Typical Properties of Glassclad® 6C (PS216)

% active	100%
Flashpoint	5°C
Specific gravity	0.98-1.00

PS216
Application Methods

Glassclad® 6C(PS216) is a chlorinated polysiloxane and is corrosive. Avoid skin and eye contact. Use in a well ventilated area.

1. Glassclad® 6C (PS216) is most frequently applied as a 2-10% solution in “dry” solvents such as hexane, methylene chloride, or 1, 1,1-trichloroethane. Articles are dipped or wiped. The articles can be cured by air drying for 24 hours at conditions of less than 75% relative humidity. Heat curing at 110°C for 15-20 minutes in an exhausted oven provides the most effective surface treatment.

2. A master batch of Glassclad® 6C (PS216) in isopropanol or ethanol is desirable when large surfaces are to be treated and the acidic byproducts are difficult to handle. A 0.5 to 2% solution of Glassclad® 6C (PS216) in isopropanol is prepared in a well ventilated area. Hydrogen chloride fumes issue during this stage. Acidic character is reduced for subsequent surface treatment. Overtreatment results in a cloudy surface. The concentration of Glassclad® 6C (PS216) should be reduced to eliminate this effect.

Figure 28

Protective Hard Coatings

Glassclad® HT(PS220) is a high temperature modified phenylsiloxane resin which has a continuous use temperature exceeding 350°C. It is used both as a thin film coating and for the production of laminated structures. It has a tensile strength of 3,500 psi and a hardness of 120R (R=Rockwell). Parts are dipped or sprayed with undiluted resin and cured 20 to 30 minutes at 240°C.

PS220 = Glassclad® HT
20% solids in xylene.

Glassclad® EG (PS225) is a thermally stable resin which forms a moderately flexible film with excellent adhesion and low chloride content. It provides an oxidation and mechanical barrier for resistors and circuit boards. Part application is by spraying or dipping. Cure is 20 minutes at 220°C.

PS225 = Glassclad® EG
20 % solids in xylene.

Glassclad® RC (PS233) is a methylsilicone resin which forms a coating with high temperature (250°C) serviceability. Its high dielectric strength, thermal resistance and mechanical strength make it ideal as an electrical component and circuit board coating. Glassclad® RC reacts covalently with glass and siliceous surfaces to form a permanent bond. It has excellent abrasion resistance properties and can be applied to materials as a protective coating. It is typically applied by dipping or brushing followed by air dry and final cure at 150°C for one hour.

PS233 = Glassclad® RC
50% solution in isopropanol

Figure 29

Silicon Dioxide (SiO_2) Sources

Glassclad® TF(PS235) is employed as a source of thick film (0.2-0.4 micron) coatings of silicon dioxide. Glassclad® TF (PS235) is a polymeric precursor of silicon dioxide. Silica formation begins at 110-120°C and is complete by 220°C. The polymer converts to approximately 36% SiO_2.

Applications for Glassclad® TF include dielectric layers, abrasion resistant coatings, and translucent films.

Glassclad® TF (PS235) can be applied without solvent or in chlorinated hydrocarbon and ester vehicles. Specific gravity is 1.13. It is 100% solids.

PS235 = Glassclad® TF

Glassclad® SO (PS222) is specifically formulated for the deposition of silicon dioxide. Undoped films are useful as protective films and as getter layers; doped silicon oxide film as getter layers. Cure is accomplished in two steps:1) 2-5 mins at 200°C; 2) final cure at 500°C.   S.G=0.84

PS222 = Glassclad® SO

Figure 30

PR6772 Hydrophobic Masonry Coating

Glassclad® MS (PR6772) is an alkaline resinous silicone solution that reacts with siliceous substrates including stone and masonry.

Uses

Masonry - renders surface water repellent.
Ceramics - increases green strength and green storage life.

Description

Glassclad® MS **(PR6772)** is a 30% sodium methyl siliconate solution in water.

Application

Glassclad® MS **(PR6772)** is diluted 10:1 with water then sprayed or brushed onto surfaces. The solution should be air-dried 24 to 36 hours prior to immersion in water.

Caution

Avoid skin contact, Glassclad® MS **(PR6772)** is alkaline.

PR6772 = Glassclad® MS

Another class of silicones which has found extensive use as photocopy releasing agents or additives for epoxies are the amino functional silicones. The basic structure of a typical amino terminated silicone is illustrated in Figure 31. Typical cure chemistries when used as additives in urethanes or epoxy formulations involve reaction of the amine with an isocyanate group in a curing urethane polymer, or the three membered epoxy ring in a curing epoxy resin. A typical reaction with the isocyanate group is illustrated in Figure 32. Silicone additives impart greater flexibility and lower glass transition temperatures to epoxy and urethane resins.

Figure 31

Aminofunctional Silicones

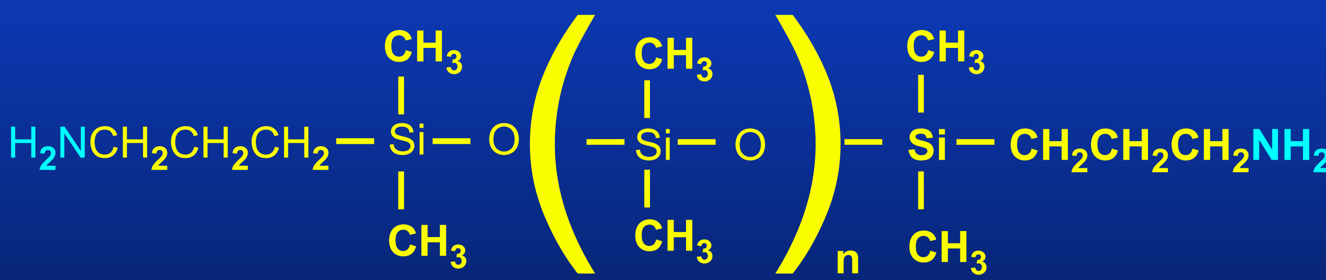


Figure 32

Reactions of Amino Functional Silicones

Aminopropyl-terminated siloxanes are used to form a variety of block copolymers including polyamides, polyurethanes and polycarbonates. A typical reaction is shown below:

The silicone is employed to produce silicone modified epoxy resins. It also has improved adhesion to both painted and unpainted metal surfaces allowing use in corrosion resistant coatings and polishes.

Amino functional silicones are reactive additives to both epoxy and urethane formulations.

Aminoalkyl functional T-structure polymers demonstrate the same range of chemical reactivity as the aminopropyl-terminated siloxanes (reactivity with epoxides, isocyanates, carboxylic acids, etc.). The branched polymers are more likely to find application as formulative additives rather than as prepolymers. Typical applications include detergent polishes, leather finishes, and internal mold releases for nylon.

The UCT product line of aminosilicones is summarized in Table 24. PS509-PS513 are difunctional in primary amine at the polymer terminals. These silicones are useful as photocopy releasing agents or chain extending additives for commercial epoxies or urethanes. PS806-PS810 are copolymeric materials with varying molar amounts of ethylenediamine functionality in the backbone. The PS811-PS820 series is similar except that the amino groups are all primary aminopropyl. All of the PS806-PS820 series are curable with atmospheric oxygen to inert films. The films have excellent adhesion to steel and have found application as syringe needle coatings.

Table 24 Amino Functional Silicones

Product # [CAS #]	Description	Viscosity	Specific Gravity	Mole% Comonomer	100 g	1 Kg
Polydimethylsiloxane, Aminopropyldimethyl Terminated						
PS509		10-15	0.98		X	X
PS510 [106214-84-0]		50	0.98		X	X
PS511		100-120	0.98		X	X
PS512		1000	0.98		X	X
PS513		2000	0.98		X	X
Polydimethylsiloxane, Amino Functional Copolymers COMONOMER = (Aminoethylaminopropyl) Methyl						
PS804		100	0.97	1	X	X
PS805		2500	0.97	2.5	X	X
PS806		50-90	0.96	3-5	X	X
PS807		50	0.97	4	X	X
PS808		100	0.97	4	X	X
PS809		250	0.97	10	X	X
PS810		2500	0.97	10	X	X
COMONOMER = (Aminopropyl) Methyl						
PS811		12500		2.5	X	X

Table 24 Amino functional silicones (contd)

Product # [CAS #]	Description	Viscosity	Specific Gravity	Mole% Comonomer	100 g	1 Kg
COMONOMER = (Aminopropyl) Methyl						
PS811.5		35000		2.5	X	X
PS812		70-110	0.98	3-5	X	X
PS813		100-200		3-5	X	X
PS814		250		4	X	X
PS815		750		4	X	X
PS816		2500		4	X	X
PS817		5000		4	X	X
PS818		7500		4	X	X
PS819		12500	0.974	4	X	X
PS820		750	0.97	10	X	X
Amino Functional T-Structure						
PS401 [71750-80-6		200-600	0.97		X	X

Amino functional T-structures containing both alkoxy and amino functionality are one part moisture curable systems. They self catalyze by the amino groups first promoting hydrolysis to silanols, then also catalyzing crosslinking of these silanols. PS401 is a representative and popular member of this series, represented in Figure 33.

Other potential chemistries applicable to aminosilicones are incorporation into polyester or urethane compositions as illustrated in Figure 34.

The only drawback to use of aminosilicones is phase incompatibility with many industrial resins. In many cases emulsified mixes still react on heating and impart the desired softening to the resin.

Figure 33

PS401

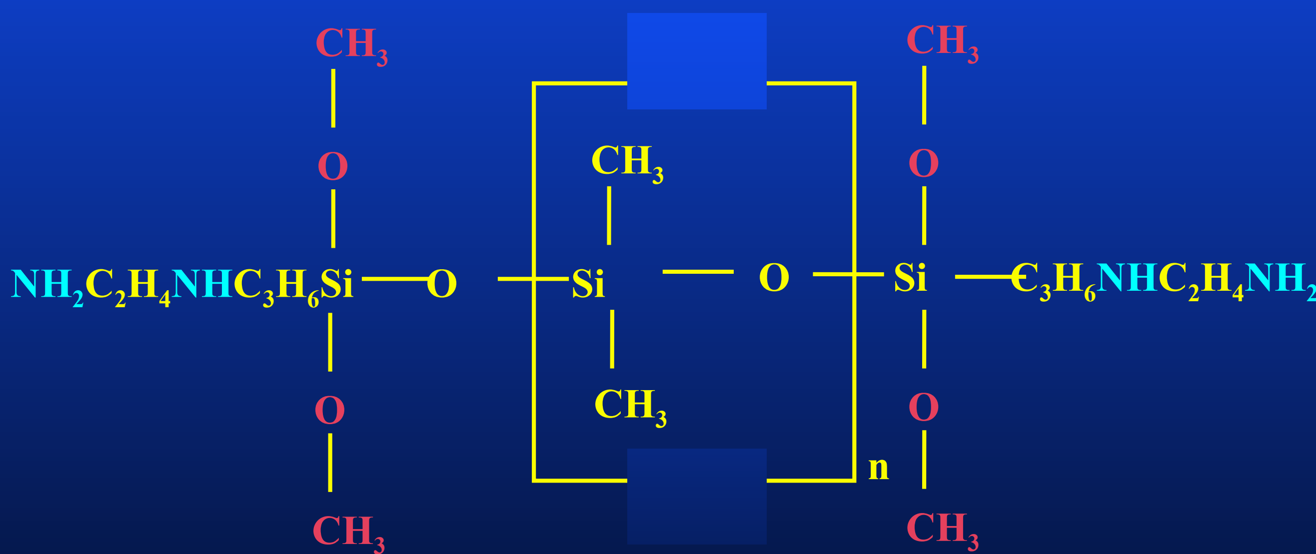
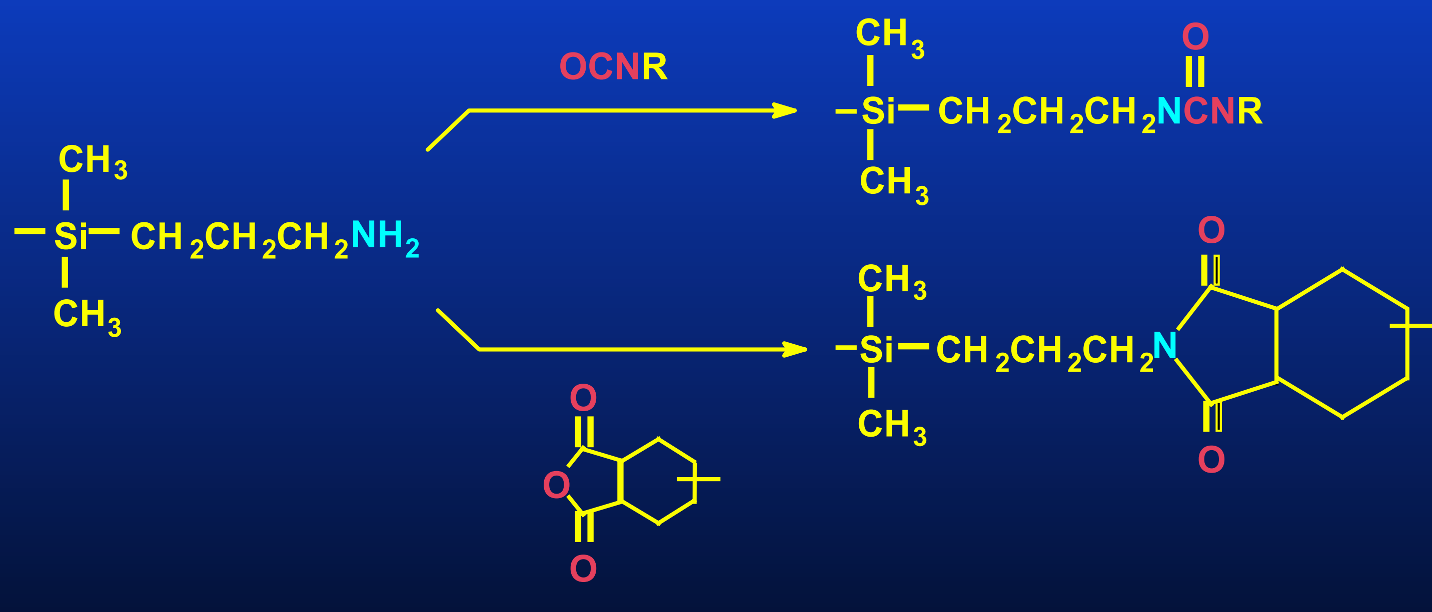


Figure 34 Reactions of Aminosilicones

$SiCH_2CH_2CH_2NH_2$



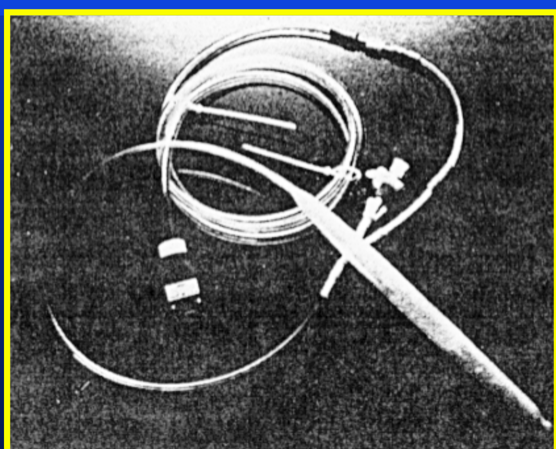
Amino functional silicones have also found utility in the Rimplast® line of thermoplastic interpenetrating network (IPN) composites. Typical physical properties for these composites are listed in Table 25. Figure 25, although now dated, depicts high performance medical devices that have in the past been fabricated with these materials.

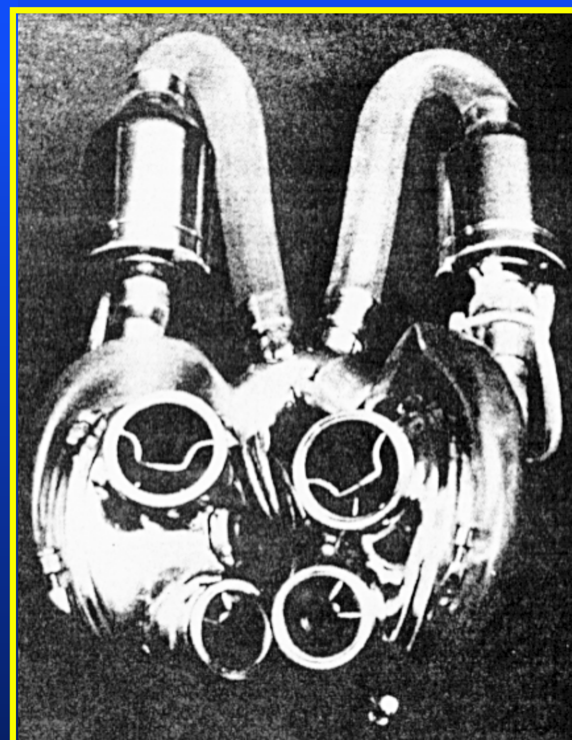
Table 25
Properties of Rimplast silicone-thermoplastic IPNs

Property	Aliphatic urethane	Nylon 12	Nylon 6/6	SEBS
Tensile strength, MPa	34.5	35.9	69.6	8.3
Elongation, %	350	20	5	1200
Flexural strength, MPa	-	55	96.5	400
Flexural modulus, MPa	-	1380	2482	3.5 at 300%
Tear strength, kN/m	>60	-	-	25

Figure 35

Intra-aortic balloon pumps, requiring mechanical and fatigue strength along with physiological inertness, are fabricated from silicone-urethanes (courtesy Kontron Cardiovascular)





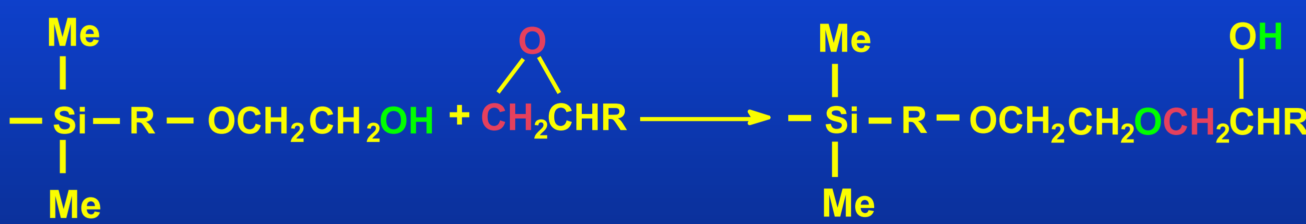
This artificial heart, a totally implantable, hydraulically driven total cardiac prosthesis, is constructed with silicone-urethanes (courtesy R. Ward, Thoratec Laboratories)

Other silicone functionalities available in a more limited selection are carbinol (C-OH terminated) and carboxy (COOH terminated) materials. Carbinol silicones are very reactive additives in epoxy or urethane resins while carboxy silicones can react directly into a polyester polymer matrix. Phase incompatibility again limits additive amounts, but low addition levels or emulsification still can allow usage.

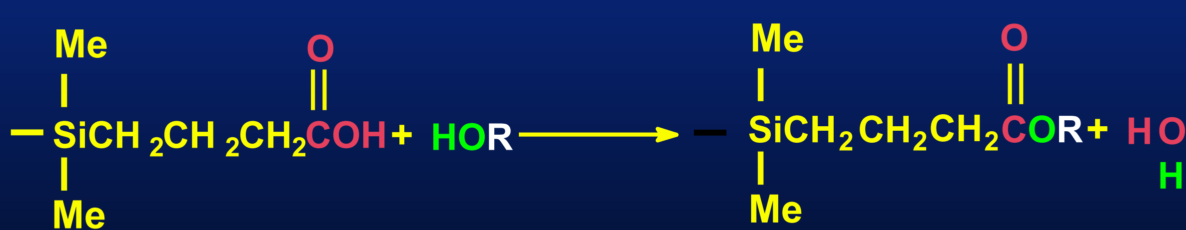
The UCT offerings include PS555 (carbinol terminated) and PS563 (carboxy terminated) silicones. Contact UCT technical support for more information. The chemical reactions described above are shown in Figure 36.

Figure 36

Miscellaneous Functionalities



Carbinol Terminated



Carboxypropyl Dimethyl Terminated

The wide range of curable silicone functionality available is summarized in Figure 37. Certain functionalities such as mercapto have not been covered here due to space limitations. See the UCT product catalog or contact technical service for more informationon these silicone materials.

Figure 37
Functional Silicone Reactivity Guide

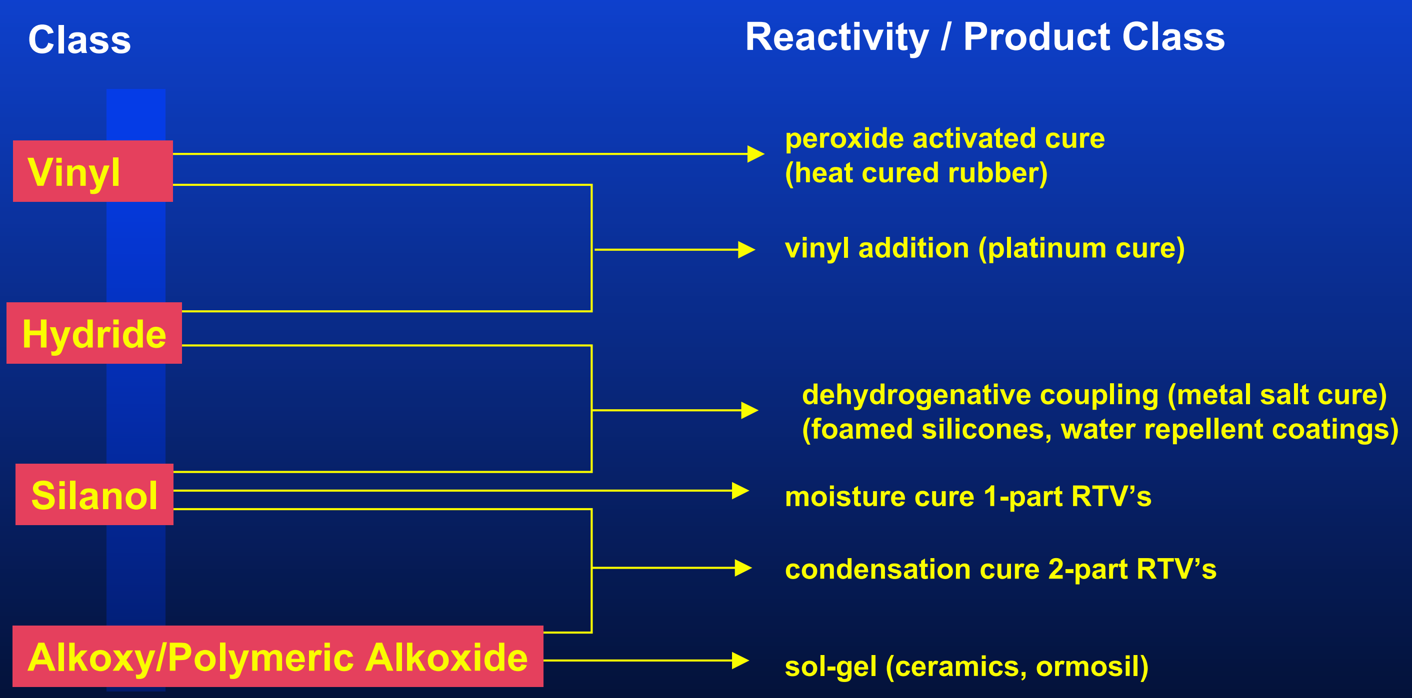
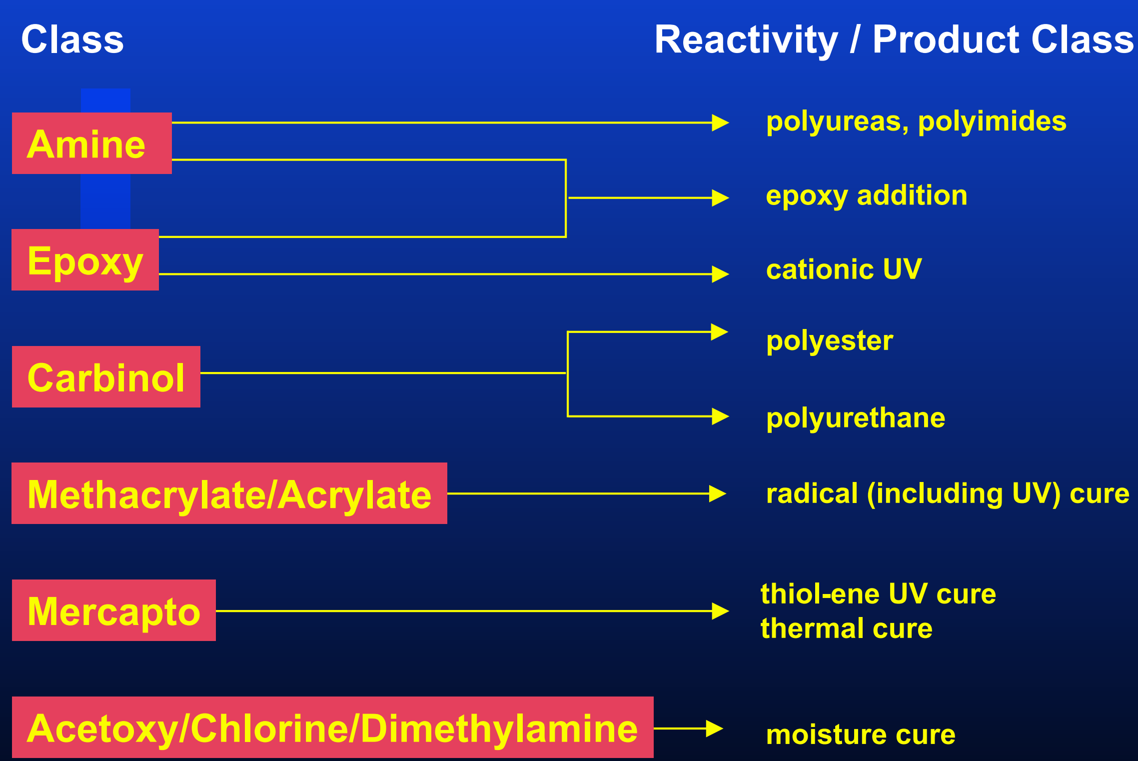


Figure 37

Functional Silicone Reactivity Guide (Contd)



In summary, this article has attempted to give the scientist, industrial chemist and formulator a basic understanding of silicone functionality, curing chemistries, catalysts and formulation techniques.

The overview has used the extensive line of United Chemical Technologies silicones as reference points. UCT is a major manufacturer of the complete line of curable and non curable silicone fluids, gums, T-resins and curing catalysts. Contact UCT at 800-541-0559 for ordering, pricing and technical support on these materials.

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