5. Silicones in the Textile Industries

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In the textile industries, silicones are used in all stages of the process, on the fiber during production, on the fabric and/or directly on the finished goods. Silicones are applied from different delivery systems to provide various benefits like lubrication, softening, foam control or hydrophobic coatings.

Silicones in Fiber Production

Higher production rates oblige artificial fiber producers to continuously search for more efficient materials to lubricate fiber and spinneret and to avoid excessive overheating due to friction during high-speed manufacturing [1-2].

Because of properties such as heat stability and good lubrication, silicones can provide a reduction of the dynamic coefficient of friction, reducing the risk of fiber melting and breakage during production. Low viscosity polydimethylsiloxane (PDMS) is generally used in combination with solid particles (e.g., those made of magnesium stearate), as this also reduces the static coefficient of friction.

During the manufacturing of artificial fibers, PDMS can also be used as a lubricant to avoid adhesion of the thermoplastic fiber material to the spinneret, which would cause unstable production and cleaning issues.

Silicones can also be used to achieve low coefficients of friction between the fibers themselves. Generally a silanol-functional silicone, a reactive cross-linker (e.g., a silane or an epoxy-functional silicone) and a condensation catalyst are formulated together into a coating to encapsulate the fiber. Such treated fibers will lead to high thermal insulating textiles and filling material for fiberfill systems as found in duvets or overalls.

Cleaning silicones used during fiber production can sometimes be an issue. To minimize this, lubricant silicone polyethers have been developed with higher hydrophilicity and easier to clean.

Silicone as Fabric Softeners

Once produced, fibers can be treated with silicones to impart initial softness to the textiles made from these fibers. Softening is considered to come from the siloxane backbone flexibility and the freedom of rotation along the Si-O bonds. This allows exposure of the low interacting methyl groups, reducing fiber-to-fiber interactions.

To enhance durability through multiple wash cycles, some methyl groups can be replaced on the silicone polymer by other functional groups to increase the silicone softener attraction to, and interaction with, the fibers to be treated.

In this respect, amino-functional groups like $-CH_2-CH_2-CH_2-NH-CH_2-CH_2-NH_2$ are particularly popular for increasing physical adsorption and providing better softening properties.

During the application generally done in acidic conditions, these amino groups are quaternized to cationic species (-NH_3^+), which have a stronger attraction for the negatively charged fabric. This is particularly true for cotton-based fabrics, which carry anionic charges on their surface. This improves deposition, performance and durability of the softener coating.

These amino-functional silicones are best delivered to the textile surface under the form of a microemulsion. This offers a number of advantages if compared to macroemulsions. The quality of a microemulsion is easily controlled: visual appearance and good clarity ensures small particle size and long shelf life without the need of any sophisticated particle size testing equipment. Microemulsions have also excellent shelf stability and allow for higher dilutions with better shear stability.

On the other side, microemulsions are often formulated with high levels of surfactants, and these can affect the softness normally provided by the silicones. Such surfactants must therefore be carefully selected.

Amino-functional silicones can also yellow upon aging via chromophores generated on the amino group, in particular from linkages between amino groups. Modifying the amino groups with adequate blocking groups overcomes this problem, offering formulators non-yellowing fiber softeners [3].

Silicones will inherently increase the hydrophobic nature of any treated fabric, a feature not desired in some applications; for example, as it results in poor water absorbency on towels. Trends here are to design amino-functional silicone polymers with higher hydrophilicity [4].

Silicones as Process Aids

As in many other processing industries, silicones are widely used in the textile industries as antifoams. Silicone antifoams can operate in a wide range of temperature and pH conditions and can manage highly foaming media. Their compositions can be complex, but there are some formulation rules well known to the silicone industry for producing highly efficient antifoams for many different applications and in various foaming media. Conditions are so diverse that a “universal” antifoam has not yet been formulated.

In the textile industry, the main use of antifoams is during the scouring step, which is the cleaning of raw fibers before further processing or during the finishing step. Both of these are high foaming steps, as surfactants are extensively used to clean, or in the formulation of fabric softener emulsions. As the industry is also trying to minimize the amounts of water used in such process steps, this results in even higher surfactant concentrations.

The greater use of high-shear jet machines requires antifoam emulsions that are stable under very high shear to avoid undesired localized deposition of silicone polymers. Such deposition can result in staining problems.

Other process aids include:

- Needle lubricants or PDMS fluids to avoid needle overheating during sewing
- Silicone polyethers to facilitate the wetting of difficult substrates that contain high levels of organic fats in their structures

Silicones as Hydrophobic Agents
Silicones provide very hydrophobic finishes on various fabrics. This treatment involves full fabric impregnation from silicone-in-water emulsions, usually via a padding process.

The silicone phase of such emulsions contains SiH-functional polymers because of their reactivity towards the fabric, but also because these polymers can cross-link with each other into a hydrophobic and durable fabric treatment, particularly if formulated with a suitable catalyst [5].

Silicones in Fabric Coatings
Silicones are not limited to fiber processing or finishing. Their use extends as coatings in diverse applications, from fashion wear such as women's stockings to technically demanding air bags. Applications here call for substantially thicker coatings, with typical coating weights up to 10 to 800 g/m^2.

These applications are based on cross-linked silicone polymers or elastomers, which can be formulated into crystal-clear coatings that can be either soft and flexible or hard and rigid. All such coatings have very similar compositions and share common raw materials for up to 70% of their formulation. They perform well over a wide range of temperatures and with better thermal stability characteristics than organics.

Apart from one-part RTV (Room Temperature Vulcanisable) elastomer used in women's stockings, liquid silicone rubbers (LSRs) are today the preferred material for such fabric coatings because of their ease of use and rapid cure when exposed to elevated temperatures. Cross-linking in these elastomers is achieved by the addition of SiH functional polymers to SiVi functional polymers using a platinum catalyst.

These LSRs, as other silicone elastomers, contain fume silica, as such fillers dramatically improve mechanical properties. However, compared to other silicone elastomers with high mechanical properties such as high consistency rubbers, LSRs can be metered/mixed with pumps and easily dispensed as coatings on various fabrics [6].

Silicone coatings remain flexible even at very low temperatures, typically -100 ºC. Service life has been reported as 30,000 h at 150 ºC and 10,000 h at 200 ºC in air. When needed, additives such as cerium or iron oxides can used to further improve heat stability [7].

Compared to many organic elastomers, silicones do not contain organic plasticizers. They are therefore not prone to plasticizer migration problems or embrittlement due to plasticizer evaporation or degradation.

Other properties make LSRs desirable as coating materials (see Table 1):

- Solventless compositions with long bath life at room temperature and low viscosity, (15,000 mPa.s) and therefore easy to process in coating operations using methods like "knife over roller" or "knife over air"
- Fast cure at elevated temperatures (e.g., 1 to 2 minutes at 160 ºC)
- Good adhesion to various coated substrates like glass, polyamide or polyester fabrics
- Good visual appearance
- Adequate data to satisfy relevant regulatory requirements (e.g., food grade, skin contact).

Table 1. Typical Properties of LSRs Used in Fabric-Coating Applications

Mixed viscosity, *mPa.s*	15,000 - 200,000
Tensile strength, *MPa (psi)*	3.5 - 9.0 (500 - 1300)
Elongation at break, *%*	100 - 800
Tear strength, *kN/m (ppi)*	5 - 40 (28 - 230)
Hardness, *Durometer Shore A*	15 - 70

In many cases, the prime purpose of silicones in such fabric coatings is to provide some form of protection from exposure to high temperatures (as in conveyor belts), low temperatures (as with many outdoor goods) or exposure to stress over long periods of time (as in air bags or compensator bellows) (see Table 2). In such applications, silicones are more stable than other elastomers.

Table 2. Typical Applications and Key Properties of Silicone Elastomer Fabric Coatings

Coating type	***Application area***	***Key properties***
Soft coating	Hold-up stockings (RTV)	Ease to process Crystal clear Soft Non slip/high elongation
	Outdoor clothing and tents (LSR, RTV)	Adhesion Flexible Thermal stability Colorless Hydrophobicity
	Air bags (LSR)	Strength Adhesion Slip Stability at elevated temp.
Hard coating	Conveyor belt coating (LSR)	Adhesion Non slip/abrasion resistance Thermal stability Food grade
	Compensator bellow (LSR)	Adhesion Chemical/Thermal stability abrasion resistance
	Medical protective wear (LSR, RTV)	Hydrophobic Autoclavable Adhesion

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This article has been published in the chapter "Silicones in Industrial Applications" in *Inorganic Polymers*, an advanced research book by Nova Science Publishers (www.novapublishers.com); edited by Roger De Jaeger (Lab. de Spechtrochimie Infrarouge et Raman, Univ. des Sciences and Tecn. de Lille, France) and Mario Gleria (Inst. di Scienze e Tecn. Molecolari, Univ. di Padoa, Italy). Reproduced here with the permission of the publisher.