

When applying silicone coatings, it is essential to view the final product, not as a series of separate product processing steps and components, but as an integrated system.

The functional performance of the silicone coating is affected not only by the physical properties of the silicone, but also by the application process and the performance characteristics required by the final product. The impact on the success of the final application could be significant if the effect of the process, in combination with the properties of the silicone coating, is not considered.

Physical property influences associated with various substrates (eg. nylon, polyethylene, polyester or glass-fibre) must also be studied. Equally important is fibre denier and fabric tightness or density, which is a function of sett for woven fabric and basis weight for nonwovens. Careful consideration must be given as to how the physical properties of the silicone will interact with the substrate's surface to determine whether the performance observed in the final product is a result of film formation versus coating penetration.

This article discusses how optimization of the coating process can help balance component properties, end-product attributes (such as barrier protection) and economic considerations. It also introduces a new silicone technology that enables the user to "dial in" the right balance of properties for the silicone application.

Table 1. Typical silicone coating physical properties.

Physical Properties	Value Range	Performance Attributes
Durometer	15-70 Shore A	Higher durometer for toughness Lower durometer for flexibility
Tear Strength	13-40 kN/m	Higher tear for durability Lower tear for economics
Elongation	150-750%	Higher elongation for flexibility Lower elongation for stability
Cure Rate	18-45 sec T-90 at 193°C (380°F)	Faster cure for economics Slower cure for surface characteristics
Rheology	Shear Thinning to Non-Newtonian	Shear thinning for film formation Non-Newtonian for coating consistency
Tensile Strength	2-8 MPa	Higher tensile for toughness Lower tensile for flexibility
Viscosity	15,000-180,000 cP	Higher viscosity for film formation Lower viscosity for penetration



Achieving Functional Excellence with Silicone Coatings

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Physical Property Considerations for Silicone Coatings

The physical properties and resulting performance attributes of silicone fabric coatings vary, usually within a certain range. Different property combinations can be achieved through crosslinker and filler changes. This will, however, require tradeoffs in either physical properties

and/or economics. For example, while it is possible to formulate a coating that delivers high tear strength, high tensile strength and high elongation, this usually comes at the expense of lower durometer, higher viscosity and greater raw-material cost.

Modifying the coating to achieve specific performance requirements

Achieving specific performance properties, such as elongation, tear strength, tensile strength and seam comb strip, may require modification of the silicone coating formulation. By

working together, the fabric coater and the coating formulator can achieve the best balance between property requirements and system economics.

Additives can be used to improve flame resistance and thermal stability, but use of these can significantly raise a formulation's cost. Therefore, while it may be possible to formulate a high-performance coating that meets the end-product requirements of most coated-fabric applications, from an economic standpoint, this is not necessarily the best solution. For example, surface attributes such as film formation versus penetration, can be achieved in a much more cost-effective manner by modifying the application process instead. This enables the coating to achieve either film formation or penetration, which, in turn, impacts barrier properties such as impermeability and fabric cohesive strength.

Silicone coating properties that affect processing are viscosity, cure rate, specific gravity and, most importantly, rheology. While most silicones can be categorized as shear thinning, the degree of shear thinning can determine whether a silicone coats more consistently at a high line speed or at a lower line speed. Fillers have the greatest impact on coating rheology. Fillers such as

silica, resins and quartz are commonly used to impart strength, elongation and, in some cases, to lower the coefficient of friction.

Figure 1 shows how the addition of a filler can change the rheology of a silicone coating. In this case, the amount of filler in the silicone was reduced by 15 percent, which reduced the initial viscosity. By plotting viscosity versus shear rate, it is apparent that one silicone is more shear thinning than the other at low shear rate.

How coating properties impact the coating process

There are many ways to apply silicone coatings, and the method of application selected can directly impact the ability to achieve desired surface characteristics. The most prominent of these characteristics is the degree of coating penetration versus film formation. Both are affected by factors associated with the coating and the parameters at the coating head. Penetration is achieved either by lowering the viscosity and thixotropic nature of the coating and/or

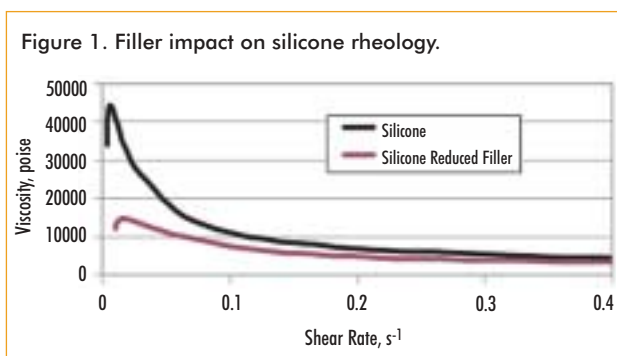
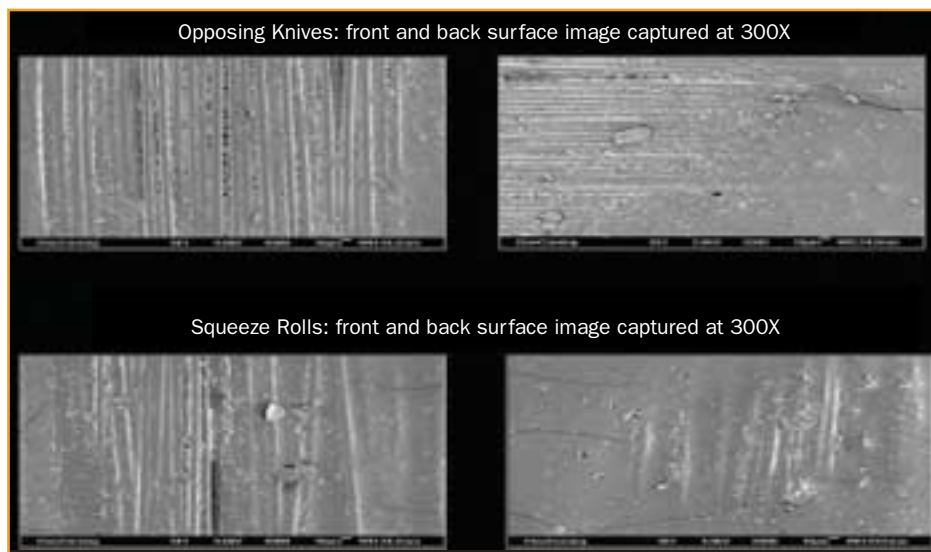


Table 2. Coating process examples.

Coating Method	Characteristics of Appropriate Coatings	Outcomes
Opposing Knives (See Figure 2)	Low to medium viscosity Shear thinning Fast cure	Typically for penetration Good coating line economics Low coefficient of friction
Squeeze Rolls (See Figure 2)	Low to medium viscosity Shear thinning Fast cure	Typically for film formation Film dependent on pressure Higher coated surface contact area
Knife Over Roll (See Figure 4)	Medium to high viscosity High add-on High line speeds	Typically for film formation Film dependent on blade and angle Higher coated surface contact area
Knife Over Air (See Figures 3 and 5)	Low to medium viscosity Low add-on High line speeds	Typically for penetration Film dependent on blade type Low coefficient of friction
Reverse Roll Coating (See Figure 5)	Medium viscosity Shear thinning Fast cure	Excellent film formation Greater uniformity of add-on Flexible to substrate variability

Figure 2. Effect of opposing knives vs. squeeze rolls on 0.48-kg (17-oz) coated glass-fibre fabric.



application of the coating via a blade that drives the coating into the substrate.

Penetration is typically balanced by line tension, which is influenced by blade type and the profile imparted by the blade angle, as well as by the substrate. Higher-penetration coatings are usually characterized by low add-on weight,

which is achieved by using a lower-viscosity material on a low-denier or lower-sett fabric (although this is not always the case).

Cure profile also impacts the film formation and adhesion characteristics to the coated fabric. Cure profile will be addressed following a discussion of silicone coating selection and application methods.

Coating Methods

Examples of commonly used silicone coating methods, characteristics of appropriate coatings and resulting outcomes are shown in Table 2.

Use of opposing knives versus squeeze rolls

SEM photos comparing the surface characteristics of fabrics coated with opposing knives versus squeeze rolls reveal the impact of the coating process on film

formation versus penetration. The 300X SEM image in Figure 2 compares two identical fabric samples coated front-to-back with the same coating applied at the same coat weight. It shows the scraping and penetration typical of opposing blades versus the film-forming properties achieved using squeeze rolls. With squeeze rolls, more of the fibres are filled and fewer exposed. The tactile features of the coated fabric also indicate a higher coefficient of friction with squeeze rolls. This is due to the more highly coated surface area.

Entrapped air bubbles are common to both methods. Although bubbles can be a function of viscosity or cure rate, they are largely due to entrapped air in the fabric and that both sides of the fabric are coated at the same time.

Fabric constructions suitable for these coating methods include high-basis-weight nonwovens or high-sett woven fabrics where high coat weight is desired for thermal or barrier protection. Needs for fabric penetration versus film formation dictate the coating method – opposing knives for penetration and squeeze rolls for film formation.

Typical product applications include pipe wrap, conveyor belts, welding blankets, architectural applications and expansion joints.

Traditional coating by knife blade

Film formation by knife blade on traditional coating lines where the fabric is fed over rollers under a knife is even more dependent on silicone properties and

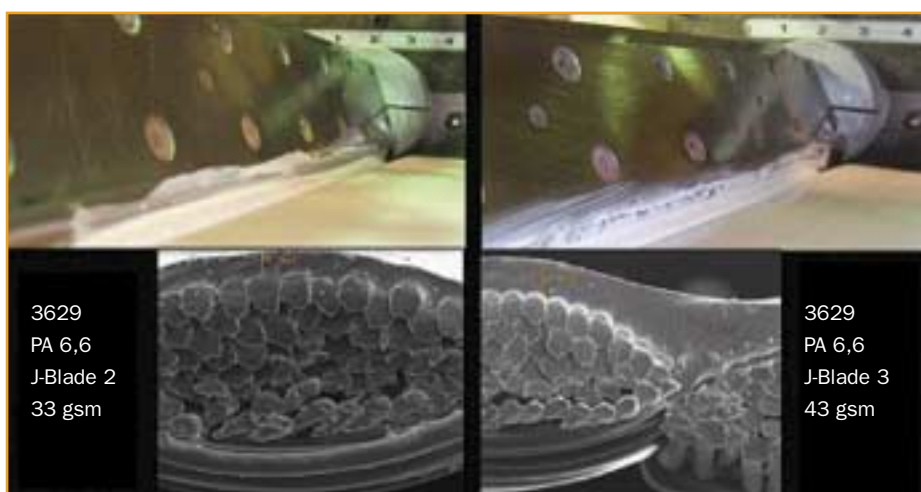


Figure 3. Impact of blade angle on coat weight.

balancing them with the application method at the knife.

Parameters that influence film formation with knife blade coating include blade type, coating arrangement (which addresses blade position relative to the table or roll), blade angle relative to the fabric and, of course, the gap. Other factors that affect the end result are fabric tension in the warp and fill direction, fabric weave density and line speed. For the purpose of this discussion, we will focus on the impact of the blade.

The blade type and coating arrangement have the most important impact on film formation. A straight spanning blade or thin knife blade used in a knife-over-air configuration can scrape the surface so that the coating is deposited only in the valleys of the weave. Alternatively, a J-blade or curved edge set at the right angle can deliver a

Table 3. Impact of various silicone properties.

Coating Reference	Add-On, gsm	Viscosity, cP
3730	142	145,000
3600	62	70,000
9252-500P	59	60,000
3650	122	70,000
3625	67	30,000

Table 4. Impact of blade angle on coat weight.

Sample #	Coating Reference	Blade Angle	Blade Position	Coater Setup	Add-On, gsm
1	3629	-2	2.00"	J-Blade	33
2	3629	-3	2.00"	J-Blade	43

continuous film at the surface of the fabric (Figure 3).

When the J-blade is angled to allow more bevel onto the blade-to-fabric interface, the result is a film at the surface of the woven fabric. The viscosity and rheology of the silicone also play a very important role in film-formation success as the higher viscosity and more shear-thinning the silicone is, the more responsive the coating process.

One way to determine the impact of various silicone properties is to coat several of them in sequence while holding the coating parameters constant. Examining the add-on of various silicones is one indicator of their difference. The results in Table 3 were obtained by coating 420 denier, polyamide 6,6 woven fabric using a J-blade set at 90 degrees.

The obvious differences in application coating weights shown in Table 3 do not relate to viscosity alone. The 3730, 3600 and 9252-500P coatings are silica-reinforced at various levels and the add-on levels follow, not only by loading level of silica, but also by the corresponding viscosity range. The silica addition to a polymer base increases the shear characteristics as evidenced in Figure 1. The 3650 and 3625 coatings contain a similar resin polymer type but differ in filler content. As you can see, the rheological properties

differ, as do the add-on levels.

A similar exercise that demonstrates the impact of blade angle on coat weight and surface characteristics is shown in Figure 3 where the silicone (DC 3629) and coating parameters remained constant, but the blade angle was changed. The values in Table 4 are the result of this experiment and indicate that using the same polyamide 6,6 fabric, the coat weight increased from 33 to 43 gsm when the blade angle was changed from -2 to -3.

The effect of various parameter and physical property changes can also be demonstrated using traditional knife blade coating methods on nonwovens. SEM photos (Figure 4) indicate that, on 145 gsm basis-weight nonwovens, lower-viscosity coating materials deliver better penetration than higher-viscosity materials.

While that is not surprising, the use of two different silicones with varying rheological properties produced very different results at the coated surface. Higher-viscosity, thixotropic materials form a better film at the surface. However, the adjustment of the blade angle can create pinholes that make the film permeable.

This type of coating method is usually used in industrial applications to coat high-basis-weight nonwovens and high-sett woven fabrics where high coat weight is desired with a tighter tolerance on coat weight across the web than can be achieved using opposing knives or squeeze rolls. This coating method expands the potential of nonwovens in a woven market by providing uncharacteristic strength and elongation, typically seen as weak points in nonwovens.

Typical product applications include building wrap, bed liners, protective barriers, roof liners and assorted architectural applications.

Reverse roll coating

Using a reverse roll process for coating woven fabric ensures optimal film formation every time. This process is sensitive to the rheological properties of the silicone. However, with the right viscosity, reverse roll coating is the most efficient method of film delivery. This can be seen in Figure 5, a SEM comparison of a standard knife-coated fabric at 30 gsm using a J-blade versus a reverse roll coater at optimal settings. The result is more uniform film delivery at the fabric surface. This yields higher coated

surface contact area, which is excellent for both adhesion and barrier protection. The drawback to such a method is the incorporation of air bubbles and higher coefficient of friction due to film formation on the surface.

Optimization of the coating and the process: solvent-based versus 100 percent silicone solids

Solvent-based silicone delivery has many advantages associated with it, including penetration of fabric weave as well as exact control of silicone viscosity at the coating head. Cure profiles for these types of operations require staging of the ovens to allow the volatile organic compounds (VOCs) associated with the solvent to be driven off in such a manner that surface bubbling does not occur. The key drawback of solvent operations is that they not only require environmental recovery of the carrier media but also present risks associated with volatiles in the oven and the workplace.

Even silicone coatings contain some silicone volatiles. These typically range from 3-4 percent but are classified as

non-VOCs and are considered safe for workplace environs.

However, while processes that use 100 percent solids silicone coatings do eliminate the need for solvent recovery, a wider range of viscosity selections is required to achieve the desired result unless process application optimization is achieved.

For higher-viscosity materials, low coat weights can easily be achieved using knife-over-air or knife-over-gap application methods. However, blade selection is important. Choosing a thinner 1 – 2 mm blade edge rather than a curved or hooked edge blade will prevent “spitballing.”

Spitballing is a function of the pressure gradient of the shear thinning silicone at the knife. The shear rheology of the silicone combined with a specific blade profile and line speed can contribute to a condition where the silicone collects on the back of the blade. While blade selection is the most critical component, the line speed and silicone viscosity selection can overcome this. However, it

is application specific and requires work to optimize the process.

This phenomena usually occurs when higher coat weights are desired, and the knife-over-gap or knife-over-roll methods are utilized to deliver a uniform film on irregular surfaces. Once again, it is important to consider the blade profile as well as optimization of the blade angle in the successful application of silicone coating.

With aqueous systems, it is difficult to balance the removal of the water during the cure process with the ability to achieve a complete film without bubbles. The aqueous approach is also limited in its ability to deliver a range of properties through the adjustment of solids content alone.

In all silicone applications – solvent, nonsolvent or aqueous – the cure profile of the oven must be optimized to deliver the desired surface and product performance requirements.

Cure Profile

While silicone selection and application method control the physical property and surface characteristics of the coated product, the cure profile of the oven is extremely important and must not be overlooked. The manner in which a coated product cures dictates the success of the final product as much as the silicone selection itself.

Cure profile of the silicone and the corresponding cure profile in the oven have to be balanced. As mentioned earlier, solvent- and aqueous-based systems require time in the oven to release the lower-temperature volatile components, or bubbles become entrapped in the surface. Bubbles give rise to increased surface deformity and a decrease in coating surface integrity.

Even 100 percent solids delivery may require a ramping of the temperature to allow the surface to achieve the desired film formation as the silicone flows after passing under the knife at higher coat weights. Other impacts include the adhesion characteristics to the substrate as well as substrate-trapped moisture to be driven out.

The cure profile is a function of the catalyst level and the inhibitor level in the coating. The balance allows the coating to cure uniformly across the surface. Under ideal conditions, the coating cures from the substrate outwards through the silicone. Fan speeds, oven temperatures and rheology of the silicone dictate the cure profile in the oven as well as the performance and surface characteristics of the coated fabric.

A typical silicone cure profile is shown in Figure 6 and provides an example of the degree of cure achieved as a function of the percent torque measured during the curing process. The moving die rheometer is often used to indicate this cure profile and shows the percent cure as a function of time as the silicone is heated to a base temperature. In the example shown, the base temperature is 120°C (248°F) and is ramped.

Figure 4. Penetration versus film formation – knife-over-roll application of silicone coating onto 145-gsm basis weight nonwoven.

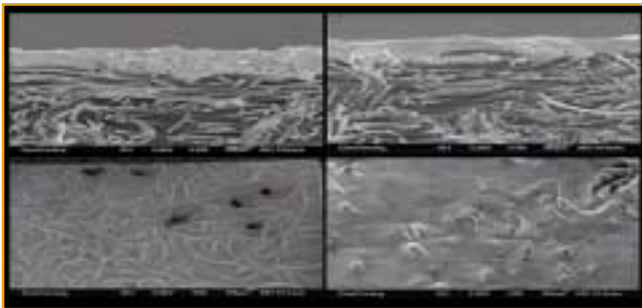
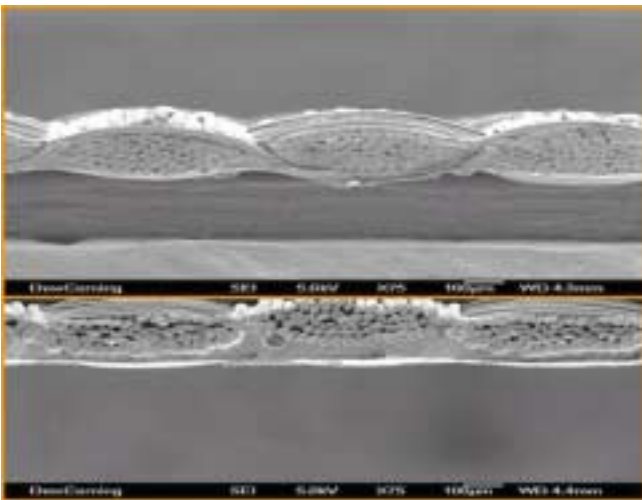


Figure 5. Knife-over-air versus reverse roll coating cross section – 30 gsm polyamide 6,6 (75X magnification).



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New Silicone-Modified Organic Technology for Fabric Coating

Dow Corning recently developed a novel terpolymer with the performance characteristics of polyisobutylene and the easy curability of silicone. This polymer has been emulsified and used as a formulation base with silicone and organic emulsions. Formulation properties can easily be tuned to deliver the desired balance of strength and flexibility. In general, these formulations have excellent barrier and dampening properties and a wide use-temperature range. They are readily applicable to glass-fibre and nylon substrates.

Through the application method, it is possible to further enhance the characteristics of the coating in its end-use application. If the coating forms a film on the surface of the fabric, the article will have superior gas retention and barrier properties. If the coating encapsulates the fibres of the fabric, the fabric will have an excellent feel.

Conclusion

To achieve functional excellence with silicone coatings, it is important to view the final product as an integrated system and to evaluate all of the factors that impact that system. These factors include the physical properties of the silicone coating, the application process and the performance requirements of the end product. While some performance properties can be achieved only through modification of

the coating formulation, others can be achieved much more economically by optimizing the coating process. There are many ways to apply silicone coatings. By understanding and maximizing the dynamic relationship between the substrate properties, coating properties, coating method and need for film-forming vs. penetration, it is possible to achieve excellent and consistently repeatable end-product performance results. ○

Figure 6. Cure profile using a moving die rheometer at a base temperature of 120°C (248°F).

