Effects of Silicone Treatments on the Dimensional Properties of Wool Fabric

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ABSTRACT

This study evaluates the effects of silicone softeners on the dimensional properties of wool fabric. Samples are treated with a simple pad-dry-cure process in an aqueous bath with aminofunctional and epoxyfunctional silicone softeners. The results indicate that dimensional stability and performance properties improve. The maximum effect is obtained with a 1:1 proportion of aminofunctional and epoxyfunctional silicone softeners, probably due to the synergistic effect of both softeners by the catalyzing reaction of the amine group. A hydrophilic epoxyfunctional silicone softener seems to increase fiber swelling and prevents the reduction of hygral expansion. As for the other properties, there are no significant variations when different kinds of epoxyfunctional silicone softeners are used. The most significant effect of the softeners is the surface coating, which reduces interfiber or interyarn friction.

Wool has excellent properties such as heat retention, elasticity, and moisture absorption. For these reasons, many consumers particularly appreciate fabric made from wool. However, wool fabrics have a dimensional instability induced by hygral expansion, which is a highly wool-specific phenomenon [7–8]. The recent trend toward lightweight wool fabrics in men's and women's suiting has increased the need for finishers to control problems of dimensional instability and wrinkling. Lighter fabrics are more prone to appearance problems, since they are less able to resist the forces responsible for the distortions [5, 16].

Fabric softeners, such as cationic or nonionic surfactants, are used in textile wet processing to improve fabric hand and mechanical properties. Adhesion of these softeners to the fiber surface is by a weak electrical attraction without any chemical linkage [10]. Durable silicone textile softeners confer additional performance properties on treated fabrics, such as improved wrinkle recovery and crease resistance and improved wear comfort [11, 17]. Thus, the use of durable silicone softeners has grown rapidly in the textile industry. Organofunctional silicone softeners containing organofunctional groups, such as amino, epoxy, and mercapto groups, have recently been developed. Conventional durable press finishing to improve wrinkle recovery results in a substantial loss of mechanical properties and hand [14, 20], but organofunctional silicone softeners are expected to improve dimensional stability as well as hand.

Thus, two kinds of organofunctional silicone softeners, aminofunctional and epoxyfunctional, of various compositions have been used on wool fabrics. Aminofunctional softeners have a higher reactivity than epoxyfunctional softeners, but are rarely used on wool due to yellowing problems [13]. As a means of modifying properties, various methods have been explored in other studies: for example, chemical modification by epoxidation or acylation and synthesis of new kinds of aminofunctional groups [13]. In this paper, we study the effects of aminofunctional and epoxyfunctional silicone softeners on the mechanical properties, dimensional stability, and wrinkle recovery of treated wool fabrics, using mixtures of various proportions. To discuss the influence of hydrophilicity on the dimensional stability of wool fabrics, we use two kinds of epoxyfunctional softeners.

Experimental

A scoured and crabbed plain-weave worsted fabric (150 g/m^2) with 62 ends/inch and 64 picks/inch was used for all experiments. The silicone softeners selected for testing included Dow Corning®108 emulsion as the aminofunctional silicone softener, and Dow Corning®4592 and hydrophilic Dow Corning®193 as epoxyfunctional silicone softeners. The chemical structure of these softeners is shown in Figure 1. Triton X-100 was used as a wetting agent. All other chemicals were reagent grade and used without further purification.

Fabric samples, 20 × 20 cm, were impregnated in an aqueous bath (bath ratio = 1:10) containing softeners and wetting agent for 2 minutes and padded 80 ± 3%

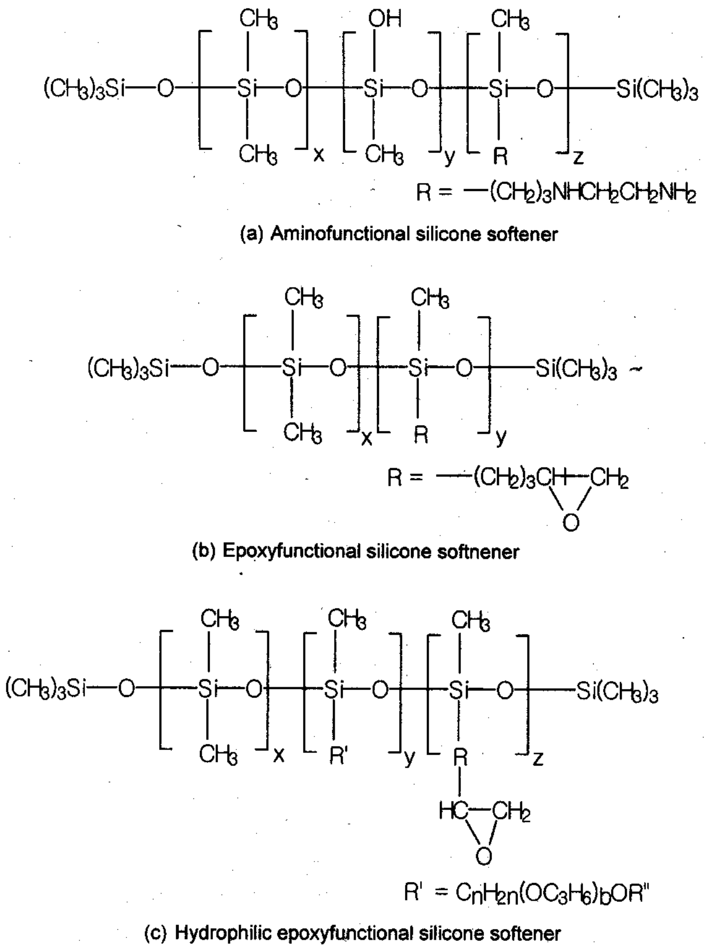

FIGURE 1. Chemical structure of silicone softeners.

through squeeze rollers under 1.5 kg/cm^2. A typical treatment bath formulation is shown in Table I. The padded samples were dried at 100°C for 3 minutes, followed by curing at 130°C for 3 minutes, then rinsed with fresh water, air-dried, and stored under standard conditions (21°C and 65%RH) before evaluating other properties.

TABLE I. Bath formulation.

Component	Concentration
Dow Corning®108 (aminofunctional silicone softener)	0–2% owf
Dow Corning®4592 (epoxyfunctional silicone softener)	0–2% owf
Dow Corning®193 (hydrophilic epoxyfunctional silicone softener)	0–2% owf
Triton X-100 (wetting agent)	0.2% owb

The KES-FB system was used to test the mechanical properties of fabric samples treated with silicone softeners under standard conditions, and measurements of sixteen mechanical properties were obtained for each sample. The primary hand value for men's summer suit was then evaluated. In order to investigate the effect of silicone softeners on dimensional stability, hygral expansion (HE) was measured according to Shaw [17].

Performance properties of the treated samples were evaluated using standard procedures, including wrinkle recovery angle (WRA) (AATCC 66-1978), breaking strength (BS) (ASTM D-1682-64), and Elmendorf tear strength (TS) (ASTM D-1424-81). Except for WRA, the others were tested in the warp direction; WRA was measured and reported as the sum of both warp and weft directions. Color differences of the samples were tested by the Mcbeth Color Eye (CIELAB10°). All measurements were repeated and averaged for the five samples with the same chemical treatment.

The surface morphology of the treated fabrics was evaluated with a scanning electron microscope (Jeol Ltd., JSM-35) after coating with gold in a vacuum. Surface analysis by electron spectroscopy for chemical analysis involved an ESCA MK II (LVG Scientific Ltd.) by irradiating a sample with monoenergetic soft x-rays and analyzing the energy emitted by the electrons. FTIR spectra of the treated fabrics were obtained from a Perkin Elmer spectrometer by attenuated total reflectance.

Results and Discussion

SURFACE ANALYSIS

The primary function of a fabric softener is to lubricate the surface by coating the fibers with a thin film layer [3]. Figure 2 shows these coated surfaces of silicone treated wool fibers as observed by the scanning electron microscope (SEM). While Figure 2a shows an untreated fiber with clear scale definition, Figure 2b indicates fiber coating and smoothing of the fiber's scale edges.

Consequently, Fourier transform infrared (FTIR) spectroscopy with attenuated total reflectance (ATR) has become the method of choice to study such chemical changes, since only the surface layers of the fibers are examined. Figure 3 shows FTIR spectra of wool, clearly revealing new absorption bands. The peak at 1270–1255 cm^{-1} is identified as the CH in the Si-CH$_3$ groups. The peaks at 1100–1000 cm^{-1} are presumed to be characteristic of Si-O bond in Si-O-Si [19]. Both peaks originate from silicone softeners.

We investigated the surface chemical composition of wool fabrics with ESCA (electron spectroscopy for chemical analysis), which is a useful technique for structural and chemical characterization of polymer surfaces. Figure 4 illustrates the x-ray induced photoelectric spectra of the wool surface. Fabrics treated with silicone soften-

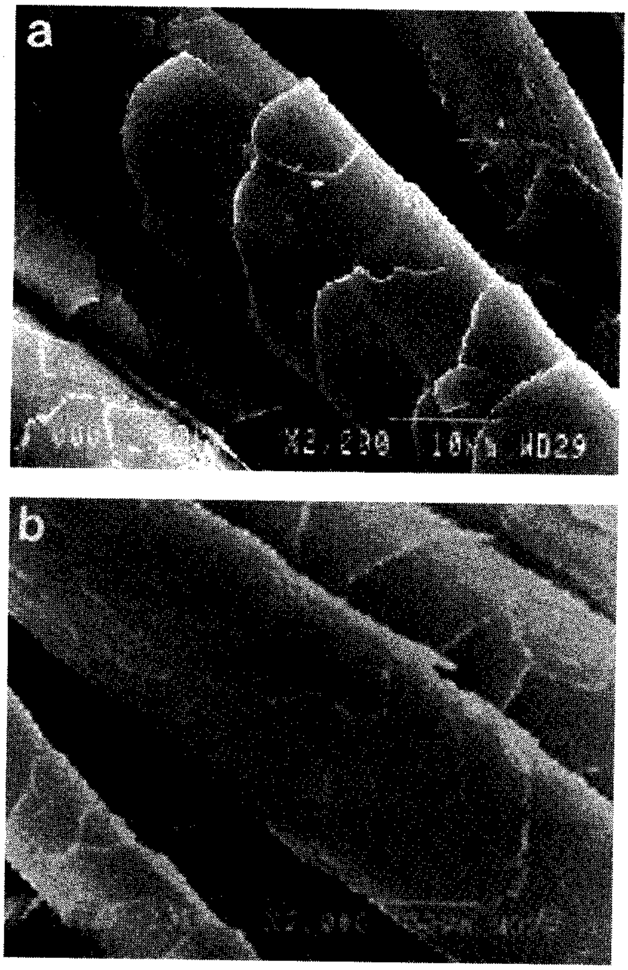

FIGURE 2. SEM photographs of wool fibers: (a) untreated, (b) silicone treated.

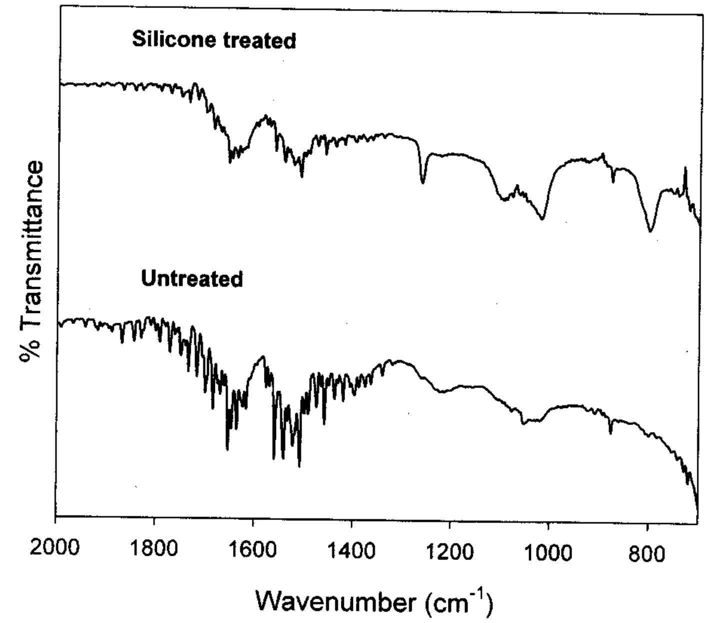

FIGURE 3. FTIR-ATR spectra of untreated and silicone treated wool.

ers show an absorption peak at 100–110 eV corresponding to the binding energy (BE) of an electron emitted from the silicone (2p) orbital [19]. Thus, these ESCA and ATR results indirectly indicate the reaction of the wool surface with silicone.

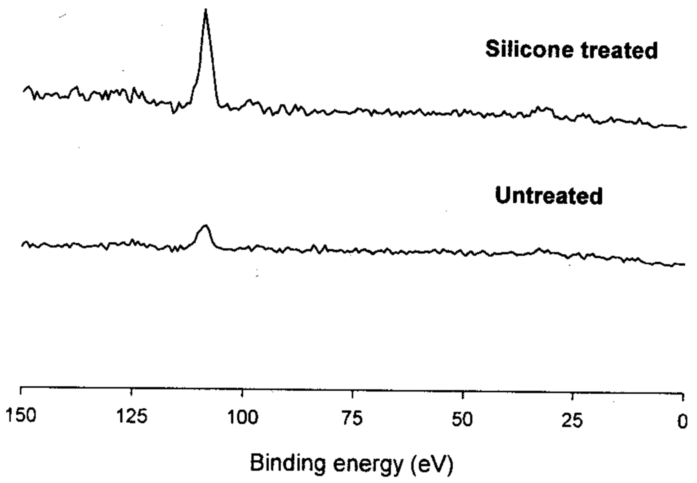

FIGURE 4. X-ray photoelectron spectra of wool surface.

MECHANICAL PROPERTIES

We examined the properties related to friction in terms of the role of silicone softeners. Figure 5 shows the changes in friction coefficients of wool fabrics treated with different softeners. When compared to an untreated sample, the friction coefficients of the treated samples decrease. Samples treated with a mixture of aminofunctional and epoxyfunctional silicone softeners at a 1:1 proportion particularly reveal minimum values. However, the trend remains unchanged with different epoxyfunctional silicone softeners, and is also present for other fabric mechanical properties. In Figures 6 and 7, which show shear hysteresis and bending hysteresis of wool fabric, the minimum values are for samples treated with a mixture of aminofunctional and epoxyfunctional silicone softeners at a 1:1 proportion. Epoxyfunctional silicone alone rarely reacts with the hydroxyl groups of wool fabric at temperatures below 140°C [9]. In the case of a mixture of epoxyfunctional and aminofunctional softeners, the amine group is expected to promote ring opening of the epoxy group, so there is an increase in the reaction [12]. The catalyzing reaction of the amine group may be responsible for the synergistic effect of mixtures of aminofunctional and epoxyfunctional silicone softeners. At the optimum mixture, these softeners further decrease interfiber or interyarn friction by acting as lubricants and influence friction-related mechanical properties.

DIMENSIONAL STABILITY

The effects of various concentrations of silicone softeners on the dimensional properties of wool fabrics are

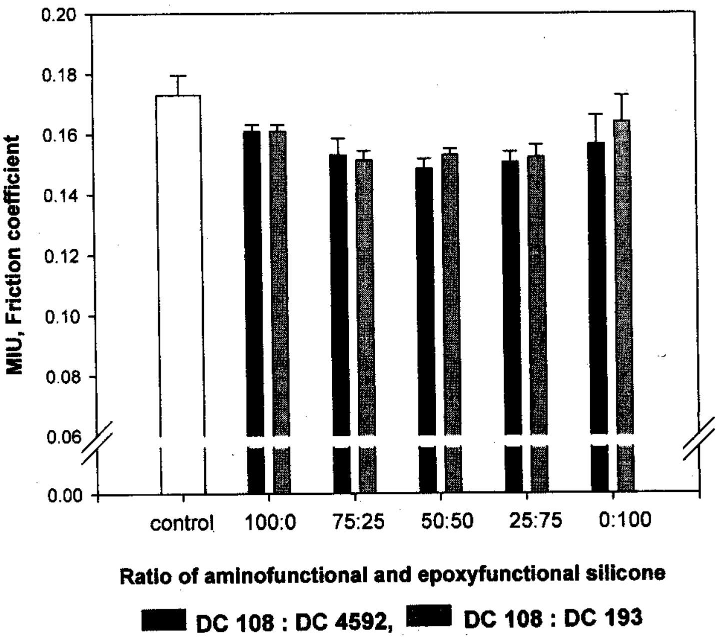

FIGURE 5. Changes in friction coefficients of silicone treated wool fabrics in the warp direction.

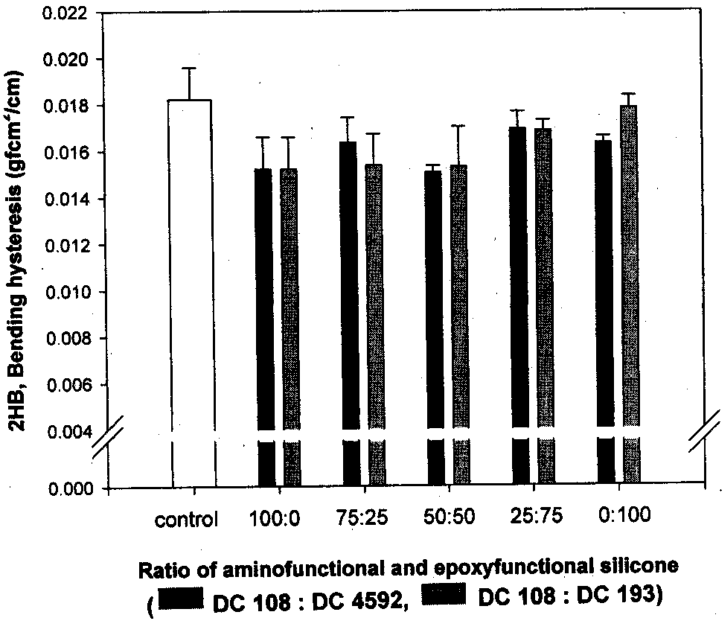

FIGURE 7. Changes in bending hysteresis of silicone treated wool fabrics in the warp direction.

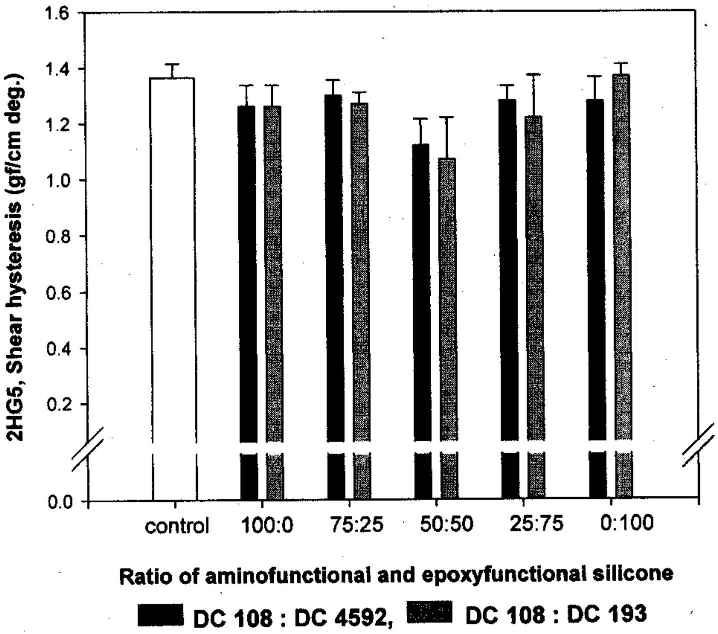

FIGURE 6. Changes in shear hysteresis of silicone treated wool fabrics in the warp direction.

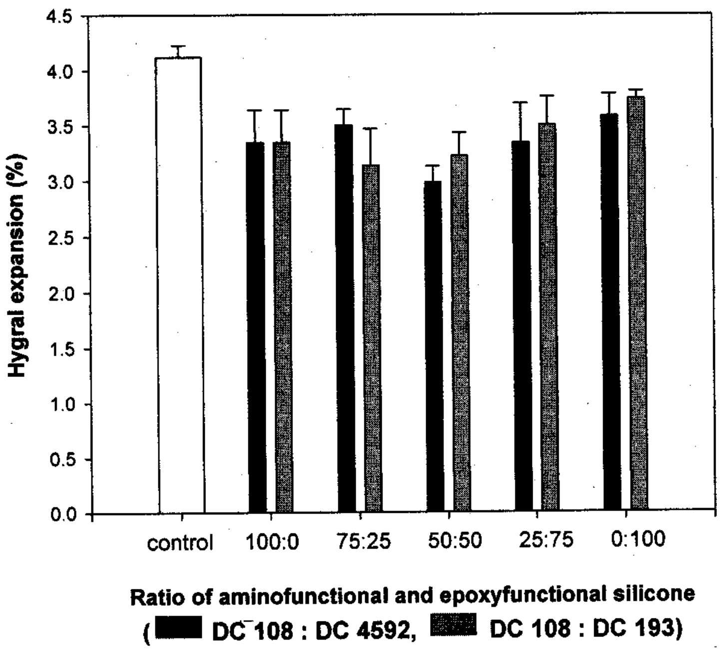

FIGURE 8. Changes in hygral expansion of silicone treated wool fabrics in the warp direction.

shown in Figure 8. The hygral expansion of wool fabrics treated with these softeners is less than that of untreated fabric. The reduced hygral expansion of these fabrics could be associated with the earlier onset of swelling shrinkage by silicone softener. Baird and co-workers observed the progressively earlier onset of swelling shrinkage with increased surfactant uptake [2]. At high regains, a point is reached with fabrics where a dimensional contraction takes place as the regain further increases, and this is referred to as swelling shrinkage [1, 4]. As the regain increases, the separation of the yarn centers at crossover points increases, leading to a reduction in the spacing between adjacent threads. Silicone softeners are thought to affect separation and induce an earlier onset of swelling shrinkage by reducing interyarn friction.

The minimum hygral expansion occurs with the 1:1 proportion of aminofunctional and epoxyfunctional silicone softeners. These synergistic effects appear in other fabric mechanical properties, but there is little difference between the two kinds of epoxyfunctional softeners in dimensional properties. In the case of a mixture with hydrophilic Dow Corning 193, the value of hygral expansion is not lower than that of a mixture with Dow Corning 4592. This is due to increased fiber hydrophilicity, which, in turn, causes an increase in fiber swelling despite the earlier onset of swelling shrinkage [6].

Performance Properties

Most chemical finishes generally cause significant changes in fabric performance properties, and softeners are no exception. The function of fabric softeners is to provide an enhanced hand or feel as well as to improve other performance properties. They soften fabrics through an outstanding surface effect.

Tables II and III show the performance properties of wool fabrics treated with silicone softeners. The fullness and softness values increase with silicone treatment. Since silicone softeners have long fatty acid chains, they soften fabrics by coating the surface and thus reducing friction between the fibers and yarns in the fabric substrate. This is the primary effect of fabric softeners.

The wrinkle recovery of fabrics treated with silicone softeners also improves. High molecular weight film-forming polymers such as silicones are confined to the surface of fibers and yarns [18]. Thus, wrinkle recovery improves probably through the surface effect of reducing the frictional component of wrinkling. This is consistent with the reduced bending hysteresis of fabrics treated with silicone softeners in Figure 7. Besides, the wrinkle recovery of fabrics treated with aminofunctional and epoxyfunctional silicone softeners together improves more than with epoxyfunctional silicone softeners alone.

We saw some reduction in grab breaking strength and increased tear strength for wool fabrics treated with silicone softeners. These results suggest that there is a significant reduction in interfiber or interyarn frictional forces with the deposition of silicone softeners on the fiber surface [15], which increases inherent slippage of the structural components.

We also investigated the yellowness index of fabrics treated with silicone softeners. The yellowing effect is conspicuous in the sample treated only with the aminofunctional silicone softener. However, it decreases with a mixture with epoxyfunctional silicone softeners. We believe the ring opening reaction of the epoxy group increases the substitution degree of the amino group and prevents chromophores from causing yellowing.

TABLE II. Performance properties of wool fabric treated with aminofunctional and epoxyfunctional silicone softeners.

		Dow Corning 108 : Dow Corning 4592			
Sample	Fullness/ softness	WRA, degree	BS, kg	TS, g	Yellowness
Untreated	4.98	265	18.51	1313.07	13.97
100:0	5.40	302	18.46	1440.00	14.70
75:0	5.34	296	17.48	1411.20	14.32
50:50	5.60	310	17.14	1472.00	14.23
25:75	5.40	294	18.32	1371.73	14.19
0:100	5.02	295	17.66	1400.00	14.02

TABLE III. Performance properties of wool fabric treated with aminofunctional and hydrophilic epoxyfunctional silicone softeners.

		Dow Corning 108 : Dow Corning 193			
Sample	Fullness/ softness	WRA, degree	BS, kg	TS, g	Yellowness
Untreated	4.98	265	18.51	1313.07	13.97
100:0	5.40	302	18.46	1440.00	14.70
75:0	5.44	299	17.74	1469.33	14.25
50:50	5.65	305	17.62	1468.80	14.11
25:75	5.25	283	17.55	1388.50	14.17
0:100	5.16	283	17.03	1333.33	14.21

Conclusions

We have evaluated the effects of silicone softeners on the mechanical properties, dimensional stability, and performance properties of wool fabrics with various compositions of silicone softeners. Dimensional stability, wrinkle recovery and tear strength improve with the mixture of aminofunctional and epoxyfunctional silicone softeners. Increased performance properties of wool fabric are obtained with a 1:1 proportion of aminofunctional and epoxyfunctional silicone softeners due to their synergistic effect. There are no significant changes in the performance properties of wool fabrics with different kinds of epoxyfunctional silicone softeners except for the dimensional properties. The hydrophilic epoxyfunctional silicone softener increases fiber swelling and interferes with the reduction of hygral expansion.

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