(REFEREED RESEARCH)

EFFECT OF NANO-SILICONE SOFTENER ON ABRASION AND PILLING RESISTANCE AND COLOR FASTNESS OF KNITTED FABRICS

NANO-SILIKON YUMUŞATICININ ÖRME KUMAŞLARIN AŞINMA VE BONCUKLANMA DAYANIMI VE RENK HASLIĞI ÜZERINDEKI ETKISI

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ABSTRACT

Silicones are the most widely used softeners in textile industry. Silicone softeners are classified into three groups according to particle size; macro, micro and nano-silicones. Nano-silicone softeners penetrate the fabric inner structure more easily than others. Due to the fact that nano-silicone softener application area widens rapidly in commercial use, we give a comparison with respect to performance and color fastness properties of knitted fabrics with and without nano-silicone softener in this study. We obtained and evaluated the properties as abrasion and pilling resistance, rubbing, dry cleaning, and washing fastness using four different knitted samples. Fabrics with nano-silicone softener exhibited poor abrasion but better pilling resistance. Nano-silicone softener treatment does not have significant effect on color fastness properties of knitted fabrics.

Key Words: Nano-silicone, Softener, Abrasion resistance, Pilling resistance, Color fastness.

ÖZET

Tekstil endüstrisinde en geniş kullanımı olan yumuşatıcılar silikonlardır. Parçacık büyüklüğüne göre silikon yumuşatıcılar üç gruba ayrılır; makro, mikro ve nano-silikonlar. Nano-silikon yumuşatıcılar kumaşın içyapısına diğerlerinden daha kolay nüfuz ederler. Ticari kullanımda nano-silikon yumuşatıcıların uygulama alanının giderek artmasından dolayı bu çalışmada nano-silikon yumuşatıcı uygulanmış ve uygulanmamış örgü kumaşların performans ve renk haslığı özellikleri açısından bir kıyaslama vermekteyiz. Performans ve renk haslığı özelliklerini aşınma ve boncuklanma dayanımı, sürtme, kuru temizleme, yıkama haslıkları dört farklı örgü kumaş numunesi kullanarak elde ettik ve değerlendirdik. Nano silikon yumuşatıcı uygulanmış kumaşlar aşınmaya karşı düşük ancak boncuklanmaya karşı yüksek dayanım sergilemiştir. Nano silikon yumuşatıcı uygulanması örgü kumaşların renk haslığı özelliklerinde önemli bir etki yapmamıştır.

Anahtar Kelimeler: Nano-silikon, Yumuşatıcı, Aşınma dayanımı, Boncuklanma dayanımı, Renk haslığı.

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1. INTRODUCTION

Weft knitted fabrics, are widely used in our daily life. They are mainly used in sportswear, free time clothes, bed time clothes, underwear, t-shirts, baby clothes and bed sheets. Loops in the knitted fabric stretch when pulled by a force and then return to its original shape by removing this force. As a result, it is achieved to change the shape of the knitted cloth by changing shape of the moving body. By this way, they provide a comfortable wear performance to users. In addition to this comfortable service, users expect a soft hand from knitted garments. So fabric softeners are used in home laundering and in textile wet processing as bath additives to improve fabric hand. However adhesion of these softeners to the fiber surface is by a weak electrical attraction without any chemical linkage and so durability is poor. On the other hand, durable silicone textile softeners render additional performance properties to cotton fabrics such as improved wrinkle recovery and crease resistance and improved wear comfort with a bulky and smooth hand (1, 2).

Due to their outstanding specific property low intermolecular forces, as well as their higher effectiveness compare to conventional auxiliaries, silicone based textile finishing agents are of enormous importance (3). Even though there are different types of softeners in commercial applications, silicone softeners are the most common in use. Silicone softeners provide better wrinkle recovery, tear strength, and abrasion resistance than the cationic softener for 100% cotton woven fabric (1). Also, modified silicone softeners provide durable soft hand beside a little tendency to yellowing (4).

Among fatty acid, polysiloxane microemulsion, polysiloxane/fatty acid mixture and quaternary ammonium compound type softeners, the hydrophilic polysiloxane microemulsion gave satisfactory results for breaking strength, color difference and light fastness properties of PET woven fabrics (5).

It is expected from a fabric applied with durable softener agent, not only a smooth, slippery and soft touch but also a warm touch and good permeability with respect to comfort properties. The silicone treated PES blended woven fabrics are warmer to touch, but less comfortable as regards their reduced water vapour per-meability (6).

Wool fabrics have a dimensional instability induced by hygral expansion, which is a highly wool specific phenolmenon. The primary function of a fabric softener is to lubricate the surface by coating the fibers within a thin film layer. As a result of silicone softener treatment dimensional sta-bility of plain woven wool fabrics can be improved. At the same time better wrinkle recovery and tear strength properties can be obtained (7).

Silicone softeners are based on macro emulsions and micro emulsions. Particle size of macro emulsion silicone softeners is 150-250 nm while the particle size of micro emulsion silicone softener is lower than 30 nm (8). Due to the fact that particle size of the micro emulsion silicone softeners are smaller, they penetrate the inner structure of the yarn or the fabric while macro emulsion silicone softeners settle on the surface of the yarn or the fabric. Similarly, the penetration effect of nano emulsion silicone softeners is higher than the micro emulsion silicone softeners. Furthermore, owing to multiplicity of bonds and ability of the molecule to easily diffuse into the fiber because of its nano molecular size, the durability of the nano finish is much better than the conventional polymer based finish (9). In the last decade the use of nano-silicone softeners has grown rapidly in textile wet processing.

The aim of this study is to investigate the effect of nano-silicone softener application on color fastness, abrasion and pilling resistance properties of knitted fabrics. In order to examine the fastness properties; dry cleaning, rubbing (dry, wet and organic solvent) and washing fastness test results were observed.

Table 1. Fabric properties of samples

Samples	Properties			
	Yarn Linear Density (Ne)	Yarn Type	Knit Structure	Loop length (cm)
1	40/1	Combed ring spun 100 % cotton	Interlock	0,29
2	24/1	Combed ring spun 100 % cotton	Single jersey	0,30
3	30/1 30/1	Combed ring spun 100 % cotton	Three thread fleecy fabric	0,40 0,40 0,16
	10/1	Rotor spun 100 % cotton		
4	28/1	Rotor spun 100 % Viscose	Single jersey	0,33

Table 2. Dyeing recipes of sample fabrics

Samples	Dyes; *CI Number*	Dye Amount (%)	Salt (g/l)	Soda (g/l)	Temperature (ºC)	Color
1	Yellow; *Yellow 3 RS* Red; *Red 3 BS* Blue; *Blue KBR*	0.011 0.0018 0.0044	10	5	60	Yellow
2	Yellow; *Yellow 3 RS* Red; *Red 3 BS* Black; *Black B H/C*	0.9 0.64 1.7	70	20	60	Dark Blue
3	Yellow; *Yellow EX-F* Red; *Red EX_F* Blue; *Blue 221*	1.44 0.68 1.18	120	20	60	Brown
4	Yellow; *Yellow 3 RS* Red; *Red 3 BS*	0.018 1.1	40	10	60	Pink

Table 3. Color differences of fabrics with and without nano-silicone softener

Samples	ΔL	ΔC	Δh	ΔE
1	-0,1	-0,5	0,26	0,57
2	0,08	-0,51	-0,26	0,58
3	-0,09	0,02	-0,18	0,21
4	-0,22	-0,16	-0,23	0,36

2. MATERIAL

Nano-silicone softeners are applied to knitted fabrics produced from with a wide range of raw materials and different knit structures. In order to identify the effect of nano-silicone treatment on fastness, pilling resistance and abrasion resistance properties of knitted fabrics, four different fabric types most widely used have been selected. Color of the samples was selected randomly, disregarding the effect of color on fabric properties. Table 1 and 2 give the properties and dyeing recipes of knitted fabric samples respectively. Table 3 shows the color differences of fabrics with and without nano-silicone softener. At this comparison, fabrics without nano-silicone softener were accepted as reference.

After dyeing process, fabrics were treated with nano-emulsion by padding. The concentration of elastomeric polyamino siloxane was 20 g/l and pH was 5,5. Padding process was done with a stentering frame as open width. After padding, fabrics were transferred to 6 staggered drying fields. The drying temperatures of fields were 180°C, 170°C, 150°C, 140°C, 140°C and 140°C respectively. The drying speed of knitted sample fabrics from these fields was constant as 22-25 m/min.

3. METHOD

Samples were conditioned for 8 hours at 20±2ºC temperature and 65±4% relative humidity according to TS EN ISO 139 (10) before testing. Sample knitted fabrics were exposed to pulling force along widthwise for nano-silicone application during stentering. It was thought that this application may change the fabric weight and thickness values. Therefore, in order to observe the differences between the values, fabric weight and thickness values were measured before and after silicone softener treatment and presented in Table 4. Thickness and fabric weight values were determined according to TS 7128 EN ISO 5084 (11) and TS EN ISO EN 12127 (12) respectively.

Table 4. Fabric weight and thickness

Samples	Fabric Weight (g/m²)		Fabric Thickness (mm)	
	Without nano-silicone	With nano-silicone	Without nano-silicone	With nano-silicone
1	267	251	0.76	0.72
2	190	189	0.45	0.44
3	384	380	1.05	1.09
4	212	197	0.45	0.41

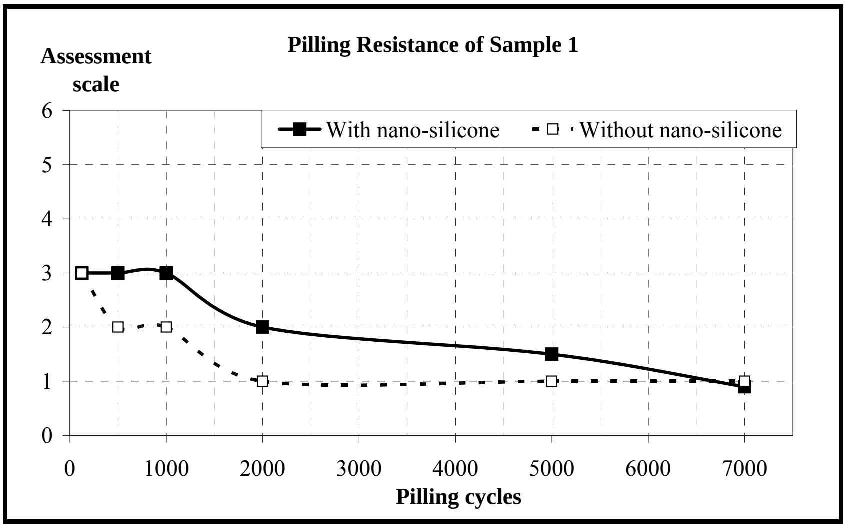

Figure 1. Pilling resistance of sample 1

To assess the effect of silicone treatment on pilling resistance, the samples were tested by a Martindale Abrasion Resistance Tester according to TS EN ISO 12945-2 (13). Three fabric specimens were tested for each fabric sample. Appearance of the fabric samples after 125, 500, 1000, 2000, 5000 and 7000 cycles of testing device were assessed according to ASTM pill grade photographic views in a viewing cabinet. Photographic standards use the following scale; 1-very severe pilling, 2-severe pilling, 3-moderate pilling, 4-slight pilling and 5-no pilling.

To determine the flat abrasion resistance, the samples were tested according to ASTM D 4966-98 (14) by a Martindale Abrasion Tester. The abrasion resistance was determined by the mass loss as the difference between the masses before and after abrasion cycles of 5000, 10000, 15000 and 20000 revolutions of the test device. Four specimens for each fabric sample were tested. Average values of the data obtained from the tests were calculated and then expressed as a percentage of the initial mass.

To investigate color fastness properties of the fabrics with and without nano-silicone, rubbing (dry, wet and organic solvents), washing and dry cleaning color fastness tests were done. These tests were carried out according to TS EN ISO 105-X12 (15), TS 7807 EN ISO 105-D02 (16), TS EN 20105- C01 (17) and TS 473 EN ISO 105-D01 (18) respectively. Fastness properties of fabrics were evaluated according to staining of multifiber fabric and change in color via gray scales. For these assessments standards of TSE 423-3 (19) and TS 423-3 EN 20105-A03 (20) were used.

4. RESULTS AND DISCUSSIONS

4.1. Pilling resistance

The average pilling resistance results of samples 1, 3 and 4 are exhibited in Figures 1, 2 and 3 respectively. Among knitted fabric samples, just only sample 2 exhibited no difference after nano-silicone softener application. This sample had an excellent pilling resistance that exhibited no pilling for all cycles (125, 500, 1000, 2000, 5000, and 7000) of pilling resistance test.

As seen in Figure 1, the sample 1 exhibits moderate pilling for 125 pilling cycle and very severe pilling for 7000 pilling cycle for both the samples with and without nano-silicone softener. On the other hand, the sample 1 with nano-silicone softener has better pilling resistance than the one without nano-silicone softener during pilling resistance test.

Figure 2 represents the pilling resistance of sample 3 with and without nano-silicone softener. Both samples have very good pilling resistance for all

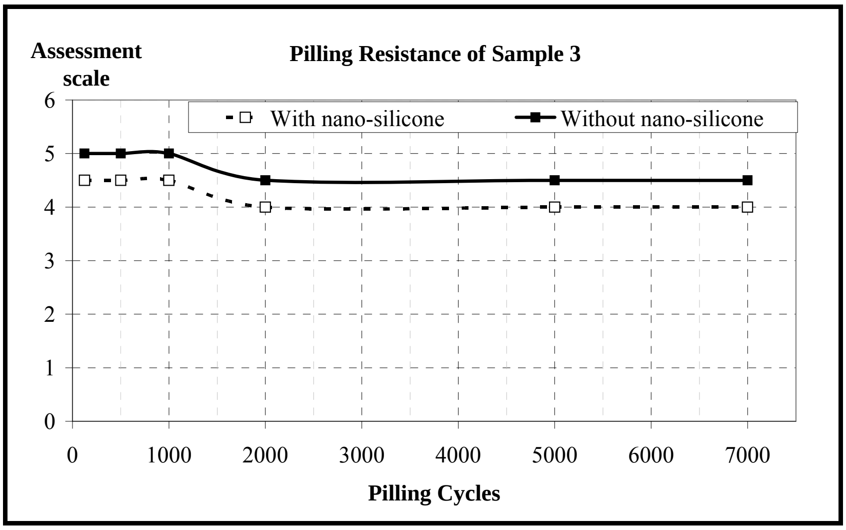

Figure 2. Pilling resistance of sample 3

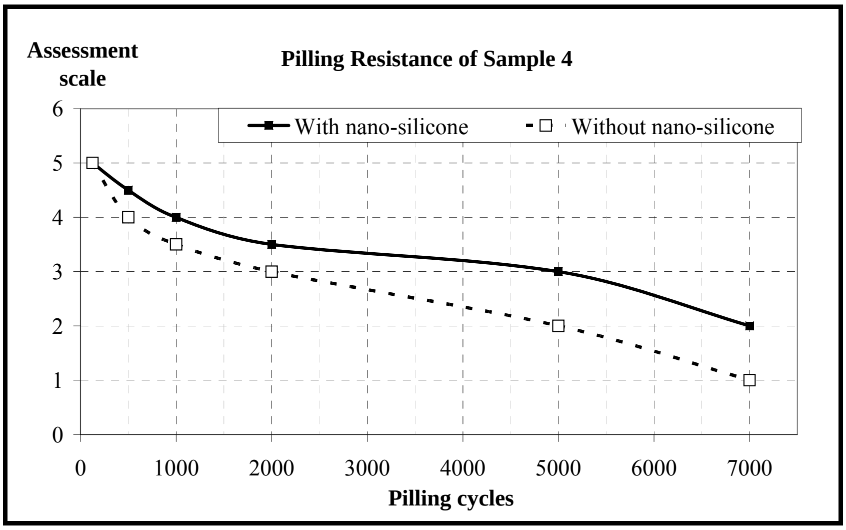

Figure 3. Pilling resistance of sample 4

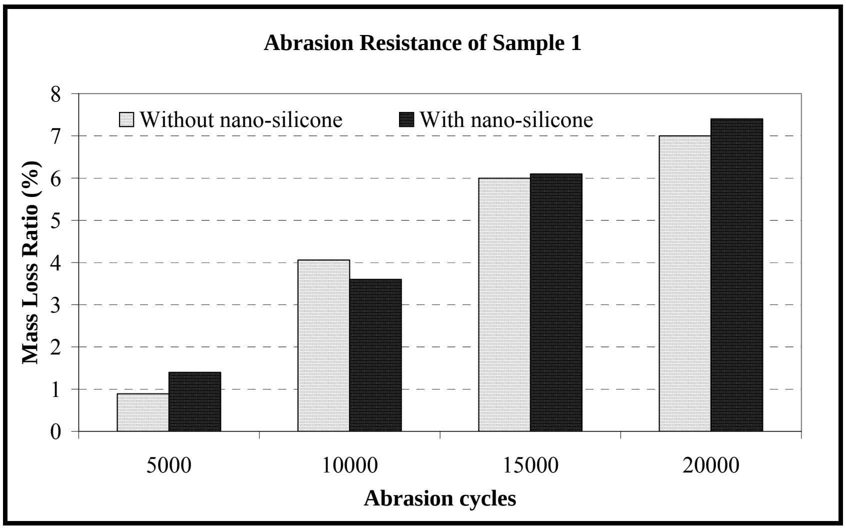

Figure 4. Abrasion resistance of sample 1

pilling cycles. There is a very little difference for pilling resistance between the samples with and without nano-silicone softener.

Figure 3 shows the pilling resistance of sample 4 with and without nano-silicone. Sample 4 with nano-silicone softener have better pilling resistance than the one without nano-silicone softener for all pilling cycles. Sample 4 without nano-silicone softener completed the test with very severe pilling while the one with nano-silicone softener exhibited severe pilling at the end of the test.

4.2. Abrasion resistance

Respectively, Figures 4-7 illustrate mass loss ratio (%) of the samples 1-4 with and without nano-silicone softener for the abrasion cycles of 5000, 10000, 15000 and 20000. As observed from these figures mass loss ratios of the samples with nano-silicone softener are higher than mass loss ratios of the samples without nano-silicone softener. The factors, which increase the fiber mobility inside the fabric, make these fibers to remove the fabric easily and consequently increase the mass loss. In this study the softener which is in nano particle size penetrates the inner structure of the fabric and reaches the fiber surface effectively and this situation increases the fiber mobility (9). According to this phenomenon nano-silicone softener treatment decreased abrasion resistance of sample fabrics.

ANOVA testing was performed to understand statistical importance of nano-silicone treatment on abrasion resistance property of knitted fabrics. Additionally, Pearson correlation analysis was done to show the relationship between mass loss ratios of knitted fabrics with and without nano-silicone. Statistical software package SPSS was used to interpret the experimental data at significance levels of $\alpha \leq 0,05$ and $\alpha \leq 0,01$.

Table 5 exhibits one-way ANOVA results for abrasion resistance test at different cycles for knitted fabric samples with and without nano-silicone softener. According to these results it can be concluded that the application

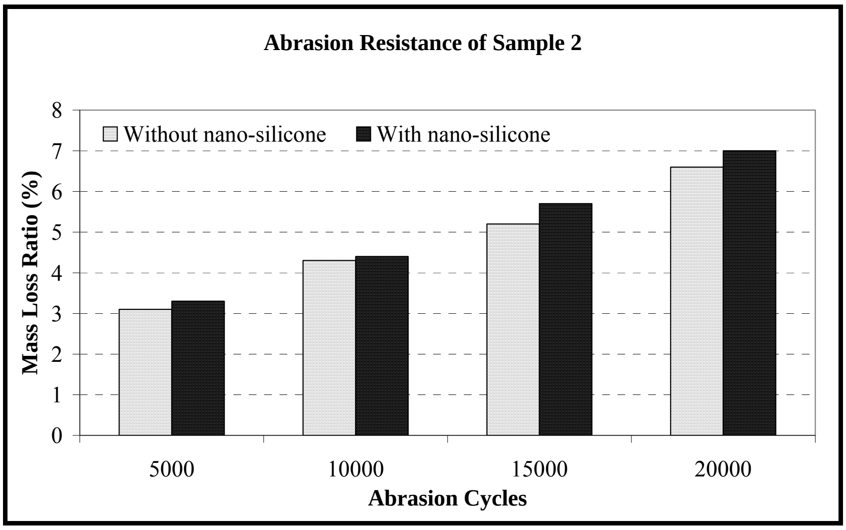

Figure 5. Abrasion resistance of sample 2

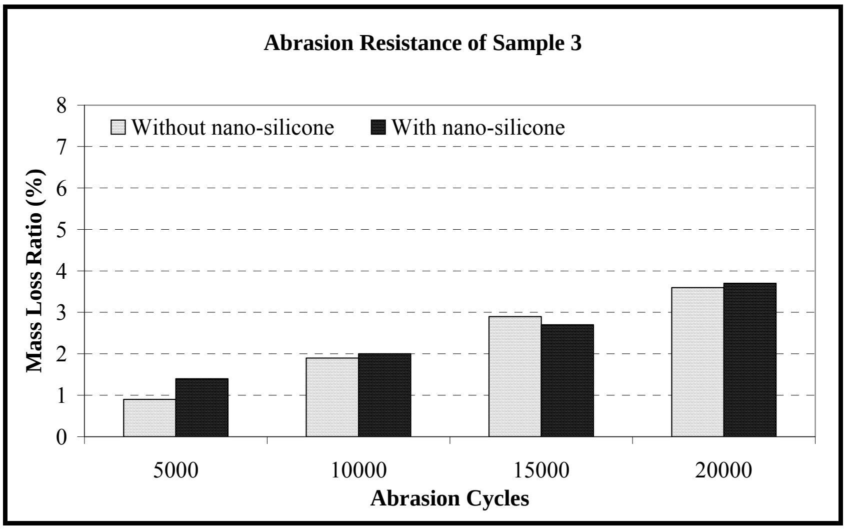

Figure 6. Abrasion resistance of sample 3

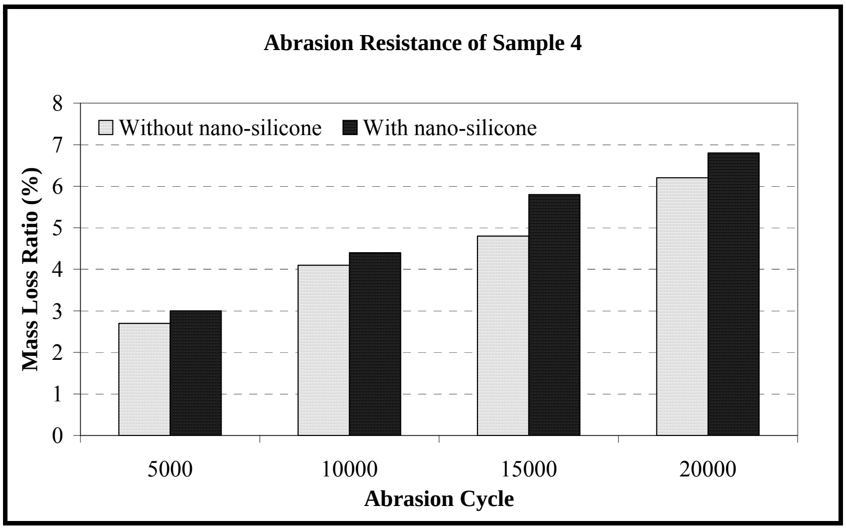

Figure 7. Abrasion resistance of sample 4

of nano-silicone softener has a statistically significant effect on abrasion resistance at significance level of α ≤ 0,01.

Table 6 gives Pearson correlation analysis results for sample fabrics. Results showed that there is a very important, positive and significant relationship between mass loss ratios of knitted fabric samples with and without nano-silicone softener. This means that deterioration of abrasion resistance is caused by nano-silicone softener treatment.

Table 5. One-way ANOVA results for abrasion resistance test

Abrasion cycle	Significance
5000	0,000
10000	0,000
15000	0,000
20000	0,000

Table 6. Pearson correlation results for abrasion resistance test

Sample	Pearson correlation coefficient
1	0,986
2	0,980
3	0,996
4	0,986

4.3. Color Fastness

Tables 7, 8 and 9 give the results of dry, wet and organic solvent color fastness properties respectively. It is seen that nano-silicone treatment has no significant effect neither on change in color nor on staining degree after rubbing tests.

Table 7. Results of dry rubbing color fastness

Samples	Change in color		Staining	
	Without nano-silicone	With nano-silicone	Without nano-silicone	With nano-silicone
1	5	5	5	5
2	4.5	4.5	4	4.5
3	4	4.5	4.5	4
4	5	5	5	5

Table 8. Results of wet rubbing color fastness

Samples	Change in color		Staining	
	Without nano-silicone	With nano-silicone	Without nano-silicone	With nano-silicone
1	4.5	4.5	5	5
2	4	4	4.5	4.5
3	4.5	5	3	3.5
4	4.5	4.5	4.5	4

Table 9. Results of rubbing color fastness to organic solvents

Samples	Change in color		Staining	
	Without nano-silicone	With nano-silicone	Without nano-silicone	With nano-silicone
1	5	4.5	5	5
2	4.5	4.5	4.5	4.5
3	4.5	4.5	4	4
4	5	5	5	5

Table 10, 11 and 12 give dry cleaning and washing fastness test results. The results of dry cleaning fastness tests showed that nano-silicone treatment had a minor effect on change in color degrees for samples 2, 3 and 4. With respect to washing color fastness according to change in color degrees it is seen that samples 2 and 3 had a better washing color fastness after nano-silicone treatment. In the case of results of staining after washing tests, neither an improving nor a deteriorating effect of nano-silicone treatment was observed.

Table 10. Results of change in color after dry cleaning color fastness

Samples	Without nano-silicone	With nano-silicone
1	5	5
2	4	4.5
3	4.5	5
4	4.5	5

Table 11. Results of change in color after washing color fastness

Samples	Without nano-silicone	With nano-silicone
1	5	5
2	4	5
3	4	5
4	5	5

5. CONCLUSIONS

The following conclusions can be drawn based on the study carried out on the abrasion and pilling resistance and color fastness properties of knitted fabrics with and without nano-silicone softener.

1. The abrasion resistance of sample fabrics deteriorates by application of nano-silicone softener. It is the probable result of fiber mobility inside the fabric which is increased by nano-silicone softener.
2. Pills on the fabric are formed by entangled fiber ends however nano-silicone softener increases the slipperiness of fiber surface and entangling of fiber ends becomes difficult. So, nano-silicone treatment improves the pilling resistance of sample fabrics.
3. The sample fabrics used in this study were selected randomly from commercial products and with respect to color fastness test results of samples without nano-silicone softener have considerably good color fastness properties. In the case of color fastness test results, it is evident that nano-silicone softener treatment has no deterioration effect on color fastness.

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Table 12. Results of staining of multifiber fabric after washing color fastness

Multifiber Fabric layers	Samples							
	1		2		3		4	
	Without nanosilicone	With nanosilicone	Without nanosilicone	With nanosilicone	Without nanosilicone	With nanosilicone	Without nanosilicone	With nanosilicone
Acetate	5	5	5	5	5	5	5	5
Cotton	5	5	5	5	4.5	5	5	5
Polyamid	5	5	5	5	5	5	5	5
Polyester	5	5	5	5	5	5	5	5
Acrylic	5	5	5	5	5	5	5	5
Wool	5	5	5	5	5	5	5	5

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