Performance of Knitted Fabrics Finished With Different Silicone Softeners

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ABSTRACT

Silicone softeners make fabric soft, brilliant, greasy and more elastic, resulting is acceptable handle. In this research work, the effect of using different silicone softeners on pilling resistance and on some physical and mechanical properties of knitted fabrics was evaluated. Industrially applied silicone softeners of three different types (macro, semi-micro, micro) were used on fabrics knitted from different fiber materials (Egyptian cotton, Tencel LF, Tencel STD, bamboo, Modal and Micro-modal). The influence of using different silicone softeners on fabric pilling resistance, seam hole, air permeability, color strength, fastness to rubbing in wet and dry states and fastness to washing was investigated. Results have shown that the pilling performance of micro-modal fabrics finished with micro silicone is better than those finished with macro silicone. The higher number of fibers per cross-section for the micro modal yarns creates weak bonds between micro-modal fibers and macro silicone particles. The macro silicone fabric has the greatest air permeability, while the micro silicone reduces the porosity of the yarn and increases air resistance. The macro silicone softener method has more fastness to color than the other finishing methods investigated.

Keywords: Silicone softeners, macro silicone, semi-micro silicone, micro silicone, pilling resistance and fastness to rubbing.

INTODUCTION

Fabric softeners are applied in home laundering and in wet processing of textile as bath additives to improve fabric hand. During wet processing (scouring and bleaching) cotton becomes less soft because oils and waxes are removed. Finishing with a different particle size silicone softeners can overcome this problem and even restore and improve softness on the resulting fabric [1-2].

Due to low intermolecular forces, silicone-based textile finishing types are of great importance [3]. The main purpose of a fabric softener is to lubricate the fabric surface by covering the fibers with a thin-film layer. As a result, the silicone softener improves the dimensional stability of plain woven wool fabrics [4]. To obtain a soft fabric, different types of softeners, such as fatty acid based and silicone based softeners are applied. However, silicone-based softeners give the fabric permanent soft handle.

Three types of silicone softeners are commercially available in the market according to particle size-macro, micro and nano silicone softeners [5]. The particle sizes of macro, micro and nano emulsion silicone softeners are 150-250 nm, less than 30 nm and 10 nm respectively [6].

Due to the fact that particle sizes of the micro and nanoemulsion silicone softeners are smaller, they have the ability to deposit between the fibers and penetrate between each fiber inside the fabric, producing an inner softness, where macro silicone softeners will mainly be deposited on the yarn surface. In the case of nanoemulsion silicone softeners, the large quantity of bonds and ability of the molecules to diffuse into the fiber due to small molecular size, the performance of nano finishes are better than traditional polymer based finishes [7-8].

Bending length is high for fabrics finished with macro- and microemulsion silicone softeners. Silicones can work as lubricants and lessen the friction between the fibers in the fabric, resulting in reduced fabric bending length [3].

Chattopadhyay and Vyas [9] demonstrated that softeners improve crease recovery of cotton fabric. Microemulsion silicones are more efficient for crease resistance development than macroemulsions [10, 11]. Macroemulsion silicone softeners can decrease the friction of fibers via formation of a silicone layer on the yarn surface.

Fabrics finished with softeners have a smooth surface and better strength [12]. Softeners increase abrasion resistance. Softened fabric samples can withstand many abrasion cycles while untreated raw samples cannot endure even one-seventh of that number of cycles before the formation of holes on the surface [13]. Çelik at al. [14] showed that knitted fabrics finished with nano silicone softeners had poor abrasion properties but improved pilling performance. Busiliene et al. [15] studied the influence of the type of fibers and chemical softeners on the tendency of fuzzing and pilling of plain and plated jersey structure knitted fabrics.

Pilling is defined as entangling of fibers on the surface of a fabric during end use, washing or testing to form fibers balls or pills that stay on the fabric surface [16]. Pilling affects fabric appearance and in general is a self-limiting process which arises in three different stages- formation of surface fuzz, entanglement, and formation of pills [17-18]. Consequently, pills are broken off the fabric surface by exaggerated friction- the anchor fibers are broken. The pills are formed during usage and washing, which means that fabrics are influenced by frictional forces during wear. Friction forces lead to the abrasion and pilling of fabrics [19].

The choice of softeners is of great importance to pilling resistance and handle of fabrics [20] [21]. The problem of pilling became even more important with the appearance of synthetic fibers such as polyester, particularly in the form of blends fibers of lower tensile strength [22]. Sivakelmar et al [23] found that twill weaves tend to pill more than plain weaves.

Zuber et al. showed that the color fastness to rubbing of dyed and printed fabric samples finished with softeners was poor compared to fabrics with no softeners [21].

No research study exists which compares the effect of different types of silicone softeners on 100% Giza 88 Egyptian cotton compared to 100% regenerated cellulosic fibers. In order to evaluate the effect of silicone softeners on different types of fibers, 100% ring-spun yarns of different fibers were used as opposed to different blends of such fibers.

MATERIALS AND METHODS

Materials

In this study, 30/1, 100%, Egyptian cotton Giza 88, Tencel LF, Tencel STD, Bamboo, Modal and Micro-Modal yarns were used to knit single jersey knitted fabrics. For this study, Tencel LF fiber of 1.3 dtex fineness and 38 mm length, Tencel STD fiber of 1.3 dtex fineness and 38 mm length, Bamboo fiber of 1.6 dtex fineness and 38 mm length, Modal fiber of 1.6 dtex fineness and 39 mm length and Micro-modal fiber of 1 dtex fineness and 39 mm length were used. Also, cotton fibers of 34.5 mm length, 86.1% uniformity, 46.2 strength, 4.1% elongation, 4 micronaire, 63 degrees of reflectance “Rd”, 10.8 yellowness “+b”, 25 trash count and 85% maturity were used. Also, the properties of the yarns used to produce all single jersey fabrics are presented in *Table I*.

FABRIC MANUFACTURE

The single jersey fabric samples were manufactured on a single-jersey circular knitting machine TOP KNIT KEUMYONG, MLBF model, with 28 gauge, 15-inch diameter, 45 feeders and with the total number of needles equal to 1320. The loop length was kept constant at 2.6 mm yarns. The yarn feeding tension was adjusted at 5 CN.

After the knitting process, all grey single jersey fabric samples were scoured, dyed, balloon squeezed, dried and finally compacted. The design of experiments studied in this research is shown in *Table II*. The yarn material and silicone softener type were determined for every sample.

TABLE I. Yarn Properties.

	Cotton	Bamboo	Tencel LF	Tencel STD	Modal	Micro-Modal
Ne	30/1	30/1	30/1	30/1	30/1	30/1
TPI	20.1	19.4	19.1	19.3	19.9	19.4
Irregularity (CV %)	10	9	9.5	8.24	10.7	10.5
Thin places (-50%)	4	0	0	0	0	0
Thick places (+50)	18	17	11	5	4	10
Neps	62	39	33	16	12	27
CN/Tex	17.3	16.36	22.5	26.73	25.92	27.6
Elongation (%)	5.4	13.54	8.2	10.32	11.3	11.8
Hairiness (H)	6.8	4.5	5	4.87	5.6	5.7

TABLE II. Design of Experiments.

Group Code	Sample No.	Sample Material 100%	Silicone Type		Group Code	Sample no	Sample Material 100%	Silicone Type
a	1	Egyptian Cotton	Without Silicone		c	13	Egyptian Cotton	Semi-Micro
	2	Tencel LF	Without Silicone			14	Tencel LF	Semi-Micro
	3	Tencel STD	Without Silicone			15	Tencel STD	Semi-Micro
	4	Bamboo	Without Silicone			16	Bamboo	Semi-Micro
	5	Modal	Without Silicone			17	Modal	Semi-Micro
	6	MicroModal	Without Silicone			18	MicroModal	Semi-Micro
b	7	Egyptian Cotton	Macro		d	19	Egyptian Cotton	Micro
	8	Tencel LF	Macro			20	Tencel LF	Micro
	9	Tencel STD	Macro			21	Tencel STD	Micro
	10	Bamboo	Macro			22	Bamboo	Micro
	11	Modal	Macro			23	Modal	Micro
	12	MicroModal	Macro			24	MicroModal	Micro

FABRIC DYEING AND FINISHING

All grey knitted fabrics were dyed in the same dye bath to remove any variation in processing. Fabrics were wetted for 30 minutes for oil removal using 1g/L soda ash and 0.5 g/L wetting agent “Seta wet HNG”. Then, all the fabrics were processed in a scouring bath using the ingredients shown in *Table III* for 45 minutes, where the temperature was raised to 98°C, followed by rinsing with hot water for 10 minutes at 80°C and finally rinsing with acetic acid for 10 minutes at 70°C to neutral PH. All fabrics were dyed at the same conditions to a red color in an Alkan H.T "high temperature" – Jet dyeing machine at 60°C for 4 hours. The dyeing recipe is shown in *Table IV*.

Afterwards, a hot rinse process was applied for 10 minutes. Then soaping was conducted at 98°C for 30 minutes two times, followed by rinsing at 80°C for 10 minutes. After that, a softener exhaust bath was used on the fabrics in the same dyeing machine with 3% fatty acid, 0.5% polyethylene and vinegar at 50°C for 30 min. to obtain 5.5 pH.

TABLE III. Scouring Recipe.

Liquor ratio	1:13
Wet Soft "Anti-crease material, g/l	1
Wetting *agent* “Seta wet HNG”, g/l	1
Soda Ash "Sodium Carbonate", g/l	5

TABLE IV. Dyeing Recipe.

Liquor ratio	1:13
Sequestering agent "progal RE30", g/l	1
Remazol yellow 3RS, %	1.53
Remazol red 3BS, %	2.7
Remazol Brilliant Blue BB 133, %	0.007
Vacuum salt, g/l	80
Soda Ash, g/l	20

Finally, the silicone softeners were added to the fabrics using a padding method. Each silicone softener was added at 1% of fabric weight with 2% fatty acid. The knitted fabrics were padded separately with each type of silicone solution in a padding mangle using a squeezing machine with a sufficient and suitable overfeed machine speed. After squeezing, the fabrics were dried using a tensionless drying machine and then calendared. The abbreviations of fabric samples are shown in *Table V*.

TABLE V. Abbreviation of Fabric Samples.

Samples Material	Without Silicone	Macro Silicone	Semi-Micro Silicone	Micro Silicone
Cotton	C	C1	C2	C3
Tencel LF	LF	LF1	LF2	LF3
Tencel STD	STD	STD1	STD2	STD3
Bamboo	B	B1	B2	B3
Modal	M	M1	M2	M3
MicroModal	MM	MM1	MM2	MM3

FABRIC TESTING

After leaving the single jersey samples 72 hours at standard conditions (Relative humidity = 65 + 2% & Temperature = 20 + 2°C), the fabric properties were measured.

The fabric count, fabric weight, thickness and air permeability were measured according to standards ASTM D3775 ASTM D 3776, ASTM D 1777 and ASTM D737 respectively.

The pilling grade was evaluated according to ISO 12945-2 testing method, "Textile – Determination of fabric propensity to surface buzzing and to pilling – Part 2: Modified Martindale method" standard, using a Martindale abrasion and pilling tester. A circular test specimen was run over the surface of the same fabric or, when suitable, a wool abrading fabric, at a constant force. The test fabric rotated around an perpendicular to the plane of the test sample. The pilling performance was evaluated visually every 1000 cycles up to 7000 cycles. The appearance of the samples was assessed according to ASTM pill grade photographic views inside a light cabinet under D65 daylight conditions. Samples were evaluated on a scale of 1 to 5 (1 for the worst, 5 for the best) [24].

An L & M sewability tester (US patent 3979951, 1976) was used to evaluate fabric seam hole "needle penetration force". This equipment simulates a sewing machine by penetrating the fabric sample with using an unthreaded needle at the rate of 100 penetrations per min [25].

Color differences were evaluated using data color device. A 100% cotton fabric without softener silicone was used as a zero reference sample.

The fastness to rubbing "in a wet and dry state" and color fastness to laundering "color change and staining" were measured according to AATCC test method 8-2004 and AATCC test method 61-2003 respectively for finished knitted fabrics. The result of color change from color fastness to laundering was evaluated visually by comparing the difference in color between the unwashed and washed fabric samples using the grey scale for color change. The result of staining from color fastness to laundering is rated by visually comparing the difference in color between the stained and unstained specimens by using the grey scale for staining.

RESULTS AND DISCUSSION

The specifications of all the knitted fabric samples are shown in *Table VI*.

TABLE VI. Specification of Knitted Fabric Samples.

Sample No.	Yarn Material 100%	Courses/cm	Wales/cm	Fabric Weight "g/m^2"	Thickness "cm"
1	Egyptian Cotton	21.8	14.7	153	0.0368
2	Tencel LF	20.6	15	150	0.0333
3	Tencel STD	21	15.6	152	0.0393
4	Bamboo	19.9	16.1	146	0.0278
5	Modal	19.2	16.4	142	0.0298
6	MicroModal	18.2	17	144	0.0273
7	Egyptian Cotton	23	14.8	140	0.0366
8	Tencel LF	21.6	14.8	136	0.0356
9	Tencel STD	22.3	15.3	137	0.0396
10	Bamboo	20.8	15.6	133	0.0306
11	Modal	20.3	16	132	0.0326
12	MicroModal	19.7	16.2	132	0.0291
13	Egyptian Cotton	22.2	14	146	0.038
14	Tencel LF	21	14.2	142	0.036
15	Tencel STD	21.4	14.4	145	0.041
16	Bamboo	20.3	14.8	140	0.0315
17	Modal	19.5	15.3	133	0.0325
18	MicroModal	19	15.5	136	0.03
19	Egyptian Cotton	24	13.6	149	0.043
20	Tencel LF	22.9	13.8	147	0.0405
21	Tencel STD	23.5	14.1	147	0.045
22	Bamboo	22.5	14.2	144	0.034
23	Modal	21.9	14.4	138	0.0375
24	MicroModal	21.6	15.1	142	0.032

PILLING GRADE

In general, the degree of pilling is determined by the rates of the following processes: a) fiber entanglement causing pill formation; b) growing of extra surface fibers; c) pill wear off. The worst situations are created in fabrics having the strongest fibers. The rate of pill formation is greater than the rate of wear-off in the case of the stronger fibers. On the other hand, the rate of pill formation is less than the rate of wear-off for the weak fiber [24].

The relation between silicone type and pilling grade for different fiber material is illustrated in *Figures 1-6*.

Generally, the Tencel has the greatest pilling grade, while the cotton has the least pilling grade, due to more crystalline regions in the Tencel fiber structure as illustrated in *Figures 1, 2 and 3*.

The pilling of the Egyptian Giza 88 cotton fabric samples is illustrated in *Figure 1*, showing that the micro silicone has a superior effect in improving the pilling performance. This is related to the penetration of the micro silicone particles between the hairiness on the fabric surface. This hairiness is excessive in the case of cotton fabric samples. It is obvious that between 2000 and 7000 rubbing cycles the pilling performance of fabrics without silicone softener fabrics and macro silicone softener fabrics is about the same.

As shown in *Figure 3*, the pilling grade of Tencel STD fabric samples finished with macro silicone softener is higher than those without silicone, followed by semi-micro silicone and then micro silicone. Tencel STD consists of very tiny macro fibrils which are very smooth and have open spaces between each other. Therefore, the big particles of macro silicone can stay inside these spaces. Consequently, the fabric will have a very smooth surface and has a low tendency to form pills.

For the Bamboo samples, the pilling grade of fabrics finished with micro silicone is the same as others finished with macro silicone, followed by semi-micro silicone and then without silicone. The serrated configuration of bamboo longitudinal fibers cross section and the smoothness of these fibers cause the micro and macro silicone softener to have the same effect on the fabric pilling grade, as presented in *Figure 4*. The influence of silicone softeners on the pilling performance of Bamboo samples is variable with increasing rubbing cycles. The softener improves pilling performance of the fabrics between 4000 and 7000 rubbing cycles, which may be due to the lower strength of bamboo fibers which promotes breaking of the pills from the fabric surface and decrease of pill accumulation [26].

As seen in *Figure 6*, the pilling grade of the micro-modal samples finished with micro silicone is greater than semi-micro followed by fabric without silicone and then macro silicone. The higher number of fibers per cross-section for the micro modal yarns creates weak bonds between micro-modal fibers and macro silicone particles. Therefore, macro silicone softener stays on the fabric surface and causes the fabric to accumulate more pills above its surface. On the other hand, the micro silicone spreads homogeneously inside the micro-modal yarn.

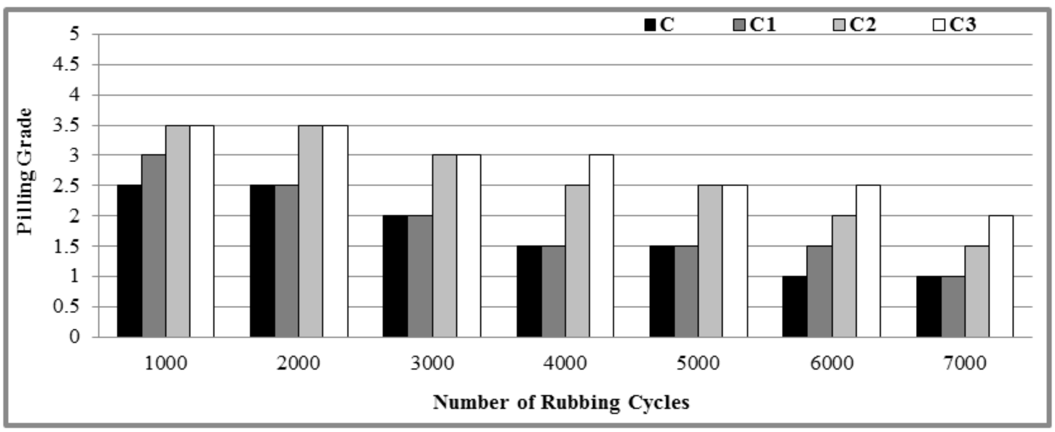

FIGURE 1. Pilling grade of cotton fabrics.

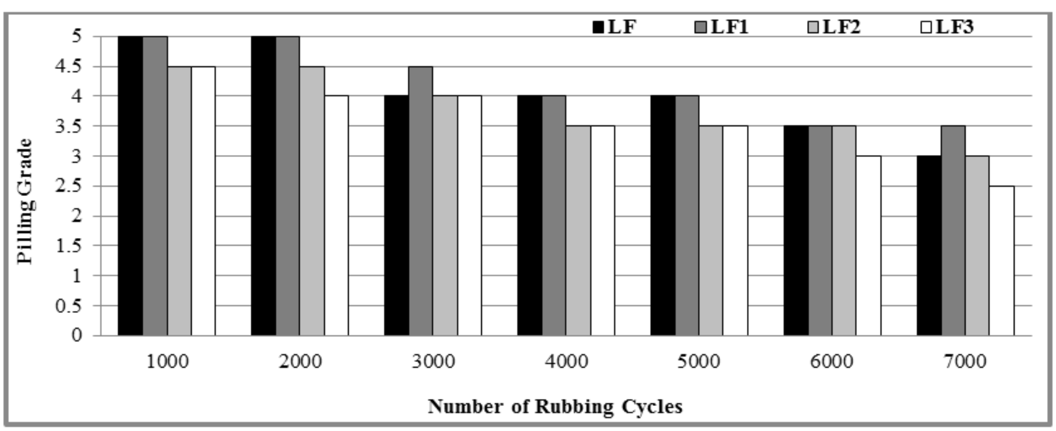

FIGURE 2. Pilling grade of Tencel LF fabrics.

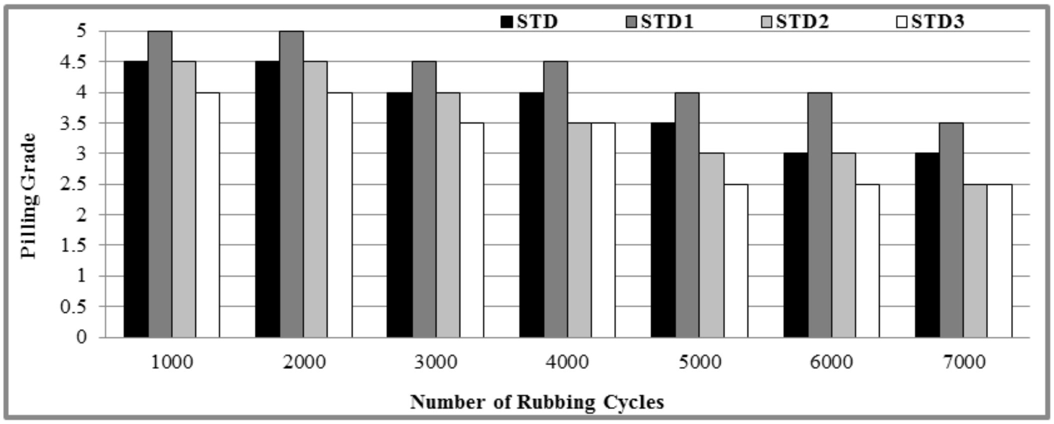

FIGURE 3. Pilling grade of Tencel STD fabrics.

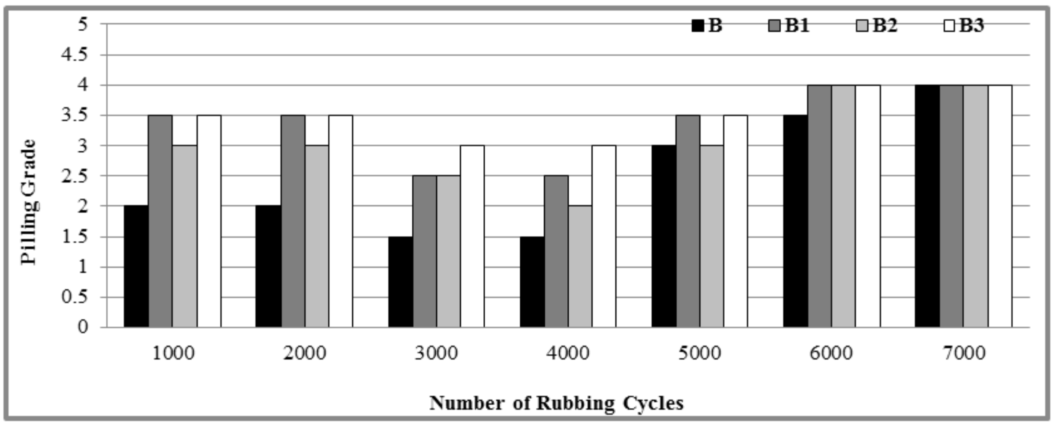

FIGURE 4. Pilling grade of Bamboo fabrics.

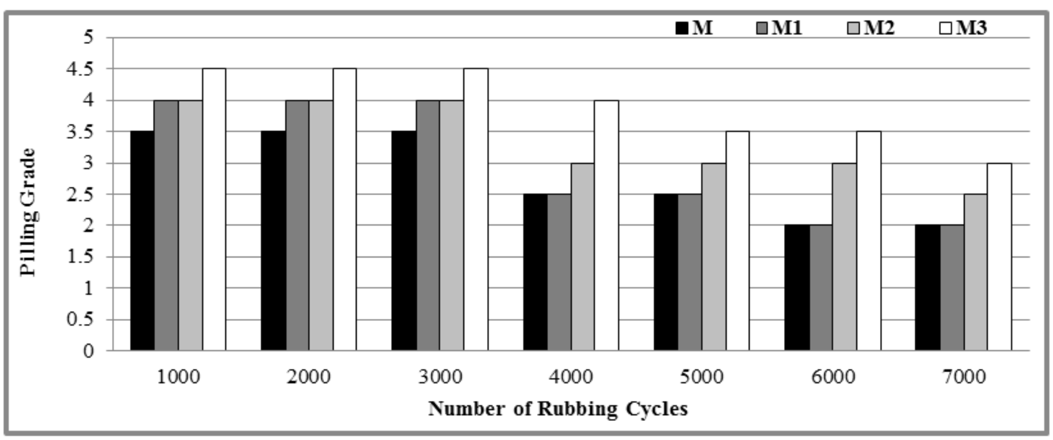

FIGURE 5. Pilling grade of Modal fabrics.

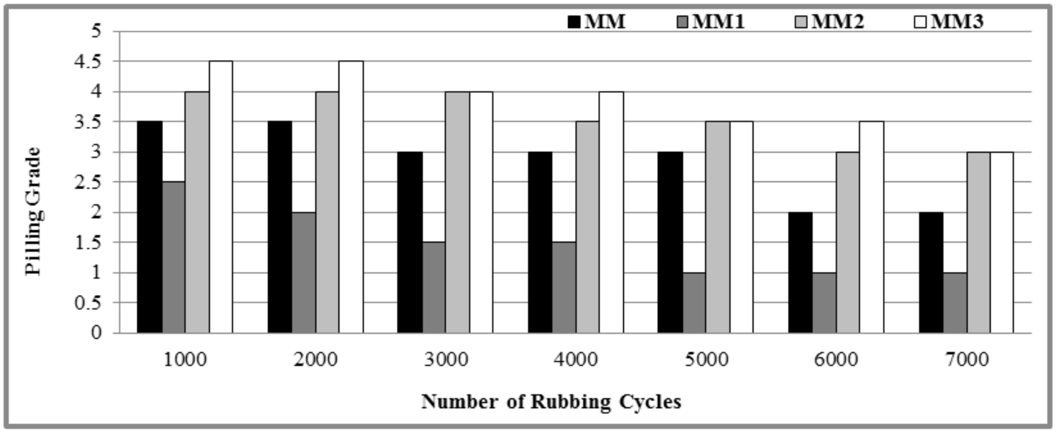

FIGURE 6. Pilling grade of Micro-Modal fabrics.

SEAM HOLE

The relation between silicone type and seam hole for different fiber materials is shown in *Figure 7*. The lower the value of the seam hole, the better the fabric sewability [27-28].

The fabric without silicone has the greatest seam hole value and the semi-micro silicone has the least seam hole value. This could be related to the improved smoothness between the fibers and yarns in the fabric after applying semi-micro silicone softener.

The cotton sample has the greatest seam hole value, while the Tencel LF has the lowest value. This is because the elasticity and smoothness of the Tencel LF fibers allows the needle to penetrate the fabric very easily without applying stress on the sewing needle.

ANOVA single factor illustrates that there are significant differences between all sample materials treated with the silicone softeners. Additionally, Tukey-Kramer Procedure analysis was applied as shown in *Table VII*. It is seen that there is a significant difference is between all groups except between macro “group b” and micro “group d” silicone treated fabrics for Tencel STD, Bamboo, modal and micro-modal fibers only.

TABLE VII. Tukey-Kramer Procedure for Seam Hole.

Group Code	a to b	a to c	a to d	b to c	b to d	c to d
Cotton	S	S	S	S	S	S
Tencel LF	S	S	S	S	S	S
Tencel STD	S	S	S	S	NS	S
Bamboo	S	S	S	S	NS	S
Modal	S	S	S	S	NS	S
Mico-Modal	S	S	S	S	NS	S

S = Significant, NS = Non Significant

AIR PERMEABILITY

Figure 8 shows the relation between silicone type and air permeability for different fiber materials. The macro silicone has higher air permeability than the micro silicone fabric. This is because the micro silicone blocks the pores inside the yarn, decreasing the air permeability. The macro silicone remains on the fabric surface, increasing the fabric air permeability.

The Tencel STD has the greatest air permeability while cotton fibers show more air resistance due to increased convolutions and more hairiness. The convolutions of the cotton fiber block the pores and decrease the air flow through the fabric [29]. Also, the spaces between the fibrils in the Tencel STD result in improved moisture absorption and smoothness, allowing air to pass easily through the fabric [30].

ANOVA single factor confirmed that there are significant differences in air permeability between all fabric materials treated silicone softeners. Also, the Tukey-Kramer Procedure analysis shows that there is a significant difference in air permeability between all fabrics groups treated with silicone softeners except between groups a and c & a and d for Bamboo fibers and groups a and d for micro- modal fibers, as shown in *Table VIII*.

TABLE VIII. Tukey-Kramer Procedure for Air Permeability.

Group Code	a to b	a to c	a to d	b to c	b to d	c to d
Cotton	S	S	S	S	S	S
Tencel LF	S	S	S	S	S	S
Tencel STD	S	S	S	S	S	S
Bamboo	S	NS	NS	S	S	S
Modal	S	S	S	S	S	S
Mico-Modal	S	S	NS	S	S	S

S = Significant, NS = Non Significant

COLOR STRENGTH

Figure 9 shows the relation between silicone type and fabric color strength for different fiber materials. It noted that the micro silicone finished fabric has the greatest color strength. This is because the micro silicone penetrates into the fabric, while the macro silicone remains on the fabric surface. The Bamboo fabric samples have the highest color strength, while cotton fabric samples have the lowest color strength values. This is because the Bamboo has micro holes and micro gaps in its structure and the moisture content of the Bamboo is higher than the other fibers. As a result, the degree of the dye uptake of the bamboo fabrics is greatest [26, 31].

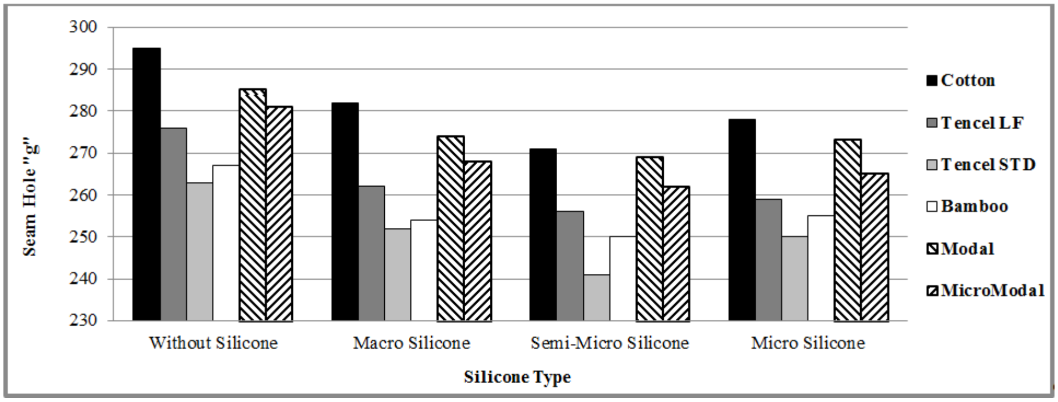

FIGURE 7. Relation between silicone type and fabric seam hole at different fiber material.

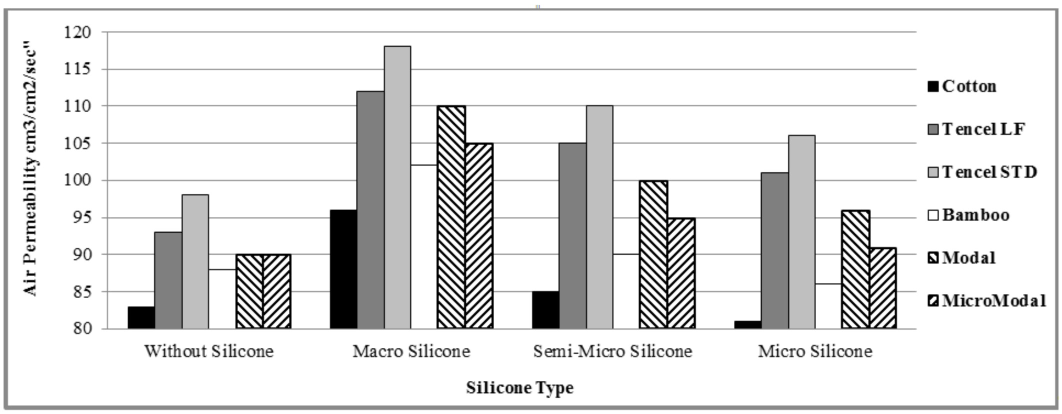

FIGURE 8. Relation between silicone type and fabric Air permeability at different fiber material.

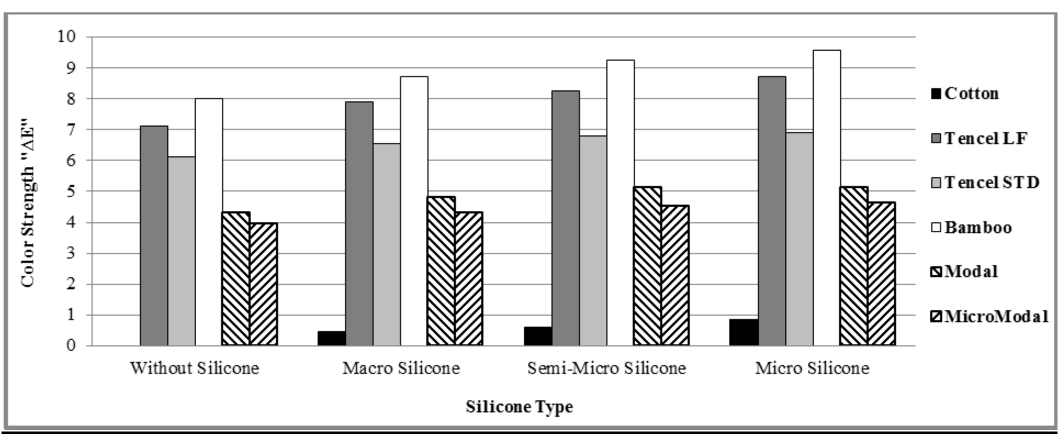

FIGURE 9. Relation between silicone type and fabric color strength at different fiber material.

FASTNESS TO DRY AND WET RUBBING & COLOR FASTNESS "STAINING" AND COLOR CHANGE AFTER WASHING

All softeners have no effect on the dry color fastness of samples [32]. All the tested samples have high dry rubbing fastness values. The relation between silicone softener type and fastness to wet rubbing, color fastness "staining" and color change after washing for the fiber materials is illustrated in *Figures 10, 11 and 12*.

The macro silicone softener has more fastness to wet rubbing & color fastness "staining" and color change after washing values than the other fabrics finishing. The macro silicone creates a protective layer above the fabric surface which acts as a barrier and thus improves the color fastness.

Changes in softener type has the same effect on all studied fibers as regards fastness to wet rubbing & color fastness "staining" and color change after washing.

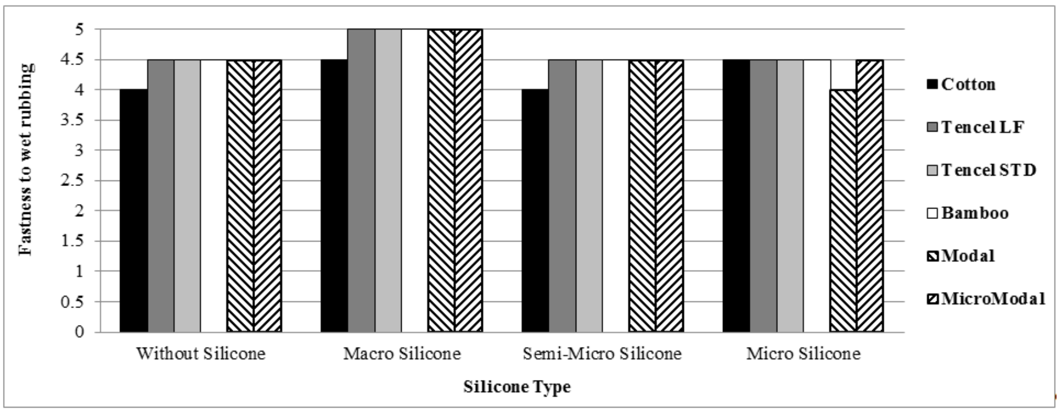

FIGURE 10. Relation between silicone type and fabric fastness to wet rubbing at different fiber material.

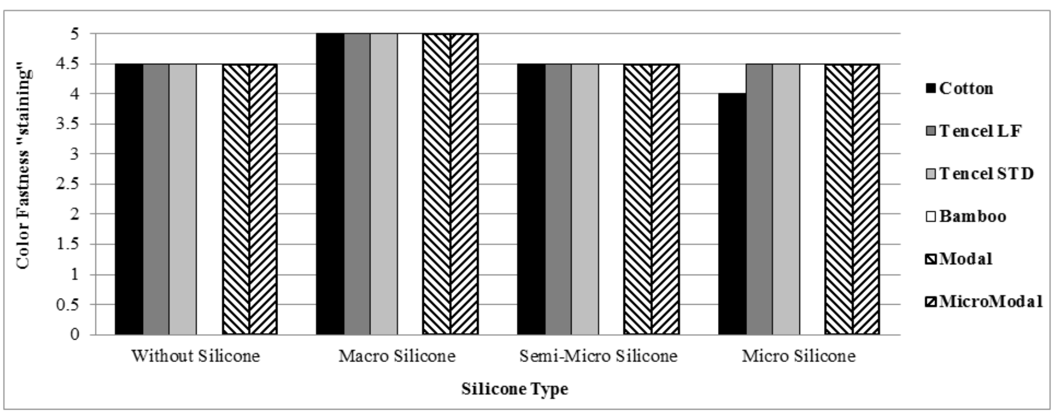

FIGURE 11. Relation between silicone type and fabric color fastness "staining" at different fiber material.

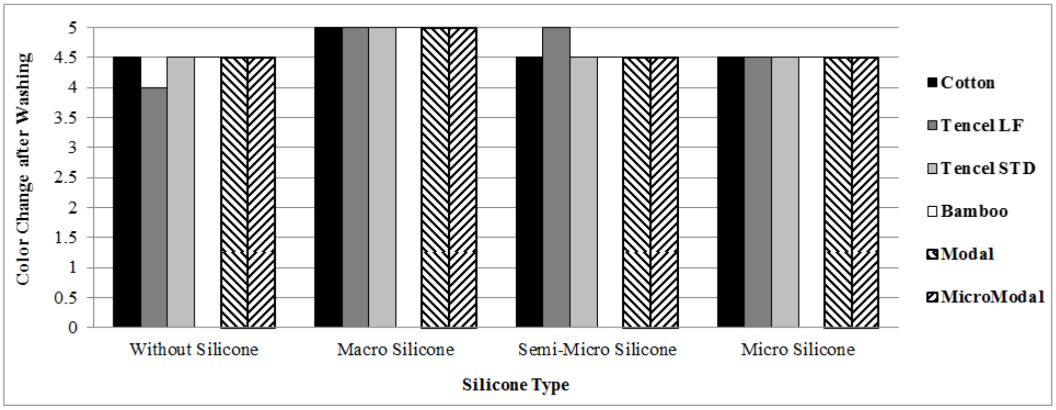

FIGURE 12. Relation between silicone type and fabric color change after washing at different fiber material.

CONCLUSION

For the Egyptian Giza 88 cotton, the micro silicone improves the pilling performance due to the penetration of the micro silicone particles inside the fabric. The pilling grade of Tencel STD fabrics finished with macro silicone is higher than those without silicone, followed by semi-micro and then micro silicone. For the Bamboo samples, the pilling grade of fabrics finished with micro silicone is the same those finished with macro silicone, followed by semi-micro and then without silicone. The softener improves pilling performance of the fabrics between 4000 and 7000 rubbing cycles, due to the lower strength of bamboo fibers.

For the micro-modal samples, the pilling grade of fabrics finished with micro silicone is greater than semi-micro followed by fabric without silicone and finally macro silicone. This is due to weak bonds between micro-modal fibers and macro silicone particles.

The fabric without micro silicone has the greatest seam hole value and the semi-micro silicone has the least seam hole value. The fabric treated with macro silicone has higher air permeability than micro silicone fabric. This is because the micro silicone penetrates the fabric and blocks the pores.

The macro silicone softener has more fastness to wet rubbing & color fastness “staining”, and color change after washing values than other studied finishing methods. The macro silicone creates a protective layer above the fabric surface.

Changes in softener type have the same effect on all studied fibers for fastness to wet rubbing, color fastness “staining” and color change after washing.

Further studies are planned on these finished methods using different types of yarn spinning technologies and fabric structures.

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