PHYSICAL AND MECHANICAL PROPERTIES OF EGYPTIAN COTTON KNITTED FABRICS FINISHED WITH DIFFERENT SILICONE PARTICLES

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Abstract

The objective of the textile finishing is to develop the suitability and serviceability of the garment and to follow the ever-changing requirements of the fashion market. For improving softness and handle of cotton fabric, silicone treatment softeners are used. Silicone softeners improve fabric feel, softness, drape, and absorbency to a higher extent. In this comprehensive research, the effect of applying different silicone softeners on some physical and mechanical properties of single jersey knitted fabrics was assessed. Consequently, commercially available silicone softeners with four various particle sizes (macro, semi-micro, micro, nano) were applied on fabrics produced from different 100% cotton Giza 86 yarn types (ring spun, ring spun singed, ring spun singed mercerized and compact). The impact of using different silicone softeners on fabric pilling performance, bursting strength, seam hole, flexural rigidity, handle force, air permeability, water vapor permeability, wettability, immersion time, dimensional stability, Spirality, color strength, fastness to dry rubbing, fastness to wet rubbing and fastness to washing were studied. Results have shown that the pilling resistance of fabrics treated with nano silicone is more than micro followed by semi-micro and then macro silicone. The nano silicone penetrates to the inner of the fabric surface and spreads homogeneously inside the cotton yarn. The fabric produced from the ring spun singed mercerized yarn has maximum pilling grade. The average bursting strength loss due to silicone treatment was high for of macro softener-treated fabrics and low in case of nano softener-treated fabrics. Among all treated samples, the compact yarn has the best color fastness to rubbing, color fastness "staining" and color change after washing because of its packed structure, while fabrics produced from ring spun mercerized cotton, has the worst color fastness and color change.

Introduction

Cotton is one of the most generally applied fiber in the textile industry. During their processing, cotton fabrics are subjected to a variety of chemical treatments. [Chattopadhyay et al. 2010 and Tzanov et al. 1999]. Finishing of cotton fabric is considered as a last stage in the fabric manufacturing process and the essential opportunity to get the desired attributes, serviceability and functional properties according to customers' requirements. The finishing of textiles with materials that enhance their service merits has been a common work for many decades. [Paul 2015 and Savin et al. 2008]. Novel textile finishing's presenting high add-in value to fabrics are achieving more value by customer market.

The finishing of fabrics with Softeners becomes an essential finishing technique of many after-treatment applications in the textile finishing. Softeners are classified based on their ionic properties and can be cationic, anionic, non-ionic, reactive, amphoteric and silicone softeners. [Chattopadhyay et al. 2010 and Parvinzadeh et al. 2008]. The softeners are commonly known as the best substance for improving the softness and handle of the fabric. [An-an 2005]

Silicone softeners can improve specific properties to cotton fabrics such as softness, smoothness, elasticity, drapability, flexibility, wrinkle recovery, crease resistance, tear strength, and abrasion resistance as well as aesthetic feel than other softener types. [Jang et al. 1993, Philippe et al. 2004, Tzanov et al. 1998 and Gutiérrez et al. 2009].Therefore, the use of silicone softeners has become well-known in the textile industry. The suitable type of softener should be determined after investigating the composition and characteristics of the fabrics. [Chattopadhyay et al. 2010 and Paul 2015]. Generally, the silicone softeners are available in different particle sizes and shades as follows: macro (150– 300 nm, milky), semi-micro (80–120 nm, hazy) and micro (below 40 nm, transparent). Lately, nano silicone has been generated with a particle size less than 10 nm. [Choudhury et al. 2012].

Silicone softener treatment enriched the pilling resistance and air permeability of regenerated cellulosic fabrics finished with silicone softeners. [Sarioğlu et al. 2015]. Saraf et al. 2007 studied the performances of different types of marketable softeners, where this research illustrated that the micro silicone provides better handle accompanied with good surface smoothness.

The particle size of the softener influenced the colour change significantly after treatment. [Taşkın et al. 2014]. Macro silicone softener enhanced the colour fastness while using micro softener decreases strength and stiffness of the fabric. [Jatoi et al. 2015].

The silicones reduce friction between fibers, which leads to increase fiber mobility; so, the fabric properties are greatly influenced. The improved penetrability and lubrication of smaller-sized nano silicones into textile fabrics provides the promising amazing soft feel and other essential properties. [Celik et al. 2010, Holmes 2007, Rajendran et al.2010 and Habereder et al. 2002].

Macro silicone provided the fabric with a softer hand and color fastness to wet rubbing while nano silicone gave less color fastness after wash and higher colour strength. [Begum et al. 2012]. The nano silicone improved the fabric softness and wrinkle recovery against traditional softener, while, it has an adverse impact on fabric properties like tensile capability, abrasion resistance and wettability. Also, Fabrics finished with nano silicone displayed better pilling performance. Nano-silicone treatment did not impact color fastness characteristics of knitted fabrics. [Chattopadhyay et al. 2010 and Celik et al. 2010]

The principle of compact yarn is to allow the fibres to be collected aerodynamically after the main draft. The spinning triangle is decreased to a minimum and all the fibres are almost completely integrated into the yarn body. Individual fibers are straightened and arranged parallel with one another through aerodynamic forces, resulting in the reduction of protruding hairs. [Website of Properties of Knitted Fabrics made from Ring and Compact Spun Yarns].

Artzt 2003, Gahlert et al. 2003, Mourad et al. 2006, Mourad et al. 2003, Pinar et al. 2004, Momir et al. 2003 and Abdus et al. 2014 have compared many studies about the properties of compact spun yarns against regular ring-spun yarns. These studies have shown the reduced yarn hairiness, improved strength and elongation properties with a reduced twist level, which supports in increasing compact yarn production speeds

The most important properties of compact spun yarns are their high breaking strength, elongation and low hairiness level. [Kim et al. 2006 and Omeroglue et al. 2007]. Omeroglue et al. 2005 investigated that fabrics woven from compact yarns exhibit lighter in color and greater in lightness compared to others produced from ring-spun yarns. In contrast, Dash et al. 2002 stated that fabrics knitted from compact yarns show higher K/S values than others produced from ring spun yarns. Also, Ozgouney et al. 2008, investigated that the air permeability, K/S and rubbing fastness are not affected by changing spinning yarn method. Taskin et al. 2007 stated that there is no any significant differences in the color strength and fastness to rubbing of fabric woven from compact and ring yarns. A.T. Ozgouney et al. 2008 studied that the fabric knitted from compact yarn has higher bursting strength, pilling performance and abrasion durability and good rubbing fastness compared to others produced from ring yarns. Also, Das et al. 2007 investigated that twill fabric woven from compact yarn displayed higher air permeability, thermal conductivity and wicking merits compared to others produced from normal ring yarns.

The fabrics manufactured from compact-spun yarns have better pilling performance and tensile strength values against the fabrics woven with singed ring-spun yarns, where the singeing process influences positively the pilling degrees. Furthermore, compact-spun yarns have features compared with conventional ring-spun yarns, like cancelling the requisite for the singeing processes. [Cankut et al. 2007].

Mercerization is applied to develop characteristics such as dye affinity, luster, smoothness, shrinkage and tensile strength of the cotton fabrics. [Kim et al. 2006 and Taskin et al. 2007]. The mercerization method makes the surface of the fabric free of fuzz and provides clean fabric surface. This enhances the fabric appearance and develops the luster of fabric considerably. The fabric drape is less showing that the fabric has come to be stiff and has a very harsh feel after dyeing stage. [Murugesh et al. 2013]. Mercerization generates fibre arrangement in the cross-section of the ring spun yarn, which is achieved by stretching. Hence, this process impacts the fibre arrangement in regular ring yarns more than in compact yarns, where the fibres are already well-arranged inside compact yarns. Consequently, if the fabrics are mercerized, there will be no obligation to use compact yarns, which are more costly than normal ring yarns. [Cankut et al. 2007].

The present work was, therefore, focused on analyzing the physical and mechanical behavior of single jersey knitted fabric made out of cotton Giza 86 with four different yarn types such as ring spun, ring spun singed, ring spun singed mercerized and compact; and with different silicone particle sizes treatments as nano silicone, micro silicone, semi-micro silicone and macro silicone. The silicone-based applications were performed to the knitted samples through padding method. This study will be a great help to the researchers who are investigating the fabric characteristics for various dress wears.

Material and Methods

Material

In this study, 30/1, 100%, Egyptian cotton Giza 86, ring spun, singed ring spun, singed mercerized ring spun and compact yarns were used to produce single jersey knitted fabrics. All the cotton yarns were obtained using the same cotton fiber. For this research, cotton fibers of 31.8 mm length, 86 % uniformity, 42.6 g/tex strength, 4.9 % elongation, 3.87 micronaire, 74.5 degrees of reflectance "Rd", 9.2 yellowness "+b", 66 trash count and 79% maturity were used. Also, the properties of the cotton yarns used to knit all single jersey fabrics are exhibited in table 1.

Fabric Manufacture

The single jersey fabrics were knitted on the single-jersey circular knitting machine with 28 gauge, ORIZIO, 26-inch diameter, 75 feeders and with 2220 total number of needles. The loop length was adjusted at 2.6 mm yarns. The pretreatment and dyeing processes of raw fabrics were carried out on the bulk production. After knitting stage, the fabrics were finished first with scouring machine followed by dyeing machine, balloon squeezing machine, tensionless drying machine and then compactor machine. The design of experiments applied in this investigation is presented in table 2, where cotton yarn type and silicone softener type were selected for every fabric type.

Table 1. Yarn Properties

	Ring Spun (R.S.)	**Singed Ring Spun (R.S.S.)**	**Singed Mercerized Ring Spun (R.S.S.M.)**	**Compact**
Ne	30/1	30/1	30/1	30/1
TPI	20	20	20	20
Irregularity (CV %)	12.2	12	12	11
Thin places (-50%)	0	0	0	0
Thick places (+50)	10	11	12	6
Neps	22	24	24	7
Breaking Force (g)	455	446	413	466
R K M (Kg*Nm)	23.5	22.5	20.5	24.5
Elongation (%)	6	4.3	4	5.6
Hairiness (H)	5.5	3.3	2.7	4.1

Table 2. Design of Experiments

Group Code	**Sample no**	**Cotton Yarn Type**	**Silicone Type**
a	1	Ring Spun	Reference " Without"
	2	Ring Spun Singed	
	3	Ring Spun Singed Mercerized	
	4	Compact	
b	5	Ring Spun	Macro
	6	Ring Spun Singed	
	7	Ring Spun Singed Mercerized	
	8	Compact	
c	9	Ring Spun	Semi-Micro
	10	Ring Spun Singed	
	11	Ring Spun Singed Mercerized	
	12	Compact	
d	13	Ring Spun	Micro
	14	Ring Spun Singed	
	15	Ring Spun Singed Mercerized	
	16	Compact	
e	17	Ring Spun	Nano
	18	Ring Spun Singed	
	19	Ring Spun Singed Mercerized	
	20	Compact	

Methodology

The influence of applying different silicone softeners on some physical and mechanical properties of single jersey knitted fabrics produced with different yarn types were evaluated for significance using ANOVA single factor. As well, multiple comparisons by Tukey-Kramer Procedure analysis was used to see the significant difference between all silicone treatment groups. The statistical analysis of the pilling, color strength, rubbing fastness "wet and dry" and color fastness to laundering "color change and staining" properties of the fabrics was not evaluated because of the subjective evaluation of these properties.

Fabric Dyeing and Finishing

All Fabrics rolls are dyed in the same dyeing machine to process all the samples in the same working conditions. First of all, fabrics were wetted for oil removal for 30 minutes with using 1g/L soda ash, 0.5 g/L wetting agent "Seta wet HNG". Thereafter, the fabrics are scoured in the same scouring bath with ingredients presented in table 3 for a time 45 minutes, wherever the temperature was reached to 98 c', then rinsing with hot water for 10 minutes at 80 c' and lastly rinse with 0.5 g/l acetic acid for 20 minutes at 70 c' to neutral PH.

After the scouring process, all fabric samples were dyed at the same dyeing bath with a dark red color shade in Alkan high temperature, Jet dyeing machine at 60 °C temperature for 4 hours. The dyeing recipe is displayed in table 4. Subsequently, the hot rinsing stage was processed at 80 °C for 10 minutes. Afterwards soaping process was applied at 98 °C for 30 minutes for two times, then by rinsing process at 80 c' for 10 minutes. Finally, a softener exhaust bath was conducted on the fabrics inside the same Jet machine with 5 % fatty acid "Seta Soft Blk", 1% polyethylene "Adaline" and Acetic Acid to get PH 4.5-5, at 50 C' for 30 min.

Lastly, the treatment of the cotton fabrics with silicone softeners was carried out to improve the mechanical properties and handle by using the padding method which provides a smooth distribution of the liquor. Each silicone softener was prepared in an external tank with adding 1 % silicone, 0.5 % polyethylene, 2 % fatty acid and acetic acid to get PH 5.5 at 40 °C. After that, the silicone mix was pumped to the padder bath of the squeezing machine with 16% of fabric weight. The fabrics rolls were treated by padding process in which the fabric is impregnated with the solution of the silicone, where every samples group were padded individually with each type of silicone in the padder of the squeezing machine with a suitable speed and a sufficient overfeed speed of the squeezing machine. Lastly, the samples rolls were dried at tensionless drying machine and consequently finished through the compactor machine.

Table 3. Scouring Recipe

Liquor ratio	1:10
Wet Soft "Anti-crease material, g/l	1
Wetting *agent* "Seta wet HNG", g/l	1
Soda Ash "Sodium Carbonate", g/l	5

Table 4. Dyeing Recipe

Liquor ratio	1:10
GB Kol SN100, g/l	1
Nova Cron red FNG, %	4.5
Remazol Blue, %	0.15
Vacuum salt, g/l	80
Soda Ash, g/l	20

Fabric Testing

The single jersey samples were left 72 hours in standard conditions (Relative humidity = 65 + 2% & Temperature = 20 + 2 c') and the physical and mechanical properties were tested.

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

The pilling grade, bursting strength and stiffness of fabric was tested according to ASTM D3512, "Random Tumble Pilling Method", ASTM D3786 "diaphragm method" and ASTM D1388 "heart loop test". The pilling grade was assessed visually according to ASTM pill grade photographs with a scale of 1 to 5 (from the worst to the best).

Also, handle force was determined by the fabric hand-meter device using the idea of the withdrawing the specimen over a circular ring wherever the maximum value of the withdrawing force occurs once the sample has nearly passed over the ring.

Needle penetration force value has been tested with L&M Sewability apparatus (L&M Sewability Tester Manual, 2010 - John Godrich), established in the Textile Department at the University of Leeds/England. It evaluates fabric sewability by observing the force necessary for a 90s ball point needle to penetrate a fabric sample (100 times). A start value was applied depending on the fabric weight "g/m^2", where it was 75 cN for this study. Good sewability is detected by getting a lower needle penetration force value.

The fabric shrinkage and Spirality were evaluated using AATCC Test Method 135-2004 "Dimensional Changes of Fabrics after Home Laundering" and AATCC Test Method 179-2004 "Skewness Change in Fabric and Garment Twist Resulting from Automatic Home Laundering" respectively.

Additionally, the fabric water vapor permeability, air permeability, gain%, and immersion time were measured using the standards of ASTM E96, ASTM D737, BS 3449 and ‘‘Textile testing by Jewel, Jewel Raul, 2005, page 58, sinking test” respectively.

The color strength was measured on the data color device. Where the sample number 1 knitted from ring spun yarn and without softener silicone has been taken as a reference sample during the measurement.
In addition to, the fastness to rubbing “in wet and dry state” and color fastness to laundering "color change and staining" were tested using AATCC test method 8-2004 and AATCC test method 61-2003 respectively.

Results and Discussion

The specifications of all the produced samples numbers are displayed in table 5. ANOVA single factor shown that there is a significant difference for every yarn type having different silicone particles for all studied samples.

Table 5. Specification of knitted Fabric Samples

Sample no	Cotton Yarn Type	Silicone Type	Courses/cm	Wales/cm	Fabric Weight "g/m^2"	Thickness "cm"
1	Ring Spun	Without “Reference”	21.8	15.4	161	0.041
2	Ring Spun Singed		22	15.1	158	0.039
3	Ring Spun Singed Mercerized		20.3	16.2	168	0.042
4	Compact		20.8	15.8	164	0.036
5	Ring Spun	Macro	22.6	15.2	150	0.041
6	Ring Spun Singed		22.6	14.8	147	0.04
7	Ring Spun Singed Mercerized		20.6	15.8	155	0.043
8	Compact		21.4	15.5	153	0.038
9	Ring Spun	Semi-Micro	22.6	14.9	154	0.042
10	Ring Spun Singed		23	14.5	151	0.041
11	Ring Spun Singed Mercerized		21.2	15.5	159	0.044
12	Compact		21.8	15.2	157	0.039
13	Ring Spun	Micro	24.2	14.7	157	0.043
14	Ring Spun Singed		24.2	14.4	155	0.042
15	Ring Spun Singed Mercerized		22.4	15.1	162	0.045
16	Compact		23.3	15.1	160	0.04
17	Ring Spun	Nano	24.6	14.2	157	0.044
18	Ring Spun Singed		24.9	13.9	155	0.043
19	Ring Spun Singed Mercerized		23.2	14.8	163	0.046
20	Compact		23.8	14.4	161	0.041

Pilling Grade

Pills are described as small balls of fibres formation accumulated at the fabric surface and entangled by the moderate frictional action during production or wearing. These pills are soft but tightly held on the material surface. During abrading of the surface of fabric, some fibers from the yarn surface become liberated and loose, and after additional abrasion caused entanglement on its surface. These entangled fibers form pills on the fabric surface accompanied with an undesirable appearance. [Website of Properties of Knitted Fabrics made from Ring and Compact Spun Yarns].

The relation between silicone type and pilling grade for different yarn types is illustrated in figure 1. The pilling grade of the single jersey fabrics finished with nano silicone is more than micro followed by semi-micro, macro silicone and then without silicone. The nano silicone has the superior effect in improving the pilling performance, where it penetrates to the inner of the fabric surface and spreads homogeneously inside the cotton yarn. The macro finished fabric shows an indication for a severe disintegration occurred for the whole yarn compared with the micro and nano finishing. In general, the silicones lubricate the surface of the separate fibres and the yarns in the textile fabrics to get down friction among them and let them move over one another more regularly. Therefore, the lubrication influence of nano treatment in the individual fibre level is essential in countering any pills formation, the nano silicone technique reduced the contact of fiber-fiber, therefore, the fiber could move independently. [Burcu et al. 2017].

Also, for nano finish, the fabric surface becomes smoother which leads to decrease the friction during the pilling test. Therefore, the accumulation of the pills on the fabric surface becomes less. On the other hand, macro silicone treatment settles and deposits on the fabric surface and gives the fabric the permission to gather more pills on its surface.

According to types of yarn, the fabric produced from the ring spun singed mercerized yarn has maximum pilling grade and fabric knitted from the conventional ring spun yarn the least pilling value because the ring spun singed mercerized yarn has less protruding fibers on its surface. Additionally, the research results illustrated that the fabrics produced from compact yarns displayed better pilling performance than ring spun fabrics. [Nilgün et al. 2005].

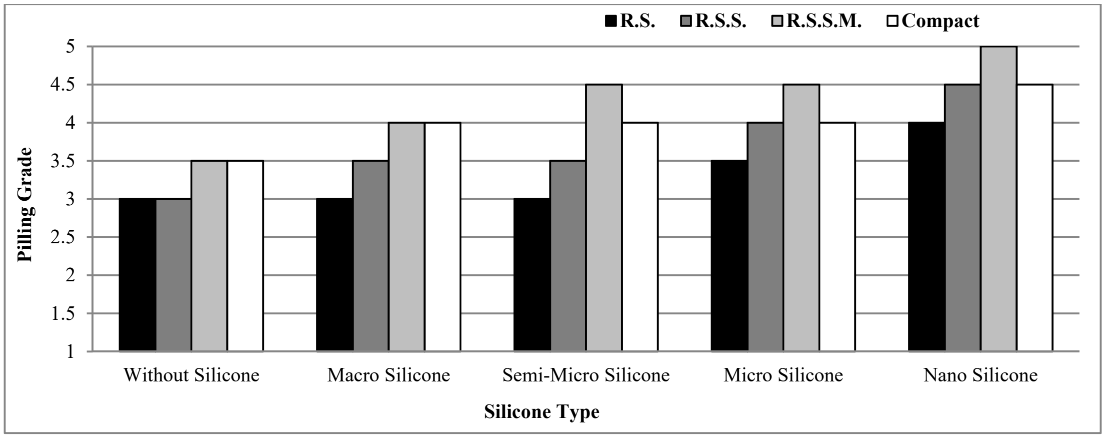

Fig.1: Relation between silicone type and fabric pilling grade at different yarn types

Bursting Strength

The relation between silicone type and bursting strength for different yarn types is illustrated in figure 2. For all fabric samples, the bursting strength was highly influenced by the particle size of the silicone softeners. It could be noticed that after the silicone treatments, the bursting strength decreased. The average bursting strength loss due to silicone treatment was superior in the case of macro softener finished samples and lowest for nano softener finished samples.

This is related to the silicone solution, which lessens the actual friction among the fibers in yarn and between yarns inside a fabric. [Chattopadhyay et al. 2010]. This decreasing of friction creates more slippage of fibers and yarns, resulting in lessening the value of bursting strength load and heighten in break extension.

Keeping in mind the particle size of the softeners, the macro silicone treated samples provides the least bursting strength results.

Furthermore, samples knitted from compact yarns shown better bursting strength values than other yarns. In general, mercerization increases yarn tenacity by improving fiber packing. It should be expected that the fabrics produced from mercerized yarn show higher bursting strength against the other fabrics, due to the decrease of internal stresses and the deconvolution of the fibres in the yarn during the swelling process. [Murugesh et al. 2013]. But unfortunately, the mercerization process has a negative effect on the bursting strength of the fabric produced from single singed mercerized yarn as it lessens single yarn's strength, unlike ply yarn.

Multiple comparisons by Tukey-Kramer Procedure analysis have cleared that there is a significant difference between all silicone treatment groups.

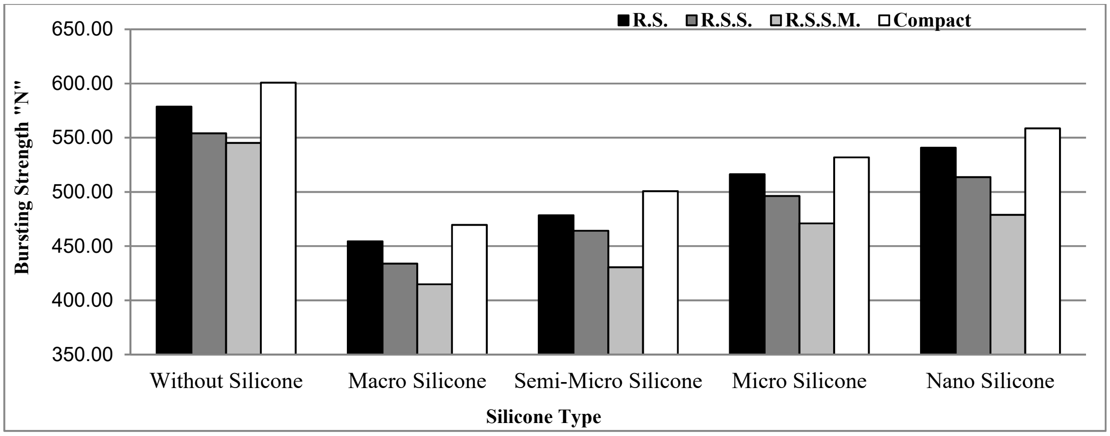

Fig.2: Relation between silicone type and fabric bursting strength at different yarn types

Seam Hole

The relation between silicone type and seam hole for different fiber material is shown in figure 3. Sewing hole defect is a very disturbing problem for the knitted garments and this defect is due to the fabric resistance to the penetration of the sewing needle during sewing stage. Silicone finishing straightway affects the spaces inside the fabrics and therefore, the sewability process of the fabrics is influenced positively. [Alime et al. 2015].
The silicone treatments enriched the sewability. Particularly, nano silicone treatment has the least needle penetration force while without silicone has the greatest seam hole. Because the molecule size is lower than the other types of used silicones, giving smooth and soft merits.

The change of yarn types has an effect of the seam hole force. Samples knitted from ring spun singed mercerized yarn has the least seam hole and others produced from conventional ring spun yarn has maximum seam hole because the mercerization process contributes in removing yarn hairiness and improving the smoothness of the fabric surface. In addition to, the compact yarn heighten the opportunity of the fabric to not have a problem with the seam hole compared with normal ring spun and ring-spun singed yarns.

Moreover, multiple comparisons by Tukey-Kramer Procedure analysis have displayed that there is an actual significant difference between all silicone treatment groups.

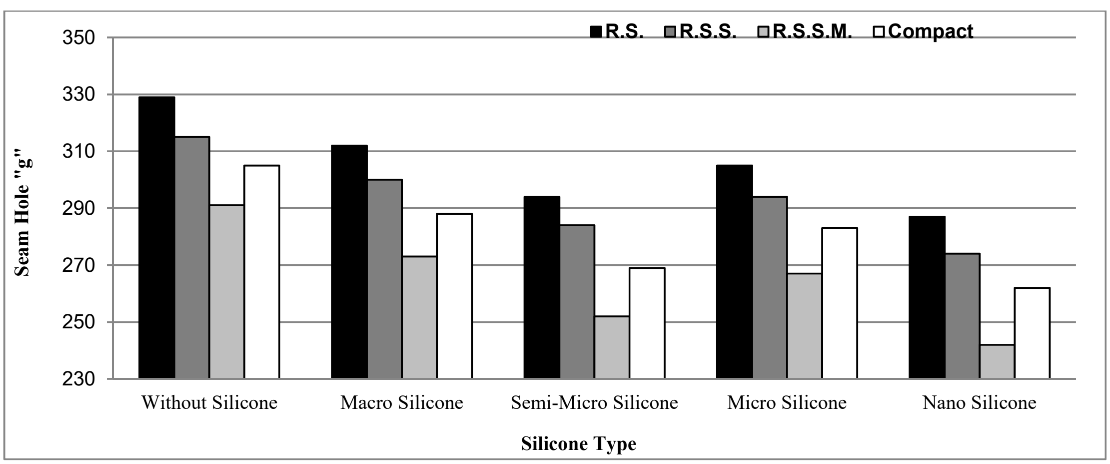

Fig.3: Relation between silicone type and fabric seam hole at different yarn types

Flexural Rigidity

Figure 4 clears the relation between silicone type and flexural rigidity for different yarn types. The recovery merit of a knitted fabric is basically controlled through the residual stresses in the yarn supporting recovery from the inter-fibre frictional restraint and bending deformation of the whole fibres in the yarn spinning process. The bending rigidity governs the handle of the fabric, where it is specified by the mutual factors of surface restraints and intrinsic stiffness of the whole fibres. The lower bending rigidity gives a higher softness of the fabric. [Choudhury et al. 2012].

Macro softeners principally deposit on the fabric surface while nano softeners penetrate more into core structure of the fabric. The macro results in a smooth surface while nano imparts inner softness accompanied with improving the softness of the surface. The micro silicone gives intermediate improving for its fabric handle property. Therefore, the bending length of untreated sample obviously shows that it is the stiffest of all fabric samples. The nano fabrics have the softest handle, the micro has the moderate and the macro finished fabrics has the poorest softness. The result is reasonably expected where the using of silicones decreases frictional restraints among fibres resulting in a soft fabric.

The ring-spun singed yarn has the least flexural rigidity followed by normal ring spun, ring-spun singed mercerized, and then compact yarns. Moreover, it is cleared that fabrics knitted from compact spun yarns are stiffer than others produced from ring yarns. [Alsaid et al. 2010 and Manonmani et al. 2013]. This is referred to the condensed fibers and better fibre integrity in the cross-section of the compact yarn, leading to higher packing density and shear behavior of these yarns accompanied with stiff effect.

Furthermore, multiple comparisons by Tukey-Kramer Procedure analysis have presented that there is an actual significant difference between all silicone treatment groups except between macro “group **b**” and semi-micro “group **c**” silicone treated fabrics for normal ring spun yarn only.

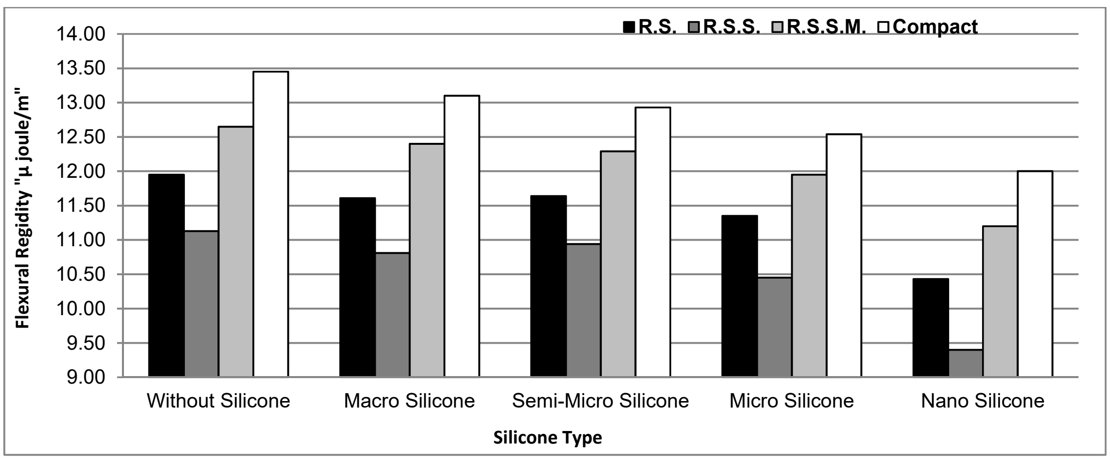

Fig.4: Relation between silicone type and fabric flexural rigidity at different yarn types

Handle Force

Figure 5 shows the relation between silicone type and fabric handle force for different yarn types. For the effect of the silicone type, silicone based softeners make the fabric permanent certainly soft hand.

While comparing the performance of four types of softeners, it can be noticed that the handle force is the least for nano softener followed by micro, semi-micro and macro silicones. Where, the macro treated fabric has least flexibility followed by semi-micro, micro and nano silicone.

The macro softener fabrics have the least softness and the nano softener fabrics have the most values. The macro softener samples have the least durability to the washing; micro softeners have a medium level while the best durability was achieved with nano softeners showing that the treatment with macro is a surface finish whereas finishing with nano is inherent inside the fibres. The macro finish generally deposits on the fibre surface, whereas the nano silicone goes through between the fibres and micro treatment takes up an intermediate effect. Therefore, the nano silicone outperformed the macro and micro silicones for the fabric handle due to its small particles that have the capability to deposit into the fiber bundle nearly completely and enter more inside the structure of the fiber and lubricate the cellulose fibrils.

Despite the mercerization stage removes the protruding fibres from the fabric surface, unfortunately, it gives the fabric a less drapability property. Consequently, the fabric becomes stiffer and less elastic as shown in figure 5. [Murugesh et al. 2013]. Also, as shown from this figure, the higher packing density of the compact yarn affects on its fabric to be less flexible than others knitted from ring-spun and ring spun singed yarns during applying the handle test. Therefore, the fabrics produced with compact yarns have the worst softness. The ring-spun singed yarn has the best touch during handle force test followed by normal ring spun, ring-spun singed mercerized, and then compact yarns.

In addition, multiple comparisons by Tukey-Kramer Procedure analysis have revealed that there is an actual significant difference between all silicone treatment groups

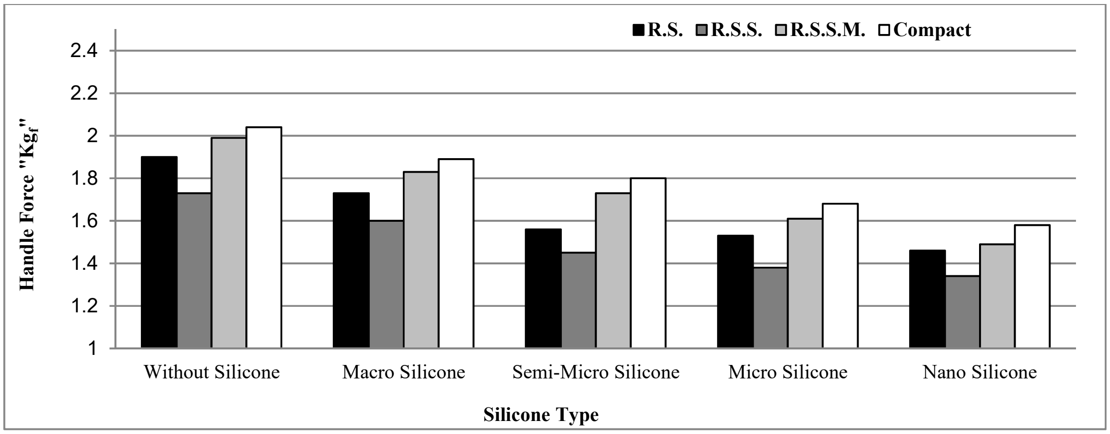

Fig.5: Relation between silicone type and fabric handle force at different yarn types

Air Permeability

The fabric transport character is air permeability, known as the passage of air flow rate per unit area through the fabric while there is a specific difference pressure between two fabric sides. The flow of outgoing gases from a human body to the surroundings and flow of fresh air to the body make the air permeability a hygienic merit of textiles, where it relies on the fabric porosity. [Mukesh et al. 2013].

Figure 6 shows the relation between silicone type and air permeability for different yarn types. For the effect of the silicone type, the macro silicone has more air permeability than nano silicone fabric and this is related to the nano silicone blocks more the porous contained in the yarn, which therefore reduces the air permeability. However, the macro silicone deposits on the fabric surface creating a growth in the fabric air permeability.

Fabric samples knitted from compact yarns have more air permeability than others produced from conventional ring spun yarns. This is referred to two phases; more hairiness accompanying with ring spun yarns blocks the pores inside the fabrics and the bulkier of ring spun yarns is considered as a hinder of the air flow through the fabrics.

Fabrics produced from mercerized yarns have the highest air permeability compared with the other samples. This is related to the fibre arrangement in the yarn cross-section. The mercerization is applied by stretching the yarn, where the fibres contained in the yarn will be arranged well than before doing this process. This decreases the loose fibres on the yarn surface.

Besides, the Tukey-Kramer Procedure analysis has exhibited that there is a significant difference in air permeability between all fabrics groups treated with different silicone particles.

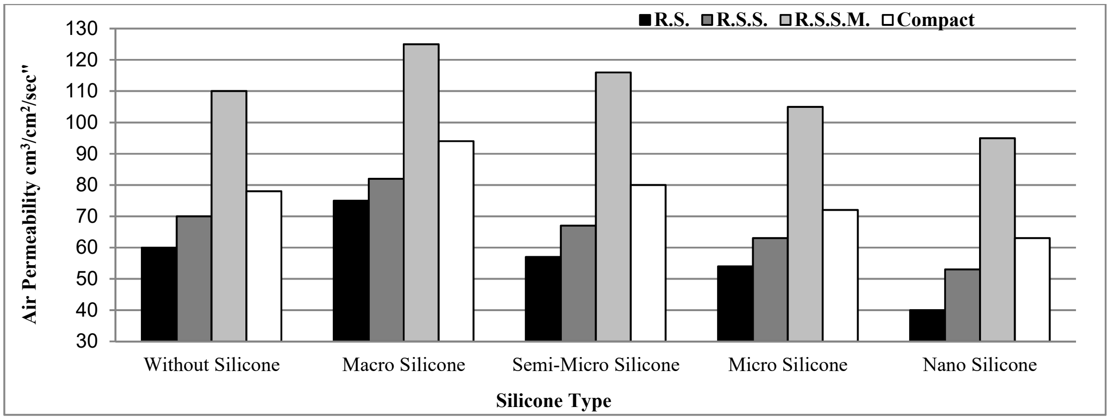

Fig.6: Relation between silicone type and fabric air permeability at different yarn types

Water Permeability & Immersion Time and Gain %:

Figures 7, 8 and 9 show the relation between silicone type and water vapor permeability, immersion time and gain % respectively at different types of yarn. According to the type of softener, macro treated samples tend to have the best water vapor permeability, high gain % and least immersion time than the nano-treated samples. The surface characteristics of fibres in nano finished samples are different than for the samples finished by macro softeners which may be attributed to the deposition of macro softeners on the fibre surface and the penetration of nano softener into the interior of the fibre. Also, that's because macro softener has the biggest particle size settled on the fabric surface making it easier to pass water vapor through it and tend to easily absorb water. Unlike nano silicon which has extra small particles that absorbed inside the fabric making it difficult for water vapor to get through and for the fabric to immerse quickly during immersion time test.

Additionally, the wettability or gain % behaviour of different fabrics relies on the capillary action and capillary rise in contained yarns. The wettability depends on the capillaries number, size of the capillary and its allocation, which are affected by packing of fibres inside the yarn. [Wiener et al. 2003]. The wettability property decreases for compact yarn fabrics than ring spun yarn. This is because as yarn compactness grows, some capillaries begin to collapse, and this leads to lessen wicking capability.
Moreover, according to the type of yarn, the mercerized yarn has higher gain % and less immersion time than compact yarn. That's because of round cross-section and big diameter achieved for the mercerized yarn which creates larger gaps between yarns inside the fabric making it easy for water to be absorbed very easily.

Furthermore, the mercerized yarn has the highest water vapor permeability while the ring spun yarn has the least value. That's because the high hairiness level covered the ring spun yarn which prevents the water vapor to go through the yarn structure easily.

Knitted fabrics produced from compact yarn had higher water vapour permeability values than others knitted from ring spun and ring-spun singed yarns. This is related to better yarn packing density and lower hairiness degree of the yarns.

Multiple comparisons by Tukey-Kramer Procedure analysis have revealed that there is an actual significant difference between all silicone treatment groups except for the water vapor permeability between without "group **a**" and micro "group **d**" silicone treated fabrics for normal ring spun yarn only and, for the immersion time, between macro "group **b**" and semi-micro "group **c**" silicone treated fabrics for normal ring spun and ring-spun singed yarns only.

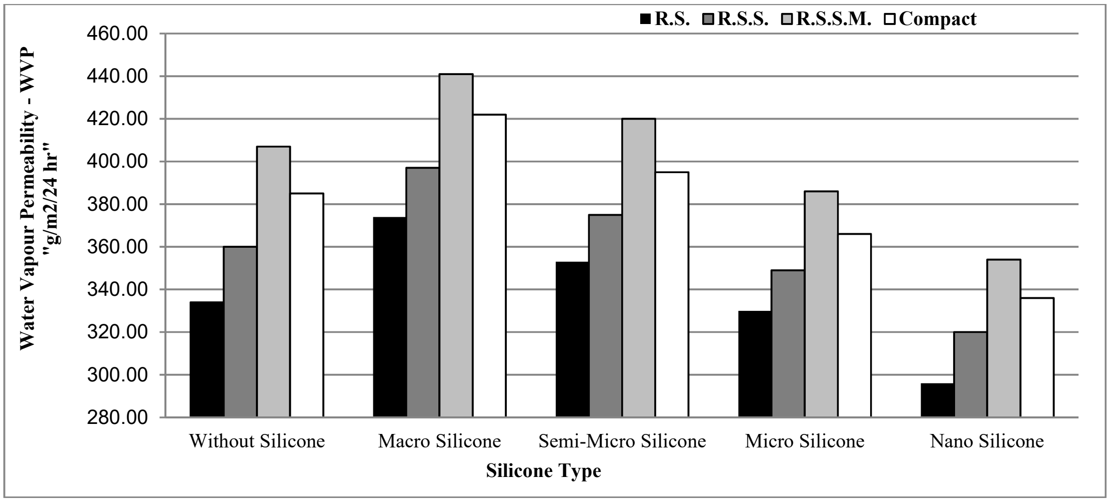

Fig.7: Relation between silicone type and fabric water vapor permeability at different yarn types

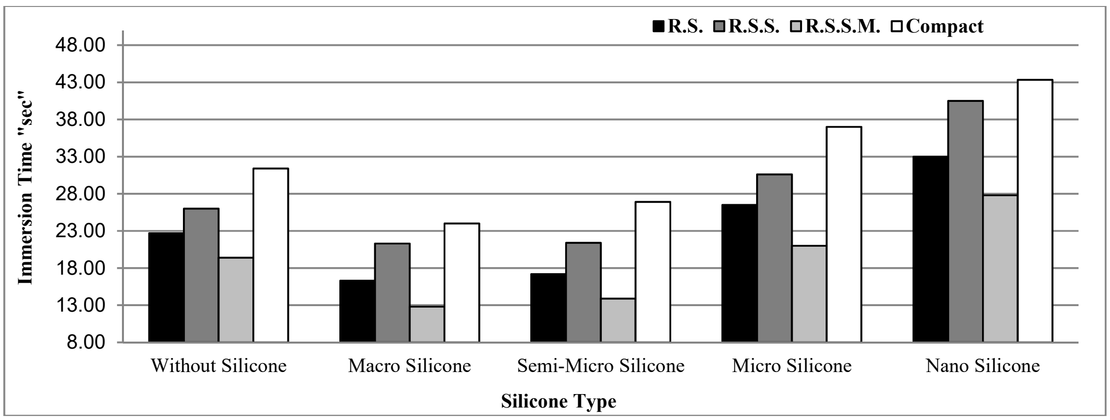

Fig.8: Relation between silicone type and fabric immersion time at different yarn types

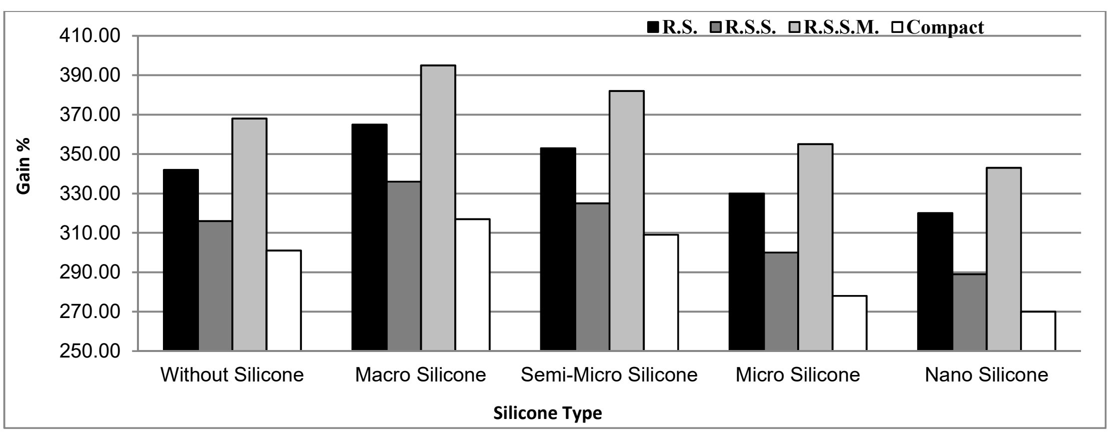

Fig.9: Relation between silicone type and fabric gain % at different yarn types

Fabric Dimensional Stability

Figures 10, 11 and 12 show the relation between silicone type and lengthwise, widthwise shrinkage % and Spirality % in turn at different types of yarn. Generally, the lower value of the length and widthwise shrinkage % means the better fabric for dimensional stability

For silicon type, the macro silicone treatment gives a fabric with high lengthwise, widthwise shrinkage % and Spirality %, while the nano silicone type gives the least values. Because nano increases fabric smoothness and gives its surface more drapability and flexibility which reflecting in improving its dimensional stability. Also, nano silicon has a magic effect in eliminating the wrapping in the fabric after repeated washings during the end use.

Also, according to types of yarn, fabric knitted from ring spun singed mercerized yarn has the highest lengthwise and the least widthwise shrinkage %, which referred to the high stiffness and a low number of courses/cm accompanied with the mercerized yarn in the lengthwise direction.
Also, this is due to the bulkiness effect happened after mercerized treatment which covers more area in the produced fabric and makes a restriction of the fabric to shrink in the widthwise direction and makes it have a high dimensional stability in this direction. Also, fabric cover of the mercerized yarn doesn't give the permission to the fabric to rotate in the long run after any following wet processing during further end use which leads to lessen its Spirality tendency.

Multiple comparisons by Tukey-Kramer Procedure analysis have presented that there is an actual significant difference between all silicone treatment groups except for the lengthwise shrinkage between micro "group **d**" and nano "group **e**" silicone treated fabrics for ring spun mercerized and compact yarns only - and as well for the widthwise shrinkage, between macro "group **b**" and semi-micro "group **c**" silicone treated fabrics for normal ring spun, and between micro "group **d**" and nano "group **e**" silicone types for ring spun singed yarns, and also between without "group **a**" and macro "group **b**" silicone types for ring spun mercerized yarn - and also for Spirality between semi-micro "group **c**" and micro "group **d**" silicone treated fabrics for ring spun and ring spun singed yarns, and between macro "group **b**" and semi-micro "group **c**" silicone treated fabrics for compact yarns only.

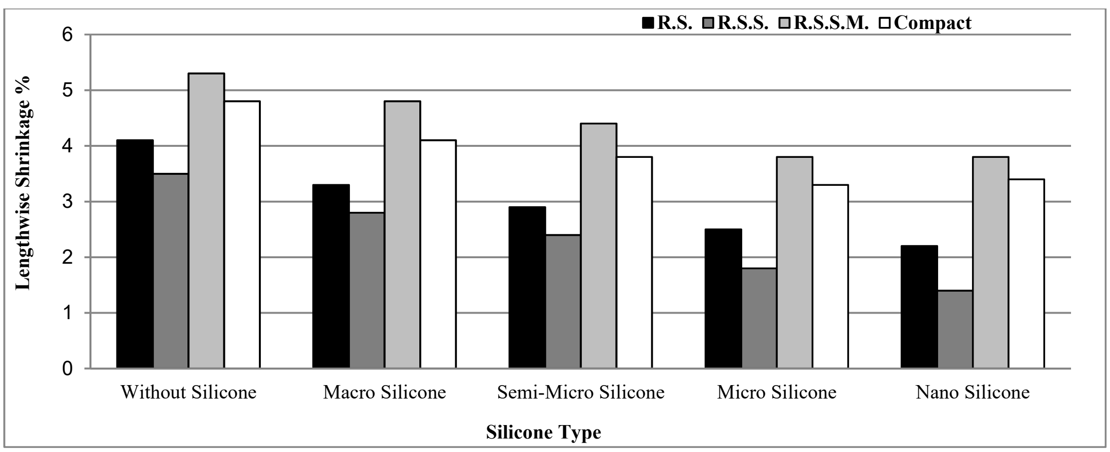

Fig.10. Relation between silicone type and fabric lengthwise shrinkage % at different yarn types

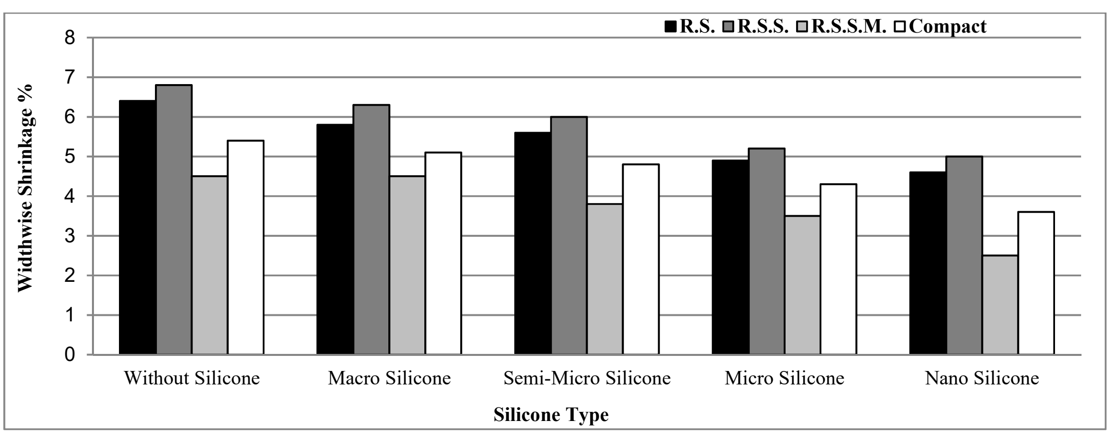

Fig.11: Relation between silicone type and fabric widthwise shrinkage % at different yarn types

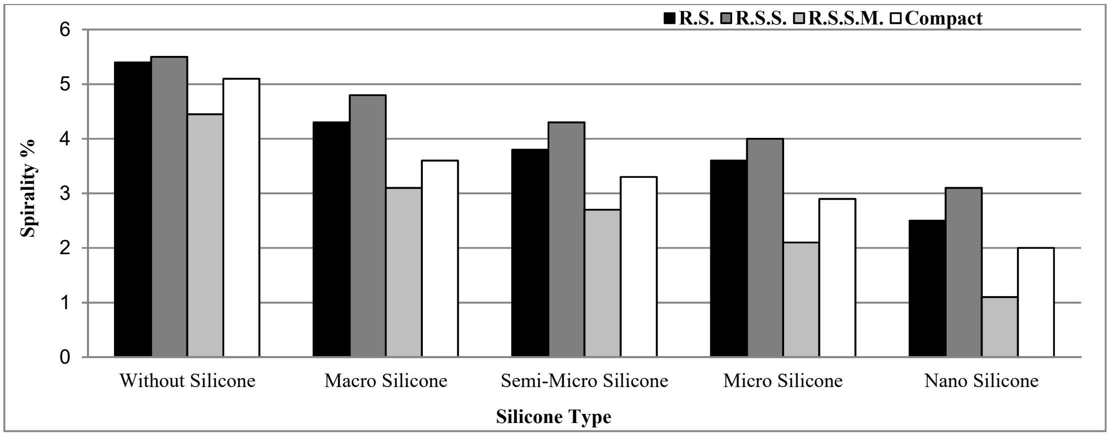

Fig.12: Relation between silicone type and fabric Spirality % at different yarn types

Color Strength

Figure 13 shows the relation between silicone type and fabric color strength for different yarn types. The nano-treated samples have more color strength than macro treated samples, that's because nano emulsion has transparent shade which doesn't effect on fabric color, unlike macro that has milky shade. Therefore, after applying nano treatment, the color of fabrics became darker. Because the transparent shade of the nano silicone reflected the light uniformly and the fabric was seen darker.

The increase in the dye uptake of the ring spun singed cotton mercerized dyed samples in comparison to the other studied yarns was due to the destruction of the crystalline regions happened during applying mercerizing process, where there is swelling and chemical, structural changes occurred for the cotton fiber. [Ihab et al. 2015]. Additionally, the orientation of the fibrils along the fiber axis improved with swelling in alkali due to the restraining impacts of the primary fiber wall.

On the other hand, the compact yarns show lower fabric color strength than other yarns. This is because the lack of gap spaces inside the compact yarns in which the dye cannot penetrate well into the fibers inside the yarn.

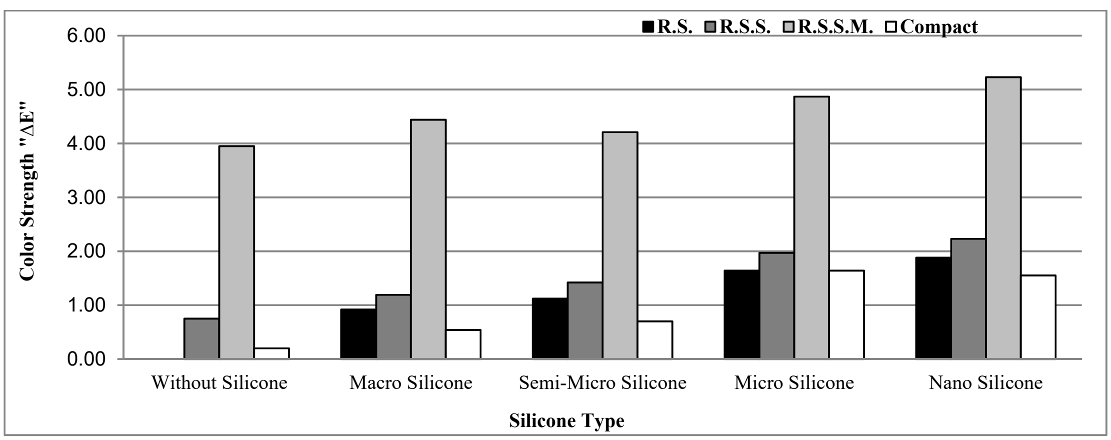

Fig.13: Relation between silicone type and fabric color strength at different yarn types

Fastness to Dry and Wet Rubbing & Color Fastness "Staining" and Color Change after Washing

The results indicated that the whole silicone applications and yarn types did not change the dry color fastness to rubbing performance of the studied samples. Figures 14, 15 and 16 show the relation between silicone treatment type and color fastness to wet rubbing, color fastness "staining" and color change after washing for different types of yarn. By using nano silicone treatment, wet fastness to rubbing of the fabrics remained nearly at the highest level while micro, semi-micro and without silicone application reduced the fastness degree conversely. This is because the nano particles give the fabric the smoothness effect which as a result there is no friction and color loss occurs during rubbing test. Also, macro silicone treatment improved wet rubbing fastness a little bit than semi-micro and micro silicone treatment.

Color fastness is usually estimated related to the loss of shade depth (color fading) and spread of staining (color bleeding). The macro and nano silicone finished fabrics have a very good resistance to color staining and color change after washing. The nano silicone displayed a somewhat lower performance with color staining and color change after washing. The macro silicon makes as a protection layer on the fabric surface, where the macro particles settle on the fabric surface. The change of the silicone type for the micro, semi-micro and without silicone has the same influence with lower values for the color fastness “staining” and color change after washing.

Moreover, from the same three figures, according to types of yarn, the compact yarn has the best color fastness to rubbing, color fastness “staining” and color change after washing because of its packed structure that makes it have the ability to get less dye uptake and lose less dye. While fabrics produced from ring spun mercerized cotton, has the worst color fastness and color change.

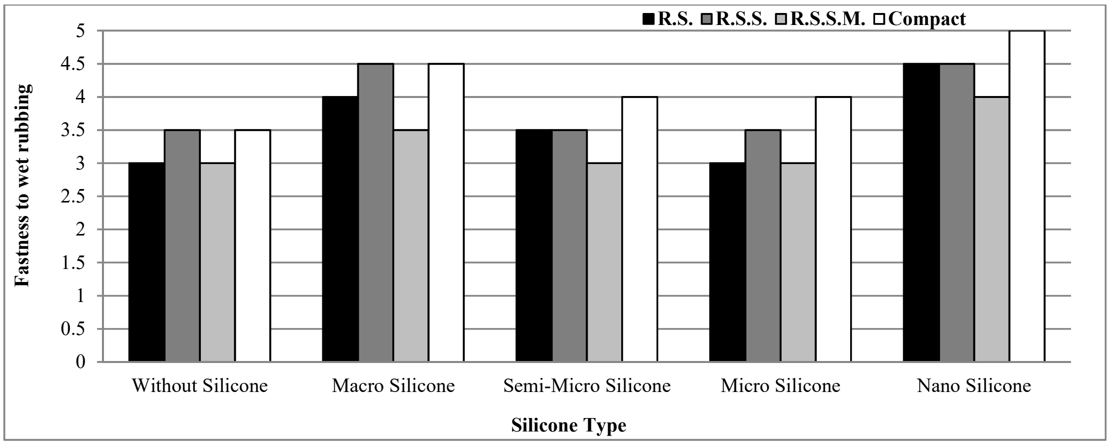

Fig.14: Relation between silicone type and fabric fastness to wet rubbing at different yarn types

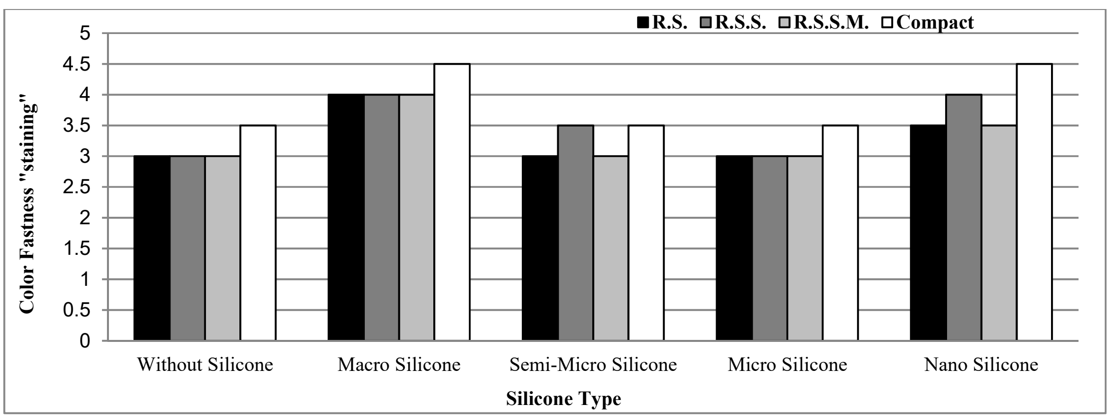

Fig.15: Relation between silicone type and fabric color fastness “staining” at different yarn types

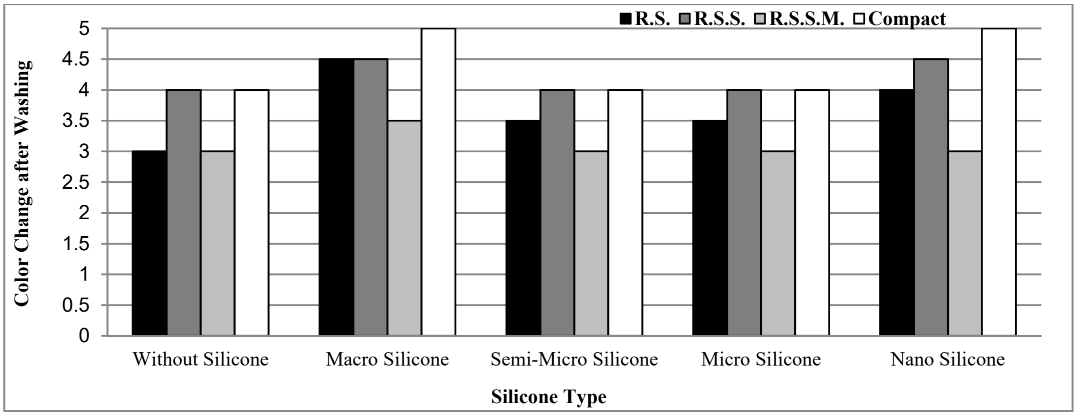

Fig.16: Relation between silicone type and fabric color change after washing at different yarn types

Summary

For the Egyptian Giza 86 cotton, the nano silicon softener has the greatest impact in improving pilling grade, dimensional stability, color strength, color fastness to wet rubbing and fabric softness and in decreasing seam hole effect and fabric flexural rigidity.

The macro silicon softener has the best air permeability, water vapor permeability, wettability (gain%) and less immersion time, and highest color fastness “staining” and color change after washing.

The bursting strength was highly influenced by the particle size of the silicone softeners negatively. The average bursting strength loss due to silicone treatment was superior in the case of macro softener and lowest for nano softener finished samples

The ring-spun singed mercerized yarn has the maximum pilling grade, air permeability, water vapor permeability, wettability (gain%), dimensional stability and color strength, and has the least immersion time and seam hole effect.

For the samples produced with the compact yarn, the bursting strength, color fastness “color staining”, color fastness to wet rubbing and color change after washing are the best.

The ring-spun singed yarn has the least flexural rigidity and the best touch during handle force test followed by normal ring spun, ring-spun singed mercerized, and then compact yarns.

The change of the softener type for the micro, semi-micro and without silicone treatment has the same effect with lower values for the color fastness “staining” and color change after washing.

Acknowledgements

The authors would like to thank the management of El-Nasr Clothing and Textile Company (*KABO*) for the facility to conduct knitting, dyeing and finishing of the fabric samples. Additionally, Special appreciations to Egyptian Spinning & Weaving Company, for supplying with the Egyptian cotton yarns. Also, Special thanks to Eng. Mohamed Kasseb, Suzhou Picardy Technology Co Ltd., for providing the chemical silicone and valuable technical support.

References

Abdus Shahid, Delwar Hossain, Nakib Ui Hasan, Ariful Islam, 2014, “Comparative Study of Ring and Compact Yarn-Based Knitted Fabric”, Elsevier, 90, pp. 154 – 159.

Alime Ash Illeez, Eylen Sema Dalbasi, Gonca Ozcelik Kayseri, 2015, “Improving of Sewability Properties of Various Knitted Fabrics with the Softeners”, Elsevier, Procedia - Social and Behavioral Sciences, 195, 2786 – 2795.

Alsaid A. Almetwally and Mona M. Salem, 2010, “Comparison Between Mechanical Properties of Fabrics Woven From Compact and Ring Spun Yarns”, AUTEX Research Journal, Vol. 10, No1, pp. 35-40.

An-an Z, 2005, “Study on complex cationic silicone softer and its application”, J Hangzhou Inst App Eng., 02:102–105.

Artzt P., December 2003, “Specific Technological Aspects of the Compact Spinning Process”, Textile Technology.

Begum MS. A., 2012, “Effect of Macro, Micro and Nano Silicone Emulsion Softeners on Physical and Colorimetric Properties of Cotton fabric”, Institutional Engineering and Technology, 2(2), 34-42.

Burcu Sancar Besen, Onur Balci, 2017, "Investigation of the effects of silicone emulsions having different particle sizes on knitted fabrics depending on the type of yarn", International Journal of Clothing Science and Technology, Vol. 29 Issue: 3, pp.394-416.

Cankut Taskin, Arif Taner Ozguney, Pelin Gurkan, Gonca Ozcelik, Arzu Ozerdem, 2007, “Comparison of Woven Fabrics’ Properties from Traditional and Compact Ring-Spun Yarns after Dyeing Processes”, Fiber &Textile in Eastern Europe, Vol. 15, No. 1 (60), pp. 86-90.

Celik N, Degirmenci Z, Kaynak HK, 2010, “Effect of nano-silicone softener on abrasion and pilling resistance and color fastness of knitted fabrics”, TekstilveKonfeksiyon, 01:41–47.

Chattopadhyay D. P., Vyas D. D., March 2010, “Effect of silicone nano-emulsion softener on physical properties of cotton fabric”, Indian Journal of Fiber & Textile Research, Vol. 35, p.p. 68-71.

Choudhury A.K. Roy, Chatterjee B., Saha S., Shaw K., 2012 “Comparison of Performance of Macro, Micro and Nano Silicone Softeners”; The Journal of the Textile Institute, Vol. 103, No. 9, 1012-1023.

Das A., Kothari V. K., and Sadachar A., 2007, “Comfort Characteristics of Fabrics Made of Compact Yarns”, Fibers and Polymers, Vol.8, No.1, 116-122.

Dash J.R., Ishtiaque S. M. 2002, ‘Properties and Processibility of Compact Yarns’, Indian J. Fibre Textile Res, vol. 27, pp. 362–368.

Gahlert E., Hellwig A., 2003, “Using Com4 yarns in piece-dyed shirting fabrics”, Melliand English, 11-12.

Gutiérrez M. C., López-Mesas M., Lacorte M. T. and Cegarra J., 2009, “Infrared analysis of the amino group content in functional aminopolydimethylsiloxanes”, Fibers and Polymers, Vol. 10 No. 4, pp. 437-441.

Habereder P, Bereck A, 2002, Part 2: silicone softeners, Rev Prog Color, 32:125–137.

Holmes I., 2007, “Innovative technologies for high performance textiles”, Color Technol 123:59–73.

Ihab El-Sayed, Saleh S.M., 2015, "Effect of Spinning Systems on Properties of Dyed Egyptian Cotton Yarns after Mercerization Treatment", Research Journal of Textile and Apparel, Vol. 19, Issue: 4, pp.48-56.

Jang, K.O. and Yeh, K., 1993, “Effects of silicone softeners and silane coupling agents on the performance properties of cotton fabrics”, Textile Research Journal, 63(10), 557-565.

Jatoi A. W., Khatri Z., 2015, “Influence of amino-functional macro and micro silicone softeners on the properties of cotton fabric”, Mehran University Research Journal of Engineering and Technology, 34(1), 70-74.

Kim S.I., Lee E.S., Yoon H.S., 2006, “Mercerization in degassed sodium hydroxide solution”, Fiber Polymers, vol. 7, pp. 186.

Manonmani G., Vigneswaran C., Chandrasekaran K., Ramachandran T., 2013, "Effect of Ring and Compact Cotton Spun Yarn characteristics on Physical and Comfort Properties of Knitted Fabrics", Research Journal of Textile and Apparel, Vol. 17, Issue: 3, pp.68-82.

Momir Nikolić, Zoran Stjepanovič, Franc Lesjak, Andrej Štritof, 2003, "Compact Spinning for Improved Quality of Ring-Spun Yarns", FIBRES & TEXTILES in Eastern Europe, Vol. 11, No. 4 (43), pp. 30-35.

Mourad Krifa, Dean Ethridge, 2003, "Compact Ring Spun Yarns: An Examination of Some productivity Issues", Textile Topics, International Textile Center, Texas Tech University, Lubbock, Texas, USA, Volume, 2, p.p. 2-8.

Mourad Krifa, Dean Ethridge M., 2006, "Compact Spinning Effect on Cotton Yarn Quality: Interactions with Fiber Characteristics", Textile Research Journal, Vol 76(5): 388–399.

Mukesh Kumar Singh and Akansha Nigam, 2013, "Effect of Various Ring Yarns on Fabric Comfort", Journal of Industrial Engineering, Volume 2013, pp. 1-7.

Murugesh Babu. K and Selvadass. M, 2013, "Influence of Wet Processing on Properties of Single Jersey Knitted Fabrics", International Journal of Fiber and Textile Research, 3(1): pp. 18-30.

Nilgün Özdil, Esen Özdoğan, Alparslan Demirel, Tülin Öktem, 2005, "A Comparative Study of the Characteristics of Compact Yarn-Based Knitted Fabrics", FIBRES & TEXTILES in Eastern Europe, Vol. 13, No. 2 (50), pp. 39-43.

Omeroglue S., Becerir B., 2005, 'Comparison of color values of plain cotton fabrics woven from Ring and compact spun yarns', Indian Journal of Fiber Textile Res., vol. 30, no. 4, pp. 402-406.

Omeroglue S., Becerir B., 2007, 'Comparison of color values of plain cotton fabrics knitted from Ring and compact spun yarns', AATCC Review, vol. 7, no. 7, pp. 41-46.

Özgüney A.T., Dönmez Kretzschmar S., Özçelik, Özerdem G. A., 2008, "The Comparison of Cotton Knitted Fabric Properties Made of Compact and Conventional Ring Yarns Before and After the Printing Process", Textile Research Journal, 78(2):138-147.

Parvinzadeh M, Hajiraissi R, 2008, "Macro and micro emulsion softeners on polyester fibers: evaluation of different physical Properties", J Surfact Deterg, 11:269–273.

Paul R., 2015, "Functional finishes for textiles: Improving comfort, performance and protection", book, United Kingdom: Elsevier.

Philippe, F., Schacher, L. and Adolphe, D.C., 2004, "Tactile feeling: Sensory analysis applied to textile goods", Textile Research Journal, 74(12), 1066-1072.

Pinar Çelik, Hüseyin Kadoğlu, 2004, "A Research on the Compact Spinning for Long Staple Yarns", FIBRES & TEXTILES in Eastern Europe, Vol. 12, No. 4 (48), p.p. 27-31.

Properties of Knitted fabrics made from Ring and Compact Spun Yarns", http://www.assignmentpoint.com/science/textile/properties-knitted-fabrics-made-ring-compact-spun-yarns.html, (August 2017).

Rajendran R, Balakumar C, Ahammed HAM, Jaykumar S, Vaideki K, Rajesh, 2010, "Use of zinc oxide nano particles for production of antimicrobial textiles", IJEST 2:202–208.

Saraf N.M., Alat, D.V., 2007, "Evaluation of softeners for cotton knits", Colourage, LIV (6), 70–71.

Sarioğlu, E., Çelik N., 2015, "Investigation on regenerated cellulosic knitted Fabric Performance by Using Silicone Softeners with Different Particle Sizes", Fiber &Textile in Eastern Europe, no 5 (113), 71-77.

Savin, I. I., Butnaru, R., 2008, "Wastewater characteristics in textile finishing mills", Environmental Engineering and Management Journal, 7(6), 859-864.

Taskin C., Ozgouney A. T., Ozcelik G., Ozerdem A. 2007, “Comparison of cotton woven fabric properties from traditional and compact ring spun yarns after dyeing process”, Fiber &Textile in Eastern Europe, no. 1, pp. 61.

Taşkın, M., Güneşoğlu C., 2014, “The effect of silicone softener particle size on color assessment of cotton fabrics”, AATCC Journal of Research, 1(5), 1-6.

Tzanov T., Betcheva R., Hardalov I., 1999, “Thermophysiological Comfort of Silicone Softeners Treated, Woven Textile Materials “, Int. J. Clothing Sci. Technol., 11 (4), 189-197.

Tzanov T.Z., Betcheva R., Hardalov I. and Hes L., 1998, “Quality control of silicone softener application”, Textile Research Journal, Vol. 68 No. 10, pp. 749-755.

Wiener J. and Dejlov´a P., 2003, “Wicking and wetting in textiles,” Autex Research Journal, vol. 3, no. 2, pp. 64-71.