Effect of Finishing Treatments on the Functional and Mechanical Properties of Jersey Knitted Fabrics

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Abstract:

Knitting has long been recognized as a leading method of forming fabrics for various end uses. So that many researches are being conducted to achieve the optimum of functional and mechanical properties of knitted fabrics. The aims of this study are twofold; firstly, Free formaldehyde cross-linking agent of cotton knitted fabrics were achieved through including some active agents, as functional agents, by using citric acid (CA), as an eco-friendly crosslinking agent, and Sodium hypophosphite monohydrate (SHP), as a catalyst, using the pad-dry-cure technique to impart difunctional eco-friendly finishing. , and secondly to study the influence of treatment finishing on the knitting parameters of jersey structure such as, loop length, tightness factor, stitch density, fabric weight and their effect on the mechanical properties of treated fabrics .

Keywords:

Cotton, Knitted Fabrics, Free Formaldehyde Cross-linking, Eco-friendly Finishing, functional Properties, Mechanical Properties

I. Introduction:

Over the last decades, there are more interest in knitted fabrics due to its simple production technique, low cost, high levels of clothing comfort and wide product range. The demands from fabrics have changed with developments in textile technology and the rise of people's living standards [(1)]. Now the requirement of the produced clothes not only style and durability, but also achieving a high functional property such as UV-protection, antimicrobial land others through functional finishes without affected the mechanical properties of produced fabrics.

Knitting is a process of making a fabric by forming loops. A knitted fabric is characterized by courses and whales that run vertically and horizontally respectively [(2)].

Plain knitting takes up about 90% of all knitted fabric consumption [(3)]. For that many researchers need to be worked out to improve functional properties of knitted fabrics. Many works have been done in multifunctional properties of knitted fabrics, has received a great attention to impart crease recovery angle, antibacterial, UV-protection, flame retardant, and water/oil repellency to treated substrate to overcome with the changing lifestyles, to provide highest levels of comfort, protection, safety and aesthetics [(4-6)].

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In this study, we attempt to investigate the function of citric acid as free formaldehyde cross-linking agent for enhanced functional properties on knitted fabric and affect the mechanical and comfort properties of the finished knitted fabrics.

II. Materials and Methods.

2.1. Materials

Mill-scoured and bleached fabrics was supplied by “Misr for spinning &weaving company”, Mehalla el-Kobra, Egypt. These fabrics were produced on a circular knitting machine (Gauge 28 and Diameter 30") with (24/1 Ne) cotton.

The fabric was not subjected to any type of finishing treatments. The fabric was further washed with a solution containing 5g\L sodium carbonate and 5g\Lnon–ionic detergents at boil for 30 min. It was then rinsed with hot and cold water and left to dry in air at room temperature.

The finishing agents used was Polyprotec BBC (organosilane -coupling quantaray ammonium; polysistec), UV-Sun® CEL LIQ UV-absorber (anionic, reactive UV-absorber based on oxalanilide; Huntsman), Pyrovatex® CP (Organic phosphorus compound, fiber-reactive; Huntsman), Oleophobol® CP-C (Dispersion of perfluorinated acrylic copolymer; Huntsman), and Hostapal® CVL-ET (nonionic wetting agent based on alkylarylpolyglycol ether, Clariant).

Citric acid and Sodium hypophosphite monohydrate (SHP) ($NaPO_2H_2.H_2O$) were of reagent grade.

2.2. Fabric Treatments

Fabrics were padded in finishing baths containing different concentrations of CA/SHP and/or different types of functional finishing agents to a wet pick up of 100%, followed by drying at 100 ˚C/3 min, and cured at 160 ˚C/3 min. The cured fabrics were then rinsed with distilled water at 50 ˚C for 30 min and rinsed and finally dried at ambient conditions.

2.3. Measurements and Testing

Many different tests were carried out on treated samples to evaluate functional properties, then different mechanical testing was applied on the samples which achieved a high functional property.

2.3.1. Evaluating Functional Properties

2.3.1.1. Anti-Microbial

Anti-microbial activity against Gram-positive bacteria (G+ve, *Staphylococcus aureus*) and Gram-negative bacteria (G-ve, *Escherichia coli*) was tested according to AATCC (147-1988).

2.3.1.2. Flame Resistance (Vertical Method)

The test was carried out according to the American standard specification of (ASTM –D6413-99).

2.3.1.3. UV-Protection

UV-protection factor (UPF) was evaluated according to the Australian/New Zealand standard (AS/NZS 4366-1996)

2.3.1.4. Spray Test

The test was carried out according to the American standard specification ofAATCC (22-2001).

2.3.2. Evaluating Mechanical&ComfortProperties

The samples which achieved a high functional property were tested for studying the effect of chemical treatments on the mechanical and physical properties.

2.3.2.1. Fabric Weight Test

This test was carried out on samples according to the American Standard Specification of (ASTM D3776:09).

2.3.2.2. Air permeability Test

This test was carried out by using The Digital Air Permeability Tester M021A (SDL ATLAS) according to the American Standard Specification of (ASTM D737 – 04 (2012))

2.3.2.3. Stiffness Test

This test was carried out by using *(Digital Pneumatic Stiffness Tester)* according to the American Standard Specification of (ASTM D4032-08)

2.3.2.4. Bursting Strength Test

This test was carried out on samples according to the American Standard Specification of (ASTM D3786).

III. Result and Discussion:

Treated samples were tested for evaluating functional property as following:

3.1. Antibacterial Activity of Treated Fabrics

Table (1) and figure (1) show that the effect of antibacterial activity carried out on the treated samples. The data in Table (1) demonstrate that the zone of inhibition was recorded. The results of untreated samples show clear growth of bacteria under them with no zone of inhibition, but treated samples inhibit bacterial growth has shown in figure (2).

It is clear that increasing the concentration of citric acid increases the nitrogen content of the treated fabric (express as % total nitrogen).

Table (1): Effect of Carboxylic Acid Concentration and Polyprotec BBC (Antibacterial) Concentration on Functional Properties

No.	CA	SHP	Polyprotec BBC conc.	^{a}N(%)	^{b}WI	^{c}UPF	^{d}ZI (mm)	
							G+ve	G -ve
B	0 g/l	0 g/l	0 g/l	0.00	50	11.5	0	0
1	25 g/l	25 g/l	25 g/l	0.04	41	11.5	13.0	7.5
2	50 g/l	25 g/l	25 g/l	0.09	40	11.5	13.5	9
3	25 g/l	25 g/l	50 g/l	0.08	38	11.5	14.0	8.5
4	**50 g/l**	**25 g/l**	**50 g/l**	**0.1**	**36**	**11.5**	**15.0**	**10.5**

—**B**: sample without treatment**; CA:** citric acid**; ^{a}N (%)**: nitrogen content; ^{b}**WI**: whiteness index; ^{c}**UPF**: UV-protection**;** ^{d}**ZI**: zone of inhibition; G +ve: *S.* aureus ; G -ve: *E.* coli

—Finishing formulation: citric acid (0, 25, 50 g/L); SHP (25g/L); nonionic wetting agent (2 g/L)); Polyprotec BBC (0, 25, 50 g/L).

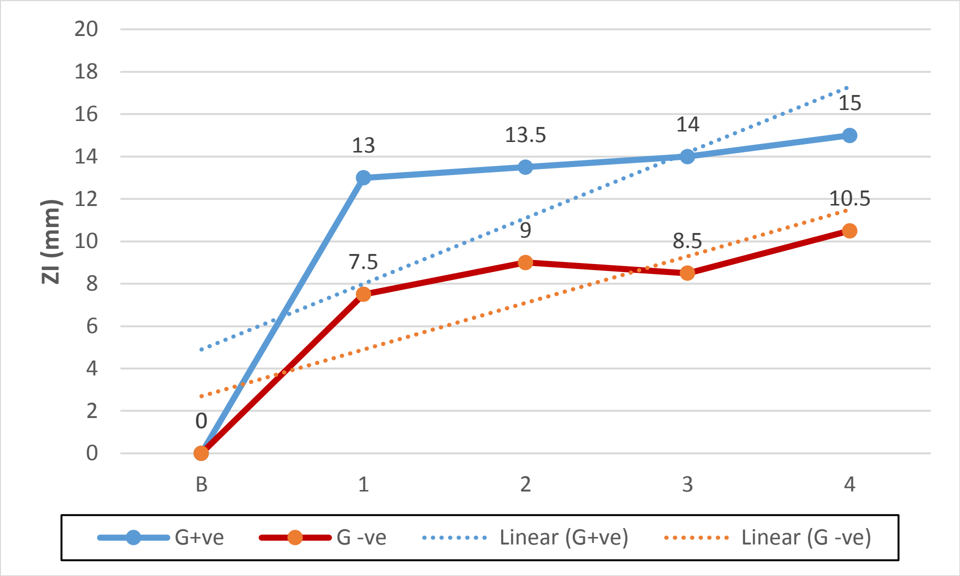
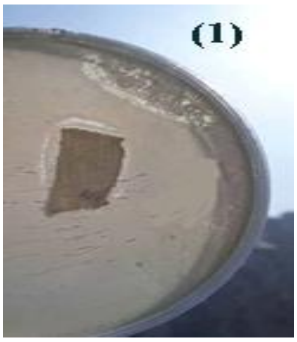


Fig. (1): The Zone of Inhibition of Treated Fabrics

The data in figure (1) shows that the high antibacterial activity towards both gram-positive and gram-negative bacteria and the antibacterial activity increased as active agent increased. The increasing of nitrogen content because the Polyprotec BBC has nitrogen groups in his structure. Also, in table (1) show also the effect of free formaldehyde cross-linking agent (citric acid) concentration. Increasing of citric acid concentration in the finishing formulation results an enhancement in antibacterial activity because its role as a crosslinker with active agent [7-8].



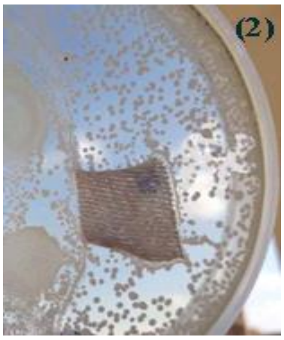


Fig. (2): Untreated Sample (1) &Treated Sample (2)

3.2. Flame Resistance (Vertical Method)

Table (2) and figure (3) shows the Results of flame resistance carried out on the treated samples.

Table (2): Effect of Carboxylic Acid Concentration and Pyrovatex CP (Flame Retardant) Concentration on Functional Properties

No.	CA	SHP	Pyrovatex CP conc.	[a] WI	[b] FR	
					char length	char area
B	0 g/l	0 g/l	0 g/l	50	**13**	**44**
5	25 g/l	25 g/l	300 g/l	37	10.5	36.5
6	50 g/l	25 g/l	300 g/l	38	6	21
7	25 g/l	25 g/l	350 g/l	31	3.5	12
8	**50 g/l**	**25 g/l**	**350 g/l**	**33**	**2.1**	**2.52**

—CA: citric acid; a N (%): nitrogen contenta WI: whiteness index; b FR: Flammability.

—Finishing formulation: citric acid (0, 25, 50 g/L); SHP (25g/L); nonionic wetting agent (2 g/L)); Pyrovatex CP (0, 300, 350 g/L);phosphoric acid 80 %(25g/L).

Table (2) shows the effect of concentration of flame resistance (Pyrovatex CP) on the flame resistance properties of treated cotton fabrics in presence of free formaldehyde cross-linking agent (50 g/l citric acid) and 25 g/l of SHP as proper catalyst by applying the pad–dry–cure technique at 160^{o}C for 3 minutes.

Introduction of citric acid in the finishing formulation (0 – 50 g/l w/v) significantly increases the crease recovery angle. This is presumably due to the increase in the number of cross–linkages in the treated fabric which resist the deformation of the cellulose structure and presumably due to minimal polymerization of the polyfunctional compound to resins by self-condensation inside the fiber. Upon using Pyrovatex CP as active agent and phosphoric acid 80% as calayst to finish cotton fabric impart flame retardancy properties. Better results are obtained with equal or over of the flammability are expressed on charred zone area at 350 g/l Pyrovatex CP in present of 50 g/l citric acid. Fabrics treated with 350 g/l Pyrovatex CP fails to exercise flame retardant with complete charred zone area. In other hand when the concentration of Pyrovatex CP up to 300 g/l the whiteness index of the treated fabric is decrease but can be acceptable [9, 10].

It is clear from the below figure (3) that there is a direct relation between char length and the charred area. This is owing to the increase in the burned area of tested fabrics associated with increasing the char length [11].

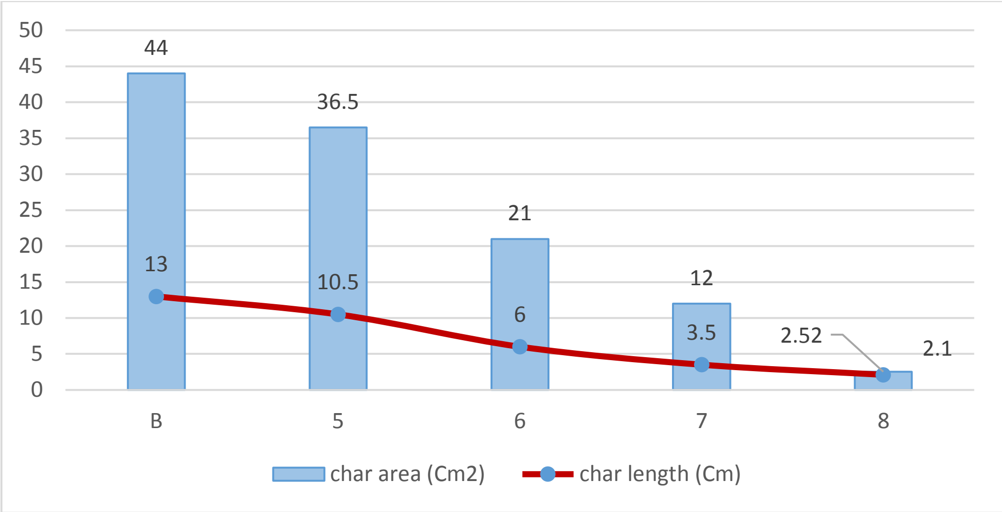


Fig. (3): Relationship between Char Length and Char Area (Fire Area)

3.3. UV-Protection

Table (3) and figure (4) shows the Results of UV-protection carried out on the treated samples

Table (3): Effect of Carboxylic Acid Concentration and UV-Sun CEL (UV Protection) Concentration on Functional Properties

No.	CA	SHP	UV-Sun CELconc.	[a] N (%)	[b] WI	[c] UPF
B	0 g/l	0 g/l	0 g/l	0.00	50	11.5
9	25 g/l	25 g/l	25 g/l	0.06	48	38.33
10	50 g/l	25 g/l	25 g/l	0.07	46	37.17
11	25 g/l	25 g/l	50 g/l	0.09	42	70.55
12	**50 g/l**	**25 g/l**	**50 g/l**	**0.11**	**40**	**77.22**

—CA**:** citric acid**;** [a] N (%): nitrogen content; [b] WI: whiteness index; [c] UPF: UV-protection;
—Finishing formulation: citric acid (0, 25, 50 g/L); SHP (25g/L); nonionic wetting agent (2 g/L); UV-Sun CEL (0, 25, 50 g/L).

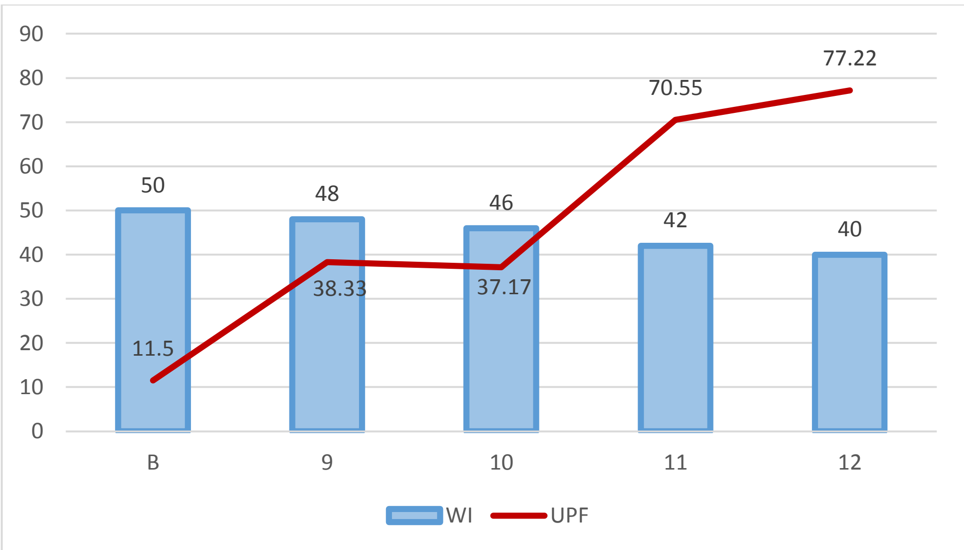


Fig. (4): Relationship between UPF Values and Whiteness IndexValues

As is evident, Table (3) and figure (4), increasing UV-Sun CEL (UV protection) concentration in the finishing formulation up to 25 g/L results in a marginal increase in the %N, a remarkable improvement in the UPF values along with a noticeable decrease in the whiteness index.

The remarkable increase in the UPF of the functionalized substrates is certainly attributed to the fixation and immobilization of the UV-absorber agent, onto the finished fabric via ether-crosslinking with citric acid and his catalyst Sodium hypophosphite monohydrate (SHP) [7, 8].

3.4. Spray Test

The data in Table (4) and figure (5) signify that the increasing the water/oil repellent agent (Oleophobol CP-C) concentration up to 25 g/L brings about a slight decrease in the in the whiteness index, an improvement in water repellency properties of fabric.

The finishing bath contain Oleophobol CP-C and free formaldehyde cross-linking agent (citric acid) come more effective imparting remarkable water repellency properties to finished fabrics [12,13]. The best result at 50 g/L of active water repellency agent (Oleophobol CP-C), 50 g/L citric acid in present catalyst (SHP).

Table (4): Effect of Carboxylic Acid Concentration and Oleophobol CP-C (Water Repellent) Concentration on Functional Properties

No.	CA	SHP	Oleophobol CP-Cconc.	[a] WI	[b] WRR
B	0 g/l	0 g/l	0 g/l	50	0
13	25 g/l	25 g/l	25 g/l	47	50
14	50 g/l	25 g/l	25 g/l	45	70
15	25 g/l	25 g/l	50 g/l	42	90
16	**50 g/l**	**25 g/l**	**50 g/l**	**40**	**100**

—CA: citric acid; a WI: whiteness index; b WRR: water repellent rating

—Finishing formulation: citric acid (0, 25, 50 g/L); SHP (25g/L); nonionic wetting agent (2 g/L); Oleophobol CP-C (0, 25, 50 g/L).

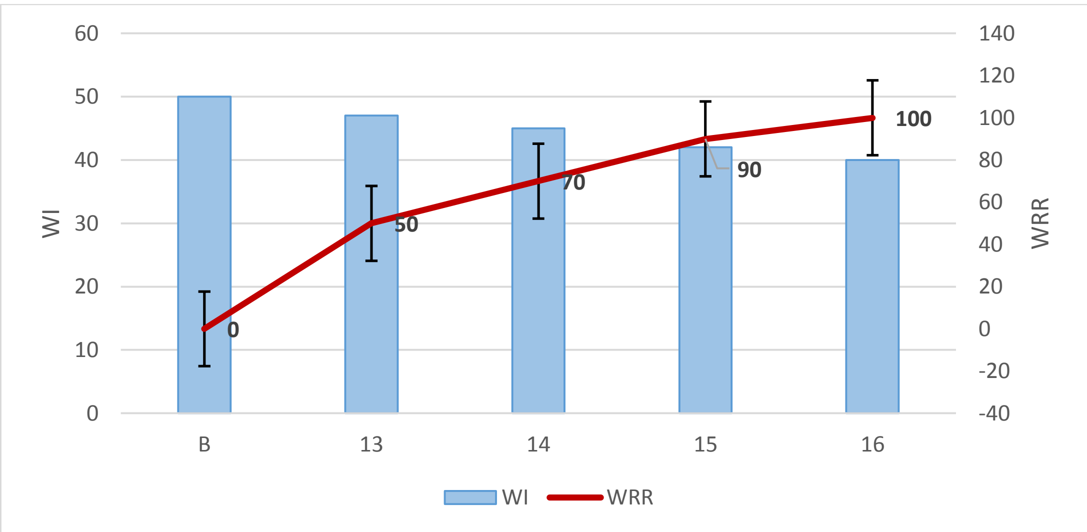


Fig. (5): Relationship between UPF Values and Whiteness Index Values

The samples which achieved a high functional property were tested for studying the effect of chemical treatments and fabric specifications on the mechanical and physical properties as shown in tables (5) & (6).

Table (5): Specifications of Treated Samples

No.	Treatment	Courses / Cm	Wales / Cm	Stitch Density Per Cm^2	Fabric Weight G/M^2	Loop Length Mm	Tightness Factor
B	Without Treatment	19.2	15.2	291.8	168.5	3.1	1.61
4	Anti-Microbi	21.2	15.4	326.5	210	2.6	1.9
8	Flame Resistance	19	15.6	296.4	176.6	2.9	1.72
12	UV-Protection	22.1	14.4	318.2	195	2.76	1.81
16	Water Repellent	21	14.8	310.8	187.5	2.8	1.79

* Tightness factor (TF) = $\sqrt{T}/L$, were ***T** the yarn linear density in tex, ***L** the loop length in mm (14).

Table (6): Mechanical and Physical Test Results

NO.	Treatment	testing results		
		Air permeability	Stiffness	Bursting
		$L/m^2/S$	N	KPa
B	Without treatment	1222.2	3.7	581.2
4	Anti-microbi	914	7.51	721.1
8	Flame resistance	1181.3	4	610.4
12	UV-protection	940.5	6.1	657.6
16	water repellent	965.5	4.82	625.2

3.5. Air Permeability

Table (7) and figure (6) shows the Results of air permeability test carried out on the treated samples

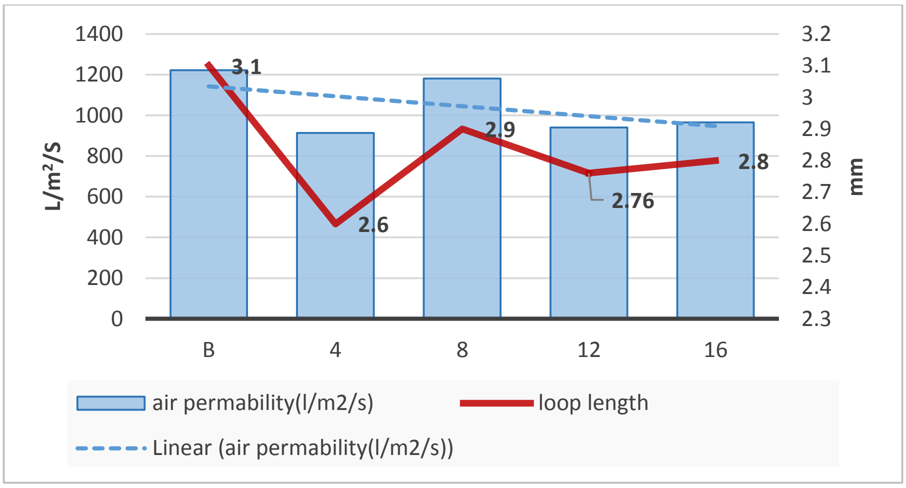


Fig. (6): Relationship between Loop Length Air Permeability

From table (7) and figure (6) it is obvious that the air permeability also tends to increase with the increase of the loop length as expected. Where the loop length increases, the compactness of the fabrics decreases due to the decrease in the number of stitches (15).

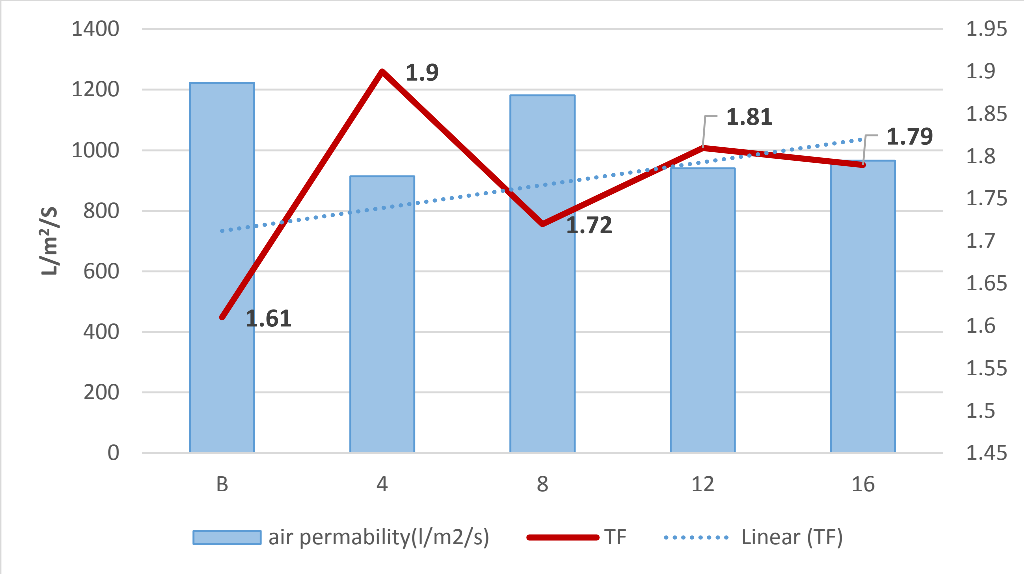


Fig. (7): Relationship between Tightness Factor (TF) and Air Permeability

From figure (7) it can be observed that there is an inverse relationship between tightness factor and air permeability this is due to the fact that, an increase in the Tightness factor increases the stitch density so the fabric becomes less porous and hence the passage of air through the fabric decreases.

3.6. Stiffness

Tables (5&6) and figure (8) shows the results of stiffness test carried out on the treated samples.

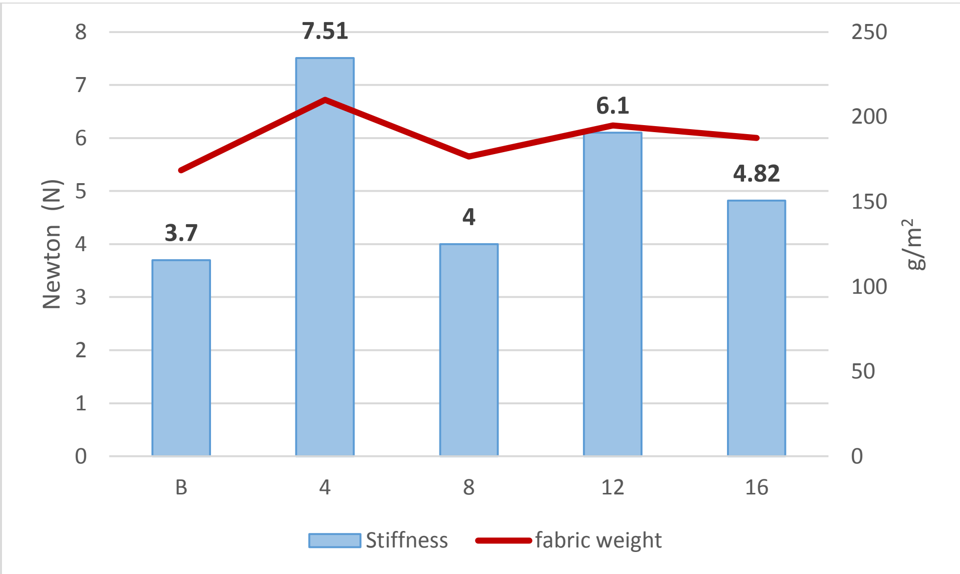


Fig. (8): Relationship between Fabric Weight and Stiffness

From figure (8) it is obvious that, there is direct correlation between the fabric stiffness and fabric weight. This is due to the increase in fabric weight per square meter leads to an increase in the bending resistance of treated fabrics. So as a result, the heavy fabrics are stiffer than others (16).

3-7: Bursting:

Tables (5&6) and figure (9&10) shows the Results of bursting strength test carried out on the treated samples.

From the figure (9&10) we can see that if the loop length increases, bursting strength is decreased. This is due to the fact that, when loop length is decreases, the stitch density is increases. Therefore, the resistance towards the force is more in case of low loop length of treated fabrics [17].

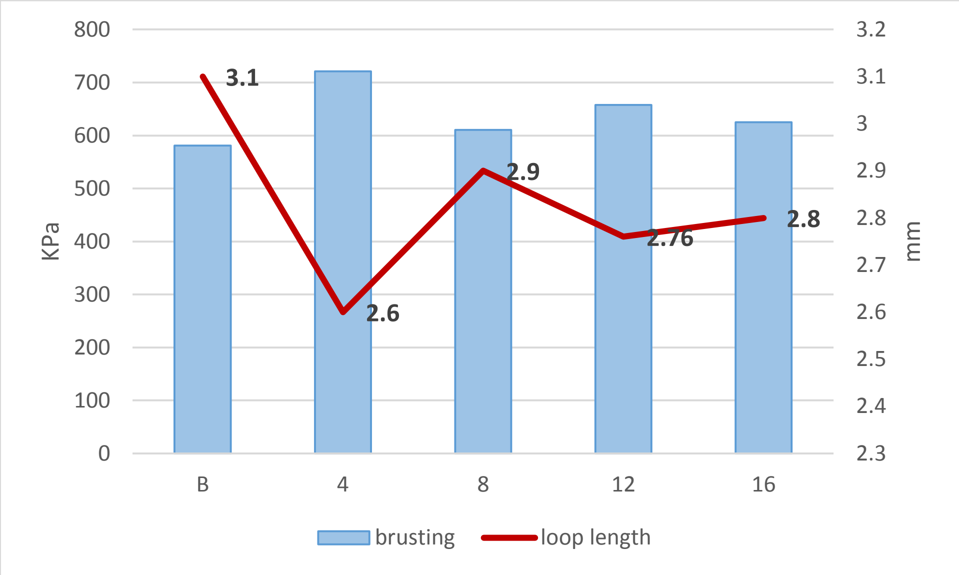


Fig. (9): Relationship between Loop Length and Bursting strength

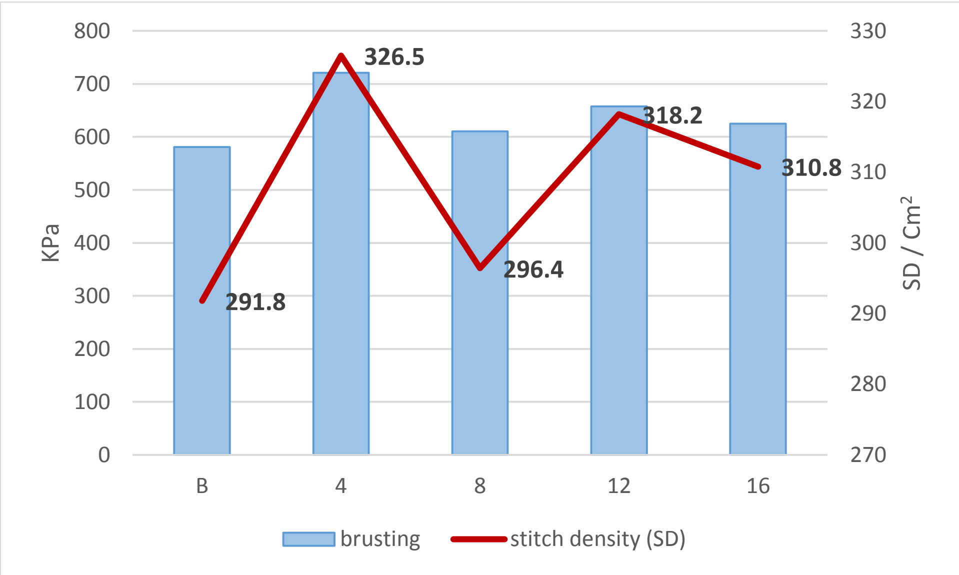


Fig. (10): Relationship between Stitch Density and Bursting Strength

IV. Conclusions:

In this research, the effect of eco-friendly finishing of knitted fabrics using some commercial active agents with CA/SHP using pad–dry–cure technique was investigated. Antibacterial activity, UV-protection, Flame resistance and water repellency properties, as well as fabric comfortable properties of imparted functional properties, were evaluated. An ideal Anti-microbial activity, UV-protection, Flame resistance, water repellency and free formaldehyde cross-linking agent properties can be achieved by applying Antibacterial activity by using Polyprotec BBC (50 g/L), (50 g/l citric acid) and 25 g/l of SHP as catalyst by applying the pad–dry–cure technique at 160^{o}C for 3 minutes. Impart UV-protection properties by using Polyprotec BBC (50 g/L each), (50 g/l citric acid) and 25 g/l of SHP as catalyst by applying the pad–dry–cure technique at 160^{o}C for 3 minutes. Impart Flame resistance properties by using Pyrovatex CP (350 g/L), (50 g/l citric acid) and 25 g/l of SHP as catalyst by applying the pad–dry–cure technique at 160^{o}C for 3 minutes.

The results obtained in the present work indicated that, fabric specification and mechanical properties changes as a different finishing treatment. It was concluded from this study that, the air permeability also tends to increase with the increase of the loop length, addition to air permeability is affected by the change in tightness factor of treated fabrics. The increase in fabric weight per square meter leads to an increase in the bending resistance of treated fabrics. So as a result, the heavy fabrics are stiffer than light fabrics. we also conclude that the loop length is one of the properties of jersey knitting fabrics which affect the bursting strength, where the loop length increases, bursting strength is decreased.

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