Achieving Optimum Functional Properties for Producing Automotive Airbags Fabrics

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Abstract: Transportation is the largest user of technical textiles where textiles provide a very high performance specifications and special properties required such as safety, weight efficiency, comfort and material durability of the transporting medium .As safety of driver and passengers is the paramount consideration in case of a collision, this research aims to produce fabrics suitable for being used in cars airbags. In this research all samples under study were woven on rapier weaving machine with polyester warp yarns of 300 denier and warp set of 36 ends/cm. Three materials of weft yarns were used, nylon and polyester of 150, 300 and 450 denier and polypropylene yarns of 300 and 450 denier. Three weft sets were also used 8, 10 and 12 picks/cm with three weaving structures plain, hopsack 2/2 and twill 2/2 weaves. The best 20 samples, according to Radar analysis, were coated with a thin layer of silicon rubber. Tests were carried out to evaluate samples under study and more results were reached.

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1. Introduction

Technical textiles are reported to be the fastest growing sector of the textile industrial sector and account for almost 19% of the total world fiber consumption for all textile uses. (1)

According to the Textile Institute in Manchester, technical textiles are textile materials intended for end uses other than non-protective clothing, household furnishing and floor covering, where fabric or fibrous components is selected primarily for their technical and performance properties rather than their aesthetic or decorative characteristics'. (1-2)

The complexity in requirements for automotive textiles is constantly raising due to the increasing functionalization of textile materials (3), for this reason transport applications (cars, lorries, buses, trains, ships and aerospace) represent the largest single end-use area for technical textiles, accounting for some 20% of the total products,(1) as textile materials no longer fulfill only aesthetic demands or general usage properties but they also cover different functionality and perform varying criteria, such as thermal functions, electrical functions, optical functions, acoustic unctions, separation/ absorption functions, adhesive functions, antibacterial functions, barrier and stretching properties. (3)

1.1 Automotive textiles

The application of textile materials in motor vehicles is becoming widely spread due to the fact that customers expect more comfort and better safety. (4)Automotive textiles are subdivided into textile and technical applications. Textiles, for example, in interior fittings; whereas technical applications include not only tires but seat belts, air bags, drive belts and reinforcements for hydraulic hosepipes.(5)

1.2 Airbags

The airbag and seat belts, used as safety devices, are one of the newest applications for textiles in automobiles and has spurred a huge market for technical textiles. Because frontal collisions are a major cause of accidental death, airbags are being introduced as a standard item in vehicles by legislation to protect the driver and the passengers in case of collision. (6)They are not alternative but supplemental to seat belts because airbags provide protection only against head-on collisions while seat belts provide protection regardless of the crash direction. (7)

Airbags were first introduced in the late 1960s, but it is only in the 1990s that their use has grown spectacularly and is set to grow even further.(6&8)An airbag is an automatic safety restrains system built into the steering wheel and instrument panel. (7) Airbags operate by a triggering device, which sets off explosive chemicals when it senses that an accident at a speed greater than about 35km/ hris about to happen,(9) as upon crash, sensors set off an igniter in the center of the airbag inflator leading to sodium azide pellets in the inflator to ignite and release gases that primarily consist of nitrogen. The gas the passes through a filter, which removes ash or any particles, into the bag, causing it to inflate.(7) and cushion the human body and prevents it from hitting a harder object. Since almost all collisions occur within 0.125 second, the airbag is designed to inflate and deflate all within a fraction of a second – less than the time to blink an eye. (7, 9)

1.3 Types of airbags

A number of different airbag systems are on the market today, for example driver and passenger airbags, side airbags in or panels, airbags in seatbelt systems, curtain airbags for the side windows and windscreen. [10]

Airbags are usually made of coated, for driver airbag, or uncoated fabrics with minimum air permeability. [6] Coated fabrics are easier to cut and sew with edges less likely to fray and air porosity can be better controlled, whilst uncoated bags are lighter, softer, less bulky and easier to recycle. [8]The sizes of air bags vary with the car they are going into and also whether they are to be used for the driver or the passenger. [9]

1.4 Materials and properties of airbags

Airbags are typically woven from high tenacity multifilament nylon 6.6 in yarn quality finenesses from 210, 420 to 840 denier [8], which have considerable success due to their high strength, favorable elongation, adequate thermal properties and relatively low cost of production. [6]Polyester ,which has good dimensional stability even at humid environmental conditions and good compaction, is beginning to be used in airbags.[7] Nylon 6 is also used in a small percentage and is said to minimize skin abrasion because it is softer.

Generally, airbag fabrics are woven on rapier weaving machines or air jet looms with electronic dobbies. [6]Airbag fabric is not dyed but it needs to be stabilized by heat setting and scoured to remove impurities which encourage mildew or cause other problems. [8]

The main requirements in airbag fiber materials are high strength, heat stability, good aging characteristics, energy absorption, coating adhesion and functionality at extreme hot and cold conditions. [7] Other properties required are high tear strength, high anti-seam slippage, controlled air permeability and be capable of being folded into confined places for over ten years without deterioration and, in the case of coated fabric, without blocking or sticking together. [6,8]

1.5 Coating of airbags

After weaving, the driver side airbag fabric is coated with black neoprene rubber or silicon rubber [7] but most airbags now are made of siliconized nylon fabric as it showed outstanding resistance to aging, as this thin silicon layer ensures that airbag can inflate within shortest time without sticking together even after being stored folded up in a very small space for many years. [10, 11] Other requirements for coating are good adhesion, anti-blocking, long term flexibility, long term stability , low air permeability and low cost.[6]

Silicon rubber is not only used for fabric coating. The seams, too, are sealed with silicon rubber.[11]

2. Experimental Work

2.1 Materials

In this research 72 samples were woven on rapier weaving machine with polyester warp yarns of 300 denier and warp set of 36 ends/cm. Three materials of weft yarns were used, nylon and polyester of 150,300 and 450 denier and polypropylene yarns of 300 and 450 denier. Three weft sets were also used 8, 10 and 12 picks/cm with three weaving structures plain, hopsack 2/2 and twill 2/2 and table (1) shows specifications of samples under study**.**

2.2 Treatment of samples under study

Samples under study were coated with thin silicon rubber layer which was imported from a German company called Wacker Silicones (ELASTOSIL @ LR 6291-Liquid Silicon Rubber). This material is a mixture of katalysator C Elastosil material, a colorless odorless elastic liquid, and silicon rubber, an odorless pure elastic liquid, using knife-knife coating machine (over air or silk screen method). The addition ratio was 75-185% of fabric weight and this differs according to fabrics structure. The treated fabrics were passed through hot oven of 170°C for 30-60 seconds to dry silicon material and bind it completely to fabrics.

Radar analysis were used in order to determine the best 20 samples which were scoured and coated with thin silicon rubber layer, which has the advantage of being Odorless, inert, good resistance to many chemicals and micro-organisms and temperature service range from-60 to+200°C. It also has High tear resistance and puncture resistance of coated fabric, Low toxicity, water repellent properties. Silicon rubber substance is available as fluid and blendable with acrylics/polyurethanes.

2.3 Tests applied to samples under study

In order to evaluate the performance properties of samples under study, before and after treatment, the following tests were carried out:-

1- **Fabric tensile strength and elongation**, this test was carried out according to the ASTM-D1982 ISO 5681 "Standard Test Method for Measuring Fabric Tensile and Elongation at Break (strip or grab method). [12]
2- **Fabric tear resistance**, this test was carried out according to the ASTM-D2261. "Standard Test Method for Measuring Fabric Tearing Strength".[13]
3- **Fabric Air Permeability** ,test was carried out according to the ASTM-D737-1996 "Standard Test Method for Measuring Fabric Air Permeability ". [14]
4- **Fabric thickness, this test was carried out according to the ASTM-D1777-**1984 "Standard

Test Method for Measuring Fabric Thickness". (15)

5- **Fabric weight**, this test was carried out according to the ASTM-D3776-1979,"Standard Test Method for Measuring Weight (Mass per unit area) of Textile Materials". (16)

2.4 Photo-scanning of sample using electronic micro-analyzer apparatus

Scanning electron microscope (SEM) apparatus was used to scan the best sample of plain weave structure to illustrate the effect and penetration ratio of Silicon rubber treatment on samples to illustrate the effect and penetration ratio of Silicon rubber treatment on samples before and after treatment on both sides of the sample and figure (1) shows Scanning electron micrograph (SEM) of plain weave sample before and after treatment on both sides of the sample as:

Figure (1.1) show the SEM (30x magnification) for the structure of plain weave sample before treatment.

Figure (1.2) show the SEM (50x magnification) for the structure of plain weave sample before treatment.

Figure (1.3) show the SEM (200x magnification) for the cross section of plain weave sample before treatment.

Figure (1.4) show the SEM (30x magnification) for the structure of plain weave sample after treatment for the upper side of the sample as it shows the complete covering of coating material to the surface of the sample.

Figure (1.5) show the SEM (50x magnification) for the structure of plain weave sample after treatment for the upper side of the sample.

Figure (1.6) show the SEM (300x magnification) for the cross section of plain weave sample after treatment for the upper side of the sample.

Figure (1.7) show the SEM (300x magnification) for the structure of plain weave sample after treatment for the back side of the sample and it also shows the reach of treating material to the other side of the fabric to achieve complete compaction.

Figure (1.8) show the SEM (300x magnification) for the structure of plain weave sample after treatment for the back side of the sample.

Figure (1.9) show the SEM (300x magnification) for the cross section of plain weave sample after treatment.

3. Results and Discussion

Results of the experimental tests carried out on samples under study are presented in the following tables and graphs. Results were also statistically analyzed for data listed and relationships between variables were obtained.

3.1. Effect of research variables on samples tensile strength

Before treatment

From the results obtained in table (2) and figure (2), it was found that samples of plain weave structure have scored the highest rates of tensile strength compared to hopsack 2/2 and twill 2/2 weaves. This may due to that plain weave 1/1 has more intersections than hopsack 2/2 and twill 2/2 weaves, which have long floats and less intersections, leading to plain weave fabrics to be more compacted and decreases yarns slippage ability and so increase its tensile strength.

It is also obvious from figures (2) and (3) that there is a direct relationship between the increase in number of picks per unit area and its tensile strength. This is mainly due to that the increase in number of yarns increases the contact areas between yarns and so their resistance to slippage will also increase leading to the increase in fabric tensile strength.

It was also found from figure (3) and that the more yarn count ,in the direct system, the more tensile strength the fabrics become and this for all weaves when all other variables are fixed. This is because that, the increase in yarn counts means increasing in yarns diameters leading to decrease the contact areas between yarns and increase the pressure between them and this cause the tensile strength of the fabrics to be increased.

It can be seen from the results and that, samples of nylon have scored the highest rates of tensile strength followed by polyester and polypropylene but the differences were insignificant. This is due to that nylon yarns have a higher breaking tenacity (7-8.5g/d)followed by polyester (4-7 g/d) and polypropylene.

After treatment

From table (4) and figure (4) it was found that treatment of fabrics has increased their tensile strength, when all other factors are fixed, in both warp and weft direction. This is mainly due to that treatment process has caused treatment material to fill the spaces in the fabric and bind the yarns together leading to the increase in fabrics tensile strength at break in both warp and weft directions.

3.2. Effect of research variables on samples elongation at break

It is obvious from the results obtained in table (3) and (6) that plain weave structure has scored the highest rates of elongation followed by twill 2/2 and hopsack 2/2 weaves. This may due to that plain weave 1/1 has more intersections per unit area and so it has more crimp percentage compared to other weave structures whereas hopsack 2/2 and twill 2/2 weaves have less crimp percentage due to their long floats and less intersections leading to plain weave fabrics to have increased elongation.

It is also obvious from figures (5) and (6) that there is a direct relationship between the increase in number of picks per unit area and its elongation. This is mainly due to that the greater the number of picks per unit area the longer must the path of warp yarns over filling, thus the crimp percentage will be increased and spaces between yarns will also be decreased due to the increase in number of intersections per unit area which delay the break of yarns and increase its elongation at break.

It was also found that the more yarn count, in the direct system, the more elongation the fabrics become and this for all weaves when all other variables are fixed. This is because that, the increase in yarn counts means increasing in yarns diameters leading to decrease the contact areas between yarns and increase the pressure between them which delay the break of yarns and increase its elongation at break.

It can be seen from the results and figure (5) that, samples of nylon have scored the highest rates of tensile strength followed by polypropylene then polyester but the differences were insignificant. This is due to nylon yarns have more extensibility compared to other yarns.

After treatment

Treatment has caused the elongation results of samples to be increased as shown in table (4)and figure (7) ,when all other factors are fixed, in both warp and weft directions. This may due to that when treating samples with silicon rubber, binding areas were formed and so yarns were bonded with each other leading to the increase in load resistance level of yarns which delay the break of these yarns and the fabric in return and so the percentage of elongation at break is increased

3.3. Effect of research variables on samples tear resistance

Before treatment

From the results obtained in table (5) and figure (8), it was found that samples of plain weave structure have scored the lowest rates of tear resistance followed by twill 2/2and hopsack 2/2 which gave the highest rates of tear resistance when all other construction factors are equal. We can state that, the intersection nature of plain weave cause yarns to act individually due to the increase in number of intersections and the decrease in floats length so yarns cannot shift to reinforce each other but in the hopsack structure the two yarns act as one and they act as one so that tearing is difficult.

It is also obvious from figure (9) and that there is an inverse relationship between the increase in number of picks per unit area and fabrics tear resistance. This is mainly due to that the increase in number of yarns increases the contact areas between yarns and so its resistance to slippage will also be increased leading to the increase in fabric tear resistance.

It is obvious from the tearing resistance results and figure (8) that samples with 450 denier have recorded the lowest rates of tear resistance followed by samples with 300 denier and then 150 denier .This is mainly due to that yarns of 450 denier are thicker than other yarns denier and so spaces between yarns will be decreased leading to the increase in friction areas between them and their resistance to slippage will also be increased causing the produced samples to be higher in their tear resistance.

It is obvious from the tearing resistance results that yarn type has insignificant effect on fabric tear resistance.

After treatment

Treatment has increased fabrics tear resistance as shown in table (6)and figure (10), when all other factors are fixed, in both warp and weft directions. This mainly due to the role that silicon rubber material has played as a binder in the fabric which increased the binding areas between yarns leading to the increase in tearing resistance of the fabrics.

3.4. Effect of research variables on samples air permeability

Before treatment

From the results obtained in table (7) and figure (12), it was found that samples of plain weave structure have scored the lowest rates of air permeability followed by hopsack 2/2 and twill 2/2 weaves when all other construction factors are equal. We can state that this is due to the difference in number of intersections per unit area for each weave structure, where the more number of intersections per unit area the less air permeability the fabrics become as with the increase in number of intersections per unit area the fabric become more compacted and spaces between yarns will decrease leading to decrease in fabrics air permeability.

It is also obvious from figure (11) that there is an inverse relationship between number of picks per unit area and fabrics tear resistance when all other construction factors are equal. This is mainly due to that the increase in number of yarns increases the contact areas between yarns and so the fabrics become more compacted and become more resistant to air permeability.

It was also found from figure (12) that the more yarn count, in the direct system, the less air permeability the fabrics become when all other variables are equal. This is because that, the increase in yarn counts means increasing in yarns diameters leading to decrease the contact areas between yarns and spaces between yarns will decrease leading to decrease in fabrics air permeability.

It is obvious from the air permeability results that yarn type has insignificant effect on fabric tear resistance when all other variables are constant.

After treatment

From table (8) and figure (13), it is obvious that treatment of fabrics has decreased its air permeability and this when all other factors are fixed. This is mainly due to that penetration of treatment material beneath yarns has caused all spaces in the fabrics to be filled with this material leading to the decrease in voids percentage of the fabric and so air permeability will also be decreased.

3.5. Effect of research variables on samples thickness

Before treatment

From the results obtained in table (7) and figure (15), it was found that samples of twill 2/2 structure have scored the highest rates of thickness followed by hopsack 2/2 and plain weaves when all other construction factors are equal. We can state that this is due to the difference in number of intersections per unit area for each weave structure where plain weave structure has the greatest number of intersections per unit area compared to other weave structures so yarns do not lie straight in the fabric because the warp and weft have to bend round each other when they are interlaced and the pressure between the ends and picks tends to distort the shape of the yarn cross-sections and change it from the circular shape to an oval shape and so the fabric thickness will be reduced, but this pressure effect is less in other structures due to less intersections and long floats.

It is also obvious from figures (14) and (15) that there is a direct relationship between the increase in number of picks per unit area and its thickness. This is mainly due to the increase in number of yarns causes increase in number of intersections per unit area and so crimp percentage will also be increased because of the increase in the bending curve of yarns round each other leading to the increase in fabric thickness.

It was also found from figure (14) that the more yarn count, in the direct system, the more thickness the fabrics become when all other variables are equal. This is because that, the increase in yarn counts means increasing in yarns diameters leading to increase the bending curve of yarns round each other when they are interlaced leading to the increase in fabric thickness.

It is obvious from the thickness results that yarn type has insignificant effect on fabric tear resistance when all other variables are equal.

After treatment

From the results obtained in table (8) and figure (16), it was found that treatment of samples has led to increase in its thickness when all other factors are fixed. This is of course due to the addition of treatment material to fabrics surface has led to the increase in fabrics thickness.

3.6. Effect of research variables on samples weight

Before treatment

From the results obtained in table (7) , it was found that samples of plain weave structure have scored the highest rates of weight followed by twill 2/2 then hopsack 2/2 weaves when all other construction factors are equal. We can state that this is due to the difference in number of intersections per unit area for each weave structure, where plain weave structure has the greatest number of intersections per unit area compared to other weave structures so crimp percentage of plain weave structure is the highest because of the increase in the bending curve of yarns round each other leading to the increase in fabric weight but the differences between the three structures were insignificant.

From figures (17) and (18) we can notice that, there is a direct relationship between the increase in number of picks per unit area and fabrics weight when all other variables are equal. This is mainly because the increase in number of yarns causes increase in number of intersections per unit area and so crimp percentage will also be increased due to the increase in the bending curve of yarns round each other leading to the increase in fabric weight.

It was also found from figure (17) that the more yarn count, in the direct system, the more weight the fabrics become when all other variables are equal. This is because that, the increase in yarn counts means increasing in yarns diameters leading to the increase in fabric weight.

It is obvious from the thickness results that yarn type has insignificant effect on fabric tear resistance when all other variables are equal.

After treatment

From table (8) and figure (19), we can notice that treatment of fabrics has increased its weight when all other factors are fixed. This is mainly due to penetration of treatment material beneath yarns has caused all spaces in the fabrics to be filled but it differs according to fabrics structure as we can notice that twill 2/2 structure has scored the highest rates of weight followed by hopsack 2/2 and plain weave structures as plain weave structure has the greatest number of intersections per unit area compared to other weave structures so it was difficult for treatment material to penetrate between its yarns compared to other weave structures with less number of intersections per unit area.

Table (1) specifications of samples under study

No.	Property	Specification
1	Warp type	Polyester
2	Weft type	Nylon, polyester and polypropylene
3	Warp count	300 denier
4	Weft count	150, 300 and 450 denier
5	Warp set	36 ends/cm
6	Weft set	8, 10 and 12 picks/cm
7	Fabric structures	Plain weave, hopsack 2/2 and twill 2/2
8	Finishing	scouring and coating with silicon rubber layer

Table (2) results of Tensile strength test applied to samples under study before treatment.

Fabric structure	Weft count	Weft set /cm	Tensile strength (kg/cm)					
			Nylon		Polyester		Polypropylene	
			Warp direction	Weft direction	Warp direction	Weft direction	Warp direction	Weft direction
Plain weave 1/1	150	8	198.33	24.66	195	26	200.66	49
		10	199.33	32	200	30	203.66	62.66
		12	202	36.66	203	34.66	205.33	74.66
	300	8	202.66	49.66	201.33	47.66	210	59
		10	205	62.33	207.33	54.66	212.33	75.33
		12	206.33	71.33	210.66	65.33	215	90.66
	450	8	206	66.33	210	66.66	-	-
		10	210	84.33	214	84.66	-	-
		12	212	115	215	99	-	-
Regular hopsack 2/2	150	8	155.66	22.66	186.66	23	186	51
		10	175.33	26.66	191.66	27.33	192.33	61.66
		12	186	36.66	195	35	198.66	73.66
	300	8	181.66	49.66	194	43.33	205	57
		10	188.66	61	200	54.66	207	76.33
		12	196.33	69	202	64.66	210	87
	450	8	195	68	195	57.66	-	-
		10	200	75	202.5	80.66	-	-
		12	205	98.66	204	96	-	-
Twill 2/2	150	8	173.66	26	193.33	25	194	53
		10	191.66	30.66	198.33	29	198.33	64.33
		12	195	37	200	35.66	206	72.66
	300	8	195.33	51	201.66	49	207	64
		10	203.5	61.66	206	56.33	210	75.66
		12	206.66	74	212	65	213	91
	450	8	207	76	210	60.66	-	-
		10	209	73.33	212.5	85	-	-
		12	210	95	216	97	-	-

Table (3) results of elongation at break test applied to samples under study before treatment

Fabric structure	Weft count	Weft set /cm	Elongation (%)					
			Nylon		Polyester		Polypropylene	
			Warp direction	Weft direction	Warp direction	Weft direction	Warp direction	Weft direction
Plain weave 1/1	150	8	40.33	47.5	40	33.33	45	37.33
		10	41.66	50	41.66	37.5	46.66	38.33
		12	43.33	51.66	45	40	51.66	40

	300	8	43.33	50	40	37.66	48	43.66
		10	45.33	51.33	45	40	48.33	45
		12	51.66	55	51.66	43	52	56
	450	8	45	51	45	40	-	-
		10	50	53.33	47	43.33	-	-
		12	53	57.66	52	45	-	-
Regular hopsack 2/2	150	8	35	43.33	35	30	38.33	34.33
		10	40	45	36.33	33.33	40	35
		12	41.66	48.33	40	35	45	39.33
	300	8	36.66	45	35.33	35	43.33	40
		10	41.66	49.33	41	35	46.33	44
		12	45	50	42.66	40	48.66	54
	450	8	38.33	49.66	40	35.66	-	-
		10	43.33	51	45	40	-	-
		12	50	54.33	45	45	-	-
Twill 2/2	150	8	40	45	35.66	32	43.33	36
		10	41	46.33	40	35	46	38
		12	43	50	43.33	38.33	48.33	40
	300	8	40	47.5	33.33	35.66	45	41.33
		10	43.33	51	45	37.5	47.33	44.66
		12	50	54	45	40.66	51.66	55
	450	8	43.33	50	41	40	-	-
		10	45.33	51.33	45	41.66	-	-
		12	51.66	56.33	46.66	43.33	-	-

Table (4) results of Tensile strength and Elongation at break tests applied to the best 20 samples before and after treatment

No.	Fiber type	Fabric structure	Weft count	Weft set /cm	Tensile strength (kg/cm)				Elongation at break (%)			
					After treatment		After treatment		After treatment		After treatment	
					Warp direction	Weft direction	Warp direction	Weft direction	Warp direction	Weft direction	Warp direction	Weft direction
1	Polypropylene	Plain weave 1/1	450	12	215	90.66	249	125	52	56	66	61
2	Nylon	Plain weave 1/1	450	12	212	115	260	124	53	57.66	57	61.5
3	Nylon	Regular hopsack 2/2	450	12	205	98.66	228	105.33	50	54.33	53	54.9
4	Polypropylene	Plain weave 1/1	450	10	212.33	75.33	246	106	48.38	45	57	50
5	Nylon	Twill 2/2	450	12	210	95	258	118	51.66	56.33	56	56.7
6	Polypropylene	Regular hopsack 2/2	450	12	210	87	235	118	48.66	54	55	57
7	Polyester	Plain weave 1/1	450	12	215	99	316	120	52	45	61	50
8	Polyester	Regular hopsack 2/2	450	12	204	96	244	115	45	45	53	45
9	Polypropylene	Twill 2/2	450	12	213	91	247	125	51.66	55	61	60
10	Nylon	Plain weave 1/1	450	10	210	84.33	253.33	101.33	50	53.33	54.5	54
11	Nylon	Plain weave 1/1	300	12	206.33	71.33	237	90	51.66	55	54	56
12	Nylon	Regular hopsack 2/2	300	12	196.33	69	216	76	45	50	49.5	50
13	Nylon	Twill 2/2	300	12	206.66	74	237	90	50	54	53	55
14	Nylon	Regular hopsack 2/2	450	10	200	75	218.66	85	43.33	51	50	51.18
15	Polypropylene	Regular hopsack 2/2	450	10	207	76.33	230	95	46.33	44	54	49
16	Polypropylene	Plain weave 1/1	300	12	205.33	74.66	225	100	51.66	40	56	44
17	Polyester	Twill 2/2	450	12	216	97	267	118	46.66	43.33	54	45
18	Nylon	Twill 2/2	450	10	209	73.33	251	90.66	45.33	51.33	50.66	52
19	Polyester	Plain weave 1/1	300	12	210.66	65.33	256	115	51.66	43	55	48
20	Nylon	Plain weave 1/1	300	10	205	62.33	228	72	45.33	51.33	48	54

Table (5) results of results of tear resistance test applied to samples under study before treatment

Fabric structure	Weft count	Weft set /cm	Tear resistance (kg)					
			Warp direction	Weft direction	Warp direction	Weft direction	Warp direction	Weft direction
			Nylon		Polyester		Polypropylene	
Plain weave 1/1	150	8	4	1.2	2	1.8	6.8	4.6
		10	5	2	3.8	2.4	8.7	5.2
		12	5.5	2.9	4.5	4	10.4	6.6
	300	8	6.2	3	3.3	2.7	7.2	5.4
		10	7.4	5.8	4.6	3.8	9.5	6.8
		12	8	7	6.6	5.6	10.8	8
	450	8	8.8	3.6	5.6	4.1	-	-
		10	9.4	6.1	7.5	4.8	-	-
		12	9.8	7.2	8.2	6.4	-	-
Regular hopsack2/2	150	8	6.2	3.4	3.5	2.8	8.7	6.3
		10	7	6	4.8	5.6	10.6	7.3
		12	7.5	7.1	6.9	6.4	11.8	8
	300	8	7.8	5.3	6.7	5.7	9.7	6.4
		10	10.5	6.6	7.8	7.4	11.5	8.4
		12	11.8	9.2	10.8	9.2	12.2	9.6
	450	8	10.2	5.8	8.2	6	-	-
		10	11.5	8.5	9.2	7.5	-	-
		12	12.5	10.8	12.4	10.5	-	-
Twill 2/2	150	8	5.3	2	2.9	2	7.7	5
		10	5.5	4	4	3.6	9.8	6.5
		12	6.2	5.8	5.7	4.5	10.9	7.4
	300	8	7.4	3.4	5.2	5	8.1	5.8
		10	8.7	6.1	6.4	6.3	10.2	7.1
		12	9.6	8.7	8.3	7.5	11	8.4
	450	8	9.1	4	7.5	5.9	-	-
		10	10.3	8.5	8.4	6.6	-	-
		12	11.7	9	9	8.1	-	-

Table (6) results of tear resistance test applied to the best 20 samples before and after treatment

No.	Fiber type	Fabric structure	Yarn count (denier)	Weft set /cm	Tear resistance (kg)			
					Before treatment		After treatment	
					Warp direction	Weft direction	Warp direction	Weft direction
1	**Polypropylene**	Plain weave 1/1	450	12	10.8	8	20	18
2	**Nylon**	Plain weave 1/1	450	12	9.8	7.2	20	18
3	**Nylon**	Regular hopsack 2/2	450	12	12.5	10.8	50	35
4	**Polypropylene**	Plain weave 1/1	450	10	9.5	6.8	26	25
5	**Nylon**	Twill 2/2	450	12	11.7	9	35	30
6	**Polypropylene**	Regular hopsack 2/2	450	12	12.2	9.6	45	28
7	**Polyester**	Plain weave 1/1	450	12	8.2	6.4	20	15
8	**Polyester**	Regular hopsack 2/2	450	12	12.4	10.5	38	35
9	**Polypropylene**	Twill 2/2	450	12	11	8.4	40	35
10	**Nylon**	Plain weave 1/1	450	10	9.4	6.1	22	20
11	**Nylon**	Plain weave 1/1	300	12	8	7	20	15
12	**Nylon**	Regular hopsack 2/2	300	12	11.8	9.2	42	32
13	**Nylon**	Twill 2/2	300	12	9.6	8.7	25	25
14	**Nylon**	Regular hopsack 2/2	450	10	11.5	8.5	40	15
15	**Polypropylene**	Regular hopsack 2/2	450	10	11.5	8.4	42	18
16	**Polypropylene**	Plain weave 1/1	300	12	10.4	6.6	25	20
17	**Polyester**	Twill 2/2	450	12	9	8.1	25	20
18	**Nylon**	Twill 2/2	450	10	10.3	8.5	30	28
19	**Polyester**	Plain weave 1/1	300	12	8	7	18	12
20	**Nylon**	Plain weave 1/1	300	10	7.4	5.8	20	18

Table (7) results of air permeability, thickness and weight tests applied to samples under study before treatment.

Fabric structure	Weft count	Weft set /cm	Air permeability (cm3/cm2/sec)			Thickness (mm)			Weight (g/m^2)		
			Nylon	Polyester	Polypropylene	Nylon	Polyester	Polypropylene	Nylon	Polyester	Polypropylene
Plain weave 1/1	150	8	59.1	50	62.6	0.46	0.435	0.52	153	153.7	177.6
		10	45.1	25	36.08	0.475	0.445	0.53	157.14	159	188.5
		12	18.04	13.7	25	0.49	0.46	0.54	161.29	162.7	1995
	300	8	40.59	45	7.5	0.475	0.48	0.54	166.9	171	202.6
		10	19.6	22.5	4.11	0.49	0.49	0.56	177	178	220.6
		12	18.4	12.5	3.97	0.51	0.50	0.58	186	187	242.6
	450	8	38.17	38.17	-	0.51	0.51	-	185	182.9	-
		10	16.06	22.48	-	0.52	0.525	-	197	193	-
		12	12.33	7.5	-	0.53	0.54	-	211.5	204	-
Regular hopsack 2/2	150	8	112.4	103.92	113.5	0.525	0.54	0.62	151.8	152	174
		10	97.3	89.67	75.68	0.54	0.55	0.64	156.5	156	185.6
		12	60.85	48.85	53.44	0.56	0.565	0.66	160	162	195.6
	300	8	84.4	93.78	40.84	0.57	0.60	0.66	166.8	168.6	201
		10	62.6	70.4	22	0.59	0.62	0.665	175	177	215.8
		12	45.1	46.34	15.44	0.61	0.635	0.69	183.6	185	232.5
	450	8	67.9	90.51	-	0.605	0.655	-	182.5	182	-
		10	49	59.12	-	0.625	0.67	-	194	189.9	-
		12	33.5	27.06	-	0.64	0.70	-	207	201.8	-
Twill 2l2	150	8	137.6	136	180	0.55	0.55	0.66	152.8	152.7	177
		10	101.88	104.94	132	0.57	0.57	0.685	157	185	187
		12	82.22	73.5	108	0.60	0.60	0.71	161	162	199
	300	8	134.4	130.4	80.81	0.62	0.61	0.69	168.6	170.7	201.5
		10	99.9	100.61	54.02	0.63	0.64	0.70	176	177.9	218
		12	80.04	67.9	35.78	0.64	0.67	0.72	184.5	186.8	236
	450	8	119	103	-	0.64	0.67	-	184	182.5	-
		10	96.3	75.76	-	0.65	0.69	-	196.6	192	-
		12	71.5	51.7	-	0.67	0.715	-	208.6	202.5	-

Table (8) Results of Air permeability, Thickness and Weight tests applied to the best 20 samples before and after treatment.

No.	Fiber type	Fabric structure	Yarn count (denier)	Weft set /cm	Air permeability (cm3/cm2/sec)		Thickness (mm)		Weight (g/m2)	
					Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
1	Polypropylene	Plain weave 1/1	450	12	3.97	0.33	0.58	0.60	242.6	423
2	Nylon	Plain weave 1/1	450	12	12.33	0.52	0.53	0.60	211.5	412
3	Nylon	Regular hopsack 2/2	450	12	12.5	1.45	0.64	0.91	207	454
4	Polypropylene	Plain weave 1/1	450	10	4.11	0.49	0.56	0.58	220.6	399
5	Nylon	Twill 2/2	450	12	71.5	5.01	0.67	0.93	208.6	579
6	Polypropylene	Regular hopsack 2/2	450	12	15.44	0.879	0.69	0.85	232.5	502
7	Polyester	Plain weave 1/1	450	12	7.5	0.55	0.54	0.55	204	401
8	Polyester	Regular hopsack 2/2	450	12	27.6	0.879	0.70	0.85	201.8	570
9	Polypropylene	Twill 2/2	450	12	35.78	1.175	0.72	0.84	236	519
10	Nylon	Plain weave 1/1	450	10	16.06	0.54	0.52	0.585	197	388
11	Nylon	Plain weave 1/1	300	12	18.04	0.54	0.51	0.55	186	411
12	Nylon	Regular hopsack 2/2	300	12	45.1	2.7	0.61	0.80	183.6	446
13	Nylon	Twill 2/2	300	12	80.04	18.4	0.64	0.83	184.5	401
14	Nylon	Regular hopsack 2/2	450	10	49	10.6	0.625	0.90	194	412
15	Polypropylene	Regular hopsack 2/2	450	10	22	1.24	0.665	0.83	215.8	475
16	Polypropylene	Plain weave 1/1	300	12	25	0.569	0.54	0.57	199.5	374
17	Polyester	Twill 2/2	450	12	51.7	1.024	0.715	0.87	202.5	577
18	Nylon	Twill 2/2	450	10	96.3	11.3	0.65	0.90	196.6	554
19	Polyester	Plain weave 1/1	300	12	12.5	0.58	0.50	0.53	187	376
20	Nylon	Plain weave 1/1	300	10	19.6	0.62	0.49	0.54	177	373

Table (9) . Regression equation and correlation coefficient for the effect weft set and fabric structure on tensile strength (warp direction), at nylon fiber and 150 denier , before treatment

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y=0.9175 X +190.7117	0.967179
Regular hopsack 2/2	Y=7.585 X +96.48	0.985649
Twill 2/2	Y=133.4233X +5.335	0.929555

Table (10) . Regression equation and correlation coefficient for the effect number of picks/cm and yarn count on tensile strength, at nylon fiber and twill 2/2, weft direction ,before treatment.

Yarn count (denier)	Regression equation	Correlation coefficient
150	Y=4.75 X +33.44333	0.9955402
300	Y=4.75 X +4.72	0.9999112
450	Y=1. 5 X +197.8333	0.99135

Table (11) . Regression equation and correlation coefficient for the effect of weft set/cm and fiber type on fabric elongation ,weft direction, at regular hopsack 2/2 and 450 denier ,before treatment.

Fiber type	Regression equation	Correlation coefficient
Nylon	Y=0.9175 X +190.7117	0.967179
Polyester	Y=7.585 X +96.48	0.985649
Polypropylene	Y=133.4233X +5.335	0.929555

Table (12) . Regression equation and correlation coefficient for the effect weft set/cm and fabric structure on fabric elongation ,warp direction, at polyester and 300 denier ,before treatment

Yarn count (denier)	Regression equation	Correlation coefficient
150	Y=1.665 X +22.23667	0.960547
300	Y=2.085 X +20.25667	0.993462
450	Y=2.917X +14.71167	0.996604

Table (13) Regression equation and correlation coefficient for the effect fabric structure and yarn count on fabric's tear resistance ,at 12 picks/cm and weft direction

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y=0.008 X +2.93333	0.98198
Regular hopsack 2/2	Y=0.013667 X +4.6	0.978412
Twill 2/2	Y=0.012 X +3.1	0.93325

Table (14) Regression equation and correlation coefficient for the effect fiber type and number of picks/cm on fabric's tear resistance, at plain weave 1/1 and 300 denier

Fiber type	Regression equation	Correlation coefficient
Nylon	Y=0.45 X +2.7	0.98198
Polyester	Y=0.825X +3.41667	0.992548
Polypropylene	Y=0.9 X +0.36667	0.999468

Table (15) Regression equation and correlation coefficient for the effect fiber type and number of picks/cm on fabric's air permeability ,at twill 2/2 and 450 denier.

Fiber type	Regression equation	Correlation coefficient
Nylon	Y=-11.875 X +214.35	0.999674-
Polyester	Y=-12.825X +205.07	0.99936-
Polypropylene	Y=-11.2575 X +169.445	0.994045-

Table (16) Regression equation and correlation coefficient for the effect yarn count and fabric structure on fabric's air permeability ,at nylon fiber and 10 picks/cm.

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y=-0.0968 X +55.96	0.916463-
Regular hopsack 2/2	Y=-0.0084X +25.84667	0.916463-
Twill 2/2	Y=-0.0186 X +104.94	0.942718-

Table (17) Regression equation and correlation coefficient for the effect of weft set and yarn count on fabric thickness, nylon and regular hopsack 2/2, before treatment.

Yarn count (denier)	Regression equation	Correlation coefficient
150	Y=0.00875 X +0.454167	0.996616
300	Y=0.01 X +0.49	1
450	Y=0.0875 X +0.007312	0.996616

Table (18) Regression equation and correlation coefficient for the effect of weft set and fabric structure on fabric thickness, nylon and 300 denier, before treatment

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y=0.47 X +0.005	1
Regular hopsack 2/2	Y=0.00875 X +0.535833	0.996616
Twill 2/2	Y=11.2575 X +169.445	0.996616

Table (19) Regression equation and correlation coefficient for the effect of number of picks/cm and yarn count on fabric's weight ,at regular hopsack 2/2 and polyester.

Yarn count (denier)	Regression equation	Correlation coefficient
150	Y=2.05X +135.6	0.99645
300	Y=4.2 X +133. 1333	0.999906
450	Y=6.125 X +133.25	0.999375

Table (20) Regression equation and correlation coefficient for the effect of number of picks/cm and yarn type on fabric's weight ,at regular hopsack 2/2 and 300 denier, before treatment.

Yarn count (denier)	Regression equation	Correlation coefficient
Nylon	Y=4.775 X +128.8833	0.99997
Polyester	Y=4X +138.6667	0.997406
Polypropylene	Y=5.775 X +133.7833	0.999448

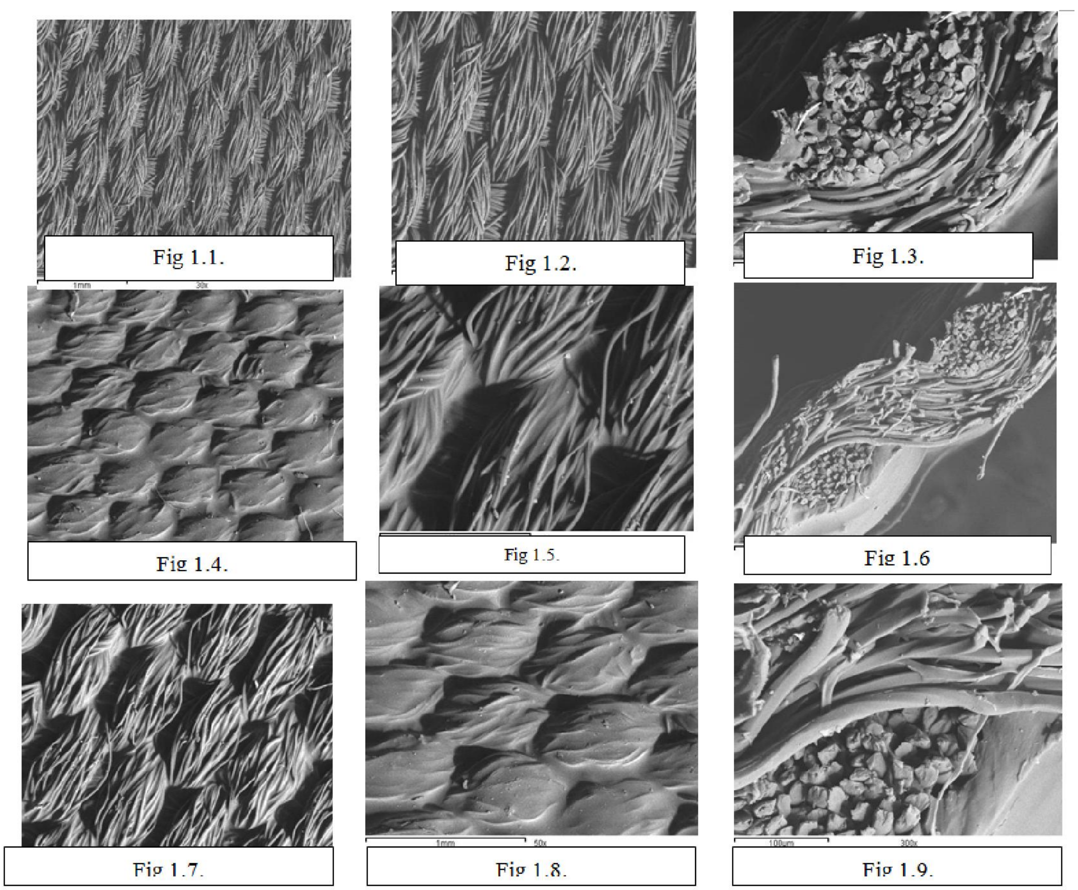


Fig. (1) Scanning electron micrograph (SEM) of plain weave sample before and after treatment

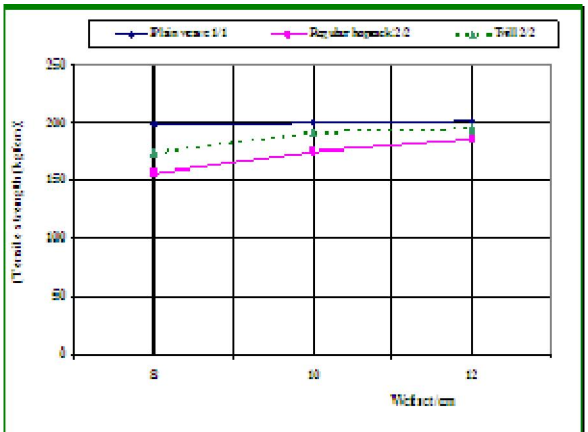


Fig.(2) the effect of weft set and fabric's structure on fabric's tensile strength (warp direction), at 150 denier and nylon fiber, before treatment

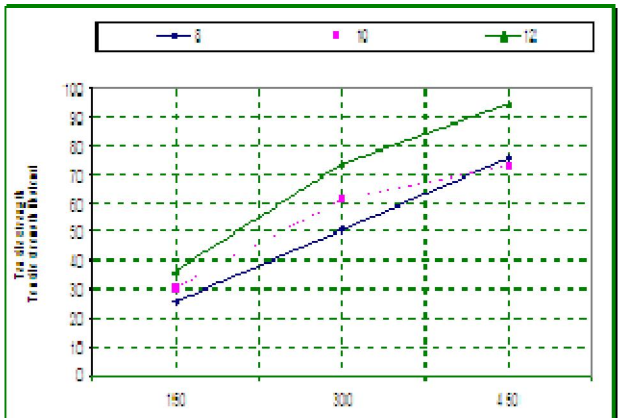


Fig.(3) the effect of yarn count and weft set on fabric's tensile strength, at twill 2/2 and nylon fiber, before treatment

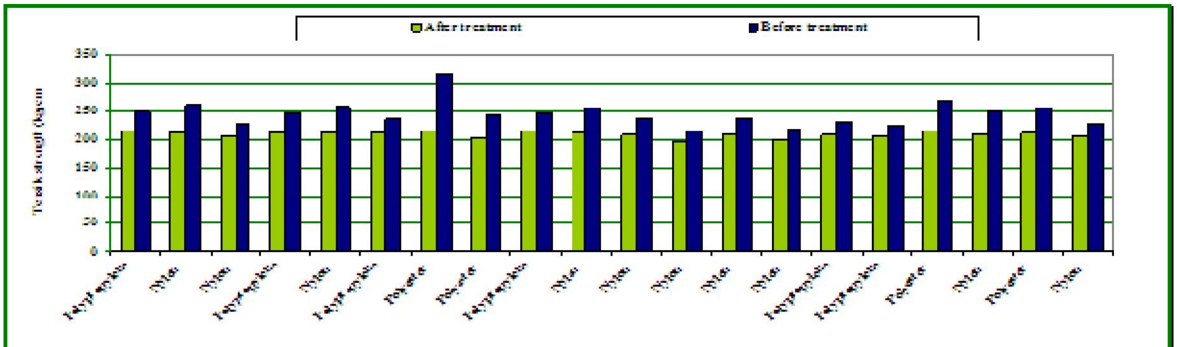


Fig. (4) comprision between tensile streng (warp direction) of best samples after and before treatmen

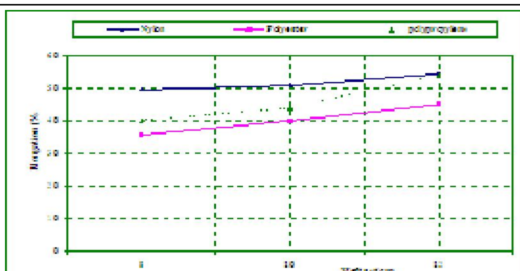


Fig.(5) effect of weft set and fiber type on fabric elongation, weft direction, at regular hopsack 2/2 and 450 denier, before treatment.

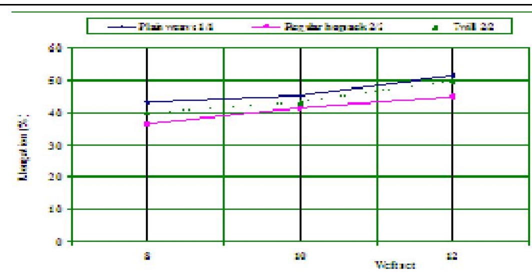


Fig.(6) effect of weft set and fabric structure on fabric elongation, warp direction, at polyester and 300 denier, before treatment.

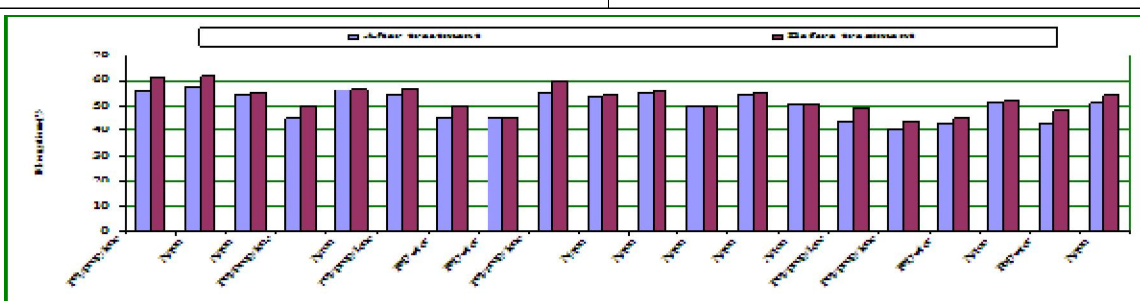


Fig. (7) comprision between elongation (weft direction) of best samples after and before treatment

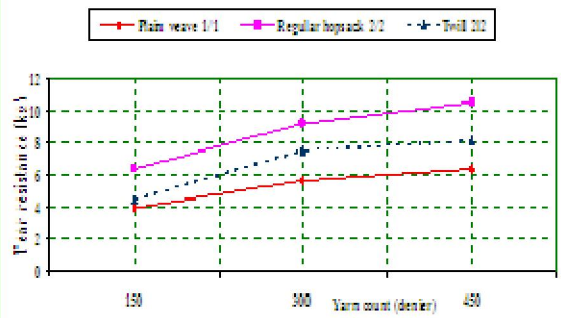


Fig .(8) Effect of yarn count and fabric structure on fabric tear resistance ,at 12 picks/cm ,weft direction ,before treatment

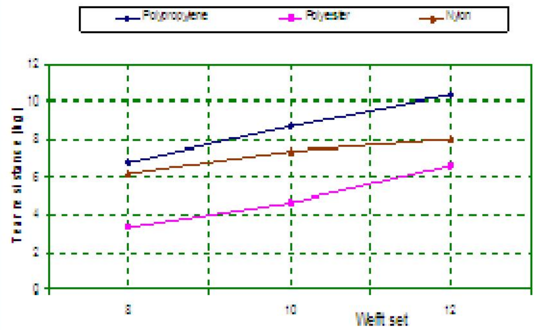


Fig .(9) Effect of weft set and yarn type on fabric tear resistance ,at 300 denier and plain weave ,before treatment

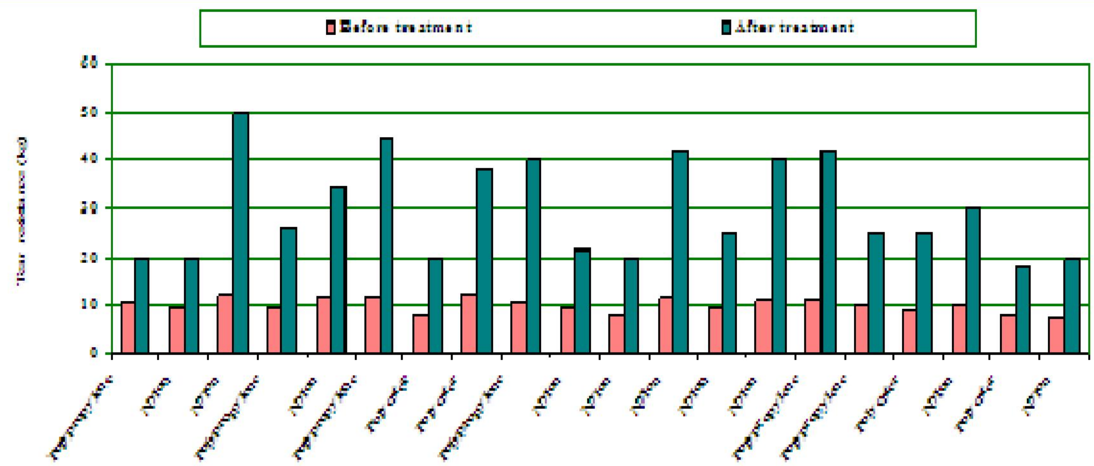


Fig. (10) comprision between tear resistance (warp direction) of best samples after and before treatment

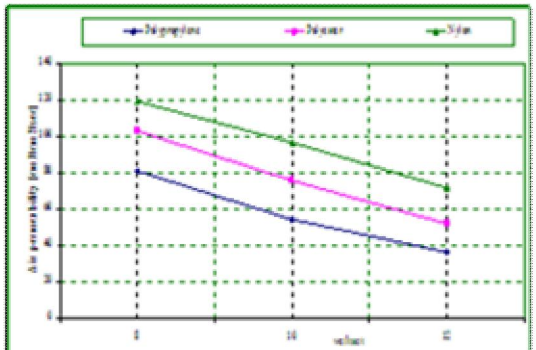


Fig.(11) Effect of weft set and yarn type on fabric air permeability ,at 150 denier and twill weave ,before treatment

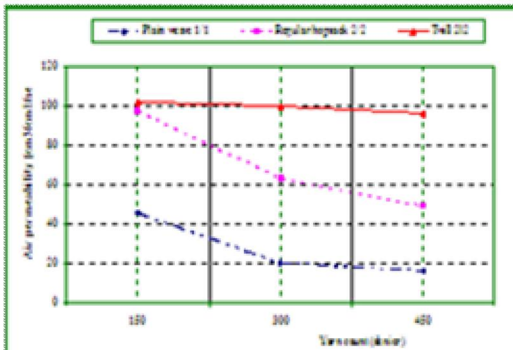


Fig.(12) Effect of yarn count and fabric structure on fabric air permeability ,at 10 picks/cm and twill weave ,before treatment

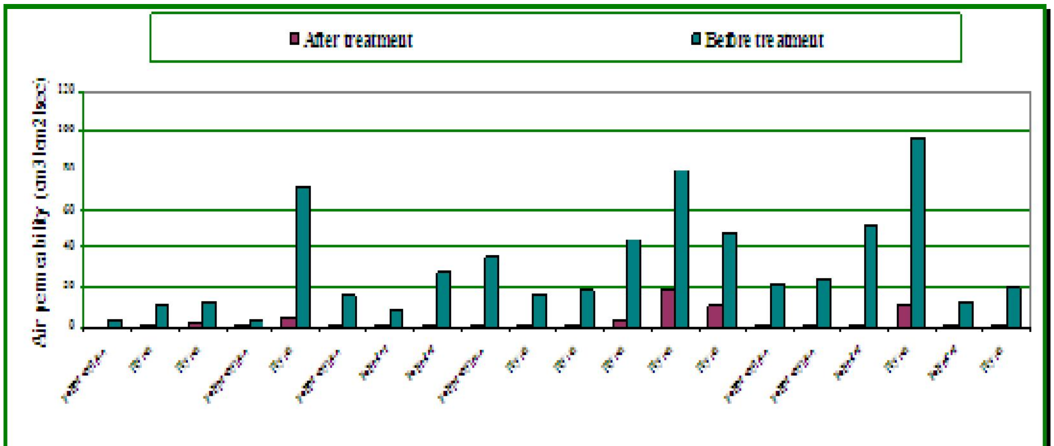


Fig. (13) comprision between air permeability of best samples after and before treatment

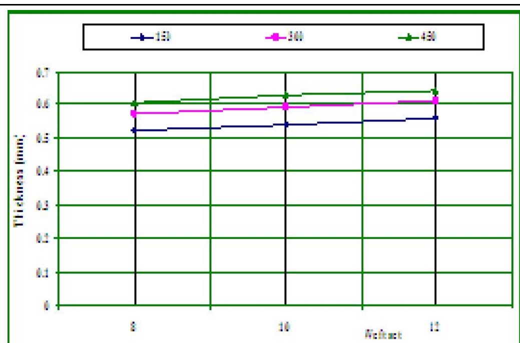


Fig.(14) effect of weft set and yarn count on fabric thickness, at nylon and regular hopsack 2/2, before treatment.

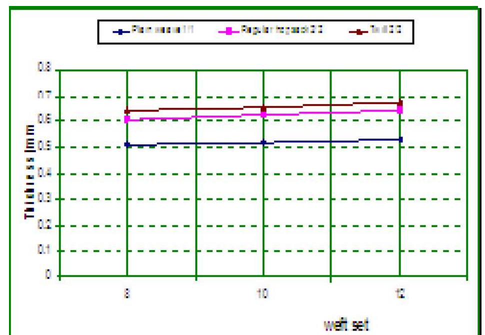


Fig.(15) effect of weft set and fabric structure on fabric thickness, at nylon and 450denier, before treatment

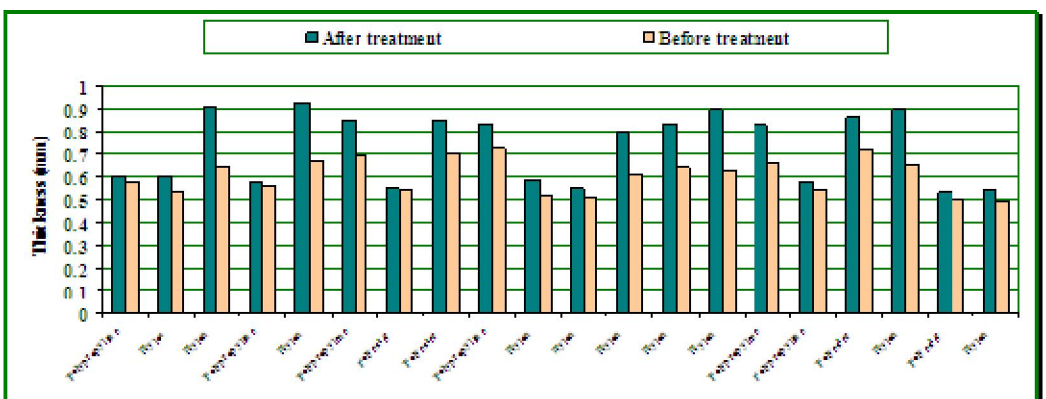
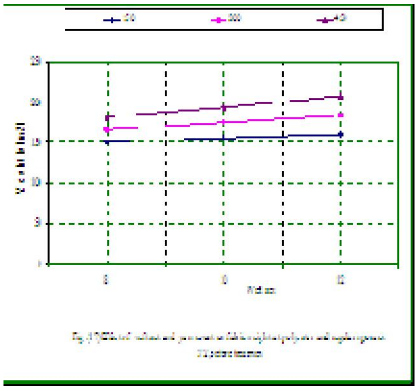
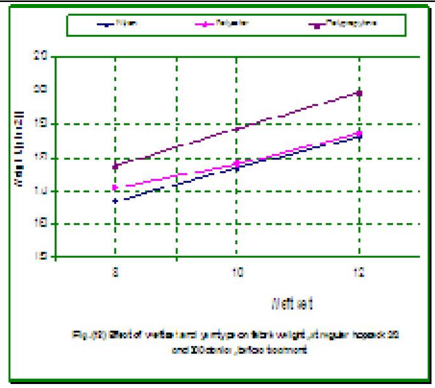


Fig. (16) comprision between thickness of best samples after and before treatment





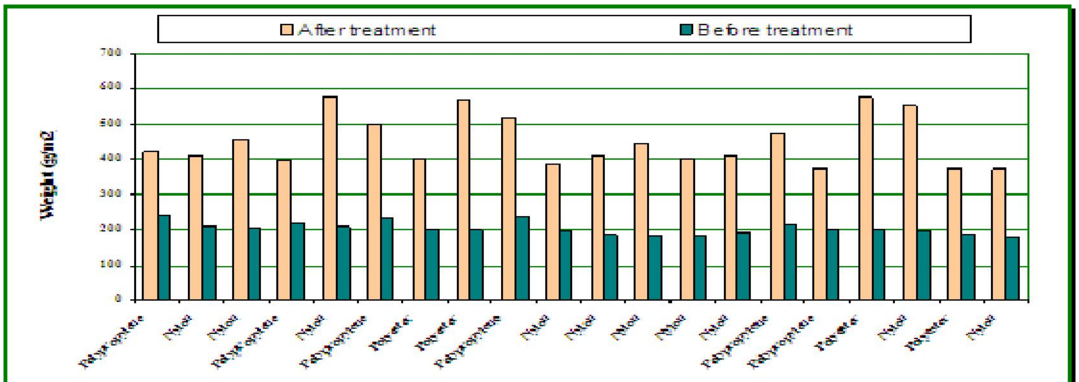


Fig. (19) comprision between weight of best samples after and before treatment

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