Designing and production of Waterproof Breathable Fabric Suitable for Sleeping Bags

Ramadan, E. M.

Associate Professor at Spinning, Weaving and Knitting Dept., Faculty of Applied Arts, Helwan University
dremanramadan@yahoo.com

Abstract: The aspect of protection and comfort are both very important for the performance of personal protective clothing and equipment. The aim of this research is to produce fabrics suitable for sleeping bags which is both waterproof and breathable (water vapor permeable) to improve user comfort by reducing the buildup of perspiration inside the sleeping bag. All samples under study were produced of polyester yarns of 100 denier for end yarns and 50, 70 and 100 denier for weft yarns. Three weft sets were also used 60, 80 and 100 picks /cm with three fabric structure (plain weave 1/1, twill 1/4 and satin 4). Samples were coated using P.V.C in order to produce a waterproof, moisture vapor permeable fabrics and having perforation to provide ventilation to the user. The influence of these variables on the performance of the end-use fabric and achieved properties were studied. On the other hand physic-chemical properties including, tensile strength and elongation, abrasion resistance, water permeability, water repellency, tear resistance, thickness and weight were evaluated according to the final product needs. Some more results were reached concerning structures and materials. Most samples have achieved the expected results.
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Key words: Technical textiles, protective clothing, sports and recreation textiles, sleeping bags, comfort properties of textiles, waterproof breathable fabrics, coated fabrics, water vapor permeability.

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)

Safety and protective textiles are considered one of the most important sector of technical textiles which refer to garments and other fabric related items designed to protect the human body from harsh environmental effects that may result in injury or death (2,3) such sun, wind, rain, chemicals, heat and fire, biological agents, microbes, molten metals, impact, etc. (3)

Waterproof breathable woven fabrics provide very good resistance against wind and rain which make them suitable for different end uses such as parachutes, sails, wind-proof clothes, sleeping bags, tents while serving light weight and high durability properties. (4)

1.1 Sleeping bags

Sleeping bags,in one form or another, are well known and generally used for outdoor camping activities for many years, (5, 7) as they are used in a wide variety of wilderness applications, including rock and ice climbing, camping, backpacking, fishing, mountain climbing, etc. by those in particular need for portable bedding. (6)

Sleeping bags are used by outdoor enthusiasts to protect themselves from the effects of the weather when camping or otherwise staying in the out of doors, (8) as when sleeping outdoors with or without a tent, it is desirable to have protection from dampness and wetness caused by rain, dew, or snow. For this reason, sleeping bags are available with waterproof outer shells. (9)

1.2 Sleeping bags construction

Sleeping bags have undergone significant development over the years in terms of the materials from which they are made, such as they are more insulated or can be packed up into much smaller bags that are easier to accommodate in a backpack. However, sleeping bag shape or design has not developed to a like degree, if at all. (7)

Most sleeping bags are still traditionally include a bottom portion, upon which an individual within the sleeping bag lays, and a top portion which extends over the person to cover the individual. Often the top and bottom portions are made of a single, large rectangular insulated or padded fabric that is folded and attached along bottom and side edges by a zipper to form a bag. (7, 10) Besides this, sleeping bags are often folded in half lengthwise and rolled into a tight ball for transportation and storage. (10)

1.3 Types of sleeping bags

Sleeping bags can be single or double which means, as their name indicates, for sleeping only one person or two persons.(11)

Sleeping bags can also be classified into disposable and conventional or reusable sleeping bags. conventional sleeping bags may be classified into two types,i.e., the feather and cotton sleeping bags, in fact, the two types have the same structure except for the internal filling elements. (12) Disposable sleeping bags structure are well known but many of them include combinations of a number of materials and involve complicated structural procedures which increase its cost. (13)

Currently, sleeping bags are designed with a weight adapted for a particular season or even for a particular temperature. (6)

1.4 Sleeping bag specifications

The shelter and insulation provided by a good sleeping bag is absolutely essential to a successful excursion. Various factors affect the viability of a good sleeping under various conditions such as, the sleeping bag must be relatively light to carry, on the other hand, the bag must provide suitable loft or thickness. (14) The material used for sleeping bags used in rain and wet conditions must also prevent liquid water from penetrating to the sleeper while at the same time permitting moisture vapor such as perspiration to pass out through the fabric. (3)

1.5 Comfort properties of sleeping bags

Keeping dry is important not only for comfort but health, safety and actual survival may depend upon it. (3) Production of water vapor by the skin is essential for maintenance of body temperature, where the normal body temperature is 37 ^{0}c (15) so moisture accumulation in sleeping bags during extended periods of use is detrimental to thermal comfort of the sleeper because the sleeper will be hot, sticky, wet and uncomfortable and in extreme cases may lead to sleep loss and hypothermia, (16)thus evaporation of moisture, usually sweat, is crucial in human thermoregulatory function as it provides cooling where otherwise body heat losses would not be able to match metabolic heat generation. (17)

Clothing can be comfortable only when it allows water vapor to permeate through it from skin, thus waterproof coated fabrics which does not allow perspiration to pass through will not enable body cooling as perspiration condenses on the inside of the fabric making the user quite wet from his or her own perspiration. On the other hand, waterproof breathable fabric has a very high standard of water resistance combined with a high level of breathability which made it perfect for sleeping bags. (3)

1.6 Waterproof breathable fabrics

The term "breathable" implies that the fabric is actively ventilated. Breathable fabric passively allow water vapor to diffuse through them yet still prevent the penetration of liquid water. In other words the ability of fabric to allow water vapor to penetrate is commonly known as breathability. (15) Breathable fabrics are available in large variety, which can be categorized as closely woven fabrics, micro-porous membranes and coatings, (15,18) and in this research one technique was used which is to apply a hydrophilic water coating to the exterior of the woven fabric to make the moisture easily evaporates but not liquid water. The mechanism of waterproof breathable fabrics depends on producing a micro-porous hydrophilic membrane which is both waterproof and breathable as each micropore is smaller than a drop of water, therefore the rain cannot penetrate. However, the micropore is bigger than a molecule of water vapor, so perspiration can penetrate the fabric and evaporate outside. (2) For woven fabrics, number of yarns per unit area, yarn linear density, weave type, fabric weight and thickness are the main fabric parameters that affect water permeability and water repellency. (4)

2. Experimental work

2.1 Specification of samples under study

The study investigates the effect of yarn fineness (yarn count), weft set, weave type and treatment of polyester woven fabrics in order to design and produce fabrics suitable for sleeping bags. All samples in the research were produced using woven technique with using three woven structure (Plain weave 1/1, twill 1/4 and satin 5), three weft sets (60,80 and 100 picks/cm),and three different yarns count(50,70 and 100 denier).

2.2 Finishing treatment of samples under study

Samples under study were treated using solution containing 250 ml P.V.C + 250 ml oxide titanium + 500 ml Dioxins-polychlorinated dibenzo dioxins solvent and then mixed together to harmony in a mixer. The fabric samples were dried at 100 ^{0}C for 3 min, then thermo-fixed at 170 ^{0}C for 1 min. All samples were treated with P.V.C solution to make the fabric repellent and a barrier to rain and in the same time produces a micro-porous sponge to allow water vapor to diffuse through them to achieve breathability.

2.3 Tests applied to samples under study

Several tests were carried out in order to evaluate the performance of samples under study, these tests were as follows :-

1-Tensile strength and elongation at break, this test was carried out according to the (ASTM-D1682) (19)

2-Water permeability, this test was carried out according to the (ASTM-D 4491-82) (20)

3-Water repellency, this test was carried out according to the (AATCC392-63) (21)

4-Fabric thickness, this test was carried out according to the (ASTM-D1777-96) (22)

5-Fabric weight, this test was carried out according to the (ASTM-D 3776- 79) (23)

3. Results and Discussion

Table (1): Specifications of samples under study

Sample no.	Specifications of samples under study					
	Fabric structure	Weft type&Warp	Warp set	Warp count	Weft count	Weft set
1	Plain weave 1/1	Polyester	120	100	50	50
2	Plain weave 1/1	Polyester	120	100	50	75
3	Plain weave 1/1	Polyester	120	100	50	100
4	Twill 1/3	Polyester	120	100	50	50
5	Twill 1/3	Polyester	120	100	50	75
6	Twill 1/3	Polyester	120	100	50	100
7	Satin 4	Polyester	120	100	50	50
8	Satin 4	Polyester	120	100	50	75
9	Satin 4	Polyester	120	100	50	100
10	Plain weave 1/1	Polyester	120	100	70	50
11	Plain weave 1/1	Polyester	120	100	70	75
12	Plain weave 1/1	Polyester	120	100	70	100
13	Twill 1/31	Polyester	120	100	70	50
14	Twill 1/3	Polyester	120	100	70	75
15	Twill 1/3	Polyester	120	100	70	100
16	Satin 4	Polyester	120	100	70	50
17	Satin 4	Polyester	120	100	70	75
18	Satin 4	Polyester	120	100	70	100
19	Plain weave 1/1	Polyester	120	100	100	50
20	Plain weave 1/1	Polyester	120	100	100	75
21	Plain weave 1/1	Polyester	120	100	100	100
22	Twill 1/31	Polyester	120	100	100	50
23	Twill 1/3	Polyester	120	100	100	75
24	Twill 1/3	Polyester	120	100	100	100
25	Satin 4	Polyester	120	100	100	50
26	Satin 4	Polyester	120	100	100	75
27	Satin 4	Polyester	120	100	100	100

Table (2): results of all tests applied to samples under study

Sample no.	Tests applied to samples under study									
	Tensile strength		Elongation (%)		Water repellency (%)	Water Permeability(%)	Thickness (mm)		Weight (g/m^2)	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	Before treatment	Before treatment	After treatment	Before treatment	After treatment
1	121	210	58	43	53	40	0.47	0.57	165	244
2	147	261	56	41	58	43	0.49	0.61	191	272
3	171	310	54	40	62	47	0.50	0.65	205	297
4	115	115	60	47	62	46	0.45	0.55	166	242
5	140	140	59	45	68	52	0.47	0.60	192	280
6	162	162	57	44	73	61	0.50	0.64	202	294
7	106	184	62	49	69	55	0.44	0.55	162	236
8	130	228	60	46	78	70	0.46	0.60	180	260
9	150	261	58	45	82	78	0.50	0.61	190	273
10	145	260	53	39	58	42	0.54	0.62	200	290
11	160	293	50	37	62	47	0.56	0.65	225	315
12	194	360	49	35	68	55	0.57	0.68	240	342
13	141	250	55	41	74	53	0.52	0.66	200	287
14	156	280	54	39	78	65	0.55	0.69	206	292
15	182	330	51	37	81	80	0.60	0.70	220	317
16	133	238	57	47	72	71	0.51	0.68	202	294
17	150	268	55	46	81	80	0.52	0.71	235	335
18	175	318	53	44	89	97	0.55	0.72	254	362
19	217	378	45	30	69	51	0.57	0.72	275	390
20	244	445	44	26	72	56	0.60	0.74	221	445
21	300	490	42	25	82	71	0.61	0.76	337	470
22	200	360	47	34	79	70	0.56	0.71	275	391
23	230	409	46	30	83	80	0.60	0.74	311	434
24	290	470	44	26	88	86	0.62	0.78	330	472
25	180	325	50	35	79	93	0.55	0.71	280	390
26	223	392	48	34	88	100	0.58	0.72	310	436
27	274	450	47	32	92	112	0.61	0.76	325	451

Tensile strength and elongation

Before treatment

It is clear from figures from (1) to (4) that there is a direct relationship between number of picks /cm and fabrics tensile strength and an inverse relationship between both of them in elongation. This is mainly because of that the increase of umber of picks/cm means an increase in the number of yarns per unit area and so the contact areas between yarns will be increased and its resistance to slippage will also be increased leading to the increase in fabric strength and decrease its elongation at break.

It is obvious from the table (2) and figures (1) and (3) that, plain weave has recorded the highest rates of tensile strength and the lowest in elongation, whereas satin has recorded the lowest rates of tensile strength and the highest in elongation. That is mainly due to that plain weave structure have more intersections per unit area compared to other structures which restrict the free movement of yarns due to the increase in number of intersections leading to the increase in fabric strength and decrease its elongation at break.

It is obvious from the tensile strength and elongation results and figures (2) and (4) that, samples with 100 denier have recorded the highest rates of tensile strength and the lowest rates of elongation followed by samples with 70 denier and then 50 denier.this is due to the yarns of 100 denier are thicker than yarns of 50 and 70 denier and so spaces between yarns will be decreased leading to the increase in friction areas between them and decrease slippage ability between yarns causing the produced samples to be higher in their tensile strength and decrease its elongation at break.

It was also found that the more picks /cm the more tensile strength and the lower elongation the samples become, so samples with100 picks /cm have recorded the highest rates of tensile strength, followed by samples of 80 picks/cm and 60 picks/cm.

After treatment

It is also obvious from the results that treated samples have achieved higher tensile strength compared to non-treated samples. It can be reported that the treatment solution has filled the voids between yarns causing a decrease in spaces between yarns and increase in friction areas between them leading to decrease in slippage ability of yarns so the fabrics become more compacted, and thus increase fabric tensile strength and decrease its elongation at break.

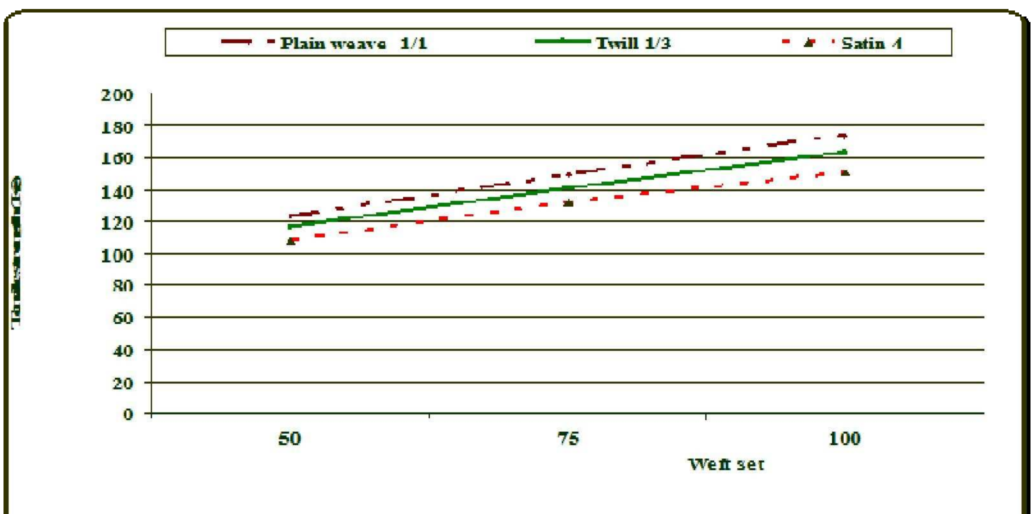

Fig.(1) effect of fabric structure and weft set on tensile strength before treatment ,using polyester 50 denier

Table (3): Regression equation and correlation coefficient for the effect of number of picks /cm and fabric structure on tensile strength, at 50 denier yarns (before treatment).

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y =1.02 X + 72.166667	0.999936
Twill 1/4	Y = 0.94 X + 70.16667	0.99925
Satin 5	Y =0.86 X + 65.83333	0.997754

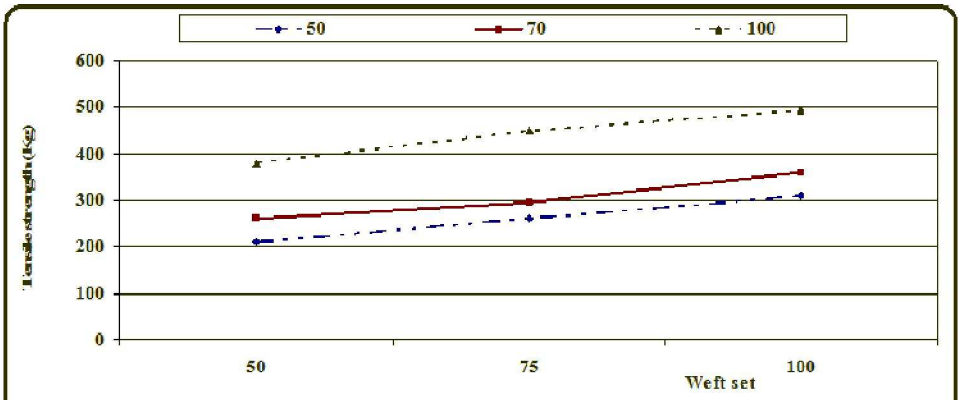

Fig.(2) effect of yarn count and weft set on tensile strength before treatment ,using plain weave 1/1

Table (4): Re[...] yarn count on tensile strengt[...]

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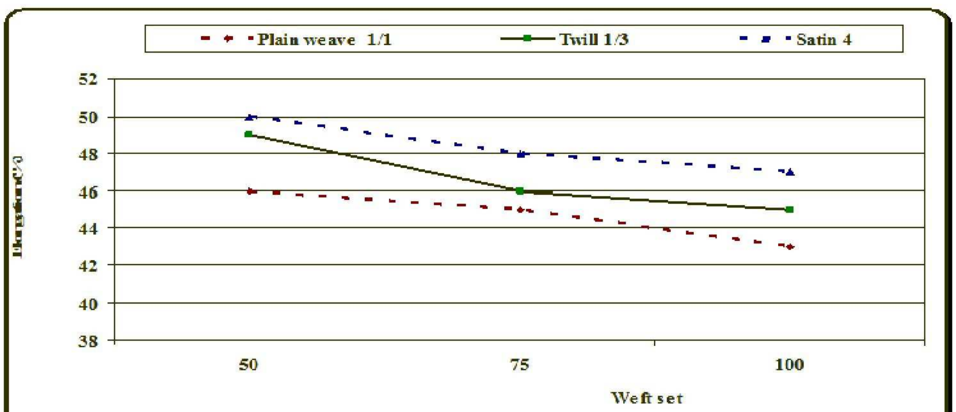

Fig.(3) effect of fabric structure and weft set on elongation after treatment ,using polyester 50 denier

Table (5): Regression equation and correlation coefficient for the effect of number of picks /cm and fabric structure on elongation, at 50 denier yarns (after treatment).

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y =- 0.06 X + 49.1667	-0.981981
Twill 1/4	Y =- 0.08 X + 52.66667	-0.960769
Satin 5	Y =0.06 X + 52.83333	0.981981

Table (6): Regression equation and correlation coefficient for the effect of number of picks /cm and yarn count on elongation, using twill 1/3 (before treatment).

Yarn count (denier)	Regression equation	Correlation coefficient
50	Y =-0.06 X + 50.16667	-0.981981
70	Y =- 0.08 X + 59.3333	-0.981981
100	Y =0.06 X + 563.16667	-0.981981

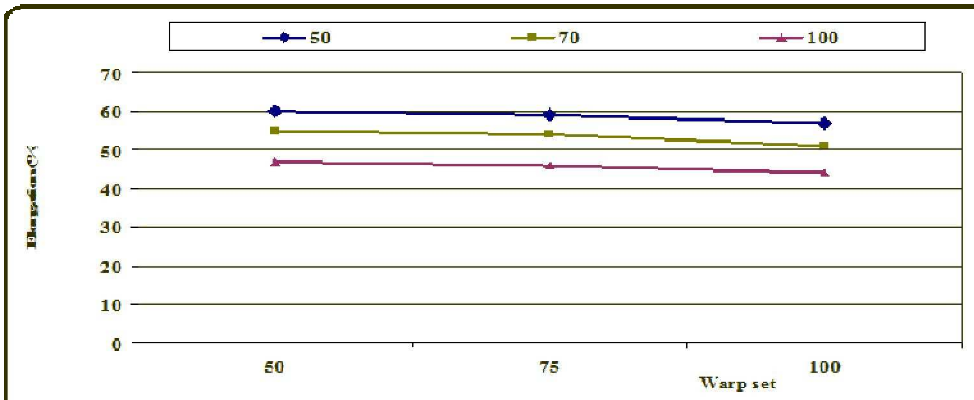

Fig.(4) effect of yarn count and weft set on elongation before treatment ,using twill 1/3

Water permeability

Before treatment

It is obvious from the results in table (2) and figure (6) that, plain weave 1/1 has recorded the highest rates of water permeability, whereas satin 4 has recorded the lowest rates. I can report that may due to plain weave have more intersections than satin and twill weave, which have long floats compared to plain weave structure, causing the produced fabrics of plain weave structure to be less compacted and rave more spaces compared to other structures leading to the increase in water permeability.

The study showed that water permeability can be reduced by increasing number of picks per unit area. This is for sake of that the increased in number of picks per unit area cause fabrics to be more compacted and decrease spaces between yarns, which decrease the passage of water.

I can also notice from figure (6) that, samples made of 100 denier have obtained the lowest rates of water permeability, compared to 70 and 50 denier samples as by increasing the diameter of yarns, the dimensions of pores become smaller, thus the water permeability decreases.

After treatment

From results obtained after treatment, all samples did not give any results (0 % water permeability), this is due to that when a woven fabric is treated, the void spaces (pores) could be situated between warp and weft threads (inter yarn porosity) and the neighboring yarns become very close and so the projected area of inter-yarn pores approaches zero,therefore its water permeability decrease.

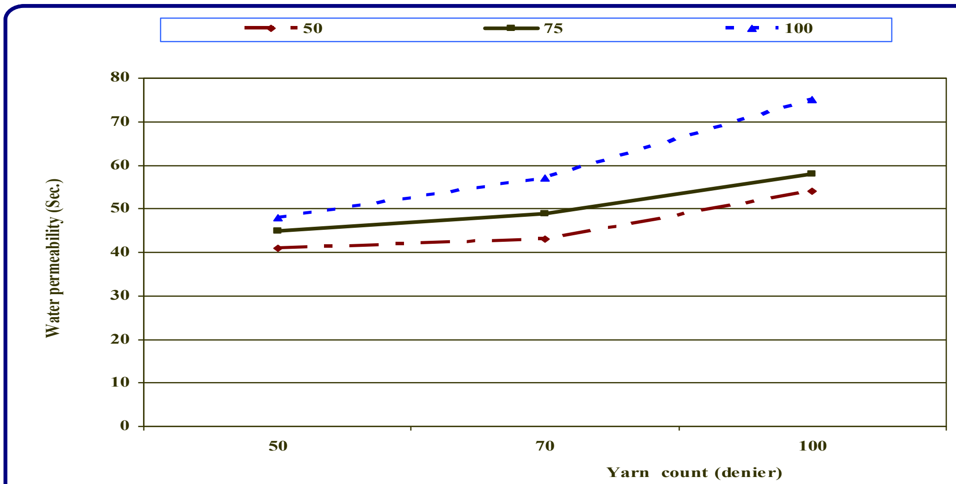

Fig.(5) effect of yarn count and weft set on water permeability before treatment ,using plain weave 1/1.

Table (7): Regression equation and correlation coefficient for the effect of number of picks /cm and yarn count on water permeability, at plain weave 1/1 (before treatment).

Yarn count	Regression equation	Correlation coefficient
50	Y =0.14 X + 34.16667	0.996616
70	Y =- 0.28 X + 28.66667	0.996616
100	Y =0.42 X + 30.83333	0.941663

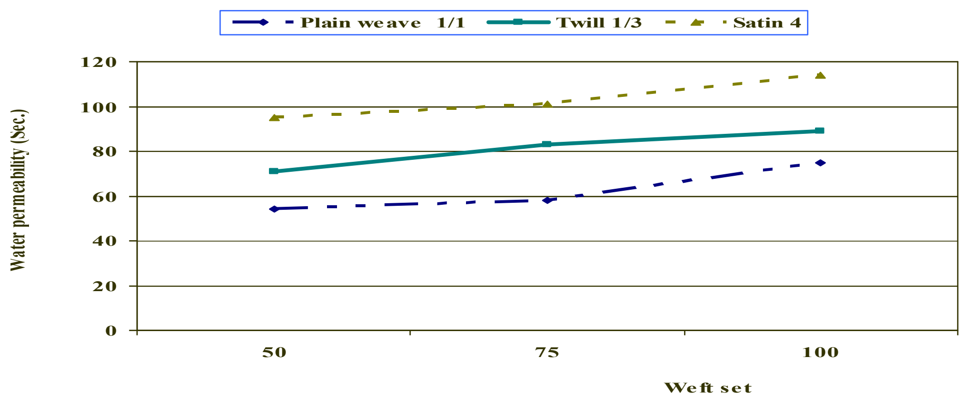

Fig.(6) effect of fabric structure and weft set on water permeability before treatment ,using yarn count 100 denier.

Table (8): Regression equation and correlation coefficient for the effect of number of picks /cm and fabric structure on water permeability, at 100 denier (before treatment).

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y =0.42 X + 30.8333	0.9416667
Twill 1/4	Y = 0.36 X + 54	0.98981
Satin 5	Y =0.38 X + 74.83333	0.978117

Water repellency

Before treatment

From table (2), it is obvious that fabrics structure had insignificant effect on water repellency readings.

From results obtained and figures (7) and (8), It is clear that samples produced of 100 denier have recorded the highest rates of water repellency followed by samples with 70 denier and 50 denier, as it could be reported that the increase in yarns thickness decrease spaces between them and the fabric become more compacted, leading to the increase in water repellency.

It was also found that, there is a direct relationship between weft set and water repellency. Where it could be reported that the increase in weft set caused a decrease in fabrics pores (blocking of the surface) and so increase fabrics compactness, and thus increasing its water repellency.

After treatment

From results obtained after treatment, all treated samples have achieved 100 % water repellency, this is due to that treatment has filled all spaces in fabrics causing blocking of the surface and so the fabrics become more compacted, and thus increasing its water repellency.

Table (9): Regression equation and correlation coefficient for the effect of number of picks /cm and fabric structure on water repellency, at plain weave 1/1 (before treatment).

Yarn count	Regression equation	Correlation coefficient
50	Y =0. 2 X + 45	1
70	Y = 0.2 X + 50	1
100	Y =0.3 X + 54.16667	0.98981

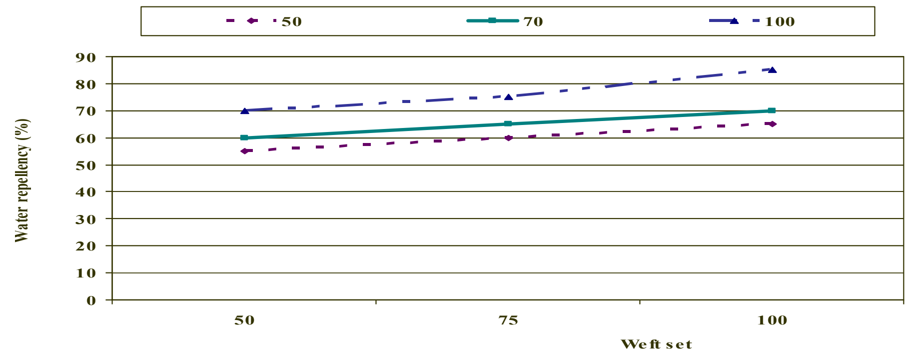

Fig.(7) effect of yarn count and weft set on water repellency before treatment ,using plain weave 1/1.

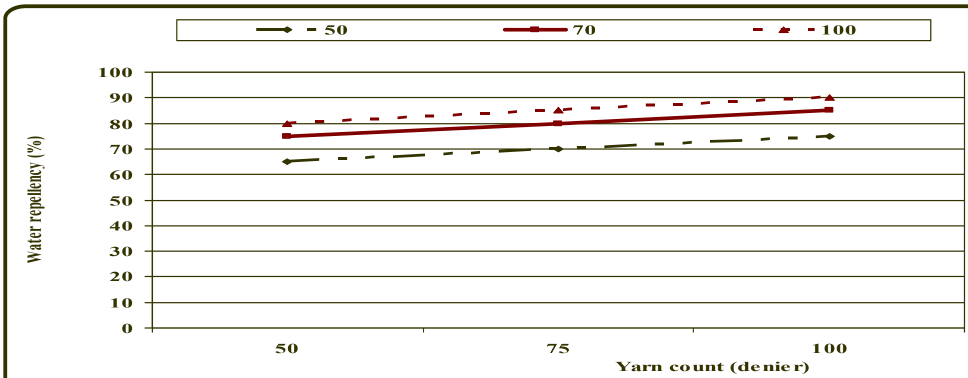

Fig.(8) effect of yarn count and weft set on water repellency before treatment ,using twill 1/3.

Table (10): Regression equation and correlation coefficient for the effect of number of picks /cm and yarn count on water repellency, at twill 1/3 (before treatment).

Yarn count	Regression equation	Correlation coefficient
50	Y =0. 2 X + 55	1
70	Y = 0.2 X + 65	1
100	Y =0.2 X + 70	1

Thickness

It is clear from the diagrams, that plain weave has recorded the highest rates of thickness, followed by twill weave, and then satin weave which achieved the lowest rates but the differences were insignificant. This is mainly for sake of that plain weave have ridges on fabric surface due to its regular intersections giving samples the ability of being thicker than the other structure.

Another reason for these differences in thickness is yarn count, as samples with 100 denier have recorded the highest thickness followed by samples with 70 denier and then 50 denier, This is due to that yarns of 100 denier are thicker than yarns of 70 and 50 denier, causing the produced samples to be thicker.

It was also found that there is a direct relationship between weft set and fabric thickness, so samples with 100 picks / cm have recorded the highest rates of thickness compared to samples of 60 and 80 picks/cm. This is due to that the increase of number of pick cause the produced fabric to be more compacted and then the thickness will be increased.

After treatment

All samples have recorded an increase in their thickness due to the effect of treatment solution.

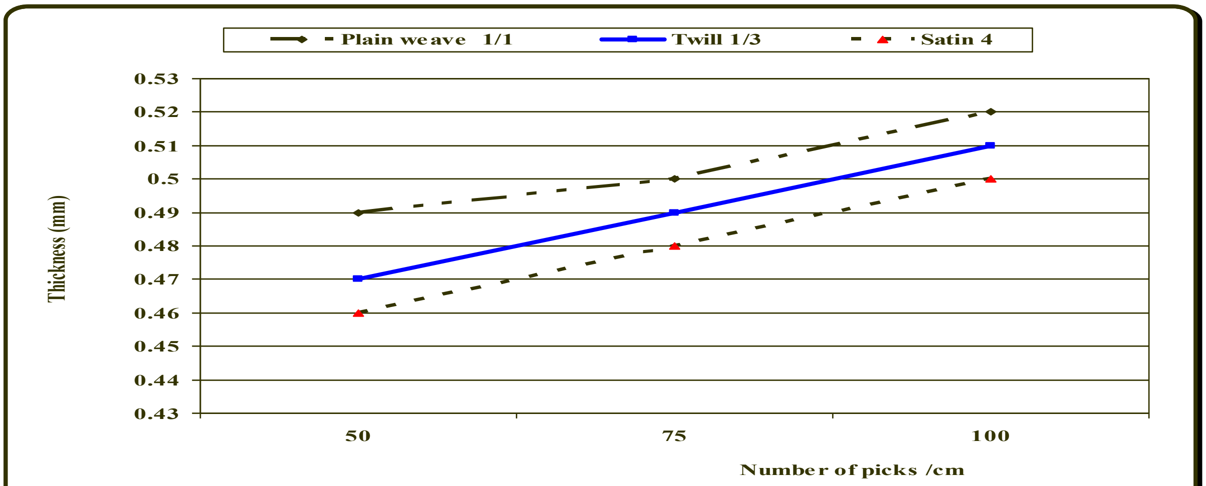

Fig.(9) effect of fabric structure and weft set on thickness before treatment ,using polyester 50 denier .

Table (11): Regression equation and correlation coefficient for the effect of number of picks /cm and fabric structure on thickness, at50 denier (before treatment).

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y =0. 0006 X + 0.458333	0.98981
Twill 1/4	Y = 0.0008 X + 0.43	1
Satin 5	Y =0.0008 X + 0.42	1

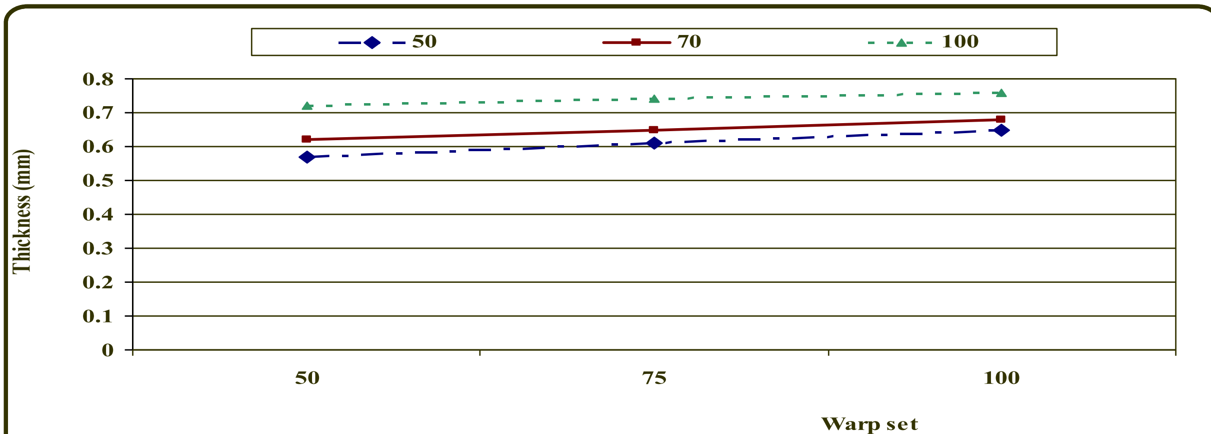

Fig.(10) effect of yarn count and weft set on thickness after treatment ,using plain weave 1/1

Table (12): Regression equation and correlation coefficient for the effect of number of picks /cm and yarn count on thickness, at plain weave 1/1 (after treatment).

Yarn count	Regression equation	Correlation coefficient
50	Y =0. 0016 X + 0.49	1
70	Y = 0.0012 X + 0.56	1
100	Y =0.0008 X + 0.68	1

Weight

Before treatment

It is clear from figure (11) that, there were insignificant differences in weight between the three structures.

It is also clear that samples produced of 100 denier have recorded the highest weight followed by samples with 70 and 50 denier. This is for sake of that yarns of 100 denier are thicker than yarns of 70 and 50 denier, causing the produced samples to be increased in weight.

It was also found from table (2) and figure (11) that, the more yarns per unit area, of weft set, the more thicker the samples become, so samples with 100 picks per cm have recorded the highest weight, whereas samples with 60 picks per cm have recorded the lowest weight.

After treatment

All samples have gained more weight due to the penetration of treatment solution between the voids (spaces) between yarns and between fibers in the threads, therefore the fabrics become heavier in weight.

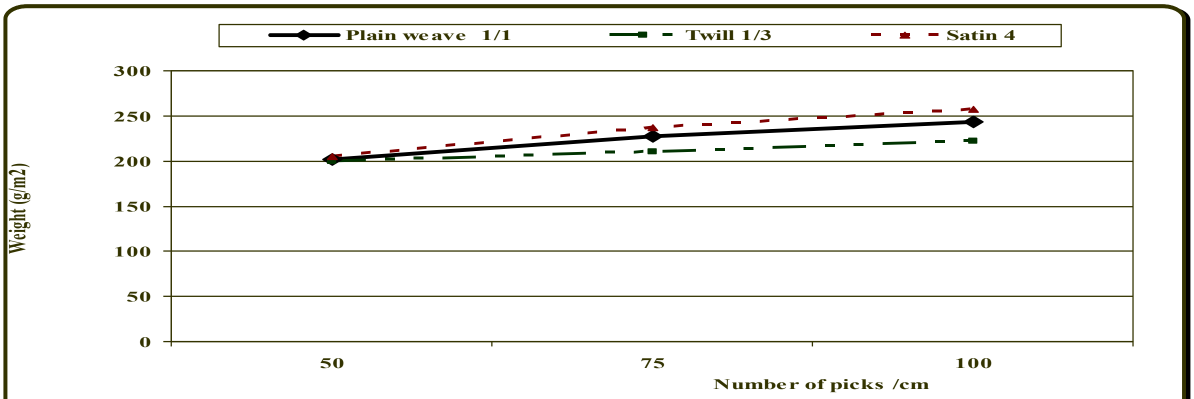

Fig.(11) effect of fabric structure and weft set onweight before treatment ,using polyester 70 denier .

Table (13): Regression equation and correlation coefficient for effect of number of picks /cm and fabric structure on weight, at 70 denier before treatment.

Fabric structure	Regression equation	Correlation coefficient
Plain weave 1/1	Y =0. 082 X + 162.5	0.992065
Twill 1/4	Y = 0.44 X + 177. 6667	0.998625
Satin 5	Y =1.04 X + 155	0.991241

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