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Investigating the effect of Joining Techniques on Waterproof and Comfort Properties

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Abstract— Waterproof clothes quality greatly depends on waterproof performance of seams. To study the effect of joining techniques on clothing comfort, Gore-Tex waterproof breathable fabric was sewn with different stitch and seam types in both weft and warp directions and seam line was sealed different sealing materials. Ultrasonic welding was used as an alternative joining method. Both seam strength and elongation were remarkable affected by sewing and sealing and welding in both directions, while using different types of seams and stitches did not affect water permeability or resistance to water penetration under pressure.

Index Terms— Resistance to Water Penetration, Seam Sealing, Seam strength, Seam & Stitch types, Ultrasonic welding, Water permeability, Waterproof breathable fabric (Gore-Tex)

1 Introduction

One of the major purposes of garments is to provide thermal protection, particularly for people who work in low temperature environments with great possibility of cold injuries and related illness [1]. The garments' insulation depends on the thickness of fabric and the quantity of enclosed dry still air within its layers, as unmoving waterless air is considered to be an excellent insulator, having a value of thermal resistance only slightly less than that of a vacuum. The total combination of wind, wetting and disturbance of entrapped air can decrease the insulation value of a clothing system by 90% [2],[3]. It is essential to focus on limiting the heat loss from the body generated from metabolism to the environment and to permit perspiration and prevent entrance of rain drops while choosing fabrics of low temperature protective outfits.

When the outermost layer of clothing system is made of waterproof breathable textile, it provides a special protection from weather conditions such as wind, rain and simultaneously permits perspiration diffusion through it to the outside atmosphere. The first and likely the best known laminated material (microporous membrane), developed and presented in 1976 by W Gore; it is known as Gore-Tex. This is a very fine film about 0.02mm of polytetrafluoroethylene (PTFE) polymer. It is proved to contain 1.4 billion fine holes per square centimeter. These holes are additional smaller than the smallest raindrops (2–3mm in comparison with 100mm), yet great larger than a water vapor molecule (40×10^{-6}mm) [4],[5].

Waterproof apparels quality largely depends on seam waterproof performance [6]. Traditional sewing using needles and threads is the most widespread method of joining textiles together, but it is not preferable to be used it in manufacturing waterproof garments, as needle may cause seam leaking. This will cause waterproof breathable textile to lose its functionality. To prevent that, sewn seams must be sealed or a new joining technique based on welding such as Ultrasonic welding, can be used to create an entirely sealed seams [7].

In 2004 Jeong and An [8] investigated mechanical properties of 22 different waterproof breathable fabrics after sewing and tape sealing in both warp and weft directions. It was found that tensile properties have extremely changed, the waterproof sealing tape strengthened the sewing thread and the shear properties increased in warp direction, although they decreased in weft direction.

It is essential to investigate the process of ultrasonic welding (USW) and the effect of its parameters, in order to achieve waterproof fabric bond with high mechanical properties [6]. The amplitude, welding speed and time are mainly the basic parameters of USW as they determine the quantity of mechanical energy changed into heat energy to be delivered to welding fabric[9]. Shi and Little [10] found that the welding strength improved up to 15% when the pressure rose of up to 30 psi then it started to decline. The same trend happened when welding time was changed. It was also observed that the weld strength improved by 80% when the amplitude rose from 42-60µm.

This study aims to study the effect using sewing variables (stitches and seams) with different seam sealing materials, and also the effect of using Ultrasonic welding on comfort properties(seam strength & water permeability) of waterproof breathable Fabric (Gore-Tex).

2 Methodology

2.1 Conventional Sewing

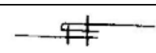
Gore-Tex was sewn with two different stitch classes and three seam types which are:
Sample A: Chain stitch (401) + Superimposed Seam (SSa).
Sample B: Chain stitch (401) + Lapped Seam (LSq).
Sample C: Cover stitches (605) + Lapped seam (LSa).

All stitching work has been done on Pegasus W500 industrial five thread cover stitch machine, with stitch density four stitches per centimeter, using 42/2 polyester sewing thread and a needle size 11/75.

TABLE 1
GORE-TEX FABRIC SPECIFICATIONS

Fabric construction	Wales /cm	Courses /cm	Weight g/m^2	Thickness mm
100%single jersey polyamide laminated by ePTFE	20.5	14.5	108.57	0.187

TABLE2
SEAM DRAWINGS

Seam	Drawing
lapped seam (LSa)	
lapped seam (LSq)	
Superimposed Seam (SSa)	

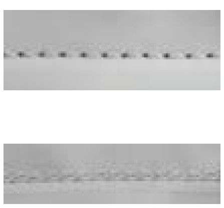


Fig. 1. Sample A

Fig. 2. Sample B

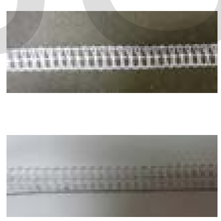


Fig. 3. Sample C

2.2 Seam Sealing Materials

Eight different materials were used to seal the already sewn seams, two of them were imported from USA which are Seam Grip Seam Sealer and Seam Seal Melco Tape. The 100% RTV–Silicon was picked from the market and it is also made in Egypt. Four were prepared in Egypt in the Protinic and Manmade fibers department laboratory of National Research Center: Polyurethane, Polyvinyl Pyridine, Polystyrene and water soluble Polyurethane. The Polytetrafluorethylene film acquired from Gore-Tex fabric.

2.3 Appling Seam Sealing Materials

2.3.1 Seam Grip Seam Sealer

The tube was soaked in warm water for 15 minutes, a thin film was drawn across the threads of the sewn samples by squeezing the tube lightly, a brush was used to coat threads under folded fabric, the specimen was left overnight (8-12 hrs) to dry. This was done according to manufacturer recommendations.

Fig. 4. Seam grip seam sealer

2.3.2 Seam Seal Melco Tape

The tape has two sides, one side is a fabric (polyester and Lycra) and the other side is formed of adhesive resin.
The adhesive side was subjected to steam and then the tape was put on the seam and ironed with low temperature so that the fabric would not be damaged.

Fig. 5. The adhesive side of Seam Seal Melco Tape

Fig. 6. The fabric side of Seam Seal Melco Tape

2.3.3 100% RTV–Silicon

A thin film was drawn across the threads of the sewn sample by squeezing the tube lightly, a brush was used to coat threads under folded fabric, and the specimen was left from 20 to 24 hours to dry at room temperature.

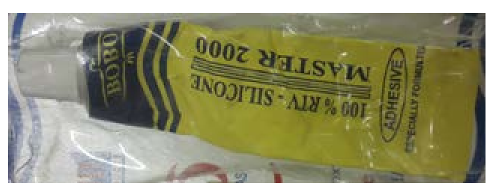


Fig. 7. 100% RTV–Silicon tube

2.3.4 Other chemical materials (polymers) obtained during the current research

2.3.4.1 Polyurethane, Polyvinyl Pyridine, Polystyrene, water soluble Polyurethane

Each one of them was applied separately on the taut seam by using a brush, then the specimen was put in the oven at 130°c ± 5 for 5 minutes to dry.

2.3.4.2 Polytetrafluorethylene film

A thin film of Polytetrafluorethylene obtained from Gore-Tex fabric was attached to the seams by using a lightweight nonwoven fusible under heat and pressure using steam press iron.

2.4 Ultrasonic Welding

Using Ultrasonic sewing machine, PFAFF, Seamsonic 8310 the Gore-Tex fabric was ultrasonically welded at ITA Istanbul. The device was prepared to sew the fabric properly. After some trails, an optimum level of sewing has been reached. According to the appearance and the experience of the engineer and the technician the best was selected

TABLE3
THE USED ULTRASONIC WELDING PARAMETERS

Sample	Pressure(Bar)	Round (dm/min)	Amplitude (%)
D	1	12	50

Fig. 8. Ultrasonic sewing machine, PFAFF, Seamsonic 8310 during welding samples used in this research

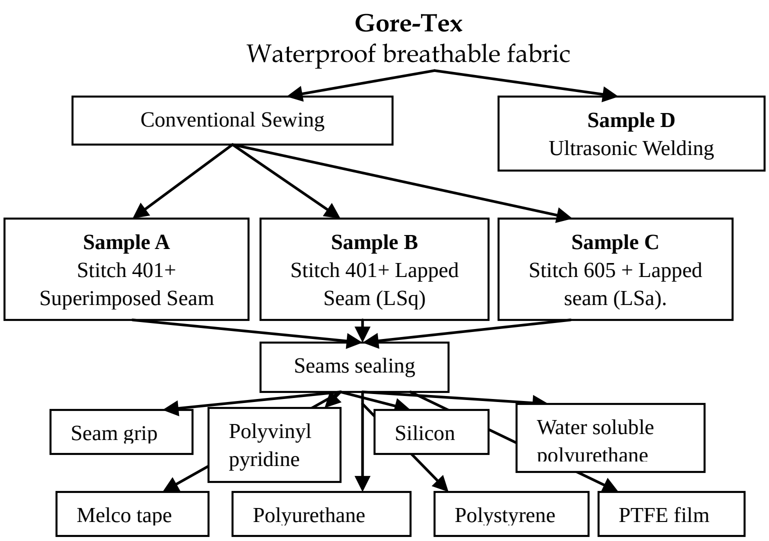


Fig. 9. Diagram illustrating Samples **A**,**B**,**C** & **D**

The seam strength of all previous samples was tested using Instron tensile testing machine, model number (2519-107), according to ISO 13935-1, the resistance to water penetration-Hydrostatic pressure was determined, according to ISO 811-1981(E) and water permeability according to ISO 12958:1999, using Hydrostatic head tester, model number (FX 3000).

3 RESULTS AND DISCUSSION

Bond strength and elongation was measured in both directions for all samples, it was observed in Tape sealed samples that Instron tensile testing machine has stopped immediately after the tape split; the sewing thread in the stitch line was not ruptured. Using tape as a seam sealer has increased the strength of seams .

TABLE4
THE AVERAGE RESULTS OF SEAM STRENGTH AND ELONGATION OF A,B &C SAMPLES IN WEFT AND WARP DIRECTIONS

Sample Description		Stress at Max.Load (kgf/mm2)	Strain at Max. Load (%)
A	Warp	0.68±0.05	115.42±6.87
	Weft	0.67±0.02	55.83±1.21
B	Warp	0.83±0.03	131.31±4.11
	Weft	0.96±0.01	67.86±0.65
C	Warp	0.81±0.03	129.58±3.37
	Weft	0.93±0.01	65.89±0.13

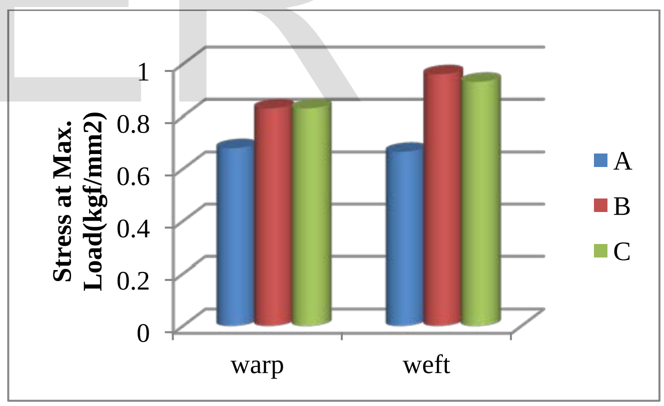


Fig. 10. The average seam strength results of A, B, C samples in warp and weft directions

The results showed that Sample A has the lowest value in seam strength in both directions, While Sample B is the highest. That confirms that seam strength increases as number of layers forming seam increase and also it increases with the increase of thread consumption and number of rows forming the stitch, as stresses applied to the seams may be carried by several stitching lines[11]. Seam strength results of sample (A) is the lowest as it consists of one row of stitches and two layers of fabric with the least thread consumption, While sample(B) consists of two rows of stitches and three layers of fabric with double thread consumption.

The strength results in warp direction are different from weft and that agrees with Domingues et al.[12], which reported that seam direction (warp and weft) has a significant effect on the seam strength.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0.03	1	0.03	32.47	1E-04	4.75
Columns	0.18	2	0.09	99.94	3E-08	3.89
Interaction	0.02	2	0.01	11.14	0.00	3.89
Within	0.01	12	0.00			
Total	0.2	17				

By running a two-way Anova with replications, a highly significant difference was found in stress results between weft and warp directions and between the samples A, B and C. Also found an interaction between type of stitch and seam and direction of sewing (warp and weft); which indicates that the seam, stitch type and direction of sewing have significant impact on strength of seams.

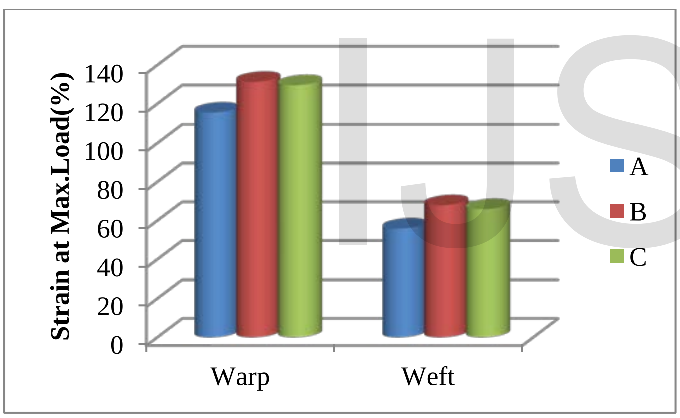


Fig. 11. The average Elongation (strain) results of A, B, C samples in warp and weft directions

The extensibility of seams in warp direction is higher than in weft direction, the seam elasticity depends on a large number of variables such as, material that is stitch bonded, stitch type, seam type, stitch density, etc.[13]. Fabric construction of Gore-Tex made it elongate more in parallel direction.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	17,433	1	17,433	1,351	0	4.75
Columns	690	2	345	26.74	0	3.89
Interaction	15.94	2	7.97	0.62	0.56	3.89
Within	154.8	12	12.9			
Total	18,293	17				

By running a two-way Anova with replications, a high significant difference was found in strain results between both directions and between the samples A, B and C; which indicates that the seam, stitch type and direction of sewing have significant impact on extensibility of seams.

TABLE5
THE AVERAGE RESULTS OF SEAM STRESS AND STRAIN IN WARP DIRECTION OF ULTRASONIC SAMPLE (D) AND A,B & C AFTER USING DIFFERENT SEAM SEALING MATERIALS

Sample Description		Stress at Max.Load (kgf/mm2)	Strain at Max. Load (%)
PLAIN	A	0.68±0.05	115.42±6.87
	B	0.83±0.03	131.31±4.11
	C	0.81±0.03	129.58±3.37
POLYURETHANE	1A	0.65±0.06	108.47±7.88
	1B	0.86±0.01	136.06±0.61
	1C	0.84±0.01	129.89±0.42
POLYVINYL PYRIDINE	2A	0.61±0.03	106.89±2.98
	2B	0.76±0.12	123.70±14.48
	2C	0.82±0	132.31±2.95
POLYSTYRENE	3A	0.55±0.04	98.78±4.61
	3B	0.82±0.05	129.56±7.3
	3C	0.79±0.01	128.03±1.51
WATER SOLUBLE POLYURETHANE	4A	0.63±0.08	107.25±8.4
	4B	0.85±0.03	132.97±5.39
	4C	0.82±0	129.39±1.05
SILICON	5A	0.62±0.02	106.94±2.52
	5B	0.85±0.01	131.78±1.42
	5C	0.83±0.02	130.19±3.7
SEAM GRIP	6A	0.52±0.24	95.31±29.16
	6B	0.85±0.05	132.39±7.64
	6C	0.79±0.04	127.75±3.2
MELCO TAPE	7A	0.26±0	63.25±0.75
	7B	0.45±0.34	84.69±42.06
	7C	0.81±0.02	130.56±3.21
PTFE FILM	8A	0.49±0.21	90.61±25.94
	8B	0.82±0.02	129.75±1.83
	8C	0.84±0.05	132.81±6.95
ULTRASONIC	D	0.12±0.01	43.5±2.55

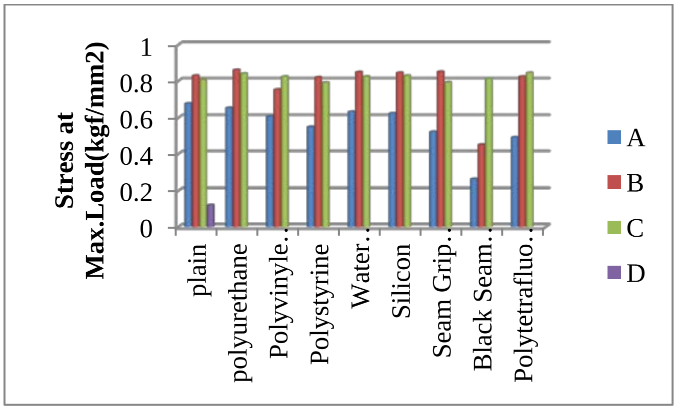


Fig.12. The average seam strength results in warp direction of Ultrasonic sample (D) and the effect of different sealing materials on A, B and C samples

The Ultrasonic welding has the lowest seam strength value in parallel direction; as a part of fabric is consumed in welding process, while Sample (2B) which is Lapped seam sewn by Chain stitch and polyvinyl pyridine sealed has the highest value.

ANOVA

Source of Var.	SS	df	MS	F	P-value	F crit
Sample	0.5	8	0.06	6.5	7E-06	2.12
Columns	1.1	2	0.54	55.9	7E-14	3.17
Inter.	0.3	16	0.02	1.9	0.04	1.83
Within	0.5	54	0.01			
Total	2.42	80				

By using two-way Anova with replications, a high significant difference was found between different materials used in seam sealing and also between the types of seams and stitches and an interaction between the effect of sealing materials and types of seams and stitches on seam strength in warp direction.

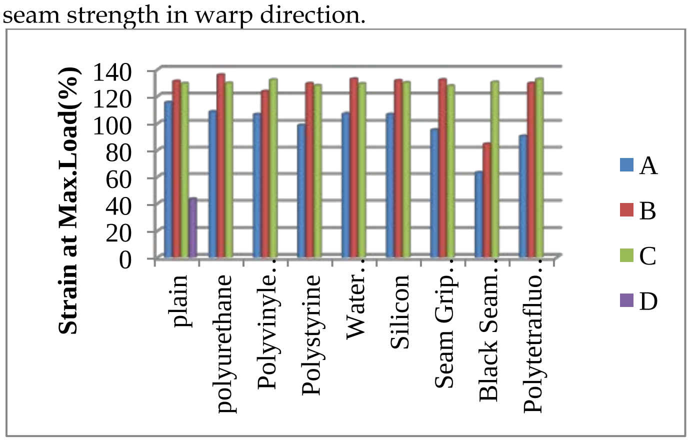


Fig.13. The average seam extensibility results in warp direction of Ultrasonic sample (D) and the effect of different sealing materials on A, B and C samples

The Ultrasonic welding has the lowest seam strain value in warp, while Sample (1B) which is Lapped seam sewn by Chain stitch and polyurethane sealed has the highest value.

ANOVA

Source of Var.	SS	df	MS	F	P-value	F crit
Sample	7153	8	894	6.03	2E-05	2.1
Columns	15074	2	7537	50.8	4E-13	3.2
Inter.	4628	16	289	1.95	0.04	1.8
Within	8011	54	148			
Total	34867	80				

By using two-way Anova with replications, a high significant difference was found between different materials used in seam sealing and also between the types of seams and stitches and an interaction between the effect of sealing materials and types of seams and stitches on seam extensibility in warp direction.

TABLE6
THE AVERAGE RESULTS OF SEAM STRESS AND STRAIN OF IN WEFT DIRECTION OF ULTRASONIC SAMPLE (D) AND (A,B & C) AFTER USING DIFFERENT SEAM SEALING MATERIALS

SAMPLE DESCRIPTION		Stress at Max.Load (kgf/mm2)	Strain at Max. Load (%)
PLAIN	A	**0.67±0.02**	**55.83±1.21**
	B	**0.96±0.01**	**67.86±0.65**
	C	**0.93±0.01**	**65.89±0.13**
POLYURETHANE	1A	**0.63±0.02**	**56.89±0.42**
	1B	**1±0.07**	**71.56±3.01**
	1C	**1±0.01**	**71.25±0.9**
POLYVINYL PYRIDINE	2A	**0.52±0.21**	**50.94±15.07**
	2B	**0.88±0.11**	**67.64±3.26**
	2C	**0.96±0.04**	**69±1.59**
POLYSTYRENE	3A	**0.68±0.04**	**59.69±1.8**
	3B	**0.97±0.05**	**71.69±3.06**
	3C	**0.96±0.03**	**70.14±1.35**
WATER SOLUBLE POLYURETHANE	4A	**0.69±0.07**	**60.94±3.58**
	4B	**0.99±0.05**	**72.5±1.76**
	4C	**0.98±0.04**	**71.08±1.52**
SILICON	5A	**0.72±0.07**	**57.19±2.86**
	5B	**0.95±0.13**	**66.72±5.24**
	5C	**0.98±0.01**	**66.42±1.09**
SEAM GRIP	6A	**0.82±0.06**	**61.44±2.29**
	6B	**0.92±0.05**	**65.33±2.13**
	6C	**0.95±0.04**	**65.25±1.13**
MELCO TAPE	7A	**0.73±0.09**	**59.56±4.39**
	7B	**0.98±0.05**	**69.28±1.86**
	7C	**0.97±0**	**68.92±0.36**
PTFE FILM	8A	**0.71±0.07**	**59.81±2.92**

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	8B	**0.97±0.07**	**69.64±3.12**
	8C	**0.94±0.03**	**67.97±1.47**
ULTRASONIC	D	**0.12±0**	**25.75±1.8**

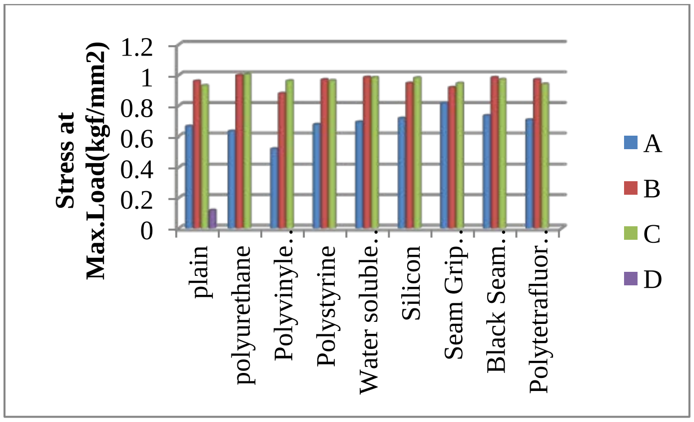

Fig.14. The average seam strength results in weft direction of Ultrasonic sample (D) and the effect of different sealing materials on A, B and C samples

The Ultrasonic welding has the lowest seam strength value in perpendicular direction this can be due to consuming a part of fabric in welding process, while Sample (1C) which is a Lapped seam sewn by Cover stitch (605) and sealed with polyurethane has the highest value, Sample (1B) is in the second place with a very slight difference.

ANOVA

Source of Var.	SS	df	MS	F	P-value	F crit
Sample	0.08	8	0.01	2.13	0.05	2.12
Columns	1.38	2	0.69	147.06	1E-22	3.17
Inter.	0.12	16	0.01	1.60	0.1	1.83
Within	0.25	54	0.00			
Total	1.83	80				

By using two-way Anova with replications, a significant difference was found between different materials used in seam sealing and also between the types of seams and stitches in seam strength results of weft direction.

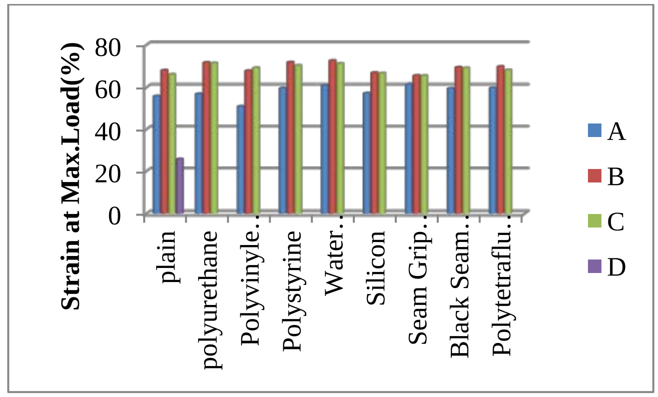

Fig. 15. The average seam extensibility results in weft direction of Ultrasonic sample (D) and the effect of different sealing materials on A, B and C samples

The Ultrasonic welding has the lowest seam strain value in weft direction; as a part of fabric is consumed in welding process, while Sample (3B) which is Lapped seam sewn by Chain stitch and polystyrene sealed has the highest value.

ANOVA

Source of Var.	SS	df	MS	F	P-value	F crit
Sample	280	8	35	2.5	0.02	2.12
Columns	2087	2	1044	74.9	3E-16	3.17
Inter.	238	16	15	1.07	0.41	1.83
Within	752	54	14			
Total	3358	80				

By using two-way Anova with replications, a significant difference was found between different materials used in seam sealing and also between the types of seams and stitches in seam extensibility of weft direction.

TABLE7

THE AVERAGE RESULTS OF RESISTANCE WATER PENETRATION (HYDROSTATIC PRESSURE TEST)

Sample		cm
plain	**A**	**25 ±1.4**
	B	**25 ±0.5**
	C	**23.5 ±0.90**
polyurethane	**1A**	**56.7 ±16.1**
	1B	**50.8 ± 14.1**
	1C	**52 ±14.37**
polyvinyl pyridine	**2A**	**41.14 ±14.14**
	2B	**61.14 ±35.1**
	2C	**93.3 ±22.3**
polystyrene	**3A**	**38.05 ±9.5**
	3B	**66.06 ±52**
	3C	**59.7 ±24.9**
water soluble polyurethane	**4A**	**27.68 ±5.8**
	4B	**28.62 ±5.4**

	4C	27.85 ±5
Silicon	5A	impermeable
	5B	impermeable
	5C	impermeable
Seam Grip	6A	impermeable
	6B	impermeable
	6C	impermeable
Melco Tape	7A	impermeable
	7B	impermeable
	7C	impermeable
PTFE film	8A	impermeable
	8B	impermeable
	8C	impermeable
Ultrasonic	D	impermeable

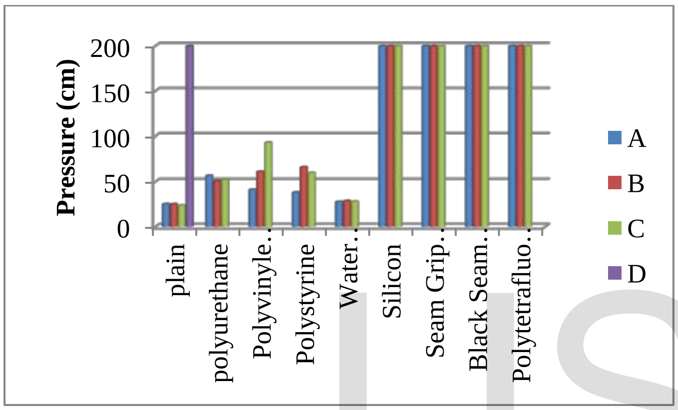

Fig. 16. The average resistance of water penetration results of Ultrasonic sample (D) and the effect of different sealing materials on A, B and C samples.

Ultrasonic welding, sealing sewn seams by silicon, seam grip, Melco tape and polytetrafluoroethylene film were observed to resist water penetration completely. Seams sealed with water soluble polyurethane has the least resistance to water penetration.

ANOVA

Source of Var.	SS	df	MS	F	P-value	F crit
Rows	163734	8	20467	208	1E-14	2.6
Columns	260	2	130	1.3	0.3	3.6
Error	1577	16	99			
Total	165572	26				

By using two-way Anova without replications, a highly significant difference was found between various sealing materials and also between conventional sewing and Ultrasonic welding, while no significant difference between A, B and C samples; using different sealing materials or another joining method (Ultrasonic welding) have great effect on resistance to water penetration while using different seams and stitches does not have.

TABLE8
THE AVERAGE RESULTS OF WATER PERMEABILITY

Sample		L/m2.sec
plain	A	0.04
	B	0.01
	C	0.02
polyurethane	1A	0.02
	1B	0.02
	1C	0.05
polyvinyl pyridine	2A	impermeable
	2B	impermeable
	2C	impermeable
polystyrene	3A	impermeable
	3B	impermeable
	3C	impermeable
water soluble polyurethane	4A	0.05
	4B	0.07
	4C	0.08
Silicon	5A	impermeable
	5B	impermeable
	5C	impermeable
Seam Grip Seam Sealer 8oz	6A	impermeable
	6B	impermeable
	6C	impermeable
Black Seam Seal Melco Tape	7A	impermeable
	7B	impermeable
	7C	impermeable
Polytetrafluorethylene film	8A	impermeable
	8B	impermeable
	8C	impermeable
Ultrasonic	D	impermeable

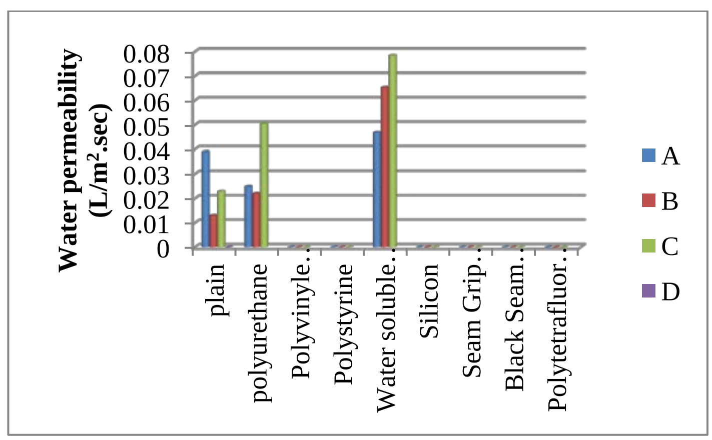

Fig. 17. The average water permeability results of Ultrasonic sample (D) and the effect of different sealing materials on A, B and C samples.

Ultrasonic welding was found to be a perfect waterproof joining technique as welding process depends on applying mechanical vibrations to soften or melt the thermoplastic fabric at the connection line without forming any holes. Sealing sewn seams by polyvinyl pyridine, polystyrene, silicon, seam grip, Melco tape and polytetrafluoroethylene film were observed to prevent water permeability as these materials perfectly sealed the needle holes. Seams sealed with water soluble polyurethane permitted water even more than the plain samples, which may indicate that it has reacted with thread or fabric causing the holes size to enlarge.

ANOVA

Source of Var.	SS	df	MS	F	P-value	F crit
Rows	0.012	8	0.002	21	4E-07	2.6
Columns	0.0002	2	8E-05	1.1	0.4	3.6
Error	0.001	16	7E-05			
Total	0.01	26				

By using two-way Anova without replications, a highly significant difference was found between various sealing materials and also between conventional sewing and Ultrasonic welding, while no significant difference between A, B and C samples; using different sealing materials or another joining method (Ultrasonic welding) have great effect on water permeability while using different seams and stitches does not have.

4 Conclusion

Gore-Tex fabric was sewn with two different stitch classes and three seam types in both weft and warp directions, the holes resulted from needle penetration were sealed by using eight different sealing materials. Also Ultrasonic welding was used as an alternative joining method. In order to study the effect of all these variables on seam strength, elongation , water permeability and resistance to water penetration under pressure.

It was observed that seam, stitch type and direction of sewing (weft, warp) have a highly significant impact on seam strength and elongation.

Using different joining techniques (conventional sewing and ultrasonic welding) also had a highly significant effect on extensibility of seams and their strength in both directions.

Using Seam Grip Seam Sealer had a significant effect on seam strength in both directions, while using Melco tape seam sealer had also significant effect in both directions but on extensibility of seams, when they are compared with plain samples.

When Polystyrene was used as a seam sealing material, it was found to have a significant effect on both extensibility and strength of seams and in both warp and weft directions.

Using Polytetrafluoroethylene film, polyurethane and Water soluble polyurethane as a seam sealing material had a significant effect on extensibility of seams in weft direction, when compared with plain samples.

The Ultrasonic welding has the lowest seam strength and strain values in both directions. Sample (2B) has the highest seam strength value in warp direction, while sample (1C) has the highest seam strength value in weft direction.
Sample (1B) has the highest seam strain value in warp direction, while sample (3B) has the highest seam elongation value in weft direction

A high significant difference was found in seam strength and strain in both directions between different seam sealing materials.
In general seam strength and elongation values of warp direction are higher than weft direction.

Using different sealing materials or another joining method (Ultrasonic welding), have great effect on resistance to water penetration and water permeability while using different types of seams and stitches does not have any significant difference.

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