Analysis of 3D Fabric by Applying Different Stitching Methods

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Abstract

At present the use of three dimension (3D) fabric is increasing rapidly. It is due to its property which cannot be fulfilled by the normal 2D fabric. The purpose of the project is to analysis various properties of 3D fabric by applying different stitching methods, such as self-stitch and using an extra thread in the warp and weft way. Due to stitching technique, variation among the properties of the fabrics were observed like tensile strength, tearing strength, stiffness, air permeability, water permeability, etc. In case of tearing strength, the sample with face to the centre and centre to back stitch has the highest tearing strength and the sample with extra weft exhibits the lowest tearing strength in warp way. For tensile strength, in case of warp way, the sample with stitched by extra warp has the highest tensile strength where the sample, stitched by extra weft has lower tensile strength. For weft way, the result gives a different view where for the sample with centre to face and back to centre having the highest value is obtained. For air permeability, the sample with face to centre and back to centre, is more air permeable and the sample with face to centre and back to centre, is less air permeable, so their end use might be different from one another. In case of water permeability, the sample with centre to face and centre to back, is less water permeable among all. For stiffness property, it is found that sample with extra weft fabric is stiffer than others.

Keywords: Three dimension; Multilayer; self-stitch; centre stitch

1. INTRODUCTION

The use of fabrics is not confined to only fabrication process, but can be used for many other technical purposes. At the same time, the use of 3D fabrics is also very important in different sectors too. 3D woven fabrics are fabrics that could be formed to near net shape with considerable thickness. The 3D woven fabric is a variant of the 2D weaving process, and it is an extension of the very old technique of creating double and triples woven cloth. 3D weaving allows the production of fabrics up to 10 cm in thickness [1]. At present, 3D woven fabric composites have emerged as a new class of light-weight material that has potential applications in the aerospace, maritime, infrastructure and medical fields [2].

A 3D fabric can be defined as the fabric that has length, width and thickness and that is woven by three sets of yarn, expanded in X, Y and Z direction and which gives an extra dimensional force to the fabric in Z direction [3]. Multilayer principle is characterized by the presence of several layers of yarns woven together by using different interlacing techniques. The layers can also be stitched together and the stitching arrangement may have either a self-stitching or a central stitching arrangement.

A fabric property is a characteristic of a material, which it should possess for it to be used in a desired application satisfactorily. In other words, it can also be termed as the requirement of a textile material for a certain purpose [4]. Parameters and properties of a fabric determine the performance of that fabric. 3D fabrics are used in various purposes such as aerospace, maritime, automotive, waterproof, sound-proof or noise barrier, civil engineering, composite, geo-textile, mechanical load bearing, sports, medical textiles, protective purpose etc. For examples, textiles are present in many forms in the automobile ranging from the seats to battery separators, from headliners to bonnet liners [5].

2. 3D MODELING TECHNIQUE

A basic common definition of 3D fabric is that these types of fabrics have a third dimension in the thickness layer. In 3D fabric structures, the thickness or Z-direction dimension is considerable relative to X and Y dimensions. Fibres or yarns are intertwined, interlaced or intermeshed in the X (longitudinal), Y (cross), and Z (vertical) directions [6]. 3D fabrics can also be defined as "a single-fabric system, the constituent yarns of which are "supposedly disposed in a three mutually perpendicular plane relationship [7]. According to Chen, structures that have substantial dimension in the thickness direction formed by layers of fabrics or yarns, generally termed as the 3D fabrics [8].

Although all textiles have a 3D internal structure, macroscopically most can be regarded as thin 2D sheets. By 3D fabrics, thick multilayer fabrics in a simple regular form or made in more complicated 3D shapes, hollow multilayer fabrics containing voids and thin 3D shells in complex shapes are meant [3]. Khokar defined 3D woven fabrics as a fabric, the constituent yarns of which are supposed to be disposed in a three-mutually-perpendicular-planes relationship [6]. 3D fabrics are defined as a single fabric system, the constituent yarns of which are supposedly disposed in a three mutually perpendicular plane relationship. 3D textiles are those materials which have a system or systems in all the three axes of plane. The 3D fabrics are basically intended for use in technical applications [9].

2.1. Classification of 3D Fabric

Based on type of weaving process there are two types of fabric, one is 2D Weaving and other is 3D Weaving.

2.1.1. Based on type of 3D Structures

- 3D Solid -Broadly there are three types, multilayer, orthogonal and angle interlocked.
- 3D Hollow - flat surface and uneven surface.
- 3D Shell is three types- By weave combination, By differential take up and By moldings.
- 3D Nodal.

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2.1.2 Based on Different Fabric Forming Systems

- 3D woven fabrics- three types- With multiple warps, With multiple wefts and Woven 3D shapes.
- 3D knitted fabrics- two types-With multi-axial Courses and With multi-axial Wales.
- Knitted 3D shapes.
- 3D non-woven fabrics.
- 3D Braids- two types -Circular braids, Compact 3D braids [7].

2.2. Importance of 3D Fabric

The 3D fabrics were firstly produced by weaving and then by braiding [10]. Then after a few years, there are new developments in manufacturing of 3D fabrics. The 3D fabrics are formed by knitting and non-woven also. To realize better strength, less weight and better easy handling, 3D fabrics are used. 3D fabrics in the absence of interlacing between warp and filling yarns allow the fabric to bend and internal shear rather easily, without bucking within the in-plane reinforcement which is not in the case of 2D fabric. The presence of Z-direction reinforcement in 3D fabric is an obvious advantage, as dramatic improvement in composite transverse strength and impact damage tolerance is well documented [11].

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2.3. Advantages of 3D Stitched Fabrics

3D fabrics are inexpensive and simple to manufacture. 3D fabrics could be manufactured on the 2D conventional weaving machines with certain modifications [9]. It has better impact damage tolerance. It has improved delimitation resistance to ballistic impact and blast loading. It is also better inter laminar fatigue resistance and improved joint strength under monotonic and cyclic loading. 3D multilayer woven fabrics are becoming increasingly important owing to their excellent performance characteristics such as permeability, compressibility, drape ability, ease of handling and ability to conform to complex shapes [8].

2.4. Manufacturing of Multilayer Woven Fabric

The conventional 2D weaving process is carried out employing the mono directional shedding operation. This enables either a single or a multiple layer warp to be displaced to form only one row-wise shed. Subsequent picking of the weft in the produced single shed results in the interlacing of the corresponding warp type with only one weft. In general, it is characterized by one filling insertion (pick) per weave cycle , unavoidable crimp, limited thickness and high production speed, whereas 3D weaving is characterized by multiple filling insertions (picks) per weave cycle or machine rpm, no internal crimp, better performance and greater thickness but lower production speed. A comparison of the traditional 2D weaving and the 3D weaving systems is presented in Figure 1. The principle of the 3D weaving process is represented here. The heart of the 3D weaving process is the dual-directional shedding operation. Subsequent picking of wefts in the corresponding sheds of the two directions results in the complete interlacing of the multiple layer warp (Z) with the two mutually perpendicular sets of wefts (X and Y) [7].

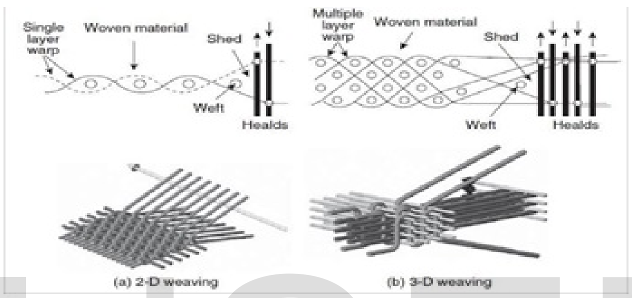


Figure 1: Comparison of 2D and 3D weaving process

2.6. Applications of Multilayer Woven Fabrics

Multiple-layer woven textile fabrics are becoming one of the most important forms of geotechnical engineering, the biomedical field and as protective clothing. In automotives, multilayer woven composites are used as drive shafts, side rails, doors, cross-members, oil pans, suspension arms, leaf springs, wheels, quarter panels, trunk decks, hoods, etc.

In the defense industry, 3D woven fabric composites are ideal materials for lightweight, mobile, easily transportable vehicles for tactical shelters, ballistic combat and logistic applications. Consequently, 3D woven composite material has been widely used in aerospace, automobile, marine, and defense industries [9].

In addition to structural body composites, composites are also used for interior parts such as overhead luggage compartments, sidewalls, ceilings, floors, galleys, etc. In aerospace applications, 40% of the composites are used for military applications [14].

Other applications for multilayer woven fabrics include narrow-width webbing products where strength or abrasion resistance are desired: belting products for conveyors, dryers and paper machine clothing; filtration products; ballistic materials; ablatives; constant-thickness structural composites in which damage tolerance or through-thickness mechanical properties are essential; and biomedical applications that utilize the high compression strength afforded by the z-fibres. In all cases there are driving technical reasons that make the 3D woven structure more desirable than a fabricated 2D fabric alternative [6].

3. MATERIALS AND METHODOLOGY

3.1. Materials

Yarn: 100% Cotton, Count: 6Ne, Color: White and Yellow, Sizing materials for 100% cotton yarn.

3.2. Preparatory Process

3.2.1 Sizing

- **Machine Specification:** Brand: CCI TECH INC, Model: 33565, MFG Date: 2015.08, Weight: 300kg, Power Source: 220V, 1Phase, 50/60 Hz, Max Power: 4KW, Pneumatic Pressure: 2KPa (kg/cm2), Origin: Taiwan
- **Sizing Recipe:** Starch: 10-20% of water, Binder: 2-4% of water, Softener: 0.5-1% of water size take up (approximately): 05%, All other ingredients are taken as required.

3.2.2 Warping

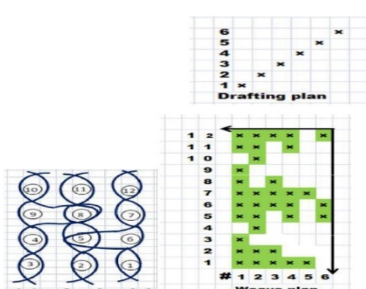
- **Machine Specification:** Brand: CCI TECH INC, Model: SW550, Serial no: W1015565M2, MFG Date: 2015.08, Weight: 550kg, Power Source: 220V, 1Phase, 50/60 Hz, Max Power: 2KW, Pneumatic Pressure: 6KPa (kg/cm2), Origin: Taiwan

3.2.3 Weaving

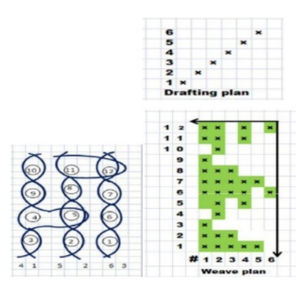
- **Specification:** Brand: CCI TECH INC (Weaving Unit), Model: EVERGREEN 500, Serial no: S4015442M5, MFG Date: 2015.08, Weight: 700kg, Power Source: 220V, 1Phase, 50/60 Hz, Max Power: 8KW, Pneumatic Pressure: 6KPa (kg/cm2), Origin: Taiwan.

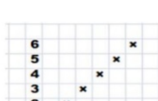
- **Stitching Technique:**
  - **Self stitch** : Face to centre and back to centre, Face to centre and centre to back, Centre to face and centre to back , Centre to face and back to centre.
  - **Stitch by extra thread:** Stitch by extra weft and Stitch by extra warp.
- **Design** As usual shedding, picking and beat up is completed for all of the samples and produced the fabrics according to weave design and drafting plan and lifting plan. A weave design with drafting plans are shown below:

Sample 1: Face to centre and back to centre



Sample 2: Face to centre and centre to back





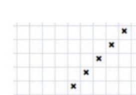


Figure 2.1: Face→Centre←Back stitch design

Sample 3: Centre to face and centre to back

Figure 2.2: Face→Centre→Back stitch design

Sample 4: Centre to face and back to centre

Figure 2.3: Face→Centre→Back stitch design

Figure 2.4: Face←Centre→Back stitch design

Sample 5: Extra Weft

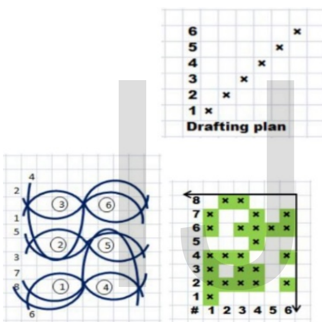


Figure 2.5: Extra weft stitch design

Sample 6: Extra warp

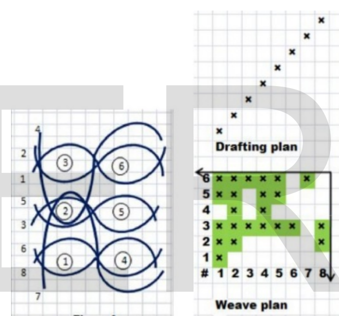


Figure 2.6: Extra warp stitch design

3.3. Experimental Details

All the experiments were done on grey fabrics, so the results obtained might be differ with finished samples.

3.3.1 Tear Strength Test

Testing Standard: 13937 part 4 (tongue shaped)

- **Specification:** Machine name: Universal Strength Tester (constants rate of elongation), Software used: Test Wise, Jaw: T27, Load Cell: Maximum 500N for fabric, Stripe: Full rubber Coating, Jaw separation distance: 100 mm, Jaw separation speed: 100 mm per minute, Test Type: Tear, Number of Specimen: 10, Direction (warp and weft way): Both, Break Detection: 10%**.**

3.3.2 Tensile Strength Test

- **EN ISO 13934-1:2013,** Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method

3.3.3 Air Permeability Test

The air permeability of a fabric is a measure of how well it allows the passage of air through it. The ease or otherwise of the passage of air is of importance for a number of fabric end usage.

- **Machine Specification:**
  - Standard**:** ASTM D1776, Machine name: Lab air, Company: TEXTEST Instrument,
  - Origin: Switzerland, Model: Fx 3300, Measuring range: 6, Test Area: 38 $cm^{2.}$
  - Test pressure: 180 Pa, Clamping of specimen : Manual clamping arm

3.3.4 Water Permeability Test

Property of a material that lets fluids (such as water or water vapor) to defuse through it to another medium without being chemically or physically affected.

- **Specification:** Machine name: Textest Instrument, Model: Fx3000 IV Hydro tester, Dynamic Test Method: Pressure gradient: 1 ... 1,000 mbar/min, Measuring accuracy: ± 0.5 % of displayed value ± 1 mbar, Aperture of test head: 40 mm Clamping of specimen: Manual clamping arm, Constant Air pressure: 20mbar per min Area: 100 cm^2

3.3.5 Stiffness Test

Stiffness is a special property of fabric. It is the tendency of fabric to keep standing without any support. It is a key factor in the study of handle and drape of fabric [15]. Test specification is given below:

- **Apparatus:** Stiffness Tester, Scissor and Scale.
- **Sample:** 3D Cotton woven fabric, Size: 6 X 1inc^2.
- **M/c specification :** Name: Shirley Stiffness Tester.

4. Result and Discussion

4.1 Tear Strength

The force necessary to tear a fabric, measured by the force necessary to start or continue a tear in a fabric. Expressed in pounds or in grams, the most commonly used method for determining the tear strength is the Elmendorf tear test procedure. The tearing strength in either warp or filling directions of a fabric can be increased either by reducing the number of threads per inch in the direction opposite to the direction of test or by increasing the yarn strength in the direction of test [16].

Here the test value of the samples for various properties by which we can come to a decision whether it is good or bad. It also helps to make a comparison among the fabric and gives a clear view of the properties.

Table 4: Tear Strength Test of different sample

Sample name	Maximum strength (Newton)
sample 1(Face to centre, back to centre)	463.22
sample 2 (Face to centre, centre to back)	503.48
sample 3 (centre to face, centre to back)	414.52
sample 4 (back to centre, centre to face)	390.46
Sample 5 (Extra weft fabric)	341.67
Sample 6 (Extra warp fabric)	414.43

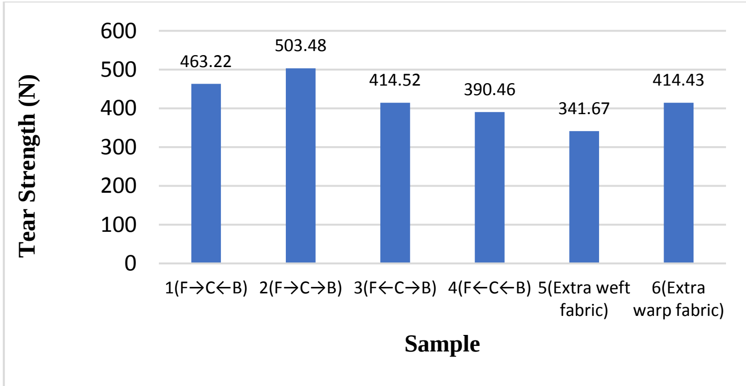


Figure 3 : Tear strength value of different samples

From the experiment it is seen that the highest value of tear strength is obtained for sample 2(Face to centre; Centre to back) and the lowest value for extra weft sample. Due to stitching effect the test results are different for different sample.

In case of sample 2, the strength imparted due to stitching is equally distributed through all three layers and for the lowest value we can conclude that, stitching by extra weft yarn has less effect on tear strength which caused it to give the lowest value.

4.2 Tensile Strength

Tensile trength of any material is the force at which specimen breaks.. in case if fabrics it is the maximum recorded force required to tear a fabric. Tensile testing of fabric involves various test (Strip test, grab test, tearing test, etc) which can give an idea about the tensile strength of fabric.

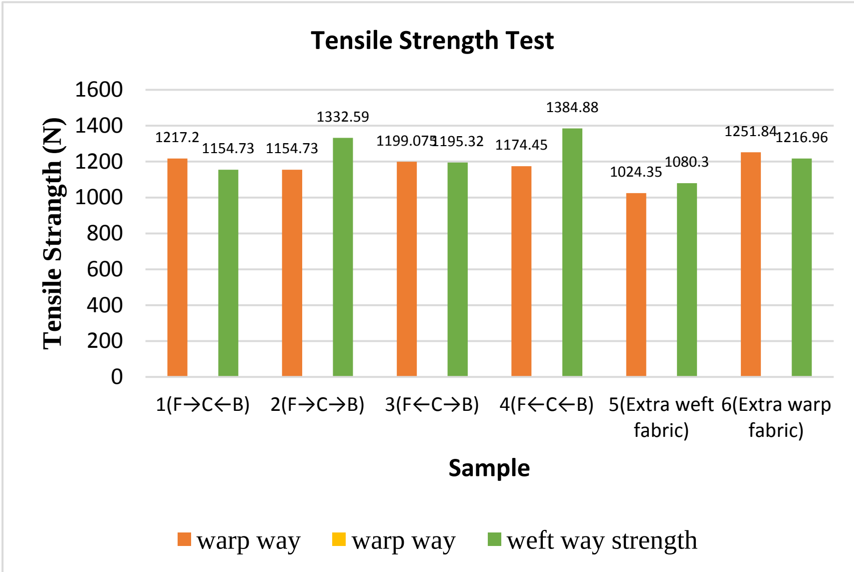


Figure 4 : Tensile strength for different samples (warp and weft way)

In case of warp way, the highest value is obtained for stitched by extra warp because the extra warp thread imparts extra strength to the fabric in the warp way and the lowest value is obtained for stitched by extra weft . In case of tensile test, extra weft has less effect in warp direction.

In case of weft way, the highest value is obtained for sample 4 which is stitched from centre to face and back to centre. Here the strength distribution has occurred equally through all three layers and the lowest value for sample 5 which is stitched with extra weft.

4.3 Air Permeability

The definition of Breathability or air permeability for all fabrics is "The amount of wind that can pass through a fabric in one minute." Air permeability is an important factor in the performance of outerwear where the wind resistance helps keep the user warm. Other applications are: Sails, parachutes or Air bags. Fabrics that have high air permeability usually have low water repellency.

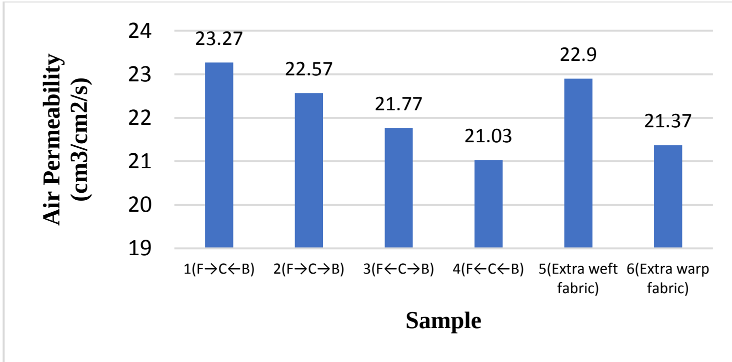


Figure 5: Air permeability Test results of different samples

For air permeability, sample 1 gives the highest value where it is self-stitched from face to centre; back to centre. Due to stitch distribution the face and back layer has less thread density and so it is more air permeable. Sample 4 gives the lowest value that means that it is less permeable as the yarn density are almost equal for all the layers

as it is stitched from centre to face.

4.4 Water Permeability

The water permeability, also know as the pure water flux is defined as the volume of water that passes through a membrane per unit time, per unit area and pre unit of trans-membrane pressure. This property indicates the effort required to generate permeate for a membrane and is an easy way to compare initial performance of a membrane, however, this technique will not provide any guide as the performance of the material for extended periods of time.

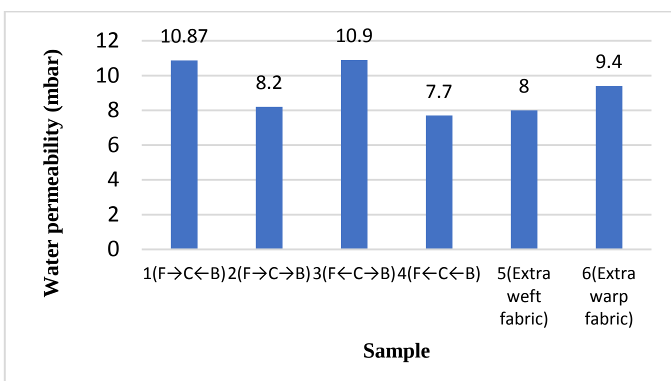


Figure 5: Water Permeability Test Results for different samples

For water permeability, sample 3 for centre to face and centre to back stitch the pressure is highest that means to see the drops of water here more pressure is required so higher water permeable. And in case of sample 4 the lowest value of water permeability is got which is more permeable to water.

4.5 Stiffness Test

Stiffness is defined as the amount of force required to extend an item by unit length [Qu0ra, web: https://www.quora.com/What-is-the-difference-between-material-stiffness-and-component-stiffness].

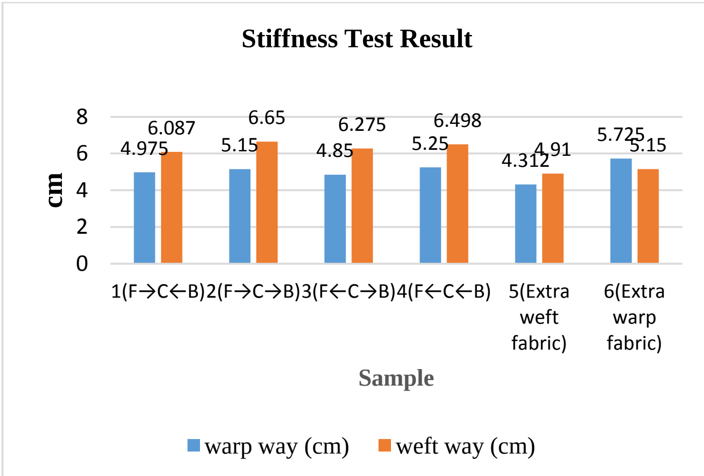


Figure 6: Stiffness Test Results of different samples

In case of warp way sample 6 stitched by extra warp is more stiff than others where in weft way sample 2 (face to centre and centre to back) is less stiff than others.

5. CONCLUSION

. All the samples are of same EPI and PPI and the yarn used are of same count. The tests are done for only grey fabrics which may differ from finished fabrics.

The fabric with face to centre and centre to back stitch has the highest tear strength and fabric with extra weft gives the lowest tear strength in warp way. In case of tensile strength the test result for warp and weft way is different. In case of warp way sample, stitched by extra warp has the highest tensile strength where the fabric with stitched by extra weft has lower tensile strength.

For weft way the result gives a different view where for the sample with centre to face and back to centre highest value is obtained. For air permeability, fabric with face to centre and back to centre is more air permeable and the fabric with face to centre and back to centre is less air permeable and so their end use might be different from one another.

In case of water permeability fabric with centre to face and centre to back is less water permeable than other fabrics and for fabric face to centre and back to centre is more water permeable among all the fabrics. For stiffness property it is found that fabric with stitched by extra warp is more stiff than others where in weft way fabric with face to centre and centre to back is less stiff than others. So it is revealed that stitch has impact on fabric properties.

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