The Influence of Knitted Fabrics' Structure on Adequate Stitch Type and Density for Performance apparel

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Abstract:
Performance apparel is playing a significant role in industry for special end use applications. One of the applications involves the formation of yarns to be made into performance fabrics through knitting or weaving. Performance CoolMax/Micro Modal, knitted fabrics, for purposes of this paper, are defined as fabrics used in specialty apparel, that are engineered for use in high-energy sports and activities performed in extreme environments. Clothing made of performance fabrics are said to be designed not only for fashion or just a passive cover for the skin, but to critically influence the comfort and performance of the wearer. Manufacturers have engineered these fabrics to manage moisture, regulate temperature, and provide protection from the surrounding environment. They are designed to interact with and modify the heat-regulating function of the skin as the surrounding environment interacts with them. In this study two different types of CoolMax/Micro Modal knitted fabrics (single jersey plated and interlock double face) with two various masses were produced for athletic sport suit. They were examined before and after sewing with two types of stitches (stitch type 512 and 601) and three different stitch densities. Tests were applied to determine the functional properties for performance depends on several factors like air permeability, water absorption and water absorbency to determine moisture management, abrasion resistance and crease recovery, which are quite important factors for knitted garments especially for sportswear. These properties may offer higher flexibility in designing such garments with optimized comfort properties. In addition to seam properties like seam thickness, seam stiffness, seam breaking force, seam pucker and seam appearance. All tests were carried out according to standards and took place into conditioned atmosphere of 21ºC and 65% RH. Comparisons have been made among them to determine the influence of knitted fabrics' structure on adequate stitch type and density for performance apparel.

Keywords:
- **Performance,**
- **CoolMax,**
- **Micro Modal,**
- **knitted fabrics,**
- **stitch type,**
- **Stitch density,**
- **Sewing properties.**

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Introduction
With the development of new technology, domestic and overseas market has been developed a variety of new performance materials which are not only to fill the demand of the traditional textile industry but also improve our quality of life, to meet the requirement of textiles "environmental protection, comfort, health and functional". (1)
The most important feature of performance apparel is to create a stable microclimate next to the skin in order to support body's thermoregulatory system, even if the external environment and physical activity change completely. Mainly, performance fabrics are engineered to keep the body dry during vigorous athletic activities. Keeping the body dry, especially during cold weather sports, ensures that the wearer does not lose heat unnecessarily by having wet skin. (2)
The thermal comfort of a garment depends on several factors as heat and vapor transport, sweat absorption and drying ability. Total heat loss from skin results from the heat loss promoted by evaporation and the heat loss conveyed by conduction, convection and radiation. Under mild environmental conditions the loss of heat by evaporation takes place in the form of insensible perspiration which accounts for approximately 15% of the heat loss through the skin. In the case of hard physical exercise or in tropical climates, the heat loss by evaporation is accompanied by

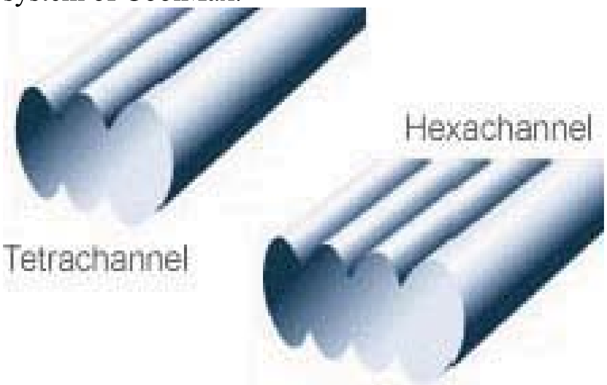
sweating and the skin becomes covered with a film of water. For wearer comfort, this sweat should be transported away from the skin surface, in the form of liquid or vapor, so that the fabric touching the skin feels dry. The transport of both moisture vapor and liquid away from the body is called moisture management. (1)

Moisture management has the following functions

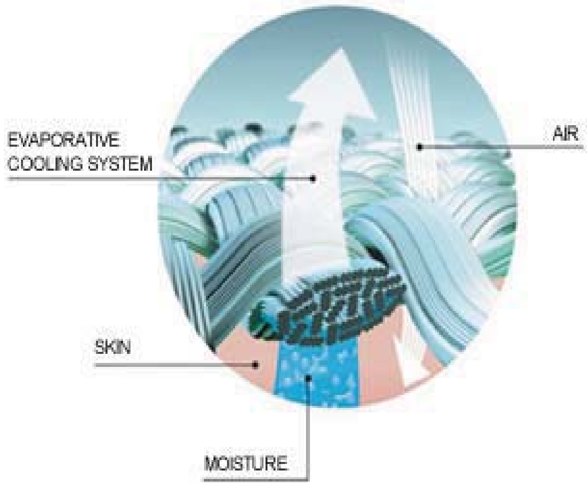
1- Regulation of body temperature when the human body core temperature exceeds 37ºC, sweat is produced. Transporting the sweat away from the skin and evaporating it to the atmosphere, reduces body temperature.
2- Control of cloth weight increase due to absorbing the moist generated by the body increases cloth weight, making it uncomfortable and with a negative effect on performance. Moisture management avoids this effect. (2)

Natural fibers such as cotton are hydrophilic, meaning that their surface has bonding sites for water molecules. Therefore, water tends to be retained in the hydrophilic fibers, which have poor moisture transportation and release. On the other hand, synthetic fibers such as polyester are hydrophobic, meaning that their surface has few bonding sites for water molecules. Hence, they tend to remain dry and have good moisture transportation and release. Moisture absorption and release properties do not coexist in common fibers. To achieve those, specialty fibers, obtained by using thermally active materials, such as CoolMax. When a textile product incorporates thermally active materials or specially designed fibers, it can provide enhanced thermal and moisture management performance in addition to the existing passive characteristics of the structure to keep the body in the comfort state. (1)

CoolMax structure: In daily activities, human sweat and moisture must be evaporated from the skin. CoolMax is one of several synthetic materials that are engineered to wick sweat away from skin and dry quickly. It's employ to improve "breathability" compared to natural fibers. 'Wick away' is a general term used for fabrics that are engineered to draw moisture away from the skin through capillary action and increased evaporation over a wider surface area. It was originally developed for high exertion sports clothing. (3) It's made of specially spun and molded polyester fibers which are not round, but are slightly oblong in cross-section with grooves running lengthwise along the threads. They are manufactured in either a tetrachannel or hexachannel style. The series of closely spaced channels creates capillary action that wicks moisture through the core and out to a wider area on the surface of the fabric which increases evaporation. These microchannels are the secret to CoolMax 'suckiness'. (2) During the wicking process, air is moved in to keep the body dry and cool. Cotton, on the other hand, absorbs and retains 14 times more moisture than Coolmax. (4) Fig(1) illustrates a cross sectional image of CoolMax. Fig(2) shows the evaporative cooling system of CoolMax.



Fig(1) A cross sectional image of CoolMax. (3)



Fig(2) The evaporative cooling system of CoolMax. (2)

CoolMax properties: It's the fastest drying high-tech material; it pulls sweat away from the skin leaving the body dry, comfortable and ready to perform. It's fully breathable, durable, and elastic and regulates temperature. It resists wrinkling, fading and shrinking. It is machine washable and dryable. Just avoid washing with chlorine bleach or water softening additives. (3)

CoolMax uses: It was originally developed for clothing intended for use during extreme physical exertion as sweat evaporates quickly so the wearer is kept dry and more comfortable while training and racing; enabling him to perform under any weather conditions. Its engineered inherence moisture management properties thus make it suitable for lightweight summer clothing. As a result, it's found in a wide variety of garments from mountain climbing gear, to casual sportswear, underwear, technical tops and socks for the summer or sports. (5) And now it's often blended with other materials, it was found that blending CoolMax with Micro Modal regenerated cellulose fibers, improve the wearing comfort ability of the CoolMax sport apparel in the static and also attach the quick dry. (6)

Micro Modal structure: There are many variety of modal fiber; here we take an example of the Micro Modal. It's a type of viscose, a semi-synthetic cellulose fiber made by spinning reconstituted cellulose, in this case often from beech trees.

These synthetic cellulose fibers are important for the day-to-day performance of the textile industry. They are included in the group of high comfort fibers. (7) It is a serious alternative to the conventional viscose then being obvious its better properties. The difference between normal viscose and modal, results from the different raw material used and the different production process. Modal is obtained by a process giving a high tenacity and high wet modulus. (8) Compared to viscose, modal has better performance properties such as higher tenacity in dry and wet states, a higher wet elastic modulus, a low water retention capacity (it dries faster), a lower degree of swelling, brighter color, a silky luster and softer handle. Therefore modal is frequently used as an alternative to viscose. (9) Conventional modal is commonly produced in the fiber fineness range of 1.3 - 5.5 dtex while Micro Modal is formed with fineness values of 0.8 and 1.0 dtex. Modal fiber or its microfiber form is often used in blends to improve other fiber properties. (10)

Micro Modal properties: It gives apparels some performances, such as the comfort and aesthetic properties of fabrics by providing softness, flexibility, smoothness, a fine textile structure, a silky appearance, moisture absorption and release, high strength, either in wet as in dry and good appearance. It provides beautiful, warm, breathable, good drape and fullness. It is highly stain resistance and therefore it is the first choice for high-grade clothes. (11) The Micro Modal excellent properties have made it possible for excellent match with natural as well as synthetic fibers rather give importance to the specific advantages of the blend components. The blend with cotton commonly enables the production of high quality knitted or woven fabrics without using high quality cotton fiber. Moreover, the blends of Micro Modal with synthetic especially with polyester as CoolMax, allow fabrics whose characteristics and aspect are very interesting as brightly colored, silky lustered and soft and pleasant to touch fabrics. (12)

Micro Modal uses: With the Modal fiber, the textile industry is being favored with a new generation of cellulosic fibers, these being used in a wide application field either in the knitted goods sector as in the woven sector with the best performance conditions and excellent physiological properties as well as fashionable. (11) Fine denier modal is the premier material for high class clothing. (10) In many applications Micro Modal is preferred for its highly bright colors and also, their silky luster and soft and pleasant touch. Due to their excellent properties it's used alone or with other fibers in apparel items such as pajamas, bathrobes and underwear. (12)

2. Experimental work

2.1. Fabrics specifications

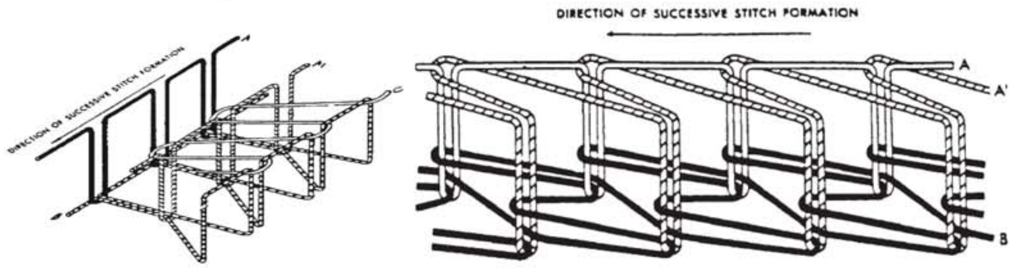
Blends of moisture management CoolMax, and micro modal with specific functionalities to produce performance knitted fabrics were examined. The following table1 illustrates the specifications of the tested fabrics.

Table1 Fabrics specifications

Fabric type	Type of knit	Machine gauge	Face yarn count	Back yarn count	Stitch Wales /cm	Stitch courses /cm	Mass (gm/m^2)	Thickness (mm)
fabric 1	single jersey plated	24	36/1	40/1	18	20	155 $\pm$ 5	0.39
fabric 2	interlock double face	20	40/1	40/1	14	20	250 $\pm$ 5	0.72

2.2. Sewing specifications

Each type of tested fabric was sewed separately with two types of stitches (stitch type 512 and 601) and three different stitch densities by using superimposed seam type (SSa-1) and intermediate foot pressure. Stitch type 512 shall be formed with four threads, two needle threads, one looper thread and one cover thread forming a purl on the edge of the seam. It has great stretch and high elongation along edge of fabric. It's ideal for medium to heavy stretchy fabrics such as double knits and sportswear. Stitch type 601 shall be formed with three threads; two needle threads and one looper thread. It's used for seaming on common fabrics. Fig(3) illustrates used stitches. The following table2 illustrates the sewing specifications of stitch type1 and table3 illustrates the sewing specifications of stitch type2.



Stitch type 512 Stitch type 601

Fig(3) Stitch type 512 and 601

Table2 Sewing specifications of stitch type1

Stitch type1	Thread type	Thread size	No. of thread	Needle size	Stitch density1 /cm	Stitch density2 /cm	Stitch density3 /cm
512	100% spun polyester	42/2	4	16	7	5	4

Table3 Sewing specifications of stitch type2

Stitch type2	Thread type	Thread size	No. of thread	Needle size	Stitch density1 /cm	Stitch density2 /cm	Stitch density3 /cm
601	100% spun polyester	42/2	3	16	6	4	3

2.3. Experimental tests

Tested samples examined before and after sewing. All tests were done by standard test methods in conditioned atmosphere of 20ºC ± 2 and 65% ± 2 RH. Tests included fabric mass per unit area which was determined according to ISO 3801:1977 standard using an electronic balance. [13] Thickness test was carried out by using Erazier Pregision Instrument, according to (B.S.-2544). [14] Thickness before and after sewing was obtained from average of four readings. Air permeability test was carried out by using Electronic air permeability tester (FX 3300), according to (ASTM D737). [15] To determine moisture management, water absorption and water absorbency tests were applied. Water absorption test was carried out by using Bundesmann Water Repellency Tester (SDL), according to (BS EN 29865). [16] Water absorbency test was carried out according to (BS ISO 4920). [17] Abrasion resistance test was carried out by Taber 515 abrasion tester, according to the (ASTM D3884). [18] The abrasion produced by a rotary action of abrasive wheels was under 250 gm weight. The number of cycles which causes two holes in the specimen was recorded digitally and the abrasion resistance was calculated by obtaining the mean of four results of each fabric. Crease recovery test based on Paramount crease recovery tester according to (BS 11313). [19] Angle of crease recovery, for both length and width directions have been viewed. Stiffness test obtained after sewing. It was carried out by using Shirley stiffness tester according to (ASTM D 1388) [20]. Seam breaking force obtained according to (AS 2001.2.20) [21]. Seam pucker has been evaluated, according to (AATCC 88B-1978) [22] and seam appearance; average of five readings has been obtained for each property.

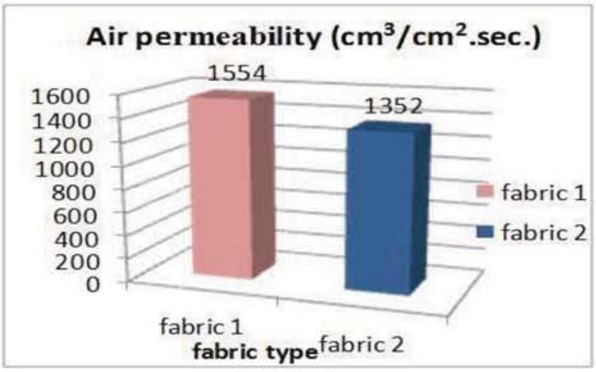
3. Results and Discussion

3.1. Functional properties of tested fabrics

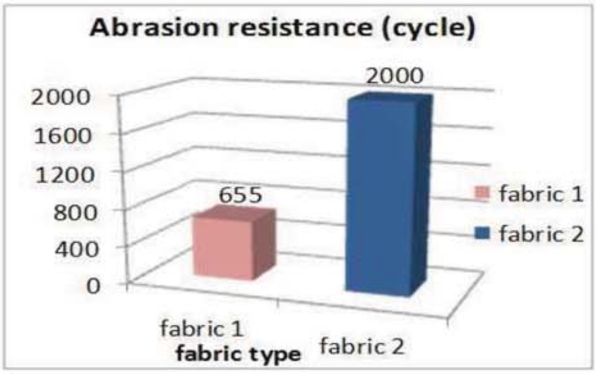
Table4 illustrates functional properties of tested fabrics

Table4 Functional properties of tested fabrics

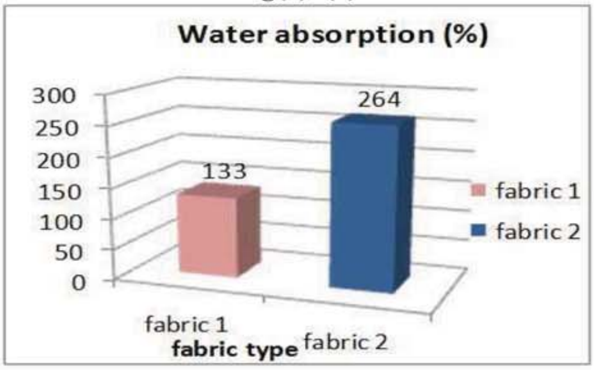
Fabric type	Air permeability (cm^3/cm^2.sec.)	Water absorption (%)	Water absorbency (cm/2 min)	Abrasion resistance (cycle)	Crease ecover length (°)	Crease recovery/ width (°)
fabric 1	1554	133	5.5	655	45	41
fabric 2	1352	264	3.9	2000	52	48



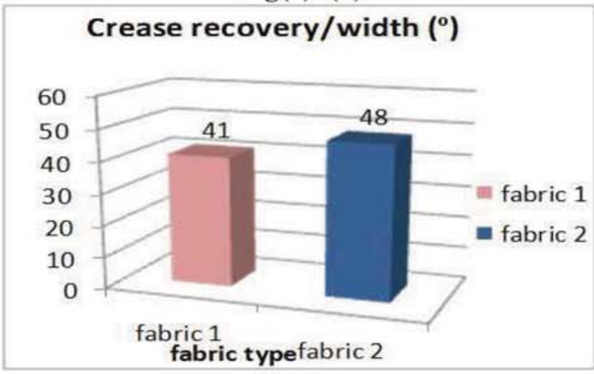
Fig(4) (a)



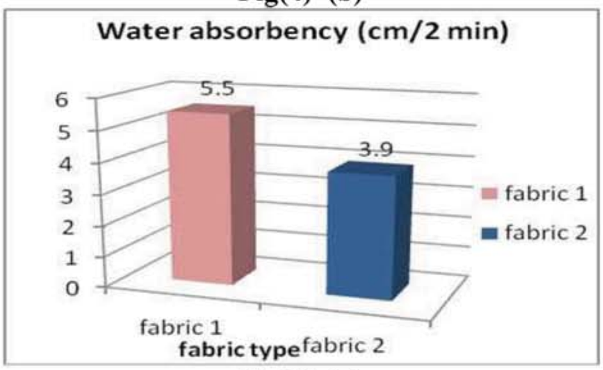
Fig(4) (d)



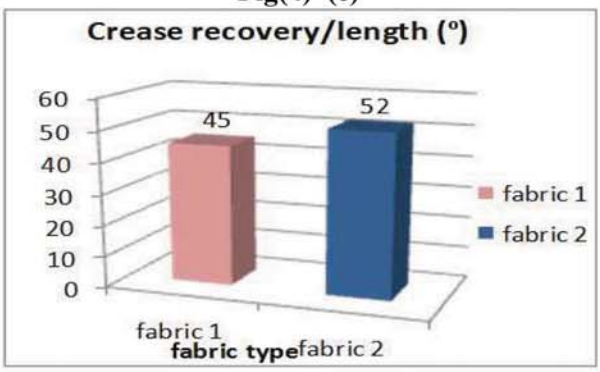
Fig(4) (b)



Fig(4) (e)



Fig(4) (c)



Fig(4) (f)

Fig(4) Functional properties of tested fabrics

3.1.1. Air permeability

It's described as the rate of air flow passing perpendicularly through a known area, under a prescribed air pressure differential between the two surfaces of a material. It is an imperative characteristic in the performance; it determines factors such as wind resistance and breathability. To avoid the condensation of perspiration in a garment, breathable materials are required. It also influences the warmth or coolness of a garment. Table4, fig(4.a) shows that fabric1 is more air permeable than fabric2 which can be attributed to their thickness and construction. Thicker fabric, generally entrap more air within the fabric structure and has greater thermal resistance. If the fabric construction is very open, radiant heat from skin can pass through the fabric and reduce its warmth. While tightness structure decreases the spaces and deters the air flow.

3.1.2. Moisture Management (water absorption & water absorbency)

For liquid transport within fabrics, two phenomena must be accounted. Wettability (water absorption) and wickability (water absorbency). The term 'wetting' is usually used to describe the change from a solid air interface to a solid liquid interface. Wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. As capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system. Many test methods have been developed to measure liquid water absorbency and water vapor transport in fabrics. These methods measure different aspects of moisture management characteristics of fabrics.

3.1.2.1. Water absorption

It determines the water absorption percentage and the aptitude of a fabric to absorb and retain water or (sweat) from surfaces such as human skin. Table4, fig(4.b) shows that fabric2 absorbs more water than fabric1. The increase in water absorption by increasing fabric mass could be attributed to the higher thickness, which absorbs more water. In addition to the tightness of fabric2 structure makes its layers enclose the water through the yarn bundles of the structure.

3.1.2.2. Water absorbency

It determines the velocity of a fabric to rapidly absorb liquid water from surfaces such as human skin. The absorbability is the ability of a fabric to take in moisture or sweat. It is a very important property, which affects many other characteristics such as skin comfort, static build-up, and water repellency. As shown in Table4, fig(4.c) fabric1 has faster water absorbency than fabric2. The capability of faster water absorbency could be explained as the existence of crinkles in the structure which makes buses allow increasing water raise. On the other hand the reduction of fabric2 water absorbency returns to its tightness and stitch density on which the water raise deter. In addition to its higher mass that leads to decrease in void ratio inside the fabric and makes the water flow slower.

3.1.3. Abrasion resistance

It's the ability of a fiber or fabric to withstand surface wear due to rubbing against another surface. Accelerated procedures allow the laboratory technician to determine wear performance or durability of a material as experienced in its actual use, so abrasion resistance test determines the degree to which a fabric is able to withstand surface against friction forces. The resistance to abrasion is affected by many factors, such as the inherent mechanical properties of the fibers, the structure of the yarns, construction of the fabrics and the thickness of the fabrics. Table4, fig(4.d) shows that fabric2 **has clearly higher** abrasion resistance than fabric1**.** Fabric2 structure gives very little spaces at all for the wales or courses, so the tightness of it and its stitch density are greater than fabric1, in addition to its high thickness; all of these basics present a higher abrasion resistance property. As well as the increase in fabric2 mass lead to high number of crossing on its surface, this produces finally higher abrasion resistance.

3.1.4. Crease recovery

The bending elasticity is the greatest importance in the phenomenon of creasing. Creases appear when the material is distorted in such a manner the ability of a material to regain its original shape after it has been wrinkled. As shown in table4, fig(4.e&f) crease recovery in length direction is higher than in width direction. Fabric2 has higher crease recovery than fabric1, which can be attributed to their thickness and mass (as thickness and mass increases crease recovery increases). Crease recovery effects on the aesthetic appeal of apparel. (As crease recovery increases a better aesthetic appeal is given).

3.2. Seam properties of tested fabrics

3.2.1. Seam thickness

3.2.1.1. Seam thickness of stitch1 at different stitch densities

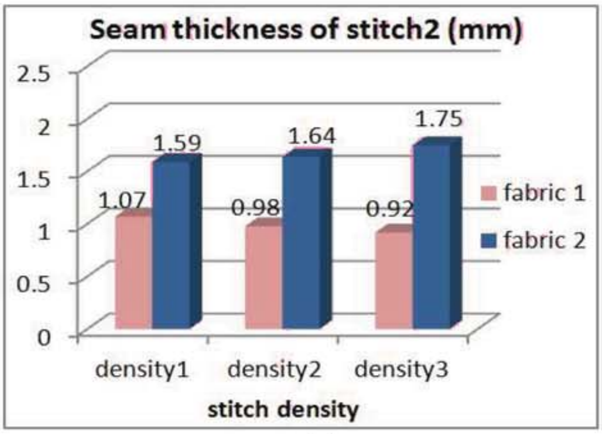
Table 5 Seam thickness of stitch1 at different stitch densities

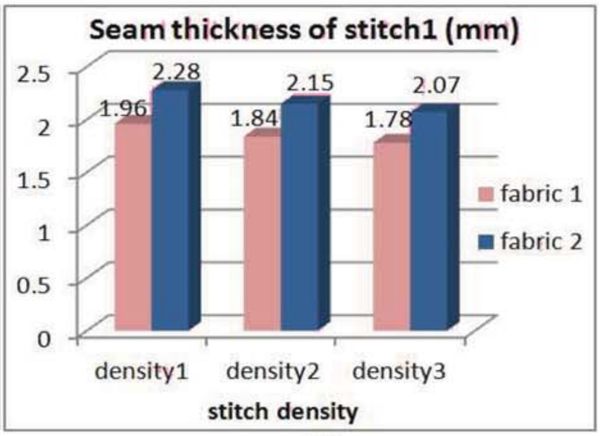
	Seam thickness (mm)		
Fabric type	Stitch1 density1	Stitch1 density2	Stitch1 density3
fabric 1	1.96	1.84	1.78
fabric 2	2,28	2.15	2.07

3.2.1.2. Seam thickness of stitch2 at different stitch densities

Table 6 Seam thickness of stitch2 at different stitch densities

	Seam thickness (mm)		
Fabric type	Stitch2 density1	Stitch2 density2	Stitch2 density3
fabric 1	1.07	0.98	0.92
fabric 2	1.59	1.64	1.75





(a) (b)

Fig(5) Seam thickness of tested fabrics

Seam thickness is the maximum dimension measured across or perpendicular to the layers of the seam. As shown in table5&6, fig(5a&b) fabric2 gives higher seam thickness than fabric1 as thickness of fabric before and after sewing are directly proportional. Stitch type1 gives more seam thickness than stitch type2 due to its more consisted thread and it's exceeding in complicated construction. Stitch density1 scored the highest seam thickness, while stitch density2 provided lower seam thickness and stitch density3 gave the lowest value. There is a direct relationship between stitch density and seam thickness (as stitch density increases seam thickness increases and vice versa). That can be referred to the amount of thread used by each density.

3.2.2. Seam stiffness

3.2.2.1. Seam stiffness of stitch1 at different stitch densities

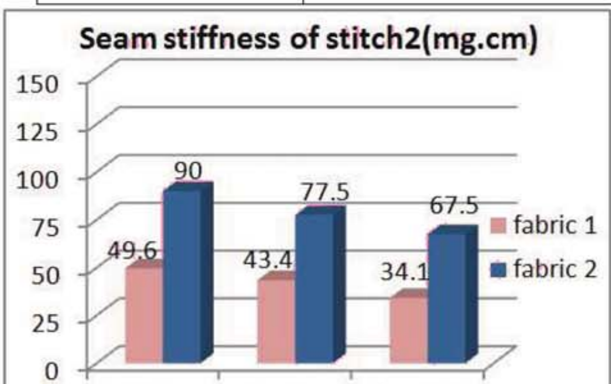
Table 7 Seam stiffness of stitch1 at different stitch densities

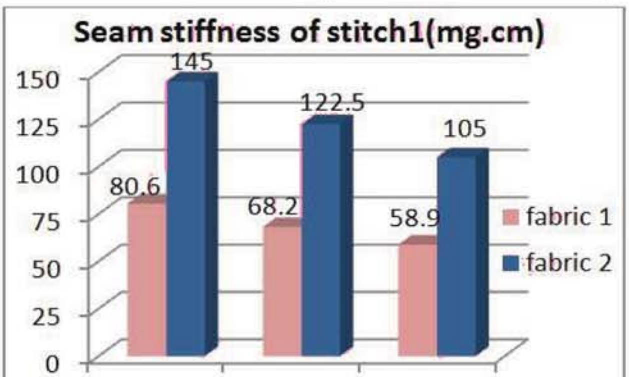
	Seam stiffness (mg.cm)		
Fabric type	Stitch1 density1	Stitch1 density2	Stitch1 density3
fabric 1	80.6	68.2	58.9
fabric 2	145	122.5	105

3.2.2.2. Seam stiffness of stitch2 at different stitch densities

Table 8 Seam stiffness of stitch2 at different stitch densities

	Seam stiffness (mg.cm)		
Fabric type	Stitch2 density1	Stitch2 density2	Stitch2 density3
fabric 1	49.6	43.4	34.1
fabric 2	90	77.5	67.5





(a) (b)

Fig(6) Seam stiffness of tested fabrics

Seam stiffness is the degree of resistance deformation during bending. It's an important factor in the apparel handle. As shown in table7&8 fig(6a&b) fabric2 gives higher seam stiffness than fabric1. This increase in seam stiffness by increasing fabric mass could be attributed to the fact that the increase in fabric mass is accompanied with decrease in loop length in addition to increase in stitch density which leads to increase stiffness.

Fabrics sewed with stitch1 are stiffer than those sewed with stitch2 which can be referred to stitch construction, as the existence of crinkles in stitch1 makes it stiffer while stitch2 has lower number of thread thus a smooth surface.

Stitch density1 has the highest seam stiffness, while stitch density2 has lower seam stiffness and stitch density3 has the lowest value. There is a direct relationship between stitch density and seam stiffness, due to the thread consumption (as stitch density increases seam stiffness increases and vice versa). There is no doubt that seam stiffness clearly plays a significant role in the draped appearance of apparel.

3.2.3. Seam breaking force

3.2.3.1. Seam breaking force of stitch1 at different stitch densities

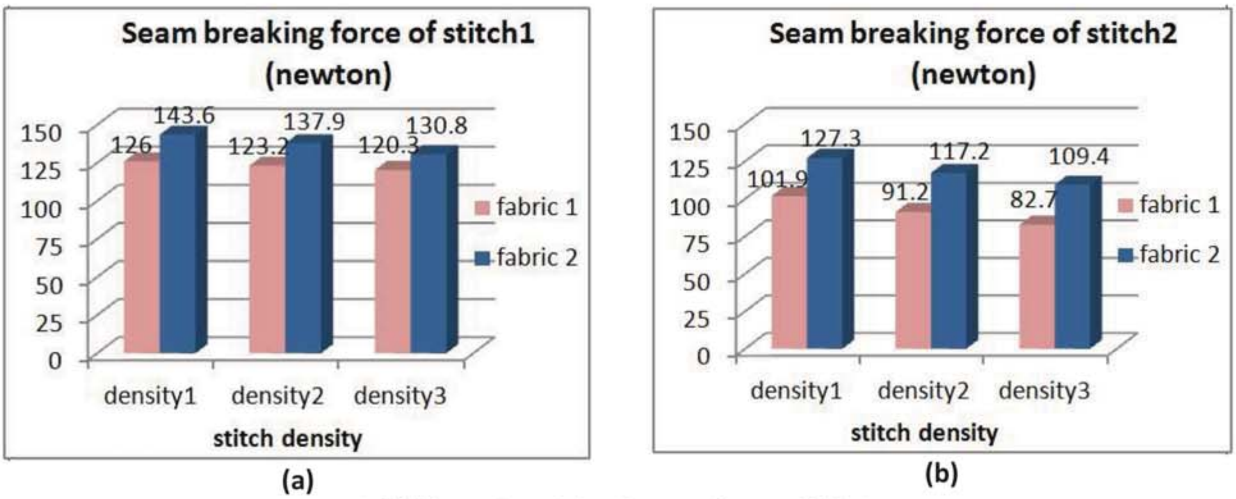
Table 9 Seam breaking force of stitch1 at different stitch densities

	Seam breaking force (newton)		
Fabric type	Stitch1 density1	Stitch1 density2	Stitch1 density3
fabric 1	126	123.2	120.3
fabric 2	143.6	137.9	130.8

3.2.3.2. Seam breaking force of stitch2 at different stitch densities

Table 10 Seam breaking force of stitch2 at different stitch densities

	Seam breaking force (newton)		
Fabric type	Stitch2 density1	Stitch2 density2	Stitch2 density3
fabric 1	101.9	91.2	82.7
fabric 2	127.3	117.2	109.4



Fig(7) Seam breaking force of tested fabrics

Seam breaking force is the maximum stress, measured as force that a material can withstand before breaking. In particular fabric tightness, have direct impact in the behavior of seams breaking force. So fabric2 gives more seam breaking force than fabric1 as shown in table9&10, fig(7a&b). In addition fabrics sewed with stitch2 have lower breaking force than those sewed with stitch1 which can be attributed to stitch tightness, as the strength of seams reduces when it is sewn with low tightness stitch. Stitch density1 record the highest breaking force, while stitch density2 has lower breaking force and stitch density3 gives the lowest value. The effect of stitch density is clear on the breaking force which increases as the density increases thus ameliorates the breaking resistance of seam.

3.2.4. Seam pucker

3.2.4.1. Seam pucker of stitch1 at different stitch densities

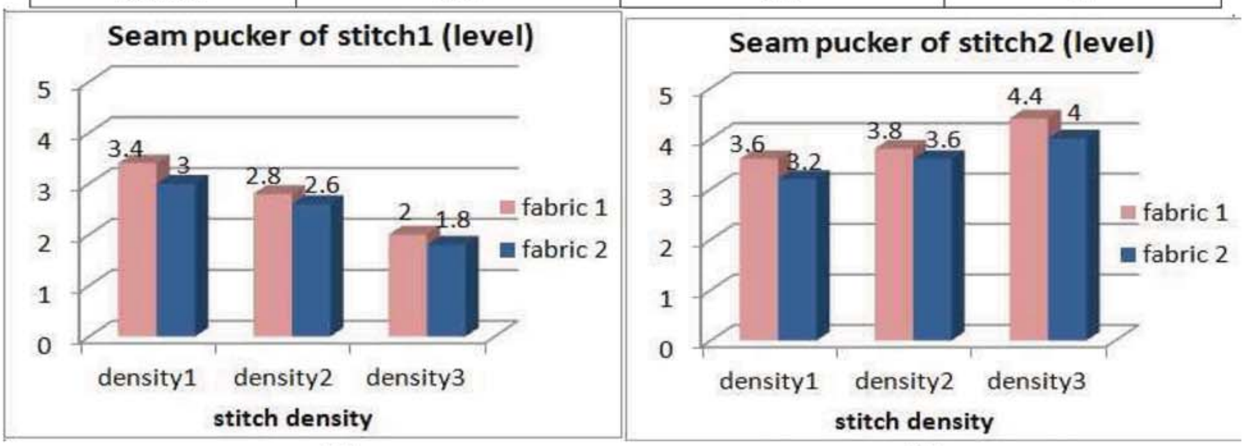
Table 11 Seam pucker of stitch1 at different stitch densities

	Seam pucker (level)		
Fabric type	Stitch1 density1	Stitch1 density2	Stitch1 density3
fabric 1	3.4	2.8	2
fabric 2	3	2.6	1.8

3.2.4.2. Seam pucker of stitch2 at different stitch densities

Table 12 Seam pucker of stitch2 at different stitch densities

	Seam pucker (level)		
Fabric type	Stitch2 density1	Stitch2 density2	Stitch2 density3
fabric 1	3.6	3.8	4.4
fabric 2	3.2	3.6	4



(a) (b)

Fig(8) Seam pucker of tested fabrics

Seam pucker phenomenon is defined as a local defect on apparel in the form of large ridges beside the seam and is considered one of the most serious defects in apparel manufacturing. This wrinkling appears due to improper selection of stitching parameters which affecting the appearance characteristics. Since sewing operation is subjected to excessive tensions, puckering can appear as a wave coming from the seams. Seam pucker evaluated (from 1 to 5) where 5 means no pucker and 1 means severely pucker. As shown in table11&12, fig(8a&b) fabric1 gives lower seam pucker (higher level) than fabric2. As in tightly fabrics, spaces between yarns are less to pass through sewing threads. When sewn threads are inserted in such fabrics to sew fabric plies together, it forms a wavy seam. In such cases pucker happen due to yarn displacement. Therefore light fabrics have lower seam pucker and show more aesthetical appearance compared with heavy fabrics. Stitch2 provides lower seam pucker than stitch1 which can be attributed to stitch construction. Stitch density1 record the highest seam pucker, while stitch density2 has lower seam pucker and stitch density3 gives the lowest value. This means that occurred pucker can be avoided by decreasing the stitch density.

3.2.5. Seam appearance

3.2.4.1. Seam appearance of stitch1 at different stitch densities

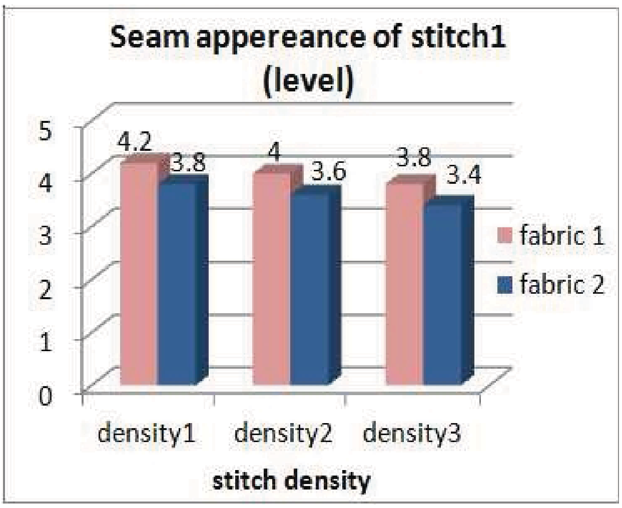
Table 13 Seam appearance of stitch1 at different stitch densities

	Seam appearance (level)		
Fabric type	Stitch1 density1	Stitch1 density2	Stitch1 density3
fabric 1	4.2	4	3.8
fabric 2	3.8	3.6	3.4

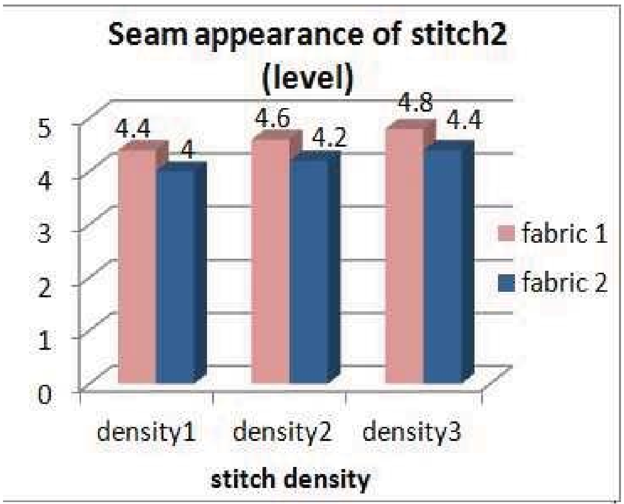
3.2.4.2. Seam appearance of stitch2 at different stitch densities

Table 14 Seam appearance of stitch2 at different stitch densities

	Seam appearance (level)		
Fabric type	Stitch2 density1	Stitch2 density2	Stitch2 density3
fabric 1	4.4	4.6	4.8
fabric 2	4	4.2	4.4



(a)



(b)

Fig(9) Seam appearance of tested fabrics

Seam appearance is very critical to apparel appearance. Seam quality is related with seam puckering, where unwanted gathers are appeared at stitch line. There are also many other factors that may cause undesired seam appearance like unevenly thread distribution upon the seam. Appearance is evaluated (from1 to5) where 5 means best appearance and 1means worst appearance. As shown in table13&14, fig(9a&b) fabric1 gives better seam appearance than fabric2 and stitch2 provides higher seam appearance compared with stitch1 which can be referred to stitch pucker. As seam appearance increases when seam pucker decreases. This fact established also by the different densities of stitch2, as stitch2 density1 provides low seam appearance, while stitch2 density2 gives better seam appearance and stitch2 density3 scored the best result. On the other hand, the opposite happened by the different densities of stitch1, regardless of their seam pucker, where stitch1 density1 provides high seam appearance, while stitch1 density2 has lower seam appearance and stitch1 density3 scored the lowest value which can be attributed to degree of evenly thread distribution upon the seam.

Conclusions

- Fabric type has a significant effect on performance.
- Fabric1 (CoolMax/Micro Modal single jersey plated) has very high breathability and moisture management, therefore authors recommend using it for T-shirts and shirts of athletic sport suits. It's also ideal for other apparel items like underwear, nightwear and lingerie due to its comfort properties.
- Fabric2 (CoolMax/Micro Modal interlock double face) has very high abrasion resistance and crease recovery which gives performance and aesthetic appeal, in addition to its good breathability and moisture management, therefore authors recommend using it for athletic sport suits. It's also suitable for polo-shirts, outer garments and active wear.
- Fabric type has a significant effect on seam properties.
- Seams of fabric2 have higher thickness, stiffness, breaking force and pucker compared with seams of fabric1. On the other hand seams of fabric1 gives better appearance than those of fabric2 because there is an inverse relation between seam pucker and its appearance.
- Stitch type and density has a significant effect on seam properties.
- Seams using stitch type1 (512) gives more thickness, stiffness, breaking force and pucker compared with those using stitch type2 (601). While stitch2 provides higher seam appearance than stitch1. Therefore authors recommend using stitch type1 for sewing apparel parts which are more exposed to high stress, whereas stitch type2 can be used for sewing apparel parts that required better aesthetic appeal.
- There is a direct relationship between stitch density and their seams thickness, stiffness, breaking force and pucker. Therefore authors recommend choosing higher stitch density to achieve seams with needed durability.
- There is an inverse relationship between stitch2 at their different densities and their

seam appearance while the relation between stitch1 at their different densities and seam appearance was directly proportional. For aesthetical seams authors recommend choosing higher stitch density in the case of stitch1 and lower stitch density in the case of stitch2 to increase performance.

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