

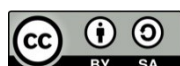
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Study of Structural Parameters of Weft Knitted Spacer Fabrics on Wound Dressing Performance

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Article

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ABSTRACT

This research aimed to develop wound dressings from weft-knitted spacer fabrics as an alternative to existing dressing options. A Stoll Type CMS530 HP electronic flat knitting machine was used to develop spacer weft knitted fabrics, which were tested with various experimental configurations by adjusting the linking distances, spacer yarn ratios, and inlays for proper optimization. Fabric physical and performance properties were evaluated to determine the application of wound dressings and the influence of structural differences. The result showed that the fabric with nylon-to-cotton yarn containing a linking distance setting of 6 needles at a ratio of 1:3, had the highest total performance value, making it the most appropriate fabric for exudate dressing in humid environmental conditions. The fabric with the highest water absorption capacity, and moisture management fabric type was the most effective.

KEYWORDS

weft-knitted spacer fabric, wound dressings, 3D fabric, structural parameters, performance rating index

INTRODUCTION

The worldwide wound care industry, estimated to be worth approximately USD 17.49 billion in 2021, is anticipated to increase from USD 18.51 billion to USD 28.23 billion, which is a 6.2% rise from 2022 to 2029 [1]. This growth was driven by the increasing prevalence of chronic and acute wounds among patients worldwide, prompting the demand for various wound care products. Additionally, innovative wound care treatments are being developed to meet this growing need resulting in an increased application rate of traditional, bioactive, and other forms of wound care treatments [1].

The largest organ in the human body is the skin which measures approximately 2 m² [2,3]. The self-renewing layers serve a variety of purposes [4], including acting as a barrier that protects the internal organs from microorganisms and ultraviolet radiation, regulating body temperature, aiding the immune system, and facilitating sensory detection [5,6]. Therefore, restoring the integrity and function promptly after the occurrence of a dermal wound is crucial.

A wound occurs when the skin barrier function is damaged, due to thermal or physical injury, leading to the loss of epithelial cohesion and connective tissue elements [7]. It can be classified as either acute or chronic based on the nature and duration of the healing process [8]. Acute wounds, sustained from accidents or surgical treatments, typically have a predictable healing duration of eight to 12 weeks, depending on the severity of the damage to the skin layers. However, chronic wounds such as burns, decubitus, and leg ulcers do not heal in a predetermined timeframe [9,10].

When the skin is injured by surgery, trauma or homeostatic abnormalities, the inflammatory response is initiated. The process includes capillary dilation, resulting in the production of fluid termed exudate around the wound, making it more porous. Exudate, comprising white cells, water-carrying electrolytes, nutrients, growth hormones, inflammatory mediators, and protein-digesting enzymes aids in repairing injured skin, and facilitates autolysis, separating dead tissues from healthy ones [11]. Typically, the volume decreases as a wound heals, but in cases of delayed recovery, it may increase or remain constant [12].

Wound healing is a complex process that entails the interaction of numerous cell types, matrix components, and biological agents, such as growth factors, proteinases, and cytokines, in a fluid environment [13]. Achieving equilibrium in this environment is crucial for effective exudate management, as with other elements of wound care [14]. While moisture aids in the healing of excessive acute wounds, it can be harmful, causing skin maceration and other problems [15]. Currently, there is no valid functional characterization of what constitutes insufficient or excessive wound surface wetness [16,17].

Though information on the ideal moisture balance in wounds is limited, it is logical to assume that similar concepts apply to both chronic and acute wounds. Excessive fluid is not the sole reason for delayed healing [18], rather the composition is of fundamental importance [14]. Effective care aims to remove excess moisture, debris, and harmful substances from the wound area while maintaining the optimal moisture balance, to facilitate cell migration and healing [19]. Symptom management, particularly, dressing performance and exudate control are critical for preserving the life of the patient [17].

Wound requires specific dressings designed for the diverse classification, with selection based on several factors. These include the ability of dressings to a) manage moisture surrounding wound, b) promote epidermal migration, c) foster the growth of connective tissue and angiogenesis, d) permit gas exchange between the wounded tissue and the environment, e) maintain proper tissue temperature to enhance blood flow and cell migration, f) protect against bacterial infections, g) be easily removable after the wound had healed, h) facilitate leucocyte movement and enzyme build up through debridement action, i) be sterile, non-toxic, and allergen-free, j) be biodegradable, biocompatible, elastic, k) alleviate wound discomfort, and l) be cost-effective [7,9].

There are several types of wound dressings, each with distinct characteristics, for example, cotton gauze is commonly used due to its softness, pliability, and ideal absorption properties [20]. However, it can disperse moisture, potentially delaying healing by not retaining moisture in the injured area [21]. Cotton gauze quickly adheres to the wound and requires frequent replacement, causing trauma and discomfort for the patient [22–24]. Alternatively, foam dressings are often applied to the wound with excessive fluid leakage, due to the excellent absorption capacity [25]. These dressings mainly consist of hydrophilic polyurethane foam, with absorption rates varying based on composition and thickness [26]. Foam dressings with high absorption rates can prolong the frequency of dressing changes, with individual pads lasting approximately seven days. The high cost, which is almost ten times the regular cotton gauze, restricts the widespread application [27]. Alginate wound dressings, made from soft fibres derived from seaweed [28], interact with wound fluid by exchanging sodium for calcium ions [29]. The gel produced by ion exchange with wound fluid helps keep the wound moist and warm. Alginates are often coated with additional dressings such as gauze, due to their high permeability and lack of sealing properties [30]. Despite the effectiveness, most alginate dressings tend to stimulate bacteria growth, leading to a foul odour and discomfort for the patient [21].

The limitations of currently available dressings [21,31–33] made of foam, alginate, hydrogel, hydrocolloid, and other materials may lose shape during use and fail to maintain the original form. Furthermore, an unpleasant odour partly caused by heat production and low air permeability of the skin, including lack of elasticity, reduces comfort in regions prone to the joint or due to body movement. Some dressings may stick to the wound, causing pain during removal, as a result of size and shape restrictions.

Recent advances in science and technology have made it feasible to discover the ideal materials for dressings suitable for diverse wound types, thereby facilitating optimal healing. Knitted spacer fabrics are a promising option in this context, offering potential solutions to overcome the limitations associated with traditional dressings and enhance effectiveness. It is characterized by a three-dimensional (3D) textile structure, composed of two layers of outer fabrics connected by spacer yarns [34–38]. The resilient pile yarn that runs between the two surfaces ensures consistent spacing, even after compression. These fabrics are designed for specific purposes and possess three changeable components, namely fabric structure, yarn material, and finishing. For example, the hollow core of fabrics may be filled with solid, liquid, or gaseous substances, such as air for insulation purposes. Additionally, yarns with excellent moisture transport qualities can be used, further enhancing their suitability for the application of wound dressings [39].

The structural characteristics of 3D knitted spacer fabrics make it an excellent material for wound dressings [21]. Air permeability is crucial for odour removal, while also aiding in managing heat and moisture transmission [38,40]. This produces a moist and thermally insulated environment conducive

to healing [21]. In addition, knitted spacer fabrics are reasonably soft and resilient, providing effective cushioning and pressure distribution on the body [41].

Weft-knitted spacer fabrics are designed to accommodate different phases of wound exudate by adjusting the knitting structure. This versatility can be altered to suit diverse requirements, including water absorption capacity, moisture resistance, and air permeability. In addition, knitted spacer fabrics are customized by modifying fabric structure, spacer yarn spacing, yarn count, fibre type, and origin, including machine settings.

The main benefit of knitted spacer fabrics is that it eliminates the need for additional expenses associated with laminating or combining processes because all three components are knitted simultaneously. Additionally, spacer fabrics are extensively used in a wide array of new goods, particularly in specialized applications where the aesthetic, functional, and technical features offer significant advantages [42].

Some research on wound dressings made from spacer fabrics, including compression and pressure dressings, had been conducted [41], although there had been a relatively slight focus on spacer fabrics intended specifically for exudate dressings [21]. Yang's study showed that weft-knitted spacer fabric can be used as wound dressing [21].

There remains an urgent demand for the development and manufacturing of spacer fabrics designed to meet the specific requirements of exudate wound dressings, with high fluid absorption and retention capabilities.

The objective of this research was to develop wound dressings using weft-knitted spacer fabrics as a potential substitute for conventional options, aiming to hasten healing. This research used various materials with varying structure parameters and test methods, unlike preliminary research [21]. The novelty of the research lies in the use of alternate cotton and monofilament nylon as spacer threads to ensure dimensional stability, thereby preventing the 3D fabric from becoming a 2D or flat fabric. In addition, the bottom surface of the lower layer of fabrics, which directly contacts the skin, is made from moisture-wicking fabrics comprising two layers of polyester and cotton. The cotton yarn was integrated as an inlay or insertion to enhance the liquid absorption ability.

EXPERIMENTAL

Materials

The yarn parameters and intended applications for weft-knitted spacer fabrics are shown in Table 1. Six yarn types with available equivalent yarn counts, were applied on a different feeder machine,

except for yarns 3 and 4. In addition, raw cotton yarn sourced directly from the spinning mills was used.

Table 1. Yarn specification and designation

No	Yarn	Yarn count*	Yarn Designation	Feeders on the machine
1	Polyester multifilament	33.3 Tex/68F	Front/upper surface of fabric	1
2	Nylon monofilament	30.0 Tex/1F	Tuck (spacer)	2
3	Polyester multifilament	33.3 Tex/68F	Rear/lower surface of fabric, Platted	3
4	Cotton	29.5 Tex	Rear/lower surface of fabric, Platted	3
5	Cotton	29.5 Tex	Tuck (spacer)	4
6	Cotton	39.4 Tex	Inlay	5

*F: number of filaments

Methods

Fabric manufacturing

Stoll Type CMS530 HP electronic knitting machine was used to manufacture weft-knitted spacer fabrics. Fabrics comprised upper and lower surface layers produced by knitting two multifilament polyester yarn cones with a plain loop separately on the back and front needle beds. Cotton yarn was also incorporated on the back needle bed alongside polyester yarn. Spacer yarns, comprising monofilament nylon and cotton yarns, were then introduced on the front and back needles, incorporating alternating tuck loops. Various sample fabrics were produced with different linking distances, spacer yarn ratios, and inlays, to achieve optimal results for wound dressings.

The first step in producing sample fabrics was to develop a knitting process plan using Stoll knitting machine software, particularly M1Plus, as shown in Table 2. In this research, plain loops were used for both surface layers of fabric, while the tuck type was adopted to connect the two layers. The spacer or tuck linking distance used ranged from two, four, to six needles. The knitting process was designed to form loops in one repetition by knitting plain ones on the front and back needles, including tuck loops using spacer yarns and inlays, which were altered in every four courses. Figure 1 shows the process diagram for manufacturing weft-knitted spacer fabrics.

Table 2. Knitting process plan

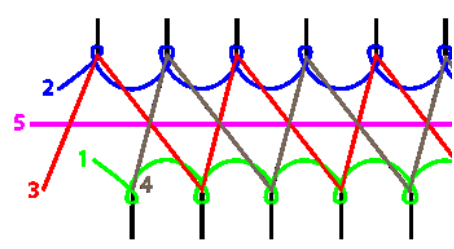
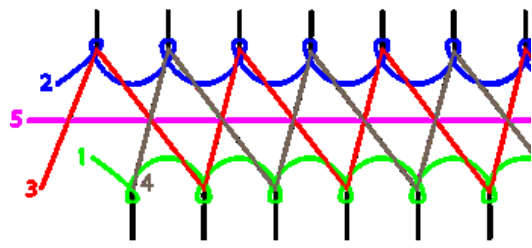
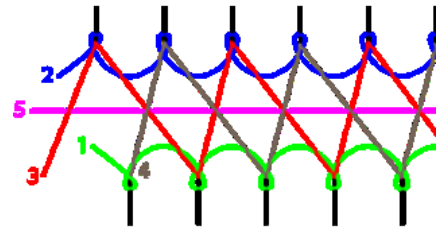
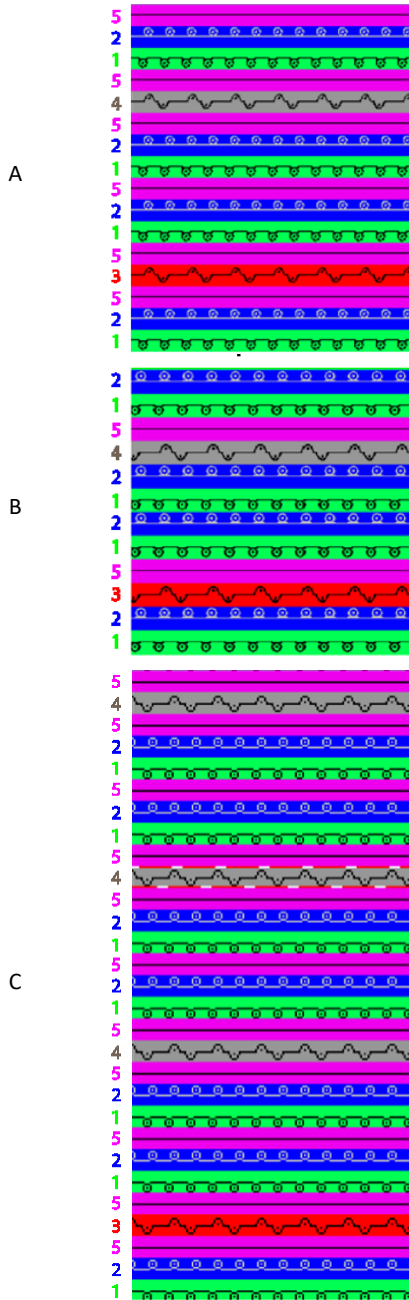
No	Fabric code	Linking Distance	Spacer yarn Ratio	Inlay yarn	Remark
1	A	2	1 nylon : 1 cotton	every 1 course	full inlay
2	B	2	1 nylon : 1 cotton	every 4 course	sparse inlay
3	C	2	1 nylon : 3 cotton	every 1 course	full inlay
4	D	2	1 nylon : 3 cotton	every 4 course	sparse inlay
5	E	4	1 nylon : 1 cotton	every 1 course	full inlay
6	F	4	1 nylon : 1 cotton	every 4 course	sparse inlay

No	Fabric code	Linking Distance	Spacer yarn Ratio	Inlay yarn	Remark
7	G	4	1 nylon : 3 cotton	every 1 course	full inlay
8	H	4	1 nylon : 3 cotton	every 4 course	sparse inlay
9	I	6	1 nylon : 1 cotton	every 1 course	full inlay
10	J	6	1 nylon : 1 cotton	every 4 course	sparse inlay
11	K	6	1 nylon : 3 cotton	every 1 course	full inlay
12	L	6	1 nylon : 3 cotton	every 4 course	sparse inlay

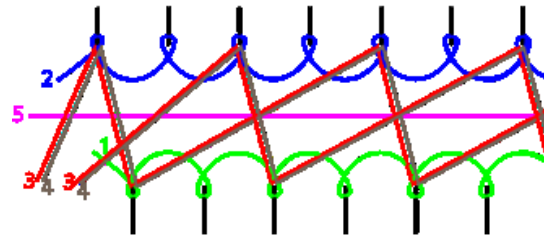
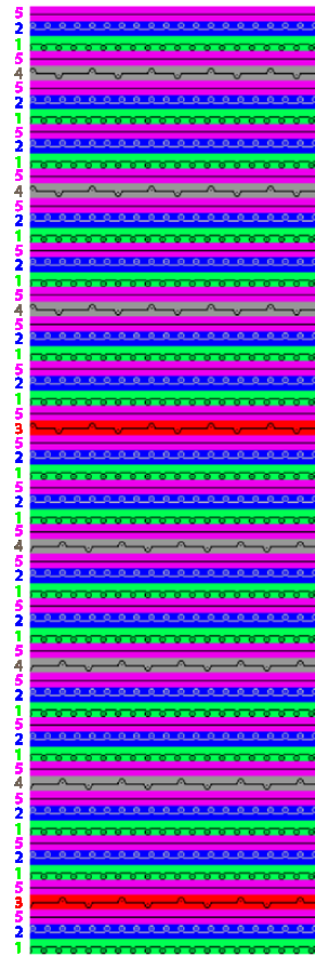
Fabric

Process diagram

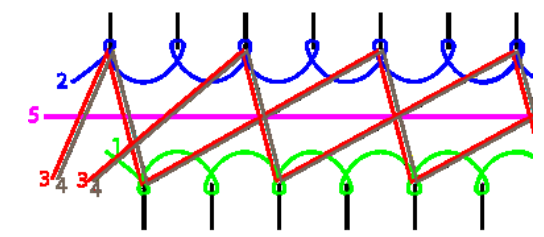
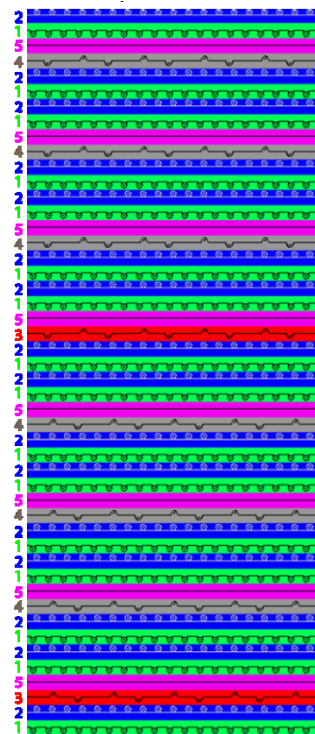
Yarn position on the feeders (refers to Table 1)

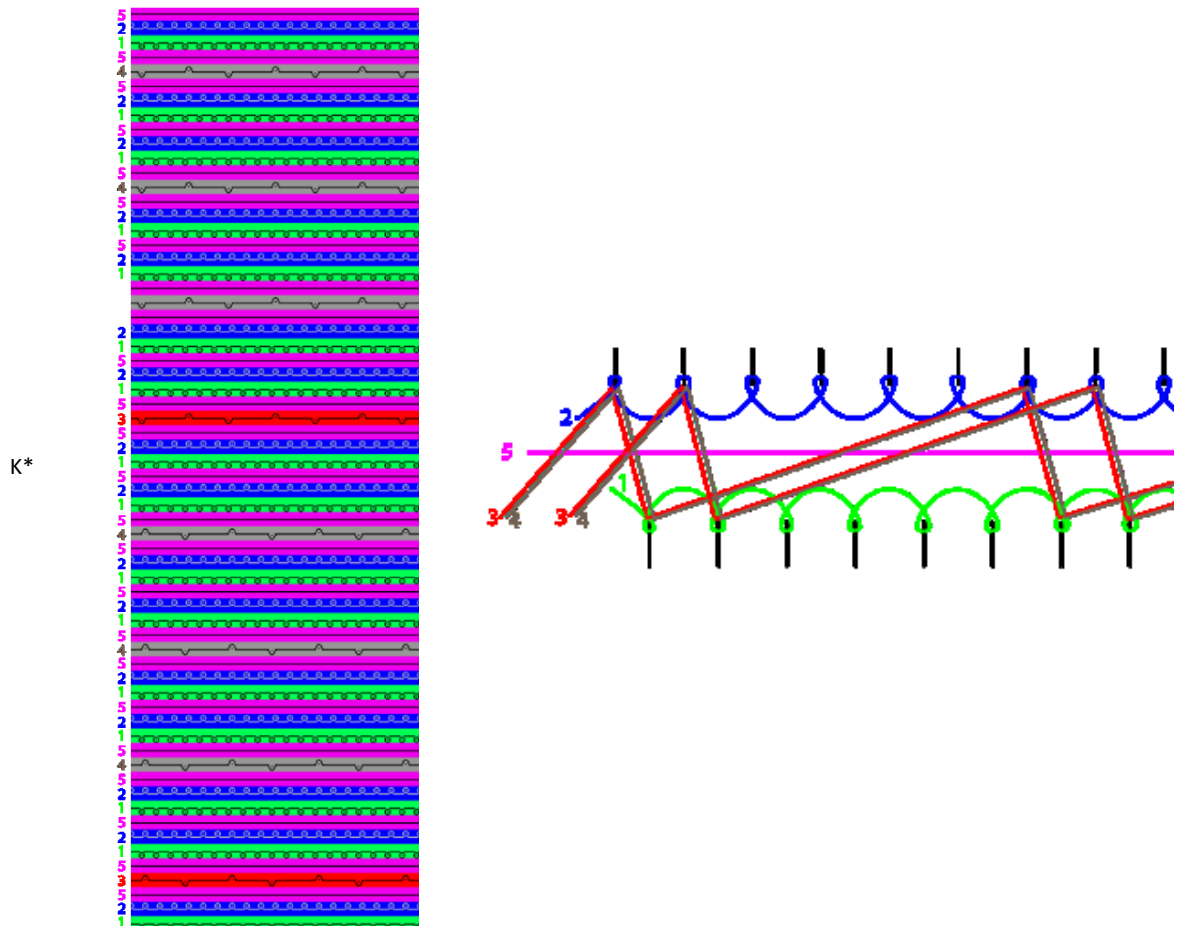


G



H





*The K sequence is purposefully swapped with the L sequence to fit the image on the paper.

Figure 1. Process diagram for manufacturing experimental spacer fabric

Fabric physical properties determination

Fabric course and wale density were determined using the Mesdan Video Analyser. The test was conducted based on the ISO 7211-2:1984 standard for determining the number of threads per unit length (inch) [45], with adjustments made to suit knitted fabrics used as samples. To ensure accuracy and reliability, five specimens were tested for each experimental fabric.

The determination of fabric mass per unit area was based on ISO 3801:1977 standards [46]. Each fabric sample was cut into 10 x 10 cm pieces and weighed using the Precisa semi-microbalance. In addition, fabric mass per square meter was calculated. To ensure precision, five specimens were tested for each experimental fabric.

Fabric thickness was determined based on ISO 5084:1996 standards [47]. It included measuring the distance between the reference plate, on which the specimen was placed, and a parallel circular presser-foot applying a specified pressure (0.1 kPa) to the textile area under test. The sample was positioned between two reference plates, exerting a known pressure. After a set time, the

perpendicular distance between the reference plates was measured and recorded. To ensure accuracy, five specimens were tested for each experimental fabric.

Fabric performance properties concerning wound dressings

Fabrics must be tested and evaluated, to ensure the suitability for wound dressings. Fabric stiffness, examined through bending length, determines the ability to conform to the body curves. The capacity of air to escape from wound dressings without causing odour was tested concerning fabric permeability. Water absorption capacity was examined to assess the effectiveness of absorbing wound fluid. Thermal and moisture resistances measured the heat required to maintain body temperature, and the evaluation of fabrics to resist moisture needed for wound healing, respectively. Liquid moisture properties were used to assess the ability of fabrics to transfer exudate from the wound. Previous research [43–45] used these methods to test wound dressings made from knitted spacer fabrics.

The Shirley Stiffness Tester was used to analyze fabric stiffness according to the ASTM D1388, Standard Test Methods for Stiffness of Fabrics [48]. In addition, test samples measuring 200 x 25 mm were used. During the test, the fabric sample was shifted lengthwise, causing the edges to curl under the mass. When the edges reached an inclined plane at an angle of 41.5 degrees, stiffness parameters such as bending length were calculated from the length of the hanging fabric and the angle. It was also observed that the stiffer the fabric, the greater the bending properties. Each experimental fabric was tested with five specimens.

The Air Permeability Tester FX 3300 LabAir IV was used to determine the permeability of fabrics based on ISO 9237:1995 standards [49]. This included measuring the rate of airflow travelling perpendicularly through a particular piece of fabric under a specific pressure differential over a certain time. Each experimental fabric was tested with five specimens to ensure accurate and consistent results.

The water absorption capacity properties of fabrics were tested according to ISO 20158:2018 standards (E-Textiles — Determination of water absorption time and capacity of textile fabrics). Test samples were diagonally cut to the wale and course directions, forming rectangles with a width of 75 mm and length adequate to weigh five grams. These samples were rolled toward the length until they formed a cylinder measuring 75 mm in height. Each sample roll was then placed in a cylindrical copper wire basket with an open end measuring 30 and 50 mm in diameter and height, respectively. The samples were immersed in water, and the absorption time until complete wetting, was measured. The absorption capacity was determined by calculating the ratio of the mass of water absorbed to the original mass after submersion. To ensure accuracy and reliability, each experimental fabric was tested for five specimens.

The thermal and moisture-vapour resistance of spacer fabrics were tested using an SDL Atlas sweating guarded hotplate (SGHP), also known as a skin model. This device accurately simulates the thermal properties of human skin and the release of moisture when clothing (fabric) is worn. The text assesses the thermal (R_{ct}) and moisture resistances (R_{et}) of textile materials, in accordance with ISO 11092 standards [50]. Each experimental fabric was tested with five specimens to ensure reliable results.

The Overall Moisture Management Capacity (OMMC) of fabrics was tested using a Moisture Management Tester (MMT) based on AATCC 195 standards [51]. This device detects changes in electrical resistance when liquid passes through a material, with sensor rings on both the bottom and top plates. Additionally, the instrument can determine fabric type based on the content on both surfaces and the wetted area. Each experimental fabric was tested with five specimens to ensure reliable and consistent results.

The overall performance of fabrics as potential exudate wound dressings and the comparison with other types were evaluated using a total performance index assessment [52-54]. This assessment considered various criteria, including water absorption capacity, fluid transfer properties, moisture, and thermal resistance, air permeability, as well as fabric stiffness.

Each criterion received a weight reflecting its significance in assessing the performance of exudate wound dressings. A weight of 30% was attributed to the water absorption capacity, highlighting its critical role in the dressing's efficacy in managing wound exudates. The type of Moisture Management Fabric, informed by the Moisture Management Test (MMT), was deemed 20% in significance due to its function in preventing re-wetting of the skin. The water vapour resistance was weighted at 15%, correlating with the necessity for a humid microclimate conducive to expedited wound healing. Air permeability was also weighted at 15%, recognizing its contribution to ventilation and odour mitigation. Thermal resistance was assigned a 10% weight, reflecting the importance of thermal comfort for the healing area. Lastly, the bending length, which determines the dressing's adaptability to body contours and flexibility, was assigned a 10% weight. Subsequently, each fabric was given a total performance rating index ranging from one to 100, with 100 representing the best and most preferred, and one being the worst. To standardize the selected parameters for comparison, each criterion was normalized to produce dimensionless values for calculating the total performance index.

- WAC/WAC maximum, prioritizing large values for better suitability in exudate wound dressings.
- Moisture management fabric (MMF) types were more suitable for exudate wound dressings.
- R_{et}/R_{et} maximum, with large values, was more suitable for exudate wound dressings due to the high humidity.
- AP/AP max, with high values suitable for exudate dressings to avoid odour.
- R_{ct} minimum/ R_{ct} with small values is more appropriate for exudate dressings to ensure comfort on the skin without excessive warmth.


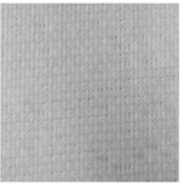
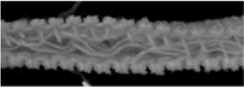


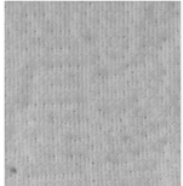
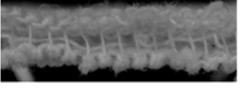

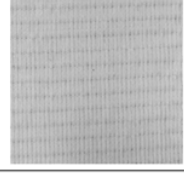
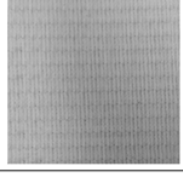


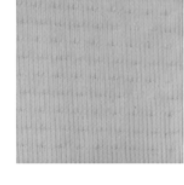
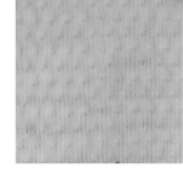
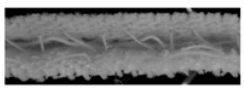




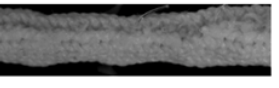
- BL minimum/BL, with small values enhancing the flexibility and conformity of fabrics to the body in exudate dressings.

The largest and smallest data points were derived from each criterion, based on the relevance to the properties required for fabrics used as exudate wound dressings. The total performance index evaluation was designed for comparison purposes, rather than providing absolute values.

RESULTS AND DISCUSSION

Weft-knitted spacer fabrics were produced in accordance with the provided process plan and diagram.

The experimental results of fabrics are shown in Figure 2.

	Lower surface	Upper surface	Course wise	Wale wise
A				
B				
C				
D				
E				

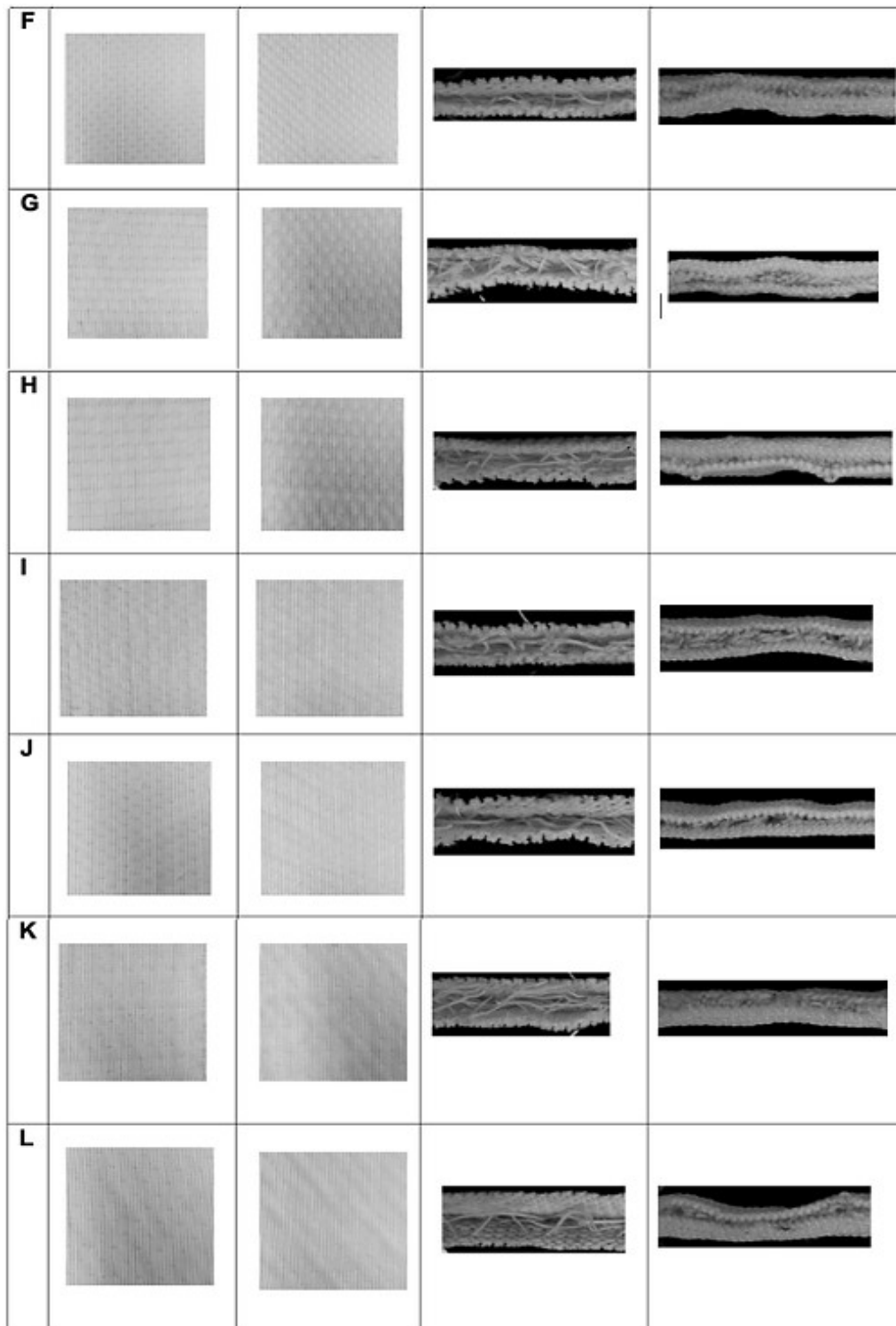


Figure 2. Experimental weft-knitted spacer fabrics

Fabric physical properties

Figure 3 shows that the course density of all experimental fabrics was significantly different (ANOVA test, p -value < 0.05). Fabrics D and A had the highest and lowest course densities, respectively. These variations were attributed to changes in yarn count and tension during the manufacturing process.

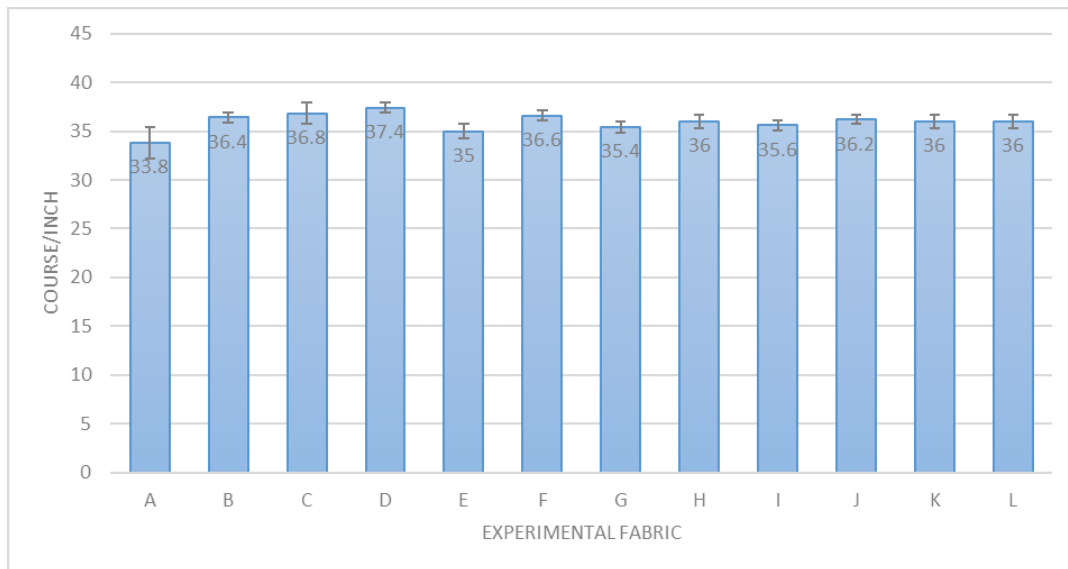


Figure 3. Course density of the twelve experimental weft-knitted spacer fabrics

Figure 4. shows that all experimental fabrics had the same wale density (p -value > 0.05). This uniformity occurred because all fabrics were produced on the same knitting machine with consistent needle density (gauge).

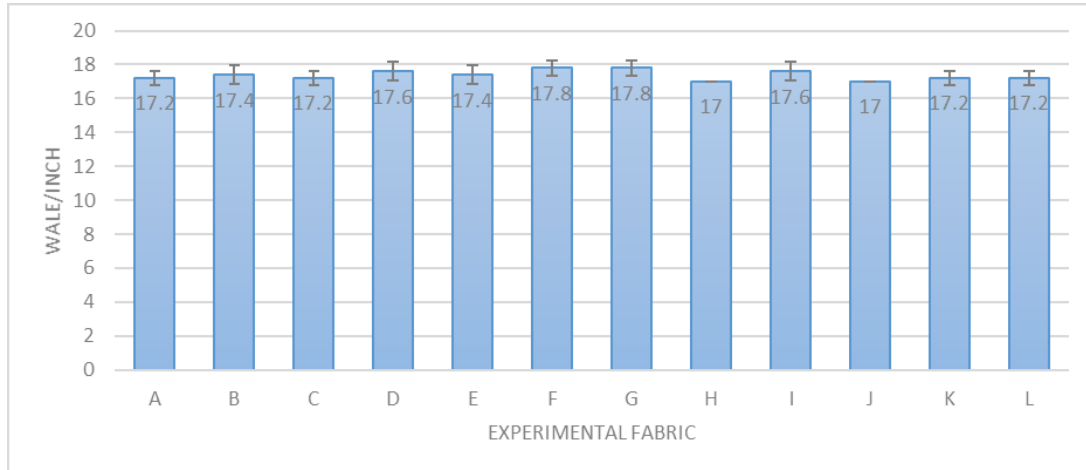


Figure 4. Wale density of the twelve experimental weft-knitted spacer fabrics

Figure 5. shows that the mass per square meter of all experimental fabrics was significantly different (p -value < 0.05). In addition, fabrics C and L were the heaviest and lightest, respectively, due to the use of different yarns for each course, with varying counts, influencing the overall mass. The fabrics with inlays were heavier, and dense yarns were heavier than those with sparse inlays.

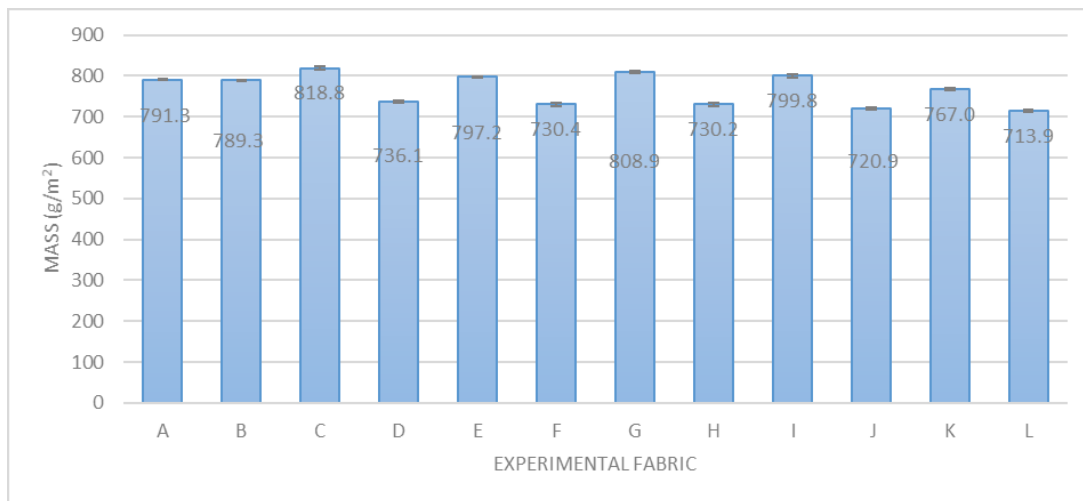


Figure 5. Mass per square meter of the twelve experimental weft-knitted spacer fabrics

Figure 6 shows that the thicknesses of all experimental fabrics were significantly different (p -value < 0.05). Fabric A had a larger thickness compared to the others, due to variations in distance affecting the spacing between spacer yarn tucks. Fabrics with a spacer yarn ratio of 1 nylon:1 cotton and a full inlay yarn in each course also showed increased thickness

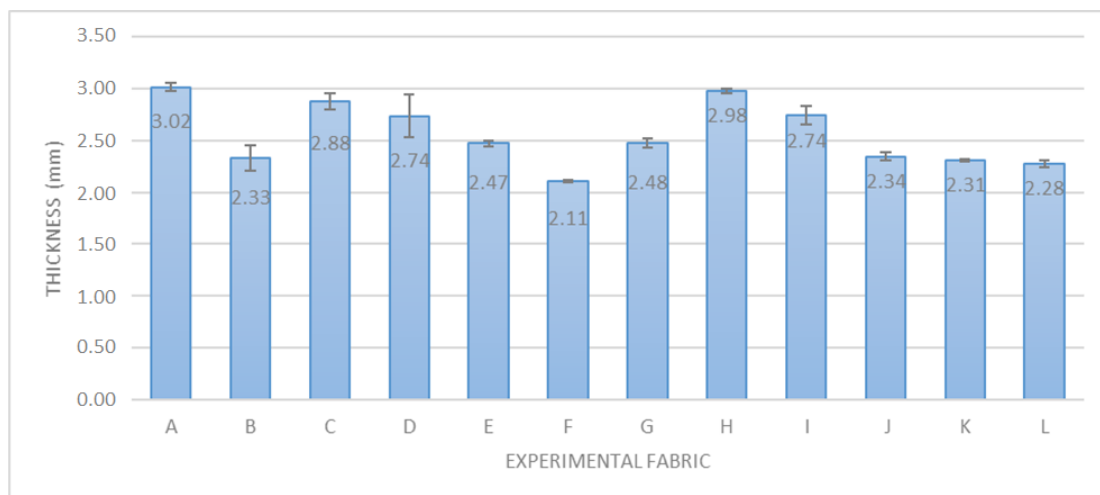


Figure 6. Thickness of the twelve experimental weft-knitted spacer fabrics

Performance of fabric

Figure 7. shows that the course and wale bending lengths of all experimental fabrics were significantly different (p -value < 0.05). Furthermore, fabrics A and B had the longest course and wale bending lengths compared to the others. This variation was attributed to differences in linking distances, where fabrics A and B had the shortest distance between two needles, resulting in a closer arrangement of spacer yarn in terms of the number of tucks per unit length.

The spacer ratio of 1 nylon to 1 cotton, resulted in a higher proportion of nylon yarn, contributing to increased rigidity. This was due to the use of monofilament nylon yarn, which had a larger diameter and was far stiffer compared to the multifilament or staple yarn. Fabrics A and B, characterized by stiffness were unsuitable for wound treatment. The longer bending length in the wale direction depicted greater stiffness. Placing wound dressings along the course direction of fabrics ensures greater flexibility, facilitating better conformity to the body contours.

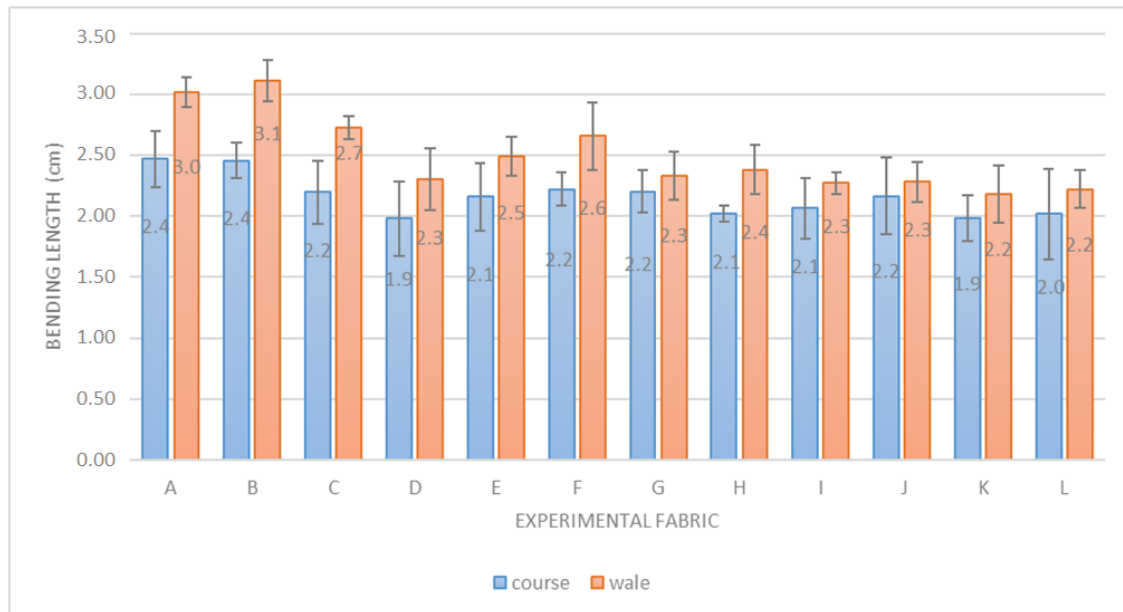


Figure 7. The bending length of the twelve experimental weft-knitted spacer fabrics

Figure 8. shows that the air permeability of each experimental fabric was considerably different ($p < 0.05$). Furthermore, fabrics L and C had the highest and lowest air permeability, respectively. Air permeability reflects how easily air can pass through the fabric, essential for a variety of applications. Since fabrics were composed of yarn, and fibers, a percentage of the volume contains air pockets. The air permeability property was influenced by the quantity, size, and distribution of these voids.

Fabric L sample had the highest air-permeability value among all experimental samples. This was due to the longer connecting distance, resulting in fewer tucks per unit length and less dense spacer yarn. Therefore, fabric L had minimal or no inlays, forming spaces between the spacer yarn. With significant connecting distance and vacant areas not filled by inserted yarn or inlays, the less dense spacer yarns enabled air to flow through fabric with ease, resulting in excellent permeability.

Each experimental fabric with an inlay yarn structure had a lower air permeability compared to those with sparse structures. The inclusion of additional inlay yarn in the fabric increased the density, hindering the passage of air.

Adequate air permeability is crucial for wound dressing materials, as anaerobic bacteria contribute significantly to the production of volatile odorous chemicals. The low air permeability of the dressing was becoming increasingly problematic, specifically for patients with chronic wounds [55]. Spacer fabrics had exceptional air permeability due to the unique textile structure, effectively addressing this

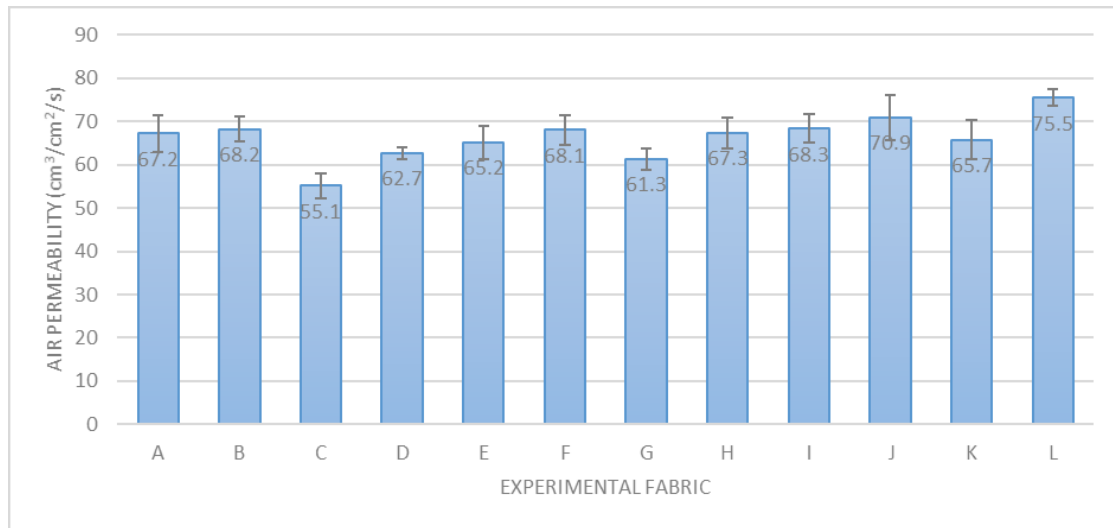


Figure 8. Air permeability of the twelve experimental weft-knitted spacer fabrics

Figure 9. shows that all experimental fabrics had significantly varied water absorption capacities (p -value < 0.05). Fabric K had the highest water absorption capacity, attributed to the spacer ratio of one nylon yarn for every three cotton yarns. With more spacer yarns made of cotton, fabric K could absorb more water. Fabrics with a high water absorption capacity are preferable for exudate dressings due to their efficiency in absorbing more liquid.

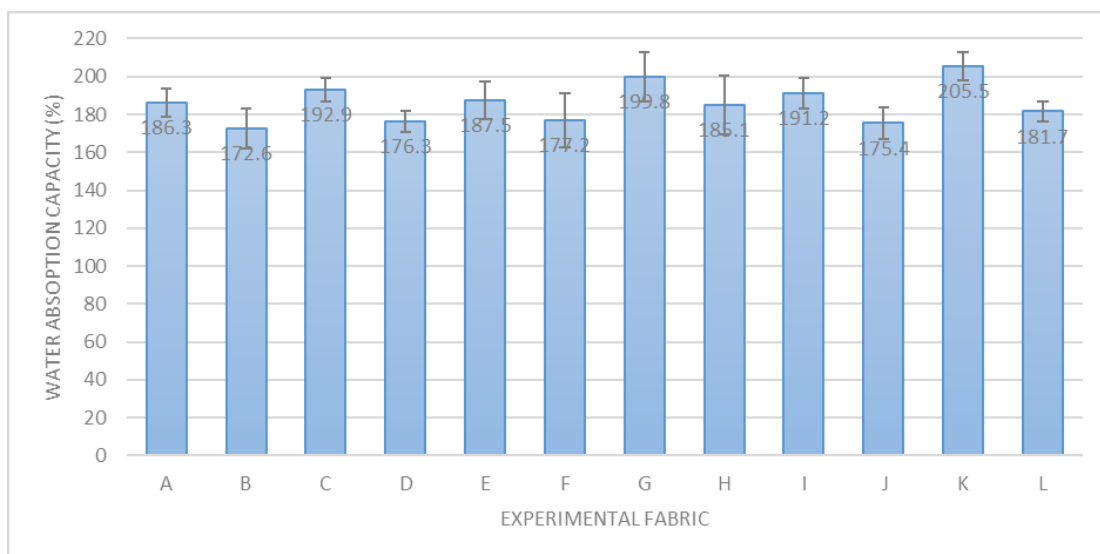


Figure 9. The water absorption capacity of the twelve experimental weft-knitted spacer fabrics

Figure 10 shows the thermal resistance of the six-weft knitted spacer fabrics. The results of the ANOVA test showed that all experimental fabrics had significantly different thermal resistances (p values < 0.05). Thermal resistance properties were evaluated only for fabrics with the highest and lowest water absorption capabilities.

The thermal resistance of fabrics C, I, and E was higher compared to the others, influenced by the thickness and amount of air trapped in the voids. Fabrics C and I were thicker than K, G, and B, while fabrics E and I had wider connecting distances, resulting in larger air space between the yarns. Fabrics with good thermal resistance are useful for exudate wound dressings, maintaining the wound at normal body temperature, for optimal healing conditions and cell division. However, excessive thermal resistance should not be avoided to prevent heat stress.

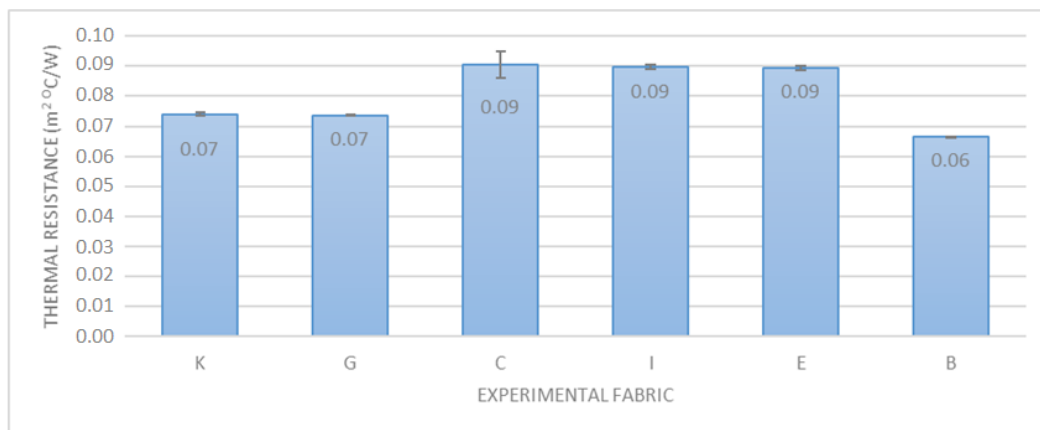


Figure 10. the thermal resistance of the six experimental weft-knitted spacer fabrics

Figure 11 shows the moisture vapour resistance of the six-weft knitted spacer fabrics. According to the results of the ANOVA test, all experimental fabrics showed substantially different moisture vapour properties (p -value < 0.05).

Not all fabric samples were evaluated for moisture vapour resistance, only those with the highest and lowest water absorption capacities were examined. Fabrics K, C, and E had greater moisture vapour resistance compared to the others. This resistance was influenced by the structure of the fabric, particularly the presence and size of air gaps between the yarns. Variations in linking distance and inlay yarn density alter the size and quantity of these air gaps. Large and numerous air gaps facilitate the transport of moisture vapour from the body to the surrounding environment, while denser threads and smaller air gaps have greater moisture vapour retention. A dressing with high moisture vapour resistance is required for wounds that need a humid environment. In addition, it prevents moisture vapour from easily escaping into the environment.

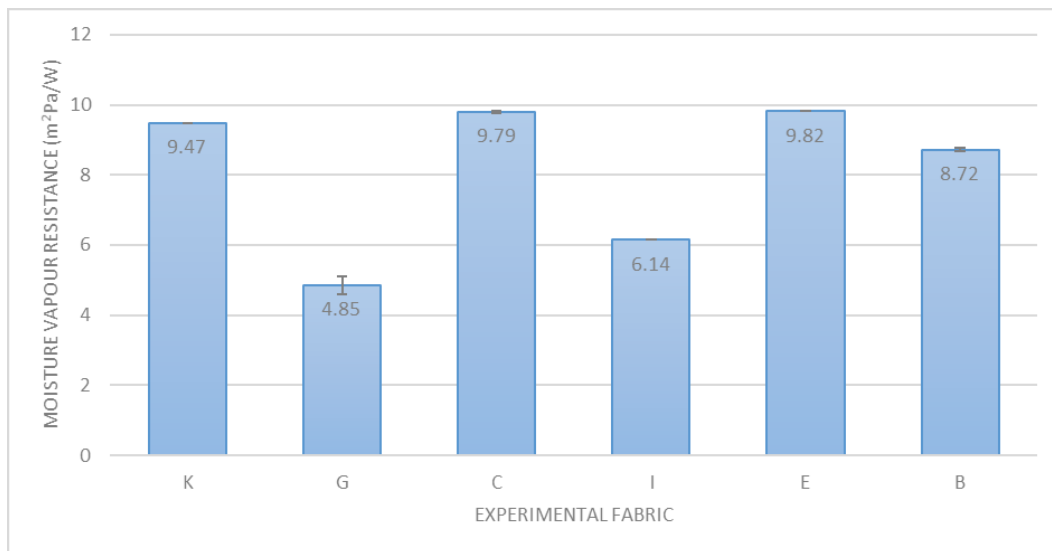


Figure 11. Moisture vapour resistance of the six experimental weft-knitted spacer fabrics

OMMC grade and fabric types identified with moisture management testers are shown in Table 3. Moisture properties were assessed only in fabrics with the highest and lowest water absorption capacities. The examined fabric surface interacts directly with the skin or wound. To facilitate testing due to the 3D or thickness of the fabric, it was divided or sliced to produce a two-sided sheet. The assessed part of the fabric was the bottom surface produced during the plating process. The fabric on the upper sensor was produced from polyester yarn and in contact with the skin, while the one on the lower sensor was made from cotton yarn. Moisture management evaluation was conducted solely on fabrics with the highest and lowest water absorption capacities.

The test results showed that all materials had OMMC with the highest grade (grade 5), depicting excellent moisture management performance. Furthermore, all fabrics were classified as moisture management fabrics, characterized by qualities such as moderate to rapid wetting, quick water absorption, wide and rapid spreading on the bottom surface, and excellent one-way transport.

Exudate fluid could travel from the body to the surface of the polyester fabric, where it would be absorbed by the cotton yarn on the opposite side. The cotton spacer and inlay yarns would also absorb and retain the fluid. Since the spacer fabric has exceptional one-way transport, the liquid transferred into it would not seep to the bottom, as a result, the skin remained moist.

Table 3. OMMC grade and type of fabrics identified with moisture management testers

Fabric	OMMC Grade	Fabric type according to MMT
K	5	Moisture management fabric
G	5	Moisture management fabric
C	5	Moisture management fabric
I	5	Moisture management fabric
E	5	Moisture management fabric
B	5	Moisture management fabric

The total performance rating index evaluation of six weft-knitted spacer fabrics is shown in Table 4. However, only fabrics that had been tested for thermal, and moisture vapour resistances, including moisture management properties, were included in the rating. Fabric K with the highest total performance index value proved to be excellent for exudate wound dressings in moist conditions. The exceptional water absorption capacity and moisture vapour resistance contributed to the high rating. Fabric G had the lowest total performance rating index due to the poor moisture vapour resistance, despite having a high water absorption capacity.

Table 4. Total performance rating index

Fabric	WAC/ WAC max	Fabric Type	Ret/ Ret max	AP/AP max	Rct min /Rct	BL min /BL	Total Performance Rating Index
K	30.00	20.00	14.48	14.44	8.98	10.00	97.90
E	27.37	20.00	15.00	14.32	7.43	8.76	92.89
C	28.18	20.00	14.96	12.10	7.34	8.01	90.60
B	25.20	20.00	13.33	14.98	10.00	7.00	90.50
I	27.91	20.00	9.39	15.00	7.42	9.60	89.31
G	29.18	20.00	7.42	13.46	9.03	9.35	88.44

CONCLUSION

In conclusion, wound dressings made from weft-knitted spacer fabrics were developed and examined. Different fabric structures, including variations in linking distance, spacer, and inlay ratios, were used to produce the experimental samples. These variations significantly influenced the physical properties and performance of the spacer fabric concerning its application as wound dressings. The fabrics were tested and evaluated to determine fabric stiffness, air permeability, water absorption capacity, thermal and moisture resistances, and liquid moisture properties. Previous research used these methods to test wound dressings made from knitted spacer fabrics.

The total rating index served as a metric for evaluating the performance of fabrics used in the manufacture of exudate wound dressings. Based on the evaluation of the total performance index,

fabric K was the most suitable choice. It had a linking distance of six needles, a nylon-to-cotton yarn ratio of 1:3 and full inlay in each course, showing the highest total performance value. The designation made the most appropriate fabric for exudate wound dressings in humid environmental conditions. Fabric K had a high total performance index mainly attributed to the superior water absorption capacity and classification of the lower fabric surface as a moisture management material.

Author Contributions

Conceptualization – Wardiningsih W; methodology – Wardiningsih W, Rudy R, Permana MI; formal analysis – Wardiningsih W, Rudy R; investigation – Wardiningsih W, Rudy R, Permana MI, Sinuraya DY, Munandar T; writing-original draft preparation – Wardiningsih W; writing-review and editing – Wardiningsih W; visualization – Wardiningsih W; supervision – Wardiningsih W, Rudy R. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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