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Characteristics of knitting transfer technology for seam-free female body armor made of ballistic Kevlar

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1 Introduction :

Recent development in body armor production were knitting transfer technology using whole garment technique, which can be defined as knit in three–dimensions without seams in the front and back body panels and the sleeves **(Padaki et al., 2006, Spencer, 2014)**. Mahbub et all, were published an article for designing a three-dimensional seamless female body armor that consist of front and back panel using kitting transfer technology **(Mahbub et al., 2014)**. The knitting transfer technology is a method which used for knitting, also it can be known as loop transfer stitches. There are different type of loop transfer stitches including; plain loop transfer stitches, fancy lacing stitches, sinker and rib loop transfer stitches. Those types were used widely in garments manufacturing. The method of plain loop transfer stitches is transferring from one loop needle to another in the same flat handle bed **(Spencer, 2014, Underwood, 2009)**. This method was used in the study of developing female body armor panel consist of front and back joint from the shoulders. The transfer were also used in the front panel to replace the darts that usually used in traditional sewing of female torso **(Mahbub et al., 2014)**. The advantage of using such a technology not only for saving material and time of production, it's also to provide good fit and comfort wear for the person as well as quality assurance. The innovation was tested for thermal comfort, the result shows that the body armor panel provide suitable range of comfort for the wearer **(Mahbub et al., 2017)**.

The examination for further characteristics of the body armor panel are needed to evaluate the strength of the knitting transfer that replaced the contour darts in the bust area. In order to identify the properties of the knitting transfer several testing

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method were selected including fabric air permeability, porosity and bursting strength.

1.1 Research objective :

This research aim to evaluate properties of knitting transfer stitches for the body armor panel made of whole garment technology. The research also has examined the strength difference among the body panel and the transfer stitches in the front contour darts in the bust area.

2 Experimental design :

2.1 Material :

The body armor panel developed by (Mahbub et al., 2014) were used in this research. It's been made of (100%) ballistic Kevlar, tow types of yarns were selected. The Kevlar (93) was used in the fabric face and Kevlar (44) was used in the back plated. The fabric Thickness was (1.13 mm) and its weight (555 g/m^2).The fabric design and the physical properties were published in the article **(Mahbub et al., 2014)**.

The comparison in this study would be between the body knitting structure of panel, which was made of single jersey stitches (Js) and knitting transfer stitches (Ts) which is the technology used to replace the bust darts.

2.2 Optical porosity :

The optical porosity of the knitting structure of the body armor panel (Ts and Js) were tested using an optical microscope (Olympus BX51-HT0200). The magnification used was (SDF PLAPO 0.5 XPF) for porosity image and (SDF PLAPO 1.6 XPF) for the kitting structure of the body panel. Image J (64) software were used for porosity percentage analysis, the image size was (1360×1024 Pixels/μm^2). The sample photos were taken from three different parts of the body panel and the knitting transfer, then the arithmetic mean and the standard deviation of the three results were calculated.

2.3 Air permeability :

Fabric air permeability was measured according to (ASTM D737-04:2016). The sample were conditioned for 24 hours be for testing, the atmosphere was set to (20±2 °C & RH 65 ± 4 %) according to (SASO-ISO-139:2005). The water pressure differential of the test was (125 Pa – 12.7 mm) the average and standard deviation of five tests result were calculated.

2.4 Breaking strength test

The textile fabrics breaking strength & elongation – Grab test (ASTM D5034-08) test method was used to determine the breaking force needed. The sample were conditioned for 24 hours for a dray test, the atmosphere was set to (20±2 °C & RH 65 ± 4 %) according to (SASO-ISO-139:2005). Three specimens for each test were cut to (100 mm) parallel to the direction tested, both wale and course directions were measured for (Js & Ts) fabrics. The test speed was set to (300 mm/min), and the gage length was (75.0 mm). The average and standard deviation of breaking strength and elongation percentage were calculated.

3 Results and dissection

This indication of the fabric porosities have been proven by **(Tàpias et al., 2010)** result from the light transmission through the fabric. The threshold is measuring the dark pixels after inverting the image, in order to calculate the pore percentage. Figure 1 shows the Js body panel made of knitted structure (single jersey) and the processing of light transmission through the fabric. In addition, the figure shows slight slope in the knitted fabric, which is due to the toughness of the Kevlar yarns as well as the quality and tensions used during knitting process. Similarly, Figure 2 illustrates the (Ts) which is the stitches overlapped in knitting transfer. According to **(Spencer, 2014)** the changes in the number wale due to knitting transfer can affect the characteristics of that parts. Hence, it is important to study and compare the properties of the knitting to analyze the differences to achieve good quality of the product. Also, the Figure shows the inverted image before process the threshold to calculate the porosities percentage.

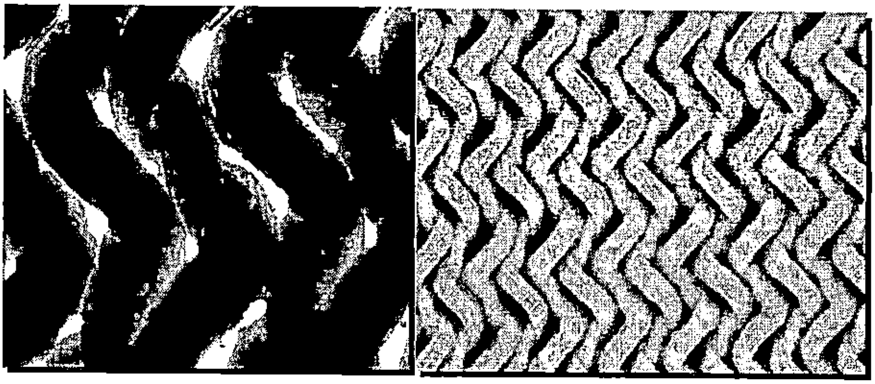


Figure 1(Js) kitted single jersey

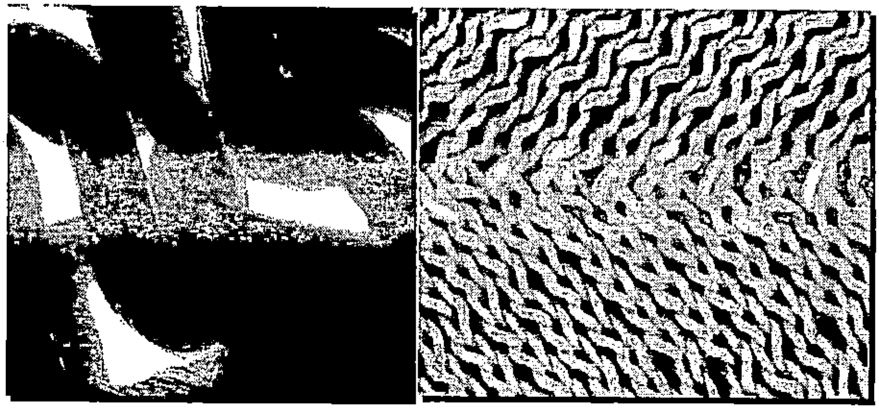
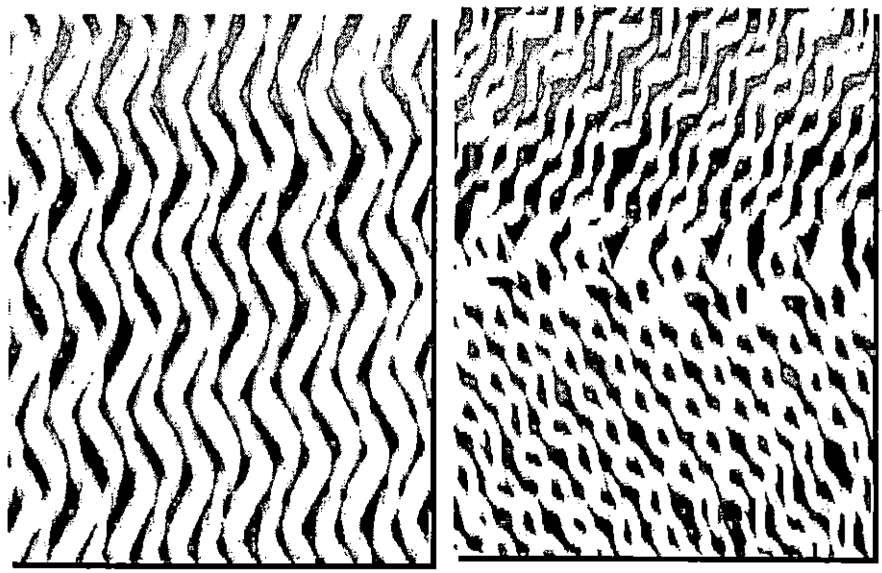


Figure 2 (Ts) knitted transfer stitches

The optical porosities were measured to determine the pore size percentage for the Js and Ts. The results indicated that the Ts has higher percentage than Js, as a result of the overlapping transfer. Meanwhile, the air permeability results confirm the above outcome, showing high velum of air pressure that could pass through the area for Ts. The results are displayed in Table 1 indicates that the Js knitting structure in the body of the panel provide less permeability to air due to the small pore size in comparison with Ts. On the other hand, the Ts kitting transfer, which was made to replace the dart of the bust, provides reasonable breathability to the body armor panel. Figure 3 illustrate the porosities of the Js and Ts, confirming the air permeability results. According to **(Zupin et al., 2012, Szosland et al., 1999)** the larger pore size led to higher permeability to air and water transfer. Accordingly, the results shows similar indication for permeability with **(Mahbub et al., 2017)**. In their study the results demonstrate the thermal comfort needed in the bust area in both dry and wet test on the thermal manikin. The results climes that the body armor panel provide better dry heat loss and moisture transfer.

Table 1 fabrics structure properties :

Measured area	Porosities (%)	Air permeability ($cm^3/s/cm^2$)
Js	24.3 ± 4.2	151.4 ± 5.8
Ts	49.4 ± 6.4	173.6 ± 4.7



(Js   (T

Figure 3 Images porosities process (Threshold)

From another perspective, the breaking strength and elongation results shows minor differences between Js and Ts. Table 2 reveals that the Ts has broken with (2661 N) while Js was (2656 N) in parallel to wale direction. The results indicated that both Ts and Js needs similar force to be broken in wale direction, when considering the Standard deviation. Though, the force needed in parallel to course direction was higher for Ts with (2230 N) than Js with (2163 N). This might be due to the overlapped stitches providing double yarns in one loop in knitting process. Figure 4 and Figure 5 illustrates the three tests results for each specimen in parallel to wale and course directions, in addition to the percentage of elongation. It can be seen from Table 1 the elongation fraction for Js and Ts in parallel to wale was (88.3 & 81.6) and in parallel to course was (180 & 166), respectively. The Figure (4 & 5) confirms that the course direction for both (Js & Ts) have higher and irregular elongation fraction thus, the breaking force was lower than the wale direction. According to **(Spencer, 2014, Yang, 2011)**, the weft knit structure for knitted fabric is less stable and distort more easily to stretch more in the courses than wale direction because of the number of loops . This clarify the irregularity that illustrates in Figure (4 & 5). The indication is that the Ts have comparable or stronger breaking strength and elongation friction as Js. Hence, the knitting transfer used in body armor panel made of 100% Kevlar would not affect the fabric strength at all.

Table 2 Breaking strengths & Elongation results :

Measured area	**Test Directions parallel**			
	Wale (N)	Elongation (%)	Course (N)	Elongation (%)
Js	2656 ± 18.7	88.3 ± 1.6	2163 ±126	180 ± 7.1
Ts	2661 ±8.4	81.6 ±3.3	2230 ± 100	166 ± 5.3

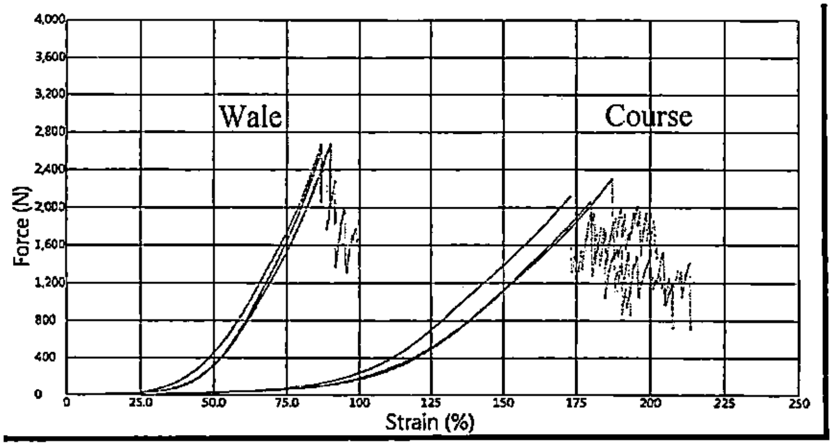


Figure 4 (Js) breaking strength force vs. strain

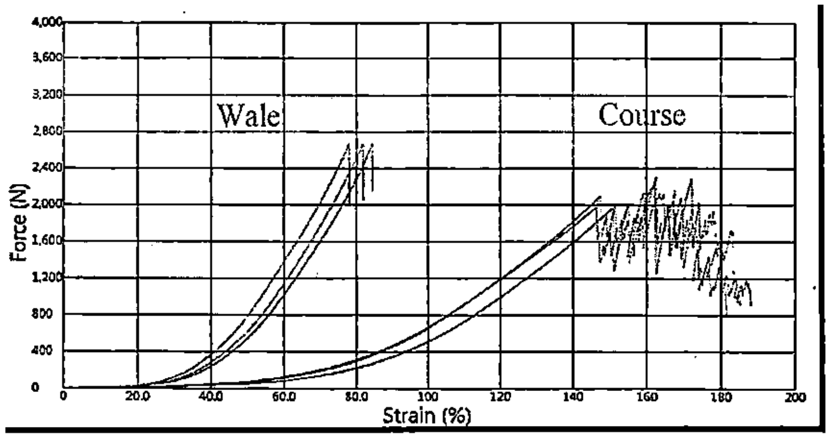


Figure 5 (Ts) breaking strength force vs. strain

4 Conclusion :

The body armor panel made of whole garment technology that used the knitting transfer technique to replace the darts of the bust were investigated. The optical porosities and air permeability results between the body panel Js and the knitting transfer Ts demonstrated that the Ts has higher percentage of porosities than Js. Hence, the air permeability result was higher as well for the Ts. On the other hand, the fabric breaking strength and elongation were comparable between the Js and the Ts, demonstrating that the knitting transfer has no effect in the panel strength. Additionally, it is providing more strength to the fabric because of the overlapping techniques.

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