THE EFFECT OF POSITIONING OF INLAID YARNS IN FILLET WARP KNIT STRUCTURES

Olena KYZYMCHUK[1] and Samuel C. UGBOLUE[2]
[1] Kyiv National University of Technology and Design, Ukraine
[2] University of Massachusetts, Dartmouth, MA 02747, USA

Abstract.
This paper presents results of an investigation on the design options available for positioning the inlaid yarn in fillet warp knit structures. The geometry and structural parameters using our previously published methodology are also presented. It is shown, for example, that if inlaying guide bar does the shifting behind the needles at two needle pitch (variants 1.11-1.13, Table.1) the filling yarn wraps the junctures from G1 ground yarns according to repeat. This position of in-laying yarn provides good stability in the fabric structure, which improves with the amount of wrapping. Thus, the different positions of the inlaid yarn within the structures offer other possibilities that could be explored when designing fillet warp knit auxetic structures. The array of data for the various design options provide analytical tool for making comparisons about the physical, structural and mechanical properties of the warp knit fillet structures. It is observed that the position of in-laying yarn has some effect on stretch characteristics of warp knit structures.

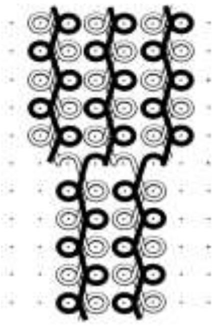
Keywords: *fillet warp knit, in-laying yarn, fabric geometry, structural parameter, mechanical properties.*

1 INTRODUCTION

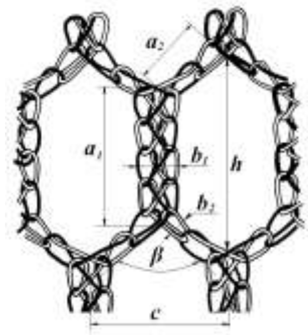
In their previous papers Ugbolue et al [1-2] considered two methods of positioning the in-laid yarns in warp knit auxetic structures and concluded that the type of in-laying influences not only the unit sizes of auxetic structure but that unit size also has significant influence on the Poisson's ratio. A method has been developed for quantifying the geometrical structural unit cell of the auxetic structure based on measured parameters, namely *a1*, *a2*, b1, *b2, h* and *c.* The factor which influences the negative Poisson's ratio was identified by the authors [3] as intrinsic unit size displacement, $(h-a_1)/c$, which depends on chain course numbers in repeat of fillet warp knit.
In the present paper we have continued the investigation on the other design options available for positioning the inlaid yarn in fillet warp knit structures. The geometry and structural parameters using the same published methodology by Ugbolue et al [1-3] are also presented. The different positions of the inlaid yarn within the structures offer other possibilities that could be explored when designing fillet warp knit auxetic structures.

2 THEORETICAL ANALYSIS

Warp knits with in-lay yarns are produced with threads laid either in the course wise direction or as in wale wise direction. When producing this kind of knitted goods the following rules should be observed [4]: the in-laying guide bars behind the needles are disposed nearly to needle backs rather than to the ground bar; there are no overlap for in-laying guide bars, but there are just underlap for this guide bars. The structure of warp knitted fabric is determined by the amount and direction of inlaying and ground guide bars' shifting behind the needles.
The fillet knit structure with hexagonal holes (Fig.1.b), which is formed by two guide bars with symmetrical yarn laying, is a base net structure. Symmetrical nets are produced when two identically-threaded guide bars overlap in balanced lapping movements in opposition (Fig.1.a). The threaded guides of an incomplete arrangement in each bar should pass through the same needle space at the first link in order to overlap adjacent needles otherwise both may overlap the same needle and leave the other without a thread. A typical net consists of vertical ribs from tricot courses of length a_1 and diagonal ribs from chain courses of length a_2.
To achieve auxetic property, it is required to employ a high elastic yarn in the such base structure. This yarn must be placed between the stitch wale in the knitting direction to insure that the fabric structure will retain necessary configuration after relaxation (Fig.2). The filling yarn must be laid between neighboring wales and provide better stability in the fabric structure. Also, minimum of two guide bars with filling yarn of an incomplete arrangement in each bar should be needed because of holes displacement.



a)



b)

Figure 1: Fillet warp knitting structure with hexagonal hole

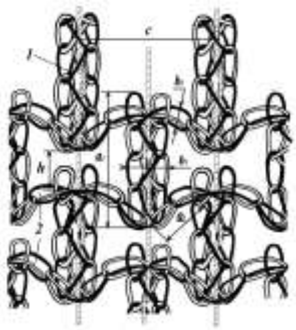


Figure 2: The structure of auxetic warp knit fabric

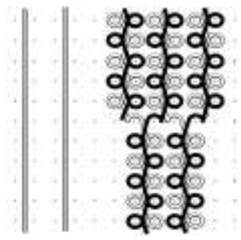
According to rules [4] two variants of disposition guide bars with filling and ground yarns are possible:

- the filling guide bars F1 and F2 are positioned between the ground guide bars G1 and G2;
- the filling guide bars F1 and F2 are positioned behind the ground guide bars G1 and G2.

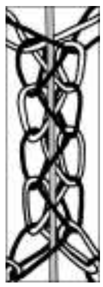
The guide bars G1 and G2 are part-threaded by ground yarns, the guide bars F1 and F2 are part-threaded by filling yarns. The position of filling yarn at the vertical ribs from tricot courses will be analyzed because filling yarn contacts ground yarn just at that place. At the other part of net the filling yarn is laying between vertical and diagonal ribs inside hole.

2.1. The Guide bars with in-laying yarn are positioned between the guide bars with ground yarn.

At the front side of fabric the filling yarn is covered by ground yarn's junctures from G2 guide bar (white yarn). A position of filling yarn in the structure depends on the amount and direction of inlaying and ground G1 (black yarn) guide bars' shifting behind the needles.
If there is no inlaying guide bar shifting behind the needles (variant 1.1, Fig.3.a), at the back side of fabric the filling yarn will be covered by ground yarn's junctures from G1 guide bar's yarn (Fig.3.b). Thus the in-laying yarn is positioned inside the structure between the tricot's junctures from different ground yarns. Such positions of in-laying yarn do not provide good stability in the fabric structure.



a)



b)

Figure 3: Variant 1.1

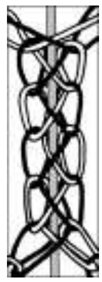
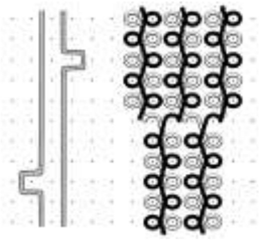
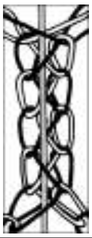
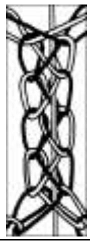
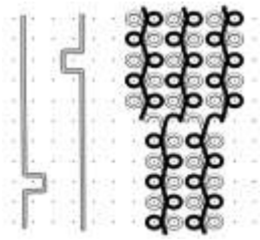
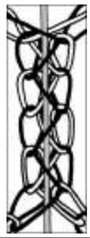
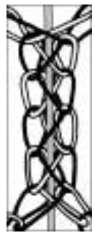
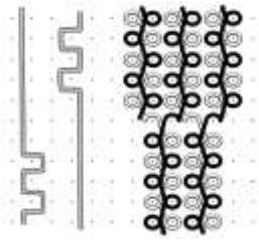
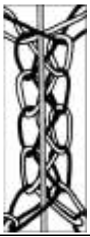
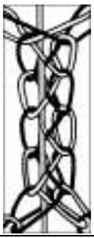
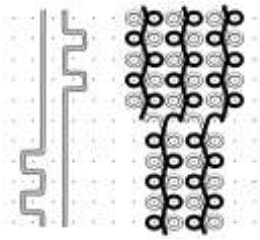
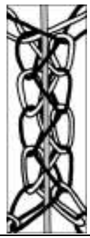
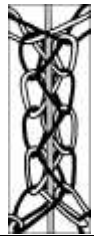
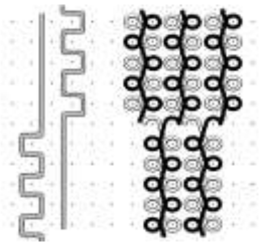
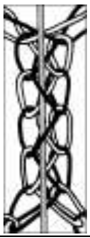
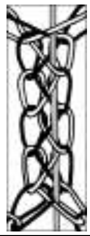
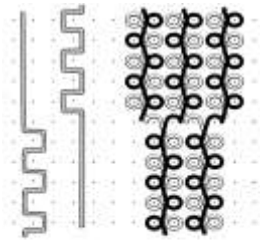
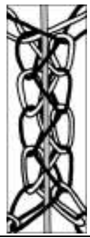
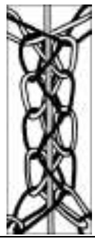
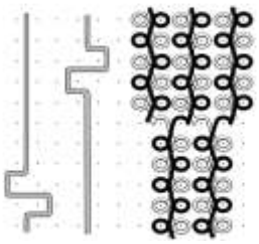
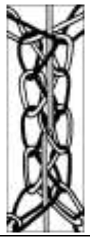
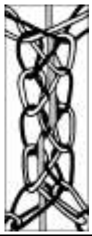
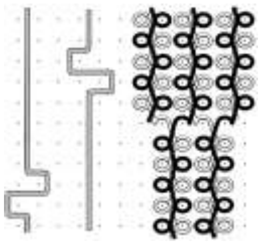
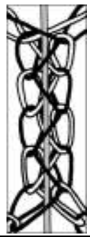
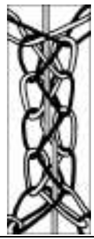
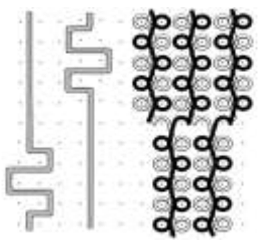
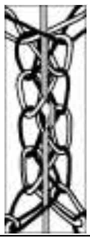
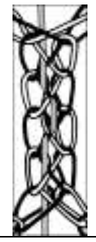
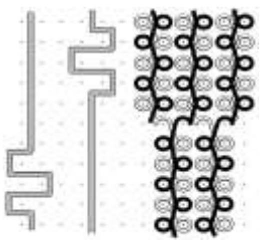
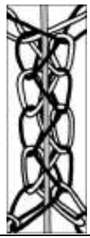
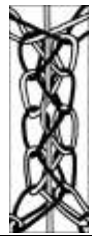
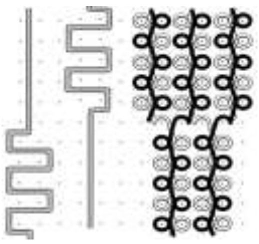
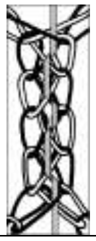
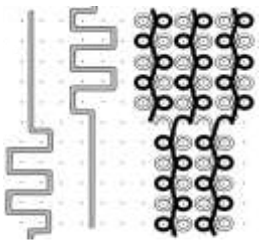
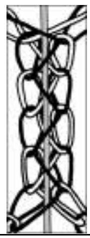
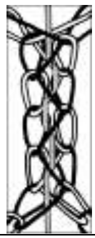


Figure 4: Variant 2.1

If inlaying and ground G1 guide bar's shifting behind the needles are in the same direction, the position of in-laying yarn (variants 1.2-1.7, Table 1) will depend on the amount of inlaying guide bar's shifting.
If inlaying guide bar does the shifting behind the needles at one needle pitch (variants 1.2-1.4, Table 1) the filling yarn covers the tricot's junctures from both ground yarns at the back side according to repeat. This position of in-laying yarn does not provide good stability in the fabric structure too.
If inlaying guide bar does the shifting behind the needles at two needle pitch (variants 1.5-1.7, Table 1) the filling yarn wraps the junctures from G1 ground yarns according to repeat. This position of in-laying yarn provides good stability in the fabric structure, which improves with the amount of wrapping.
If inlaying and ground G1 guide bar's shifting behind the needles are at the opposite direction, the position of in-laying yarn (variants 1.8-1.13, Table 1) is the same as at variant 1.1 and does not depend on the shifting amount.

Table 1

The filling F1 and F2 guide bars’ shifting behind the needles are at the same direction with					
the ground G1 guide bar’s shifting			the ground G2 guide bar’s shifting		
	the filling guide bars are positioned			the filling guide bars are positioned	
	between the ground guide bars	behind the ground guide bars		between the ground guide bars	behind the ground guide bars
	Variant 1.2 	Variant 2.2 		Variant 1.8 	Variant 2.8 
	Variant 1.3 	Variant 2.3 		Variant 1.9 	Variant 2.9 
	Variant 1.4 	Variant 2.4 		Variant 1.10 	Variant 2.10 
	Variant 1.5 	Variant 2.5 		Variant 1.11 	Variant 2.11 
	Variant 1.6 	Variant 2.6 		Variant 1.12 	Variant 2.12 
	Variant 1.7 	Variant 2.7 		Variant 1.13 	Variant 2.13 

2.2. The Guide bars with in-laying yarn are positioned behind the guide bars with ground yarn.

If there is no inlaying guide bar's shifting behind the needles, the filling yarn is not well positioned in the knit structure (variant 2.1, Fig.4). It is just laying at the front side of fabric without any contacts with ground yarns.
If inlaying and ground G1 guide bar's shifting behind the needles are at the same direction (variants 2.2-2.7, Table 1), the in-laying yarn makes contacts with yarns from both G1 and G2 ground bars. Thus the structure depends on the amount of shifting behind the needles. If there is no shifting, the course filling yarn covers both junctures at the front side.
If inlaying and ground G1 guide bars' shifting behind the needles are at the same direction at one needle pitch (variants 2.2-2.4, Table1) the filling yarn covers the tricot's junctures from both ground yarns in turn from the back to the front side and the other according to repeat. This position of in-laying yarn provides good stability in the fabric structure, which increases with the amount of transition from front to back side and vice versa..
If inlaying and ground G1 guide bars' shifting behind the needles are at the same direction at two needle pitch (variants 2.5-2.7, Table 1) the filling yarn wraps the tricot's junctures from both ground yarns according to repeat. This position of in-laying yarn provides very good stability in the fabric structure, which becomes much more stable with increasing amount of wrapping.
If inlaying and ground G2 guide bar's shifting behind the needles are at the same direction (variants 2.8-2.13, Table 1), at the back side of fabric the filling yarn is covered by the ground yarn's junctures from G1 guide bar's yarn. The type of contacts the in-laying yarn makes with yarns from G2 ground guide bars depends on the amount of shifting behind the needles.
If inlaying and ground G2 guide bars' shifting behind the needles are in the same direction at one needle pitch (variants 2.8-2.10, Table 1) the in-laying yarn is positioned inside the structure between the tricot's junctures from different ground yarns. At other courses, the repeat filling yarn covers both junctures at the front side. Such positioning of in-laying yarn will provide poor stability in the fabric structure which depends on the repeat. It should be noted that structure 2.10 is the same as structure 1.1.
If inlaying and ground G2 guide bars' shifting behind the needles are at the same direction at two needle pitch (variants 2.11-2.13, Table 1) the in-laying yarn wraps the junctures from G2 ground guide bar and covers both junctures at the front side at other courses according to the repeat. This position of in-laying yarn provides good stability in the fabric structure, which improves with the amount of wrapping. Thus on the basis of this theoretical analysis it is possible to choose the structure with better stability to produce auxetic warp knit structure.

3 EXPERIMENTAL SAMPLES

In order to undertake the detailed study of the influence of in-lay yarn positioning, conventional fillet warp knit fabric and twelve types of fillet warp knit fabrics with in-lay yarn were produced. The guide bars with in-lay yarn are placed behind the guide bars with the ground yarn.
These fabrics were made on a 10 gauge crochet knitting machine with one needle bed. The warp knit fabrics were made from polyester yarn as ground. The linear density of the polyester yarn is 250 den x 2. It is manufactured by Du Pont and its tenacity is 1.454 gf/den based on a test gauge length of 25.4 cm (10in), and a crosshead speed of 10.16 cm/min (4in/min).
The 150 denier (96 filaments) polyester sheath serving as the cover yarn for polyurethane core yarn provided a high elastic in-lay component. The yarn is supplied by Unifi Inc. and the linear density of polyurethane core yarn is 70 denier .

4 RESULTS

4.1 Production data, structural parameters and unit size of warp knit fabrics

The details of the production data for the twelve warp knit fabrics are given in Table 2. It is observed that the number of courses per 100 mm depends on the variant associated with inlaying and decreases with the amount of contacts between the in-laying and ground yarns, while the number of wales per 100 mm remains constant for all the fillet knit fabric with in-laying yarn. Similarly, the thickness of fabric and its basis weight depend on the type of inlaying and decrease with the amount of contacts between the in-laying and ground yarns.

Table 2: Physical Data and Tensile Test results of Warp knit Structures

Sample		Number per 10 sm		Thickness, mm	Basis weight, g/sq.m	The tensile test results	
		of wales	of courses			breaking load, kgf	breaking elongation, %
Fillet knit structure		60	116	0.82	181.00	9.17	40
Fillet knit structure with in-laying yarn	**2.2**	40	196	0.97	233.52	10.82	200
	2.3	40	172	0.89	217.40	10.81	200
	2.4	40	153	0.82	193.61	10.35	164
	2.5	40	191	1.03	227.21	9.83	200
	2.6	40	176	0.95	217.60	9.84	160
	2.7	40	149	0.79	185.60	9.86	138
	2.8	40	208	1.09	243.17	10.22	186
	2.9	40	203	1.01	240.77	9.88	193
	2.10	40	202	1.02	231.48	9.84	192
	2.11	40	213	1.04	249.23	9.88	187
	2.12	40	196	1.06	243.43	9.85	190
	2.13	40	185	1.02	231.40	9.85	190

According to the results of the measured unit sizes of the warp knit fabrics, the types of in-laying influence the unit sizes of warp knit structure. The length of the vertical ribs (*a1*) increases and the length of the diagonal ribs (*a2*) decreases with the amount of contacts (wrapping or in turning from the back to the front and vice versa between the in-lying and ground yarns, while widths of the ribs (*b1*, *b2*) are almost constant. The factor which influences the Poisson's ratio is identified [3] as measured unit size ratios h/c and h/a1 and more significantly the intrinsic unit size displacement (tangent), (h-a1)/c. The diagrams in Fig.5 show the effect of different types of in-laying on the intrinsic unit size displacement.
The displacement $(h\text{-}a_1)/c$ is negative at all variants of fillet warp knit structure with in-laying yarn, and one could infer from previous studies [1, 2, 3] that these fabrics possess auxetic properties. Only two types of in-laying (B-2.6 and A- 2.12) have been previously analyzed and results published [5-7]. In this study a more elaborate fabric design has been undertaken to establish the best performing inlaying type. The results indicate that the designed structure 2.4 would have best auxetic properties.

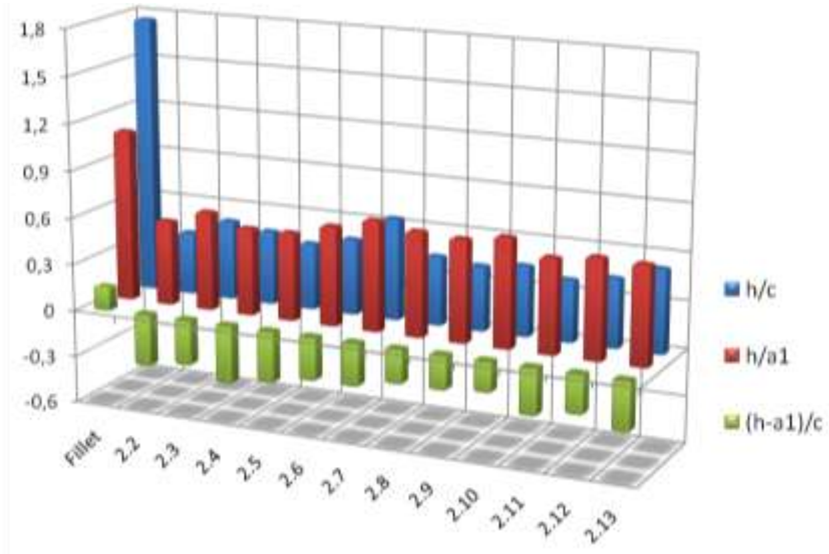


Figure 5: Intrinsic unit size displacement

4.2. Mechanical properties of warp knit fabric

The tensile test results presented in Table 2 show the maximum load and elongation respectively along the walewise direction. The maximum load of warp knit fabric with in-laying yarn is larger than the maximum load of fillet warp knit fabric. The maximum elongation of warp knit fabric with in-laying yarn is up to 5 times larger than maximum elongation of fillet warp knit fabric.

The type of in-laying does not have much influence on the maximum load, but it has some effect on the strain along the walewise direction. The maximum elongation of samples 2.8-2.13, where the inlaying F1 and F2 guide bars' shifting behind the needles are in the same direction as ground G2 guide bar's shifting, is about 180 %.
The maximum elongation of samples 2.2-2.7, where the inlaying F1 and F2 guide bars' shifting behind the needles are also in he same direction as ground G1 guide bar's shifting, depends on type of in-laying. The elongation of samples 2.5-2.7, where filling yarn wraps the junctures of the ground loops, is less than the elongation of samples 2.2-2.4, where filling yarn does not wrap the junctures of the ground loops. Thus, the maximum elongation depends on the number of wrapping (samples 2.5-2.7).
In prior studies, strain has been shown [6, 7] to be a factor that influences the Poisson's ratio test results and the data showed that strain is positively correlated with Poisson's ratio. It is observed that the position of in-laying yarn has some influence on the stretch characteristics of warp knit structures. The full strain of warp knit fabric with in-laying yarn is up to 40 times larger than the full strain of fillet warp knit fabric.

5 CONCLUSION

The array of data for the various design options provide analytical tool for making comparisons about the physical, structural and mechanical properties of the warp knit fillet structures. It is observed that the position of in-laying yarn has some effect on stretch characteristics of warp knit structures. The position of in-laying yarn provides good stability in the fabric structure which improves with the amount of wrapping. Thus, the different positions of the inlaid yarn within the structures offer other possibilities that could be explored when designing fillet warp knit auxetic structures.

References

[1] UGBOLUE, S C, et al. The formation and performance of auxetic textiles. Part I: theoretical and technical considerations // *Journal of the Textile Institute*, 1754-2340, Volume 101, Issue 7, 2010. – P.660 – 667
[2] UGBOLUE, S C, et al. The formation and performance of auxetic textiles. Part II: geometry and structural properties // *Journal of the Textile Institute*, 1754-2340, Volume 102, Issue 5, 2011. – P. 424 – 433
[3] UGBOLUE, S C, et al. // 45th International Congress International Federation of Knitting Technologists (IFKT) Ljubljana, *27-29 May 2010. Symposium proceedings*. – P. 984-993
[4] SHALOV I., DALIDOVICH A., KUDRYAVIN L. *Knitting technology*. – Moscow: Legprombytizdat, 1986. – 376 p.
[5] UGBOLUE, S C, et al., The Formation and Performance of Auxetic Textiles, *NTC Project F06-MD09*, National Textile Centre Annual Report, September 2007.
[6] UGBOLUE, S C, et al.,, The Formation and Performance of Auxetic Textiles, *NTC Project F06-MD09*, National Textile Centre Annual Report, November 2008.
[7] UGBOLUE, S C, et al., The Formation and Performance of Auxetic Textiles, *NTC Project F06-MD09*, National Textile Centre Annual Report, October 2009.

Corresponding author:

Olena KYZYMCHUK
Department of knitting technology
Kyiv National University of Technologies and Design
2 Nemirovicha-Danchenko str.
Kyiv, 01011
Ukraine
Phone: (+38) 0442562135
E-mail: kyzymchuk_knutd@ukr.net

Co-author:

Samuel C UGBOLUE, Ph.D
Department of Materials and Textiles
College of Engineering, University of Massachusetts Dartmouth
285 Old Westport Road
North Dartmouth
MA 02747, U.S.A.
Email: sugbolue@umassd.edu