

THE PRINCIPLES OF HEXAGONAL CELL FORMATION IN WARP KNITTED FABRIC

Olena Kyzymchuk and Inna Ermolenko

*Kyiv National University of Technologies and Design, 2, Nemirovich-Danchenko str., Kiev, 01011, Ukraine
Kyzymchuk_knutd@ukr.net, Kyzymchuk.o@knutd.com.ua*

Abstract: Mesh fabric is widely used for different purposes especially in the technic and medicine. Warp knitting with its fillet interlooping is the most common technology for mesh production. The vast majority of fillet structures has typical mesh macrostructure and provides the wide range of cell's shapes and sizes, which affect the physical-mechanical properties and basic density of knitted fabric. It's possible to change the cell's size from the minimum to the maximum at a constant shape and constant technological conditions of knitting in warp knit fabric with hexagonal cells that is preferred for technical textiles. For this reason, the two tasks have been solved in this research: to establish rules of the hexagonal cells formation in the fillet knit structure and to determine the factors that influence the cells size.

The basic principles of formation of hexagonal cells in fillet warp knitted structures have been formulated in this article as a result of the theoretical analysis of geometrical models. The analytical dependences of the cell's size on the number of tricot and chain courses in the interlooping repeat and of the cell's square on the width and height of cell have been defined based on experimental data. They confirm the theoretical positions of this research.

Key words: Fillet interlooping, hexagonal cell, warp knitting, tricot loop, chain loop, cell size

1 INTRODUCTION

Mesh fabric is widely used for different purposes especially in the technic and medicine [1, 2] such as geotextile grid, agro mesh and nets for fishing, filtering and packaging materials, as well as finishing materials in the automotive, shipbuilding and aircraft industries. Scrim and personal protective equipment are very important military applications for knitted mesh now.

It should be noted that warp knitting with its fillet interlooping is the most common technology for mesh production. In fillet structure, there exist no links between separate neighboring wales in one or several courses in succession [3]. The vast majority of fillet structures has typical mesh macrostructure and provides the wide range of cell's shapes (diamonds, hexagons, etc.) and sizes, which affect the physical-mechanical properties and basic density of knitted fabric.

Fillet knit can be divided on one, two or three guides' structure depending on number of guide bars that take part in manufacturing of fabric [4]. Prof. L. Kudryavin and prof. I. Shalov [3] proposed to classify the fillet structures depending on the number of guide bars, their drawing-in and underlapping movements on the following types: simplest, simple, combined and complex.

It is interesting to consider the possibility of creating a specific cell's shape in the each type of fillet knitted structure. So by the using one guide bar and simplest fillet interlooping it's possible to create

triangular (Figure 1a) and quadrangular configuration of cells. By the using two guide bars (simple and combined fillet interloopings) square (Figure 1b), hexagonal (Figure 1d) and diamond-shaped (Figure 1c) cells are formed. Rectangular cells (Figure 1f) are formed by using three guide bars one of which is inlaying extra weft yarn for connection the vertical ribs. Thus, mesh fabrics with cells of various shapes can be produced with fillet interlooping [4].

Today the more important issue in mesh production is a creation the structure with cells which sizes can be changed easily. In fillet warp knitted structure, the cell that is formed by wales interconnected by loops or segments of filaments have the limited size [5, 6]. It is well known that at the same interlooping the cell's size depends on the gauge of knitting machine, type and linear density of the yarn or filament and technological condition: yarn tension of each guide bars and drawing-out force. Moreover, at the same technological conditions of knitting the cell's size can be varied by the interlooping repeat.

The fillet knit structure that is formed by a combination of tricot and t-tricot loops is showed on Figure 1d. The shape of the cells is similar to the hexagonal honeycomb [3]. It is obvious that an increasing of the number of tricot courses results in lengthening of vertical ribs of the cell and the cell's elongation. From the other side an increase of the number of t-tricot courses results in growing the areas where the wales are linked, so the distance between cells walewise increases too.

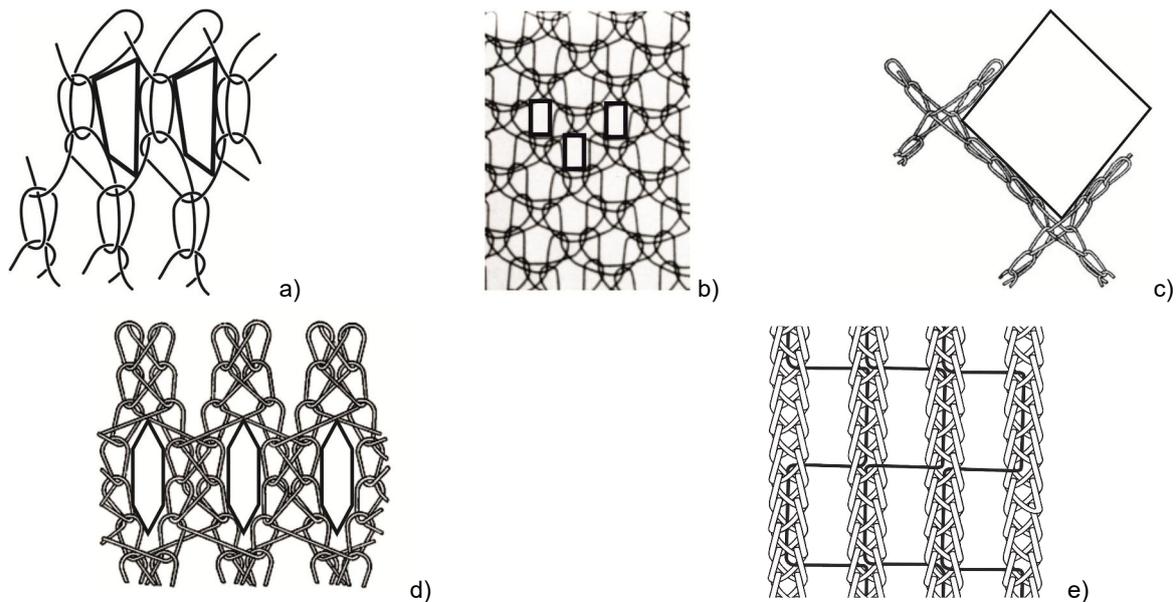


Figure 1 Fillet knitted structures

Knit structure of combined fillet interlooping that is formed by alternating of chain and tricot courses is shown at Figure 1c. Such structure is used for manufacturing knotless knitted nets with cells of unlimited dimensions [3]. In this knitted structure, the knots are formed by mutually crossed tricot closed loops and the carcasses are formed by chain loops. It is obvious that an increase of the number of chain courses in the repeat leads to extension of the cell's rib and the cell's size increases too, but cell's shape is constant

It's possible to use the same principles for changing the cell's size from the minimum to the maximum at a constant shape and constant technological conditions of knitting in warp knit fabric with hexagonal cells that is preferred for technical textiles. For this reason, the two tasks have been solved in this research: to establish rules of the hexagonal cells formation in the fillet knit structure and to determine the factors that influence the cells size.

2 THEORETICAL PART

Cell's shape primarily depends on the shape and size of loops, their combination and mutual position in the knitted structure. At the equal conditions, the size and shape of single loop of warp knit depend on the type of loop and the positioning of the skeleton and the junctures that was analyzed in detail by Moiseenko [7]. He found that width of closed loop with one-sided arrangement of junctures increases and its height is reduced as a result of elastic forces of bent filament. In the knitted structure that is formed by one full set yarn's system, the skeletons of closed loop are inclined in relation to the wales in the opposite direction to the junctures position. The degree of loop inclination

increases with the yarn elasticity and density of knitted fabric. Furthermore, in such structure loop's skeletons can be rotated from the frontal plane of knitted fabric to the perpendicular plane depending on the junctures' lengths. In the matter of open loops with two-sided arrangement of junctures, it was investigated [7] that skeleton's width decreases and its height increases. In the knitted structure, the open loops are inclined in the opposite direction to outgoing juncture. In general, the open loop has a smaller slope in the frontal plane of the fabric and does not rotate to the perpendicular plane of the fabric.

However, such arrangement of loops is characteristic for the single warp knitted structure that is produced with one full set guide bar. Fillet interlooping has following features of manufacturing: the using of multiple systems of threads, the partial drawing-in of guide bars, and the presence of few different types of loops in the interlooping repeat (open and closed with different junctures length). Therefore, it is advisable to consider the shape and position of each loop in the repeat of fillet structure.

To achieve the mesh with hexagonal cells it is rational to use the fillet warp knitted structure [8] that is produced by using two guide bars with partial drawing-in and symmetric movement. The interlooping repeat is formed by alternating tricot and atlas courses [9, 10]. In this case, one set of yarn forms a closed tricot loops 1, 4 and 5 with one-sided arrangement of junctures and open tricot loop 8 with two-sided arrangement of junctures (Figure 2a). The second guide bar performs the symmetrical movement and forms similar closed tricot loops 2, 3 and 6 with one-sided arrangement of junctures and open tricot loop 7 with two-sided arrangement of junctures.

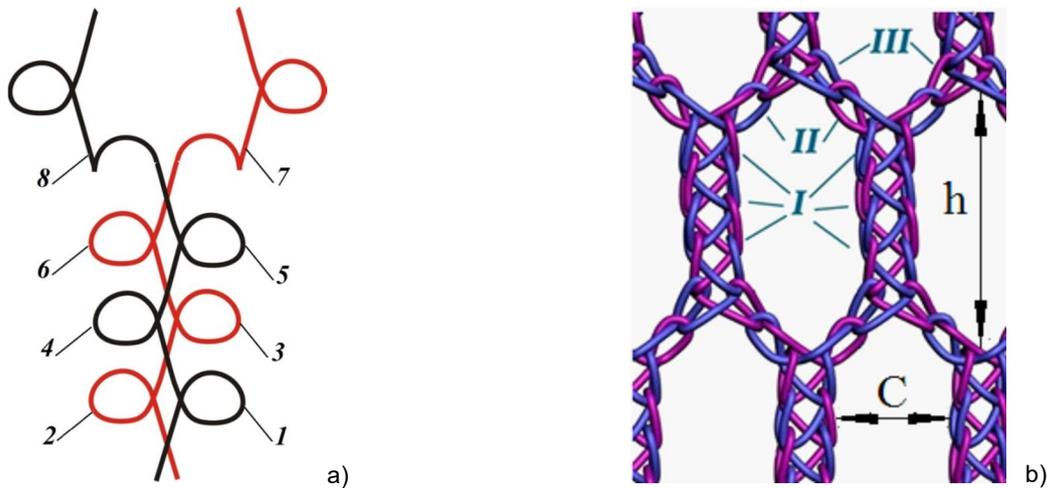


Figure 2 Fillet structure with hexagonal net

The inclination of the closed tricot loop 1 is prevented by the closed tricot loop 3 of the next course. The pressure force of loop 3, so there is no general inclination of loop 1 in the plane of the fabric. The same force balance is between closed loops 3 and 5. Therefore, the closed tricot loops 1 and 3 as well as closed tricot loops 2 and 4 are positioning vertically in the knitted structure (type I, Figure 2b). Nevertheless, skeletons of those loops are rotated in a perpendicular plane, so that we will see only one of the arms in the frontal plane of fabric. These loops of type I form the vertical ribs of cells.

The closed tricot loops 5 and 6 are followed by the open tricot loops 7 and 8 at the next course that is why there is no similar balances of forces. The skeletons of closed loops 5 and 6 are inclined in an opposite direction of junctures positions. Thus, tricot closed loops 5 and 6 (type II, Figure 2b) are arranged obliquely at the beginning of diagonal rib. The forces balance in open loops 7 and 8 are caused with a smaller inclination of the loops skeleton. Therefore, these loops are turned in the same direction as the previous loops 5 and 6. That is the loops 7 and 8 (type III, Figure 2b) also placed obliquely in the knitted structure and form the diagonal ribs of cell.

Such positioning of loops in the mesh knitted fabric

forms the vertical and diagonal ribs of hexagonal cell (Figure 2b). The cells size can be easily changed without changing its hexagonal shape by adding additional courses of tricot loops or/and chain loops into an interlooping repeat.

The Increasing the number of tricot courses in the repeat leads to cell extension in vertical direction. These tricot courses consist of closed loops with one-sided arrangement of junctures that positioned in knitted structure vertically. Addition chain courses in the repeat leads to extension of diagonal ribs of hexagonal cell. Consequently, the cell is extended: lengthened and widened. These open chain loops (type V and VI, Figure 3) are positioned obliquely in a structure similar to the tricot loops in previous course.

It should be noted the open chain loops are mirror positioned if there are two or more chain courses in the repeat. The outcoming junctures are placed in alternating left and right [11]. Next regularity in alternation of loop types have been revealed during investigating the fillet warp knitted structure. The followed tricot course is formed by the closed loops (type IV, Figure 3a) if interlooping repeat consists of odd number of chain courses and the followed tricot course is formed by the opened loop (type III, Figure 3b) if the interlooping repeat consists of an even number of chain courses.

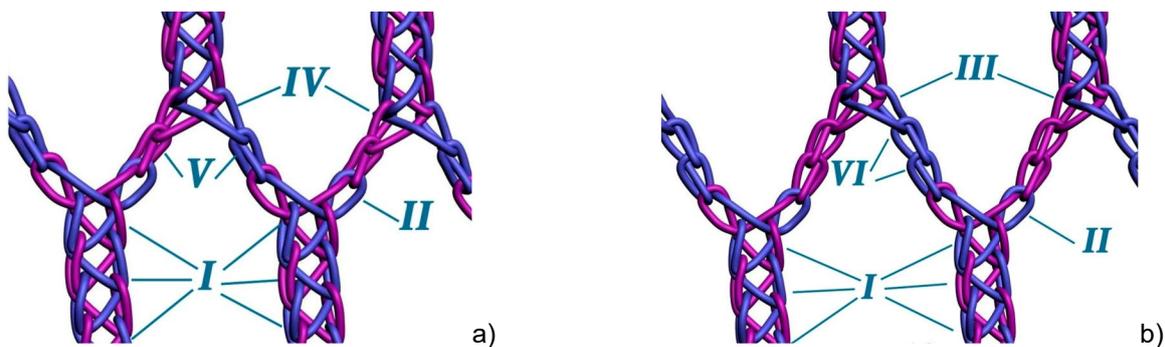


Figure 3 Extension of diagonal rib

The main principles of hexagonal cell formation in warp knitted fabric have been formulated as a result of geometrical modeling of mesh knitted structure:

1. Fillet interloping formed by alternating tricot and chain courses in the repeat and produced using two guide bars with partial drawing-in (1 in, 1 out) and symmetric movement is recommended to achieve the mesh with hexagonal cells.
2. The incoming and outgoing junctures are positioning beside on loop's arc, if next course is formed by closed loops, and the incoming juncture is positioning behind outgoing juncture on loop's arc, if next course is formed by closed loops.
3. Closed tricot loop with one-sided arrangement of junctures is positioned vertically and forms vertical rib of cell if the loop at the next course is the same tricot loop, which formed by yarn from other guide bar.
4. Closed tricot loop with one-sided arrangement of junctures is positioned obliquely and forms diagonal rib of cell if the loop at the next course is open tricot loop or chain loop. They are positioned obliquely too.
5. If interlooping repeat has consisted of odd number of chain courses, the next tricot course is formed by the closed loops, and if the interlooping repeat has consisted of an even number of chain courses, the next tricot course is formed by the opened loop.

6. The tricot loops (closed and open) followed chain loops in the repeat are positioned obliquely in relation to the wale.
7. The Increasing the number of tricot courses in the repeat leads to cell extension in vertical direction. Addition chain courses in the repeat leads to extension of hexagonal cell as in vertical as in horizontal direction.

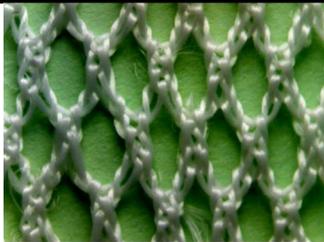
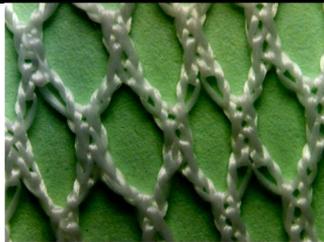
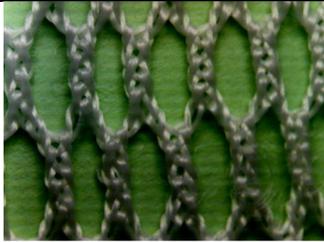
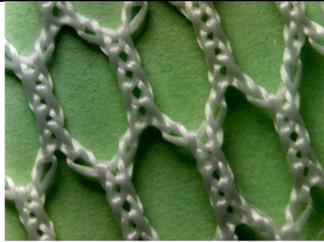
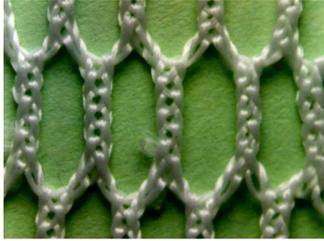
3 EXPERIMENTAL PART

Two-factors' experiment according Kono's plan have been planned and realized for investigation the cell's size in this research. As input factors were accepted: x_1 - the number of tricot courses n_t in the repeat 3, 5 or 7; x_2 - the number of the chain courses n_c in the repeat from 0 to 2. Nine variants of fillet warp knitted fabric with hexagonal cells were produced in accordance with this plan.

250 denier x 2 polyester yarns manufactured by Du Pont were used for fabric production on 10-gauge Muller Crochet Knitting machine (RD3MT3/630). This machine is equipped with latch needles and eight guide bars with electronic drive. Four bars can operate both with the "weft mode" and "knit mode" to obtain single-bed warp knitted fabrics.

Photos of fabric (Table 1) are shown that all variants of fillet warp knitted fabric have hexagonal cells. A boundary value of an angle between diagonal ribs is from 60' to 80'.

Table 1 Samples photos

Repeat	$n_c = 0$	$n_c = 1$	$n_c = 2$
$n_t = 3$			
$n_t = 5$			
$n_t = 7$			

The studies of cell sizes in the warp knit structure was performed by using a digital microscope Microsafe Shiny Vision MM-2288-5X-BN with minimum scale of 0.001 mm. 25 measurements for each of the studied parameters (width, height and square of cells) have been made.

The equations of regression (Table 2) have been established by the mathematical processing of experimental data. The equations are describing adequately the dependences between the cells sizes and the interlooping repeat.

The experimental results indicate that the width and height of the cell as well as its square depend on

the repeat of interlooping, as showed at the corresponding diagrams (Figure 4). Thus, simultaneous extension and enlargement of the cell occur by increasing the number of courses as tricot as chain in the repeat that leads to an increasing of cell's square.

Another interesting point is the studying of the effect of cell size on its square. The analytical dependencies that have been established in this research ($R^2 = 0.9$) describes the influences of width and height of cell on the cell's square. Graphics dependencies are shown on Figure 5.

Table 2 Equations of regression

Sell's size	In code parameters	In natural parameters
Width C [mm]	$Y_C = 2,56 + 0,35x_1 + 0,62x_2 + 0,30x_2^2$	$C = 1,37 + 0,17n_t - 0,01n_c + 0,30n_c^2$
Height h [mm]	$Y_h = 7,11 + 1,55x_1 + 1,95x_2$	$h = 1,27 + 0,78n_t + 1,95n_c$
Square S [sq.mm]	$Y_s = 10,59 + 4,00x_1 + 4,47x_2 + 2,76x_2^2$	$S = -1,08 + 2,00n_t - 1,10n_c + 2,79n_c^2$

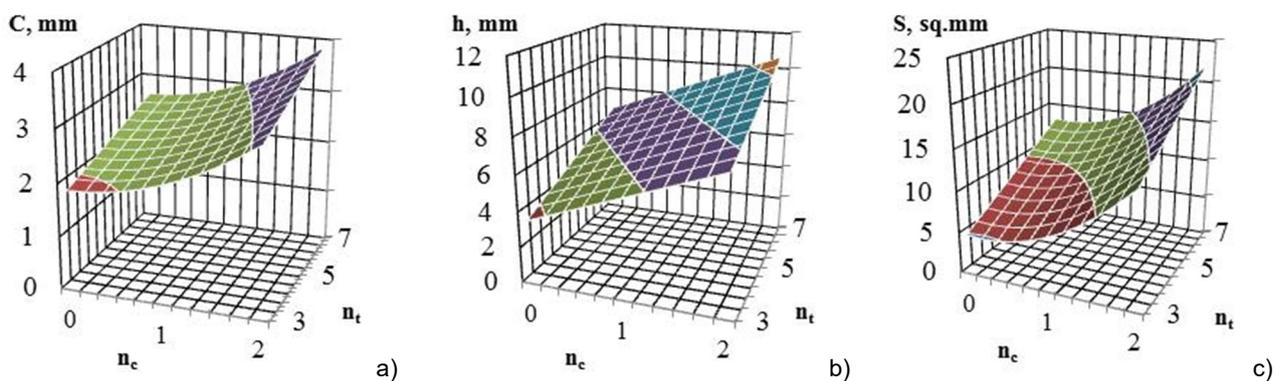


Figure 4 Dependences of cell's sizes on number of tricot and chain courses at repeat

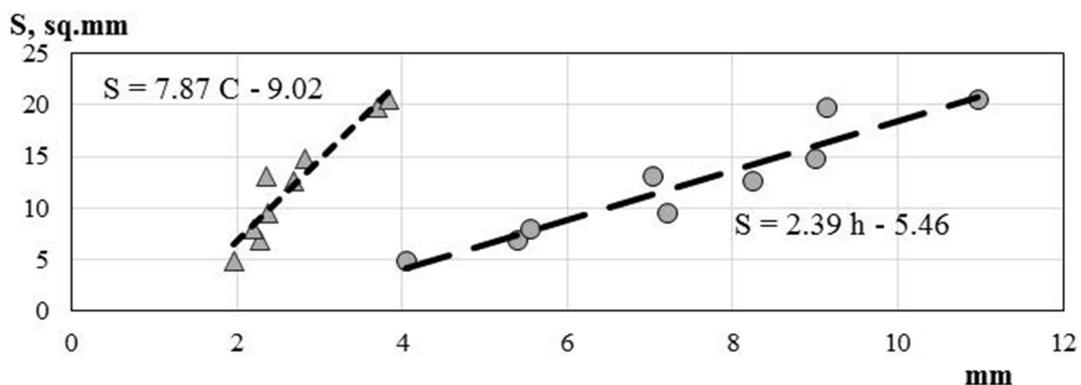


Figure 5 Dependences of cell's square on cell's size

4 CONCLUSION

The basic principles of formation of hexagonal cells in fillet warp knitted structures have been formulated as a result of the theoretical analysis. The analytical dependencies of the cell's size on the number of tricot and chain courses in the interlooping repeat and of the cell's square on the width and height have been defined based on experimental data. They confirm the theoretical positions of this research.

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