Investigation into the Curling Intensity of Polyester/Cotton Single Jersey Weft Knitted Fabric Using Finite Element Method

Shohreh Minapoor, Saeed Ajeli and Hossein Hasani

Abstract— **Curling of knitted fabrics edges is one of the complicated problems of these structures. Therefore, study and measurement of curling in knitted fabrics is important. In this study, it is tried to model the three-dimensional wale wise curl of the fabric using finite element modelling. In this model the tensions in different parts of a knitted loop due to bending and torsional forces in knitting process, is calculated numerically. The result of the FEM model is considered as a measure indicator of the curl loop. By applying the same conditions of loop deformation in all fabric samples, the accumulated force was measured. Developed force is defined as an indicator of the level of curling in the fabric and was compared with experimental results. The comparison between experimental results and the mechanical model is in good correlation.**

Keywords: Polyester/cotton yarn, knitted fabric, finite element method; curling force.

I. INTRODUCTION

One of the major problems in weft-knitted fabrics is curling of their edges. Since curling of the knitted goods can cause problems and waste production in sewing and finishing, the study and measure of curling of knitted fabrics, is important. Therefore, the study and measurement of curling of knitted fabrics and determining the factors affecting it has been considered by many researchers. Numerous studies have been undertaken to reduce this phenomenon in knitted fabrics. Doyle explained the curling behaviour of plain knitted fabrics using a structural model of the knitted loop [1]. Munden justified the curling behaviour of plain knitted fabrics by providing a three-dimensional model for a plain knitted structure [2]. Davis and Owen studied the tendency to curl in warp-knitted fabrics [3]. The results of their research showed the bending hysteresis curve of warp-knitted fabric is asymmetric. The movement of bending hysteresis curve's center for warp-knitted fabric compared with woven fabric, was called curling couple. Hamilton and Postle also analysed the curling behaviour of single jersey weft knitted fabrics using its bending hysteresis curve [4]. The distance between curve's centers for unrelaxed and wet-relaxed fabric was investigated as curling couple about the course and wale directions. Bühler et al. proposed a method for measuring the curling of edges of plain knitted fabrics [5]. Ucar predicted curling distance of dry-relaxed cotton plain knitted fabrics, using the multiple regression analysis [6]. The ratio of yarn diameter to the loop length, the moment on a single loop with the influence of yarn bending rigidity and the ratio of moment of mass inertia of a single loop to the moment on the single loop has been included in regression analysis. Kurbak and Ekmen offered a geometric model for the cross curling of plain knitted fabrics [7]. Ajeli et al have also examined the effect of yarn and fabric parameters on the curling of weft and warp knitted fabrics [8, 9].

Due to the complexity of fabric's structure behaviour during deformation, today, the vastly used methods of modelling such as finite element method are used to study the mechanical behaviour of different types of fabrics. In mathematics, the finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. Nasr-Isfahani et al set forth a non-linear, explicit, three-dimensional finite-element code in ABAQUS 6.4 software to simulate the response of plain-woven fabric under high-speed projectile impact [10]. Gan predicted deformation of fabrics using the nonlinear finite element method associated with a shell element [11]. Knag and Yu also analyzed drape of woven fabrics with finite element method [12]. Tarfaoui and Drean estimated the stress-strain behavior of woven fabrics via FEM [13]. A unit cell of plain-knitted fabric in a series of studies, using finite element analysis, was presented by Loginov et al [14]. The aim of this paper was to generate new models of the

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mechanical behaviour of knitted fabrics in quasi-static deformation from an initially relaxed state to the extended state. Kallivretaki et al was modeled the deformation of warp-knitted fabric via ANSYS software [15].

The edge curling of plain weft-knitted fabrics has not yet been investigated using the finite element method. The aim of this study was to provide a mechanical model by calculating the internal forces in a loop that make the loop to move out from the fabric plate, or in other words, that causes the curling phenomenon. In this model the tensions in different parts of the knitted loop because of bending and torsional forces in the process of forming a loop is calculated and compared with experimental results as an indicator of the level of curling in the fabric.

II. Experimental and Method

For measuring curling intensity, curling test was done five times on three plain knitted fabrics with the same density. Yarns with same blend type and twist factor but different yarn counts were spun on a conventional ring spinning machine (Howa, U32606) for producing these fabrics on a single jersey circular knitting machine. Details of yarns, fabrics and knitting machine used in this study are shown in Table I, II and III. It should be noted that the number of test repeats for yarn count and yarn TPM (Twist Per Meter) was 3 and 5 respectively.

TABLE I
THE YARN CHARACTERISTICS

No.	Material	Nominal yarn count *(Ne)*	Twist factor (α_e)	Measured yarn count *(Ne)*	Measured TPM
1	50P/50C	20	3.75	19.7	640.8
2	50P/50C	25	3.75	24.6	728.8
3	50P/50C	30	3.75	28.5	736.8

P: Polyester
C: Cotton

TABLE II
THE YARN CHARACTERISTICS

Fabric code	Fabric structure	Yarn count *(Ne)*	Density *(course/cm)*	WPC	CPC	Thickness *(mm)*	Weight *(g/m^2)*
1	Plain	20	10.5	10.0	11.0	0.49	158.3
2	Plain	25	10.5	11.0	11.0	0.45	136.4
3	Plain	30	10.5	10.3	10.3	0.39	103.4

TABLE III
THE YARN CHARACTERISTICS

Company	Model	Number of feeders	Gauge (Needle per inch)	Diameter of cylinder (Inch)	Feeding type	Needle type
Falmac	FSB3XSK	48	24	16	Positive	Latch

For preparing the samples for testing the curling, the fabric was cut as 70*40 *cm* dimensions. According to proposed method by Buhler [5], the sample was put on a smooth surface without any wrinkles. Four sides of the sample fabric was kept by a frame of glass that is consists of five slots for cutting the sample by blade as exemplified in Figure 1. After removing the frame, the cut parts, which have a length of 10 *cm*, were curled as shown in Figure 2. The distance between the two curled edges in each cut, is the curling distance of sample that were photographed using a digital camera. Then using image processing techniques, the curling distance was measured. To obtain a good and same image of the samples, the experiments were conducted in a same location and light intensity; to eliminate the camera lens error, an indicator object was used in photos as Minapoor et al (2013) were explained.

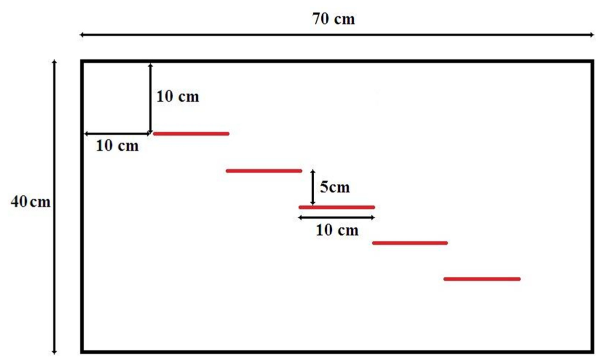

Fig. 1. Schematic of glass frame and the slots on it.

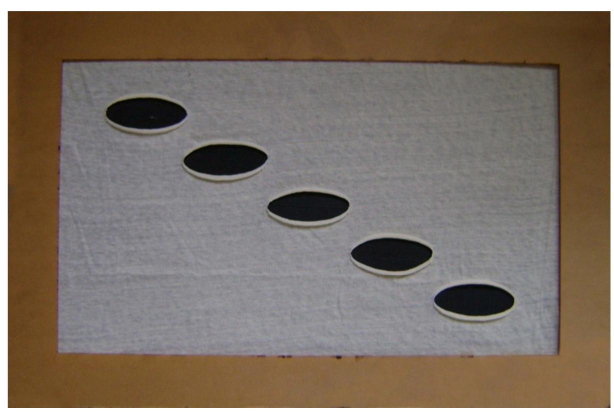

Fig. 2. Curled edges after removing the frame.

Regarding more impact of the yarn number due to cut two legs of the loop in the course direction, wale wise curling is considered in this research. The curling distances for fabrics are shown in Table IV.

TABLE IV
RESULTS OF CURLING MEASURMENT

Fabric code	Curling distance (cm)	
	Mean	CV%
1	1.65	0.03
2	2.08	0.05
3	2.22	0.02

A. Finite Elements Simulation

Curling of the knitted fabric edges is caused by the release of stored energy in the fabric during the formation of the loops. Hence, given the complex nature of the fabric, the finite element method was used to model the curl loop level of the fabric.

Geometry, physical and mechanical properties of the loop was defined according to the geometry and properties of the yarn and samples with plain knitted structure. Then, after applying the same conditions for formation of loops in all samples, the present force in the loop was measured. This force was considered as an indicator of the curling level in the fabric and was compared with experimental results.

In this mechanical model, for formation of a loop, the straight yarn is bent due to the bending force and the two-dimensional elastic shape (in the xy plane) which is seen in Figure 3, is formed. For this purpose, the two ends of the yarn (as circular rod) applied the same displacement but in the opposite direction. Then the loop is under the second bending force perpendicular to the plane. Crossing the next course's yarn inside the loop, bends its head in the z plane and results the two legs torsion; this makes the three-dimensional structure of loop in the knitted fabric. Therefore, in the second step, two basements of the legs in the place of yarn link with the head of the previous course's loop were fixed, and the displacement in the z direction is applied with respect to the actual condition of the loop structure in the fabric to form the three-dimensional structure of the loop as shown in Figure 4. Tensions in the loop that makes return to its original shape during the curling, is the total tensions in the second step of bending. This tension is the indicator for fabric curling force.

To model the loop, Finite Element software (ABAQUS version 6.8) is used. The geometry and attributes similar to the geometry and properties of loops in the plain knitted samples are used. Yarn linear density is considered according to the mean of the actual measured values of the yarn samples. The loop length and density values of the model for the three loops are considered the averaged loop length in the fabric and averaged density of cotton-polyester fibers obtained by a Mettler–Toledo densitometer (USA, Columbus, Ohio) Using Archimedes′ Principle. Also, Young's modulus is considered the mean of the actual measured values of the samples and Poisson's ratio get, its mean value for cotton and polyester fibers used by Peel and Jensen. Geometrical and mechanical properties of yarns in loop models are shown in Table IV. The loop geometry is defined as a rigid deformable bar of "sweep" type in three-dimensional space. The diameter of yarn is used for formation of the cross-section of the structure, and the loop length, in terms of millimetres, is used for drawing its direction. Also, the material behavior is assumed elastic.

TABLE V
RESULTS OF CURLING MEASURMENT

Model code	Yarn diameter *(mm)*	Loop length *(mm)*	Density *(g/cm^3)*	Young's modulus *(10^9 N/m^2)*	Poisson's ratio
1	0.2	4	1.37	3	0.36
2	0.18	4	1.37	3	0.36
3	0.16	4	1.37	3	0.36

The post-buckling solution (Explicit Static General Method with nonlinear geometry) and three-dimension solid element are considered for this analysis. The element type of C3D8R was chosen for mesh. The C3D8R element in ABAQUS/CAE is a reduced-integration eight-node brick element with hourglass control. For all models, the initial conditions, is fixed the ends of the bar in y and z directions. In loading step, 1.5 mm displacement was act to the both ends of the bar in the x direction and in the opposite sides. The loop models of three plain knitted fabrics are created and named model 1, 2 and 3 according to fabric codes. The formed shapes of two-dimensional loops are shown in Figure 3.

Then after fixing the yarn ends, the head of the loop is under the same displacement of 0.4 *mm*, in the *z* axe direction and 0.6 *mm* in the *y* axe direction. The final three-dimensional shape of the loops is shown in Figure 4. As is expected, the maximum stress is in two legs of the loop, and the legs tend to return to their original shape after releasing loop from the adjacent loops. Therefore, the reverse amount of stress in the resistance will affect in the curling of the fabric structure.

The maximum tensions for formation of the three-dimensional loop modelled for fabric types are 0.337, 0.242 and 0.168 (GPa) respectively.

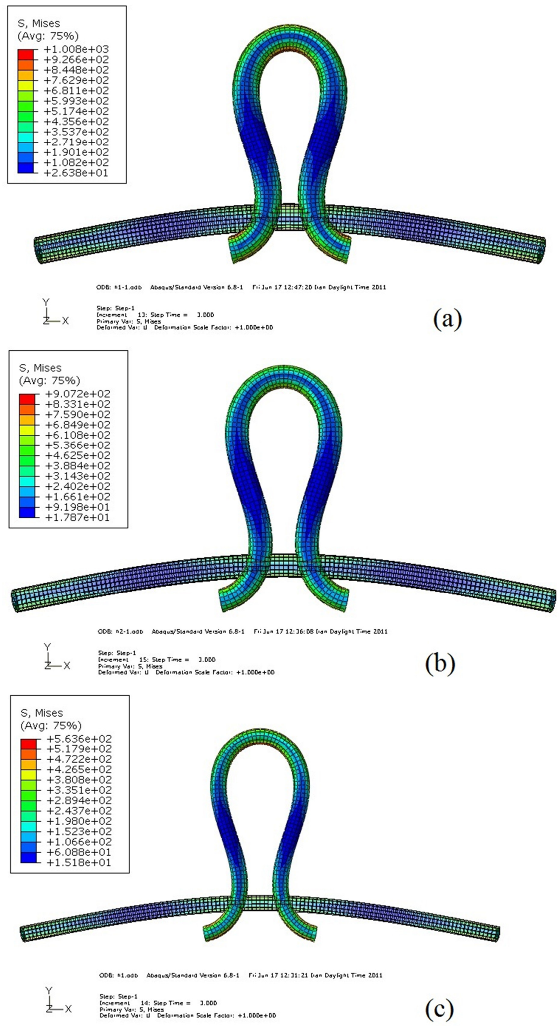

Fig. 3. The two-dimensional loops formed in the loop model (a) 1, (b) 2 and (c) 3.

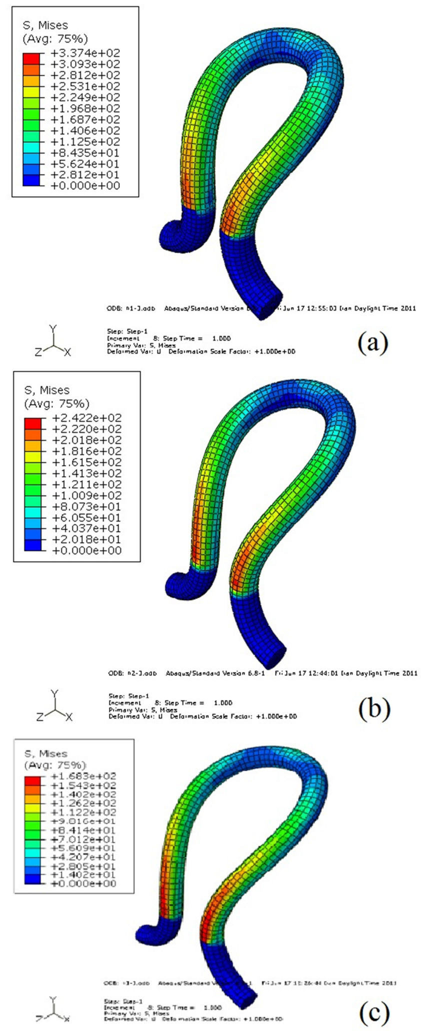

Fig. 4. The three-dimensional loop formed in the loop model (a) 1, (b) 2 and (c) 3.

III. RESULTS AND DISCUSSION

As is clear, the yarn count is related with its diameter, and the diameter has a high impact on the flexural and torsional stiffness of the yarn, therefore, by increasing the diameter of the yarn, its flexural and torsional rigidity increases and the force needs to curl the loops increases. On the other hand, increasing the diameter of the yarn increases the contact surface between yarns in the fabric structures and will increase the friction and decrease the curling distance. According to the experimental results, yarn diameter increase lead to curling distance decrease. So, the dominant role of increased friction by increasing the yarn diameter is evident. According to the model results, as the yarn diameter increases, the force required bending the loop and as a result, the stress in loop increases. This is because only one loop was modeled and the role of friction between loops in the fabric wasn't considered in this model. So, comparing the process of decreasing curling distance and reversed stress by increasing yarn diameter are shown in Figure 5 and 6. Good correlation in decreasing process based on the experimental and the model results can be seen.

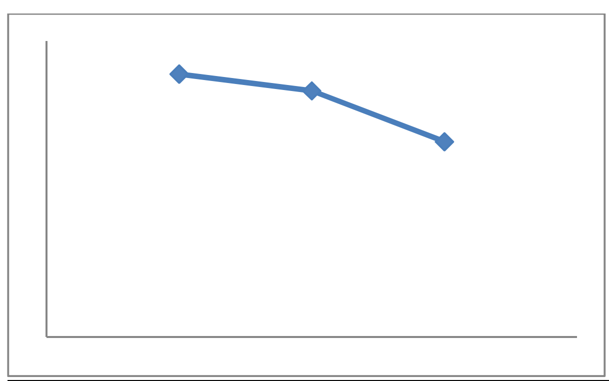

Fig. 5. Comparison results of samples curling distance in various yarn diameters

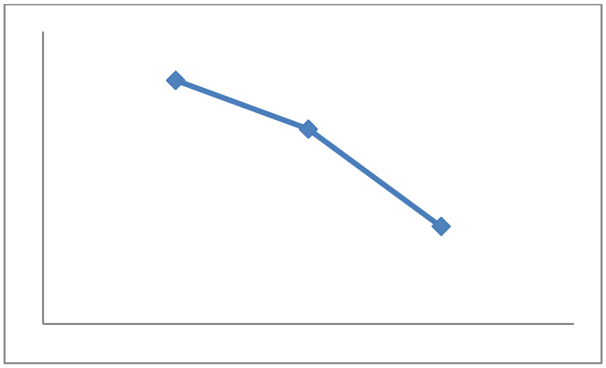

Fig. 6. Comparison model's results of reversed stress in various yarn diameters

IV. CONCLUSIONS

One of the major problems of knitted fabrics is curling of their edges. In a knitted structure, after changing the straight yarn to a loop form which is associated with bending and twisting yarn during knitting operation, the residual inner force in the produced fabric is stored. These forces can cause the edge to get up out of the fabric plane as well as deformation and curling. This phenomenon, in the sewing operation of fabric can cause problems and producing wastes, therefore, study and measurement of curling in the knitted fabrics is important. In this research, to understand more detailed analysis of curling phenomenon, the loop of plain weft-knitted structure was modelled using the finite element method in three dimensions. The results of the tension on the yarn in formation of the loop in this model were considered as an indicator for curling of the fabric. Also, by some experimental tests, the curling amount of the fabric structure was measured. By comparing the results of the tests and provided FEM model a good correlation was observed between the obtained results. Based on the results of the experiments and the model, by reducing the diameter of the yarn, tension forces created in the model are reduced. This model makes it possible to study the yarn and fabric structure parameters like as yarn type, fiber type, fiber tightness factor and etc on curling intensity.

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