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Numerical modeling of bagging behavior of plain weft knitted fabric using finite element method

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This study focuses on the applicability of finite element method to analyze the bagging behavior of plain single jersey weft knitted fabrics in the term of bagging resistance. The findings show that the numerical modeling of the bagging resistance of the plain knitted fabric using solid elements and yarn transverse Isotropic properties has good agreement with experimental values.

Keywords: Finite element method, Bagging resistance, Plain weft knitted fabric, Numerical modeling

Bagging is a permanent deformation of garments seen at places like knees and elbows, in which the repeated deformation are caused by moving parts of the body and leads to the deterioration in the appearance of the garments. Several methods have been developed to determine the bagging behavior of woven and knitted fabrics[1-7]. Most publications have focused on measuring the residual bagging height and the related fabric mechanical properties. Zhang *et al.*[2-4] measured the bagging height of woven fabric using an Instron tensile tester and predicted the bagging height of woven fabric as a function of bagging resistance and bagging fatigue. Yokura *et al.*[7] predicted the bagging volume of woven fabrics from in the term of the mechanical properties of the fabrics using the KES-FB system. Doustar *et al*.[8] investigated the effect of weave design and fabric weft density on the bagging behavior of cotton woven fabric in terms of fabric mechanical properties using FAST system. Yeung and Zhang[9] developed a method to evaluate the garment bagging by image processing with different modeling techniques. Zhang *et al.*[10] also developed a mathematical model to simulate the rheological behavior of fabric bagging. This model was based on the assumption that stress-strain relationships in fabrics consist of three essential components including the elastic deformation, viscoelastic deformation, and the friction between fibers and yarns within the fabric structure.

Due to structural differences, the bagging behavior of knitted fabrics is different from woven fabrics. Uçar *et al.*[11] studied the relationships between residual bagging height obtained from the bagging test and the fabric mechanical properties measured by the KES-FB system. They predicted residual bagging height for knitted fabrics using the standard KES-FB test, without performing fabric bagging fatigue tests. Jaouachi *et al.*[12] predicted the residual bagging height of knitted fabrics using fuzzy modeling and neural network methods. Hasani and Hassanzadeh[13] predicted the bagging fatigue percentage of knitted fabrics produced from viscose/polyester blended rotor yarns by considering the blend ratios and structural cell stitch lengths as predictor variables. In other investigation, Karimian *et al.*[14] studied the effect of yarn and fabric parameters on the bagging behavior of weft knitted fabrics in term of bagging fatigue percentage.

Numerical simulation of bagging phenomenon will be useful to predict the mechanical behavior of the fabric without performing any test for fabrics. This method has been used in different studies to predict the mechanical behavior of the textile fabrics[15-18]. In order to simulate the bagging test, Zhang *et al.*[6] investigated the effect of fabric anisotropy and the friction between woven fabric samples and the rigid bagging ball by using the finite element method. They reported that the fabric anisotropy and the friction affect non-uniform distribution of deformation energy during fabric bagging process. But the application of this method to analyze the bagging behavior of weft knitted fabrics has not been reported in the literatures.

To reach to this aim, this study was undertaken to investigate the applicability of finite element method to analyze the bagging behavior of plain single jersey weft knitted fabrics.

Experimental

Sample preparation

In order to prepare the knitted samples for bagging test, 1468 den polypropylene yarns with 111 twist/m

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were fed to the Stoll flat knitting machine (E5, CMS400) to produce plain single jersey weft knitted fabrics. The only variable parameter considered during the samples production was stitch density. The characteristics of samples with two different stitches are given in Table 1.

The apparatus used for bagging test is schematically shown in Fig. 1. Circular knitted samples with 110 mm diameter were prepared and placed into the clamp with 56 mm diameter. The samples were then deformed using a steel ball with a diameter of 48 mm attached to the Instron tensile tester. Bagging height of 21 mm, corresponding to approximately 25% elongation at a cross-head speed of 20 m/min was applied[19]. The bagging deformation were repeated five times for a particular sample and the bagging resistance was measured according to the following equation:

$$\text{Bagging resistance} = \frac{\text{Work of first cycle of loading (J)}}{\text{Sample weight (g/m}^2\text{)}} \quad \dots (1)$$

Finally, the average of seven measurements was reported as a result.

Table 1—Characteristics of knitted samples

Loop length, mm	Weight g/m^2	Thickness mm	Courses/ cm	Wales/ cm	Structure	Fabric code
13.5	230	1.73	2.7	3.4	Plain	K
9.5	410	1.75	3.8	6	Plain	P

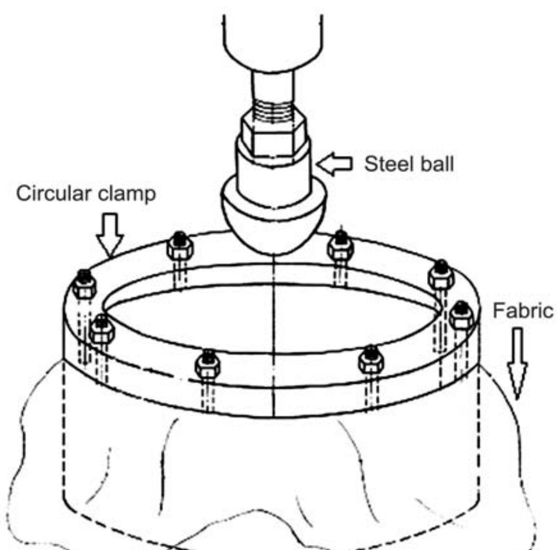

Fig. 1—Schematic drawing of bagging test principle (ref. 14)

Modeling

Since the knitted fabrics are subjected to a large number of deformations during the bagging test, it could be effective to use the MESO fabric modeling in terms of the yarns properties for investigating the behavior of fabrics while bagging in occurred. MESO requires a geometrical shape of a fabric unit for model optimization. Three-dimensional geometrical model of Vassiliadis ***et al.*** [20] was used for modeling.

A program was created in MATLAB software based on the mentioned model and governing equation in relaxation condition. Entering wales and courses distance and yarn diameter as input data, the program obtained three dimensional dots coordinates. Plain loop modeling is feasible through solid and wire elements.

Using CATIA software, a solid loop and consequently a complete course of the fabric modeled by repeating one loop were achieved [(Fig. 2(a)]. Considering the small strain condition, it was assumed that the yarns of knitted loops reveal the elastic behavior during the bagging deformation. Although the yarn was considered homogenous elastic, its length and cross section properties were not alike after deformation. Thus, transverse isotropic is the best term to describe the real behavior of yarn.

In order to define the condition of yarns at loop intersection points, the yarn-to-yarn frictions coefficient should be determined. Experimental results also show that there is a frictional coefficient about 0.41 between the yarns in knitted samples. It should be noted that a fixed coordinate system cannot be useful

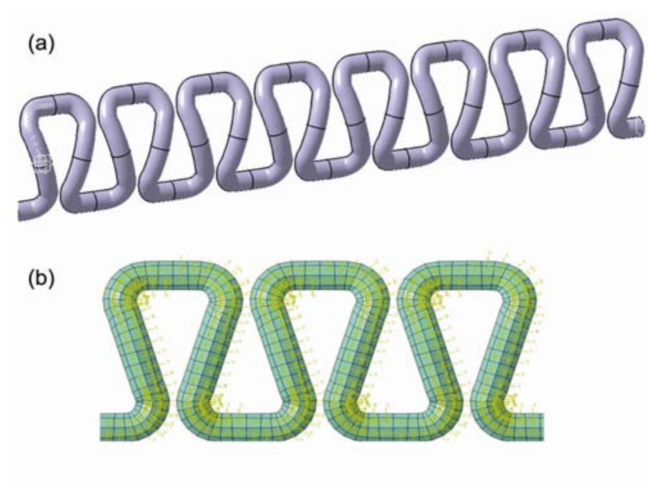

Fig. 2—Modeled knitted loops (a) complete course modeled in CATIA software, and (b) mesh-like structure of loops derived from the python program

to present the yarn position on any point because of the three-dimensional shape and rotation of the knitted loop. Thus, coordinate system must be flexible and tailored to any desired point on the yarn used. For this reason, a mesh-like structure was created for the loops of the knitted fabrics. After the geometrical design, meshing phase is a stage of great significance for the accuracy of the simulation; since it presides over the success of the load transfer as well as the stress and strain distribution. Usually the definition of the type of finite elements, the mesh density and the pattern of the mesh arise from the experience obtained by a series of tests. Particularly, the role of the mesh is o distribute evenly the stresses and strains among the finite elements.

A Fine mesh provides obviously a more even distribution than a coarser one. On the other hand, the finer the mesh the higher is the computational time required for the solution. So each course is meshed to 3753 finite elements of different sizes. Subsequently, a script was written with python program to define coordinates for each element with its transverse isotropic. An example of the program output is demonstrated in Fig. 2(b).

In the bagging test, considering that all segments have symmetry planes, it is sufficient to model only half of the procedure in order to decrease the amount of calculations. In this model, according to Fig. 3(a), the places in which the samples contact with circular clamp were defined as rigid elements and the other parts were defined as deformable ones. Since remarkable momentary changes occur on contact surfaces while the fabric is being deformed with the high change rates, the analysis of this research is provided with dynamic explicit method. Thus, a full Newton-Raphson solution procedure was implemented for the analysis.

Conditions such as $U_X=UR_Y=UR_Z=0$ were defined on boundary elements on the plane with x=0 to make the whole attainable fabric simulation. All degrees of freedom were also restricted in fabric-holder contact place ($U_X=U_Y=U_Z=UR_X=UR_Y=UR_Z=0$). The steel ball displacement was responsible for experimental loading and its movement in perpendicular direction of fabric plane was determined as 21 millimeters. The accuracy in analyzing the results is affected by the mesh creating process as well as the accuracy definition of force transfer, stress and strain distribution through the fabric structure. This analysis covers two wire and solid elements. Due to large number of loops in this model, big meshes were used.

The ratio of cross-sectional diameter to length of the loop yarn was less than 0.1 in this model. Therefore, solid element was replaced by wire one in this model. The fabric modeled via wire element is illustrated in Fig. 3(b). Transverse isotropic properties cannot be defined for the yarn in this model. As a result, homogeneous elastic properties were allocated to elements. Circular cross-section and cross-section direction were determined for elements. The rest of wire modeling procedure was carried out like the previous one.

In the wire model of the bagged knitted samples, a faster and easier analysis would be applied compared to the proposed solid model due to the fewer number of knots. Yarn elongation and stress distribution in different parts of the loops in a knitted sample are computable and provided in Figures 4(a) and 4(b) respectively. As it is illustrated, the loops cross-points are responsible for the highest amount of elongation

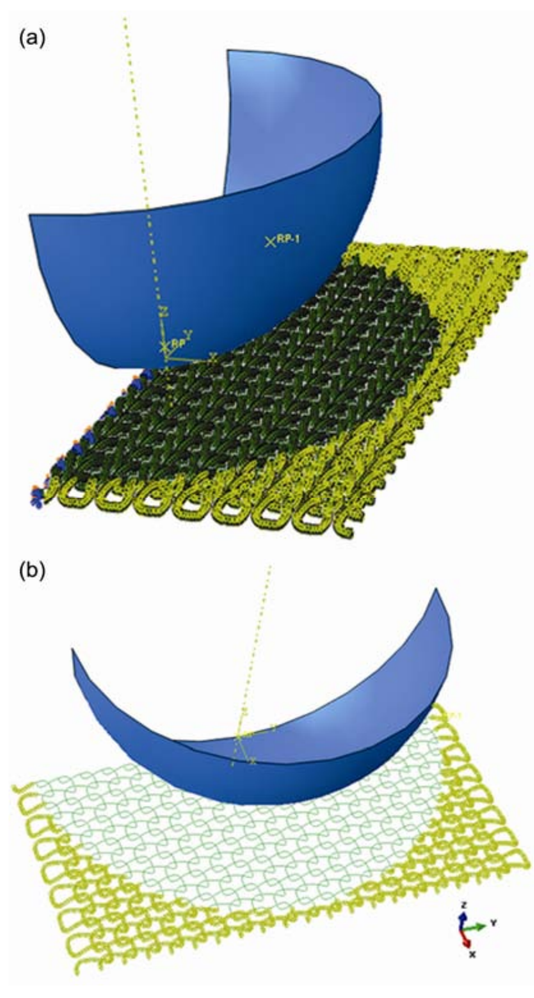

Fig. 3—Proposed model of bagging deformation (a) via solid element, and (b) via wire element

and stress concentration, which leads to decreasing the yarn diameter. It should be noted that the elongation distribution is not identical in all fabric parts (Fig. 4(a)). The amount of the applied forces to the yarns is related to the loop's position in the fabric structure. In other words, force components in wale and course directions are different.

However, the highest amount of yarn elongation which is illustrated with green printed points (Fig. 4(a)) is less than total fabric elongation. It can be concluded that fabric elongation results from yarn slipping and straitening in fabric structure. The amount of bagging work done by the steel ball can be calculated via lower surface area of curves. The above mentioned curves are also attainable through modeling regarding software facilities. Bagging was considered as the criteria for models assessment. By calculating the bagging work done in the first cycle as well as the fabric sample weight, the bagging resistance values would be determined.

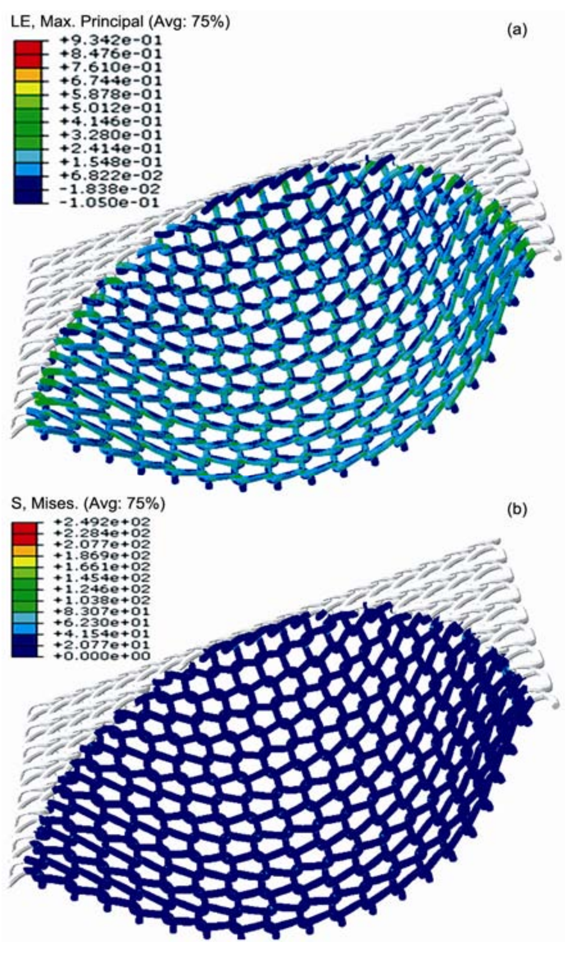

Fig. 4—Technical face of a deformed knitted sample (a) yarn elongation distribution, and (b) stress distribution

Results and Discussion

In Table 2, the values of bagging resistance obtained from both wire element modeling and elastic modeling (isotropic and transverse isotropic) as compared to the experimental results are given. According to Table 2, the values of bagging resistance derived from the wire element modeling are much less than the experimental ones with no difference between low and high fabric densities. This can be attributed to the fact that yarn diameter is not taken to consideration during deformation and this leads to the worse loop entanglement. Deformation of loops modeled by wire element is shown in Fig. 5. The main deficiency of this model is the contact surface distinction.

In the proposed elastic model for low density fabrics, both isotropic and transverse isotropic properties are being considered for yarns. Comparing the bagging resistance values of both isotropic and transverse isotropic elastic modeling (Table 2) reveals

Table 2—Comparison of bagging resistance values between different models and experimental results

Fabric code	Elastic modeling		Wire element modeling	Experimental results
	Isotropic elastic properties	Transverse isotropic elastic properties		
K	12.32	2.19	0.16	2.11
P	10.87	1.38	0.16	1.3

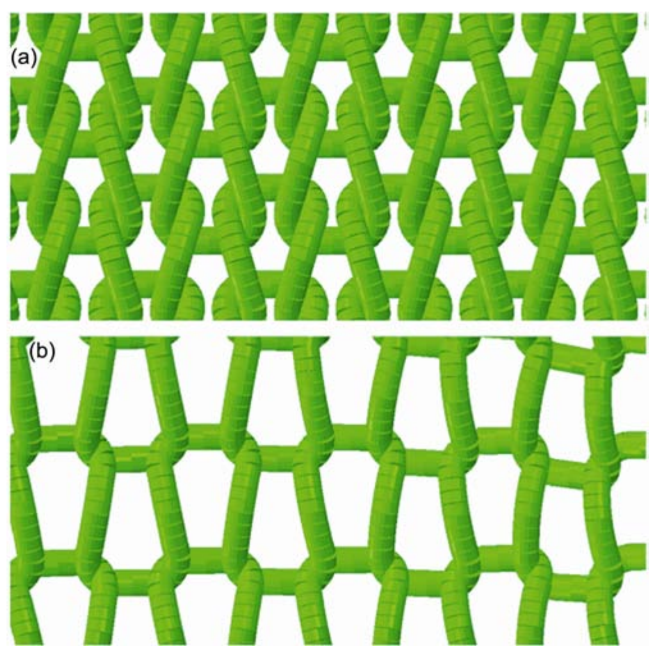

Fig. 5—Knitted structure modeled via wire element modeling (a) before deformation, and (b) after deformation

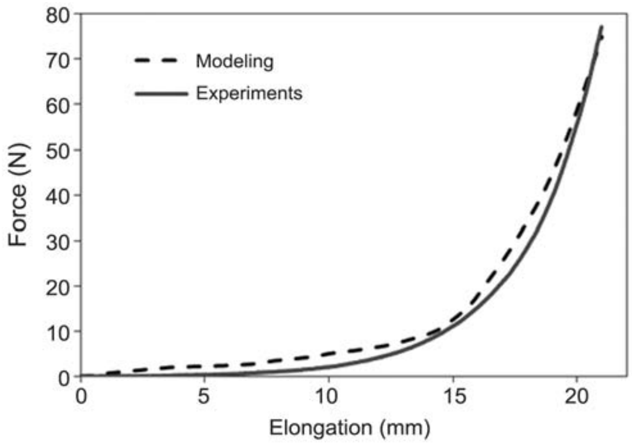

Fig. 6—Force-elongation curve during the bagging test modeled via transverse isotropic elastic properties

that the values derived from the latter model are more consistent to the actual results. This can be attributed to the differences between the Young's moduli of these two models in perpendicular direction to the yarn axis. The Young's modulus in perpendicular direction to the yarn axis for isotropic elastic model is defined as 900 MPa, while this parameter is 10 MPa for the transverse isotropic elastic model. Accordingly, the isotropic elastic model couldn't be an ideal model for describing the yarn properties through the bagging deformation. A typical force-elongation curve of a weft knitted sample subjected to the bagging deformation test, which is modeled via the transverse isotropic elastic properties, is depicted in Fig. 6.

The findings show that the numerical modeling of the bagging phenomenon using solid elements and yarn transverse isotropic properties has an acceptable correlation with the experimental values. Also, the finite element method can be accurately applied to the textile problems.

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