Computer-Aided Design 75–76 (2016) 61–75

Contents lists available at ScienceDirect

Computer-Aided Design

journal homepage: www.elsevier.com/locate/cad

Knitted fabrics design and manufacture: A novel CAD system for qualifying bagging performance based on geometric-mechanical models

Mao Aihua [a,*], Luo Jie [b,*], Li Yi [c], Lin Yinglei [c], Han Yanxia [c]

[a] School of Computer Science & Engineering, South China University of Technology, Guangzhou, 510006, China
[b] School of Fine Art and Artistic Design, Guangzhou University, Guangzhou, 510006, China
[c] Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 15 September 2015
Accepted 2 February 2016

Keywords:
Knitted fabrics
Bagging performance
CAD system
Industrial applications

ABSTRACT

Knitted fabrics have excellent formability and tensile ability and are widely used in textile-related products and industrial applications. The traditional quality control on fabric's performance is undertaken by repeated measurement and testing which is very time-consuming and has great expense. There are urgent requirements for the designers and manufacturers to validate and control the mechanical performance of knitted fabrics. In this paper, we present a novel simulation-based CAD system for evaluating and qualifying the bagging performance of knitted fabrics. A set of geometric-mechanical models are developed with characterization of the fibers/yarns and fabrics for available inputs, which make it feasible for practical applications. Through encapsulating the models and presenting with a series of friendly interfaces, the CAD system offers users the abilities of data management, numerical design, bagging simulation and performance preview of knitted fabrics. The simulation capability of the models is validated by comparing the predicted results with measured data from experiments under same bagging testing conditions. The potential industrial applications of this system is demonstrated, and the designers and manufacturers can achieve the knitted fabric products with desirable mechanical functions effectively and economically.

1. Introduction

Today, the increasing demands for functions, comfort and durability on the products of apparels, sports wears, uniforms and also many industrial applications have created the need of high quality control on the fabrics [1]. As the basic material for textile-related products, the fabrics should be designed and manufactured to ensure to meet with the final products' specification and desired functions. Traditionally, the common quality control on fabrics' performance, such as tensile ability, stiffness, surface rubbing, thermal resistance, is undertaken by repeated measurement and testing and then marks the performance on the labels [2]. This process, however, is very time-consuming and usually has great expense.

Bagging is a kind of three-dimensional residual deformation, which comes from a perception of people about bagged dome shape and specially happens in elbows, knees pockets, hips and heels parts during wearing. Different from the other kinds of deformation, the prolonged and repeated deformation caused by bagging greatly reduce the durability and damage appearance of the fabric. Thus it is an important performance criteria for the fabric designers and manufacturers to evaluate and control their products' quality.

In literature, there are many research studied the bagging fatigue behaviors and proposed different methods to evaluate the residual bagging height of woven fabrics. Zhang et al. proposed a mathematical model for woven fabric bagging behavior [3]. Several international standards including Chinese standard (FJ 552), British Standards(BBS 4294) and Turkish Standard (TS 6071) addressed the testing methods related to bagging [4–6]. Yeung and Zhang proposed an image-processing method by testing and comparing visual features [7]. A alternative method is using KES-FB apparatus

* Corresponding authors.
E-mail addresses: ahmao@scut.edu.cn (A. Mao), jieluo@gzhu.edu.cn (J. Luo).

http://dx.doi.org/10.1016/j.cad.2016.02.001

which evaluate the tensile, bending and shearing by some readable variables on the apparatus [8].

However, due to the different structure from that of woven fabrics, knitted fabrics have different mechanisms in bagging behaviors but generally have excellent formability and drape ability. They are required to have a dimensional stability under exerted force which may cause fabric fatigue. Thus, bagging phenomenon is an important research problem of knitted fabrics. Uçar et al. studied the bagging behaviors height of knitted fabrics using a similar mechanism of woven fabrics [9]. de Araújo et al. used FEA (finite element analyses) model to calculate the deformation of planar knitted fabric [10]. Hasani et al. predicted the bagging fatigue of viscose/polyester blended knitted fabrics with different blend ratios and structural stitch lengths [11]. Ajeli et al. proposed an energy model for the bending behavior of warp-knitted fabrics based the measurement using a Kawabata evaluation system [12]. These work explored different methods to measure and simulate the deformation of knitted fabrics, however, few of them systematically developed bagging models based on rheological mechanisms and accessible inputs of the fibers and fabrics' structure and properties, which are rather useful for practical application.

In engineering design, the most challenge for the designers and manufactures is that they need to deal with functional behaviors of the fabric and map them onto a set of parameters of realizable structure, properties and manufacturing methods. In fact, there are only a few experts who are capable to handle this problem [13]. However, the computer-aided design approach can help the common users to achieve it with a basis for structural mechanics, data availability and functional prediction [14]. Researchers had paid many efforts from the earlier application of 2D design tools to the recently growing usage of 3D modeling system, such as geometric 2D/3D pattern modeling by Charlie Wang et al. [15–17], 3D cloth virtual modeling and trying by Magnenat-Thalmann et al. [18–20], CAD systems for clothing functional design by Mao et al. [21–23].

This paper presents a novel CAD system for designers and manufactures to evaluate and qualify the bagging performance of knitted fabrics. Different from previous work on investigation of the bagging behavior of knitted fabrics, we develop a set of mathematical models systematically for simulating the bagging performance of knitted fabrics based on their rheological mechanism, geometric structure and mechanical properties. These geometric-mechanical models can provide accurate simulation capacity, which are validated through comparison with experimental data. Furthermore, the parameters of the fibers/yarns and fabrics are characterized, provided with available measurement and calculation methods. The CAD system are developed with encapsulation of the models and presents friendly interfaces to numerically design and simulation. Thus, a feasible strategy oriented to the designers and manufactures to evaluate knitted fabrics' bagging performance is realized with basis of available data input, scientific model-based simulation and friendly virtual analysis. This CAD system is beneficial in shortening design cycles and reducing design cost and also demonstrates many potentials in industrial applications.

2. Bagging mechanisms and terms of knitted fabrics

When the finished fabric in plane form is applied a force perpendicular to its plane, the force which maybe static or dynamic is distributed planar in the fabric, and the planar continuous structure of fabric is deformed by the spatial stress. This imposes a difference in the material and causes spatial deformation in the fabric, which is called bagging [24]. Almost every fabric shows some degree of elongation when being exerted upon an external force, if it can fully recover after the force is removed, which is said the fabric is elastic. However, if the recovery is not full in the fabric, the viscoelastic behaviors take place, where the strain is determined by the change in shape and also the differential time equation [25]. In this situation, the Young's modulus, which measures the force needed to stretch a material sample, begins to change and the strain is subject to superposition principles [26]. In theory, creep increases in elongation under constant force, and relaxation decreases in force at constant elongation [27]. Meantime, during bagging deformation, the bagging force may induces internal stress of the fabric at three directional ways [28].

In structure, the knitted fabric is an aggregate of fibers linked to each other at varying compactness, varying degree and type of order and varying degree of extension, curl and twist. Generally the linkage is due to frictional forces that is dependent on frictional coefficient, normal pressure and effective contact areas [29]. Kawabata pointed out that textile materials can be very easily distorted and be extremely resistant to the application of high loads to prevent fiber redistribution during fabric extension, which leads to a kind of self-locking mechanisms among the fibers within the fabric [30]. This suggests that frictional restraint to fabric deformation exists during the whole process of fabric deformation.

Due to these reasons, when to derive a mathematical model to describe the rheological mechanism involved in the knitted fabric bagging deformation, there is a need to compromise between theoretical investigation and practical utilization. A key issue is the assumptions, which determine on the one hand the degree of realism of the model and on the other hand the practicality of the model for achieving a numerical solution. Before the model development, here are some terms and definitions of knitted fabrics will be used in the following sections. The fabrics are specified as warp knitted which is knitted by multiple sets of yarns and can be very complex and intricate in structure, as shown in Fig. 1.

Course and course density: course is a row of loops across the width of the fabric, which determines the length of the fabric, and are measured as courses per centimeter or inch. The number of the knitted loops per 50 mm length in the course direction is defined as course density.

Wale and wale density: wale is a column of loops along the length of the fabric, which determine the width of the fabric, and are measured as wales per centimeter or inch. The number of the knitted loops per 50 mm length in the wale direction is defined as wale density.

Bagging residual: the bagging residual reflects the growth of fabric in the bagging process. After the first bagging cycle, the growth of fabric measured at the beginning of each bagging cycle is called bagging residual.

Elastic modulus ($\boldsymbol{E1}$)*:* the elastic modulus describes the tensile elasticity, or the tendency of fiber/fabric to deform along an axis when opposing forces are applied along that axis; it is defined as the ratio of tensile stress to tensile strain.

Viscoelastic modulus ($\boldsymbol{E2}$)*:* the viscoelastic module describes the fiber/fabric that exhibit both viscous and elastic characteristics which can be modeled as linear combinations of springs and dashpots, respectively.

Viscosity of fiber/fabric ($\boldsymbol{\eta}$)*:* the viscosity of fiber/fabric ($\boldsymbol{\eta}$) is measured as the friction coefficient of the dashpot which models the viscosity property of the fiber/fabric.

Relaxation time ($\boldsymbol{\tau}$)*:* the relaxation time is the time for the fiber/fabric to reach equilibrium after they are deformed. It can be calculated by the relationship $\boldsymbol{\tau} = \boldsymbol{\eta}/\boldsymbol{E2}$.

Yarn Specific work ($\mathbf{Y_{work}}$)*:* yarn specific work describes the tensile property of the yarns taken from the fabric, which can be obtained by $\boldsymbol{Y_{work}} = \textbf{\textit{loading work of first circle/yarn count}}$ (kg-mm/tex)