REVIEW

Journal of Textile Engineering (2006), Vol.52, No.1, 1 - 8

Fabric Handle and Its Basic Mechanical Properties

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Received 18 November 2005; accepted for publication 7 December 2005

Abstract

Published research works concerning fabric handle and its basic mechanical properties were surveyed in this review. Fabric handle and its mechanical properties have been studied continuously using KES system for various kinds of fabrics in the period between 1998 and 2005. Statistical investigation by neural network model has been very popular in these years and the accuracy of prediction is higher than that of conventional regression methods. Some novel works concerning fabric sound have also been reported. Quite a lot of works concerning drape behavior of fabrics, seam puckering, wrinkles and pillings have been carried out by using image processing system. In order to evaluate clothing comfort objectively, clothing pressure to human body is investigated precisely.

Key Words: Fabric handle, Mechanical property, Fabric appearance, Clothing comfort, Clothing pressure

1. Introduction

Fabric handle is related to basic mechanical properties of fabrics, especially initial low-stress region of those properties. Fabric handle includes not only soft and/or smooth touch of fabrics, but also drape shape and/or appearance of fabrics and clothes, and comfortable feeling of clothes, in a broad sense. Recent research works about those themes are surveyed and reviewed in this paper. Previous published works between 1989 and 1998 have been already reported in the former report[1] for the representative research journals such as "Journal of the Textile Machinery Society of Japan" (Sen-i Kikai Gakkaishi), "Journal of the Society of Fiber Science & Technology" (Sen-i Gakkaishi), "Journal of the Japan Research Association for Textile End-Uses" (Sen-i Seihin Shouhi Kagaku), "Journal of Home Economics of Japan" (Nihon Kasei Gakkaishi), "Textile Research Journal" (USA), and "Journal of the Textile Institute" (UK). In this report, published research works shown in the period between 1998 and 2005 in those research journals including "Journal of Textile Engineering" (Japan) and new journal "Fibers & Polymers" (Korea) are surveyed.

2. Objective Evaluations of Fabric Handle

Madeley et al.[2−4] studied about fine Merino wool and showed effects of fiber crimp frequency, fiber diameter, and fiber curvature on fabric handle. They concluded that the softness of handle of fine Merino wool varied inversely with loose fiber resistance to compression. The best single parameter indicating softness was resistance to compression. A reduction in staple crimp frequency or mean fiber diameter or both lowered resistance to compression and increased softness. In woolen system processing, a reduction in fiber crimp/curvature resulted in greater sliver bulk, more slubbing, hairier yarns, and loftier knitted fabrics.

Kim and Slaten[5] showed that a simple extraction method, in which hand force was measured, effectively measured the changes in hand resulting from different fabric types, flame retardant finishes, and fabric wetness. Amano et al.[6] tried to evaluate the objective hand value of a fabric by using not numerical but only qualitative data for its properties, such as large/small, high/low, excellent/poor and so on.

KES system has been applied to various kinds of fabrics to evaluate those handle objectively. Matsuo et al.[7] studied about "Shingosen" fabrics by modifying surface parameters of KES system. Niwa et al.[8] studied about blankets, Inoue and Niwa[9,10] evaluated about ladies' garments fabrics, Yokura and Niwa[11,12] examined about top sheet nonwoven fabrics of disposable diapers and toilet papers, and they derived objective evaluation equations for various textile end-uses by multiple regression methods using mechanical parameters measured by KES system. Matsudaira et al.[13] also derived the another equation for

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original primary handle of the top sheet. Morino et al.[14,15] tried to derive the objective evaluation equation of fabric handle from basic parameters of weave structure such as crossing-over firmness factor and floating yarn factor. Ahn et al.[16] tested lyocell fabrics. Park and Hwang[17] investigated about double weft-knitted fabrics, and Choi and Ashdown[18] studied for weft-knitted fabrics using KES system.

On the other hand, neural network models were applied to evaluate fabric handle by many researchers[19−24] and most of them concluded that the estimation accuracy was higher than that by conventional regression methods. Chen et al.[25] tried to use the method of fuzzy comprehensive evaluation to solve the problem of grading fabric softness using KES instruments.

The effects of enzyme treatments and and/or various finishing treatments on fabric handle have been investigated widely[26−34] using the data measured by KES system. Mechanical parameters measured by KES system are very effective to discriminate the small differences between each finishing chemical agents.

3. Subjective Evaluation of Fabric Handle

Matsudaira and Shiota[35] examined about handle of "Tatami" surface made of polyacylonitrile (PAN) fiber and concluded that PAN showed higher thermal insulation value than natural rush "Tatami". Sukigara and Ishibashi[36] studied the relationship between subjective evaluation and both compression and surface properties of cosmetic sponges. Izumi et al.[37] assessed surface roughness and slipping resistance of "Shingosen" fabrics. Na and Chung[38,39] proposed prediction models for subjective hand ranking and handle of silk neckties were compared with purchasing performance.

Alimaa et al.[40] carried out sensory measurement of knitted fabrics and compared with the mechanical properties obtained from KES system and concluded both results agreed well. Park and Hwang[41] evaluated total hand of single knitted fabrics and the results of Korean panels were compared with those of New Zealanders. Cho et al.[42] also compared the results of sensory evaluation with those of KES parameters. Mackay et al.[43] studied the effects of laundering on the sensory and mechanical properties of 1×1 rib knitwear fabrics and discussed in terms of the washing process variables such as agitation level, detergent product, and drying method. Kweon et al.[44] found that female students responded with more receptiveness and sensitivity than male students in the category of woven fabric evaluation. Philippe et al.[45] have concluded that assessors of fabric hand should be trained to evaluate and to score the fabrics on a linear scale, and the performance of each panelist should be checked for validity and reproducibility before the panel was acknowledged as operative.

To evaluate fabric handle accurately, the motion of fingers and/or samples is very important. Fujimoto et al.[46] studied about the effect of gloves on fabric hand especially in the case of hand movements in the daily life. Lee et al.[47,48] investigated active tactile motion of fingers in discriminating cloth and found that the correct answer ratio of female group was higher than that of male group. They concluded that linear finger movement was the important factor to improve the discrimination ability in evaluating the fabric handle by the experimental glove type measurement system with accelerator.

Some results concerning wearing comfort are reported. Nishimatsu et al.[49] studied about the influence of fiber material of socks. Cardello et al.[50] tested military fabrics and a labeled magnitude scale of comfort was developed using consumer magnitude estimates of the semantic meaning of verbal phrases denoting different levels of comfort/discomfort.

Sitting comfort evaluation has been carried out by Tada et al.[51,52] and Nishimatsu et al.[53,54] for various automotive seats with and without top covering fabrics.

Fabric handle according to fabric sound has been investigated in these days. Yi and Cho[55] analyzed fabric sound in the forms of sound spectra through Fast Fourier Transform analysis. Sukigara et al.[56] evaluated rustling sound of fabrics. Cho et al.[57,58] compared level pressure of total sound, level range, and frequency differences of fabric sound with mechanical parameters by KES system. They studied physiological responses evoked by friction sounds of warp knitted fabrics to the data of electroencephalogram, the ratio of high frequency to low frequency. Yi[59] tested cross-cultural comparison of sound sensation and established its prediction models for Korean traditional silk fabrics including sound parameters such as level pressure of total sound, Zwicker's psychoacoustic characteristics, and mechanical parameters by KES system.

4. Basic Mechanical Properties of Fabrics

Smita et al.[60,61] studied the biaxial tensile deformation behavior of spun-bonded nonwovens by Finite Element Method (FEM). Tarfaoui et al.[62] investigated the stress-strain behavior of woven fabrics using FEM. Bao et al.[63] analyzed large non-linear elastic deformation of fabrics by FEM. General force-displacement relation of tensile properties has been investigated by Potluri et al.[64], Taibi et al.[65], Pan[66], and Jeon et al.[67]. Hearle[68] introduced the energy-based approach for mechanics of textile fabrics especially for industrial uses. Application of "Linearizing Method" was reported by Niwa et al.[69] and Yamada et al.[70]. Postle[71] introduced structural mechanics of knitted fabrics for apparel and composite materials. Loginov et al.[72-74] studied about the load-extension behavior of plain-knitted fabric based on unit cell model. Dai et al.[75] proposed a new particle model to simulate anisotropic woven fabric deformation. Mitsuishi et al.[76] tested about tetra-axial woven fabrics, and Hanada and Nishiwaki[77,78] evaluated braids on the market.

Fabric bending properties have been measured and analyzed by Zhou and Ghosh[79,80]. Zhang and Matsudaira[81−83] studied about bending vibrational properties of fabrics and proposed new parameters which distinguish fiber material, fabric structure, and various types of "Shingosen" fabrics. Jiang and Hu[84] studied characterizing and modeling bending properties of multiaxial warp knitted fabrics. Hu and Chung[85] tested the bending behavior of woven fabrics with vertical seam. Hu et al.[86] showed bending hysteresis of plain woven fabrics in various directions and concluded that Cooper's model is the most reliable in predicting polar diagrams of bending hysteresis in cotton plain woven fabrics. Alimaa et al.[87] studied the effects of yarn bending and fabric structure on the bending properties of plain and rib knitted fabrics. Zhang and Xu[88] analyzed buckling of woven fabric under simple shear along arbitrary directions. Kang et al.[89] studied fabric buckling based on nonlinear bending properties.

Furukawa et al.[90] analyzed anisotropic elastic body like woven fabrics especially in dynamic shear deformation using FEM. Takatera et al.[91] derived equations to calculate the strains along the yarn directions and crossing angle of yarns in shear deformation. Matsudaira et al.[92] studied about the vibrational properties of woven fabrics based on in-plane shear deformation and showed the existence of an optimum value for both weave density and yarn twist to give the smallest value of the damping ratio. Sugimura and Matsudaira[93−95] examined the shear vibration behaviors of "Shingosen" and silk fabrics. Leaf[96] introduced a method of estimating the real shear modulus of the fabric and the results is compared with those of KES system. Lo and Hu[97] studied shear properties of woven fabrics in various directions and found strong linear relationship between shear rigidity (G) and shear hysteresis at two angles (2HG, 2HG5). Wang et al.[98] established theoretical equations expressing the relationship between the shearing rigidity and the fabric structure.

Some works were carried out concerning compressional properties of fabrics. Matsudaria et al.[99] studied about "Shingosen" fabrics using new parameters proposed by the authors. Schoppee[100] showed a Poisson model of nonwoven fiber assemblies at high stress. Morooka et al.[101] studied compressive properties of pantyhose fabrics. Aliouche and Viallier[102] examined the effect of hairiness on tactile compression. Jeong and Kang[103] analyzed compressional deformation of woven fabrics using FEM. Beil and Roberts[104,105] modeled the compressional behavior of fiber assemblies and the effects of hysteresis, crimp and orientation were studied. Taylor and Pollet[106] tried to explain dynamic compression by a Kelvin-Voigt model.

Ajayi et al.[107] indicated the effects of sled velocity on fabric friction for weft pile fabrics. Hirai and Gunji[108] studied the relationship between slipperiness and coefficient of friction on the carpets. Azuma et al.[109] tested the difference of surface roughness between samples of pantyhose fabric. Militky and Bajzik[110] introduced the surface height variation trace obtained by KES system. Hwa et al.[111] studied surface abrasion of nonwoven fabrics.

Bassett and Postle[112] reviewed experimental methods for measuring fabric mechanical properties. Yokura and Niwa[113] studied the handle of wet disposable diapers. Mori et al.[114] investigated the effects of fabric weave and fabric count on twisting properties of fabrics. Sukigara et al.[115], Inoue and Yamamoto[116] reported about recycled polyester fabrics. Yoshida et al.[117] tested mechanical properties for top sheet of disposable diapers.

The effects of finishing agents, enzyme treatments, and repeated laundering on fabric mechanical properties, wrinkle recovery, and dimensional stability were studied widely by many researchers[118−128].

Fan and Hunter[129,130] introduced fabric expert system using neural network model for predicting the properties of worsted fabrics. Chen et al.[131] developed a new computerized data acquisition system for KES instruments. Lai et al.[132] compared the results of KES system and that of FAST and concluded that KES discriminant model had better classification ability than FAST discriminant model for cotton, linen, wool and silk fabrics.

5. Drape Shape of Fabrics and Appearance of Clothes

Jeong[133-135] studied fabric drape behavior with image analysis and showed the effect of cover factor and bending length on drape. Nagai et al.[136−139] introduced the similarity rule of F.R.L. draped figures for fabrics. Hu et al.[140−142] investigated the effect of mechanical properties on drape, the effect of seam allowance on drape, and showed numerical simulation of drape. Postle and Postle[143] modeled the dynamics of fabric drape and conclude that the fabric deformation was dynamically analogous to waves traveling in a fluid. Bao et al.[144] studied the effect of mechanical properties on MIT drape behaviors of fabrics by a non-linear FEM.

Yang and Matsudaira[145−155] could define new dynamic drape coefficients such as revolving drape increase coefficient, D_r, revolving drape coefficient at 200 rpm, D_{200}, and dynamic drape coefficient at swinging motion; D_d, by image analysis system. Regression equations for those coefficients were also derived using KES parameters. They showed the changes of those drape coefficients through various finishing stages precisely. Drape features of "Shingosen" fabrics and silk fabrics could be distinguished more reasonably by using those new dynamic drape coefficients.

Theoretical studies about drape model and drape prediction system were reported by many researchers such as Bendali et al.[156], Bruniaux and Vasseur[157], Fan et al.[158], Lo et al.[159], and Termonia[160]. Many investigations about simulation model of drape behaviors of fabrics were also studied by many workers[161−167]. Mizutani et al.[168] introduced drape generation mechanism.

Miki et al.[169] evaluated comfort and aesthetics of flared skirts with different number of gore panels. Niwa et al.[170] proposed the optimum silhouette design for ladies' garments based on the mechanical properties of a fabric. Nakanishi and Niwa[171] studied mechanical parameters related to the beauty of fabric movement of ladies's garments brought about by human motion. Takatera et al.[172] studied pattern making of flared skirts. Zhang and Matsudaira[173,174] reported the effects of mechanical properties of fabric on the static and dynamic shapes of flared skirt. Sugimura and Matsudaira[175−178] tried to develop objective evaluation equations for the beautiful appearance of flared skirts in dynamic state.

Investigations about seam puckering and wrinkles were shown by many researchers[179−186], especially in the point of objective evaluation of those grades. Fabric bagging was studied widely by Zhang et al.[187−193] and others[194,195]. Some works[196−198] concerning pilling and surface texture of fabrics are also reported. Lai[199−205] investigated precisely about objective evaluations for visual appearance of fabrics and/or skirts.

6. Comfort Feeling of Clothes Based on Mechanical Properties of Fabrics

Matsudaira and Asou [206−208] developed objective evaluation equations of the comfort items for women's autumn/winter woven and knitted pajamas. They also measured heart-rate interval variation to evaluate wearing comfort of pajamas and showed that power of high frequency; [HF] and its ratio of low frequency to high frequency; [LF]/[HF] were considered to become significant indexes of comfortable pajamas. Lau et al.[209] indicated tactile sensation of fabrics was very important for wearing comfort before sweating. Wong et al.[210−214] and Wang et al.[215] studied widely about clothing sensory comfort and proposed hybrid model to predict wearing comfort. Yuki et al.[216] measured the electroencephalograph for evaluating comfort pajamas.

Clothing pressure were measured by many researchers[217−226] for the evaluation of clothing comfort in relation to mechanical properties of fabrics, and the various effects on physiological responses were studied.

7. Testing Method of Fabric Mechanical Properties

Nishimatsu et al.[227] measured the speed of finger movement to judge fabric handle. Kisilak[228] proposed a new method evaluating spherical fabric deformation. Fan et al.[229] presented a portable tester for nondestructively measuring fabric machine. Matsunashi and Shimazaki[230] introduced sonic method to evaluate a bending rigidity of sized fabrics. Xu et al.[231] developed a new profilometer for assessing fabric smoothness appearance by using laser triangulation and image processing techniques. Bueno and Renner[232] compared a new tribological method for the evaluation of the state of a fabric surface with the KES surface tester. Lima et al.[233] used "FRICTORO", a novel fabric surface tester. Ucar and Boyraz[234] measured surface fuzz using image analysis method.

Prediction and objective evaluation method of seam puckering were reported by many researchers such as Tasaki and Kanamitsu[235], Fan et al.[236−238], Kang et al.[239], Park and Kang[240,241], Ota and Shibuya[242,243].

Kuzuhara et al.[244,245] introduced a new testing method for wrinkle recovery of wool fabrics. Various objective methods for measuring fabric wrinkles were developed by many workers[246−258] using image processing system. Some of them used neural network models and they applied colored and patterned fabrics and relation to fractal dimensions were proposed.

Fabric pillings were also evaluated using image analysis techniques[259−263] and predicted by neural network model[264].

Kondo et al.[265−267] measured density and knitting stitch by image processing system and proposed design supporting system for knitting fabrics. Lin[268] applied a co-occurrence matrix to automatic inspection of weaving density for woven fabrics. Saeki et al.[269,270] introduced representation of fabric textures by texture mapping technique using surface reflection characters and thread pattern.

8. Summary

Fabric handle and its mechanical properties have been studied continuously using KES system for various kinds of fabrics in these 8 years. Statistical investigation by neural network model has been very popular and the accuracy of prediction is higher than that of conventional regression methods. Some novel works concerning fabric sound have been reported recently. Quite a lot of works concerning drape behavior of fabrics were studied using image processing system and new dynamic drape coefficients were defined. Image analysis is widely used for evaluating surface appearance such as seam puckering, wrinkles, pillings and surface textures. Clothing pressure to human body is measured precisely and the effect on physiological responses has been becoming clear.

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