METHODS TO DIGITIZING PHYSICAL PROPERTIES OF FABRIC FOR VIRTUAL SIMULATION

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Scientific paper
UDC: 677:681.5
doi: 10.5937/tekstind2003036M

Abstract: *This investigation is undertaken based on the indicated improvements for fabric simulations. According to the expert opinions, there is no coherency between methods used to measure the fabric properties and the simulated results of the same fabric among the different software packages. In praxis, fashion brands use different 3D software packages and need to measure a fabric with different methods to obtain the same fabric properties. In addition to the time investment, the simulated results for the same fabric vary significantly between the different software packages. The experts indicated the lack of standardization in material measurements, the lack of correlation between the data of the different measurement systems, and the lack of correlation between the simulated results of the different software packages for the same material.*

This paper investigates, on the one hand, the suitability of the two measurement technologies for retrieving fabric parameters for precise virtual fabric and garment simulations. The focus is on the main properties required by the software packages - bending, shear, tensile and friction - aiming to identify and specify the most suitable methods to retrieve mechanical fabric properties and to start a standardization process for fabric measurements for virtual simulations.

Key words: 3D fabric simulations, virtual prototype, kawabata, SWOT.

METODE DIGITALIZOVANJA FIZIČKIH SVOJSTAVA TEKSTILNIH MATERIJALA NAMENJENIH ZA VIRTUALNU SIMULACIJU

Apstrakt: *Istraživanje je bazirano na uočenim poboljšanjima kod rešenja za simulacije tkanina. Prema ekspertskim mišljenjima, ne postoji koherencija između metoda koje se koriste za merenje svojstava tkanine, kao i simuliranih rezultata iste tkanine između različitih softverskih paketa. U praksi, modni brendovi koriste različite 3D softverske pakete i ispituju tekstilne materijale različitim metodama da bi dobili podjednak rezultat i odgovarajuća svojstva materijala. Uz vremensko ulaganje, simulirani rezultati istog materijala značajno se razlikuju između različitih softverskih paketa. Stručnjaci su ukazali na nedostatak standardizacije u merenjima tekstilnih materijala, kao nedostatak je navedena neodgovarajuća povezanost podataka različitih mernih sistema i nedostatak korelacije između simuliranih rezultata različitih softverskih paketa za isti materijal.*

Ovaj rad istražuje, s jedne strane, pogodnost dveju mernih tehnologija za pronalaženje fizičkih parametara tekstilnih materijala za precizne simulacije virtualnih tkanina, pletenina i odeće. Fokus je na glavnim svojstvima koja zahtevaju softverski paketi - savijanje, smicanje, zatezanje i trenje - sa ciljem da se identifikuju i preciziraju najprikladniji metodi za merenje mehaničkih svojstava tkanine i trasiranje procesa standardizacije za sisteme merenja fizičkih osobina tekstilnih materijala za virtualne simulacije.

Ključne reči: 3D simulacije materijala, virtualni prototip, kawabata, SWOT.

1. INTRODUCTION

1.1. Background

In recent years, the fashion industry has been increasingly shifting to use simulations for virtually assessing new products before they are actually produced [1-3]. Even if it is impossible to simulate a product with 100% accuracy since all real influencing factors cannot be known, the virtual prototype has to be precise enough so that important decisions can be taken within the product development process. For a 2D pattern optimization, which is done with millimeter precision, the virtual prototype should be in the same range of precision. Depending on the field of application, simulations approach reality with various mechanical models that consider forces and impulses and reduce the influencing factors to the most important ones. Fabrics are complex non-linear viscoelastic materials that, when subjected to stress, flow and only gradually come to rest when the force is removed. Their simulation is not easy, as their behavior is difficult to describe and predict. Fabrics must have sufficient strength and at the same time they must be flexible, elastic, and easy to pleat and shape. The knowledge of the viscoelastic behavior of a material is based on empirical data from characterization experiments. The accuracy of virtual garment simulations is dependent on the mechanical model of the simulation system and the precision of fabric input parameters, derived from fabric physical and mechanical fabric properties [4–15].

1.2. Research aim and scope

The aim of this research is to investigate the principle and methods applied by the currently used measurement technologies for retrieving fabric parameters for virtual garment simulations. The main focus is on bending, shear, tensile, and friction properties because these are widely considered to be among the most important fabric properties determining fabric behavior. The following fabric measurement methods are studied:

- Kawabata Evaluation System (KES)
- CLO Fabric Kit 2.0,

1.3. Research questions and methodology

The leading research question is as follows:

What is the most suitable fabric measurement method to retrieve mechanical properties required for precise virtual fabric and garment simulations?

The sub questions addressed are as follows:

- 1) What is, for each property, as defined in the aim, the measurement principle for each system?
- 2) What are, for each property, the characteristic values for each system?
- 3) What are, for each principle, the strengths, weaknesses, opportunities, and threats?

Secondary and primary research methods were applied.

To answer the third question, SWOT analysis were made based on the findings for each system.

2. FABRIC PROPERTIES, EXISTING MEASUREMENT RINIPLES AND DEVICES

Table 1: Fabric properties measured by the KES-F system

PARAMETER		DEFINITION	UNIT
Tensile	LT	Linearity	—
	WT	Tensile energy	gf cm/cm ²
	RT	Resilience	%
	EM	Max. extension	%
Bending	B	Bending rigidity	gf cm ² /cm
	2HB	Hysteresis	gf cm/cm
Shearing	G	Sheer stiffness	gf/cm ⁻⁰
	2HG	Hysteresis at 0.5°	gf/cm
	2HG5	Hysteresis at 5°	gf/cm
Compression	LC	Linearity	—
	WC	Compressional energy	gf cm/cm ²
	RC	Resilience	%
Surface	MIU	Coefficient of friction	—
	MMD	Mean deviation of MIU	—
	SMD	Geometric roughness	µm
Weight	W	Weight/unit area	mg/cm ²
Thickness	T	Thickness at 0.5 gf/cm ²	mm

Besides his studies on the standardization of objective fabric hand assessment, Kawabata went on with research on measuring mechanical and physical

fabric properties. This part of research was driven by the question of how a broad variety of fabrics should be tested in the same way so that the obtained data represents a significant statement about that textile. When a fabric is touched and squeezed during subjective hand assessment, only small forces occur. For example, no fabric would break during this manipulation. For this reason, Kawabata designed his measurement standard for small deformation regions. In conclusion, Kawabata considered six measurement blocks, which were improved in 1980, named KES-FB and reduced to only four machine blocks, KES_FB 1, 2, 3, and 4 [28].

Figure 1: Diagram KES-FB 1: tensile measurement

- The derived characteristic values are as follows:
- EM: extension at maximum load (%)
 - LT: Linearity
 - WT: Tensile energy per unit area (gf*cm/cm²)
 - RT: Resilience (%), (to which degree the fabric recovers, after the release of the force)

Figure 2: Shear diagram

- The derived characteristic values are as follows:
- G: Shear rigidity (gf/cm * degree)
 - 2HG: Hysteresis at shear angle Ø = 0.5 degree (gf/cm)
 - 2HG5: Hysteresis at shear angle Ø = 5 degree (gf/cm)

2.1. Clo fabric kit 2.0 (CFK2.0)

The measurement tools consist of a digital scale, digital thickness gauge, a bending tester, for the tensile test a short and a long fabric feed, and a digital

force gauge, which are attached to a long base with ruler. The kit needs to be assembled by the user (Figure 3).

Figure 3: Overview of the CLO KIT

In total, one warp, one weft, and one bias fabric specimen, each of 22 cm by 3 cm, are required to measure the weight, thickness, bending, and tensile properties.

All measurements need to be read from the rulers and/or devices, next written on a form, and then input into the fabric emulator of the software; the characteristics are given in Table 4 [39].

Table 2: CLO measured characteristic value

Property	Symbol	Unit	Measured
Stretch test (Tensile)			Length (mm) / Force (kgf)
Bias stretch test (Shear)			Length (mm) / Force (kgf)
Bending test		mm	Contact distance
		mm	Length
Thickness		—	mm
Mass Density (Weight)		g	The three cut specimen are weighted on a scale provided with the Fabric Kit

2.2. Weight and thickness

First, the three required fabric specimens are folded and put on the scale [Figure 12(A)] to measure the weight. Second, the thickness is measured with a digital thickness gauge [Figure 12 (B)], in both cases the values are written on the form.

Figure 4: Measuring (a) weight and (b) thickness

2.3. Bending

The contact distance and the bending length is obtained by testing one warp and one weft swatch. The procedure follows the cantilever principle; however, in contrast to the standard, the fabric is fed into the instrument and rolled outside the canal with a wheel. Next to this, the contact length is taken as soon as the fabric specimen reaches the ruler instead of under a corner of 41.5° [Figure 13(A), (B)]. The fabric is

manually lifted and the higher sliding ruler is moved under the fabric to obtain the bending length [Figure 13(C)], as see in CLO3D [39]. The bending measurements are manually obtained and written on the form by the user.

The CLO KIT does not distinguish between face up and down and fabrics can be tested randomly. This is in contrast with the standard procedures, such as BS 3356:1990 [22] and ASTM D1388-96 (2002) [30], where both sides are tested. As well as to the significant differences between the face and back drape coefficient (DC) that some fabrics have, the DC is closely related to the bending length [19].

A general deficiency of the cantilever principle is the limitations with jersey fabrics, which tend to curl up [20]. CLO advises to solve this by manually pulling the fabric further outside the device and rolling it back until it is hanging free from the ruler. It is unclear how the bending measurement is influenced by the manual interaction and/or by dragging the specimen over the ruler surface, especially given the intricacy of the bending measurement described in the comment at the bottom of Table 5 in Chapter 2.10. Another deficiency of the cantilever is visible in Figure 12(B), where two contact distances can be obtained.

Figure 5: Bending, (a, b) contact distance, (c) bending length

Figure 6: Tensile testing

3. SWOT ANALYSIS OF THE MEASUREMENT TECHNOLOGY

3.1. Introduction to the swot analysis

The analysis is based on the review and in some cases observations during tests with the instruments.

The purpose is to give an overview and insight into the differences, as well as the similarities between the methods used to obtain bending, shear, tensile and friction properties.

3.2. SWOT KAWABATA evaluation system—KES

Strengths	<ul style="list-style-type: none">— Validated by worldwide research;— Automated system;— Still available with updated automated versions;— Measures bending, shear, tensile, friction and compression;— Graphs with full curves representing the raw measured data;— Nonlinear shear and tensile measurement: including recovery data;— Pure bending and hysteresis data;— Suitable to simulate fabric drape, with $r = 0.97$, $p < 0.0001$.
Weaknesses	<ul style="list-style-type: none">— Hysteresis behavior of fabrics is not captured;— The shear measurement does not correspond to how this fabric property is modeled in state-of-the-art simulation systems;— Metal wire is not suited for friction measurements;— Higher price range;— Not developed to retrieve fabric simulation properties;— Values are not presented in SI units.
Opportunities	<ul style="list-style-type: none">— Haptic data.
Threats	<ul style="list-style-type: none">— Availability of skilled operators;— Intricacy of the instrument.
<p>The KES system is still under development by KatoTech and is used for haptic data by fabric and textile industries, automotive, cosmetics, food, medical, and pharmaceutical to name a few [57].</p> <p><u>Recommendation based on the review:</u></p> <p>A sophisticated system, with opportunities in the connection with haptic data. The measurement principles of the tensile, shear, and friction properties are suitable to represent fabric drape; however, to represent the behavior during wearing, the suitability needs to be further investigated. Due to its price and dedicated handling not easy to apply on large scale in the fashion industry.</p>	

3.3 SWOT CLO FABRIC KIT 2.0

Strengths	<ul style="list-style-type: none"> — Clear instruction video regarding testing with the KIT.
Weaknesses	<ul style="list-style-type: none"> — Not automated, due to this prone to manual error, in 4 phases of the process (interpretation, reading, writing and inserting in the emulator); — Measurements might be influenced by (in)stability of the instrument and/or vibrations in the surrounding; — Bending: not suitable for very limb or stiff fabrics; — Bending: Jersey fabrics tend to curl up at the edges. The solution with reverse testing might influence the bending properties; — No average results are used; — Only one swatch is tested per weave direction; — Handling of the swatches during the weight and thickness measurement; — Bending is related to the cantilever principle; however, not according the standard; — Bending differences between face up and down are not taken in consideration; — Price in relation to the results.
Opportunities	<ul style="list-style-type: none"> — Easily comprehensible instruction video also gives non-expert users a quick idea about fabric measurements. However, this could mislead non-expert users to interpret the measurements as precise enough for all uses. Further development is required.
Threats	<ul style="list-style-type: none"> — What is the impact of the rolling system on the fabrics measurements, compared to the sliding system with the cantilever? — Conflict of interest due to development of this mechanical physical measurement instrument by a software developer.
<p><u>Recommendation based on the review:</u></p> <p>Not validated. Not automated, its instability and manual interference makes it prone to error; also, the deviation from the standards makes it less suitable for use in a professional situation.</p>	

4. CONCLUSION

Some 3D software developers use currently available measurement technologies to obtain the physical and mechanical properties, required to simulate a garment. Others develop their own instruments, in both cases with the purpose to facilitate the user's needs to digitalize the mechanical and physical behavior of their own material. The latter is a key requirement to enable true virtual fitting, based on the measured properties. The cloth should be simulated exactly as it is, not more appealing, but representing the shortcomings of the material as well as the faults in the pattern in an accurate way.

In general, the same properties are measured in most of the cases according to a similar principle with slight differences, often not following already existing

standards for the methods used. Testing protocols are unclear and tests are done under random conditions: swatch sizes differ and palliative measures are taken to retrieve the properties. In some cases, only one fabric specimen is tested. Calculation and output data are in most cases not transparent. It is unclear how the inaccuracies are corrected in the software, or to what extent the software is able to use the refinement and interaction between the properties.

Bending measurement is executed according different principles, while the cantilever principle is closely related to the hang or fabric drape of a garment, other bending tests represents the pure bending curve. It will be important to investigate more in-depth if the cheaper cantilever is accurate enough or if the more expensive pure bending tests are better suitable for garment simulations. Tensile properties

are measured by motor-controlled length extensions (KES) The instruments can be customized to the purpose we need for simulation. In most cases the shear is derived from the bias extension according the same principle as the tensile test, what corresponds to how this parameter is integrated in most state-of-the-art simulation systems.

Measurement principles have always been developed and optimized and finally been standardized for a certain purpose. Kawabata and FAST principles have been optimized to imitate the subjective hand evaluation, manipulating a fabric in the hand. Measurements for virtual garments simulations, however, have to imitate something different, namely what happens to a fabric during the wear of garments. Discussions about a future standard should keep this basic and main requirement in mind.

To improve the physical and mechanical measurement of the properties required for garment simulation, the next step to be taken is a transparent discussion with the software suppliers.

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Rad primljen: 06.08.2020.

Rad prihvaćen: 02.09.2020.