(REFEREED RESEARCH)

A STUDY ON THE MECHANISM OF FABRIC "WAVE" PLASTICITY

KUMAŞ "DALGA" PLASTİKLİĞİ MEKANİZMASI ÜZERİNE BİR ÇALIŞMA

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ABSTRACT

Test of pulling out yarns from fabrics was designed to study the mechanism of fabric "wave" plasticity. F that frictional forces per area in the warp and weft interlacing unit was proposed to characterize the frictional forces between yarns in fabrics. Results showed that the values of F of the fabrics with better fabric "wave" plasticity were bigger. Furthermore, in order to further understand the mechanism of fabric "wave" plasticity and test the application value of F, correlation analysis was carried out between F and fabric's mechanical index which could represent fabric "wave" plasticity. It was found that F and the mechanical index had a high positive correlation. Therefore, it can be concluded that fabric "wave" plasticity is the reflection of frictional forces in fabrics. Moreover, the values of F could be used for characterizing the frictional forces in fabrics.

Key Words: "Wave" plasticity, Mechanism, Pull-out test, Frictional force, Correlation.

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1. INTRODUCTION

Fabric "wave" plasticity is a shaping element of garment, with which fabric can be shaped into a curved surface with certain curvature above the body surface (1). Garments with concavo-convex curved shapes, and their shapes mainly depend on fabric "wave" plasticity (Figure1). These garment silhouettes mainly rely on fabrics rather than accessories, so the garments lightweight, easy care and just meet the needs of the modern fast-paced life. Traditional garment with concavo-convex curved shapes, like Figure 2, whose shapes depend on the support of attachment, resulting in bulky, difficult to care and unsuitable for daily wear.

The fashion of garments with concavo-convex curved shapes shown in Figure 1 is unique and exaggerating, which meets the need of modern people to express individuality. In addition, the garments highlight fabrics' shapes rather than human bodies, and their surface areas are far greater than those of bodies, so the binding forces applied to bodies are smaller, and the garments can also cover the imperfect bodies. Therefore, the garments just to meet the modern consumers' psychological needs, such as, pursuing personality and creating happiness. As such, the garments catch the attentions of several major companies, both domestic and overseas, which invest significant amount of money in the fabrics' study and development. Fabric "wave" plasticity is a new fabric characteristic proposed by our team, and until now, its mechanism has not been studied yet at home and abroad. The paper will deeply study the mechanism of fabric "wave" plasticity to provide a theoretical reference for designing and developing such products.

Figure 1. Garments with concavo-convex curved shapes

Figure 2. Traditional garment with concavo-convex curved shapes

According to previous studies (2), fabric "wave" plasticity might have some relations with frictional forces in fabrics. That was, fabric was fiber assembly, and deformation of fabric involved not only the deformation of fibers' configurations but also the change of their relative locations. At this point, fabric had the trend of recovering to its original shape because of fibers' elastic recovery. However, the interactive frictional forces between yarns and fibers prevented fabric from recovering. When the total elastic recovery stress was not large enough to overcome the frictional forces, the fabric could not return to its initial shape and maintained its changed shape, showing better fabric "wave" plasticity at the macro. The explanation was proposed basing on existing theories without experimental data supporting. The paper will deeply study the mechanism of fabric "wave" plasticity and use experimental data to prove the validity of the explanation. Therefore, the aim of the study is to test the frictional forces in fabrics, moreover, to study the relationship between the frictional force and fabric "wave" plasticity.

Test of pulling out yarns from fabrics is the most direct method to test the frictional forces in fabrics. Currently, pull-out test is widely used, especially in the textile industry. Taylor was probably the first person who analyzed the role of yarn pulling out on fabric properties(3). He developed a theory relating yarn interaction in crossing points to fabric tear strength. Sebastian and his partners (4,5) studied the effect of a cationic softening agent on the processes involved in pulling out a single warp yarn from fabric. Chen and Yao (6) tested the interweave resistance in fabrics by pull-out test. Liu and Yao (7) tested the pulling forces of rabbit hairs slipped or fractured from fabrics, and furthermore, to study the factors which affected rabbit hair fabrics' hair loss. Liu et al (8) studied the action of pulling fibers from non-woven fabrics, and then studied the utilization rate of fiber strength in fabrics. In addition, pull-out fiber or yarn test was used by many researchers in their studies about fiber or fabric reinforced composites (9-14). Summing up the above studies, most of the pull-out tests were used directly for studying a certain kind of properties of materials, and the differences of the samples were not so significant. Pull-out test used in this work had some differences from the previous. Firstly, specimen preparation method designed in this paper was suitable for different density and different materials of fabrics. Secondly, the test method was improved, basing on the characteristics of specimens. Thirdly, direct experimental data was processed, and an index was proposed to characterize the frictional forces between yarns in fabrics. In addition, tests in the paper involved only pull-out yarn tests, and did not include monofilaments, since some samples used in the tests were high-density fabrics, and it was impossible to pull out monofilaments from the fabrics.

2. EXPERIMENTAL

2.1. Samples preparation

Samples are listed in Table 1, including poly(trimethylene terephthalate) (PTT), poly(ethylene terephthalate) (PET), Nylon, cotton, wool, silk, cotton/PTT mixture and PET/Cotton blended fabrics. Cotton and PTT yarns are the wefts and warps of cotton/PTT mixture fabric, respectively; PET/cotton blended fabric is a spun fabric, and the blending ratio is 65% to 35%.

2.2. Specimens preparation

The tests were conducted in a constant temperature and humidity environment. The following steps were the specimen preparation of warp direction. (1) Firstly, a specimen (8cm×1cm) was cut from sample; (2) as shown in figure 3, cut the outer warps along weft direction in 4cm length of warps, leaving three warps in center, and then removed the cut warps and the crossover wefts; (3) cut a hole at the place 4mm from the edge, and ensured that the embedded ends of the three warps prepared in step (2) were cut (noted that the hole should be smaller so as to reduce experimental error); (4) made each specimen and its test data can be one to one correspondence by marking for the specimens, because yarns crossover with the pull-out yarn would be counted, and the number of the yarns should correspond to the test data. Similarly, the specimen of weft direction could be prepared.

It should be noted that the pull-out distance 4mm was determined by experiment. This distance not only could make yarns be pulled out from tight fabrics smoothly, but also ensured enough yarns in the distance crossover with the pull-out yarns of low-density fabrics.

Table 1. Specification of fabrics

No.	Material	End use	Textile weave	Yarn count (warp×weft)(Tex)	Cover factor (warp×weft) (%)	Total cover factor (%)	Thickness (mm)	$2HG_1$ (cN/cm)
A1			$\frac{1}{2}$	8.33×8.33	97.2×55.3	98.7	0.264	12.45
A2			$\frac{1}{1}$	8.33×8.33	99.0×39.9	99.4	0.235	10.65
A3			$\frac{1}{2}$	10.2×9.45	106.2×54.0	102.9	0.227	5.18
A4			$\frac{1}{1}$	11.4×9.40	97.4×46.1	98.6	0.214	11.31
A5	PTT/PTT	Between season coat	$\frac{1\ 1}{1\ 3}$	9.63×9.15	108.9×52.3	104.2	0.257	8.55
A6			$\frac{1}{1}$	8.33×8.33	92.9×47.0	96.2	0.234	13.83
A7			$\frac{1}{1}$	8.33×8.33	87.6×34.8	91.9	0.253	11.32
A8			$\frac{1}{1}$	10.1×9.30	107×47.4	103.7	0.232	13.40
A9			$\frac{1}{1}$	10.8×9.10	101.9×45.6	101.0	0.224	12.32
B1			$\frac{1}{1}$	8.33×8.33	92.9×44.3	96.1	0.212	12.61
B2		Between season coat	$\frac{1}{1}$	8.33×8.33	93.4×75.3	98.4	0.230	9.08
B3	PET/PET		$\frac{1}{1}$	8.33×8.33	76.9×41.7	86.5	0.214	4.12
B4		Lining	$\frac{1}{1}$	6.05×6.10	39.6×32.0	58.9	0.072	2.14
B5		Down-proof	$\frac{1}{1}$	6.35×7.85	57.6×52.6	79.9	0.136	1.70
B6		Drape fabric	$\frac{4\ 1}{1\ 2}$	19.7×17.8	119.6×47.8	110.2	0.512	0.63
C1	PA/PA	Livery cloth	$\frac{4\ 1}{1\ 2}$	3.33×23.3	45.9×57.2	76.8	0.307	1.45
C2			$\frac{2}{2}$	7.78×15.6	80.5×59.9	92.2	0.219	3.43
D1		Crepe georgette	$\frac{1}{1}$	6.53×6.48	39.7×36.7	61.9	0.456	0.02
D2	Real silk	Crepe de chine	$\frac{1}{1}$	5.85×8.55	44.3×41.7	67.5	0.196	0.03
D3		Necktie silk	$\frac{2}{2}$	3.90×4.05	92.6×38.5	95.4	0.224	0.03
D4		Plain habutai	$\frac{1}{1}$	5.18×3.98	50.5×31.0	65.9	0.113	0.01
E1		Serge	$\frac{2}{2}$	28.3×25.1	65.0×55.6	84.4	0.388	0.35
E2		Palace	$\frac{1}{1}$	19.9×20.8	53.6×46.4	75.2	0.311	1.45
E3	Wool	Fancy suiting	$\frac{1}{1}$	55.4×54.8	59.2×53.4	81.0	0.509	0.96
E4		Valitin	$\frac{1}{1}$	32.5×40.5	66.4×61.2	87.0	0.486	0.56
E5		Valitin	$\frac{1}{1}$	30.4×27.9	65.3×33.2	76.8	0.392	0.35
E6		Gabardine	$\frac{2}{2}$	52.2×51.4	65.5×63.7	87.5	0.514	0.32
F	Cotton/PTT	Blouse fabric	$\frac{1}{1}$	14.3×10.6	70.0×36.1	80.8	0.231	3.25
G	PET/Cotton	Blouse fabric	$\frac{2}{2}$	8.33×25.0	63.5×78.6	92.2	0.384	5.45
H1		Plain fabric	$\frac{1}{1}$	9.40×9.80	69.8×58.5	87.5	0.324	3.55
H2		Plain fabric	$\frac{1}{1}$	24.9×30.5	42.5×44.3	68.0	0.489	0.73
H3	Cotton	Poplin broad-cloth	$\frac{1}{1}$	16.8×13.3	81.1×34.7	87.7	0.375	5.11
H4		Poplin broad-cloth	$\frac{1}{1}$	19.2×19.4	56.7×39.1	73.7	0.395	1.95
H5		Poplin broad-cloth	$\frac{1}{1}$	29.7×29.7	79.5×39.7	87.6	0.518	3.78
H6		Poplin broad-cloth	$\frac{1}{1}$	14.9×14.9	78.7×56.3	90.7	0.353	6.67

Note: (1) $2HG_1$ represents the shear hysteresis of warp at a 0.5° shear angle; (2) except cotton and wool, other materials are in filament forms for the samples listed in Table 1; (3) only PTT fabrics are advanced fabrics which developed recent years in Table 1, and their twist values of warps and wefts are only (40~80) twists per 10 centimeters, and other fabrics are conventional fabrics with common twist values.

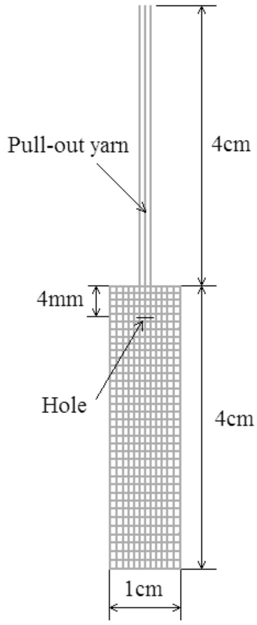

Figure 3. Specimen for pull-out test

2.3. Experimental procedures

Pre-test was carried out to determine the number of specimens for each sample, since pull-out test did not have reference standard. Six specimens for each sample were adopted by analyzing the pre-test data.

Six fabric strips, 8cm×1cm, were cut along the warp and weft directions of the fabrics, respectively. Specimens were prepared according to section 2.2. XQ-1 Fiber Tensile Tester was used for testing pull-out force. Experimental steps were as follows: (1) The middle one of the three yarns of each specimen was clamped by the upper jaw of the tester, which ensured the pull-out yarn was not damaged; (2) the tester's under jaw clamped the place of specimen which below the hole, shown as Figure 3, ensuring the yarn could be pulled out; (3) started the tester and determined pull-out force.

3. RESULTS AND DISCUSSION

The typical curve of pull-out yarn test is shown in Figure 4. The region AB was the decrimping of pull-out yarn. The slope of BC region was nearly constant, and the slope might reflect the ability of fabric's transfering shear stress and resisting deformation in pull-out process(15), both pull-out yarn and the fabric had elastic deformation in the region. Point C was the critical point and the force in the point was junction rupture force, and the pull-out force was the maximum as well. Pull-out yarn slipped the first crossover after point C, and static friction changed into dynamic friction; pull-out force in CD region decreased sharply since dynamic friction was less than static friction. Dynamic friction changed into static friction in DE region, and pull-out yarn slipped the second crossover after point E. In short, whenever slipped a crossover, the change of friction state occurred, and pull-out force reduced with the number of crossovers decreasing.

3.1. Extracting of characteristic index

In this work, twill fabric is used for showing the method of extracting the characteristic index. Figure 5 is the warp-wise profile of $\frac{1}{2}$ twill fabric. For comparison purposes, the problem is simplified and the following assumptions are made:

(1) The direct data of the test is junction rupture force, which composes of two kinds of frictional forces, cross point and level segment frictional forces, see figure 5. Suppose that a cross point and a level segment make up an interlacing unit, therefore, junction rupture force is equal to the frictional forces of all the interlacing units through which pull-out yarn slips.

(2) Suppose that cross points of warps and wefts are surface-contact, and the area of an interlacing unit is the product of the diameters of warp and weft.

(3) In order to quantitatively compare the frictional forces between yarns in different fabrics, frictional forces per area in the warp and weft interlacing unit *F* is used for characterizing the frictional forces in fabrics.

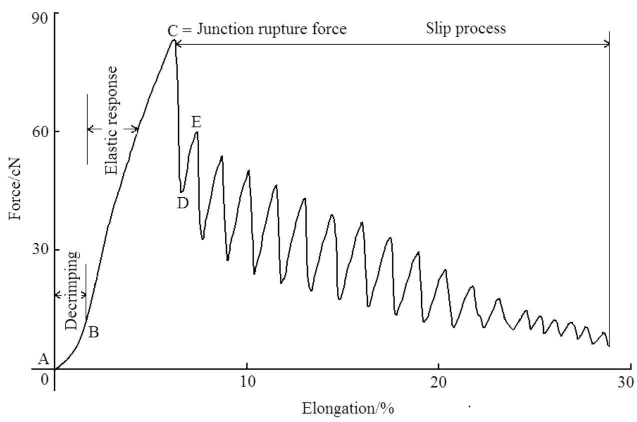

Figure 4. Pull-out force-elongation profile illustrating various regions

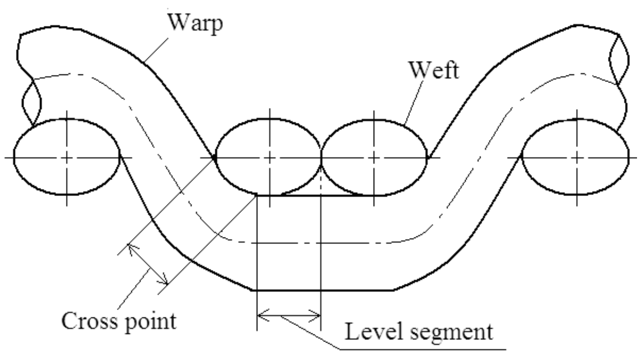

Figure 5. Warp-wise profile of $\frac{1}{2}$ twill fabric

In addition, yarn diameter *d*, volume weight *δ* and linear density N_{tex} have the following relationship (16):

$$d = 0.03568\sqrt{\frac{N_{tex}}{\delta}}(mm) \quad (1)$$

Yarn volume weight (δ) of conventional yarns can be got from reference (16). PTT is a new textile material and the calculation method of PTT yarn's volume weight was given in the former paper (1).

Therefore, the area of a warp and weft interlacing unit *A* can be calculated by the following formula:

$$A = d_w \times d_f = 0.03568\sqrt{\frac{N_{tex_w}}{\delta}} \times 0.03568\sqrt{\frac{N_{tex_f}}{\delta}} \quad (2)$$

Where d_w and d_f are the diameters of warp and weft, respectively. N_{tex_w} and

N_{tex_f} are the linear densities of warp and weft, respectively.

Therefore, the formula of *F* is as follow:

$$F = \frac{\left(\frac{F_w}{A} + \frac{F_f}{A}\right)}{2} \quad (3)$$

Where $\frac{F_w}{A}$ is the frictional force per area in the warp and weft interlacing unit when pulling out warp, while $\frac{F_f}{A}$ is the frictional force per area in the warp and weft interlacing unit when pulling out weft.

$$F_w = \frac{F_{cw}}{(n_f / n_{xf}) \times n_{iw}} \quad (4)$$

$$F_f = \frac{F_{cf}}{(n_w / n_{xw}) \times n_{if}} \quad (5)$$

Where F_w and F_f are the frictional forces in the warp and weft interlacing unit when pulling out warp and weft, respectively. F_{cw} and F_{cf} are the junction rupture force when pulling out warp and weft, respectively. n_f is the number of wefts that warp slipped through in pull-out distance when pulling out warp, while n_w is the number of warps that weft slipped through in pull-out distance when pulling out weft. n_{xw} and n_{xf} are the number of warps and wefts per repetition of weave, respectively. n_{iw} is the interlacing times of warp to wefts per repetition of weave, while n_{if} is the interlacing times of weft to warps per repetition of weave.

3.2. Test results and analysis

Test results are shown in Figure 6.

Figure 6 showed that the values of *F* of PTT fabrics were larger, especially for plain weave fabrics, and all values were above 0.5cN/mm^2, much higher than traditional PET fabrics, wool fabrics and silk fabrics (all of them were less than 0.2cN/mm^2). PTT fabrics used in this study had dense constructions (either plain weave or twill), lower linear density (shown in Table 1), and were made from either untwisted or low-twist yarns, and without deweighting process technology (17), (18). These factors resulted in high frictional forces between the fibers and yarns.

For PET fabrics, both B1 and B2 had larger *F* values, since they had a similar manufacturing process to the PTT fabrics used in this study. Other PET fabrics were traditional fabrics, and all of them had smaller *F* values. All the real silk fabrics had smaller frictional forces between yarns, with D2 excepted, since it without degumming treatment. Wool fabrics had good elasticity, and all of their internal frictional forces were smaller.

3.3. Relationship between fabric "wave" plasticity and frictional force

In order to test the application value of *F* and research the relationship between fabric "wave" plasticity and frictional forces in fabrics, correlation analysis was done between *F* and the index which could represent fabric "wave" plasticity. Previous study (1) showed that it was possible to use fabric "wave" plasticity of one direction to predict those of other directions. Therefore, correlation analysis was carried out between fabric "wave" plasticity of 45° direction and *F*. Previous studies (1) also found that shear hysteresis of warp at a 0.5° shear angle ($2HG_1$) could be used for evaluating the fabric "wave" plasticity of 45° direction. So, correlation between *F* and $2HG_1$ substitute for the frictional forces in fabrics and fabric "wave" plasticity was analyzed. The results are shown in Figure 7.

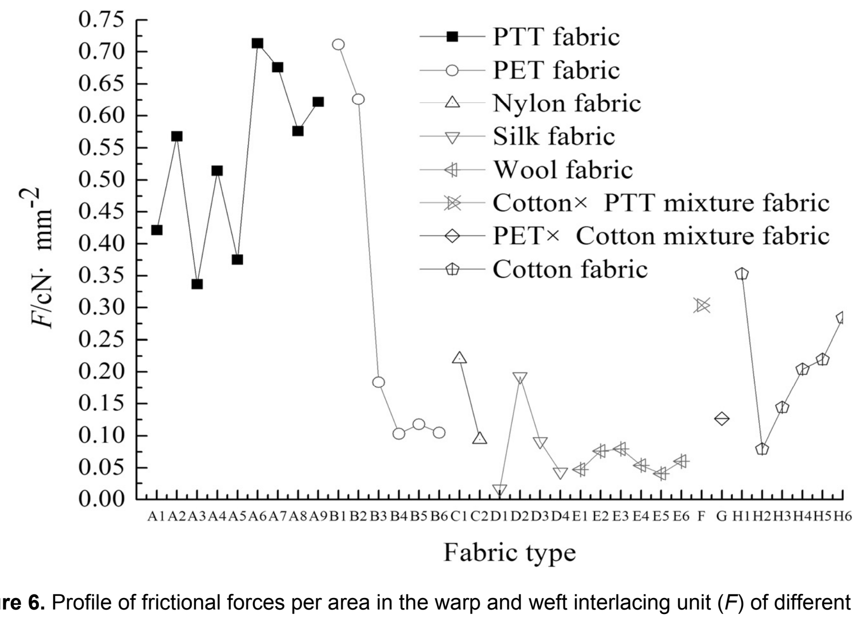

Figure 6. Profile of frictional forces per area in the warp and weft interlacing unit (*F*) of different fabrics

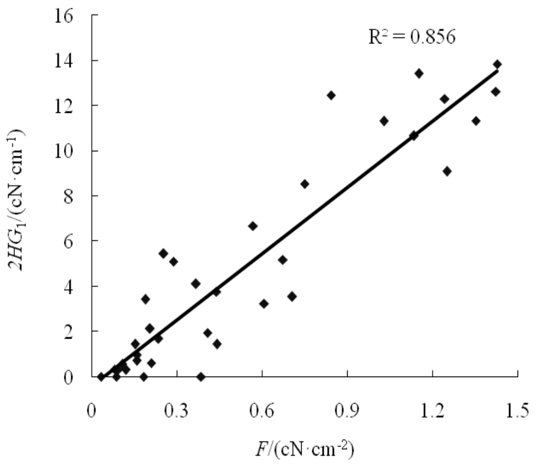

Figure 7. Correlation coefficients between frictional forces per area in the warp and weft interlacing unit(F) and shear hysteresis of warp at a 0.5° shear angle ($2HG_1$)

As could be seen from Figure 7, correlation coefficient between F and $2HG_1$ was above 0.91. Therefore, fabric "wave" plasticity was closely related to frictional forces per area in the warp and weft interlacing unit, furthermore, excellent fabric "wave" plasticity indicated that the fabric with larger internal frictional forces. The results strongly proved the validity of the explanation about the mechanism of fabric "wave" plasticity proposed in the paper, that was, powerful internal frictional forces provided fabrics with good fabric "wave" plasticity. Moreover, the results also showed that F could reflect the internal frictional forces in fabrics.

4. CONCLUSIONS

Fabric "wave" plasticity is one of the inherent characters of fabric, with which fabric can be shaped into a curved surface above body surface. The property is critical to concavo-convex curved shape garments which welcomed by consumers. In order to better design and develop such fabrics and garments, the mechanism of fabric "wave" plasticity was deeply studied in the paper.

Test of pulling out yarns from fabrics was designed. Feature index F that the frictional forces per area in the warp and weft interlacing unit was used for characterizing the frictional forces between yarns in fabrics. Results showed that the values of F of PTT fabrics which had excellent fabric "wave" plasticity were much larger than those of traditional PET fabrics, wool fabrics and real silk fabrics. Besides, PET fabrics which had similar manufacturing technology with the PTT fabrics used in the paper had large values of F as well.

In order to test the application value of F and study the relationship between F and fabric "wave" plasticity, and then determine the mechanism of fabric "wave" plasticity, correlation analysis was carried out between F and the mechanical index which could represent fabric "wave" plasticity. It was found that F and the mechanical index had a high positive correlation with correlation coefficient above 0.91. The results also reflected the mechanism of fabric "wave" plasticity, that was, fabric "wave" plasticity was a reflection of frictional forces in fabrics. Moreover, the results indicated that F proposed in the paper could reflect the frictional forces in fabrics.

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