Twist Redistribution of Folded Yarns in Woven Fabrics

Comparison of Single and Folded Yarn Fabrics

織物における双糸の撚りの再分配

単糸と双糸の布間の比較

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Abstract

In the present study, the concept of twist redistribution of folded yarns in a woven fabrics is introduced and the reasons for the twist redistribution of folded yarns have been given.

Two pure cotton woven fabrics are compared. These two fabrics have similar industrial specifications, except that one is made of 100s/2 folded yarns, the other of single 50s yarns. Using the concept of twist redistribution of folded yarns in a woven fabric and variation of yarns in a woven fabric, this paper makes use of these two fabrics to explain why 100s/2 woven fabrics are becoming more and more popular or how the folded yarn fabrics are superior to the single yarn fabrics.

Through comparing the measured geometrical and mechanical properties of these two fabrics, it is shown that, in addition to their better appearance than 50s woven fabrics, 100s/2 fabrics have better quality in terms of mechanical properties and handle.

It is believed that the twist redistribution takes place during the formation of woven fabric made of folded yarns. However, it may be more realistic to see the redistribution as a tendency rather than an exact relationship between fabric sett and yarn twist.

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摘 要

本研究では、織物における双糸の撚りの再分配の概念が導入され、双糸の撚り再分配の理由が示されている。

100s/2 双糸と 50s 単糸を用いた以外はほぼ同一の仕様の 2 種の純綿織物間の比較を行っている。織物における双糸の撚りの再分配と糸むらという視点から、なぜ 100s/2 織物の人気がますます出てきているのか、またはいかに双糸布が単糸布より優れているか、をこの 2 種の布を用いて説明している。

この 2 種の布の幾何学的並びに力学的性質の測定結果を比較し、双糸布は単糸布よりより優れた外観を持つばかりでなく、力学的特性と風合いの点でもより高品質であることを示している。

撚りの再分配は双糸からの製織時に生じると思われているが、布目と糸の撚り間の厳密な関係よりも、むしろ一つの方向としてこの再分配が生じるものとみるのがより現実を反映しているようである。

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1. Introduction

It was reported, in JTN (Japanese Textile News), May, 1990¹⁾, that 100s/2 pure cotton woven fabrics boast the second largest demand

sale next to 50s pure cotton fabrics. In regard to 50s woven fabrics, buyers increasingly consider that the inferior quality cannot be recovered by finishing since it is extremely difficult to produce such fabrics in consistent quality. By con-

trast, 100s/2 woven fabrics are made of two-fold yarns; the poor quality is less conspicuous than 50s woven fabrics.

In the present study, the phenomenon of twist redistribution of folded yarns in woven fabrics is observed, and the reasons for this tendency is explained. Two pure cotton woven fabrics are compared. These two fabrics have similar industrial specifications, except that one is made of 100s/2 folded yarns, the other of single 50s yarns. Using the concept of twist redistribution of folded yarns in a woven fabric and variation of yarns in a woven fabric⁹⁾, this paper will make use of these two fabrics to explain why 100s/2 woven fabrics are becoming more and more popular or how the folded yarn fabrics are superior to the single yarn fabrics. Through comparing the measured geometrical and mechanical properties of these two fabrics, it will be shown that, in addition to their better appearance than 50s woven fabrics, 100s/2 fabrics have better quality in terms of mechanical properties and handle.

2. Experiment

2.1 Tests of Mechanical Properties

In practical terms, the strain or stress applied to woven fabrics during manufacturing, finishing, garment construction and wear, are generally within the low-stress region. The major stresses involved in fabric deformation under low-stress conditions are tensile, shear, bending and compression. Thus the analyses in the present work are based on the mechanical properties tested on the Kawabata Evaluation System (KES).

All samples were tested in both the warp and weft directions for:

- (1) Tensile and shear properties,
- (2) Pure bending properties
- (3) Surface and friction properties, and one value for
- (4) Compression properties.

2.2 Tests of Geometrical Parameters

A. Preparation of Samples

In examining fabric structure, it is necessary to set the fabric in resin. This is done by cutting small pieces of the fabric such that its length and width are 25×25 (mm), and sticking one piece on a stiff paper frame with a square hole of about 20×20 (mm) in the middle. The stiff paper with the sample fabric was inserted into a rubber mould vertically. A prepared liquid mixture of epoxy resin of ARADITE MY753 and ARALDITE HARDENER HY951 (ratio is 10:1) is poured into the mould. After 24 hours, the resin block containing the fabric can be taken out. Following this, the block is cut into very thin slices by a slow speed saw. The thickness of a slice is usually larger than a_i (major diameter of thread) and smaller than p_j (thread-spacing), where i and j take the values of 1 and 2 for warp and weft. So the thickness is about 0.1~0.3mm for fabrics used in the present investigation. Embedding agents which are transparent are commercially available. The slices are then employed for the observation and measurements of various geometrical parameters such as crimp height h using the VIDS image analysis system, optical and Scanning Electron Microscope.

B. The VID Image Analysis System

Most of Geometrical parameters were measured by the VIDS image analyzer.

The VIDS system²⁾ combines the video output from a TV camera with the graphics display of the APPLE computer so that measurements may be made directly from the TV image. A Calcomp digitizing tablet allows the operator to measure a range of feature parameters using VIDS software package. VIDS software package contains general measurement, area fractions measurement, 4-dot measurement, 2-dot measurement, linear measurement, twist angle and point count programmes. The results of these measurements may be displayed on the computer screen, printed using a printer or stored on a floppy disk.

The VIDS general measurement programme

allows the user to draw round features displayed on the computer screen using the digitizing tablet and four-button cursor. The following results may be obtained for each feature as well as the mean and the standard deviation of each: Area, perimeter, form factor, maximum projected horizontal and vertical lengths.

This programme was used to measure area of yarn cross-section and crimp height of yarns in the present study.

The VIDS Two-Dot measurement programme allows the rapid measurement of features which can be defined by two points. This programme was used for measuring major and minor diameters of yarns in a fabric.

C. Sett, Thread-Spacing

The number of warp and weft threads per centime were determined by using parallel-line gratings as described in The British Standard BS 2862: 1972. Five reading of every sample were taken to represent the threads per unit length of one fabric. The average number of threads per centime and the threads-spacing were then calculated. If n stands for the threads per unit length, p the spacing can be calculated by using the following formulae and the tested sett and thread-spacing are listed in Table 1.

$$p_i = \frac{1}{n_i} \quad i, j = 1-2 \tag{1}$$

D. Crimp

The determination of 1, the yarn length per unit is a key parameter for crimp calculation as shown in eq. (2).

Yarn crimp was measured by applying a specified tension to a length of yarn and measuring the resultant extension, which may be

$$c_i = \frac{1-p_i}{p_i} \times 100\% \quad i, j = 1-2 \tag{2}$$

dependent on the particular tension used in testing. The testing method referred to British Standard BS 2863: 1972.

E. Crimp Height

As shown in Fig. 1, the crimp height of yarns were measured using the general measurement programme introduced above. The sample is

Fig. 1 Measurement of crimp height

positioned to ensure that the surface of the fabric touches the horizontal line.

In order to do this, peaks of the weave of the tested fabric are positioned on the horizontal line. We need only spot three points to form a closed triangle. The height of the triangle is read by the maximum vertical projected length, which is the crimp height of a yarn within the fabric.

F. Yarn Diameters

Minor and major diameters of yarns, as shown in Fig. 2, were measured using the two-dot programme. The measurements are made by positioning the screen cursor over the first point to be marked and pressing down a button on the cursor so that a dot appears on the screen in the middle of the cursor. The button on the cursor is then lifted, moved and pressed down again to give a second dot, a beep indicates that a complete 2 dot measurement has been made.

Fig. 2 Measurement of yarn diameters in fabric

G. Area of Yarn Cross-section in a Fabric

To measure the area of yarn cross-section, one draws round the border of the cross-section of a yarn using the general measurement programme. When the beginning and the end of the border line are overlapped, the complete measurement of area of a yarn has been made.

H. Images of Yarn Cross-section and Fabric Surface

The cross-section photographs used in this paper were taken using a camera attached to the eyepiece of an ordinary optical microscope. Two photographs of each direction of a sample were obtained. The images of fabric surface were obtained by using Acaning Electronic Microscope.

2.3 Calculations of Geometrical Parameters

A. Yarn Diameter

According to the Peirce's treatment⁴⁾, $1/d$, the number of diameters per inch in the cotton system, is given by:

$$\frac{1}{d} = \frac{29.3\sqrt{N}}{v} \quad (3)$$

where v is the yarn's specific volume. In a woven structure, $v = 1.1$.

$$\frac{1}{d} = 28\sqrt{N} \quad (4)$$

$$\begin{aligned} d &= \frac{1}{28\sqrt{N}} = 0.0357 \frac{1}{\sqrt{N}} \text{ (inch)} \\ &= \frac{36}{\sqrt{N}} \text{ (mils)} = 0.91/\sqrt{N} \text{ (mm)} \end{aligned} \quad (5)$$

Hence, the calculated area of yarns before weaving is:

$$A = \pi \frac{d^2}{4} \quad (6)$$

B. Fabric Cover Factor

Fabric cover factor is defined by Hamilton³⁾ geometrically as the proportion of fabric area covered by actual yarns. In practice cover factors are normally calculated for warp and weft independently. For example, a fabric having 50 warp threads per centime, each 0.01 centime in major diameter, would have a warp cover factor K_1 of 0.5 or 50%. In the case of circular section threads,

$$K'_1 = n_1 d_1^2 \quad K'_2 = n_2 d_2^2 \quad (7)$$

For

flattened threads, warp and cover factors for plain weave are thus given by

$$K_1 = n_1 a_1 \quad K_2 = n_2 a_2 \quad (8)$$

and over-all cover factor K is calculated as follows:

$$K = K'_1 + K'_2 - K'_1 K'_2 \quad (9)$$

Or

$$K = K_1 + K_2 - K_1 K_2 \quad (10)$$

The cover factor thus indicates the degree of closing or cover, the projection of area which is covered by the projection of the threads, ooiness of yarn, flattening in finishing increase the cover of cloth.

3. Twist Redistribution of Folded Yarns in Woven Fabrics

Figure. 3 shows the surface images of several woven fabrics made of folded yarns. From Fig. 3 (a), which represents a very open woven fabric, it can be seen that the length of a folded yarn in one twist is inserted into one repeat of plain weave fabric. Other samples shown in Fig. 3(b) and (c) exhibit a similar effect. For very close fabrics with few turns of twists, one turn of twist

Front side

Back side

Fig. 3(a) Surface image of an open fabric with folded yarns

Front side

Front side

Back side

Back side

Fig. 3(b) Surface image of a Poplin fabric with folded yarns (Sample 2)

Fig. 3(c) Surface image of a Canvas fabric with folded yarns

may be inserted into one and half or two repeats of a plain weave fabric. There is no literature reporting that a designer would match sett and twists exactly as they are finally found in a woven fabric. The phenomenon is called “twist redistribution” in a woven fabric because twists of a folded yarn are subjected to adjustment when a woven fabric is formed. This phenomenon may suggest in most cases the contraction of folded yarns in the longitudinal direction, expansion in the diametrical direction in a woven fabric. It can be explained in the following way:

From the above figures, it is also very clear that the two folds of a yarn become parallel to each other and to the fabric plane at the contact region of the two yarn systems of a woven fabric in most cases. This can be explained by the principle of minimum energy when a system reaches a equilibrium state. Figure. 4 shows a

two-cylinders system with the constraints of walls, in which the equilibrium state must be the (b) state.

There may be many states between (a) and (b), whatever state the system of the two cylinders stands at the beginning, eventually, they will reach the (b) state if there exists little friction. In the case of a folded yarn in a woven fabric, which is constrained by the twists and the adjacent yarns, the parallel state of two folds is enforced by the compression force between warp and weft yarns, and this will increase the twist angle of the folded yarn, thus it contracts the folded yarns per centime length of fabric and the measurement in the diametrical direction will increase if the density of yarns remains the same as that before weaving. Therefore more yarns are contained in one centime length of fabric when folded yarns are used. We may think it is

Fig. 4 Equilibrium condition of two cylinders system

similar to the increase of yarn twists.

Figure. 5 shows the dimensional changes of folded yarns in certain section of a woven fabric. (a) represents the length of folded yarns before weaving, in which γ is the twist angle of the two folds. (b) represents the length of yarns within a fabric with the assumption that there is no twist redistribution, in which the twist angle and the width of yarns remain the same as before weaving. (c) describes the actual length of a folded yarn due to the twist redistribution, in which the length of the folded yarn becomes shorter and thicker than before weaving because twist angle

γ is increased by δ .

In addition, the twist redistribution might affect the sett of a woven fabric, or make the spacing smaller than designed. But the tested geometrical and mechanical data listed later suggests this possibility may exist but not very large. In addition, the rule of the twist redistribution described above is the general trend, and not necessarily always, in any segment of yarn, exactly true because the actual twists may not be exactly matched with the sett even after twist redistribution. This finding, with the phenomena of yarn variation in thickness may be useful for understanding the geometrical, mechanical and quality differences of two fabrics, of which one poplin fabric (Sample 2) is made of folded yarns, whereas the other fabric (Sample 4) is a poplin with single yarns, and the two have similar other industrial specifications.

4. Comparison of Single and Folded Yarn Fabrics

4.1 Comparison of Geometrical Properties

The experimental results show that the above two fabrics have different geometry and the observed differences in geometrical properties are consistent with the anticipated. Table 1 lists the geometrical data for the two fabrics

Fig. 5 Dimensional changes of folded yarn in woven fabric with twist redistribution

Table 1 Geometrical parameters for sample 2 and sample 4

Parameter	Sample 2			Sample 3		
	Warp	Weft	Mean	Warp	Weft	Mean
N	100s/2	100s/2		50s	50s	
n (threads/cm)	58.7	28.7	43.7	57.9	26.8	42.35
a (mm)	0.21	0.24	0.225	0.17	0.19	0.18
b (mm)	0.08	0.1	0.09	0.09	0.09	0.09
e	2.63	2.4	2.515	1.89	2.11	2
K' (%)	75.55	36.94	84.58	74.68	35.52	83.68
K (%)	123.27	68.88	107.24	88.23	52.14	94.49
C (%)	9.91	6.27	8.09	8.34	5.36	6.85
h (mm)	0.187	0.062	0.125	0.200	0.066	0.266
A' (mm ² × 10 ²)	1.306	1.306	1.306	1.306	1.306	1.306
A (mm ² × 10 ²)	1.419	1.717	1.568	1.236	1.517	1.377

Note : (1)the means of cover factors K and K' are the overall cover factors (see chapter 3), not the averages,
(2) A' and K' are calculated values, A and K the measured ones,
(3) e is the flattening coefficient (a/b)

From Table 1, the following facts can be noticed:

From Table 1, Sample 2 and Sample 4 have similar specified cover factors K' in percentage, the same calculated original yarn cross-sectional areas A' . Whereas in a final woven fabric, a folded yarn is more flattened than a single yarn, the average flattening coefficients are 2.515 for Sample 2 and 2 for Samle 4. This leads to the larger cover factor of the folded yarn fabric than the one with single yarns, which is indicated by the values of K , the measured cover factors. The total cover factors of these two fabrics are 107.24 and 94.49 respectively. This is required by the equilibrium condition of the two-fold yarn system, at which the two folds of yarns tend to become parallel to each other. In addition, the measured warp and weft yarn cross-sectional areas for Sample 2 are larger than those of Sample 4. The values of crimp of folded yarns are larger than the single yarns also, which is due to the contraction of folded yarns during twist redistribution. When a folded yarn is released from fabric, and stretched afterwards, the contraction of yarn length due to the twist redistribution is mainly responsible for this increase of the yarn crimp.

Figure. 6 shows the cross-sections of the two fabrics. Figure. 7 demonstrates the surface images of them.

From these figures, we can see that fabric 2

has a high cover and it is clear that the structure of fabric 2 has a larger variation in yarn thickness along the fabric plane and other directions, or fabric is more non-uniformly flattened than fabric 4. By contrast, the fabric made from single yarns has a smaller cover, or is comparatively much more open. The non-uniform flattening of sample 2 can automatically adjust the thickness of yarns to fill places between threads which can give a denser structure and better handle, but the defects of single yarns are very difficult to

Sample 2 Poplin with folded yarns

Sample 4 Poplin with single yarns

Fig. 6 Comparison of the cross-sections of two fabrics (warp direction)

Sample 2 Poplin fabric with folded yarns

Sample 2 Poplin with single yarns

Fig. 7 Comparison of surface image of two fabrics hide because there exists little non-uniform flattening in them.

In the above table, the setts of Sample 2, the folded yarn fabric, are slightly larger than those of sample 4. This may suggest that the using of folded yarns may cause the change of sett, but in the present case, this change seems not very large. If we assume these two fabrics have exactly the same design sett, and the increase of folded threads per centime (sett) compared with that of single yarns is about 3%.

B. Comparison of the KES Data

The KES data, as shown in Table 2, reveal significant differences in the mechanical and surface properties of these two fabrics. These differences in fabric properties may be related to the geometry of the two fabrics. Pronounced differences can be summarized as follows:

Except for *RC*, *MMD* and *SMD*, all values of the KES properties of Sample 2 are larger than those of Sample 4.

First of all, the weight of Sample 2 is much

larger than Sample 4, which is caused by the contraction of folded yarns during the twist redistribution when a fabric is formed, and in turn the increase of the tension crimp values.

Secondly, folded yarns produce a fabric that is more extensible and more resilient in stretching. The larger extension and larger tensile work is attributable to the larger crimp of Sample 2, which results from increased twist angle during twist redistribution of folded yarns Sample 2 as well. The larger value of *RT*, tensile resilience, may be due to the tendency of the recover of twist redistribution to fit the fabric structure again when the fabric is released from tension.

Thirdly, the larger values of shear properties for Sample 2 are attributable to the larger cover factors²⁾.

Bending properties show significant differences between two fabrics. The bending response of single yarn fabric is indicative of higher initial resistance and low recovery and they can be associated with the following: the larger bending stiffness and hysteresis (*B*, *2HB*) are firstly caused by the decrease in the portion of free bending along yarn axis, which is caused by the increase of cover factor for folded fabric. Secondly, they can be associated with the increase of twist angle of folded yarns, which is similar to the increase of twist index and produces larger interfibre compression, thus increasing the interfibre friction because, as discussed²⁾, the bending stiffness is related to interfibre friction. Bending hysteresis is obviously caused by the increase of interfibre friction.

Fourthly, Sample 2, folded yarn fabric, is more compressible but less resilient than Sample 4, single yarn fabric, in compression. Surface test data show that folded yarns produce a fabric that is comparatively smoother, that is, smaller geometrical roughness, and lower deviation of friction coefficient; however, surface friction coefficient is somewhat higher than those for the single yarn fabric. The smaller values of *MMD* and *SMD* of folded yarn fabric may result from the larger cover factor and the automatic adjust-

Table 2 Mechanical properties of two fabrics

Parameter	Sample 2			Sample 4		
	Warp	Weft	Mean	Warp	Weft	Mean
<i>LT</i>	0.567	0.761	0.664	0.56	0.695	0.628
<i>WT</i>	9.34	10.12	9.73	8.05	9.18	8.62
<i>RT</i>	57.1	56.6	56.8	53.3	50.7	52
<i>EMT</i>	6.6	5.33	5.97	5.75	5.3	5.53
<i>G</i>	1	0.88	0.94	0.66	0.58	0.62
<i>2HG</i>	1.72	1.51	1.62	1.1	0.93	1.02
<i>2HG5</i>	3.06	2.81	2.94	2.17	2	2.09
<i>B</i>	0.0631	0.0382	0.0507	0.06	0.0268	0.0434
<i>2HB</i>	0.0508	0.0279	0.0394	0.0433	0.0265	0.0349
<i>MIU</i>	0.16	0.203	0.182	0.136	0.162	0.149
<i>MMD</i>	0.0082	0.0119	0.0101	0.0112	0.0103	0.0108
<i>SMD</i>	2.85	2.09	2.47	3.47	1.94	2.71
<i>LC</i>			0.325			0.315
<i>WC</i>			0.114			0.085
<i>RC</i>			42			48.6
<i>TO</i>			0.35			0.299
<i>T_M</i>			0.209			0.188
<i>W</i>			11.36			9.91

Table 3 Kawabata primary hand values
(Evaluation equations:KN-201-LDY)

Japanese name	English name	Values	
		Sample 2	Sample 4
<i>Koshi</i>	Stiffness	6.093	5.9411
<i>Hari</i>	Anti-drape stiffness	7.9539	7.7307
<i>Fukurami</i>	Softness and Fullness	6.1798	5.9156
<i>Kishimi</i>	Cashmere-like	3.5955	3.43

ment of non-uniformly distorted variation of folded yarns. The larger thicknesses of Sample 2 accounts for the larger areas of folded yarns.

4.3 Comparison of Fabric Hand

In fact, the fabric made from folded yarns has not only a denser structure, but also a better handle, soft lustre, and better quality. The twist redistribution and non-uniform distortion of folded yarns contribute to the superior behaviour of the folded yarn fabric. The above results show that folded yarn increases fabric resistance to bending and shear deformation, but smaller resistance to tensile and compression; the folded yarn fabric has higher thickness and larger weight. All these contribute to the better fabric hand and quality. Kawabata primary hand

values are shown in Table 3.

From Table 3, it is noticed that all values of primary hand of Sample 2 are larger than those of Sample 4. They can be explained as the following.

- 1. Using folded yarns improves fabric quality primarily by increasing the fabric's cover factor, fabric thickness, weight, tensile resilience, larger ability to absorb the compression energy, and by reducing the geometrical roughness and the deviation of friction coefficient.
- 2. Fabric made with folded yarns is inherently stiffer in bending and shear than the fabric made with single yarns. The hysteresis of these two deformation modes also larger. These factors contribute to the *Koshi* (higher) stiffness and *Hari* (anti-drape stiffness) of fabrics made

with folded fabrics.

The benefit of using folded yarns is particularly great for the fuller and softer, and higher *Kishimi* (cashmere-like) primary hand values. We believe that the higher thickness, larger weight, lower tensile stiffness and higher tensile resilience combined with greater absorption of compressional energy, lower surface roughness and lower deviation of friction coefficient give a fuller and softer cashmere-like hand for fabrics made with folded yarns.

5. Conclusions

The concept of twist redistribution of folded yarns in a woven fabric is introduced and the reasons for the twist redistribution of folded yarns have been given. Finally the effects of twist redistribution together with the yarn variation on the geometrical and mechanical pro-

perties as well as the fabric hand have been used for the explanation of the differences two samples made of folded yarns and single yarns.

It is believed that the twist redistribution takes place during the formation of woven fabric made of folded yarns. However, it may be more realistic to see the redistribution as a tendency rather than an exact relationship between fabric sett and yarn twist. In addition, it is desirable that the redistribution can be microscopically and quantitatively pursued.

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