USING SIROMAT TO DISTINGUISH FIBER MATURITY RELATED ISSUES IN THE MILL

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Abstract

Fibre maturity is regarded as a central characteristic of cotton fibre through its direct and indirect correlation with physical and chemical properties of commercial and technical importance. SiroMat is an automated version of the polarized light microscopy technique, which analyzes interference colours transmitted by cotton fibres when they are placed between crossed polars and a first order retardation plate. The percent areas of colours in images of fibre snippets relate directly to fibre maturity. Moreover, because fibres are analyzed on an individual basis a maturity distribution for a sample can also be measured. In this study two sub-sets of cotton each with the same average Micronaire but with different fibre maturity values as measured by SiroMat were processed from raw fibre through to dyed finished knit fabric. The objective of the study was to examine the sensitivity of SiroMat average maturity and distribution values in predicting differences in griege yarn and dyed fabric quality. Results of the study demonstrate the relevance of SiroMat test results in terms of predicting fibre maturity and fineness related quality problems and in particular the potential for SiroMat to be used as a tool for managing dye uptake problems at the mill laydown.

Introduction

From the spinners' perspective, both fibre maturity and fineness are key parameters in determining mill productivity and quality. For example, yarn is specified in terms of its weight per unit length and fibre linear density or fineness determines the number of fibres in a given yarn cross-section. The use of finer fibres increases the number of fibres in the cross section of a given yarn, which improves spinning efficiency and yarn evenness. Equally cotton fibre maturity is an important property to spinners and fabric manufacturers. Whilst many textile processing stages in the transformation of fibre through to fabric are sensitive to fibre properties that are contiguous with fibre maturity, the property of fibre maturity *per se* is more often not the dominant factor [Smith, 1991] in the same way that fineness, staple length and bundle strength dominate yarn quality parameters. The exception is perhaps the non-uniform dyeing of fabric; manifest as shade bands and repeats along fabric lengths, colour yield, barré and under-dyed or undyed neps, which is directly related to fibre maturity variations in the cotton being processed.

A central problem in managing fibre fineness and maturity has been the absence of accurate and convenient test methods to assess these properties. CSIRO Textile and Fibre Technology have developed the SiroMat technology that measures fibre maturity directly and automatically using polarized light microscopy [Gordon et al., 2005]. The interference colors transmitted by cotton fibres under this system are the result of the optical phenomena where cotton fibres behave like uni-axial optical (birefringent) crystals under polarized light. Previous work has shown that specific interference colours vary directly with theta (θ) [Gordon and Phair, 2005], which is generally accepted as being the 'true' expression of cotton fibre maturity [Lord and Heap, 1988].

By combining SiroMat values of maturity, which are calibrated in terms of maturity ratio, with the specimen's Micronaire value a measure of fineness can also be calculated using Lord's quadratic [Lord, 1956].

The objective of this study was to examine the sensitivity of SiroMat average maturity and distribution values (standard deviation and skewness values) in predicting differences in griege yarn and dyed fabric quality. Results of the study demonstrate the relevance of SiroMat test results in terms of predicting fibre maturity related quality problems such as non-uniform dyeing, and the potential for SiroMat to be used as a tool for managing mill laydowns.

Materials and Methods

Eight, small fibre samples (150 grams) of CSIRO pre-release cotton varieties grown on experimental plots at the Australian Cotton Research Institute (ACRI) in Narrabri, NSW were selected and processed through to a dyed knit fabric. The fibre samples were selected on the basis of having the same or similar Micronaire value but different maturity and fineness combinations. Table I lists the primary properties of the samples (designated A through to H) determined by an Uster Technologies 1000 high volume instrument (HVI). Two equal sub-sets are evident in the set of samples collected; one sub-set with samples having Micronaire values around 4.8 and one with Micronaire values of 4.4.

Specimens of each cotton sample were prepared for SiroMat testing by blending them through one passage of a 'Shirley' Analyser. Specimen preparation then involves guillotining a fibre beard prepared using a 'Fibrosampler' to obtain between 2 to 3 mg of 1 mm snippets from two cuts near the aligned end of the beard. The snippets were collected and then spread in an annular pattern on a 5 cm x 7 cm glass slide using an OFDA™ fibre spreader. A clean 5 cm x 7 cm slide was used to cover the specimen. Castor oil (refractive index = 1.477 – 1.481) was used as the mounting medium to enhance the contrast of the fibre snippets to their background. Preparing the SiroMat instrument involved adjusting the digital camera settings (U balance, V balance and shutter speed) and the microscope lamp intensity to match a prescribed background (magenta) colour in terms of red, green and blue ratios. Background colours were also checked at regular intervals during testing to minimize drift in instrument readings. Three specimens were tested per sample.

SiroMat maturity ratio (M) results were combined with HVI Micronaire (X) results to calculate fibre linear density or fineness (H) using Lord's quadratic equation [Lord, 1956] – see Equation (1). Table II lists the measured and derived SiroMat test results for each cotton sample.

$$MH = 3.86X^2 + 18.16X + 13 \qquad (1)$$

Spinning

One hundred and twenty-six grams (3 x 42 g lots) of machine harvested ginned lint (not lint cleaned) was sub-sampled from each experimental sample. Each 42 g lot was separately carded twice and drawn once using a 'Shirley' miniature spinning plant card and draw frame (Platt brothers, England); machine settings (e.g. roller distances and draft ratio) were constant for all samples. The four miniature drawn slivers were then drawn together once using a Trützschler HSR1000 draw frame. The resulting single sliver was converted into twisted roving using a Zinser 660 roving frame, which was then spun into yarn using a Zinser 350 ring spinning frame. For the full-scale processing, draft and twist was optimised for each sample to deliver a 20 tex yarn with a twist factor (αe) of 4.0 (798 turns per metre). Yarn bobbins were collected (two per sample) and tested for count, evenness (Uster Tester 4) and tensile (Uster Tensorapid) properties using industry standard methods. Table III lists standard yarn test results for each cotton sample.

Knitting and Dyeing

Yarn bobbins were waxed and wound but not cleared onto packages for knitting into fabric. Yarns were then knitted with a cover factor of 1.32 and a tightness factor of 15.4, on a Lawson Hemphill 10 inch F.A.K. knitting machine.

Knitted fabric was scoured and then dyed with Cibacron blue LS3R (1%) reactive dye. Colour measurements ($L^*a^*b^*$) were taken of fabrics illuminated using a D65 source at 10 degrees in a Gretag-Macbeth Color-Eye 7000A spectrophotometer. Average $L^*a^*b^*$ values (Table IV) represent nine spectrophotometric measurements taken in different places along the length of fabric from each cotton sample. Table V lists the ΔE values between each sample.

Selected dyed fabric samples (A, D, F & H) were also subject to extended pilling tests using the Atlas Random Tumble method [ASTM D3512]. Fabric samples were graded at 10 minute intervals up to 30 minutes and then subject to an additional 30 minutes treatment in the device. Fabric weight was recorded before and after the treatment in order to determine fibre loss.

Data Analysis

Fibre, yarn and fabric property results for each sample were cross-correlated using Minitab 15.1 to determine significant inter-relationships between samples in the set, and the fibre properties best used to predict yarn and fabric quality. The emphasis in this analysis is to investigate the ability of the SiroMat instrument to predict product quality in a mill. Table VII lists the primary fibre, yarn and fabric properties examined in the discussion. Significance was measured in terms of the Pearson Correlation Co-efficient (r) and the (linear) relationship probability. Whilst a linear relationship may not accurately describe particular relationships here, it is satisfactory in describing the significance of differences between extreme values in the small sets (n = 8) examined here.

Colour differences between the dyed fabric samples were measured in terms of ΔE on the CIELAB system [Westland and Ripamonti, 2004], which allows for differences to be better recognised in surface colours. Delta E describes the mathematical distance between two colours, e.g. $L_1a_1b_1$ and $L_2a_2b_2$, where $L_1a_1b_1$ might, although not in the case here, be a reference colour – see Equation (2).

$$\Delta E = \text{SQRT } (L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2 \qquad (2)$$

We identify ΔE values near or greater than one between any two fabrics here as being significant on the basis of the monochromatic nature of the dyed samples and the fact that in industry the samples would be viewed side-by-side as adjacent bands in knitted fabric.

Results and Discussion

The cotton samples were grown and harvested under near commercial conditions and as such reflect fibre maturity and fineness values that might be expected in similar grade cottons for a particular season. The range of maturity values in the set as measured by SiroMat was 0.90 to 0.98. According to Lord and Heap [Lord and Heap, 1988] this range qualifies all cottons in the set as being 'mature' or 'above average' in maturity; the 'mature' range extending from 0.85 to 0.95 and the 'above average' range extending from 0.95 – 1.00. From this perspective none of the cotton samples selected rate as being dangerous in terms of the impact their maturity (or fineness) might have on processing efficiency or product quality.

Of the samples in the set, sample H is nominally the best on the basis of its length (1.31 inches), strength (35.3 g/tex), fineness (171 mtex) and maturity (0.98). These properties clearly enabled a yarn with the best evenness and tensile properties to be spun (see Table III). In terms of fabric properties, sample H achieved a deeper colour (lowest L^* value) as dyed fabric, and exhibited, albeit together with a sample (F) with the lowest measured maturity, the best pilling grade after extended tumbling treatment. The pilling results whilst completed in triplicate and conducted according to the ASTM Standard [ASTM D3512] rely on subjective assessment and must therefore be viewed with caution.

Following the above example, examination of the correlation coefficient matrix (see Table VII) shows that fibre fineness measured either as Micronaire or linear density, staple length and bundle strength have a strong influence on basic yarn quality parameters such as evenness, imperfections and tenacity. No fibre maturity measurements were highlighted as being significant contributors to yarn properties.

However, average SiroMat maturity ratio and the SiroMat measure of the skew of the fibre maturity ratio distribution were strongly associated with bulk dye uptake measured in this study by reflectance (L^*) (lightness) measurements on the dyed fabric. Fabric samples constructed from more mature fibre, e.g. a maturity ratio > 0.94, dyed a deeper blue colour (lower reflectance) than samples with maturity ratio values < 0.94 by virtue of the greater uptake of blue dyestuff by the secondary cellulose of the more mature cotton. Skew values indicate that more mature cottons have a longer immature tail. This relationship has been described previously [Gordon, et al, 2007]. Figure 1 illustrates a typical fibre maturity distribution and the long immature tail of 'mature' cotton, as measured by SiroMat. Figures 2 and 3 illustrate the relationship between reflectance measurements and average maturity and the skew of a fibre maturity distribution. Relationships between fibre properties and actual colour (hue) values, a^* (red-green) and b^* (yellow-blue) were subdued because the hue components of the CIELAB colour system are not significantly affected by the achromatic changes measured by L^*.

The extent of the differences in dye uptake between cotton samples in this set as a result of their different maturity properties is demonstrated by calculating the ΔE values between pairs of the samples. Table V lists the ΔE values. Noted is that sample F, which has the lowest maturity ratio value (0.90) records ΔE values close or in excess of one for 4 out the five more mature samples, i.e. A, B, C and H in the set.

Conclusion

In this study we have demonstrated the value of SiroMat maturity, maturity distribution and calculated fineness values to predict primary quality in yarn, fabric and dyed fabric. Calculated fibre fineness from HVI Micronaire and SiroMat maturity ratio values was very strong in predicting yarn evenness and imperfections, whilst SiroMat skewness of the maturity distribution and average maturity ratio were strong in predicting dye shade variation. Interestingly, significant shade variation between samples occurred even though the range of maturity ratio values was between 0.90 and 0.98, which by convention would classify all samples examined as being 'mature' or 'above average' in maturity. The results show that mixing (yarn) samples that differ in terms of their maturity ratio scale by > 0.04 maturity ratio units will create dye shade problems, i.e. ΔE > 1.00, irrespective of the fibre being 'immature'.

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Table I – HVI Test Results

Sample	LEN (inches)	SFC (%)	STR (g/tex)	MIC (µg/inch)
A	1.18	9.1	30.6	4.8
B	1.20	10	31.4	4.8
C	1.21	8.9	31.7	4.9
D	1.21	8.3	33.4	4.7
E	1.24	9.8	31.8	4.4
F	1.26	8.7	32.9	4.4
G	1.27	9.9	32.6	4.4
H	1.31	8.2	35.3	4.4

Table II – SiroMat Test Results

Sample	SiroMat MR	SiroMat MR SD	SiroMat MR SK	SiroMat FIN
A	0.97	0.44	-2.37	194
B	0.95	0.47	-2.43	199
C	0.94	0.46	-2.28	207
D	0.93	0.48	-2.29	198
E	0.93	0.48	-2.21	180
F	0.90	0.50	-2.12	185
G	0.96	0.45	-2.41	174
H	0.98	0.44	-2.49	171

Table III – Yarn Test Results

Sample	Evenness CVm (%)	Thin -50%	Thick +50%	Neps +200%	Tenacity (cN/tex)	Elongation (%)
A	17.5	35	368	234	14.7	6.1
B	18.1	45	463	242	14.9	6.2
C	18.1	30	587	658	16.3	5.9
D	16.5	18	318	274	18.9	5.4
E	16.0	9	282	298	17.1	6.1
F	15.7	14	230	266	16.5	5.6
G	15.7	2	266	233	18.5	5.2
H	15.1	3	255	274	19.7	5.4

Table IV – Dye Uptake in Fabric Results

Sample	L	a	b
A	42.98	-2.06	-28.36
B	42.59	-1.95	-28.42
C	42.91	-2.12	-28.07
D	43.27	-2.25	-28.03
E	43.51	-2.14	-28.31
F	43.89	-2.21	-28.03
G	43.30	-2.18	-28.19
H	42.48	-2.08	-28.26

Table V – Differences in Colour (ΔE) between Dyed Fabric Samples

Sample	ΔE A vs.	ΔE B vs.	ΔE C vs.	ΔE D vs.	ΔE E vs.	ΔE F vs.	ΔE G vs.
B	0.411	-	-	-	-	-	-
C	0.301	0.497	-	-	-	-	-
D	0.471	*0.834*	0.387	-	-	-	-
E	0.529	*0.937*	0.647	0.386	-	-	-
F	**0.969**	**1.374**	**0.985**	0.619	0.477	-	-
G	0.374	0.775	0.412	0.175	0.247	0.609	-
H	0.515	0.235	0.470	*0.840*	**1.031**	**1.432**	*0.828*

Table VI – Differences in Pilling (Grade & Weight Loss) between Selected Dyed Fabric Samples

Sample	Pilling Grade				Weight in (g)	Weight out (g)	Fibre loss (%)
	10 min	20 min	30 min	60 min			
A	3	2.5	2	1.5	3.403	3.364	1.14
D	3.3	3	3	1.8	3.495	3.456	1.11
F	4	4	3.6	3	3.577	3.536	1.13
H	4	3.2	3.2	3	3.352	3.309	1.28

Table VII – Correlation Coefficients between Selected Fibre and Yarn and Fabric Properties

	CVm	Thin	Neps	Ten	*L**	*a**	*b**
LEN	**-0.870** ***0.005***	**-0.848** ***0.008***	-0.181 *0.667*	**0.746** ***0.033***	0.051 *0.905*	-0.260 *0.533*	0.185 *0.661*
STR	**-0.748** ***0.033***	-0.690 *0.058*	-0.145 *0.733*	**0.880** ***0.004***	-0.123 *0.772*	-0.348 *0.399*	0.367 *0.372*
MIC	**0.943** ***0.000***	**0.876** ***0.004***	0.481 *0.227*	-0.587 *0.126*	-0.443 *0.272*	0.403 *0.322*	-0.093 *0.826*
SM MR	0.036 *0.933*	0.018 *0.967*	-0.145 *0.733*	0.137 *0.747*	**-0.799** ***0.017***	0.538 *0.169*	-0.592 *0.122*
SM FIN	**0.898** ***0.002***	**0.833** ***0.010***	0.539 *0.168*	-0.588 *0.126*	-0.146 *0.731*	0.179 *0.672*	0.150 *0.724*
SM SDMR	-0.077 *0.856*	-0.004 *0.992*	-0.018 *0.966*	-0.098 *0.817*	**0.713** ***0.047***	-0.433 *0.284*	0.456 *0.256*
SM SKMR	-0.063 *0.882*	-0.080 *0.851*	0.220 *0.600*	0.193 *0.647*	**0.864** ***0.006***	-0.579 *0.132*	0.557 *0.152*

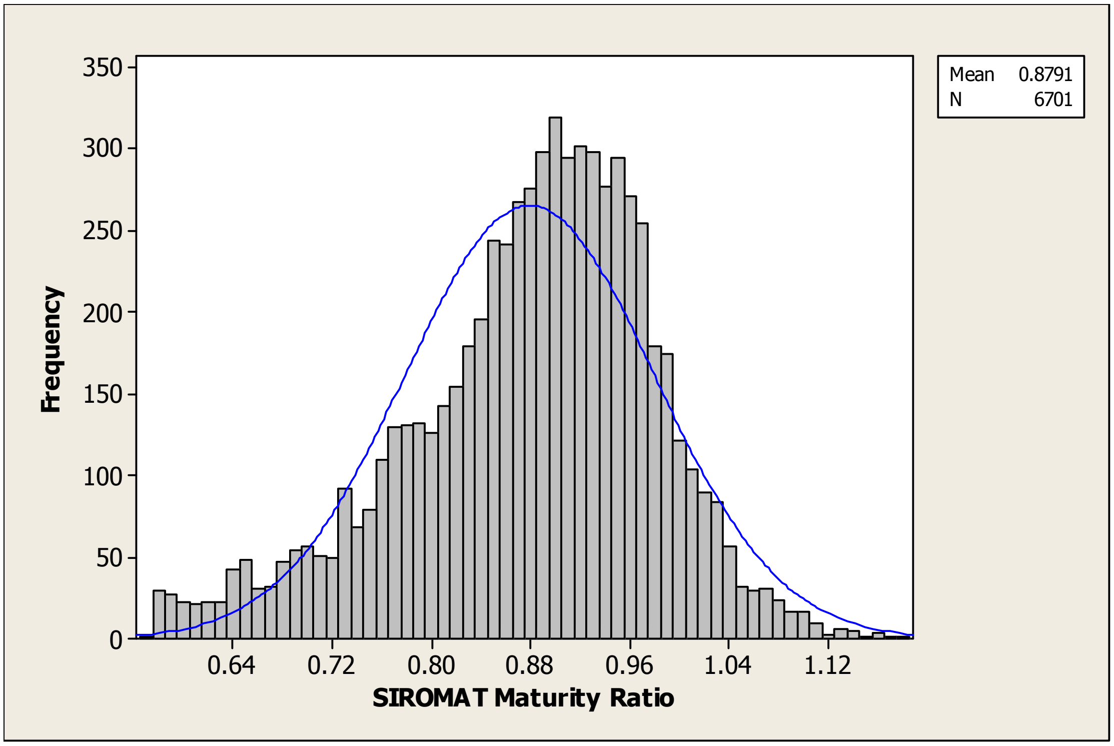

Figure 1 – Typical SiroMat MR distribution obtained for 'mature' cotton. Note negative skew with long immature tail for the average MR value of 0.88

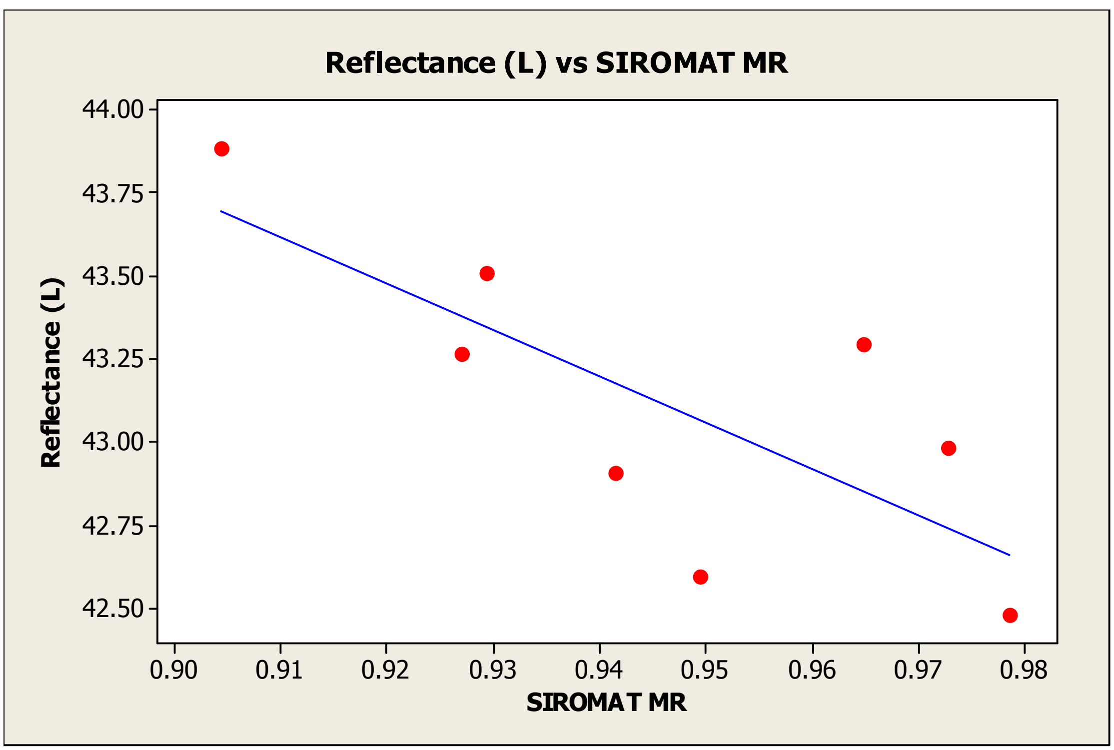

Figure 2 – Relationship between SiroMat MR and bulk dye uptake as measured by the reflectance off blue dyed knit fabric

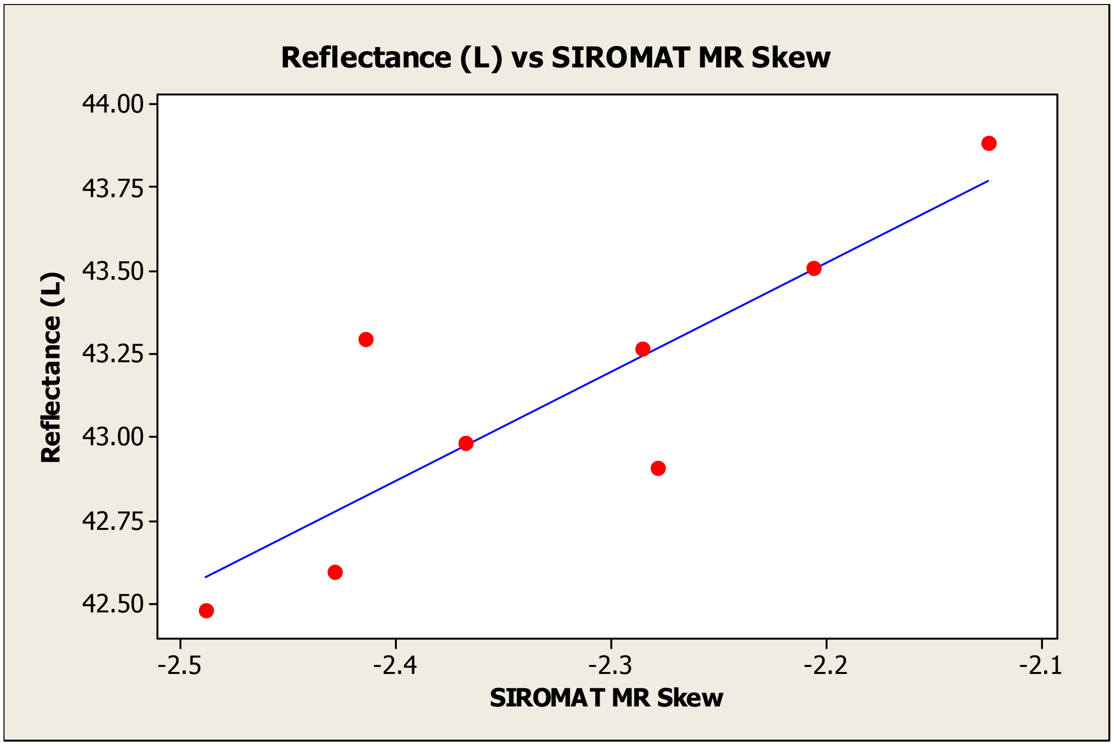

Figure 3 – Relationship between the skewness of the SiroMat MR distribution for each sample and bulk dye uptake as measured by the reflectance off blue dyed knit fabric