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An Investigation into the Parameters of Terry Fabrics Regarding the Production

Abstract
This paper aims at introducing an approach for determining the constructional parameters of a terry fabric for weaving. Experimental work has been conducted with 72 different terry fabric samples designed and produced for this purpose. The weaving contractions of the terry fabrics are found to change between 1.5 -2.0% in both warp and weft directions. Contractions after washing are between 5.5% and 11.5 depending on the fabric construction. The weight per square metre, shearing waste and weft, ground warp and pile warp yarn ratios have been measured, and the effects of the constructional parameters of terry fabrics on these values are discussed. The shearing waste is found to amount to between 9.4% and 17.4% for different fabric constructions. Mathematical expressions are derived for the calculation of weight per square metre in terms of terry fabric constructional parameters, and for the required weft density and pile length satisfying a desired weight per square metre. A close agreement is found between the calculated and measured weight per square metre. A close match is also found between the measured pile lengths and the distance between the short and full beat-up points. It is concluded that the use of mathematical expressions, with the support of some experimental data such as the contractions, minimises or in some cases even eliminates the need for trial production.

Keywords: *terry fabric, terry fabric construction, terry fabric production parameters.*

Introduction

Terry fabrics are used in various fields because of their water absorption properties. Piles are formed on one or both sides by the variable periodic movement of the reed or cloth fell position, mostly over three picks. Figure 1 shows the pile formation in terry fabrics with the three-pick principle. According to this principle, the first two picks are beaten up by the short movement of the reed some distance before the cloth fell position. In the third pick, the reed makes an exact movement, and all three picks are carried up to the cloth fell position. During this movement, the three picks slide between the ground warp yarns. The pile warp yarns move forward together with three picks and take on the pile form. The distance 'x' shown in Figure 1 corresponds to the pile length. It can be adjusted on terry weaving machines to obtain different pile heights. If piles are to be formed on the surface of a terry fabric, the pile warp yarns must be over the third and first picks; similarly, if the piles are to formed on the back side of a terry fabric, then the pile warps must be under the third and first picks.

Terry fabrics must be produced at a certain weight per square metre, using mostly 100% cotton yarns as weft-, ground- and pile warp yarns. Certain yarn counts, such as Ne20/2, Ne24/2, Ne16/1 1), and warp density are used by factories producing terry fabrics. After the ground and pile warp yarns are prepared and drafted as one ground and one pile warp yarn, the weight per square metre of a terry fabric is adjusted by changing the pile height, or in some cases the weft density. Generally, the trial and error method is used in the terry fabric industry to adjust the weight per square metre; this method is based on experience, and therefore requires an experienced person to do the adjustment. The warp density, weft density and pile height should be changed by keeping a balance among them in adjusting weight per square metre. Otherwise, the weight per square metre, the widthwise and lengthwise contractions, pile height and shearing waste of a terry fabric will not attain optimum values.

A quick determination of the terry fabric's constructional parameters on a weaving machine for the production of a given finished terry fabric is of paramount importance from the practical point of view under today's hard competitive market conditions. Establishing a method of adjusting terry fabric weight per square metre practically and quickly, as well as establishing a correct relationship between warp density, weft density and pile height for a given weight per square metre will bring an analytical and practical approach to the terry fabric production sector.

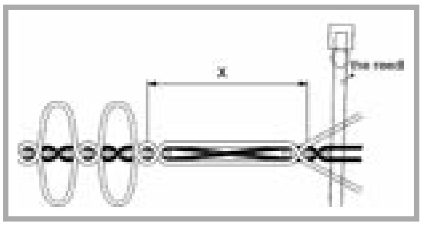

***Figure 1.** Cross-section of the three-pick pile formation system [1].*

The literature about terry fabrics is mainly based on the principles of terry fabric formation and patterning [2-5]. Apart from the technical specifications and patterning of terry fabrics, Kienbaum in his paper [6] introduces a mathematical method to determine the terry fabric settings. He presents charts for weft and warp density ranges which consider yarn counts, pile ratio, fabric weight and percentage of pile to total weight. He comments that optimum settings are determined empirically, and that the theoretical approach might be useful in complementing practical experience.

The aim of this study is to present an approach to producing a finished terry fabric at the required weight per square metre and dimensions without needing a lengthy trial production process. The study consists of two parts, theoretical and experimental. In the theoretical part, the weight per square metre of a terry fabric is expressed analytically in terms of terry fabric parameters. Furthermore, the weft density and pile length are expressed analytically for a given terry fabric weight per square metre. In the experimental part, 72 different terry fabric constructions are woven with the combination of 6 different warp densities, 4 different weft densities and three different pile lengths. The off-loom and after washing lengthwise and widthwise contractions, the weight per square metre, the shearing waste ratio and weft yarn, the ground warp and pile warp yarn ratios of the terry fabrics are measured, and the changes in these parameters are discussed. The measured weight per square metre and pile length are compared with those calculated, and the applicability of the theoretical approach is tested.

A study has also been carried out on the water absorption properties of terry fabrics using the same terry fabric samples. This will be the subject of a separate paper.

Material and Method

Material, fabrics

The three-pick pile formation principle was used in the production of the terry fabrics discussed in this study. The properties of 100% cotton weft yarn, ground and pile warp yarns are as follows:

- Pile warp - carded ring spun Ne 20/2, twist 216 t/m;
- Ground warp - carded ring spun Ne 20/2, twist 480 t/m;
- Weft yarn - carded ring spun Ne 16/1.

The warp densities in the reed, the weft densities on the loom and the pile lengths are given in Table 1 for the different terry fabric constructions woven for the purpose of this research. The terry fabrics were woven at four different weft densities for each warp density by using three different pile lengths. In this way, 72 different terry fabric constructions were obtained. The warp density, weft density and pile lengths of these terry fabrics were chosen to cover the wide range of terry fabric constructions produced in industry.

Method

Production method of the fabrics

The terry fabrics were produced on a 360 cm-wide Nouva Pignone TPS 500 terry weaving machine with a dobby. Figure 2 shows the reed specially designed and manufactured for this work. There are 6 different densities over the width of the reed, and each reed density is 50 cm wide. Using this reed made it possible to weave terry fabrics at 6 different warp densities side by side at a time with the same weft density and pile length. In this way, terry fabrics at 6 different warp densities were produced under the same conditions. Table 2 shows the number of ends for each warp density in the reed.

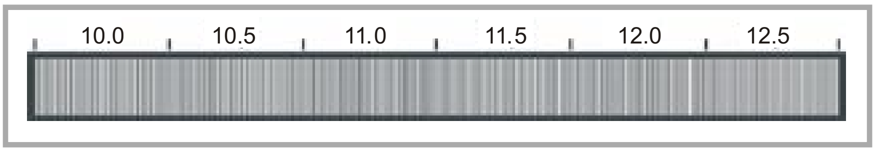

Figure 2. *The weaving reed manufactured at different densities, dents/cm.*

Table 1. *Parameters of the terry fabrics.*

Warp density on the reed, ends/cm	10.0	10.5	11.0	11.5	12.0	12.5
Weft density on the loom, picks/cm	16.0	17.1	18.0	19.5	-	-
Pile length	low	medium	high	-	-	-

Table 2. *Number of ends for each reed density.*

Reed density, dents/cm	10.0	10.5	11.0	11.5	12.0	12.5
Number of ends	540	566	594	620	646	674

Test methods

The measurements and measurement methods applied to the terry fabric samples are explained below.

Measurement of weight per square metre of the fabrics

Samples were prepared for each of the 72 terry fabric constructions under laboratory conditions, and the weight per square metre values were measured according to the standard ASTM D3776. In the measurements, a Sortius electronic balance with a precision of 1/10,000 gr was used.

Measurement of shearing waste of velour type terry fabrics

Terry fabrics are used as a velour type in some applications. For this purpose, the piles on one side are cut at a certain height. This process produces some waste. It is important to determine the pile waste ratio to correctly calculate terry fabric costs. To determine the pile waste ratio, the terry fabrics (whose weight per square metre were determined in advance) were passed through the pile cutting machine at the same speed. The shearing height was adjusted for each pile height until a satisfactory shearing quality was obtained. Next, the weight per square metre of the velour type of the terry fabrics was measured. By comparing the pre- and post-cutting weight per square metre values, the shearing waste ratio was calculated as a percentage.

Measurement of pile yarn length

The pile length in a terry fabric construction affects weight per square metre and the weft, ground warp and pile warp yarn ratios. The pile lengths were determined in this work for 72 different terry fabric constructions. For this, the 10-cm length samples were prepared for each terry fabric construction, and the pile warp yarns were taken out. The length measurements were carried out according to the standard ASTM D3883-99 , and then the pile length was calculated for three picks.

Measurement of weft, ground warp and pile warp ratios

10×10 cm of terry fabric samples were cut and the weft yarns, ground warp yarns and pile warp yarns in each sample were taken out. The weight of each group of yarn was measured under laboratory conditions using an electronic balance of 1/10,000 gr precision. The ratio of each group of yarn to the measured sample weight was calculated as a percentage as weft yarn, ground warp yarn and pile warp yarn ratios.

Dimensional stability tests

Dimensional stability tests were carried out according to the AATCC 135/150 method. The terry fabric sample dimensions were measured before washing, and then after three successive washings. The lengthwise and widthwise dimension changes were calculated as percentages.

Calculation of weight per square metre of terry fabrics

There are three yarn systems in a terry fabric, namely weft yarn, ground warp yarn and pile warp yarn. The terry fabric weight per square metre can be formulated by taking into account the weight of each yarn system in a square metre of a terry fabric. The following is the derivation of a terry fabric weight per square metre considering the weight of the three-yarn system. The Ne-numbering system is used in the formulation.

$$W_2 = \frac{n_2 \cdot 100 \cdot (1 + C_2/100)}{1.69 \cdot N_2} \quad (1)$$

where:

W_2 - the weight of weft yarn in a square metre of terry fabric, g

n_2 - the weft density, picks/cm

C_2 - the weft yarn crimp, %

N_2 - the weft yarn count, Ne.

$$W_{1g} = \frac{n_1 \cdot 100 \cdot (1 + C_1/100)}{1.69 \cdot N_1} \quad (2)$$

where:

W_{1g} - the weight of ground warp yarn in a square metre of terry fabric, g

n_1 - the ground warp density, ends/cm

C_1 - the crimp of ground warp yarn, %

N_1 - the ground warp yarn count, Ne.

$$W_{1p} = \frac{(n_2/3) \cdot 100 \cdot n_1 \cdot 100}{1690 \cdot N_1} h \quad (3)$$

where:

W_{1p}- the weight of pile warp yarn in a square metre of terry fabric, g

h - one pile length, mm.

The weight per square metre of a terry fabric

$$(W) = W_2 + W_{1g} + W_{1p}$$

$$W = \frac{n_2 \cdot 100 \cdot (1 + C_2/100)}{1.69 \cdot N_2} + \frac{n_1 \cdot 100 \cdot (1 + C_1/100)}{1.69 \cdot N_1} + \frac{(n_2/3) \cdot 100 \cdot n_1 \cdot 100}{1690 \cdot N_1} h \quad (4)$$

W - the weight per square metre of a terry fabric, g.

As seen from equation (4), the weight per square metre of a terry fabric changes linearly with warp density, weft density and pile length. It is essential to use the exact values of the yarn counts, the warp and weft densities, together with warp and weft crimps and pile length in equation (4) to obtain results as close as possible to the measured weight per square metre. In the terry fabric production sector, companies mainly use standard warp and weft yarn counts as well as warp density. For a required terry fabric weight per square metre, the weft density and pile length remain two parameters to be adjusted. Equations (5) and (6) are derived for the calculation of the weft density and the pile length for a given fabric weight per square metre.

$$n_2 = \frac{W - \dfrac{n_1 \cdot 100 \cdot (1 + C_1/100)}{1.69 \cdot N_1}}{\dfrac{100 \cdot (1 + C_2/100)}{1.69 \cdot N_2} + \dfrac{100 \cdot n_1}{1690 \cdot 3 \cdot N_1} h} \quad (5)$$

$$h = \frac{(W - W_{1g} - W_2) \cdot 1690 \cdot N_1}{(n_2/3) \cdot 100 \cdot n_1 \cdot 100} \quad (6)$$

In the 'Results and Discussion' part, the calculated weight per square metre values are compared with those already measured to test the validity of these equations in practice.

Results and Discussion

Analysis of dimensional changes in terry fabrics after washing

Table 3 shows the widthwise and lengthwise contractions of the terry fabrics after the washing process. In general, the widthwise and lengthwise contractions vary between 5.6% and 11.8% depending on the construction of the terry fabrics. Statistical tests were carried out to analyse the effect of pile length, warp density and weft density on the widthwise and lengthwise contractions.

With Anova tests conducted with a 95% confidence interval, no significant effect of pile length on after washing contractions was found. However, the weft density and warp density had a significant effect on the lengthwise and widthwise contractions respectively. The decrease in lengthwise contraction is not significant with the increase in weft density up to 19.5 picks/cm. At 19.5 picks/cm, it becomes significant. Similarly, the widthwise contraction decreases after 12 ends/cm warp density on the reed. Up to 12 ends/cm warp density, no significant change in widthwise contraction is observed. The widthwise contraction is around 10.0% at 10.0 ends/cm warp density, while it is about 7.0% when the warp density is 12.5 ends/cm. It was also found out in Anova tests with a 95% confidence interval that the weft density had some effect on the widthwise contraction, and the warp density had almost as significant an effect as weft density on the lengthwise contraction.

Table 3. *The widthwise and lengthwise contractions after washing in percent;* ***W*** *- represents widthwise contraction and* ***L*** *- represents lengthwise contraction.*

Weft density, picks/cm	Pile height, mm	Contractions after washing, % at warp density in the reed, ends/cm											
		10.0		10.5		11.0		11.5		12.0		12.5	
		W	L	W	L	W	L	W	L	W	L	W	L
16.0	6.8	8.9	8.1	7.9	8.9	8.8	7.4	8.7	8.9	7.8	9.0	6.8	9.0
	9.3	9.8	8.1	9.8	8.9	9.7	8.1	8.7	9.8	6.8	9.8	5.8	9.8
	11.2	9.8	7.3	9.8	8.9	9.7	8.1	9.6	9.7	6.8	8.9	7.7	9.0
17.1	7.1	9.9	6.8	8.9	7.8	7.9	7.0	7.8	7.8	8.7	-1.9	6.8	8.8
	9.4	9.9	7.7	9.8	7.8	8.8	8.6	8.7	7.8	7.8	8.7	6.8	9.6
	11.0	9.9	7.7	9.8	8.6	9.7	9.4	8.7	8.6	7.7	9.5	7.7	8.7
18.0	6.6	11.7	7.2	10.8	8.1	9.8	7.3	9.7	8.2	7.8	8.2	6.9	9.2
	9.3	10.9	6.3	10.8	8.1	9.8	8.1	8.7	8.2	8.7	8.2	6.8	9.2
	11.2	10.9	7.1	11.8	7.2	9.8	8.1	8.8	8.2	7.8	8.2	6.8	10.0
19.5	6.6	10.0	5.8	10.9	5.9	9.9	6.9	8.8	7.8	8.8	7.9	7.8	7.9
	9.2	9.9	6.8	10.8	6.9	9.8	6.9	9.7	7.8	7.8	7.8	6.9	7.9
	11.2	9.9	5.6	10.8	6.7	8.8	7.9	9.8	7.9	7.8	8.0	7.8	8.0

Table 4. *Weight per square metre of the terry fabrics before shearing.*

Weft density, picks/cm	Pile length, mm	Weight per square metre, g/cm2 at warp density in the reed, ends/cm					
		10.0	10.5	11.0	11.5	12.0	12.5
16.0	6.8	336.0	345.0	361.0	377.0	388.0	403.0
	9.3	413.0	426.0	441.0	464.0	494.0	507.0
	11.2	483.0	502.0	528.0	552.0	568.0	588.0
17.1	7.1	360.0	370.0	387.0	399.0	408.0	436.0
	9.4	450.0	464.0	493.0	496.0	510.0	531.0
	11.0	517.0	534.0	553.0	560.0	579.0	609.0
18.0	6.6	375.0	376.0	398.0	405.0	421.0	434.0
	9.3	471.0	486.0	512.0	515.0	532.0	550.0
	11.2	531.0	551.0	581.0	587.0	604.0	628.0
19.5	6.6	384.0	403.0	422.0	428.0	445.0	460.0
	9.2	502.0	517.0	539.0	549.0	569.0	586.0
	11.2	545.0	579.0	601.0	616.0	645.0	668.0

The lengthwise and widthwise contractions can be explained as follows; when terry fabrics get wet, the internal stress in the yarns is removed, and the volume of cotton yarns increases because of the swelling of cotton fibres. As a resul, the yarns have to follow a longer path around each other, and this causes contractions in the lengthwise and widthwise directions. When there is sufficient space between the yarns, the change in the yarn volume is fully reflected to the widthwise and lengthwise fabric contractions. As the fabric gets denser, the space between the yarns decreases, and after some contractions the yarns rest on each other and prevent any more contractions. As the weft density is lower than the warp density and the weft yarn is finer than warp yarn, the effect of warp density on lengthwise contraction is more significant than the effect of the weft density on the widthwise contraction.

It was observed during the production of terry fabrics that both the lengthwise and lengthwise weaving contractions were around between 1.5% and 2.0% and therefore the weft and warp densities increased by the same amount in the terry fabrics after being taken off the loom.

Analysis of weight per square metre of terry fabrics

The weight per square metre of the terry fabrics before the shearing process is presented in Table 4. As expected, the increase in weft density, warp density and pile length increase the weight per square metre. The increase in pile length causes the weight per square metre to increase because of an increase in total pile warp length in a square metre of a terry fabric. However, the effect of weft density and warp density on weight per square metre is two-fold. An increase in warp and/or weft density increases the weight per square metre due to an increase in the amount of ground warp and/or weft yarn in a square metre on the one hand, and on the other increases the total pile length due to the increase in the number of pile in a square metre . A close examination of the data in the table shows that the weight per square metre changes linearly with weft density, warp density and pile length, as equation (4) indicates.

The ratios of weft yarn, ground warp and pile warp in the terry fabric constructions are presented in Table 5 as percentages. Pile warp yarns constitute the largest portion of terry fabric weight. As shown in the table, the pile warp constitutes between 65.0% and 79.0% of the total weight, depending on the terry fabric construction and pile length. The weft yarn ratio fluctuates between 9.0% and 15.0% and the ground warp yarn ratio varies between 11.0% and 20.0%. Changing warp density while keeping the weft density and pile length constant causes no significant change in the pile warp yarn ratio. However, the weft density change between 16.0 picks/cm and 19.5 picks/cm increases the pile warp yarn ratio up to 4.0% depending on the terry fabric construction. Changing the pile length between its low and high values caused a change of around 10.0% in the pile warp yarn ratio. Although these values may show some variations with the use of different yarn counts, they reflect the general situation regarding the terry fabric structure, because the yarn counts, warp and weft densities and pile lengths used to produce the terry fabrics in this study are within the range for industrial application. The data in Table 5 can be very useful in practice for calculating the necessary amount of the weft yarn, ground and pile warp yarns for a terry fabric to be produced. Normally in industry, the calculations are carried out by taking the pile warp ratio at 70.0%, the ground warp ratio at 15.0% and the weft yarn ratio at 15.0%. However, the results in the table show that the ratios of weft yarn, ground and pile warp yarns differ significantly from these assumed ratios. This deviation leads to the wrong cost as well as the wrong yarn requirement calculations. The wrong yarn requirement calculations can cause interruptions in production because of a shortage of the required yarn, or stock build-up due to an excess amount of the required yarn. The data presented in Table 5 should be expanded to cover the warp density, weft density and the pile heights used in a company, and should be taken as a reference in the production of terry fabrics. Also, the weft yarn ratio, the ground warp yarn and pile warp yarn ratios can be prepared as W_{1p}/W, W_{1g}/W and W_2/W by using the mathematical approach given on page 22.

The terry fabrics are sometimes used with the piles shorn on one side, i.e. velour-type terry fabric. In this case, it is important to keep shearing waste at a minimum to reduce the terry fabric production costs. It is also important to know the shearing waste ratio in order to obtain the correct finished terry fabric weight per square metre, and to correctly calculate the amount of pile warp yarn required for a certain terry fabric. The face of terry fabrics produced for

Table 5. *The Ratio of pile warp, ground yarn, and weft warp yarns in the terry fabrics;* ***PW*** *- the pile warp ratio,* ***GW*** *- the ground warp ratio,* ***W*** *- the weft yarn ratio.*

Weft density, picks/cm	Pile length, mm	Ratio of pile warp, ground yarn, and weft warp yarns, at warp density in the reed, dents/cm																	
		10.0			10.5			11.0			11.5			12.0			12.5		
		PW	GW	W	PW	GW	W	PW	GW	W	PW	GW	W	PW	GW	W	PW	GW	W
16.0	6.8	65.2	19.6	15.2	65.2	20.0	14.8	65.9	19.9	14.1	67.1	19.4	13.5	66.8	20.1	13.1	67.2	20.1	12.7
	9.3	71.7	16.0	12.3	71.8	16.2	12.0	72.1	16.3	11.6	73.3	15.7	11.0	73.9	15.8	10.3	74.0	16.0	10.1
	11.2	75.8	13.7	10.6	76.1	13.7	10.2	76.7	13.6	9.7	77.5	13.2	9.2	77.3	13.7	9.0	77.6	13.8	8.7
17.1	7.1	67.5	17.8	14.7	67.3	18.4	14.3	67.2	18.9	14.0	68.4	18.3	13.3	67.9	19.1	13.0	69.3	18.6	12.2
	9.4	74.0	14.2	11.8	73.9	14.7	11.4	74.2	14.8	11.0	74.6	14.7	10.7	74.3	15.3	10.4	75.2	15.0	9.8
	11.0	77.4	12.4	10.3	77.2	12.7	10.1	77.0	13.2	9.8	77.5	13.0	9.5	77.4	13.5	9.2	78.0	13.3	8.7
18.0	6.6	66.7	17.9	15.5	67.0	18.1	14.9	67.3	18.3	14.3	68.4	18.0	13.6	68.2	18.8	13.1	68.7	18.7	12.7
	9.3	73.5	14.2	12.3	74.9	13.8	11.3	74.6	14.3	11.1	75.1	14.2	10.7	74.8	14.8	10.3	75.3	14.7	10.0
	11.2	76.5	12.6	10.9	77.9	12.2	10.0	77.8	12.6	9.6	78.2	12.4	9.4	77.8	13.1	9.1	78.3	12.9	8.8
19.5	6.6	67.4	15.9	16.7	68.0	16.9	15.1	68.2	17.3	14.5	68.7	17.5	13.8	69.4	17.3	13.3	69.8	17.4	12.8
	9.2	75.1	12.2	12.7	75.0	13.2	11.8	75.1	13.5	11.3	75.6	13.7	10.7	76.1	13.5	10.4	76.3	13.7	10.1
	11.2	77.1	11.2	11.7	77.7	11.7	10.5	77.7	12.1	10.1	78.2	12.2	9.6	78.9	11.9	9.1	78.7	12.4	8.8

the purpose of this study was shorn to determine the shearing waste ratio for different terry fabric constructions. The shearing height in the machine was adjusted depending on different pile heights until the satisfactory shearing quality was obtained. The shearing waste ratios are presented in Table 6 as percentages. As seen from the table, the shearing waste ratios change between 9.4% and 17.4% for different fabric constructions, and the concentration is around between 13.0% and 14.0%. When the shearing waste ratios are analysed, no logical relation is found between the shearing waste and weft density, warp density or pile height. However, some comments can be made about the shearing waste regarding the terry fabric construction based on practical experience. It is important for the piles to be as vertical as possible during shearing. Increasing the pile height reduces its bending rigidity, which adversely affects the shearing quality. Because of this, it is necessary to cut the piles more deeply, which naturally increases the shearing waste. At very low pile heights, it is expected that the shearing waste ratio will increase because the shearing waste constitutes a larger portion of the total pile weight of a terry fabric, compared to terry fabrics with a higher piles. In general, the shearing height on the machine is not often adjusted in factories because of time restrictions and some fabric waste. A reduction of a few percent in the shearing waste ratio will be a significant gain when the yearly production of a company is considered. Therefore, the optimum values of shearing waste should be determined according to the satisfactory shearing quality for different fabric constructions in the factories.

Table 6. *The shearing waste ratios in percent.*

Weft density, picks/cm	Pile length, mm	Shearing waste ratios, % at warp density in the reed, ends/cm					
		10.0	10.5	11.0	11.5	12.0	12.5
16.0	6.8	12.5	13.0	10.8	14.1	14.4	13.4
	9.3	10.2	11.7	12.0	12.1	13.4	13.8
	11.2	13.7	14.7	15.2	15.2	13.2	13.3
17.1	7.1	13.3	13.5	14.5	11.5	11.3	14.7
	9.4	14.2	14.9	14.4	11.7	15.5	14.9
	11.0	13.5	13.9	14.3	14.6	13.8	14.5
18.0	6.6	13.9	12.2	12.6	12.6	13.3	13.6
	9.3	13.4	14.4	14.5	13.0	13.2	14.6
	11.2	16.6	17.4	17.2	12.8	12.8	15.9
19.5	6.6	13.5	13.7	13.7	13.1	13.3	13.7
	9.2	14.7	13.9	14.3	14.4	14.6	14.3
	11.2	9.4	10.7	12.5	11.7	14.3	14.7

Table 7. *The calculated weight per square metre for 72 different terry fabric constructions.*

Weft density, picks/cm	Pile length, mm	Weight per square metre at warp density in the reed, ends/cm					
		10.0	10.5	11.0	11.5	12.0	12.5
16.0	6.8	345	359	376	390	402	416
	9.3	427	445	464	485	500	519
	11.2	492	514	535	554	575	596
17.1	7.1	365	380	395	409	424	439
	9.4	452	471	491	510	529	549
	11.0	518	541	564	586	609	632
18.0	6.6	381	397	412	428	444	459
	9.3	473	493	514	534	554	574
	11.2	543	567	591	614	638	662
19.5	6.6	406	423	440	456	473	489
	9.2	506	527	549	571	592	614
	11.2	581	607	632	657	683	708

Table 8. *The 'x' distance, the measured and calculated pile lengths.*

'x' distance, mm	Measured pile length, mm	Calculated pile length, mm	Weight/m^2, g
7.0	7.5	7.5	433.0
9.0	8.8	8.4	466.0
10.5	10.3	10.2	536.0

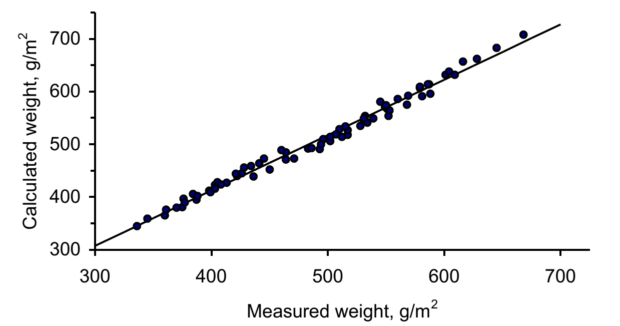

Figure 3. *Regression curve between theoretically calculated and measured weight per square values.*

Comparison of the calculated and measured results of weight per square metre of terry fabrics

The weight per square metre of 72 different terry fabric constructions were calculated using equation (4) to see to what extent the calculated weight per square metre values match with the measured ones. The calculated weight per square metre values are presented in Table 7. The measured values were given in Table 4. As the weight per square metre is measured for the off-loom terry fabrics, the off-loom terry fabric warp and weft densities, 2.0% weaving contractions and the measured pile lengths were used in the calculations. It is clearly seen in Table 4 and 7 that the calculated and the measured values are very close to each other. The correlation coefficient between the calculated and measured values was found to be 0.994. This value ndicates no significant difference and a very strong match between the measured and calculated values. In some fabric constructions, there is a deviation of up to 7.0%. The deviations occur between the calculated and measured values due to the variations in the weft and warp yarn counts, as well as errors in measuring warp and weft crimps as well as the pile length etc. Despite this, the calculated weight per square metre values of the terry fabrics are mostly within the acceptable practical limits. This result shows that the mathematical approach can be used in practice. Even if some deviation occurs between the calculated and the measured weight per square metre, the calculated weight per square metre can be taken as a first approximation. Then, the desired weight per square metre can be reached with small alterations very quickly. In this way, the dependence on the experience for the adjustment of weight per square metre of terry fabrics is largely eliminated, and the waste during the trials is reduced to a minimum.

Figure 3 shows the regression curve between the measured and theoretically calculated weight per square metre values. x and y represent the measured and theoretically calculated values respectively. The regression equation is found as follows.

$$y = 1.0496\,x - 7.616$$

Regression analysis also shows a very good match between the theoretically calculated and measured weight per square metre values.

A series of further experiments were conducted to find out whether the ‘x’ distance is equal to the pile length. The results of the experiments are given in Table 8. There is a maximum of about 0.5 mm deviation between the ‘x’ distance and the measured or calculated pile lengths, which is within the accuracy limits of the millimetre ruler used in the pile length measurements. Therefore, the calculated pile length of a terry fabric can be used to adjust ‘x’ distance on the pile formation mechanism of a terry weaving machine.

A computer program has been written for the mathematical approach presented in this paper, and has been successfully used in a company producing terry fabrics.

Conclusion

The following conclusions have been drawn from the experimental and theoretical study on terry fabrics:

- The widthwise and lengthwise contractions of terry fabrics after they are taken from the loom were found to be between 1.5-2.0% in the experiments covering a wide range of terry fabric constructions. The contractions after washing changed between 5.0% and 11.0% depending on the terry fabric construction. The pile length did not have any effect on contractions either during weaving or after washing. The increase in weft density only caused a reduction in the lengthwise contraction after washing at 19.5 picks/cm; similarly, the warp density increase only reduced the after-washing widthwise contraction after 12.0 ends/cm. The warp density change also had a significant effect on the lengthwise contraction. However, the effect of weft density on widthwise contraction was found to be less significant.
- The shearing waste changed between 9.4% and 17.4% depending on the fabric construction. No logical relation was found between the shearing waste and terry fabric constructional parameters.
- The calculated and measured weight per square metre values of terry fabrics produced for the experiments show a very close agreement. A similar agreement was found between the ‘x’ distance and the measured and calculated pile lengths. This result largely eliminates the dependence of terry fabric producers on experience in obtaining the required weight per square metre. The mathematical approach introduced in this paper enables the terry fabric weaver to start production with minimum waste and time loss. Also, this mathematical approach can be adopted to calculate the ‘x’ distance on new-generation terry weaving machines, in which the pile formation mechanism is servo-motor driven and computer-controlled.

Acknowledgement

We would like to express our sincere thanks to the Penta Textile Company for the production of the terry fabrics used in this research.

Editional remark

1) As all data and calculations have been formulation in the English Ne-count-system, exceptionally this system has been accepted in this paper, instead of the obligatory description of the linear density in tex.

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Received 22.04.2004 Reviewed 19.01.2005