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Hamdy Ebraheem
Textile Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

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Yarn Crimp Ratio in Woven Fabrics
Theory and Practice

By: Hamdy A. A. Ebraheem
Lecturer in Textile Eng. Dept. Mansoura University

نسبة تشريب الخيوط فى الأقمشة المنسوجة
نظريا وعمليا

الخلاصة:

تعتبر نسبة تشريب الخيوط فى الأقمشة المنسوجة من الأهمية بمكان بحيث يلزم قياسها وتحديدها بدقة عالية. وفى هذا البحث تم إستحداث صيغ رياضية لحساب نسبة التشريب بدلالة التركيب النسجى ، والمواصفات الإنشائية للقماش المنسوج من كثافة الخيوط ونمرها. كما تم التمييز بين القماش المنسوج ذو التشييف ، وبين القماش المنسوج المعروف بنسيجه الممتد الذى تتعاشق فيه الخيوط فى صورة مجموعات بحيث لا يفصل الخيوط سوى التعاشقات. ولزيادة دقة قياس نسبة التشريب عمليا وتقليل الوقت والجهد فى القياس، تم إدخال طريقة عملية جديدة لتحديد نسبة التشريب عن طريق وزن الخيوط بدلا من فردها ، وذلك بعد تسميلها من القماش المنسوج.

I. Abstract:

Because of the importance of accuracy in measuring and estimating yarn crimp ratio in woven fabrics, non classical methods were searched for. In this paper mathematical formulae were derived to express yarn crimp ratio in terms of weave structure, yarn spacing, and yarn diameter. It is descriminated between floated weaves and extended weaves. In floated weaves yarn spacing is constant and equal to yarn spacing at the point of intersection. In extended weaves, yarns are separated only at points of intersection. To increase accuracy and safe effort and time consumed in measuring yarn crimp ratio, a new experimental method is introduced. In this method yarn crimp ratio is determined by weighing crimped yarns instead of decrimping them.

II. Introduction:

There have been many simple empirical models to relate fabric parameters. These models need more modifications by using the electronical computing systems [1]. Simple mathematical models had been improved and modified in the from of dimensionless relations [2]. The weave structure can be expressed in terms of average float or float ratio. It was found that the mean value of warp tension decreases by increasing the float ratio [3].

Fabric abrasion resistance is affected by yarn crimp ratio because crowns formed as yarn bends round a transverse thread will protrude from the fabric surface and meet the destructive abrasive agent first. The largest amount of fabric shrinkage is that represented by increase of crimp. Control of crimp percentage is necessary when a fabric is designed to give a desired degree of extensibility and when crimp balance between warp and weft is required after finishing processes. Knowledge of crimp value is useful in calculating fabric cost and yarn requirement [4].

It is clear that yarn crimp ratio plays important parts in fabric analysis, fabric research and design, process control, and economics of fabric production.

III. Nomenclature:

A_i	The number of weft yarns over which the warp end passes in the i^{th} fraction of warp weave repeat.	
B_i	The number of weft yarns under which the warp end passes in the i^{th} fraction of warp weave repear.	
C_1	Warp crimp ratio in the woven fabric.	
C_2	Weft crimp ratio in the woven farbic.	
$(C_1)_{1/1}$	Warp crimp ratio in plain - woven fabric.	
$(C_2)_{1/1}$	Weft crimp ratio in plain-woven fabric.	
d_1	Diameter of warp end	(cm).
d_2	Diameter of weft yarn	(cm).
F_1	Average float of warp end.	
F_2	Average float of weft yarn.	
G_i	The number of warp ends over which the weft yarn passes in the i^{th} fraction of weft weave repeat.	
H_i	The number of warp ends under which the weft yarn passes in the i^{th} fraction of weft weave repeat.	
K_1	Warp cover ratio.	
K_2	Weft cover ratio.	
L_1	Warp modular length	(cm).
L_2	Weft modular length	(cm).
L	Lenght of weave repeat	(cm).
m	Number of fractions in repeat of weft interlacing.	
n	Number of fractions in repeat of warp interlacing.	
n_1	Average number of ends / cm.	
n_2	Average number of picks / cm.	
N	Number of yarns.	
P_1	Distance between two neighbouring warp ends at a weft intersection (cm).	
P_2	Distance between two neighbouring weft yarns at a warp intersection(cm).	
W	Width of weave repeat	
θ_1	Warp weave angle	
θ_2	Weft weave angle	

IV. Mathematical Derivation:

Figures 1 and 2 show an example of floated weaves and extended weaves (3/1) respectively.

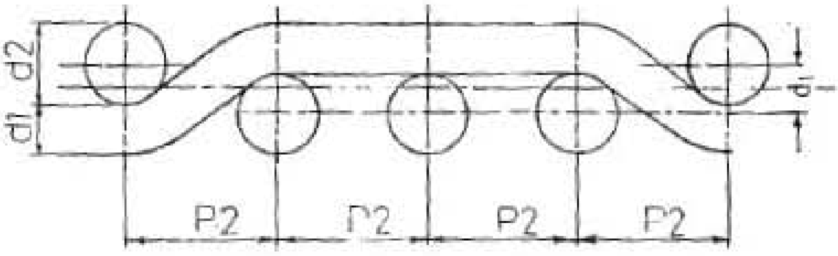

Fig. (1): A cross - section floated weave 3/1

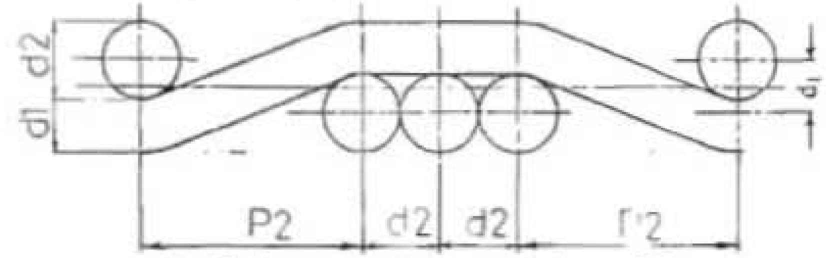

Fig. (2): A cross - section in extended weave 3/1

IV.1. Fabrics of Floated Weaves:

Let warp interlacing repeat be $\frac{A_1 \; A_2 \; A_3 \; \ldots\ldots \; A_n}{B_1 \; B_2 \; B_3 \; \ldots\ldots \; B_n}$ and weft interlacting repeat be $\frac{G_1 \; G_2 \; G_3 \; \ldots\ldots \; G_n}{H_1 \; H_2 \; H_3 \; \ldots\ldots \; H_n}$

Then Number of warp interlacings / repeat = 2n

Number of picks / repeat $= \sum_{i=1}^{n} A_i + \sum_{i=1}^{n} B_i$

Warp length / repeat $= 2\,nL_1 + P_2 \left(\sum_{i=1}^{n} A_i + \sum_{i=1}^{n} B_i - 2n \right)$

Length of repeat $= P_2 \left(\sum_{i=1}^{n} A_i + \sum_{i=1}^{n} B_i \right)$

∴ Warp Crimp Ratio

$$C_1 = \frac{2n\,(L_1 - P_2)}{P_2\left(\sum A_i + \sum B_i\right)} = \frac{2n}{\sum A_i + \sum B_i} \left(\frac{L_1 - P_2}{P_2} \right)$$

$$C_1 = \frac{2n}{\sum A_i + \sum B_i} \cdot (C_1)_{1/1} \qquad (1)$$

$(C_1)_{1/1}$ is warp crimp ratio in plain woven fabric. Similarly

$$C_2 = \frac{2m}{\sum G_i + \sum H_i} \cdot (C_2)_{1/1} \qquad (2)$$

$(C_2)_{1/1}$ is weft crimp ratio in plain woven fabric.

$$C_1 = \frac{(C_1)_{1/1}}{F_1} \qquad (3)$$

and

$$C_2 = \frac{(C_2)_{1/1}}{F_2} \qquad (4)$$

F_1 and F_2 are average float of warp and weft, respectively.
From a previous study [5].

$$(C_1)_{1/1} = \mathrm{Sec}\,\theta_1 - \frac{2d}{P_2} \tan\theta_1 + \frac{2d}{P_2}\,\theta_1 - 1 \qquad (5)$$

when $\theta_1 < \frac{\pi}{2}$

$$(C_2)_{1/1} = \mathrm{Sec}\,\theta_2 - \frac{2d}{P_1}\tan\theta_2 + \frac{2d}{P_1}\,\theta_2 - \qquad (6)$$

when $\theta_2 < \frac{\pi}{2}$

When $\theta_1 = \frac{\pi}{2}$, $\theta_2 = 0$, $C_1 = \frac{\pi d}{P_2} - 1$, and $C_2 = 0$

When $\theta_2 = \frac{\pi}{2}$, $\theta_1 = 0$, $C_2 = \frac{\pi d}{P_1} - 1$, and $C_1 = 0$

$$\mathrm{Sin}\,\theta_1 = \frac{2\,d\,P_2 - d_1\sqrt{P_2^2 - d_2\left(2d + d_1\right)}}{P_2^2 + d_1^2} \qquad (7)$$

$$\mathrm{Sin}\,\theta_2 = \frac{2\,d\,P_1 - d_2\sqrt{P_1^2 - d_1\left(2d + d_2\right)}}{P_1^2 + d_2^2} \qquad (8)$$

$$d_1 + d_2 = 2d \qquad (9)$$

d_1 and d_2 are warp yarn and weft yarn diameters, and P_1 and P_2 are yarn spacing for warp and weft, respectuvely.

Yarn crimp ratio can also be expressed as follows:

$$C_1 = (C_1)_{1/1} \cdot \frac{\text{Warp int erlacings / repeat}}{\text{Picks / repeat}} \qquad (10)$$

$$C_2 = (C_2)_{1/1} \cdot \frac{\text{Weft int erlacings / repeat}}{\text{Ends / repeat}} \qquad (11)$$

$(C_1)_{1/1}$ and $(C_2)_{1/1}$ are functions of

- warp diameter d_1
- warp spacing P_1
- weft diameter d_2
- weft spacing P_2

The contribution of weave structure in the value of C_1 and C_2 is represented in warp interlacings / repeat as a ratio of picks / repeat and weft interlacings / repeat as a ratio of ends / repeat (equations 10 and 11). In other words the contribution of weave structure is represented in warp arerage float and weft average float (equations 3 and 4).

Example:

Let $d_1 = 0.02$ cm $d_2 = 0.03$ cm
$P_1 = 0.05$ cm $P_2 = 0.07$ cm

∴ Weave angles can be calculated from equations 7 and 8.

$\theta_1 = 27.43°$ $\theta_2 = 28.07°$

Crimp ratios can be calculated from equations 5 and 6.

$(C_1)_{1/1} = 0.0979$ $(C_2)_{1/1} = 0.08995$

Table (1) shows the effect of weave structure (average float) on yarn crimp ratios:

Table (1): Average float of different weaves and the corresponding values of crimp ratio (d_1 = 0.02 cm, d_2 = 0.03 cm, P_1 = 0.05 cm, and P_2 = 0.07 cm).

Yarn Interlacing Repeat	Average Float	C_1	C_2
$\frac{1}{1}$	1	0.0979	0.08995
$\frac{1}{2}$	1.5	0.0653	0.05997
$\frac{1\ 1}{3\ 3}$	2	0.0489	0.04479
$\frac{1\ 2\ 2}{2\ 3\ 3}$	2.5	0.0392	0.03598
$\frac{2}{4}$	3	0.0326	0.02998

IV.2. Fabrics of Extended Weaves:

In the above-mentioned analysis yarn spacing P is taken constant i.e yarns are uniformly spread along and across the woven favric. In extended weaves every group of yarns interlace alike and behave as one yarn i.e they run side by side without gaps except at points of intersection where yarn set is divided into groups. Basket weave, warp rib and weft rib are popular examples of such weaves. In this case yarn spacing is not constant.

Length of weave repeat $L = 2n\,P_2 + \left(\sum A_i + \sum B_i - 2n\right) d_2$ (12)

Warp length / repeat $= 2n\,L_1 + \left(\sum A_i + \sum B_i - 2n\right) d_2$

$$\therefore \text{ Warp Crimp Ratio } C_1 = \frac{2n\,(L_1 - P_2)}{2n\,P_2 + \left(\sum A_i + \sum B_i - 2n\right) d_2} \tag{13}$$

$$C_1 = \left(\frac{L_1 - P_2}{P_2}\right) / \left\{1 + \frac{\left(\sum A_i + \sum B_i - 2n\right) d_2}{2n\,P_2}\right\} \tag{14}$$

From (12)

$$P_2 = \frac{L - \left(\sum A_i + \sum B_i - 2n\right) d_2}{2n} \tag{15}$$

$$\begin{aligned} P_2 &= \frac{L}{2n} - (F_1 - 1)\,d_2 \\ &= \frac{F_1}{n_2} - (F_1 - 1)\,d_2 \end{aligned} \tag{16}$$

n_2 is overall weft denisty (picks/cm).

Similary

Weft Crimp Ratio

$$C_2 = \left(\frac{L_2 - P_1}{P_1}\right) / \left\{1 + \frac{\left(\sum G_i + \sum H_i - 2m\right) d_1}{2m\,P_1}\right\} \tag{17}$$

If width of repeat is w

$$P_1 = \frac{w - \left(\sum G_i + \sum H_i - 2m\right) d_1}{2m}$$

$$P_1 = \frac{w}{2m} - (F_2 - 1)\, d_1$$

$$P_1 = \frac{F_2}{n_1} - (F_2 - 1)\, d_1 \qquad (18)$$

n_1 is overall warp density (ends / cm).
From (14) and (17)

$$C_1 = \frac{2nP_2}{L} (C_1)_{1/1} \qquad (19)$$

and

$$C_2 = \frac{2mP_1}{w} (C_2)_{1/1} \qquad (20)$$

It may be more appropriate to count the number of weft threads / unit length of the fabric than to measure the lenght of weave repeat. The unit lenght must be as great as possible in order to obtain as many complete weave repeats as possible. After counting the number of picks / unit lenght, the overall number of picks / cm (n_2) can be computed.

$$L = \frac{\sum A_i + \sum B_i}{n_2} \qquad (21)$$

Similarly

$$W = \frac{\sum G_i + \sum H_i}{n_1} \qquad (22)$$

It can be derived that

$$C_1 = \left[1 - \frac{n_2\, d_2 \left(\sum A_i + \sum B_i - 2n\right)}{\sum A_i + \sum B_i}\right] (C_1)_{1/1}$$

$$C_1 = \left\{1 - \frac{K_2\,(F_1 - 1)}{F_1}\right\} (C_1)_{1/1} \qquad (23)$$

and Similarly

$$C_2 = \left\{1 - \frac{K_1\,(F_2 - 1)}{F_2}\right\} (C_2)_{1/1} \qquad (24)$$

$$K_1 = n_1\, d_1 \qquad (25)$$

and $$K_2 = n_2\, d_2 \qquad (26)$$

V. Procedure of Calculations:

V.1. Fabrics of Floated Weaves:

Given: Weave structure, yarn diameters (warp and weft), and yarn spacings (warp and weft).

Calculations:

- From weave structure, yarn arerage float is estimated (warp and weft).
- From yarn diameters and yarn spacings, weave angles and yarn crimp ratios of plain weave can be calculated.
- From yarn crimp ratio of plain weave and yarn average float, yarn crimp ratio of the considered weave structure is estimated.

V.2. Fabrics of Extended Weaves:

Given: Weave structure, yarn diameters (warp and weft) and average yarn densities (warp and weft).

Calculations:

- From weave structure, yarn average float is estimated (warp and weft).
- From yarn diameter and yarn density, yarn cover ratio can be estimated (warp and weft).
- From yarn average float, yarn dianeters, and yarn densities, yarn spacing for plain weave (yarn spacing at points of intersection) can be estimated.
- Fram yarn spacing at points of intersection and yarn diameters, yarn crimp ratis for plain weave can be estimated.
- From yarn cover ratios, yarn average floats, and yarn crimp ratios for plain weave, yarn crimp ratios for the considered weave structure can be estimated.

Figures 3 and 4 show a descrimination between floated and extended weaves with respect to crimp ratio.

VI. A New Method for Measuring Yarn Crimp Ratio:

The usual procedure followed to estimate yarn crimp ratio [5] is to measure:

1- The distance bet. two points on the yarn in the plane of the fabric (L_C).

2- The distance between the previously considered two points when the yarn is straightened i.e. decrimped (L_S).

Then yarn crimp ratio is estimated as follows:

$$C = \frac{L_s - L_c}{L_c} \qquad (27)$$

Determining the lenght L_S needs straightening the crimped yarn by applying a certain tensile load (decrimping load). The decrimping load is that sufficient to straighten the yarn without causing any elongation. This decrimping load is a function of [4] yarn material, yarn structure, and yarn count i.e. yarn properties. It is clear that the value of the decrimping load is not only difficult to be specified but also a critical value. This means that a load less than the proper decrimping load results in a value of crimp ratio less than the real value and a load more than the proper decrimping load results in a value of crimp ratio more than the real value. There is no doubt that the previous formula (equation 27) of calculating yarn crimp ratio is right but the problem lies in determining the value of L_S. This problem can be overcome by the following procedure:

Multiplying the numerator and denominator in (27) by yarn cross sectional area and yarn density (weight / unit volume), then

$$C = \frac{W_s - W_c}{W_c} \qquad (28)$$

W_S is the weight of the unravelled yarn, W_C is the weight of a portion of the yarn of lengh equal to the distance between the ends of the unravelled yarn in the plane of the fabric. This formula is based on the imporvement of yarn regularity as it is suitable for only regular yarns. W_C can be calculated from yarn count and L_C. If L_C is in meters and yarn count is in N_m (metric count), then

$$W_c = \frac{L_c}{N_m} \qquad (29)$$

W_C is in gm.

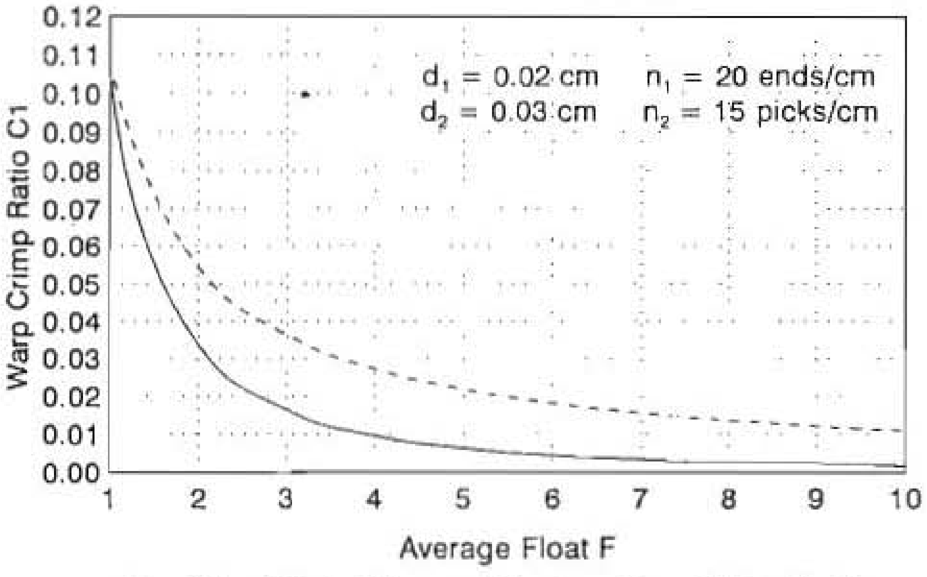

Fig. (3) : Effect of Aerage Float on Warp Crimp Ratio

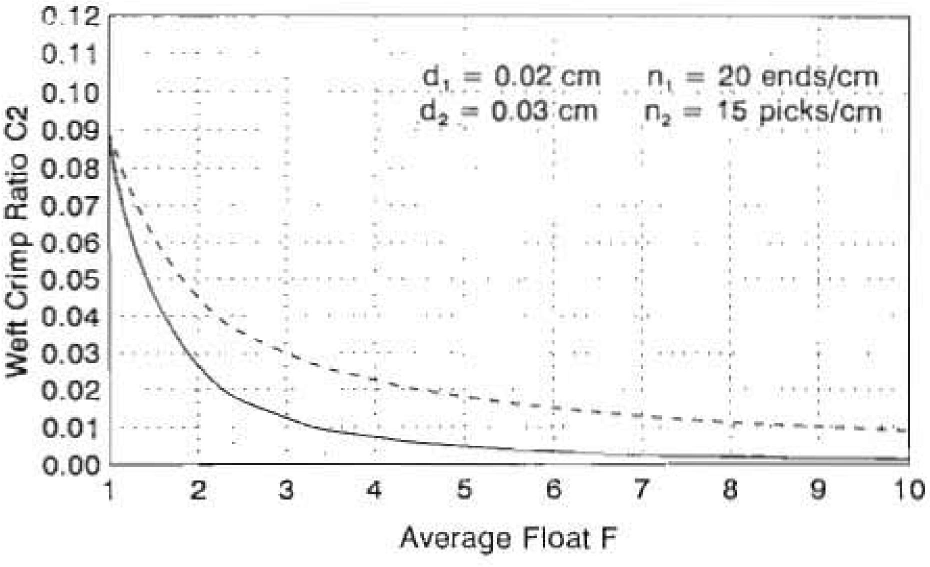

Fig. (4) : Effect of Aerage Float on Weft Crimp Ratio

$$C = \frac{W_s - L_c / N_m}{L_c / N_m}$$

$$C = \frac{W_s . N_m}{L_c} - 1 \qquad (30)$$

If W_s is the weight of one unravelled yarn, C will be the corresponding crimp ratio. If W_s is the mean weight of a number of unravelled yarns of the same L_c , then C will be the average yarn crimp ratio. It can be concluded that if N yarns have a weight W, the W_s will be equal to the total weight divided by the number of yarns i.e .

$$W_s = \frac{W}{N}$$

$$C = \frac{W . N_m}{N . L_c} - \qquad (31)$$

It is worth saying that this relation is another form of the formula used to calculate weight of N crimped yarns of the same crimped lenght L_c, yarn crimp ratio C, and yarn count N_m. The last formula can be rewrittm as follows:

$$C = \frac{N_m}{(N_m)_c} - 1 \qquad (32)$$

$(N_m)_c$ is the metric count of the crimped yarn.

VII. Procedure of Crimp Ratio Testing:

1- Prepare a rectangular or square sample of fabric of adequate dimensions.
2- Measure lenght and width of the sample to obtain the yarn crimped lengh L_c of each of warp and weft.
3- Unravel a number N of yarns (e.g. warp) and weigh them to obtain the weight W of N yarns.
4- Estimate the yarn count N_m of each of warp and weft if it is unknown.
5- Substitute in formula (31) to give the average crimp ratio of N yarns.

VIII. Verification:

Yarn crimp ratio in different samples of woven fabric is estimated by 4 different methods: 3 experimental methods besides the theoretical method considered in this paper. The 3 experimental methods are:

1- Decrimping method.
2- Weighing method and using nominal counts.
3- Weighing method and using estimated values of counts (counts are estimated by decrimping and weighing).

Table (2) shows the results of these 4 methods. It is clear that although styles 1 and 4 have the same constructional details, they differ in values of crimp ratios estimated by the 3 experimental methods. It is also clear that the first and third methods give the same results. In square fabrics where warp and weft specifications are the same (styles 1, 2, 4, 5 and 8) the experimental values of crimp ratio are not the same for warp and weft.

To determine the most suitable method for crimp ratio estimation, fabric weight (g/m^2) is measured and also estimated using crimp ratios obtained from the different 4 methods. This is shown in Table (3). It is clear from the table that the decrimping method and the weighing method (estimated counts) of crimp estimation give nearly the same value of estimated fabric weight. It is also clear that the weighing method (nominal counts) give fabric weight which is the nearest to the measured value in 4 styles and the theoretical method is the nearest in 3 styles whereas the other 2 methods are the nearest in 1 style.

Table (3): Fabric Weight (g/m^2) Measured and Estimated Using Crimp Ratios Obtained by the 4 Different Methods of Crimp Ratio Estimation

Style	Fabric Weight (g/m^2)				
	Measured Value	Estimated Value			
		Decrimping Method	Weighing Method (nominal counts)	Weighing Method (estimated counts)	Theoretical Method
1	166.67	151.71	161.70	151.71	159.80
2	218.18	205.40	211.27	205.40	209.90
3	200.00	177.49	186.40	177.78	172.85
4	168.75	156.95	157.30	156.95	159.80
5	206.00	195.10	181.99	195.00	207.90
6	168.57	161.07	166.69	161.10	146.68
7	180.00	168.70	163.60	169.29	161.00
8	240.00	227.20	246.30	227.00	243.56

IX. Conclusion:

Both the weighing method (nominal counts) and the theoretical method can be preferably used in estimating yarn crimp ratio in woven fabrics. Weighing methods comprises unravelling yarns from fabric, weighing them and then estimating yarn nominal count (as in specifications of fabric), number of unravelled yarns, and yarn crimped length (the new method of crimp estimation). The theoretical method needs measuring yarn densities (or yarn spacing), and yarn diameter (from yarn count), and determining yarn average float (from weave structure repeat). Then substituting in mathematical formulae derived in this paper gives the values of yarn crimp ratios.

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Table (2): Yarn Crimp Ratio for Different Woven Fabrics by Different Methods

Style	Structure		Specifications	Crimp Ratio							
	Weave	Average Float		Decrimping Method		Weighing (nominal Method counts)		Weighing (estimated Method counts)		Theoretical Method	
				C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
1	Plain 1/1	1	$\frac{20/1 \times 20/1}{24 \times 24}$	0.252	0.089	0.164	0.118	0.052	0.089	0.1279	0.1279
2	Dobby $\frac{1\ 1\ 1\ 2}{1\ 2\ 1\ 1}$	1.25	$\frac{14/1 \times 14/1}{22 \times 22}$	0.098	0.115	0.165	0.111	0.098	0.115	0.1308	0.1308
3	Twill 2/2	2	$\frac{10/1 \times 10/1}{16 \times 12}$	0.10	0.033	0.084	0.180	0.103	0.033	0.0316	0.0588
4	Plain 1/1	1	$\frac{20/1 \times 20/1}{24 \times 24}$	0.105	0.11	0.091	0.129	0.105	0.11	0.1279	0.1279
5	Plain 1/1	1	$\frac{16/1 \times 16/1}{24 \times 24}$	0.123	0.08	0.016	0.039	0.121	0.081	0.174	0.174
6	Plain 1/1	1	$\frac{12/1 \times 6.5/1}{10 \times 10}$	0.1475	0.15	0.184	0.192	0.148	0.015	0.0663	0.0357
7	Warp Rib 2/2	2	$\frac{20/1 \times 6.5/1}{10 \times 14}$	0.063	0.079	0.063	0.039	0.061	0.084	0.0673	0.0103
8	Plain 1/1	1	$\frac{14/1 \times 14/1}{24 \times 24}$	0.119	0.125	0.34	0.092	0.119	0.123	0.2026	0.2026