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Weavability Limit of Yarns with Thickness Variation in Shuttleless Weaving

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Abstract: Theoretical weavability limit relationships of fabrics from regular warp yarns and fancy filling yarns with thickness variation in shuttleless weaving are reviewed. The relationships correlate maximum warp and filling cover factors, warp and filling yarn characteristics, the distribution of thick and thin places of filling yarn over the fabric surface, and the warp and filling weave factor. The research considers single filling feeder and multiple feeders cases. Additionally, comparisons between the weavability limit of regular yarns and fancy yarns in shuttle and shuttleless weaving are given.

Keywords: Weavability limit, Shuttles weaving, Cover factor, Fancy yarns, Filling feeder

Introduction

For the last hundred years, numerous empirical maximum weavability (or weavability limit) relationships were developed by researchers to aid fabric designers with useful tools to check whether a proposed fabric construction is weavable. The recognized benefits of such relationships are: (1) Avoiding weaving difficult or unachievable constructions that are close to or exceed the limit, (2) Avoiding excessive warp yarn breaks, and (3) Prevention of excessive wears and damage to weaving machine parts. Additionally, a limit fabric construction can be used as a reference fabric to describe a tightness or firmness of an observed fabric. Extensive critical review of the previous work regarding weavability limit, the benefits of fabric tightness and different tightness expressions proposed by previous researchers was published recently [1,2].

Only few publications have been identified that dealt with weavability limit from theoretical viewpoint. In these publications, however, the authors assumed uniform yarns [3,4]. Recently this assumption was challenged by conducting theoretical research work regarding prediction of weavability limit of fabrics from uniform warp yarns and fancy filling yarns with periodic and random thickness variation in shuttle weaving [5]. The theory was verified experimentally [6]. The increasing popularity of shuttleless weaving technologies and their ability to weave filling yarns with thickness variation has raised the need to expand the weavability limit research efforts to fabrics constructed on shuttleless weaving machines. Theoretical relationships of such fabrics have been derived for single filling yarn feeder case [7].

In this paper the previous work on the weavability limit relationships of fabrics from regular thickness warp yarns and filling yarns with thickness variation is reviewed. Additionally, the weavability limit relationships in shuttleless weaving with multi-feeders filling are considered.

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Theory

Assumptions

The assumptions made to facilitate the derivation of the weavability limit relationships are: (1) The warp and filling yarns are completely flexible, (2) The warp yarns are uniform cylinders, (3) The filling yarns are formed of cylindrical parts of two different diameters, (4) The warp and filling crimp are uniformly distributed along and across the fabric, respectively, (5) The warp yarns under a filling floats, in case of weaves other than plain, follow racetrack shape with vertical dimension of the original warp diameter, (6) The filling yarns under a warp floats follow a racetrack shape with the vertical dimension of the original circular thick filling diameter, and (7) The packing density of the yarns under a float is uniform. These assumptions were proven to be reasonable for plain weaves and other simple weaves up to 8-harness [5,6]. In this paper, the discussion is limited to the plain weave fabrics.

Distribution of Thick and Thin Filling Places on the Fabric Surface in Shuttleless Weaving

Since the filling yarns contain thick and thin places, the warp and filling spacing would vary depending on the distribution of the filling thick and thin places in the fabric. Figure 1 of reference 7 shows a periodic thickness variation filling yarn with wavelength $\lambda = 20$ units, thin place length of $b = 12$ units and thick place length of $a = 8$ units. If fabrics of different widths were woven from such yarn in a shuttleless machine, different distributions of thick and thin places of filling yarn in the fabric would be obtained. The symbol s in the figure denotes the shift of the thick (or thin) part per pick. The shift s is obviously dependent on the fabric width w and λ. The value of s is obtained from the remainder of dividing w/λ; it is the nominator of the non-reduced remainder fraction. The symbol k represents the number of picks per repeat in the pattern. The repeat size k equals the denominator n of the reduced remainder fraction. The value of k could be even or odd number.

If the same filling yarn were produced in a shuttle weaving machine under the same conditions, the patterns of Figure 1 of reference 5 would result. Unlike the shuttleless weaving k must be even number since the insertion of filling yarns takes place from both sides.

Observing the patterns of Figure 1 of reference 7, one notice that the thick (or thin) places form a right hand or a left hand twill line because the filling insertion takes place from one side of the weaving machine. In case of shuttle weaving, Figure 1 of reference 5, two opposite twill lines are formed.

Average Pick Spacing in Terms of Number of Overlaps and No Overlaps of Thick Places

Periodic Thickness Variation Filling Yarns

The overlap and/or the no overlap of thick places in successive picks have to be found in order to get the pick spacing. It has been shown that in shuttle weaving the number of overlaps and no overlaps depend on which point of the filling yarn along the wave length λ is intersecting with the left hand selvage (as reference). This point was termed "starting point". In shuttleless weaving, however, the pattern is independent of the starting point. To illustrate this, the pattern of Figure 1(b) of reference 7 was selected to produce the patterns of Figure 2 in the same reference by changing the starting point one unit at a time. The patterns are identical, only the order of the picks has changed. This leads to an important conclusion, the overlap of thick places in any two successive picks is certain for some patterns while the others show no overlap of thick places in any two successive picks. Thus the condition of overlap is

$$0 \le s < a \quad \text{or} \quad b < s \le \lambda \tag{1}$$

And the condition of no overlap is

$$a \le s \le b \tag{2}$$

Where a is the length of filling yarn thick place, b is the length of filling yarn thin place and $\lambda = a + b$.

As indicated above, in shuttle weaving the pattern is impacted by the starting point. To illustrate this, the pattern of Figure 1(j) of reference 5 was selected to produce the patterns of Figure 4 in reference 5. These patterns are produced by shifting the starting point by one unit. If the first pick were shifted to the right, the second pick would be shifted to the left. From all possible starting points, we have shown that [5] the probability of overlap of thick places in two successive picks is given by:

$$p = \frac{2a}{\lambda} \tag{3}$$

Random Thickness Variation Filling Yarns

In shuttleless weaving, definite solution for random distribution of the thick and thin places along the filling yarn to determine overlaps is possible provided that the locations of the thick places along the yarn are known. This is because the fact that the pattern of the thick place distribution over the fabric surface is not affected by the starting point. Methods to monitor the random distribution of slubs (generated by a control system) along the yarn during spinning using computer are provided by fancy spinning frame producers. In such methods computer systems allow many random patterns of yarns to be stored and reproduced if desired. These methods can be further modeled to determine the number of overlaps and no overlaps of thick places. Once these are known weighted average of pick spacing can be found. When the length of thick and thin places and fabric width are known, the solution reduces to one-dimension by locating the thick places relative to a reference point (left fabric edge, say) and hence the overlap or no overlap for successive picks can be easily determined.

In shuttle weaving, prediction of the pattern is impossible since it depends on the starting point. The proposed solution above could be used here provided that fair number of patterns with different starting points is produced to estimate the number of overlaps and no overlaps.

Average Warp Spacing

Periodic Thickness Variation

The objective here is to calculate the weighted average of the number of warp spacing where thick filling places interlace with warp yarns and the number of warp spacing where thin filling places interlace with warp yarns. A general solution was established for the shuttle weaving case by developing the so-called "two pick equivalent system" for any pattern repeat. In shuttleless weaving the system is reduced to "one pick equivalent system" since the pattern is independent of the starting point. The one pick equivalent system is a pattern repeated on one pick developed by projecting all the thick places on the first pick. The one pick equivalent system would allow the calculation of the number of warp spacing where thick filling interlaces with warp ends n_1' and the number of warp spacing where thin filling interlaces with warp yarn n_1. Hence weighted average warp spacing can be calculated.

Random Thickness Variation

As discussed above the location of the thick places ends can be located on the one pick equivalent pattern to get the average warp spacing. In this case, however, it can be argued that in most cases one warp spacing should be used, where thick filling places interlace with warp ends. This is due to the large size of the pattern repeat and the random distribution of thick places that would cause them when projected on the one (or two in case of shuttle) pick equivalent system to cover the entire fabric width.

Weavability Limit Relationships in Shuttleless Weaving of Single Filling Feeder

Periodic Thickness Variation

In shuttleless weaving, it has been shown that there are two cases for the pick spacing and two cases of warp spacing. Since these are independent, four weavability limit relationships should be derived for periodic novelty filling yarns to cover all combinations. The relationships were derived for any weave following the geometrical models and procedure established in reference 5. In this paper, however, the relationships of plain weaves are shown.

Case 1: *Thick Places Overlap and Thick Filling Interlaces with Warp Ends*

It can be shown that the weavability limit equation for this case is,

$$\sqrt{1-\left[\frac{27.9_1}{\bar{K}_1(1+\beta')}\right]^2}+\sqrt{1-\left[\frac{27.9\beta}{\bar{K}_2(1+\beta')}\right]^2} = 1 \qquad (4)$$

Where

$\beta = \frac{d_{2eq}}{d_1}$ = Yarn balance of the equivalent regular filling yarn

$\beta' = \frac{d_2'}{d_1}$ = Yarn balance of thick filling portion

$\bar{K}_1 = \frac{27.9 d_1}{\bar{p}_1}$ = Average warp cover factor

$\bar{K}_2 = \frac{27.9 d_{2eq}}{\bar{p}_2}$ = Average filling cover factor

d_1= Warp yarn circular diameter

d_{2eq}= Equivalent regular filling yarn circular diameter

d_2' = Filling circular diameter of thick portion

$\bar{p}_1$ = Average warp spacing

$\bar{p}_2$ = Average filling spacing

Case 2: *Thick Places do not Overlap and Thick filling Interlaces with Warp Ends*

Here the weavability limit equation is,

$$\sqrt{1-\left[\frac{27.9}{\bar{K}_1(1+\beta')}\right]^2}+\sqrt{1-\left[\frac{55.8\beta}{\bar{K}_2(2+\alpha\beta+\beta')}\right]^2} = 1 \qquad (5)$$

Where $\alpha = \frac{d_2}{d_{2eq}}$, and

d_2 = thin filling circular diameter

Case 3: *Thick Places Overlap and Thick and Thin Filling Interlace with Warp Ends*

For this case the weavability limit relationship is,

$$\sqrt{1-\left[\frac{27.9/\bar{K}_1}{r_1(1+\alpha\beta)+r_1'(1+\beta')}\right]^2}+\sqrt{1-\left[\frac{27.9\beta}{\bar{K}_2(1+\beta')}\right]^2} = 1 \qquad (6)$$

Where $r_1 = \frac{n_1}{n_1+n_1'}$ and $r_1' = \frac{n_1'}{n_1+n_1'}$

n_1' = number of warp spacing where thick filling interlaces with warp ends

n_1: number of warp spacing where thin filling interlaces with warp ends

It is clear that $r_1' + r_1 = 1$.

Case 4: *Thick Places do not Overlap and Thick and Thin Filling Interlace with Warp Ends*

Here the weavability limit equation is,

$$\sqrt{1-\left[\frac{27.9/\bar{K}_1}{r_1(1+\alpha\beta)+r_1'(1+\beta')}\right]^2}+\sqrt{1-\left[\frac{55.8\beta}{\bar{K}_2(2+\alpha\beta+\beta')}\right]^2} = 1 \qquad (7)$$

Random Thickness Variation

It has been justified previously [5] that one warp spacing should be considered here where thick place interlaces with warp yarns due to the large size of the pattern repeat and the random distribution of the thick places. This lead to thick places covering the entire length of the one pick equivalent system. The overlap and no overlap of successive picks should be considered. The weavability limit for this case can be deduced as,

$$\sqrt{1-\left[\frac{27.9}{\bar{K}_1(1+\beta')}\right]^2}+\sqrt{1-\left[\frac{55.8\beta/\bar{K}_2}{r_2(2+\alpha\beta+\beta')+2r_2'(1+\beta')}\right]^2} = 1 \qquad (8)$$

Where $r_2 = \frac{n_2}{n_2+n_2'}$ and $r_2' = \frac{n_2'}{n_2+n_2'}$

n_2'= Number of pick spacing of overlap,

n_2 = Number of pick spacing of no overlap

It is clear that $r_2' + r_2 = 1$.

It can be shown that equations (4)-(8) are special cases of the general equations developed for shuttle weaving (Equation 42, reference 5). For example, equation (4) can be obtained if $p = 4/k$, $p = 1$, and $q = 0$ are substituted in Equation 42 of reference 5.

Weavability Limit Relationships in Shuttleless Weaving of Multi-Filling Feeders

Assume two filling feeders are used. Further assume each feeder is supplying a periodic thickness variation yarn with the same characteristics. Each yarn thick places will form a twill line. Both twill lines are of the same direction. Depending on the starting point of each yarn, the two twill lines will form different patterns. Infinite number of patterns is possible. The probability of overlap of thick places in two successive picks depends on the starting point. This situation is identical to shuttle weaving with single shuttle with one difference. Only the direction of the two twill lines is opposite in shuttle weaving. The probability of overlap of thick places can be, however, estimated here in exact manner as shuttle weaving. Hence average filling spacing and warp spacing can be found. In fact Equation 42 of reference 5 is valid here as well. This equation can be applied to random thickness variation as discussed previously here and in reference 5.

Influnce of Weavability Limit Parameters on Maximum Warp and Filling Cover Factors

Figures 1-8 show graphical presentation of the weavability limit relationships (equations (4)-(8)) for plain weaves. The figures were generated for broad range of weavability limit parameters. The curves marked "Regular" in Figures 1-3, 5, and 7 are generated by substituting $\beta' = \beta$. These curves represent the maximum weavability of regular thickness filling yarns.

The graphs of Figures 1-8 show that the weavability limit relationships (or the maximum fabric cover factors; $\bar{K}_1 + \bar{K}_2$) are significantly impacted by the parameters β', r_1', and r_2' for a given yarn balance β. The level of significance of these parameters, however, differs from case to another. The influence of β' is more pronounced in the cases where the thick filling portions overlap than the cases where they do not overlap. The graphs of Figures 4 and 6 indicate that r_1' has little effect on the maximum fabric cover factors for the condition $\bar{K}_1 \gg \bar{K}_2$.

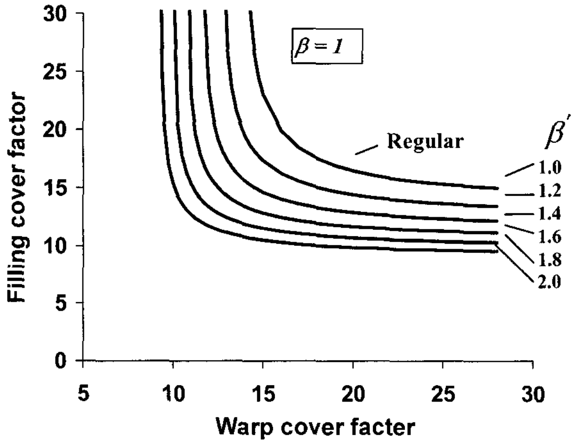

Figure 1. Effect of β' on the weavability limit of plain weaves for the case: thick filling portions overlap and thick filling interlaces with warp ends (equation (4)).

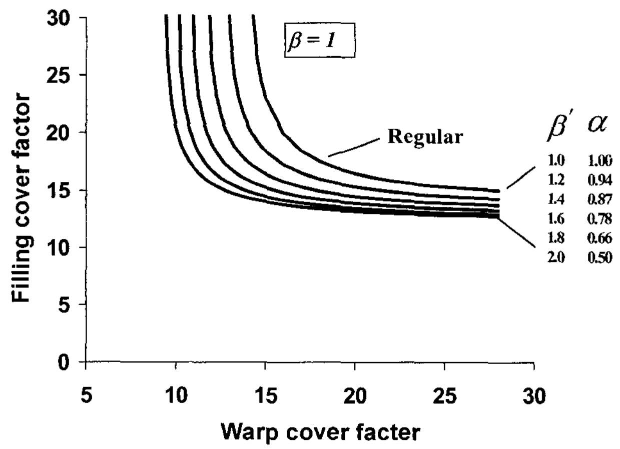

Figure 2. Effect of β' on the weavability limit of plain weaves for the case: thick filling portions do not overlap and thick filling interlaces with warp ends (equation (5)).

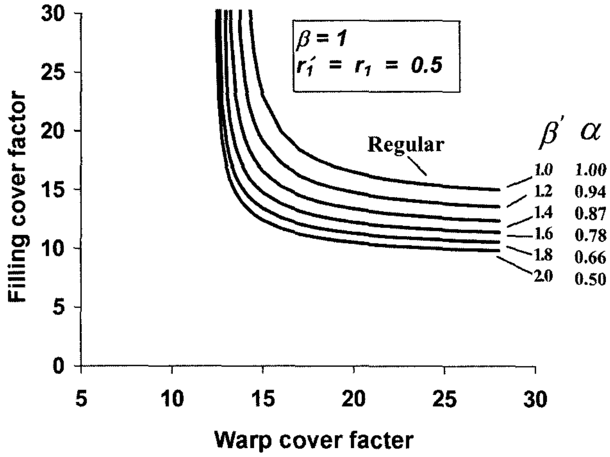

Figure 3. Effect of β' on the weavability limit of plain weaves for the case: thick filling portions overlap and thick and thin filling interlaces with warp ends (equation (6)).

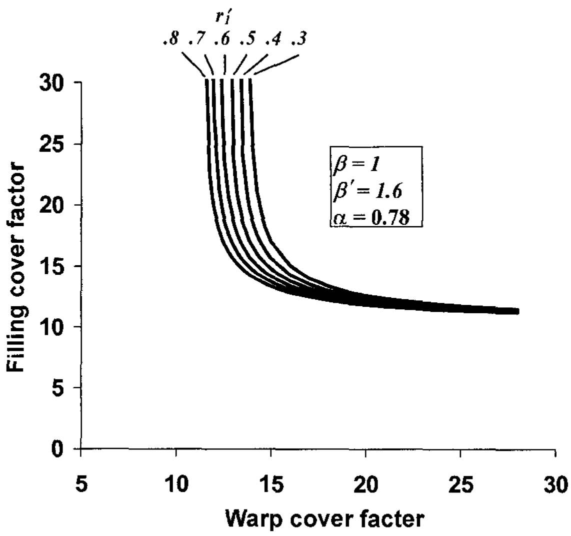

Figure 4. Effect of r_1' on the weavability limit of plain weaves for the case: thick filling portions overlap and thick and thin filling interlaces with warp ends (equation (6)).

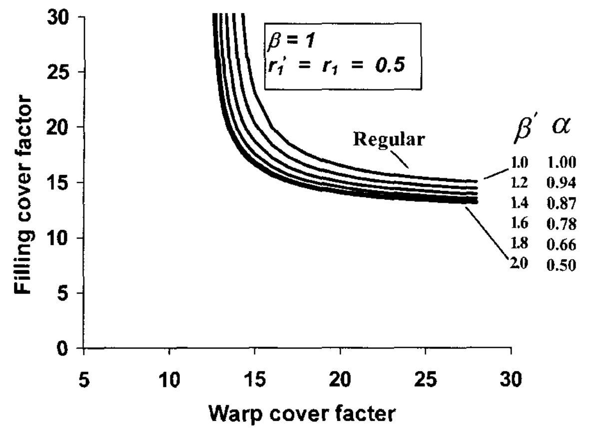

Figure 5. Effect of β' on the weavability limit of plain weaves for the case: thick filling portions do not overlap and thick and thin filling interlaces with warp ends (equation (7)).

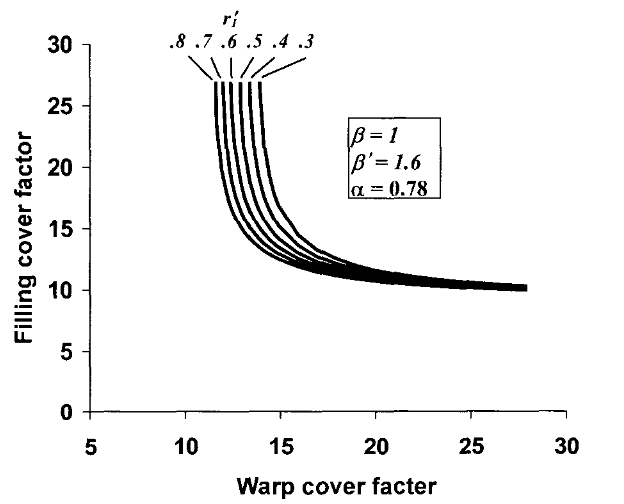

Figure 6. Effect of r_1' on the weavability limit of plain weaves for the case: thick filling portions do not overlap and thick and thin filling interlaces with warp ends (equation (7)).

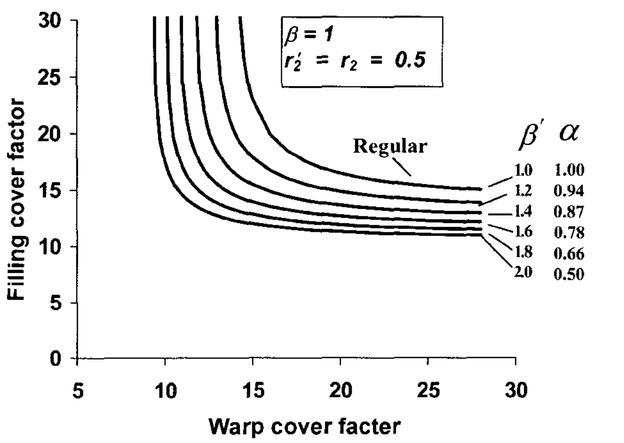

Figure 7. Effect of β' on the weavability limit of plain weaves from random thickness variation filling yarns (equation (8)).

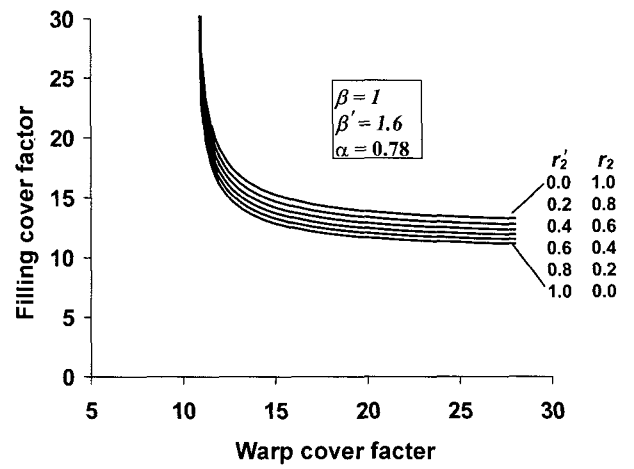

Figure 8. Effect of r_2' on the weavability limit of plain weaves from random thickness variation filling yarns (equation (8)).

Figure 8 illustrates the influence of r_2' for plain fabrics woven from random thickness variation filling yarns. The figure shows the maximum fabric cover factors for the entire possible range of r_2' (0.0-1.0) at constant β and β'. The condition $r_2' = 0.0$ corresponds to the cases of no overlap of thick filling portions and the condition $r_2' = 1.0$ corresponds to the cases of overlap of thick filling portions. The values $0.0 < r_2' < 1.0$ correspond to the cases where there is combination of overlap and no overlap of thick filling places. It is clear from the graphs of Figure 8 that the maximum cover factors are not very sensitive to r_2'.

Conclusion

We have shown that the patterns produced from thick and thin places of novelty filling yarns in shuttleless weaving is independent of the starting point for the single feeder case. This indicates for given novelty filling yarn and fabric width the pattern is the same no matter which filling portion is presented to the filling insertion mean when weaving starts. Thus, in shuttleless weaving with single feeder (unlike shuttle) designers can fully control (or predict) the pattern by changing the thick and thin places lengths and fabric width. The predictability of the pattern has dictated four cases for periodic thickness variation filling yarns and additional case for random thickness variation that have to be considered when deriving weavability limit relationships. These cases are special cases for the general equation derived previously for the shuttle weaving. Weavability limit relationships for multiple feeder case in shuttleless weaving can be derived in the same manner as the shuttle weaving.

The theoretical relationships and their graphical presentation have shown that the maximum fabric cover factors are influenced by the dimensionless parameters β, β', r_1', and r_2'. Woven fabric designers can take advantage of this investigation to create different fancy effects through different patterns with desired weight while avoiding unachievable constructions.

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