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The effect of loom settings on weavability limits on air-jet weaving machines

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Abstract

In this paper, the effect of weaving machine settings on weavability limits of air-jet looms was investigated by weaving plain weave fabrics with polyester warp and weft yarns. For this purpose, firstly, weavability limits were determined for 16.7 tex weft by setting back-rest height, total warp tension, frontshed angle and shed closing time at different levels without changing the properties of warp. For each machine setting, weft density was increased gradually until reaching the weavable limit. During the experiments, weaving continuity, unfavorable effects interrupting this continuity, negative changes on fabric and yarns were observed. In the mean time, the warp yarn tension and cloth-fell distance were measured. Later, the weaving with 7.8 and 33.3 tex wefts was carried out at the settings required to produce a weave at the maximum weft density for 16.7 tex weft. The maximum weavable weft densities were determined for these two weft yarns. Finally, the obtained maximum weft densities and cover factors with three different weft yarns were compared with the results obtained from theoretical equations of Pierce, Love and Brierley.

It was found that the warp tension had the most significant effect on the weavability limits. Changing shed adjustment from the zero level of the back rest to higher values, increased the weavability limit slightly, but increasing the shed asymmetry further did not have a significant effect on the weavability limit. The shed closing time had some effect on the limit. But this was less than the effect of the warp tension. Changing the front shed angle did not have any effect on weavability limits.

Keywords

Weft setting, warp setting, cover factor, weaving machine settings, weavability limit, cloth-fell, warp tension

Introduction

The main purpose of designing a woven fabric is to develop new fabric structures having the most appropriate properties for end-use applications, to achieve a high level of performance and to enhance fabric quality. Good fabric quality and high weaving efficiency can be obtained by just performing specific weaving process conditions. The most basic of these conditions is that the previously designed fabric must be within the weavability limits. The weavability limit is defined as reaching maximum weft density for a given fabric construction without interrupting the continuity of weaving. If the designed fabric exceeds the maximum density limits, this design can not be manufactured on a loom.

Studies regarding weavability and weavability limits were carried out in two main fields as theoretical and experimental. The first one was to design geometrical models symbolizing some weaves and to derive mathematical equations. The latter was to investigate the effects of loom settings on weavability limits and to compare the experimental results with theoretical ones.

Developing geometrical models was based on designing the yarn cross-section geometry, and calculating the diameter of this cross-section and the distances between two yarns under the intersections or floats. During the theoretical studies, the most serious problem is the determination of yarn geometry representing the cross-section of a yarn in the fabric. Based on the assumption of yarn cross-section, the geometrical relationships are derived to obtain maximum weavability limits. The solution of

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the maximum weavable woven fabric construction enables the woven fabric designer to predict whether or not the designed fabric can be produced on a loom. For the theoretical studies, the following researchers and their studies came forward.

Ashenhurst[1] was the first researcher doing theoretical works about maximum woven fabric densities. For this purpose, he put forward two theory-named end plus intersections and curvature theories. Peirce[2] had designed two geometric models that had cylindrical and elliptical yarn cross-sections for plain weave fabric and he derived mathematical equations for these models to calculate maximum densities and cover factors. Kemp[3] presented the theory named race-track that could represent the jammed cross-section of yarns under floats well. Hamilton[4,5] built up a geometrical model based on the theories of Peirce and Kemp and he derived equations from his model to calculate the cover factor. Love[6] developed the equations of Peirce for the weaves other than plain weave. In his later studies, he produced graphical solutions of his equations so that the manufacturers could easily use these equations. Paintert[7] had also developed graphical solutions based on Peirce's equations that included the type of fiber, weave, dimensional changes, crimp and the counts of yarns. Olofsson[8] considered the mechanical behavior of fabric under various loads to develop geometrical model. He applied the theory of mechanics of elastic structures and energy method. Seyam and Al-Shaeke[9,10] investigated weavability limits of yarns with thickness variations and derived the equations that could predict the weavability limits before weaving. Ozdemir and Baser[11] studied the simulating view of real fabric for twill and basket weaves by using a digital image analysis method to obtain the most appropriate geometrical model that would be used for predicting weavability limits.

In experimental works, the following researchers and their research works draw attention. Law[12] constructed an empirical study on weavability limits. He compared the warp and weft densities calculated by the equations of Ashenhurst with maximum settings of different woven fabrics. Brierley[13–26] did comprehensive studies on weavability limits of straygarn woollen and worsted fabrics. In his first investigation, he developed graphics that showed the relationships between average float and densities and then he derived the equation of weavabilty limits from these graphics. Later, he presented the equations that indicated the weavability limits of unbalanced fabrics in terms of densities and in terms of yarn counts as well as in terms of both densities and yarn counts. Armitage[27] analyzed a lot of cotton, straygarn woollen and worsted fabrics with maximum weft densities. He presented the equation of weavability limit containing weave coefficient, yarn count and fabric coefficient. Dickson[28] improved the new equations for the cover factor since he provided the weavability limit graphics of Love to use for yarn types other than cotton yarn. Snowden[29] investigated the effects of static warp tension for various weaves on the weavabilty limit. He had also compared experimental results with the results of Love's graphs for these weaves. Sharma and Bhargava[30] produced woven fabrics with different warp densities, static warp tensions and weft yarn counts to see the effects of these factors on weavability limits on the loom. Ashton[31,32] investigated the effects of back-rest height, static warp tension, shed closing time and warp density on the weavability limit on shuttle and water-jet looms. He tested his results with the results calculated from Peirce's equations. Gong[33] monitored the cross-section of yarns in the fabric by using the technique of synchrotron radiation X-ray image analysis to achieve the most appropriate geometric shape of yarn used in the fabric geometrical model. Kumpikaite and Milasius[34,35] investigated the effects of fabric structural parameters, such as yarn count and yarn type, weave, warp density and loom particulars on weavability limits.

When experimental studies are evaluated generally, it is seen that most of the research has been done on weavability limits of fabrics woven with natural staple fiber yarns on shuttle and rapier weaving machines. The lack of this kind of research on air-jet looms, having high running speeds and modern control and drive mechanisms, using synthetic staple and continuous filament yarns attract attention. Developments in electronics have enabled weaving machines to be more productive. Because of accurate control of yarn loading during weaving, the rate of yarn breakage has been decreased. In addition to technological developments in weaving machines, the technique of yarn production has also shown progress. Thus, the yarns have higher mechanical and structural properties that resist the loads during weaving. All the developments have a feature that can provide weavability limit to rise.

The aim of this study is to investigate the effects of machine settings on weavability limits on a high speed air-jet loom using continuous filament yarns.

Materials and methods

Weft and warp yarns

The properties of warp and weft yarns used in the experimental study are shown in Table 1 and Table 2 respectively.

The weaving particulars are as follows:

Weave type: plain
Total number of ends: 5626
Width of the reed: 1669 mm

Table 1. Warp yarn used in the experimental study[a]

Fiber type	Yarn count (tex/fil)	Yarn twist (turn/m)
Polyester	16.7/36	400

[a]ASTM Standards D2256-80

Table 2. Weft yarns used in the experimental study

Fiber type	Yarn count (tex/filament)	Yarn type
Polyester	7.8/72	Texture-semimatt
Polyester	16.7/96	Texture-semimatt
Polyester	33.3/70	Texture-semimatt

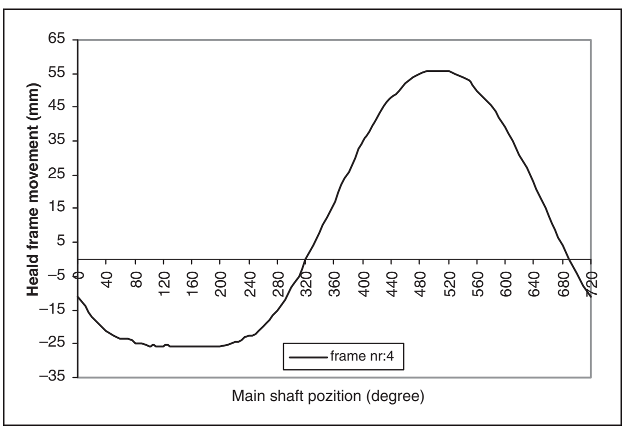

Figure 1. Displacement curve of the fourth heald frames with respect to main shaft angle for two loom revolution (shed closing time: 320°).

Table 3. Weaving machine settings

Adjusted total warp tension (kN)	Back-rest height (cm)	Front shed angle (degrees)	Shed closing time (degrees)	Weft yarn number (tex)
0.90	0	26°	280°	7.8
1.25	1.50	28°	290°	16.7
1.50	2.50	30°	305°	33.3
1.75	3.50	32°	320°	–
–	–	34°	340°	–

The reed number: 16.75 dents/cm
The reed denting plan for fabric: 2 ends/dent (the number of total ends: 5524)
The reed denting plan for fabric sides: 3 ends/dent (the number of total ends: 102)

The movement of a harness is shown in Figure 1. The measurement, on Figure 1, was carried out according to a reference point which was taken from the machine. The height of the frame in the shed closing time was considered as 0 mm. As seen from the figure, the heald frames have an asymmetric motion. With this type of motion, heald frames displace more upwards than downwards with respect to the closed shed line. Because of this, warp yarns at the upper shed elongate more and therefore have higher tension than warp yarns forming a lower shed even when the back-rest height is at zero reference level.

Weaving machine

A Picanol (OMNI) air-jet weaving machine with electronic let-off and take-up mechanisms and positive cam shedding motion was used in weaving fabrics. The loom was run at 700 rpm.

Measurement and data saving

Warp tension was measured by using a SCHMIDT single end tension measurement unit having a measurement range of 0–200 cN. The tension measurement system consists of a measuring head and an amplifier circuit. For 0–200 cN measurement interval, an output voltage was obtained between 0 and 10 V with a linear change. A proximity inductive type of switch was used to measure the angle of the main shaft of the loom. Leading edge of the signal of the proximity switch corresponded to the most forward position of the reed. Both proximity switch and tension measurement unit were interfaced to a personal computer using a data acquisition card. A computer program was developed in Turbo C programming language to collect and save the proximity switch and tension sensor outputs. In this way, warp tension data was collected and saved to a PC with respect to loom main shaft angle. 270 readings of warp tension were taken for each loom revolution.

Methods

In this study, the following parameters were changed and their effects on weavability limits were investigated.

(I) Warp tension
(II) Front shed angle
(III) Back-rest height (shed asymmetry)
(IV) Shed closing angle (time)

Weaving trials were carried out by changing these parameters (i.e. machine settings) with certain steps as given in Table 3.

The machine settings were changed according to an experimental work program. Weaving conditions were observed and the maximum weavable weft density was

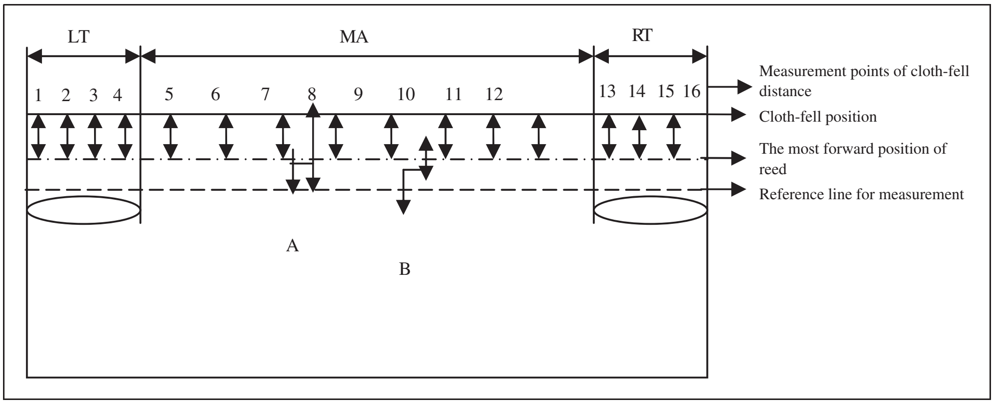

Figure 2. Cloth-fell distance measuring regions through the width of fabric (LT: Cloth-fell distance measurement region on the left temple region; RT: Cloth-fell distance measurement region on the right temple region; MA: Cloth-fell distance measurement region in the middle of the fabric).

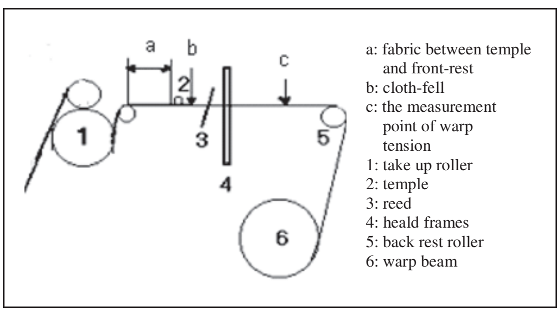

Figure 3. Region of the loom in which warp tension was measured.

determined for each machine setting group. Machine setting groups will be given in the results and discussion part. First group of experimental studies were carried out by using 16.7 tex weft yarn. After finding the machine settings allowing to weave with maximum weft density by inserting 16.7 tex weft yarn, the maximum weavable weft densities were investigated for 7.8 and 33.3 tex weft yarns by using these machine settings.

Measurement of the cloth-fell distance and warp tension

Cloth-fell distance was measured for all machine settings and weft densities. Cloth-fell distance was measured from right and left temple regions and between the temples. Eight measurements were taken between the temples and four measurements were taken from each temple region. For cloth-fell distance measurement, some fixed points on the machine frames were determined as the reference point for each region. Reference point is the bottom side of metal plate extending through the loom width under the fabric and it can be seen from the fabric surface. Measurement and reference points have been shown in Figure 2.

A: distance between cloth-fell position and reference line
B: distance between the most forward position of the reed and the reference line

Cloth-fell distance = A−B

Warp tension data was measured for single yarn on warp sheet between the back-rest roller and droppers (Figure 3).

During weaving of all fabrics, negative effects interrupting the continuity of the weaving process like stoppages resulting from the warp and weft were observed and the maximum weavable weft density was decided when the continuity of weaving was disrupted.

Results and discussion

Weavability limits with different warp tension values and back-rest heights

In this group of experimental studies, the back-rest height and warp tension data were changed as shown in Table 4, but the shed closing time and front shed angle remained the same. Changes in these parameters are shown in Table 4. For each back-rest height, fabrics were woven with four different warp tensions up to a maximum weavable weft density.

The maximum weavable weft densities are shown in Table 5. It can be seen from Table 5 that the increase in warp tension increased the maximum weavable weft density. Increase of total warp tension from 0.9 kN to 1.75 kN caused 3 picks/cm increase in maximum weavable weft density for 0 back-rest height and 4 picks/cm increase in other back-rest heights. This is a very significant effect and agrees well with the findings in the literature.[29–31] The way warp tension affects maximum

Table 4. The machine settings in different back-rest height and warp tension

Weft count (tex)	16.7														
Shed closing time (degrees)	320°														
Front shed angle (degrees)	26°														
Spring rigidity of back rest (N/mm)	165.17 N/mm														
Back-rest height (cm)	0				1.5				2.5				3.5			
Total warp tension (kN)	0.90	1.25	1.50	1.75	0.90	1.25	1.50	1.75	0.90	1.25	1.50	1.75	0.90	1.25	1.50	1.75

Table 5. Maximum weft densities obtained with different levels of back-rest height and warp tension

Back-rest height (cm)	Total warp tension (kN)	Adjusted weft density on the loom (picks/cm)	Weft density of the gray fabric (picks/cm)	Warp density of the fabric on the loom (ends/cm)	Warp density of the gray fabric (ends/cm)
0	0.9	26	26	34	35.2
	1.25	27	27.3	34.3	35.3
	1.5	28	28.4	34.3	35.3
	1.75	29	29.6	34.3	35.7
1.5	0.9	26	26.4	34	35.2
	1.25	27	27.4	34.3	35.3
	1.5	29	29.3	34.3	35.4
	1.75	30	30.66	34.3	35.8
2.5	0.9	26	26.5	34	35.3
	1.25	27	27.3	34.3	35.3
	1.5	29	29.4	34.3	35.6
	1.75	30	30.66	34.3	35.6
3.5	0.9	26	26.3	34	35.2
	1.25	27	27.6	34.3	35.2
	1.5	29	29.3	34.3	35.3
	1.75	30	30.66	34.3	35.7

weavable weft density can be explained by the cloth-fell distance change with warp tension.

The cloth-fell distance change over the fabric width for 18 picks/cm at the back-rest height of 2.5 cm has been shown in Figure 4. As the figure is evaluated, in low weft densities like 18 picks/cm, it is seen that cloth-fell is positioned almost at the most forward position of the reed independent of warp tension. The cloth-fell position slightly shifts towards the back at the selvage sides. This is due to the lower warp tension at the selvages than the middle region of the fabric. Therefore at low weft densities, the cloth-fell does not move together with the reed during beat-up except for a slight movement at the selvages.

The cloth-fell distance variation over the fabric width is presented in Figure 5 for 26 picks/cm at the back-rest height of 2.5 cm for different warp tensions. As seen in these curves, when the weft density is increased from 18 to 26 the cloth-fell moves away from the weaver at a significant amount. The cloth-fell displaces more at the selvage areas than in the middle of the fabric. Another noticeable point is that when the warp tension decreases in weaving at 26 picks/cm, the cloth-fell position moves more away from the weaver. A significant difference

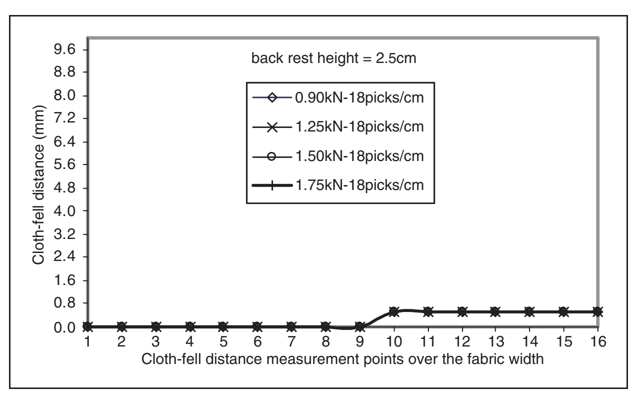

Figure 4. Cloth fell distance variation over the fabric width for 18 picks/cm.

is seen in the cloth-fell shift between 0.9 kN and 1.75 kN total warp tensions. More shift in the cloth-fell position at decreasing warp tensions decreases the shed opening and affects the weft insertion conditions adversely. This has a limiting effect on the maximum weavable weft density. As seen from the figures, the cloth-fell distance variation over the fabric width decreases with increasing warp tensions. Therefore, increasing warp tension improves the weaving conditions to obtain a maximum weavable weft density by decreasing cloth-fell shift as well as by decreasing the variation of it over the fabric width. It should be mentioned here that fabrics were woven under bumping conditions at weft densities of 26 picks/cm and higher and bumping conditions were more severe at lower warp tensions.

Figure 6 shows the relationship between the adjusted total warp tension and single end tension as well as cloth-fell distance. Single end warp tension increases as expected with adjusted total warp tension. But, the cloth-fell displacement decreases with the increasing adjusted total warp tension. This is thought to be due to the supporting effect of warp tension according to which the picks beaten up to the fabric fell are held firmly by warp yarns at higher warp tensions. The picks beaten up to the fabrics slide back because of lower holding force exerted to the picks by warp yarns at low warp tensions. This causes a higher shift of the cloth-fell. It can be stated at this stage that warp tension has a significant effect on the maximum weavable weft density.

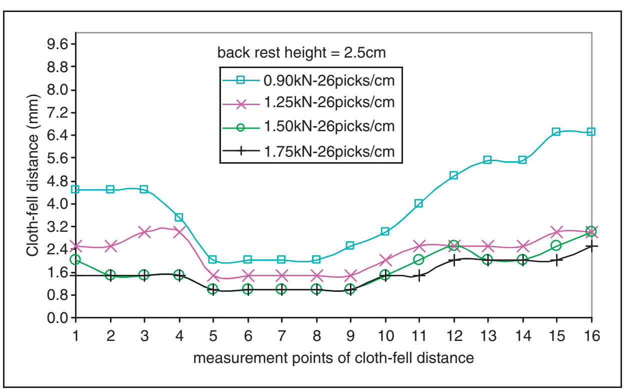

Figure 5. Cloth fell distance variation over the fabric width for 26 picks/cm.

Weavability limits with different back-rest heights and front shed angles

The effects of back-rest height and front shed angle on weavability limits were investigated at the machine settings given in Table 6. As the increase in warp tension increased the weavability limits, the experiments were conducted with the maximum total warp tension of 1.75 kN as it allowed to weave fabrics with maximum weft density. In this group of experiments, the back rest was adjusted at four different heights. A zero value indicates the straight line between the cloth-fell and back-rest roller tangent. For each back-rest height, the maximum weavable weft density was investigated with five different front shed angles.

The maximum weft densities that can be woven with the above settings are shown in Table 7. The data in Table 7 shows that the effect of front shed angle on

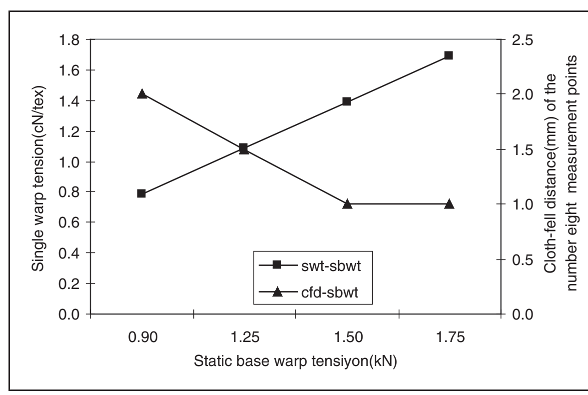

Figure 6. The relationship between the adjusted total warp tension and average single tension and cloth-fell distance on the number eight measurement points for 26 picks/cm weft density. (swt-bwt: relation between single end tension and adjusted total warp tension, cfd-bwt: relation between cloth-fell distance and adjusted warp tension).

Table 6. Weaving machine settings with different back-rest heights and front shed angles

Weft yarn count (tex)	16.7															
Shed closing time (degrees)	320°															
Total warp tension (kN)	1.75															
Back-rest spring rigidity (N/mm)	165.1															
Back-rest height (cm)	0				1.5				2.5				3.5			
Front shed angle (degree)	26°	28°	30°	32°	26°	28°	30°	32°	26°	28°	30°	32°	26°	28°	30°	32°

Table 7. Maximum weavable weft densities for different front shed angles and back-rest heights

Back-rest height (cm)	Front shed angle (degree)	Adjusted weft density on loom (picks/cm)	Weft density of the gray fabric (picks/cm)	Warp density of the fabric on the loom (ends/cm)	Warp density of the gray fabric (ends/cm)
0	26	29	29.6	34.3	35.3
	28	30	30.66	34.3	35.66
	30	30	30.66	34.3	35.66
	32	30	30.66	34.3	35.66
	34	30	30.66	34.3	35.66
1.5	26	30	30.66	34.3	35.66
	28	30	30.66	34.3	35.66
	30	30	30.66	34.3	35.66
	32	30.5	31	34.3	36
	34	30.5	31	34.3	36
2.5	26	30	30.66	34.3	35.66
	28	30	30.66	34.3	35.66
	30	30	30.66	34.3	35.66
	32	30.5	31	34.3	36
	34	30.5	31	34.3	36
3.5	26	30	30.66	34.3	35.66
	28	30	30.66	34.3	35.66
	30	30	30.66	34.3	35.66
	32	30.5	31	34.3	36

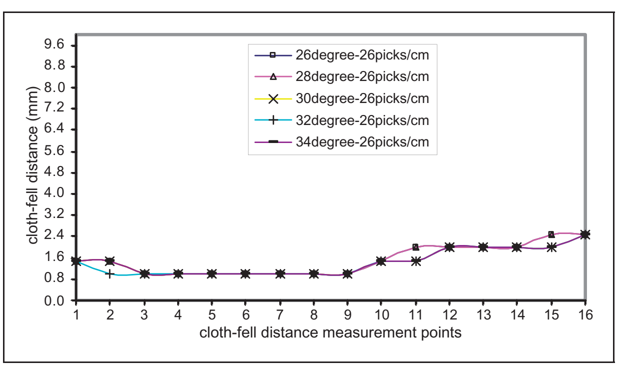

Figure 7. Cloth fell distance in the area between two selvages for all front shed angles at 2.5 cm back-rest height.

the weavability limits is limited. Maximum weavable weft density increased by 1 pick/cm between front shed angles of 26 and 28 degrees when the back-rest height is zero. In other back-rest heights, maximum weavable weft density increased only 0.5 picks/cm between front shed angles of 30 and 32 degrees.

Figure 7 shows the cloth-fell distance variation over the fabric width for five different front shed angles at 26 picks/cm weft density and 2.5 cm back-rest height. All the curves match and in all front shed angles almost the same cloth-fell variation over the fabric width is obtained.

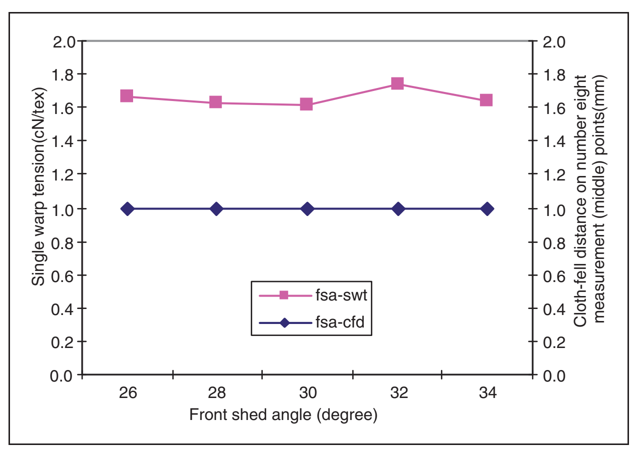

Figure 8. Average single end warp tension and cloth-fell distance values for different front shed angles at 26 picks/cm and 2.5 cm back-rest height. (fsa: front shed angle; swt: single warp tension; cfd: cloth-fell distance).

Figure 8 shows cloth-fell distance and average single end warp tension with respect to front shed angle for 26 picks/cm weft density and 2.5 cm back-rest height. There is no change in cloth-fell distance with respect to front shed angle but there is only a slight change in the average warp tension for different front shed angles which seems to be insignificant from a practical point of view.

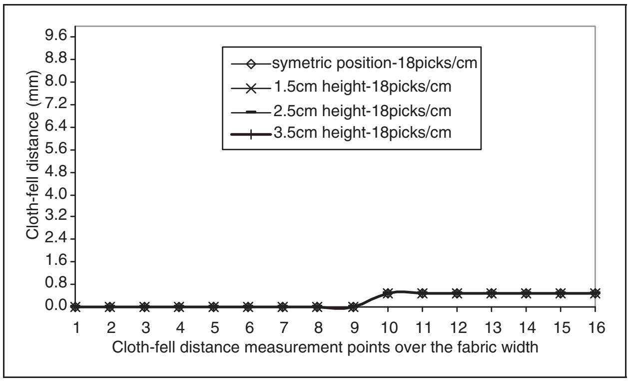

Figure 9. Variation of cloth fell distance over the fabric width for different back-rest heights at 18 picks/cm (1.75 kN).

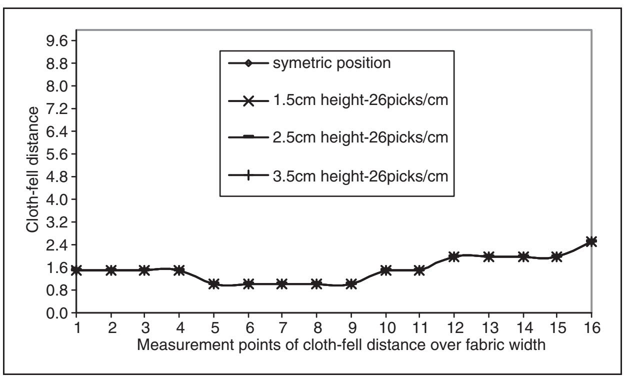

Figure 10. Variation of cloth fell distance over the fabric width for different back-rest heights at 26 picks/cm (1.75 kN).

Weavability limits at different back-rest heights

From the analysis of the data in Table 5 and Table 7, it is seen that the back-rest height affects the maximum weavable weft density only between 0 and 1.5 cm heights. Increasing shed height from 0 to 1.5 cm increased the shed asymmetry. This increased the maximum weavable weft density by 1 pick/cm. Increasing shed asymmetry further by increasing shed height to 2.5 and 3.5 cm did not have any effect on the maximum weavable weft density.

In Figures 9 and 10, the variation of the cloth-fell distance over the fabric width is shown for four different back-rest heights for 18 and 26 picks/cm respectively. Figure 9 and Figure 10 were obtained for a front shed angle of 26 degrees and 1.75 kN total warp tension. In both figures, all the curves matched and no change occured in the cloth-fell distance between different back-rest heights.

In Figure 11, the difference of average single end warp tension between upper and lower warp sheets in all back-rest heights is presented for 18 and 26 picks/cm. An increase in the difference in single end average warp tension between upper and lower warp tensions is higher when the back-rest height is changed from 0 to 1.5 cm. A further increase in the back-rest height increases the warp tension difference between lower and upper warp sheets at a lower rate. The difference between the warp tensions in upper and lower warp sheets may have a positive effect on decreasing fabric resistance and increase the weavable weft density limit in this way.

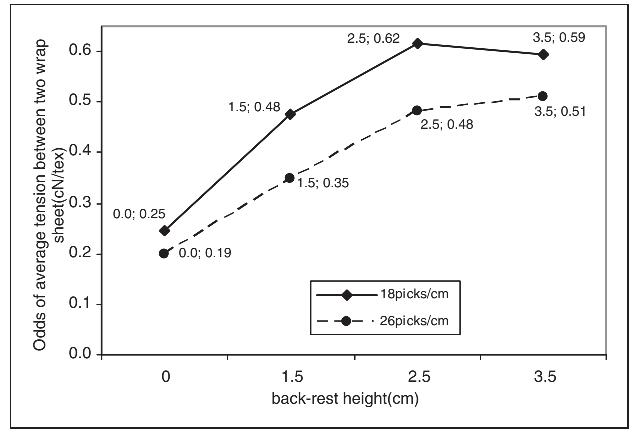

Figure 11. Average single end warp tension difference between upper and lower warp sheets for different back-rest heights.

Table 8. Weaving machine settings for five different shed closing times

Weft count (tex)	16.7				
Back-rest height (cm)	2.5				
Total warp tension (kN)	1.75				
Front shed angle (degrees)	26°				
Back-rest spring rigidity (N/mm)	165.1				
Shed closing time (degrees)	280°	290°	305°	320°	340°

Weavability limits at different shed closing times

In this group of experiments, the machine settings that allowed weaving at a maximum weft density in the previous experiments were kept constant and the shed closing angle was changed in five steps from 340 degrees to 280 degrees. In Table 8, weaving machine settings for five different shed closing times are seen. The maximum weavable weft density was investigated under these conditions. Maximum weavable weft density was determined for each shed closing angle as giving in Table 9.

It is seen from Table 9 that weaving became possible up to a shed closing angle of 290 degrees. After that, it became impossible as warp yarns entered into the profile of the reed before the weft insertion was completed. This is due to the design of the loom mechanisms. No change

Table 9. Maximum weft density obtained with five different shed closing time

Shed closing time (grade)	Adjusted weft density on the loom (picks/cm)	Weft density of the gray fabric (picks/cm)	Warp density of the fabric on the loom (ends/cm)	Warp density of the gray fabric (ends/cm)
280°	Weaving impossible			
290°	31	31.6	34.3	35.66
305°	30.5	31	34.3	36
320°	30	30.66	34.3	35.66
340°	30	30.66	34.3	35.66

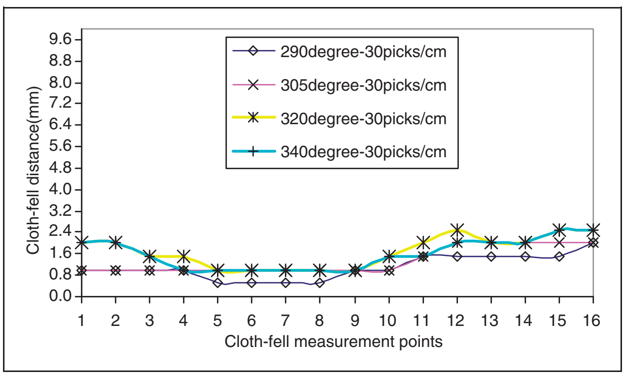

Figure 12. Variation of the cloth fell displacement over the fabric width for different shed closing angles (weft density: 30 picks/cm).

was found in maximum weavable weft density between shed closing angles of 340 and 320 degrees. Maximum weavable weft density increased by 0.5 picks/cm between shed closing angles of 320 and 305 degrees and also between shed closing angles of 305 and 290. According to the data in Table 9, it can be concluded that early shedding (i.e., closing the shed earlier) improved weaving conditions and increased maximum weavable weft density at the shed closing angles around 310 degrees and lower.

Figure 12 shows the variation of the cloth-fell displacement over the fabric width at 30 picks/cm weft density for different shed closing angles. Cloth-fell displacement had the lowest values with 290 degrees shed closing angle. Curves for shed closing angles of 340, 320 and 305 degrees are very close to each other. But, cloth-fell displacement variation for a shed closing angle of 305 degrees has lower values than the 340 and 320 degree curves. This result shows that adjusting the shed closing angle earlier improves the holding effect of the warp yarns in the fabric and therefore the recently beaten picks slide back less. Reduction in the cloth-fell displacement in this way allows more shed opening for weft insertion and contributes to some increase in weavable weft density.

Table 10. Weaving machine settings for weaving fabric with 7.8 and 33.3 tex weft yarns

Back-rest height (cm)	2.5		
Front shed angle (degrees)	26°		
Total warp tension (kN)	1.75		
Shed closing time (degrees)	290°		
Back-rest spring rigidity (N/mm)	165.1		
Weft count (tex)	7.8	16.7	33.3

Weavability limits with different weft yarns

In the fourth group of experiments, 7.8 and 33.3 tex weft yarns were inserted at the machine settings that allowed maximum weavable weft density for 16.7 tex weft yarn. Maximum weavable weft densities were determined for 7.8 and 33.3 tex weft yarns in this way. The weaving machine settings are shown in Table 10 and the maximum weavable weft densities are presented in Table 11. As expected, the maximum weavable weft density decreased as the weft yarn became thicker. Weft cover factors were calculated as 11.4, 13.5 and 15.3 for maximum weavable weft densities of 7.8, 16.7 and 33.3 tex weft yarns, respectively. The highest weft cover factor was obtained with the thickest weft yarn. This is also an expected result.

Comparison of the experimental results with Peirce, Brierley, Dickson and Love's Theories

Table 12 shows the cover factors obtained from this experimental work and from the previously developed theories. The data in column 3 and 5 were obtained from this experimental work. Column 7, 8 and 9 show the weft cover factors calculated from the equations developed by Peirce, Brierley and Love's graph. Dickson's equations were included in the cover factor calculations to be able to use Love's graphs for the fabrics other than cotton. Peirce's equation did not give any solution for 7.8 tex weft yarn. The calculated weft cover data are the

Table 11. Maximum weft densities obtained with different weft yarns

Warp yarn count (tex)	Weft yarn count (tex)	Adjusted weft density on the loom (picks/cm)	Weft density of the gray fabric (picks/cm)	Warp density of the fabric on the loom (ends/cm)	Warp density of the gray fabric (ends/cm)
16.7	7.8	39	39.3	34.3	37.3
16.7	16.7	31	31.6	34.3	35.66
16.7	33.3	24	25.3	34.3	34

Table 12. Comparison between the experimentally obtained maximum weavable weft cover factors with theoretical ones (weft and warp yarn count: 16.7 tex)

Warp yarn count (tex)	Weft yarn count (tex)	Warp cover factor (K_1) (on the loom)		Weft cover factor (K_2) (on the loom)		Weft cover factor (K_2) (theory)		
		$=\frac{ends/inch}{\sqrt{Ne_w}}$	Dickson[3]	$=\frac{picks/inch}{\sqrt{Ne_f}}$	Dickson[3]	Peirce[6]	Brierley[4]	Love graph[5]
16.7	7.8	15.90	16.79	11.44	12.08		12.04	18.20
16.7	16.7	15.20	16.05	13.48	14.23	17.67	13.25	16.25
16.7	33.3	14.49	15.31	15.26	16.11	17.89	14.85	17.40

maximum weavable weft cover factor for the given fabric.

Conclusions

The following conclusions can be drawn from the results presented above. The warp tension had the most significant effect on the maximum weavable weft density which was seen to increase with an increase in warp tension. The shed asymmetry showed a small effect on the maximum weavable weft density in this research. One of the reasons for this limited effect can be the already asymmetrical shed structure of the loom. Shed closing angle had some effect on the maximum weavable weft density. Taking the shed closing angle earlier improved weaving conditions and increased the weavable weft density limit. The shed closing angles earlier than 320° showed the improving effect on weavable weft density. Front shed angles changed between 26 and 34° during the experimental work showed a limited effect on maximum weavable weft density. As expected, fabrics were woven at higher weft cover factors as thinner weft yarns were inserted.

It was observed during weaving with maximum weavable weft densities that the loom stopped mainly due to weft stops. In the majority of loom stoppages, weft yarn got entangled with warp yarns especially at the selvage regions. The cloth-fell moved backwards (towards the heald frames) with increasing weft density and decreased the front shed size. However, the cloth-fell position moved backwards more at the selvages due to the lower warp tension. This decreased shed openness at the selvages even more and warp yarns got into the profile of the reed before the completion of weft insertion. This was observed as the main reason causing weft stops very often and limited the maximum weavable weft density. It was observed very rarely that the loom stopped due to the warp breaks.

It can be concluded that the maximum weavable weft density is limited by weft stops because of decreasing shed openness rather than fabric structure in air-jet looms. Because of this, special attention should be paid to the adjustment of shed geometry. Also, false selvage timing and construction should be set in such a way that weft slip inside the fabric is minimized during beat-up. This will reduce cloth-fell shift at the selvage and improve shed opening and weaving conditions. All these precautions can help increase the weavable weft density in air-jet weaving machines.

Brierley's limit equations have given the closest results to the experimental results obtained from this experimental work. However, more experimental work with different PES warp yarn count and densities should be done to be able to draw a more general conclusion.

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