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Efficacy of whip roller setting on physical attributes of denim fabric

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Abstract

Whip roller settings in a weaving machine is one of the vital factor to adjust warp yarn tension properly as well as delivering fault free fabric. The present study was undertaken with an aim to explore the influence of whip roller settings on various physical and mechanical properties of both grey and finished 100% cotton denim fabric in order to select suitable position of whip roller for producing particular (3/1 twill) denim fabric. For this purpose total eight positions of whip roller were selected keeping constant depth with variable height in five cases and constant height with variable depth in three cases. The samples were produced in an air jet loom and some prominence like EPcm, PPcm, areal density, tensile strength, dimensional stability, air permeability, crimp% and skewness were checked. Data analysis of all the results showed that with the ascendance of whip roller, crimp% of warp yarn was decreased whereas crimp% of weft yarn was increased both in grey and finished state. Decreasing the depth of whip roller caused increment of both warp and weft crimp% in both state. Tensile strength in warp way direction was found to increase gradually up to a certain roller height and then decreased whereas air permeability showed reverse trend in both state. Warp density, Weft density as well as areal density was also affected by the alteration in settings of whip roller. Due to reduction of roller depth, warp way tensile strength and lengthwise shrinkage were reduced but air permeability had improved.

Keywords: Whip roller, Denim fabric, Warp and weft density, Tensile strength, Crimp%, Air permeability, Dimensional stability, Skewness

Introduction

Identifying and keeping yarn tension variation as low as possible is important in textile processes. In weaving process, it is desired to obtain constant uniform warp tension across the width of the warp. Since during fabric formation, low warp tension creates clinging that causes unclear passage for the filling. While high tension increases yarn breaks. Detecting and controlling the optimum warp tension will maximize the weaving efficiency, improves fabric quality, fabric dimensional stability due to better ratio of warp crimp to weft crimp and enhances the uniformity of color shade (Gahide 2001). The running tension should be at a value neither to over-elongate nor to entangle the yarn (Eskew 2006).

Different initial force, which depends on the fabric purpose, weave and weft setting, can be given for warp (Galuszynski 1981; Gu 1984; Hepworth 1984). High initial tension can influence high cyclic deformation of thread and high fluctuation of tension of whole system. When initial warp tension increases, the amplitudes of changes of warp tension and deformations of loom setting system are almost constant (Shih et al. 1995; Zhang and Mohamed 1989; Jeong and Kang 2001; Katunskis 2004).

The backrest or whip roller is one of the most important parts of a weaving machine, and lengthwise yarn of the fabric known as warp yarn passes over the backrest. One of the main functions of the backrest oscillation is to compensate variation in warp tension as they are unwound from the weaver's beam during each weaving cycle of the loom. This tension can not be kept constant during the process and also during each weaving cycle of the loom. But due to have a very negligible difference among the tensions of each loom cycle, an average value of tension is maintained throughout the weaving process in factory. If this tension is kept at a constant then the fabrics will be woven with minimum number of warp breakages yielding a better loom efficiency and higher quality. The correct selection of the backrest of a loom is vital in producing high quality woven fabric. Adjustments to the positioning of the backrest, its type are inevitable when the performance of the weaving machine can no longer be tolerated with standard settings for low weft density, high weft density, and extra heavy fabrics. Vary in fabric density is a crucial especially in technical textiles and smart textiles (Fernando 2014). Denim fabrics have developed into a part of the garment fashion since the ninetieth century. Most consumers around the world prefer cotton apparel; in particular, they enjoy wearing denim. The success of denim is due to its ability to change with every social and cultural evolution (Card et al. 2006). According to Textile terms and definition published by Textile Institute Denim is traditionally a 3/1 warp faced twill fabric made from yarn dyed warp and undyed weft yarn. As denim is one type of woven fabric so it is obvious that like other woven fabrics, properties of denim is also affected by position of whip roller.

On a loom, warp yarns are divided into two half to make a shed. This division makes up a specific geometry of divided warp yarns called Shed Geometry. Shed geometry plays a vital role in controlling warp yarns tension, elongation and friction between them (Javaid 2011).

Besides the aesthetic properties, mechanical and physical properties of fabric are considered as decisive quality parameters. Fabric structure plays a critical role for predicting the fabric properties. Among other fabric properties, fabric strength is one of the most important properties of woven fabric, especially for technical textiles application (Pavlinic and Geršak 1989; Hearle et al. 1969; Majumdar et al. 2008).

Breaking strength is the maximum tensile force recorded in extending a test piece to breaking point. It is generally referred to as strength. The force at which a specimen breaks is directly proportional to its cross-sectional area, therefore when comparing the strengths of different fibers, yarns and fabrics allowances have to be made for this. The tensile force recorded at the moment of rupture is sometimes referred to as the tensile strength at break (Saville 2002).

The breaking load of a fabric in either the warp or weft direction is primarily determined by the strength of the yarn. The other important fabric variables effecting strength of woven fabrics are fiber properties, yarn properties, warp and weft densities, fabric weave, crimp and finishing process. Fabric strength tends to increase as the thread densities in both directions increase (Greenwood 1975; Adanur 2001; Mohamed and Lord 1973; Lee et al. 1996; Bassett et al. 1999; Cook 2001).

An increase in the weft density or warp density also leads to an increase in crimp. This has detrimental effect on fabric strength because, as the crimp increases, the yarn lies more obliquely in relation to the plane of the fabric. Thus a greater force is required in the yarn to balance a load applied in that plane (Greenwood 1975).

Skewness is a known fabric defect which occurs in both woven and knitting fabrics. Skewness is created when the pattern is distorted across the fabric width. In other words, it is a condition resulting when weft yarns are angularly displaced from a line perpendicular to the fabric selvage, usually, due to uneven distribution of tension (ASTM-International 2006; Lee 1989).

Research on fabric skewness is very scarce, and no studies have been found that investigate the effect of loom settings on fabric skewness. Some studies (Alamdar-Yazdi 2005; Moore et al. 1995) have shown that fabric shear properties and drape are affected by skewness. It was found (Alamdar-Yazdi and Khojasteh 2006) that there is a positive correlation between twist liveliness and fabric skewness, and the skewness is higher when the twist direction of the warp and weft yarns are opposite to each other. Only Nasan and Stylios (2014) analyzed the influence of backrest position on skewness of woven fabric where they found no significant effect of whip roll settings on fabric skewness.

Fabric porosity and air permeability depend on many factors, such as raw material, yarn type, fabric construction, machines working conditions and other parameters. However fabric porosity and air permeability are not constant in the width of the fabric, they are higher in the central part of the fabric than in the border parts. This will limit especially the use of industrial fabric in its whole width (Milašius and Rukuižien 2003).

The waviness or distortion of a yarn that is due to interlacing in the fabric is termed as crimp. In woven fabrics, the crimp is measured by the relation between the length of the fabric sample and the corresponding length of yarn when it is removed there from and straightened under suitable tension. Crimp may be expressed numerically as percentage crimp or crimp ratio. Position of whip roller has significant effect on Crimp% of woven fabric as warp yarn tension is an important player in case of crimp%. It has been found that raising the backrest above the normal height reduces the warp crimp, increasing the weft crimp (Talukdar et al. 1998). In present study, this result was verified both in case of grey and finished state of denim fabric whereas earlier study it was not checked.

Sheikhzadeh et al. (2007) investigated the relationship between the ratio of the force applied on the warp yarn by the whip roller to the warp yarn tension, and the vertical and horizontal position of the whip roller with variations in warp beam radius during the weaving process. Adanur and Qi (2008a) established an on-line tension measurement system by producing denim fabric on an air-jet loom in order to evaluate yarn tensions. Adanur and Qi (2008b) studied the effects of tension on the properties of denim fabrics made on an air-jet weaving loom. The variations in warp yarn tension during the weaving process become smaller by the backrest roller's swinging motion. At a high speed of the weaving machine, it could be possible to obtain a suitable relationship between movements of the whip roller and warp yarn tension (Kloppels et al. 2002).

Sheikhzadeh et al. (2007) investigated the relationship between the ratio of the force applied on the warp yarn by the whip roller to the warp yarn tension, and the vertical and horizontal position of the whip roller with variations in warp beam radius during the weaving process.

Weinsdorfer et al. (1991) analyzed the distribution of warp tension over the warp width connected with the changes in shed geometry (whip positions). They found that by changing the shed geometry, the warp tension also varies. By lifting the whip, the elongation of warp yarn in the lower shed increases, as a result the warp tension in the lower shed also increases. On the other hand, the warp tension in the upper shed decreases.

Turhan et al. (2007) presented experimental, computational intelligence based, and statistical investigations of warp tensions in different back-rest oscillations. To have different backrest oscillations, springs with different stiffness were used. For each spring, fabrics with various weft densities were woven, and the warp tensions were measured and saved during the weaving process. The empirical data were analyzed by using linear multiple and quadratic multiple regression, and an artificial neural network model. Osthus et al. (1995) reported that the warp end tensions are influenced by changing the height of the backrest roller. They evaluated the fabric appearance using an image processing system. The results for different backrest heights show that in the higher position of the backrest, the colour of the fabric become darker; and the fabric density is greater with an increasing backrest height.

Bilisik and Yolacan (2011) assessed the tensile and tearing properties of large and small structural pattern denim fabrics after an abrasion load and compared them with traditional denim fabrics. They obtained better tensile properties of abraded small structural pattern and traditional denim fabrics than those of large structural pattern denim fabric. They also concluded that with the increment of abrasion cycle, the tensile and tearing properties of all denim fabrics generally decreased.

Turhan and Eren (2012) studied the effect of weaving machine settings on the weave ability limits of air-jet machines. They found that changing the shed adjustment from the zero level of the backrest to higher values increased the maximum weavable weft density slightly; however, increasing the shed asymmetry further (backrest height) has no significant influence on the weave ability limit.

Bilisik and Demir (2010) studied the dimensional and mechanical properties of newly developed denim fabrics based on experimentally determined property and structural pattern. They found significant differences on pilling, tensile and tear properties for small and large structural patterns.

Haghighat et al. (2012) inspected the effect of the backrest roller position on the physical and mechanical properties of worsted fabrics. The results showed that the position of the backrest roller has a significant effect on the breaking strength in the warp direction, weight per area unit, and thickness of fabric.

In this experimental work, which has been done on the factory shop under commercial manufacturing conditions, the effect of changing backrest roller position on some physical properties such as EPcm, PPcm, areal density, tensile strength, crimp%, dimensional stability, air permeability and skewness of denim fabric both in grey and finished state has been investigated.

Methods

Materials

A 100% cotton 3/1 twill denim fabric was used to conduct this work. 26 EPcm, 17.5 PPcm, 65.6 tex^{oe} warp and weft yarn and fabric width 165.1 cm was selected to produce the fabric.

Ball warping

In this section total l447 cone packages were set to the creel. Then machine was run at 300 rpm and produced ten ball warper beam. Each ball warper beam contain 4200 m length rope with 447 ends.

Rope dyeing

Then these ten ball warper's beam were fed to the dyeing machine. After dyeing and drying of the rope according to recipe mentioned in Tables 1, 2, it was taken in large coiler can. In dyeing machine, topping (first indigo and then black) was done in total eight box. At first scouring was done, then six box was used for indigo dyeing, one for black and one for wash were used.

Long chain beaming

In long chain beaming (LCB) section, these ropes were opened into the sheet form of yarn and wound onto a warper beam. After ending of the LCB process ten warpers beam were produced for sizing.

Sizing

In sizing machine, warper beams were fed in two segment. Then sizing was done according to the recipe mentioned in Table 3. After sizing required number of sized yarn were wound to the weaver's beam. Finally weaver's beam were taken to the weaving section to produce required denim fabric.

Weaving

An air jet loom of Picanol NV (Model No: OMNI plus 800-2-P) was used to produce all the samples of denim fabric. All samples were produced by changing the height and depth of the backrest roller's position at an average value of warp tension (2.75 KN).

Table 1 Recipe of scouring

Chemical name	Amount
Pre-treatment (scouring)	
Secho	2 gpl
Caustic	30 gpl
RD-999	6 gpl
Total volume	2700 L
Softener	14 gpl
Total volume	1700 L

Table 2 Recipe of rope dyeing

Chemical name	Amount
Sulfotex	60 gpl
Caustic	61 gpl
RD-999	5 gpl
Reducing agent	25 gpl
Total volume	600 L

Table 3 Recipe of sizing

Chemical name	Amount
Water	1000 L
K_{2000}	46 kg
B_{120}	58 kg
CMS_{60}	8 kg
$UEXD_{12}$	24 kg
Wax	5.6 kg
Ecosize	2.4 kg

Total 8 samples with 165.1 cm width were prepared here at the height position of +8, +10, +12, +14, +16 (difference between height positions are 1 cm) when whip roller depth was constant at the position of 4. Similarly the samples were prepared at the three different depth position of 3, 4, 5 (difference between depth positions are 5 cm) when the whip roller height was constant at the position of +12.

Finishing

After producing 8 samples, 457.2 cm fabric from each sample were cut and finished in a machine where following processes were carried out sequentially:

Fabric unwinding
↓
J-box
↓
Brusher
↓
Singeing
↓
Chemical box
↓
Squeeze roller
↓
Dryer
↓
Sanforizing
↓
Calendering
↓
Fabric delivery

After completing the finishing process both grey and finished fabrics were conditioned for 4 h (Table 4).

Fabric quality evaluation

Warp and weft density

Warp and weft density was measured as per ISO 7211-2 method by using counting glass and needle.

Table 4 Recipe of finishing

Chemical name	Amount (gpl)
Belfasin	5
Adasil	20

Areal density

Areal density measurement was carried out in ISO 3801 method by GSM cutter.

Crimp%

Crimp% of warp and weft yarn for both grey and finished fabric was measured according to test method ASTM D3883 by using Digital Crimp Tester.

Tensile strength

Tensile strength of grey and finished fabric both in warp and weft way was assessed as per BS EN ISO 13934-2 method by Tinious Olsen Universal Strength Tester.

Air permeability

Air permeability was measured by Shirley Air Permeability Tester according to ISO 9237 method using the following formula:

Air permeability = $(R_1+R_2+R_3)/S$, where R = rotameter reading and S = sample size.

Dimensional stability

Dimensional stability of all the samples both in grey and finished state was assessed in ISO 6330 method by Electrolux Wascator and Electrolux Dryer using the formula stated as follows:

$$\mathrm{DC}\ \% = 100\ (\mathrm{B} - \mathrm{A})/\mathrm{A}$$

DC = dimensional change, A = original dimension and B = dimension after laundering

Shrinkage was denoted as "−" which was decrease in dimensions. Elongation was denoted as "+" which was increase in dimensions.

Skewness

Skewness test was carried out according to ISO 16322-2 method using same apparatus as like dimensional stability test and calculation was done by following formula:

$$\text{Skewness (\%)} = 2 \times (AC - BD)/(AC + BD) \times 100$$

where AC and BD were the diagonal line of the specimen which was marked before wash and displacement line after wash.

Result and discussion

Warp and weft yarn density

Warp yarn density of produced fabric at different positions of height with fixed depth and variable positions of depth with fixed height of backrest roller were shown in Fig. 1a, b respectively.

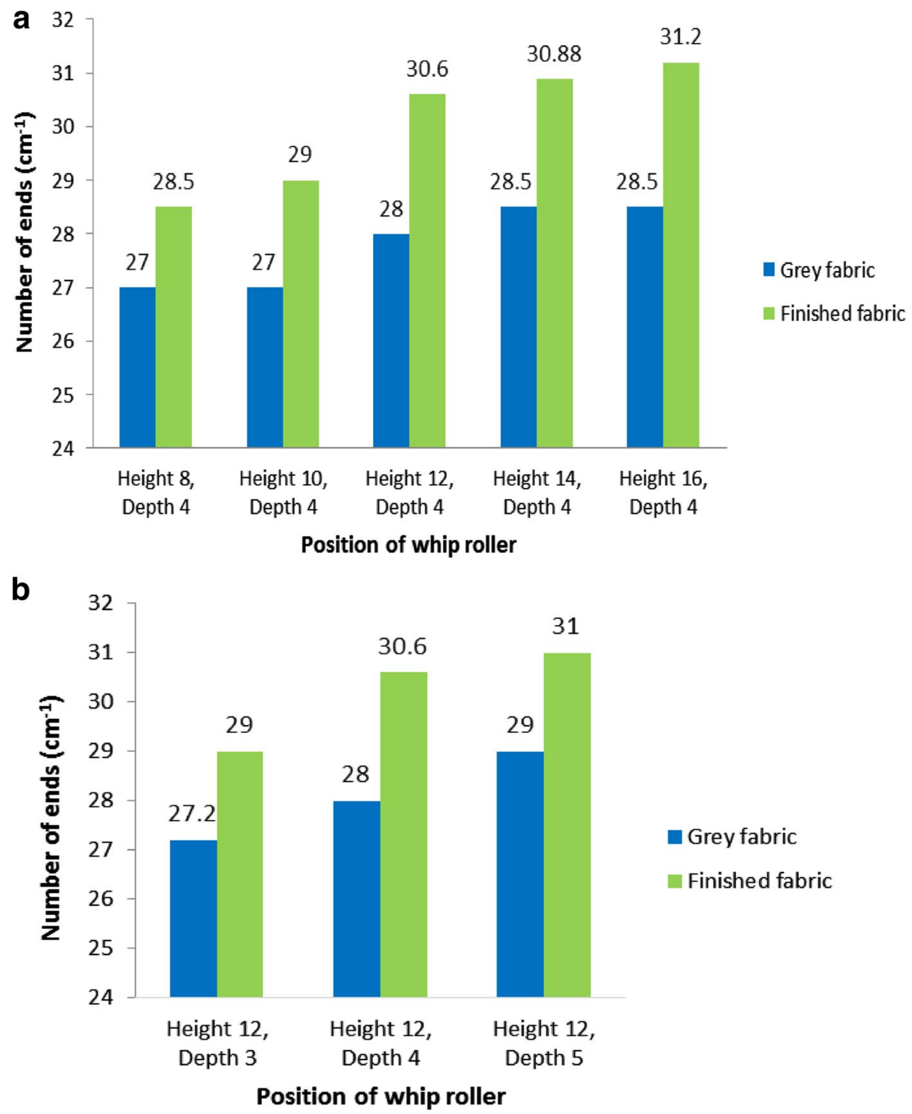

Fig. 1 **a** Warp density at variable height and constant depth of whip roller. **b** Warp density at constant height and variable depth of whip roller

The above graph showed that with increasing the height of backrest roller's position at constant depth, warp density of grey and finished fabric also increased but slightly. Comparing to grey fabric, finished fabric had greater change in this property due to being passed through a number of finishing treatments. When backrest roller's depth decreased at constant height same results were found.

Weft yarn density of produced fabric at different positions of height with fixed depth and variable positions of depth with fixed height of whip roller were shown in Fig. 2a, b respectively.

In case of changing whip roller's position both in case of height and depth, weft density of grey fabric were more or less equal as there was no significant effect of whip roller on weft density and equal number of weft yarns were inserted through the shed at a certain time. But in case of finished fabric, weft density was changed up to a certain position owing to had different ending processes.

Areal density

Areal Density in gm/m^2 of grey and finished fabric at different height and different depth of whip roller were displayed in Fig. 3a, b respectively.

With the variation of whip roller's height and depth, there was no significant effect on areal density in grey state of denim fabric as shown in above figures. But in finished state, GSM was changed because of variation in EPcm, PPcm, warp crimp%, weft crimp% and also the finishing treatments of fabrics.

Crimp%

Figure 4a represents that with ascending of whip roller's position at constant depth, warp crimp % was decreased both in grey and finished state where Fig. 4b shown the increasing of crimp% with decreasing of depth of whip roller position.

The reason behind such phenomenon may be explained hypothetically such as that with increasing height of whip roller, tension of warp yarns was increased as a result warp yarns become straighter and crimp(%) of grey and finished fabric decreased. But when depth of whip roller's position was decreased at constant height as shown in Fig. 4b, tension of warp yarns also decreased at long shed area thus warp crimp (%) increased. In finished state, value of crimp (%) was higher than grey state, because in finishing process more tension was applied as fabric had to undergo through more processes thus relaxation was more in finished fabric. The alteration in case of weft density is another cause of such result in warp crimp%.

The changes in weft way crimp% of both grey and finished denim fabric at different height and different depth position of whip roller were presented in Fig. 5a, b respectively.

From the above graphs it was seen that with ascending of whip roller's position at constant depth and descending the roller's location at constant height, the crimp (%) in weft yarn was motivated in both state because of light change in EPcm of the samples at various settings. In finished state, value of weft crimp (%) was higher than grey state as like warp crimp% because of the same reason.

Tensile strength

Figure 6a represented that with raising height of backrest roller's position at constant depth, tensile strength increased in the warp direction up to a certain position, then deceased. The good strength was found in settings of height +14; depth 4. Same result was found both in case of grey and finished samples. By analyzing load-elongation curves (Figs. 7a, 8a), it was obtained that 761.77N and 688.06N force were required to break grey and finished specimen in warp way respectively which was maximum. The changes of warp way tensile strength at constant height and variable depth position of backrest roller was shown in Fig. 6b. When depth of backrest roller's position decreased at constant height, tensile strength increased and then again decreased in both state but the change in norms was nearer as the time required to break the specimen was 0.24, 0.26 and 0.25 s accordingly (Tables 5, 6).

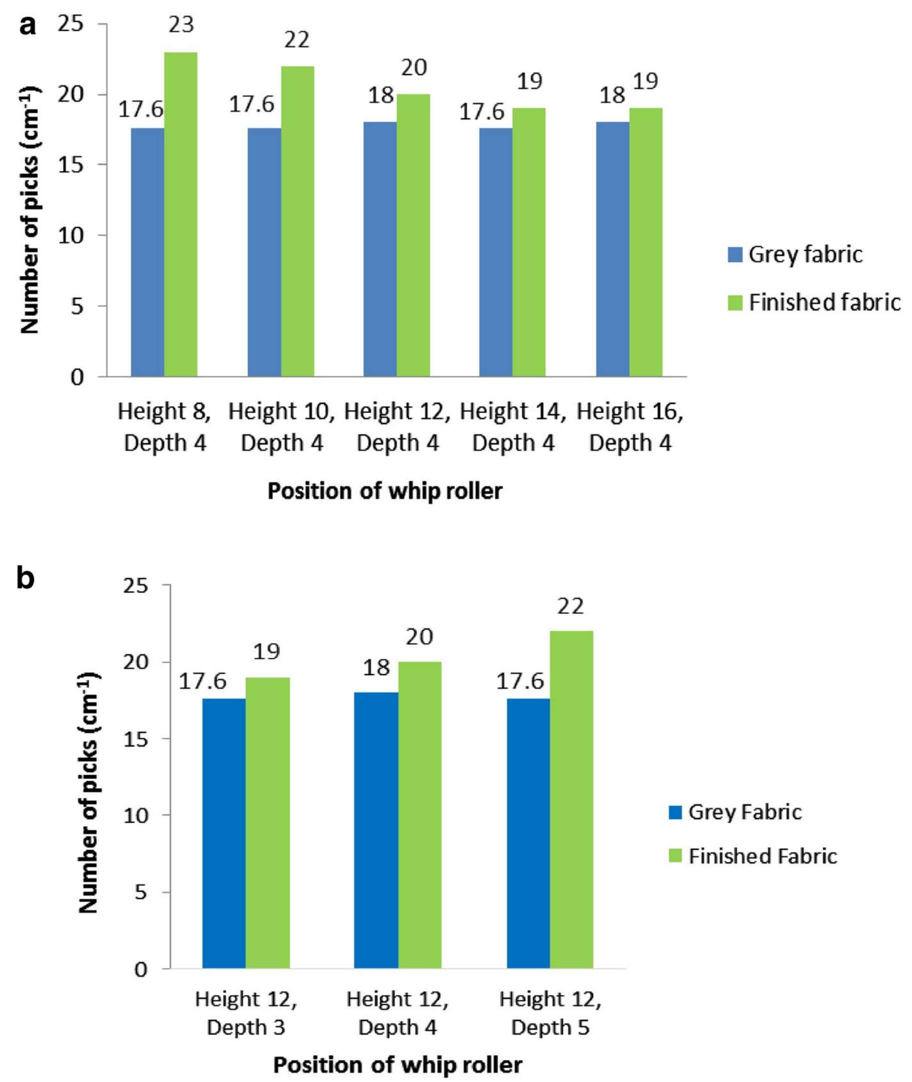

Fig. 2 **a** Weft density at variable height and constant depth of whip roller. **b** Weft density at constant height and variable depth of whip roller

The impact of changing whip roller position on weft way tensile strength of grey and finished denim fabric at constant depth and constant height were presented in Fig. 9a, b. Though the highest strength of fabric was found in whip roller position of height +14; depth 4, no remarkable effect was obtained in weft way owing to had no direct relation of weft yarn strength with whip roller settings.

Air permeability

Air permeability of grey and finished fabric at different height and different depth position of whip roller were displayed in Fig. 10a, b accordingly.

From Fig. 10a it was found that with increasing height of whip roller's position at constant depth, air permeability of grey and finished fabric decreased up to a limit then increased again. Air permeability is mainly related to fabric porosity and also yarn type.

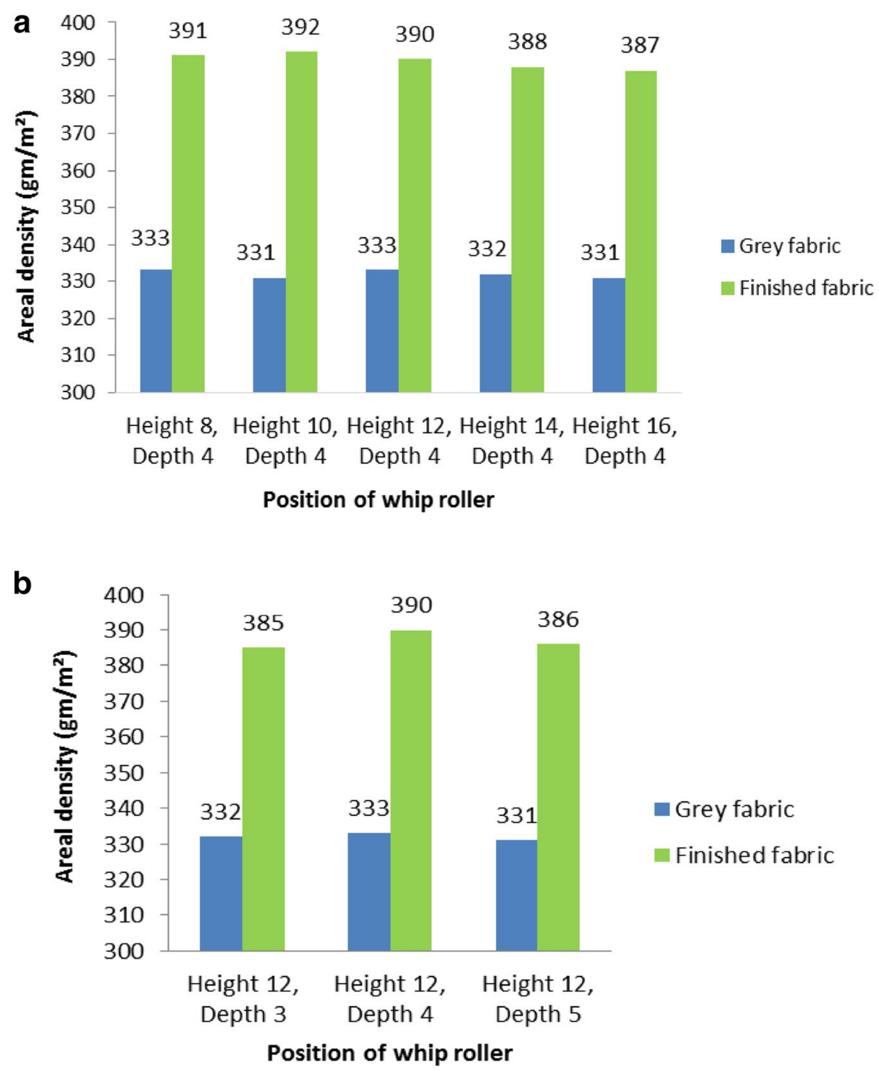

Fig. 3 **a** Areal density at variable height and constant depth of whip roller. **b** Areal density at constant height and variable depth of whip roller

But in this case it could be characterized by yarn porosity as backrest roller position is directly related to tension on yarn. In this sense it could be summarized that with an increase in the height, the warp tension increased, void places of yarn was reduced, so yarns became compact causing reduction of free space between warp yarns up to a certain time, thus the flow of air that passes through the fabric decreased up to a limit. After that certain position, may be slippage of fibers was occurred so no. of fibers in yarn cross section became less which makes yarn more permeable to flow more air. So, air permeability was started to increase again.

From Fig. 10b, it was found that when whip roller's depth decreased at constant height, air permeability of grey and finished fabrics increased. During taking whip roller in less deeper position, shed area was becoming long. In long shed area, the warp yarns in the fabric structure became loose. So, free space between yarns in the fabric was increased.

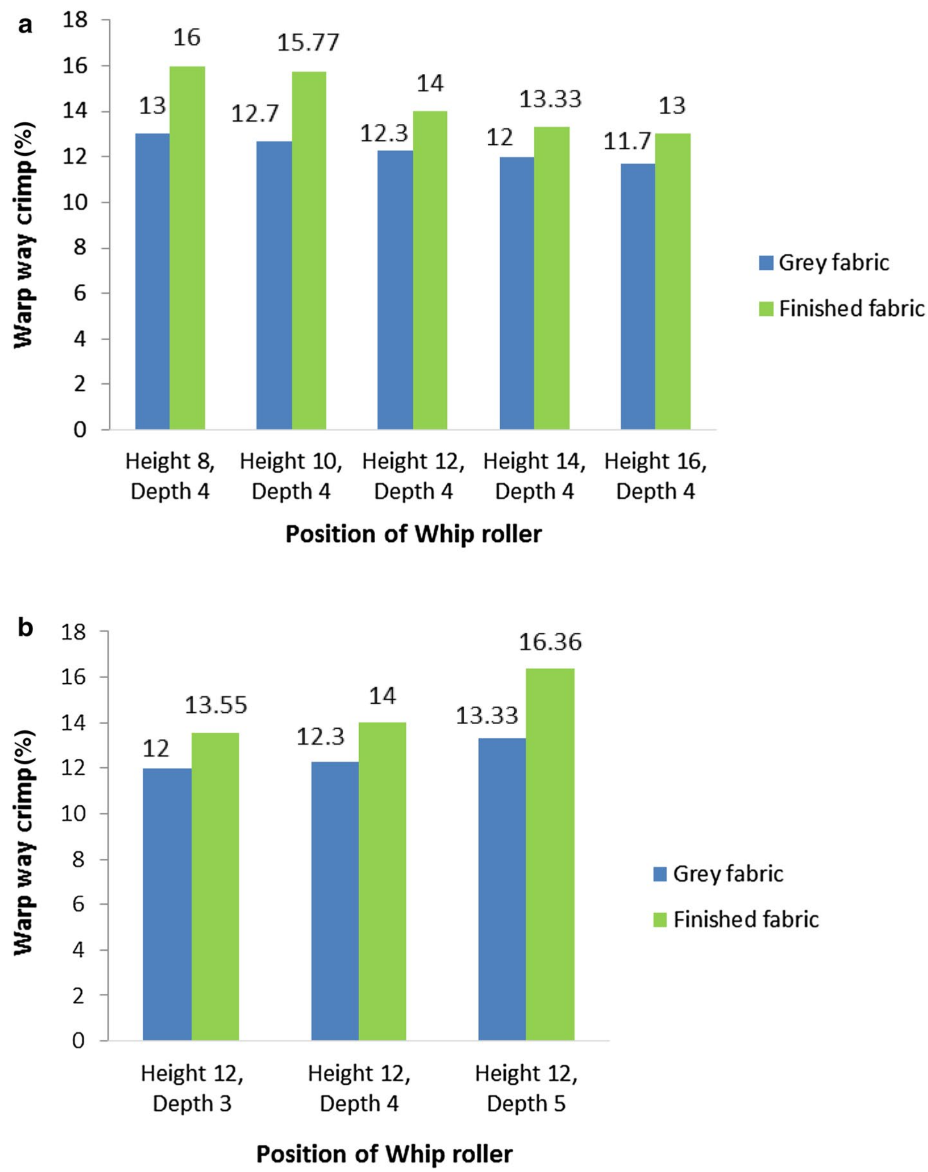

Fig. 4 **a** Warp way crimp (%) at variable height and constant depth of whip roller. **b** Warp way crimp (%) at constant height and variable depth of whip roller

Thus a large amount of air could pass through the fabric during air permeability test. This phenomenon was found in both state of denim fabric.

Shrinkage

From Fig. 11a it was analyzed that with growing height of whip roller's position at constant depth, shrinkage of grey and finished fabric increased in lengthwise direction because relaxation of fabric was more. As warp yarns were in more tension in higher position of whip roller in loom state, so relaxation became gradually higher in fabric of different height position.

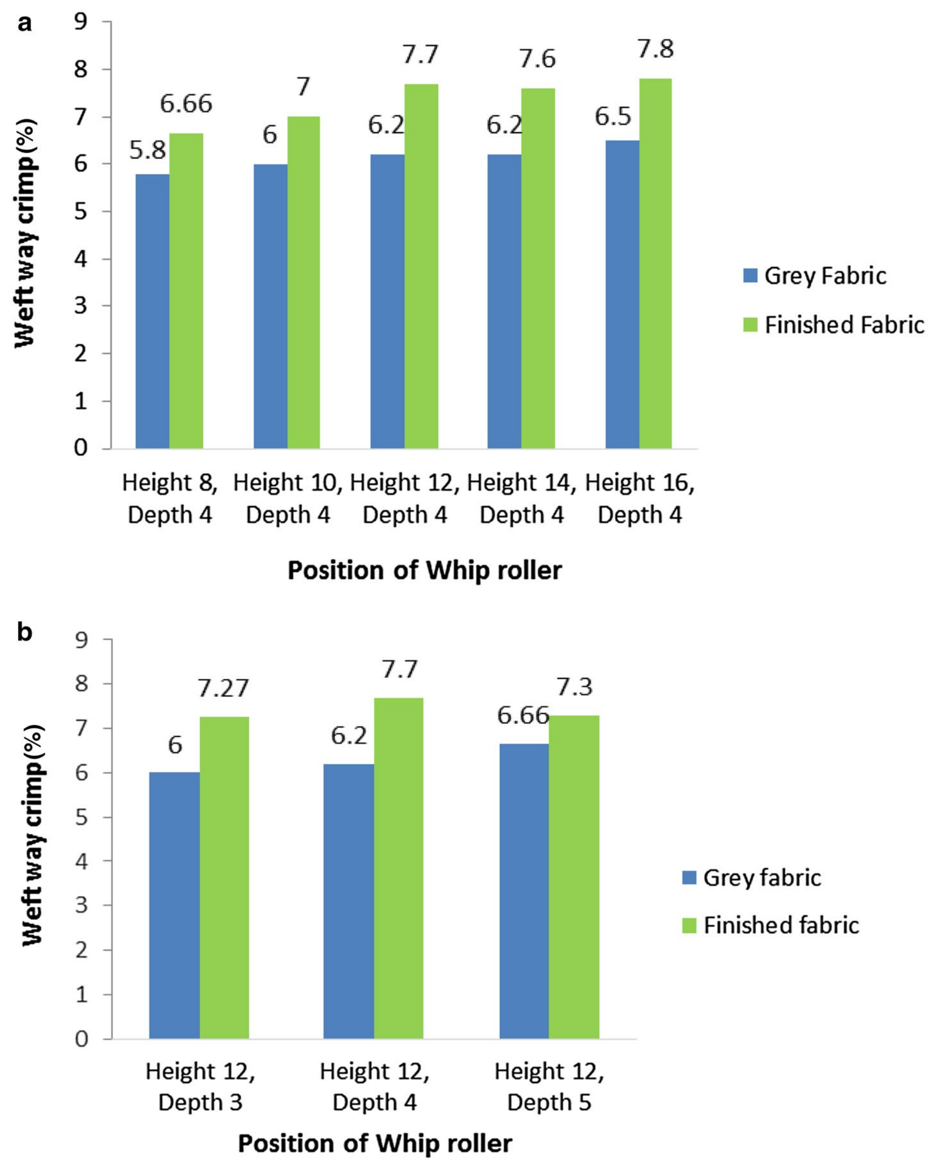

Fig. 5 **a** Weft way crimp (%) at variable height and constant depth of whip roller. **b** Weft way crimp (%) at constant height and variable depth of whip roller

But in Fig. 11b a different trend was observed. When depth of whip roller's position was decreased at constant height, shrinkage decreased in both state because tension of warp yarns was gradually decreased at long shed area. It was also seen in both figures that shrinkage was lower in finished fabric than grey fabric because of finishing treatment on denim.

From both figures i.e. Fig. 12a, b it was found that the whip roller's position has no significant effect on the shrinkage of grey and finished fabric in width wise direction. The change in position of Whip roller cannot affect weft yarn tension but warp yarn tension thus shed area. Though in case of crimp% a trend of result had be seen both in case of warp way and weft way but in case of dimensional stability this change was not so

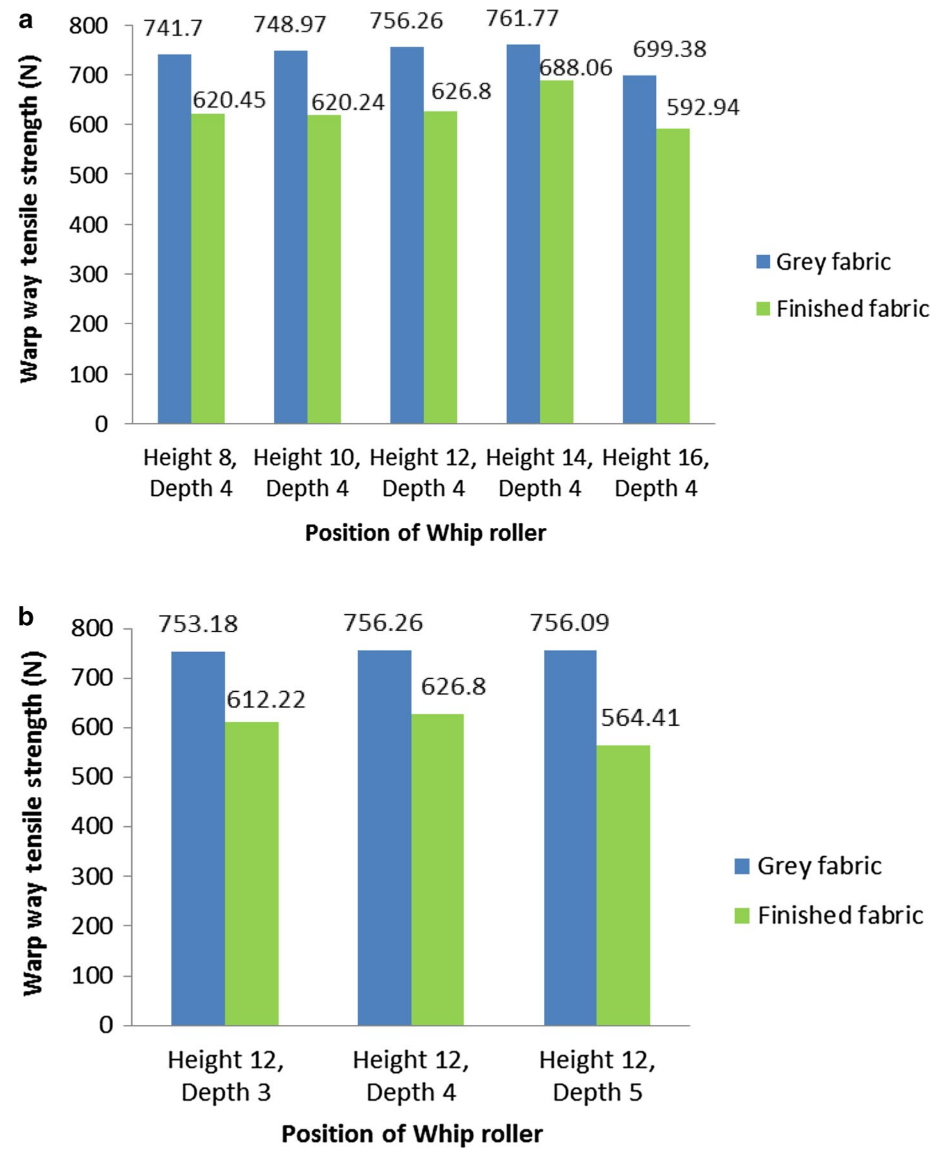

Fig. 6 **a** Warp way tensile strength at variable height and constant depth of whip roller. **b** Warp way tensile strength at constant height and variable depth of whip roller

prominent especially in terms of widthwise. This may be due to use of cotton yarn. Again it was also seen that shrinkage value was lower in finished fabric than grey because of finishing treatment.

Skewness

Skewness of grey and finished fabric at different height and different depth position of whip roller were displayed in Fig. 13a, b respectively.

In Both graphs, it was shown that the whip roller's position has no significant effect on the skewness of grey and finished fabric. Because there no such trend was found with

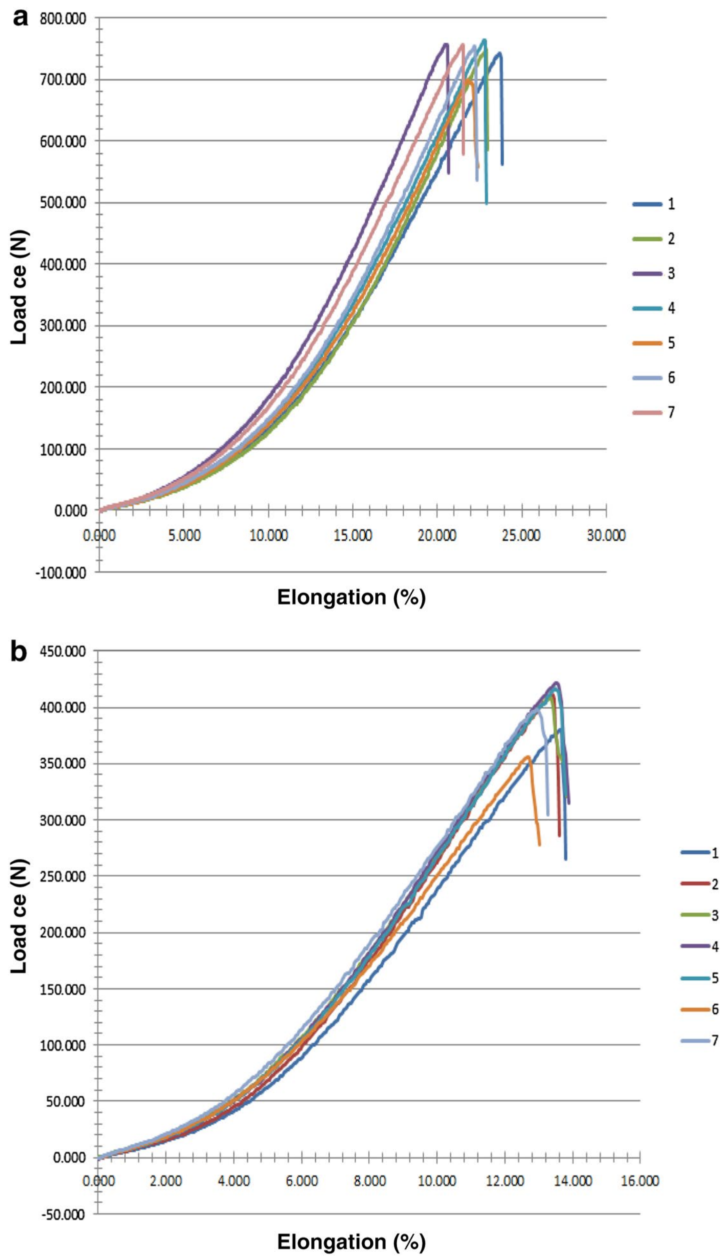

Fig. 7 Load-elongation curve of grey fabric both in warp (**a**) and weft (**b**) direction

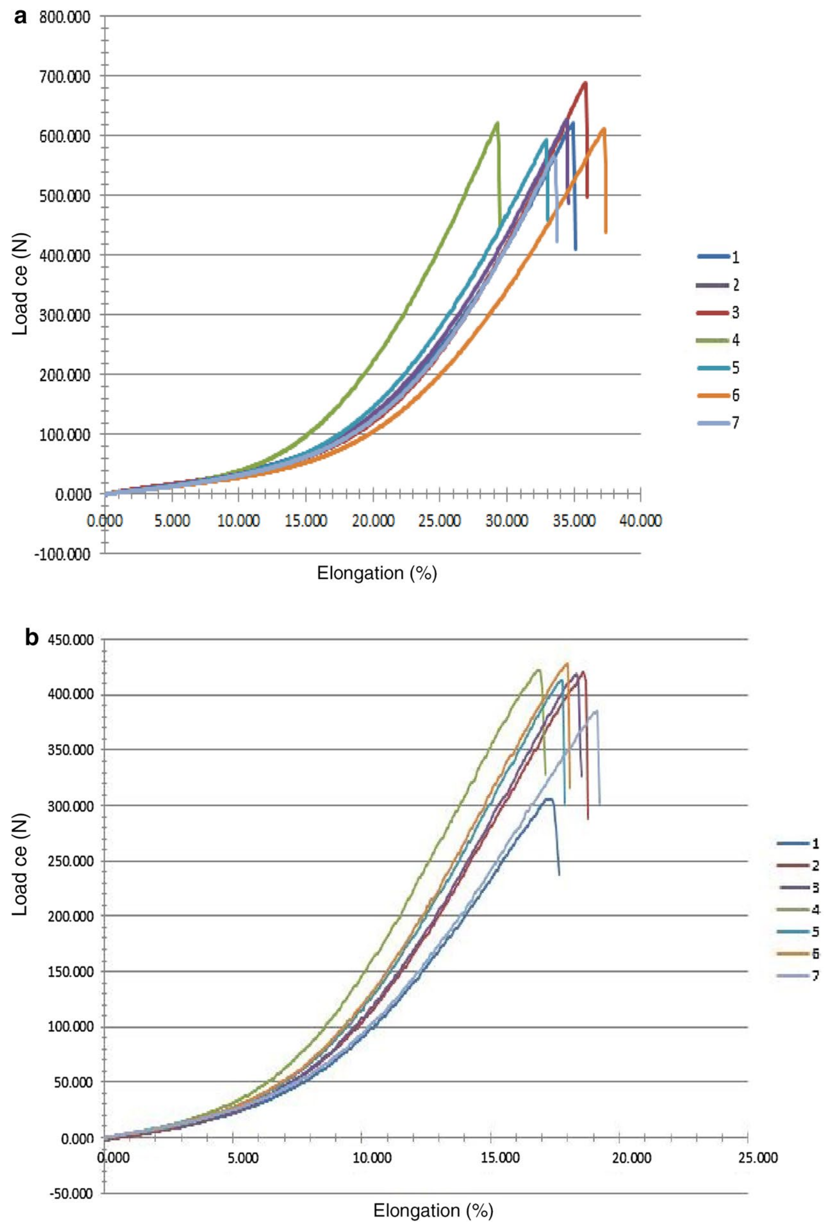

Fig. 8 Load-elongation curve of finished fabric both in warp (**a**) and weft (**b**) direction

Table 5 Tensile strength test results in grab method for grey fabric in warp and weft way

Test direction	Specimen no.	Whip roller position	Maximum force (N)	Elongation at max. force (%)	Force at rupture (N)	Elongation at rupture (%)	Time to break (s)
Warp way	1	Height 8, depth 4	741.7	23.7	563.03	23.83	0.28
	2	Height 10, depth 4	748.97	22.94	585.52	22.98	0.27
	3	Height 12, depth 4	756.36	20.56	548.47	20.64	0.24
	4	Height 14, depth 4	761.77	22.82	500.28	22.91	0.27
	5	Height 16, depth 4	699.38	21.78	558.01	22.41	0.26
	6	Height 12, depth 3	753.18	22.23	535.92	22.35	0.26
	7	Height 12, depth 5	756.09	21.53	579.7	21.56	0.25
Weft way	1	Height 8, depth 4	379.7	13.62	265.59	13.79	0.16
	2	Height 10, depth 4	411.19	13.41	286.64	13.62	0.16
	3	Height 12, depth 4	408.47	13.37	320.93	13.83	0.16
	4	Height 14, depth 4	421.21	13.54	315.68	13.87	0.16
	5	Height 16, depth 4	416.41	13.49	323.14	13.78	0.16
	6	Height 12, depth 3	355.9	12.68	277.79	13.02	0.15
	7	Height 12, depth 5	397.88	12.94	305.09	13.28	0.16

Table 6 Tensile strength test results in grab method for finished fabric in warp and weft way

Test direction	Specimen no.	Whip roller position	Maximum force (N)	Elongation at max. force (%)	Force at rupture (N)	Elongation at rupture (%)	Time to break (s)
Warp way	1	Height 8, depth 4	620.45	34.9	411.9	35.07	0.42
	2	Height 10, depth 4	620.24	29.26	450.22	29.43	0.35
	3	Height 12, depth 4	626.8	34.44	489.2	34.57	0.41
	4	Height 14, depth 4	688.06	35.86	497.37	35.99	0.43
	5	Height 16, depth 4	592.94	32.9	459.89	33.03	0.39
	6	Height 12, depth 3	612.22	37.25	439.88	37.38	0.44
	7	Height 12, depth 5	564.41	33.48	424.24	33.73	0.4
Weft way	1	Height 8, depth 4	305.63	17.34	238.83	17.67	0.21
	2	Height 10, depth 4	419.69	18.6	289.19	18.77	0.22
	3	Height 12, depth 4	418.33	18.34	327.72	18.55	0.22
	4	Height 14, depth 4	422.42	16.27	328.69	17.13	0.2
	5	Height 16, depth 4	413.2	17.81	303.06	17.9	0.21
	6	Height 12, depth 3	428.39	18.01	316.51	18.1	0.21
	7	Height 12, depth 5	385.42	19.17	302.44	19.25	0.23

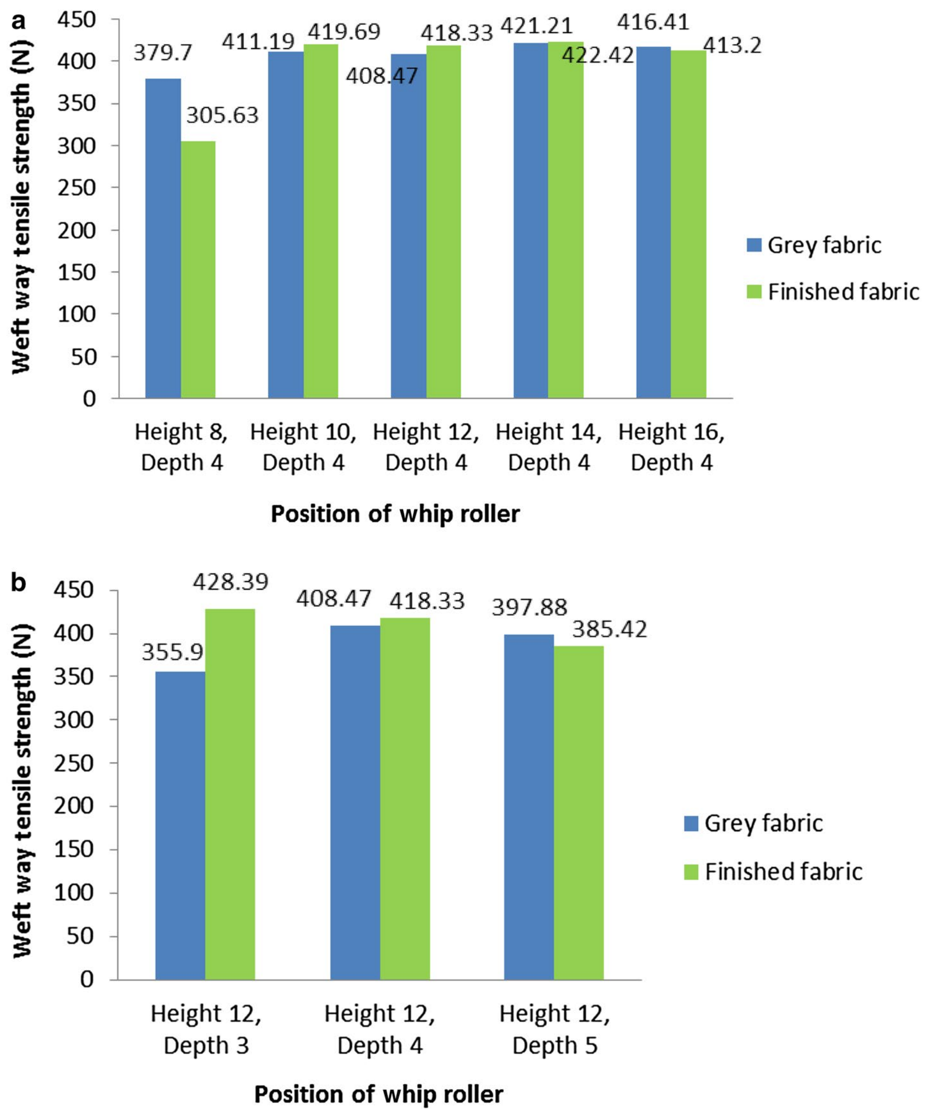

Fig. 9 **a** Weft way tensile strength at variable height and constant depth of whip roller. **b** Weft way tensile strength at constant height and variable depth of whip roller

increasing height and decreasing depth of position. Normally in denim fabric skewness is a minor problem. Though a little bit amount of skewness% could be found in grey fabrics but after a certain finishing treatment by using skew roller it is possible to bring this problem under control.

Conclusions

Based on this experimental study, it can be concluded that warp density and weft density of denim fabric were changed due to change in position of whip roller both in horizontal and vertical way. That's why areal density was also affected by backrest roller position. Warp way crimp% gradually decreased with increasing height at fixed depth of whip roller both in grey and finished state while it showed vice versa result with increasing

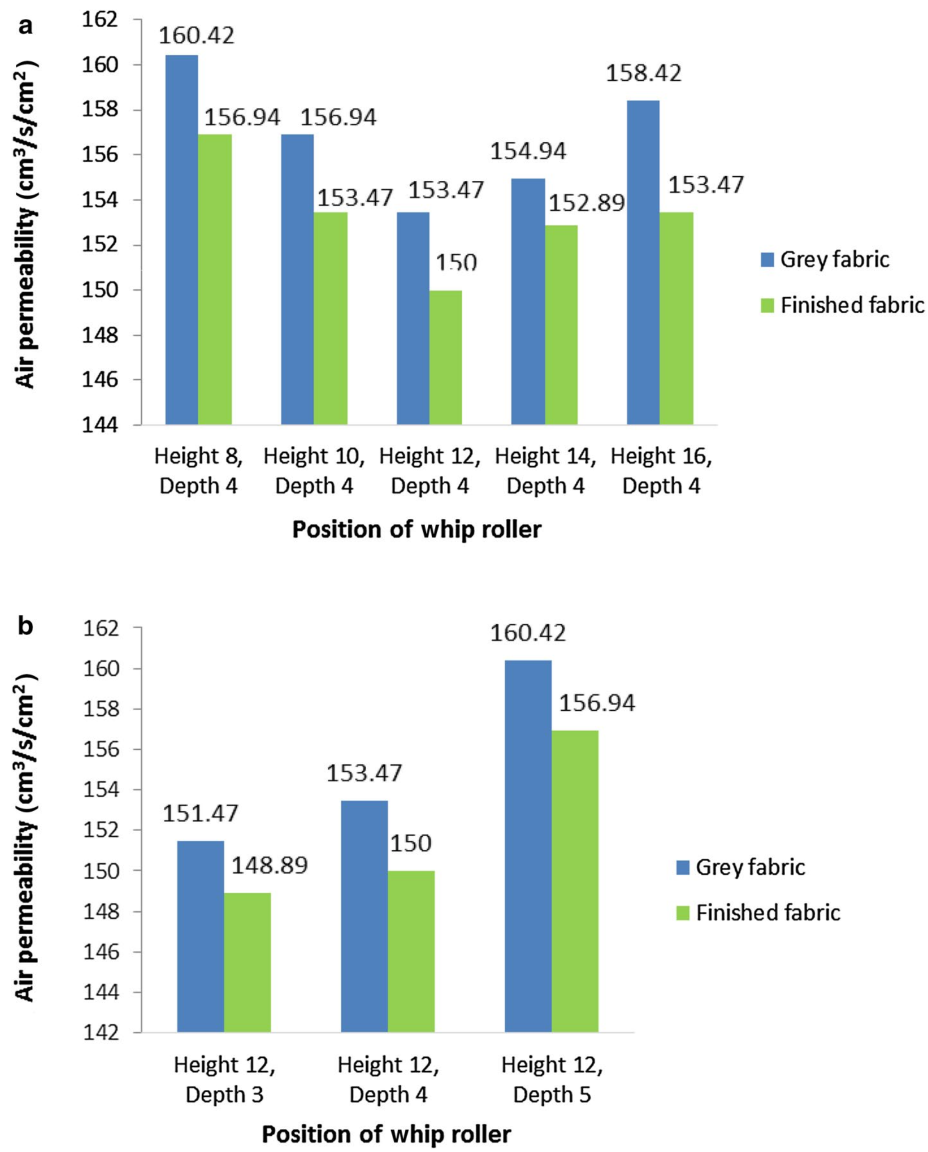

Fig. 10 **a** Air permeability at variable height and constant depth of whip roller. **b** Air permeability at constant height and variable depth of whip roller

depth at fixed height in both state of fabric. The sample made at height position of +12 and depth 5 showed maximum warp crimp% value of 13.33 and 16.36 in grey and finished state respectively. Weft way crimp% also showed a significant result in finished state. The maximum finished weft crimp% value found at the position of +16 height and depth 4 was 7.8. The position of whip roller affects grey fabric's weft way crimp% slightly. Warp way tensile strength tremendously increased with ascending of whip roller position. But after a certain position again it gradually decreased in both state. Warp strength had a similar relation with decreasing depth position of whip roller in fixed height. The maximum warp strength value for grey and finished fabric were 761.77N and

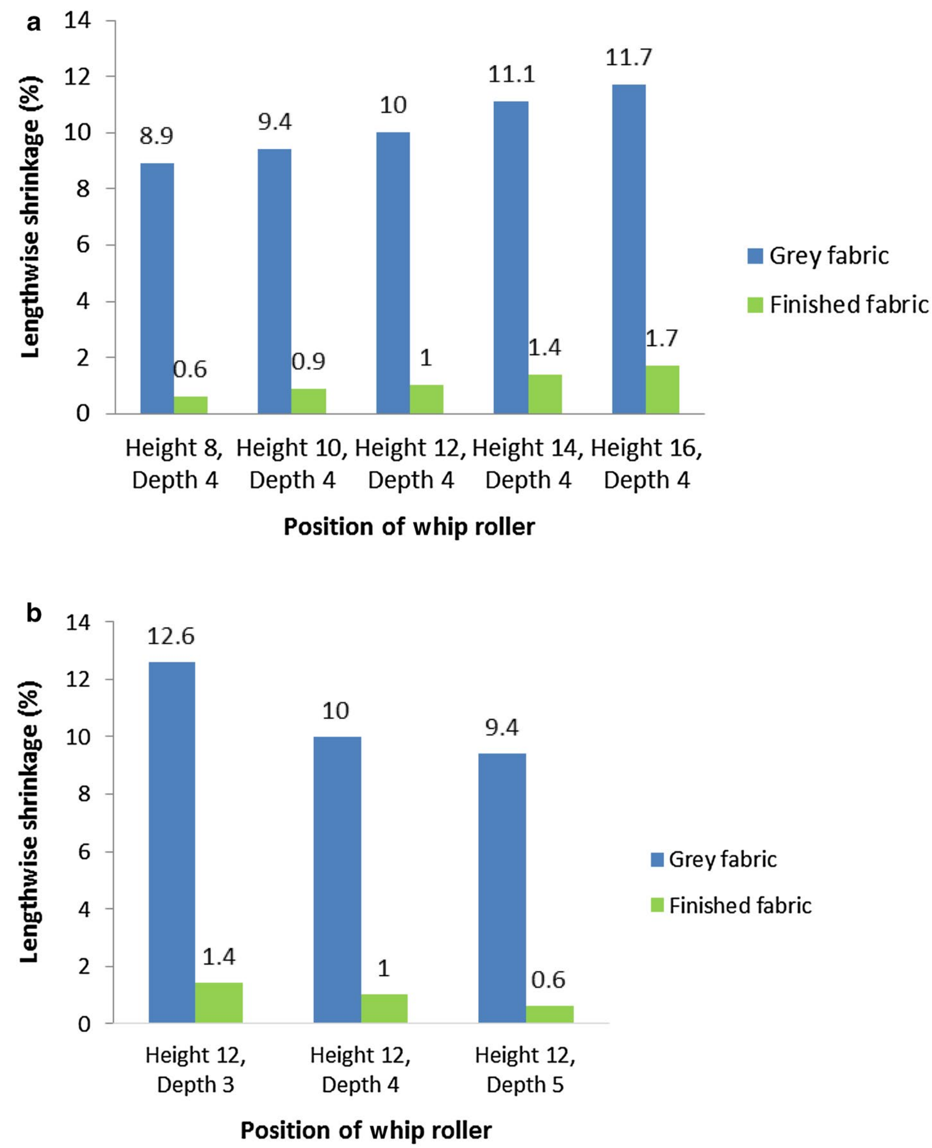

Fig. 11 **a** Length wise shrinkage (%) at variable height and constant depth of whip roller. **b** Length wise shrinkage (%) at constant height and variable depth of whip roller

688.06N respectively found at height position of +14 and depth position of 4. No significant effect was found on weft strength, width wise shrinkage and skewness of denim fabric both in grey and finished state due to change in settings of whip roller. Air permeability of denim fabric simultaneously decreased with increasing height of whip roller but after a certain position it started to increase. This trend was found for both (grey and finished) fabric at fixed depth position of whip roller. But air permeability changed in

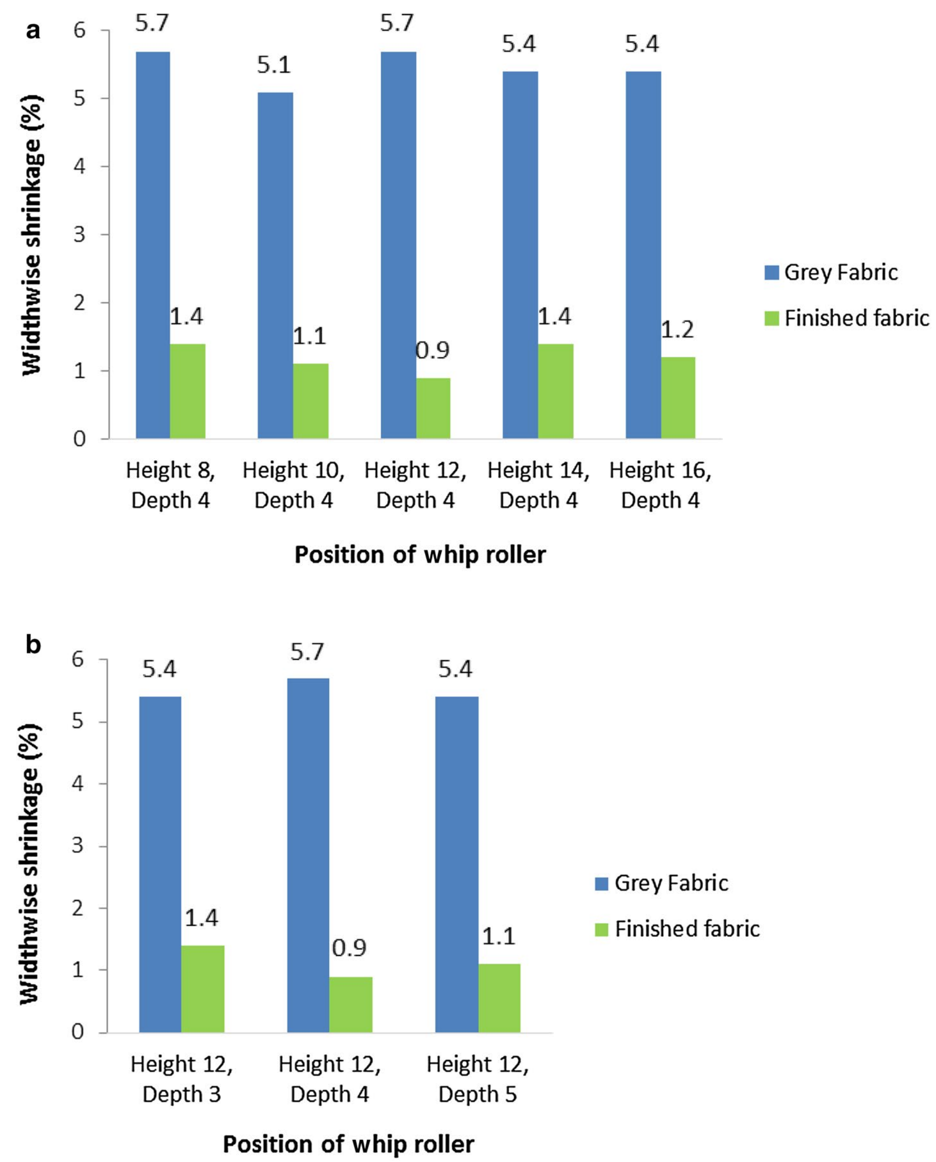

Fig. 12 **a** Width wise shrinkage (%) at variable height and constant depth of whip roller. **b** Width wise shrinkage (%) at constant height and variable depth of whip roller

inversely proportional way with variable depth at constant height position of whip roller. The highest value of air permeability (in $cm^3/s/cm^2$) for grey and finished denim was found 160.42 and 156.94 respectively at the position of height +8 and depth 4. Width wise fabric shrinkage gradually increased with increasing height position of whip roller at fixed depth and similarly decreased with decreasing depth of whip roller at fixed height setting but only in case of grey state. The maximum value of shrinkage% was 12.6 at height +12 and depth 3. In finishing state of fabric, shrinkage% had so negligible value

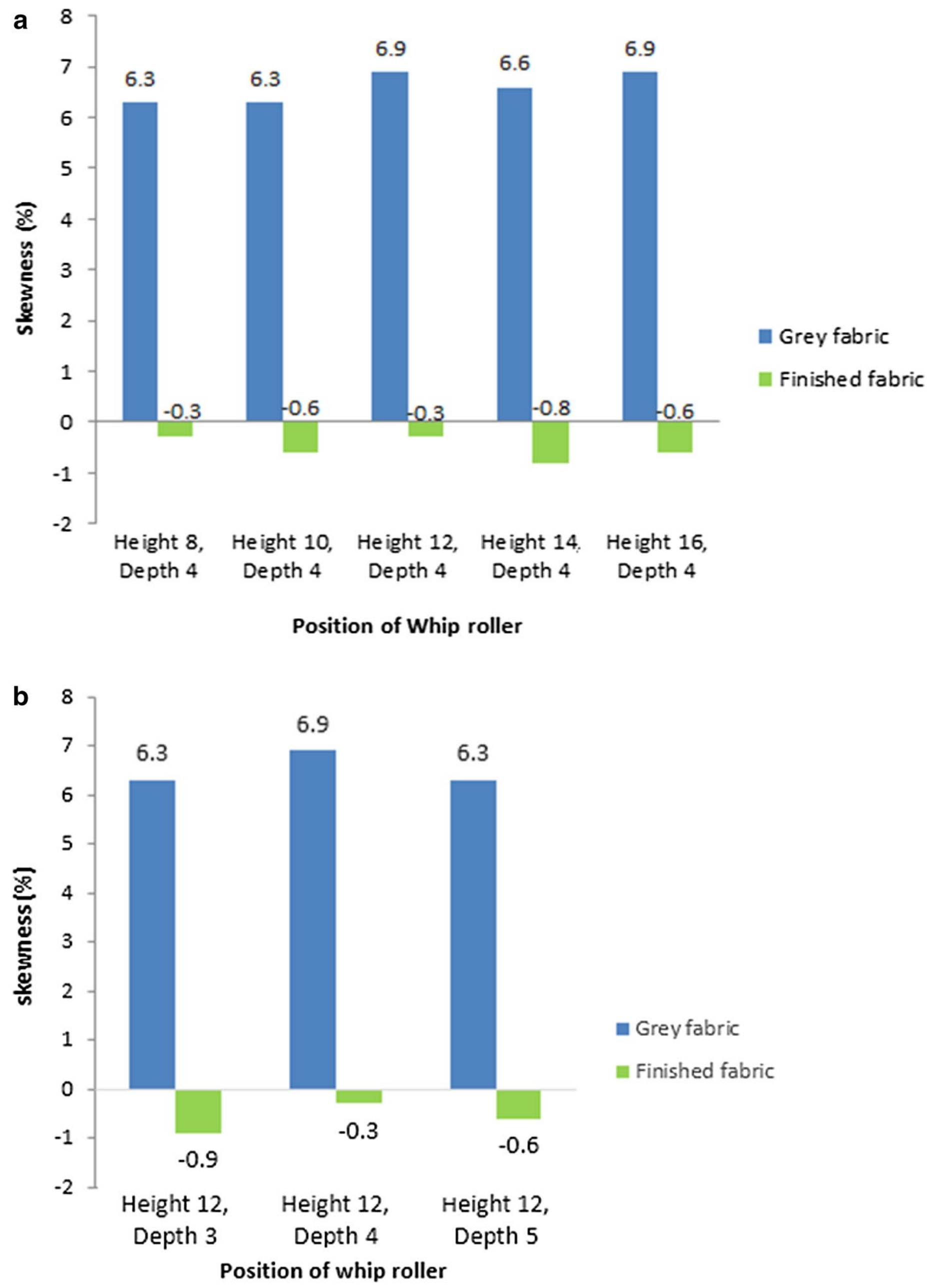

Fig. 13 **a** Skewness (%) at variable height and constant depth of whip roller. **b** Skewness (%) at constant height and variable depth of whip roller

due to different finishing treatment. Generally whip roller setting is kept unchanged in different woven fabric production. But it directly affects EPcm and PPcm which change the cover factor of fabric. Moreover, the research result shows that it also deviates different physical properties of fabric. So if this position is optimized, fabric properties can be enriched as well as faults can be minimized.

Authors' contributions

FIF acquired the fabric samples, designed and carried out the experiments as well as drafted the manuscript. FS and MRI contributed in the data analysis of some test results. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

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