EFFECTS OF NANO-SILVER FINISHING ON THE PHYSICAL AND MECHANICAL PROPERTIES OF COTTON FABRICS

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Abstract
Fabric comfort is determined by its physical and mechanical properties which are being influenced by the finishing treatment such as finishing by nano materials.
In this study the effects of nano-silver finishing on the physical and mechanical properties of plain weave cotton fabrics have been examined. Specimens have been finished with four distinct solution concentrations (100,200,300 and 400 PPM) and finally they have been compared to the raw fabric. The physical and mechanical properties including air permeability, wrinkle recovery, water vapor permeability, breaking strength, breaking elongation and bending length have been measured. The results show that by increasing the solution concentration of the nano-silver finish, air permeability has been dwindled and there is a great difference between nano-finished specimens and the unfinished one. Also by increasing the solution concentration, a slight decrease in wrinkle recovery and an irregular decline in water vapor permeability have been observed. Also an irregular increase in breaking strength has been perceived and a considerable raise in the breaking elongation and bending length in both warp and filling directions was observed.
It is worthwhile to be mentioned that all these consequences have been confirmed by the mean of statistical analysis.

Key words: physical and mechanical properties, woven fabric, nano-silver finish

1. Introduction

Nanotechnology is one of the most significant and recent concerns in the world which has been considered particularly by the textile industry. Thus there should be a lot of practical and developing applications in this realm. Generally, this utilization can be categorized into two main areas: firstly, application of nanofibers and secondly, application of nano-particles in different domains. Here some of these applications can be named. For instance, using of polymeric nanofibers and their composites for drug delivery systems [1], tissue engineering, reinforcement of some composites, transistors, capacitors etc. can be mentioned [2,3]. On the other side, following implementations are remarkable achievements in this domain:

- improving the water-repellent property of the fabric by creating nano-whiskers (hydrocarbons which are 1/1000 size of typical cotton fibers) on the fabric [4],
- imparting anti-static properties of textile which can be provided by TiO_2, ZnO, antimony-doped tin oxide (ATO) and silane nano sol [4],
- increasing the surface energy and thus giving a very high particle retention to filters by the usage of nanofibrous webs on them [5],
- employing nano-titanium dioxide and nano-silica to advance the wrinkle resistance of cotton and silk respectively [4],
- employing nano-sized TiO_2 and ZnO in order to absorb and scatter UV radiation more effectively regarding the larger surface area and blocking ability of so-called particles [4],
- covering the cotton fibers in a fuzz of minute whiskers and creating fewer points of contact of dirt, thus the fabric has been rendered super-hydrophobic and the self-cleaning property can be developed in this way [6],
- And eventually, anti-bacterial properties can be imparted by using nano-sized silver, titanium dioxide and zinc oxide. In respect to our study nano-silver particles should be discussed more which they have an extremely large relative surface area, so their contact with bacteria or fungi is increased, thus their bactericidal and fungicidal effectiveness has been vastly improved.

Furthermore, the multiplication and growth of those bacteria and fungi is inhibited in this way. Hence, nano-silver particles are widely applied to contribute the prohibition of bacteria growth in socks. In addition, they can be applied to a range of other healthcare products, take scald, dressings for burns, skin donor and recipient sites as examples [4]. Thereby nano-silver particles may have some effects on the fabric properties which they should be taken into consideration.

2. Materials and methods

2.1 Materials

Five different specimens were tested in order to study the effects of nano-silver finishing on the physical and mechanical properties of the fabric. Fabrics were 100% cotton with plain weave and their complete specifications are demonstrated in table 1. The unfinished sample is labeled 'A' and samples which were finished with four solution concentrations of 100 PPM, 200 PPM, 300 PPM and 400 PPM are labeled as 'B', 'C', 'D' and 'E' respectively. Four different concentrations thus have been chosen so that an overall trend in changes could be identified.

Table 1. The fabrics samples specifications

Density		Yarn count(Nm)		Fabric mass per unit area (gr/m^2)				
Warp(ends/cm)	Weft(picks/cm)	warp	Weft	A	B	C	D	E
25	23.5	36	34	137.38	153.37	154.95	156.21	156.69

2.2 Finishing method

Any textile finish that inhibits or kills micro-organisms can accurately be described as 'anti-microbial' [7]. In this case, fabrics soaked in 50$^{\circ c}$ suspensions with four distinct concentrations of nano-silver particles (as they were mentioned above) for 30 minutes. Fabrics have been dried in the open air afterward. This kind of finishing is generally called 'exhausting finishing'. PPM stands for particle per million and it is the mass concentration of the batches.

2.3 Testing procedure

2.3.1 Air permeability

The volume of air (cc) which passes through one square centimeter of the fabric at a given pressure (1cmh$_2$o) in a second is described as air permeability. First of all, the range of permeability should be examined and then the appropriate pressure has been chosen. Ten different areas of the fabric were subjected to the air stream with constant pressure of 100 Pa so that this property could be compared easily [8].

2.3.2 Wrinkle recovery

The ability of the fabric to return after the crease is called Wrinkle recovery. For this purpose, fabrics exposed to a given force (20N) for one minute and then the angle of recovery in each specimen was measured after one minute in both weft and warp directions [8].

2.3.3 Water vapor permeability (WVP)

The mass of water vapor which passes through a given area (1m^2) of the textile in an hour because of the pressure difference is known as WVP. In this part specimens were placed on bowls full of water, with 9 centimeters in diameter. These bowls have being rotated on a rotary plate so that the air circulation has been facilitated [8]. WVP of fabrics are calculated afterwards by Eq. (1)

$$M = M_1 - M_2 \quad , \quad m = m_2 - m_1 \quad , \quad N = M - m \quad , \quad WVP\% = N / (m + M) \tag{1}$$

Where ‘M’ is the total mass of evaporated water which goes out of the system, ‘m’ is the mass of evaporated water which is locked up in the fabric and ‘N’ is the mass of evaporated water which passes the fabric.

2.3.4 Thickness

The distance between two flat plates (usually metal ones) at a given pressure ($1lb/inch^2$) is called fabric thickness (t). This test has been done to find out the fabric thickness which is needed for estimating the bending modulus [8].

2.3.5 Breaking strength

The force which is needed to overcome the fabric strength and eventually lead to break it (N) is known as the fabric breaking strength. This test has been accomplished by Instron strength tester and according to the range of fabric strength (which was 500N), ‘C.M’ load cell was chosen. Five fabric strips in both warp and weft directions were subjected to the load and then the average force is expressed as the fabric breaking strength [8]. It should be taken into consideration that yarns have been pulled out from the fabric’s margins in order to prevent the jamming phenomena, so that all of the yarns contribute the tensile stress thus uniform load sharing has been achieved.

2.3.6 Breaking elongation

Breaking elongation is defined by Eq. (2), where ‘L_0’ is the initial length of strip (strain gauge = 20cm), ‘L’ is the length of strip at breaking point, and ‘E%’ is the breaking elongation [8]. According to the testing conditions, the speed of jaws was set to be 5 cm/min.

$$E\% = [(L - L_0) / L_0] * 100 \tag{2}$$

2.3.7 Bending length

Length of fabric which causes it to bend at a given angle due to its weight is defined as the fabric bending length [8]. Eq. (3) expresses this definition, where ‘L’ is the fabric strip length and ‘C’ is the bending length.

$$C = L \, . \, F(\theta) \tag{3}$$

Where $F(\theta)$ is: $F(\theta) = [\cos(\theta/2) / 8 * tag(\theta)]^{1/3}$

Five strips in both warp and weft directions have been tested and bending length at the angle of $\theta = 41.5$ was measured.

Bending rigidity is a value which represents the fabric’s resistance to bending. It is calculated by Eq. (4) where ‘W’ is the fabric unit area weight (gr/cm^2) and ‘G’ is the bending rigidity.

$$G = W \, . \, C^3 * 10^3 \tag{4}$$

Bending modulus is the Maximum stress per unit area that a specimen can withstand without breaking when it is bent. Bending modulus is calculated by Eq. (5) where ‘t’ is the fabric thickness and ‘B’ is the bending modulus.

$$B = (12 * G * 10^{-6}) / t^3 \tag{5}$$

3. Results and discussion

Principally two main categorized characteristics were tested in this study, physical properties and mechanical properties. Therefore it is better to discuss the fulfilled consequences discretely. Table 2 shows a brief overview of these results.

Table 2. The physical and mechanical test results of fabric samples

Property			Raw sample	Nano-finished samples with different concentrations			
			A	B(100PPM)	C(200PPM)	D(300PPM)	E(400PPM)
Air permeability	average		348.8	202.7	194.7	184.7	184.5
	CV%		6.56%	5.89%	4.97%	4.96%	3.96%
Wrinkle recovery angle	Warp dir.	average	87.5	85.4	84.8	80.6	70.8
		CV%	2.29%	7.84%	4.60%	7.78%	4.40%
	Weft dir.	average	102.7	80.7	74.6	75.4	73.8
		CV%	10.82%	7.11%	3.86%	3.46%	2.94%
WVP%	average		98.85%	98.67%	98.84%	98.73%	98.39%
	CV%		0.21%	1.12%	0.06%	0.16%	0.82%
Thickness (mm) in (1 lb/in²)			0.32	0.37	0.37	0.37	0.37
Breaking strength (N)	Warp dir.	average	355.8	359	387.6	377.4	359.6
		CV%	1.63%	15.33%	4.71%	15.73%	7.48%
	Weft dir.	average	373.2	373.8	373.6	408.8	374.4
		CV%	2.17%	15.86%	16.17%	4.55%	11.36%
Breaking elongation	Warp dir.	average	9.90%	16.18%	15.73%	16.69%	14.35%
		CV%	2.88%	4.61%	3.77%	3.34%	3.81%
	Weft dir.	average	12.20%	22.12%	21.65%	23.39%	22.97%
		CV%	1.71%	1.91%	3.97%	3.14%	3.25%
Bending rigidity(mgr.cm)	Warp dir.		62.8	80.8	93.4	95.7	110.9
	Weft dir.		63.9	85.0	104.6	105.5	109.2

3.1 Effects of nano-silver finish on Physical properties

3.1.1 Air permeability

Results of the air permeability test are illustrated in fig.1. It can be clearly seen that there is a drastic fall in the air permeability property by applying nano-silver finish on the fabric; also a gradual decline has been occurred by increasing the solution concentration. This has been happened due to the reduced fabric pores which have been filled by nano-silver particles. But as these nano-particles are extremely tiny, increasing the concentration does not have any considerable effect on the air permeability property.

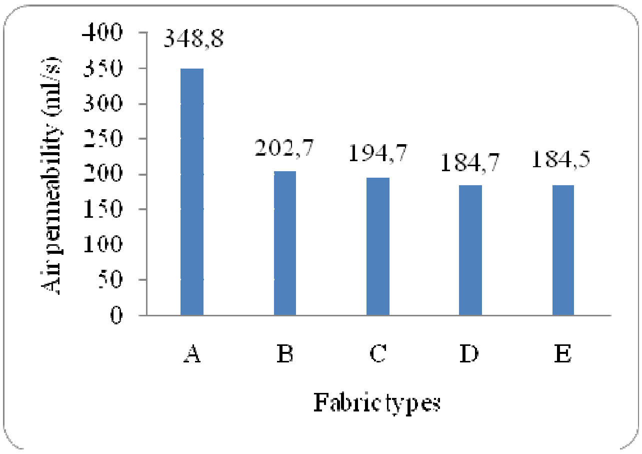

Figure 1. Air permeability of fabric samples

3.1.2 Wrinkle recovery

Wrinkle recovery test results in the warp and weft directions are shown in fig.2 and fig.3 respectively. The angle of recovery in the warp direction started at 87.5 degrees in sample A and it went down gently to 70.8 in sample E. A downward trend in wrinkle recovery can be clearly seen due to the links which have been generated by nano-silver particles on the fabric. The angle of recovery in the weft direction was 102.7 in sample A and there was a moderate drop in this value for the other samples but here, no regular trend can be observed and this can be attributed to the finishing unevenness.

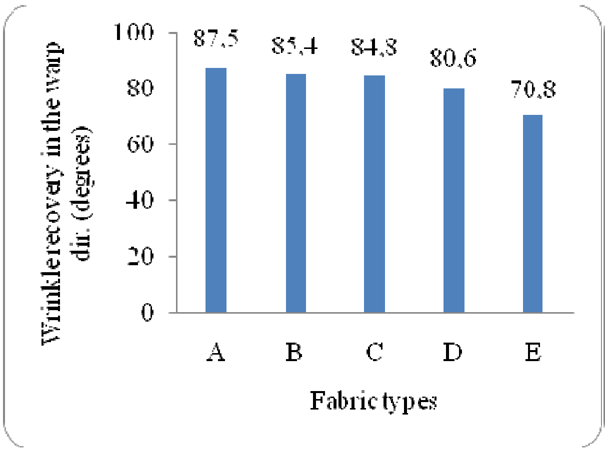

Figure 2. Wrinkle recovery angle of fabric samples in the warp dir.

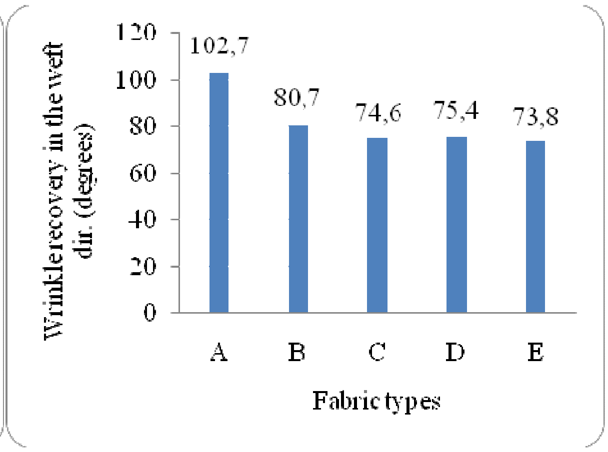

Figure 3. Wrinkle recovery angle of fabric samples in the weft dir.

3.1.3 Water vapor permeability (WVP)

Fig.4 shows the WVP% of the fabrics. Generally, it can be concluded that WVP% of nano-finished fabrics are lower than the unfinished one. This result can be justified by the same explanation which was discussed in 3.1.1. Fabric A had the most WVP% while fabric E had the least WVP% at 98.39%. The irregularity which is seen here is caused by the unevenness of finishing process in those parts of fabrics which were subjected to the WVP test.

3.1.4 Thickness

Thickness values of the samples are illustrated in fig.5. It is crystal clear that the thickness values of nano-finished samples are more than the unfinished fabric. More thickness values of the nano-finished fabrics are the consequence of the yarn swelling phenomena which happens during the finishing process. It should be mentioned that these values measured when the fabric was subjected to 1lb/inch^2 pressure.

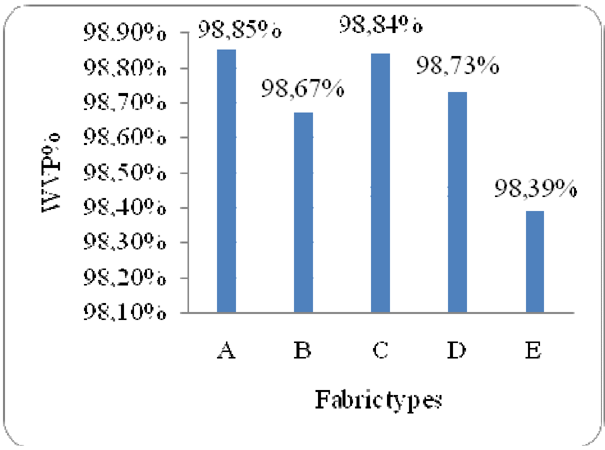

Figure 4. WVP% of fabric samples

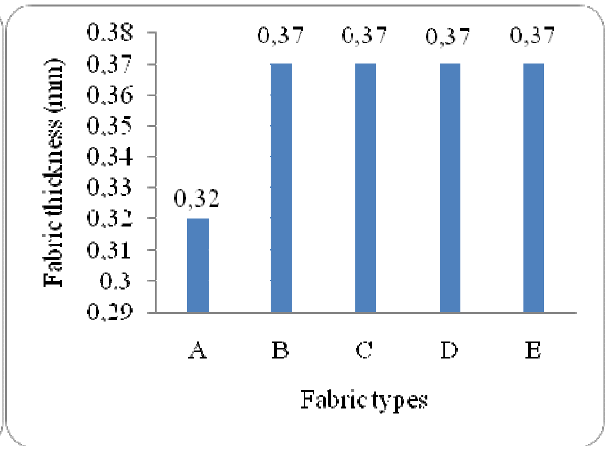

Figure 5. Thickness of fabric samples

3.2 Effects of nano-silver finish on mechanical properties

3.2.1 Breaking strength

The breaking strength of the fabrics in the warp direction is demonstrated in fig.6. Sample A had the least breaking strength (355.8) and fabric C had the most one (387.6). Generally it can be inferred that the breaking strength of nano-finished samples is more than unfinished fabric owing to the linkage formation between fibers and yarns, while there is no determinable trend in this property. Fig.7 shows the breaking strength of the fabrics in the weft direction. The highest breaking strength pertains to sample D but no considerable difference can be observed between other specimens.

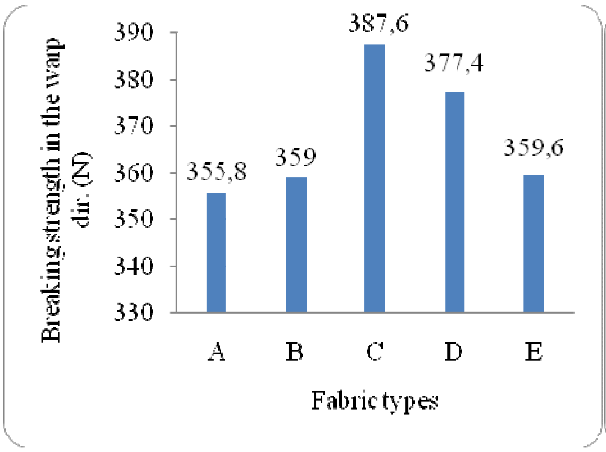

Figure 6. Breaking strength of fabric samples in the warp dir.

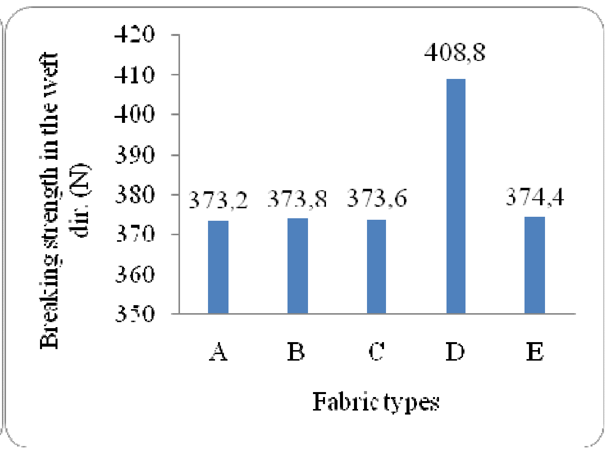

Figure 7. Breaking strength of fabric samples in the weft dir.

3.2.2 Breaking elongation

The breaking elongations of samples in warp and weft directions are presented by fig.8 and fig.9 respectively. It can be observed that there are significant differences in the breaking elongation of fabrics between nano-finished and unfinished specimens. This substantial distinction is due to reinforcement of fibers and yarns by the nano-silver particles.

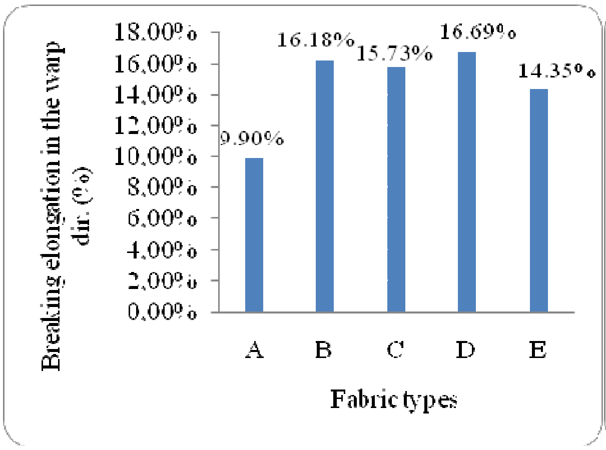

Figure 8. Breaking strength of fabric samples in the warp dir.

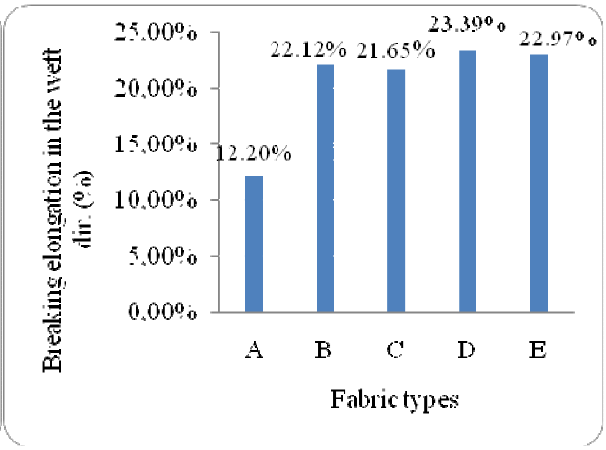

Figure 9. Breaking strength of fabric samples in the weft dir.

3.2.3 Bending rigidity

Bending rigidity values of samples in the warp and weft directions are shown in fig.10 and fig.11 respectively. Bending rigidity of sample A is 62.8(mgr.cm) in the warp direction and 63.9(mgr.cm) in the weft direction. After that the bending rigidity values started to increase and they reached to 110.9(mgr.cm) in the warp direction and 109.2(mgr.cm) in the weft direction in sample E. This gradual upward trend is caused by the links which was formed on the yarns and fabrics by nano-silver finishing.

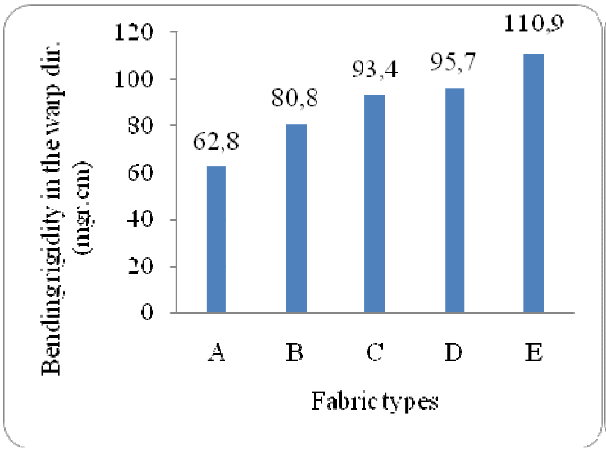

Figure 10. Bending rigidity of fabric samples in the warp dir.

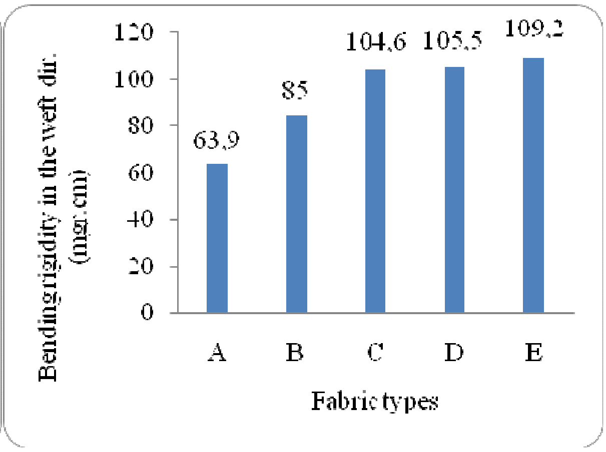

Figure 11. Bending rigidity of fabric samples in the weft dir.

4. Conclusion

In the present study in order to investigate the effects of nano-silver finishing on the mechanical and physical properties of cotton fabrics, fabric samples were subjected to the nano-silver finishing process with four different solution concentrations of 100, 200, 300 and 400 PPM. Eventually the following conclusions have been readily drawn:

- Nano-silver finishing lessened the air permeability and water vapor permeability of the fabric and this can be attributed to the nano-silver particles which fill the fabric pores.
- Wrinkle recovery angle of the nano-finished fabrics was declined in both directions because of the generation of links on the fabric by nano-silver particles.
- Yarn swelling phenomena happens during the finishing process in cotton fabrics which means increment of occupied space by fibers and yarns, and thus rise in the fabric thickness.
- Owing to reinforcement of fibers and yarns by the nano-silver particles, the breaking elongations of fabrics in both warp and weft directions was inclined by applying the nano-silver finishing process.
- Applying the nano-silver finishing process led to formation of links on the fabric, and consequently bending rigidity of the fabrics was increased in both warp and weft directions.

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