COMPARISION OF SPUN SILK FABRIC PROPERTIES PRODUCED USING DIFFERENT TYPES OF VOID SPUN SILK YARNS PRODUCED IN RING DOUBLING PROCESS

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ABSTRACT:

In order to develop the utilization of spun silk yarns in garment sector, CSTRI has developed void spun silk yarns in ring doubling process in spun silk mill by introducing PVA yarns along with spun silk yarn. For this purpose, two varieties of PVA yarns are sourced and converted into 2, 4 and 6 ply yarns and doubled along with spun silk yarn in ring doubling process, which is termed as void spun silk. These yarns were utilized for the production of fabrics in power looms with bivoltine silk as warp and void spun silk as weft. After weaving the fabrics, the fabric samples were degummed and dyed using reactive dyes in HTHP dyeing machine, wherein, the PVA component was dissolved so as to create void in the spun silk fabrics and hence improve the fabric comfort properties. Results indicate that 4 ply Japan PVA fabric and 2 ply Indian PVA fabric has shown improved properties compared to control spun silk fabrics.

Key words: Void spun silk, Japan PVA yarn, Ring doubling machine, Spun silk fabrics.

INTRODUCTION:

Presently spun silk yarns produced from silk wastes generated in silk reeling and twisting processes are mainly used for the production of silk carpets. The demand for spun silk is decreasing over the years and hence alternative utilization of spun silk fabrics in garment sector with cost reduction would boost its consumption. The spun silk yarns are quite different from spun yarns produced from other fibres as the lustre is better in spun silk yarns. However the cost differentiation between cotton spun fabrics and silk spun fabrics are quite high. Hollow cotton yarns using PVA yarns as core and cotton fibres as sheath in friction doubling process and studied various characteristics (Merati, A.A.et al 2000). They reported that the strength of the hollow yam after PVA extraction does not change with the PVA content, and it is the same as that of the equivalent cotton yam whereas the breaking elongation of the hollow yam is more than that of the cotton yarn. The relationship between cotton hollow yarns on the tensile strength was reported by Gao Shi Yu et al. Development of innovative cotton hollow yarn was also attempted by Andrysiak et al 2014 and claimed that thermal properties have been improved. No reports are available on silk or spun silk on hollow yarns or fabrics. In this context, CSTRI thought of producing void spun silk yarns in ring doubling process by introducing PVA yarns along with spun silk yarn in spun silk mill. Compared to raw silk the spun silk is having more thickness and hence it was thought to ply 2 ply, 4 ply and 6 ply PVA yarns along with the spun silk yarn single ply in ring doubling frame, which was tried by Merati. A. A. et al 1999 for cotton in friction doubling. The resultant yarns thus doubled termed as void spun silk. These void spun silk yarns are used as weft in organza fabrics in power loom with plied bivoltine raw silk as warp to produce void spun silk fabrics, which are later processed to remove the PVA component thus making fabrics with void, which have better functional, aesthetic and comfort properties suitable for garment sector. The thermal comfort properties of the fabrics are also studied.

MATERIALS AND METHODS

PVA yarns: Two varieties of PVA yarns viz., Japan PVA and Indian PVA are sourced from M/s Nitivity Co, Japan and from M/s, Shakthi Traders, Mumbai. Both the PVA yarns are converted into 2 plied yarn, 4 plied yarn and 6 plied yarn in doubling machine and twisted with 4 TPI. The twisted plied yarns are converted into cones in cone winding machine. The characteristics of PVA yarns are tested and given in Table 1. These PVA yarns are spun along with spun silk yarn is doubled in ring doubling machine to produce void spun yarns.

PRODUCTION OF VOID SPUN YARNS

The raw material, silk wastes generated in the process of silk reeling and twisting are accumulated from the units. These silk wastes are sorted and degummed with soap and soda to remove the sericin present in the fibres. The degummed silk waste are dried and stored. For the production of spun silk yarn, the degummed waste is processed in opening machine to convert into lap followed by staple cutting and again processed in opening machine to form lap. The laps are processed in the breaker card initially to convert the lap into sliver form. The slivers are combined in the lap former to form a small lap. Three such laps are once again fed into the finisher carding machine to form into sliver. The slivers are processed in the roving frame to convert the sliver into roving bobbins. The roving's in the bobbins are drafted in the ring frame to convert them into spun silk yarn of desired count [Eric Oxtoby, 1987]. The process parameters maintained are ring spindle speed of 5000 rpm and front roller speed of 70 rpm. The spun silk yarns thus produced were doubled in ring doubling machine along with PVA yarns plied to the requirement of void to be created, and twisted to produce ring doubled void spun silk as shown in Figure 1. One control yarn i.e., two cones of spun silk plied without PVA and 6 void spun silk yarns with 2, 4, 6 ply Japan / Indian PVA yarns along with one cone of spun silk were produced. These yarns were characterized for various characteristics viz., denier, tenacity, elongation, microscopic cross section and longitudinal and wicking characteristics. The results are given in Table 2. The results have been analyzed for ANOVA test and are given in Table 3. It could be observed that significant difference exists among the characteristics studied between control spun silk yarns and void spun silk yarns produced in ring doubling process.

PRODUCTIONOF VOID SPUN SILK FABRICS:

Using the 2 ply spun silk yarn doubled without PVA yarn and 2 ply void spun silk yarns produced with spun silk along with 2ply, 4 ply and 6 ply Japan and Indian PVA yarns were again doubled and twisted with required TPI and used as weft in the production of fabric. The bivoltine raw silk was single twisted, doubled and double twisted and used as warp in fabric preparation. Seven different varieties of fabrics were developed for characterization. The developed fabrics were then degummed and dyed in HTHP dyeing machine in order to remove the PVA component from the fabrics. Both the raw and dyed fabrics were studied for functional, aesthetic and comfort properties. The dyed void spun silk fabrics were also assessed thermal comfort properties using Kawabata Evaluation System (KES).

Data collected: The seven varieties of spun silk and void spun silk fabrics were studied for various fabric characteristics viz., Fabric mass, fabric thickness, EPI, PPI, Warp and weft count, Cover factor, crimp warp / weft, twist warp / weft, tensile strength viz., breaking load and elongation warp / weft, crease recovery, flexural rigidity, abrasion resistance, air permeability, drape coefficient and bursting strength. The fabrics were also subjected thermal comfort properties of the fabrics viz., Q max values, clothing insulation values (CLO) and Thermal insulation value (TIV) of the spun silk and void spun silk fabrics were also assessed for the seven different varieties of fabrics. The data were analyzed statistically.

Standard test methods to study the functional, aesthetic and comfort properties of fabrics: The spun silk and void spun silk fabrics of different combinations were tested for various characteristics following the standard testing procedures viz., Fabric thickness IS 7702:1975, Threads in cloths IS 1963:1981, Count of warp / weft IS 3442:1980, Crimp percentage of warp / weft IS 1963:1981, Tensile strength IS 1969:1985, Crease recovery IS

4681:1981, Flexural rigidity ASTM D 1388-96, Option A, Drape coefficient percentage IS 8357:1977, Air permeability IS 11056:1984 (Bureau of Indian standards IS 6936, (1984)).

The data thus obtained were analyzed statistically using SPSS package.

SEM studies: The spun silk fabrics produced with 2/40s yarn and void spun fabrics produced with 4 ply Japan PVA yarn and 2 ply Indian PVA yarns in ring doubling process were tested in JOEL 100 X II ASID 4D S scanning electron microscope under 250 magnifications. The sample for SEM were fixed for 2 hours in glutaraldehyde in 0.2 M cacodylate buffer (pH 7.2) dehydrated in graded ethanol-acetone series and dried in critical point using CO_2 as transition fluid. After drying, the samples were mounted on to copper stubs, coated with gold and examined using scanning electron microscope at 20 kv. The results of spun silk and void spun fabrics in raw and dyed stage are depicted in Fig. 3 a to f.

RESULTS AND DISCUSSIONS:

The fabric characteristics results of the raw and dyed spun silk and void spun silk fabric samples are given in Table 4 & 5 and Fig. 2 a to l. The ANOVA results of all the fabric characteristics of spun silk and void spun silk fabric samples are given in Table 6. The spun silk and void spun silk fabric characteristics produced in ring doubling process was analyzed for Z score and subjective analysis are given in Table 7 & 8. Table 9 indicate the Thermal comfort characteristics of spun silk, void spun silk fabrics in ring doubling process. In order to arrive at the best combination, principal component analysis was carried out and the results are given in Table 10.

Functional, Aesthetic and Comfort properties of spun silk / void spun silk fabric characteristics:

Fabric mass and thickness: From the Table 4, it could be observed that fabric mass and thickness of spun silk fabric in raw stage was 170.4 g/m^2 and 0.294 mm whereas fabric mass and thickness of 2, 4, 6 ply Japan PVA void spun silk fabric was altered to 0.24, 3.4, 14.5% and 19.25, 42.1, 55.7% and for 2, 4, 6 ply Indian PVA void spun silk fabric was 18.8, 29.8, 37.9% and 53.8, 70.2, 74.3%. These fabrics after degumming and dyeing was found to have fabric mass and thickness as 181.4 for dyed spun silk fabric whereas dyed void spun silk fabric mass and thickness of 2, 4, 6 ply Japan PVA void spun silk fabric was altered to 2.4, 7.3, 12.1% and 8.4, 9.4, 14.1% and for 2, 4, 6 ply Indian PVA void spun silk fabric was 9.5, 14.6, 16.1% and 9.8, 20.3, 14.4% (Table 5). The dyed fabric thickness and mass of void spun silk reduced significantly compared to raw void spun silk fabrics due to removal of PVA yarn from fabrics.

Weft crimp in weft: From Table 4, it could be observed that weft crimp was 2.0% in spun silk fabrics in raw stage and varies from 14 to 26% and from 16 to 44% for 2 to 6 ply Japan PVA / Indian PVA void spun silk fabrics in raw stage whereas for dyed spun silk fabrics 86 to 252% and from 141 to 270% for 2 to 6 ply Japan PVA / Indian PVA void spun silk fabrics (Table 5). No significant different is observed in control spun silk fabrics. The results indicate that due to removal of PVA yarns during dyeing process, the weft crimp significantly improved in void spun silk fabrics for both Japan and Indian PVA yarns as the yarn ply increased. The Indian PVA yarns of 6 ply decreased the weft crimp, which may be due to too coarser yarns.

Twist in weft: From Table 4, it could be observed that twist in weft was 491 in spun silk fabrics in raw stage and varies from 1.5, 7.7, 13.5% and from 22.7, 25.2, 34.7% for 2 to 6 ply Japan PVA / Indian PVA void spun silk fabrics in raw stage whereas for dyed spun silk fabrics 349 TPM for control fabric and varies from 12.2, 11.7, 18.7% and from 15.9, 28.9, 16.1% for 2 to 6 ply Japan PVA / Indian PVA void spun silk fabrics (Table 5). The results indicate that twist in weft significantly reduced from raw stage to dyed stage spun / void spun silk fabrics, which is due to loosening of structure as the PVA yarns are dissolved.

Cover factor: From Table 4, it could be observed that cover factor of spun silk fabrics in raw stage was 21.53 and changed to 2.7 to 4.9% and to 3.7 to 6.1% for 2 to 6 ply Japan PVA / Indian PVA void spun silk fabrics in raw stage. The dyed spun silk fabrics have reduced the cover factor to 1.5% in control fabric, 0.7 to 6.0% in 2 to 6 ply Japan PVA fabrics and to 0.5 to 4.9% for 2 to 6 ply Indian PVA void spun silk fabrics (Table 5). The results indicate that cover factor significantly reduced after degumming and dyeing of fabrics.

Tensile properties: From the results in Table 4, it could be seen that the breaking load of the spun silk raw fabrics in warp direction did not alter much whereas in weft direction 51.3% increased. Similarly the breaking load of the void spun silk raw stage fabrics in warp direction found to vary from 0.55 to 7.73% whereas in weft direction 1.3 to 18.4% for 2, 4, 6 ply Japan PVA void spun silk fabrics and 1.3 to 12.4% and 6 to 10.9% in warp and weft direction of for 2, 4, 6 ply Indian PVA void spun silk fabrics (Table 5).

The elongation properties of the spun silk raw fabrics in warp direction reduced to the extent of 12.4% compared to degummed fabrics whereas in weft direction 27.7% increase was observed (Table 4 & 5). The void spun silk produced with both 2 to 4 ply Japan PVA yarns have reduced the elongation in warp direction 4.1 to 6.1% but increased to 2.8% for 6 ply Japan PVA yarn fabrics. For 2 ply Indian PVA yarn fabrics shown 5.4% reduction in elongation in warp direction, 1.7% increase in 4 ply and 21% reduction in 6 ply PVA yarns void spun silk fabrics. The weft elongation properties have improved from 20.7 to 149% for Japan PVA yarn fabrics and 36 to 122% for 2 to 4 ply yarns and reduced by 69% for 6 ply Indian PVA yarn fabrics. Thus indicating that, removal PVA yarns has shrunk the fabrics and improved weft elongation. In case of 6 ply fabrics excess removal of fabric has altered the fabric geometry and reduced the elongation properties of the void spun silk fabrics.

Crease recovery angle total: Crease recovery angle of the spun silk fabric has shown significant improvement of 40.5% in case of dyed fabrics compared to raw fabrics. The void spun silk fabrics produced with 4 ply Japan PVA yarns has shown 41.6% improvement and 49.7% in case of 2 ply Indian PVA yarn void spun silk fabrics between raw and dyed fabrics (Table 4 & 5).

Flexural rigidity: The flexural rigidity of void spun silk fabrics produced with both Japan and Indian PVA yarns both in raw and dyed stage have shown an increasing trend between 2 to 6 ply fabrics, indicating that the void spun silk fabrics are more flexible and less stiff compared to spun silk fabrics.

Abrasion resistance: Abrasion is one aspect of wear due to rubbing of yarn of the fabric during usage. The abrasion resistance of void spun silk fabrics has decreased in case of Japan PVA fabrics to the extent of 22 to 30% whereas in case of Indian PVA yarns the decrease is very low to the extent of 8 to 15%.

Air permeability: Air permeability is the reciprocal effect of the air resistance. The resistance of the fabric to the flow of air is a measure of initial warmth / cool feeling when the garment is worn. The air permeability of the void spun silk produced with 2 ply Japan PVA yarns has shown 184% more air permeability compared to spun silk fabrics and Indian PVA yarns void spun silk fabrics has shown 116% more air permeability compared to spun silk fabrics (Table 5), Thus the air permeability of void spun silk fabrics are significantly higher compared to spun silk fabrics so that these fabrics will have more intensity of warm / cool feeling when converted into garments.

Drape coefficient: Drape is the ability of the garments to assume graceful appearance when it is used. Lower the drape coefficient better is the drape of the fabric. Drape coefficient of the raw spun silk fabrics was decreased from 9 to 36% in case of void spun silk fabrics produced with 2 to 6 ply Japan PVA yarns and 11% in case of 2 ply Indian PVA yarns (Table 4), whereas in case of dyed void spun silk fabrics only 6 ply PVA yarns have shown better drapeability, due to removal of PVA yarns from the fabrics (Table 5).

Bursting strength: Bursting strength is a measure of fabric resistance in multidirectional force. It could be observed that bursting strength of void spun silk fabrics with 2, 4 , 6 ply Japan PVA yarns in raw stage has shown significant reduction whereas Indian PVA yarn fabrics have shown significant increase in bursting strength (Table 4), which may be attributed to the strength of Indian PVA yarns. The dyed void spun silk fabrics have shown reduction in bursting strength since the PVA yarns are removed during the process of dyeing (Table 5).

Based on the analysis, it was found that the fabric characteristics of void spun silk fabrics were found to be superior in terms of thickness, cover factor, crimp in weft, twist in weft, crease recovery, breaking load in weft, elongation in weft, flexural rigidity and air permeability characteristics.

Analysis of spun silk and Void spun silk fabrics:

From the results in Table 6, it could be observed that breaking load warp and drape coefficient of void spun silk fabrics produced in ring doubling process did not show significant difference where as all the other characteristics were found to be significantly different at 1% level.

Arriving at the best trait fabric:

In order to arrive at the best trait, an attempt has been made to find out Z-scores for each character using the formula

$$Z = (X - \mu) / \sigma$$

Where X is the mean of each trait under each character and

μ is the population mean of the trait and

σ is the population Standard deviation.

These Z-Scores were calculated for each trait on fabric characteristics to arrive at the best. From the results given in Table 7, it could be observed that void spun silk fabrics produced with 4 ply Japan PVA yarn and 2 ply Indian PVA yarn in doubling process has given highest scores indicating that both are better having better fabric characteristics followed by void spun silk fabrics produced with 2 ply Japan PVA and 4 ply Indian PVA yarns. The void spun silk fabrics produced with 6 ply Japan as well as Indian PVA yarns did not have better fabric characteristics as well as productivity in ring doubling process were very low compared other yarns used in the study.

Subjective analysis of the void silk fabrics:

In order to assess consumer preference of the void silk fabrics, the fabrics were presented to different people for subjective assessment. The fabrics were assessed for appearance, lustre, surface finish, Drape and bulkiness with scale of 1 to 5. In appearance 1 means plain without crepe effect and 5 means prominent crepe effect, in lustre 1 means dull, 5 means shiny, in surface finish 1 means poor and 5 means very good, in Drape 1 means stiff, poor drape, 5 means good drape, in compression 1 means thin and 5 means bulky. Based on the subjective assessment of the fabrics by various peoples like business men, consumers, researchers, traders, etc., the data has been analyzed. The subjective assessment data given in Table 8, it was found that the void spun silk fabrics produced with 4 ply Japan PVA yarn and 2 ply Indian PVA yarn in doubling process has attracted many consumers.

Analysis of Thermal comfort characteristics of spun silk, void spun silk fabrics:

Q-max value: The Q-max value largely depends on the contact area between skin and fabric surface. Thus, the surface characteristic of a material is important to sensations on how warm or cool a fabric feels to an individual. The Q-max values spun silk and void spun silk produced with 2, 4 & 6 ply Japan and Indian PVA yarns in doubling process of spun silk yarn production given in Table 9. It could be seen that, there is no significant difference between the Q-max values of spun silk and void spun silk fabrics produced in ring doubling process.

Clothing insulation value (CLO): The Clothing insulation values of spun silk and void spun silk produced with 2, 4 & 6 ply Japan and Indian PVA yarns in doubling process of spun silk yarn production given in Table 9, it could be seen that, the CLO values of void spun silk fabrics are slightly higher than that of spun silk fabrics. The void spun silk fabrics produced with 4 ply Japan PVA yarns and 2 ply Indian PVA yarns in doubling process have shown maximum CLO values of 0.54 and 0.48 respectively.

Thermal insulation value (TIV): From the results given in Table 9, it could be seen that, the TIV values of void spun silk are slightly higher than that of spun silk fabrics. The void spun silk fabrics produced with 4 ply Japan PVA yarns and 2 ply Indian PVA yarns in doubling process have shown maximum TIV values of 34.60 and 46.38 respectively.

Factor analysis of the void spun silk fabrics characteristics: In order to confirm the above results, the data were subjected to Factor analysis (Principle component) and confirmatory factor analysis in order to reduce and group identical factors together, which in turn explains observed variations in the larger number of variables. Further, Kaiser Meyer Olkin (KMO) and Bartlett's test (measures the strength of relationship among the variables) have been attempted, which showed a value more than 0.5 (significant at 5% level), indicating the acceptance of Barley.

Eigen value reflects the number of extracted factors whose sum should be equal to number of items which are subjected to factor analysis. Eigen value more than 1 has reduced the level of number of factors to 2 in the present study. Further the rotation component matrix of void raw silk fabrics are given in Table 10.

Void spun yarns produced with 4 ply Japan PVA yarns in doubling process has shown positive highest loading on fabric thickness, crimp warp & weft, twist warp, air permeability, bursting strength and negative loadings on twist weft, drape coefficient, breaking load warp & weft under component 1, whereas positive highest loading on fabric thickness, flexural rigidity, breaking load warp and elongation warp & weft and negative highest loading on fabric thickness, crimp warp, twist warp, abrasion resistance under component 2. The void spun silk with 2 ply Indian PVA yarns in doubling process has shown highest positive loading on crimp warp & weft, twist warp & weft, flexural rigidity, abrasion resistance, air permeability, breaking load warp, elongation warp and highest negative loadings on crease recovery, breaking load weft under component 1, shown highest positive loading on cover factor, crimp weft, drape coefficient and negative relation with fabric thickness, bursting strength, elongation weft under component 2.

Scanning Electron Microscopic studies: In order to confirm the above results, the spun silk fabrics produced with 2/40s spun silk as weft and bivoltine raw silk as warp was tested in raw stage and after dyeing the fabrics were tested for SEM image (Fig. 3a & b). Similarly the void spun silk fabrics produced with 4 ply Japan PVA yarn doubled with spun silk and 2 ply Indian PVA yarn doubled with spun silk in ring doubling machine were used as weft along with bivoltine raw silk warp were tested in raw and dyed stage for SEM photos with 250 magnifications (Fig. 3c & f). From the Fig. 3a & b, it could be seen that the spun silk fabrics after dyeing slightly loosened the structure, whereas the Fig. 3c & d show that void spun silk fabrics due to removal of PVA yarns from the fabrics, the structure has loosened and improve the fabric characteristics.

CONCLUSION

Based on the studies it could be conducted that fabric characteristics of void spun silk fabrics were found to be superior in terms of crimp, crease recovery, tensile properties, air permeability, bursting strength and drape characteristics. The ANOVA results indicate that abrasion resistance of void spun silk fabrics produced in ring doubling process did not show significant difference where as all the other characteristics were found to be significantly different at 1% level. Using the Z-score analysis and subjective analysis, it could be found that void raw silk fabrics produced with 2 Ply Indian PVA yarns and 4 ply Japan PVA yarns have scored more thus indicating that these fabrics are better fabrics in all fabric characteristics followed by void spun silk fabrics produced with 4 Ply Indian PVA yarn and 2 ply Japan PVA yarns in doubling process.

The thermal comfort properties of these fabrics viz., the clothing insulation values (CLO) of the void spun silk fabrics produced with 4 ply Japan PVA yarns and 2 ply Indian PVA yarns in doubling process have shown maximum CLO values and Thermal insulation value (TIV) of void spun silk are slightly higher than that of spun silk fabrics, with fabrics produced using 4 ply Japan PVA yarns and 2 ply Indian PVA yarns in doubling process. The unique appearance developed on the surface on the fabrics due to removal of PVA yarn, has created curiosity among the consumers and exporters. Thus it could be concluded that void spun silk fabrics produced in doubling process could be effective alternative for new silk applications in the silk garment industry. The fabrics developed using void spun silk fabrics are shown in Fig. 4.

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Fig.1: Concept of Void spun silk production in ring doubling machine.

Table 1: Details of quality of PVA yarns used for spinning void spun silk

Type of PVA yarn	Contents	Denier	Tenacity (g/d)	Elongation (%)
Japan PVA yarn	**Single**	**30.3**	**2.8**	**15.5**
	2 Ply	**60.0**	**3.0**	**13.9**

	4 Ply	89.0	3.1	12.8
	6 Ply	178.7	2.2	17.2
Indian PVA yarn	Single	91.0	1.7	12.4
	2 Ply	189.0	2.4	19.2
	4 Ply	367.0	2.3	20.0
	6 Ply	576.0	2.1	20.4

Table 2: Characteristics of the spun silk and void spun silk yarns produced in ring doubling process

Characteristics	Spun silk (40s count)	Void spun silk produced in ring doubling machine with					
		2 ply Japan PVA	4 ply Japan PVA	6 ply Japan PVA	2 ply Indian PVA	4 ply Indian PVA	6 ply Indian PVA
Denier	528.7	565.9	659.9	791.5	831.6	1006.2	1163.5
Tenacity (g/d)	15.7	15.2	18.4	18.6	15.2	15.1	13.6
Elongation (%)	7.8	8.4	10.9	12.6	12.2	14.4	17.1
Microscopic cross section (Microns)	360	280	465	375	156	390	457
Microscopic longitudinal width (Microns)	497	381	371	488	547	546	571
Wicking (cm)	0.0	2.2	2.8	3.2	2.6	2.5	2.7

Table 3: ANOVA of characteristics of the spun silk and void spun silk yarns produced in ring doubling process

Characteristics	Degree of freedom	Sum of square	Mean sum of square	F – Value	P - Value
Denier	6	1616934	269489	393.7	0.000**

Tenacity (g/d)	**6**	**203.8**	**33.97**	**17.8**	**0.000****
Elongation (%)	**6**	**639.5**	**106.6**	**130.5**	**0.000****
Microscopic cross section (Microns)	**6**	**347089**	**57848**	**28.0**	**0.000****
Microscopic longitudinal width (Microns)	**6**	**194159**	**32360**	**32.3**	**0.000****
Wicking (cm)	**6**	**33.1**	**5.52**	**81.0**	**0.000****
**** - Significant at 1% level.**					

Table 4. Spun silk fabric characteristics produced in Ring doubling process using Japan and Indian PVA yarns in raw stage

Sl No.	Characteristics	Control 2/40S Spun silk (Doubling)	Void spun silk 2 ply Japan PVA (Doubling)	Void spun silk 4 ply Japan PVA (Doubling)	Void spun silk 6 ply Japan PVA (Doubling)	Void spun silk 2 ply Indian PVA (Doubling)	Void spun silk 4 ply Indian PVA (Doubling)	Void spun silk 6 ply Indian PVA (Doubling)
1	**Fabric mass (g/m^2)**	170.4	170.0	176.2	195.2	202.4	221.1	235.2
		(0.058)	(0.000)	(1.000)	(1.000)	(1.000)	(0.058)	(1.000)
2	**Fabric Thickness (mm)**	0.294	0.350	0.417	0.457	0.452	0.500	0.512
		(0.006)	(0.000)	(0.009)	(0.004)	(0.003)	(0.006)	(0.007)
3	**Threads in cloth**							
	Ends / inch	124	120	120	120	120	120	120
		(0.894)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	Picks / inch	56	60	50	46	54	48	44
		(0.894)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
4	**Yarn count (denier)**							
	Warp	34.9	36.6	34.5	36.0	35.3	36.2	36.5
		(2.256)	(0.644)	(0.200)	(0.785)	(0.496)	(1.172)	(0.522)
	Weft	558.0	638.6	688.2	833.4	784.1	967.7	1180.8
		(12.98)	(9.688)	(15.691)	(37.601)	(21.809)	(17.891)	(21.487)
5	**Crimp (%)**							
	Warp	22.20	22.64	24.08	27.28	25.84	27.92	27.96
		(0.053)	(0.084)	(0.042)	(0.155)	(0.052)	(0.092)	(0.057)
	Weft	2.00	2.28	2.40	2.52	2.32	2.52	2.88
		(0.000)	(0.048)	(0.047)	(0.048)	(0.042)	(0.048)	(0.042)
6	**Twist (TPM)**							
	Warp	756	755	758	749	759	766	760
		(2.807)	(3.268)	(2.677)	(3.466)	(2.616)	(3.273)	(3.018)
	Weft	491	498	529	557	602	614	661
		(6.484)	(9.146)	(9.370)	(14.292)	(4.803)	(4.341)	(12.14)
7	**Cover factor**	21.53	20.52	20.95	20.47	20.74	20.40	20.23
		(0.574)	(0.160)	(0.050)	(0.202)	(0.133)	(0.294)	(0.133)
8	**Tensile strength**							
	Breaking load (Kg)							
	Warp	29.9	30.1	32.2	31.2	29.5	31.5	26.2
		(0.936)	(1.020)	(0.178)	(0.720)	(1.938)	(0.023)	(0.012)
	Weft	133.5	131.8	109.0	143.9	141.5	148.1	120.5
		(2.117)	(4.419)	(6.864)	(5.590)	(1.966)	(2.804)	(2.600)
	Elongation (%)							
	Warp	37.0	35.5	34.7	38.0	35.0	37.6	29.2
		(1.426)	(1.211)	(0.377)	(1.097)	(2.212)	(0.620)	(0.270)
	Weft	11.2	14.1	13.5	27.9	15.3	25.0	18.9
		(0.346)	(0.065)	(2.412)	(0.316)	(0.581)	(1.454)	(0.315)
9	**Crease recovery angle**							
	Warp	76.4	79.1	76.9	78.6	79.5	77.9	77.9
		(1.647)	(0.876)	(1.287)	(1.506)	(2.321)	(1.853)	(1.287)
	Weft	76.9	79.2	80.0	80.9	78.9	82.4	79.9
		(1.287)	(1.687)	(1.247)	(1.595)	(1.969)	(1.350)	(1.370)
	Total	153	158	157	160	158	160	158
		(2.669)	(1.889)	(1.912)	(2.759)	(3.893)	(2.163)	(1.476)
10	**Flexural rigidity (mg - cm)**	0.352	0.347	0.380	0.488	0.597	0.613	0.697
		(0.025)	(0.012)	(0.026)	(0.029)	(0.020)	(0.028)	(0.050)
11	**Abrasion resistance (Cycles)**	4000	2667	3633	3400	3900	4067	3600
		(500.0)	(288.7)	(1171.9)	(360.6)	(754.9)	(550.8)	(600)
12	**Air permeability (m3/m2/m)**	6.58	8.36	26.61	24.24	6.59	11.36	15.25
		(0.981)	(0.894)	(2.434)	(1.273)	(1.420)	(2.484)	(1.062)
13	**Drape coefficient (%)**	77.78	70.66	66.95	65.66	69.24	71.80	78.08
		(0.793)	(2.362)	(4.823)	(2.742)	(3.353)	(4.889)	(1.255)
14	**Bursting strength (Kg/cm^2)**	23.4	22.3	20.7	23.2	24.6	25.5	25.8
		(1.002)	(1.026)	(0.945)	(0.200)	(0.058)	(0.306)	(0.153)

(Values in the parenthesis are standard deviation values)

Table 5. Spun silk fabric characteristics produced in Ring doubling process using Japan and Indian PVA yarns in dyed stage

Sl No.	Characteristics	Control 2/40S Spun silk (Doubling)	Void spun silk 2 ply Japan PVA (Doubling)	Void spun silk 4 ply Japan PVA (Doubling)	Void spun silk 6 ply Japan PVA (Doubling)	Void spun silk 2 ply Indian PVA (Doubling)	Void spun silk 4 ply Indian PVA (Doubling)	Void spun silk 6 ply Indian PVA (Doubling)
1	**Fabric mass (g/m^2)**	181.4	177.1	159.4	168.2	164.2	151.2	155.0
		(0.000)	(0.058)	(0.058)	(0.058)	(0.000)	(1.000)	(0.000)
2	**Fabric Thickness (mm)**	0.422	0.457	0.461	0.481	0.463	0.507	0.482
		(0.009)	(0.009)	(0.009)	(0.007)	(0.0095)	(0.0095)	(0.009)
3	**Threads in cloth**							
	Ends / inch	128	124	124	120	124	124	122
		(2.191)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	Picks / inch	64	60	52	50	54	48	46
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
4	**Yarn count (denier)**							
	Warp	38.9	37.1	37.1	38.6	37.2	36.4	38.6
		(1.755)	(1.194)	(0.720)	(1.121)	(1.692)	(1.025)	(0.736)
	Weft	534.1	574.3	575.8	617.8	582.8	565.5	645.5
		(9.528)	(16.089)	(32.686)	(15.137)	(23.920)	(13.853)	(61.581)
5	**Crimp (%)**							
	Warp	19.56	24.40	24.52	24.36	28.72	24.48	22.40
		(0.338)	(0.067)	(0.157)	(0.099)	(0.155)	(0.079)	(0.141)
	Weft	2.04	3.80	4.44	7.20	4.92	7.56	6.28
		(0.074)	(0.085)	(0.120)	(0.094)	(0.200)	(0.110)	(0.067)
6	**Twist (TPM)**							
	Warp	759	763	773	748	755	778	740
		(7.729)	(6.701)	(9.390)	(5.850)	(11.12)	(6.328)	(3.107)
	Weft	349	391	390	414	404	450	405
		(11.19)	(15.28)	(14.15)	(2.211)	(8.863)	(9.163)	(7.200)
7	**Cover factor**	21.2	21.1	21.0	19.9	20.9	21.1	20.2
		(0.593)	(0.298)	(0.182)	(0.260)	(0.402)	(0.266)	(0.180)
8	**Tensile strength**							
	Breaking load (Kg)							
	Warp	29.3	29.3	30.2	31.6	27.9	29.8	27.8
		(1.086)	(0.801)	(0.971)	(1.040)	(1.894)	(1.568)	(0.211)
	Weft	151.3	123.8	108.5	102.5	100.6	85.1	60.5
		(4.466)	(5.587)	(4.474)	(0.781)	(7.907)	(8.113)	(1.300)
	Elongation (%)							
	Warp	32.4	30.8	30.2	31.1	29.0	28.0	29.1
		(1.254)	(0.962)	(0.820)	(0.646)	(1.581)	(1.715)	(0.400)
	Weft	14.3	16.2	18.5	18.5	16.7	18.6	17.3
		(0.603)	(0.616)	(0.956)	(0.482)	(0.642)	(0.637)	(0.200)
9	**Crease recovery angle**							
	Warp	92.4	112.3	113.2	116.8	116.8	112.1	113.6
		(29.50)	(4.084)	(4.050)	(8.337)	(5.673)	(4.999)	(2.011)
	Weft	98.85	101.8	109.1	116	119.7	116.2	115.9
		(2.550)	(6.957)	(4.254)	(4.110)	(1.829)	(3.327)	(1.912)
	Total	191.9	214.1	222.3	232.8	236.5	228.3	229.5
		(28.86)	(9.422)	(4.990)	(8.753)	(4.170)	(7.212)	(3.206)
10	**Flexural rigidity (mg - cm)**	0.072	0.048	0.042	0.035	0.039	0.027	0.033
		(0.007)	(0.004)	(0.016)	(0.004)	(0.004)	(0.003)	(0.003)
11	**Abrasion resistance (Cycles)**	3933	2633	3067	2787	3600	3350	3934
		(404.1)	(503.3)	(503.3)	(646.9)	(529.2)	(259.8)	(191.1)
12	**Air permeability (m3/m2/m)**	13.25	17.12	37.70	33.77	28.70	25.64	76.86
		(1.062)	(1.370)	(3.079)	(5.721)	(2.559)	(1.185)	(9.272)
13	**Drape coefficient (%)**	25.36	27.65	27.56	23.24	25.65	25.06	23.75
		(1.916)	(0.413)	(0.322)	(0.198)	(1.906)	(1.420)	(0.864)
14	**Bursting strength (Kg/cm^2)**	22.9	22.65	17.95	19.6	19.1	18.5	18.9
		(0.150)	(0.850)	(0.050)	(0.300)	(0.950)	(0.700)	(0.000)

(Values in the parenthesis are standard deviation values)

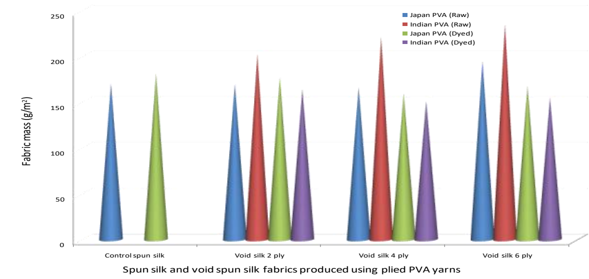

Figure 15 a: Comparision of fabric mass of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

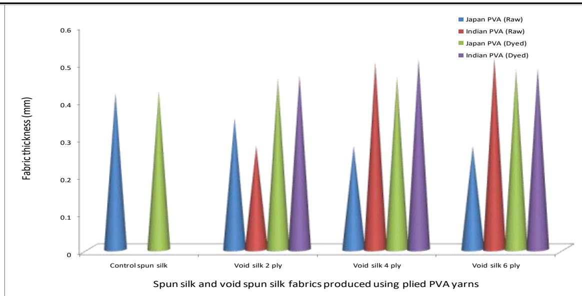

Figure 15 b: Comparision of fabric thickness of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

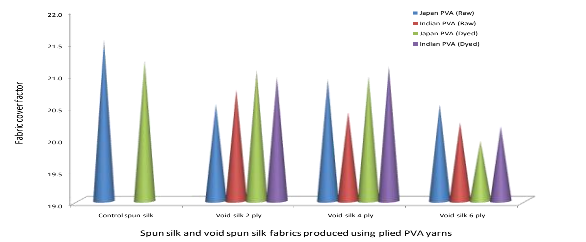

Figure 15 c: Comparision of fabric cover factor of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

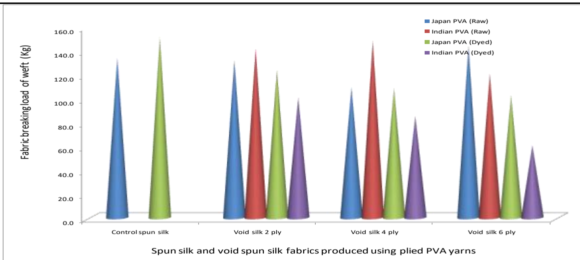

Figure 15 d: Comparision of fabric breaking load for weft of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

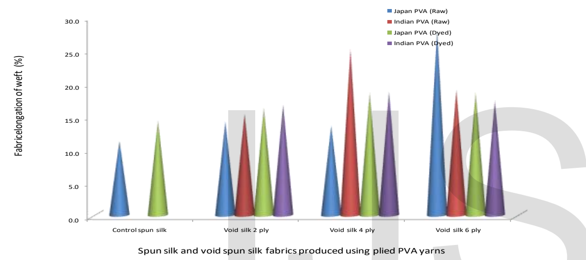

Figure 15 e: Comparision of fabric elongation for weft of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

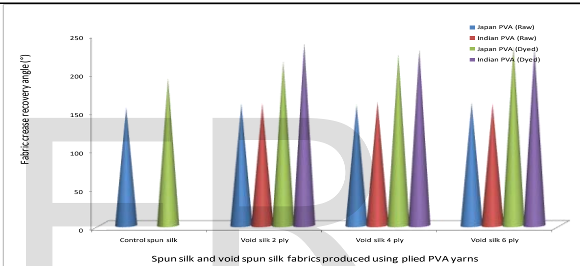

Figure 15 f: Comparision of fabric crease recovery angle of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

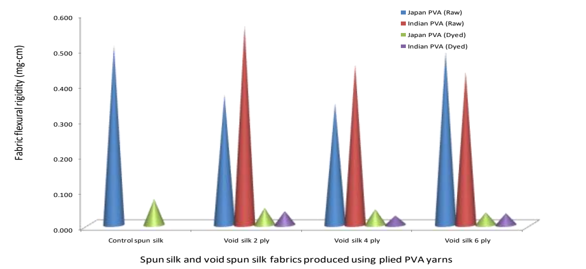

Figure 15 g: Comparision of fabric flexural rigidity of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

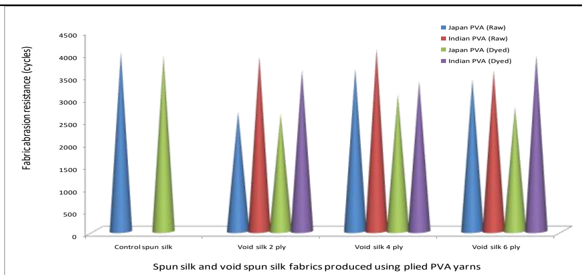

Figure 15 h: Comparision of fabric abrasion resistance of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

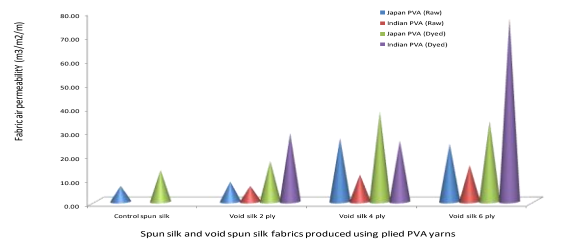

Figure 15 i: Comparision of fabric air permeability of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

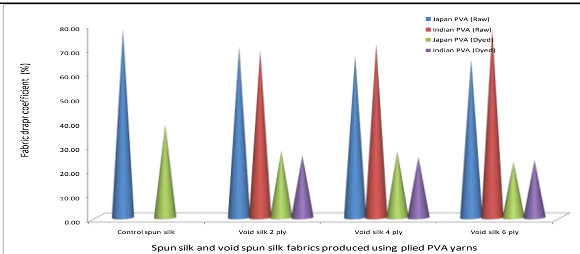

Figure 15 j: Comparision of fabric drape coefficient of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

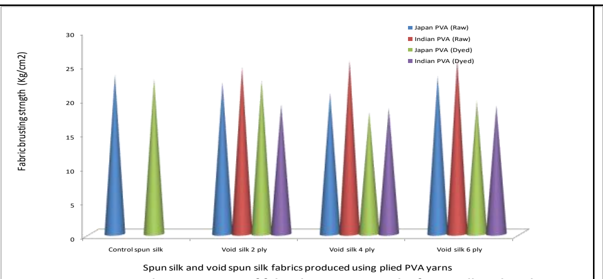

Figure 15 k: Comparision of fabric brusting strength of spun silk and void spun silk fabrics produced in doubling process (Raw / Dyed stage)

Fig. 2. Spun silk and void spun silk fabric charactetristcis produced in Ring doubling process

Table 6: ANOVA results of dyed spun silk and void spun silk fabric characteristics produced in ring doubling process

Fabric characteristics	Degree of freedom	Mean sum of square	F - Value	Significance
Fabric Thickness (mm)	7	0.003	104.5	0.000**
Cover Factor	7	0.684	26.95	0.000**
Crimp Weft (%)	7	14.47	410.8	0.000**
Twist Weft (TPM)	7	43566	798.7	0.000**
Breaking load – Warp	7	4.461	3.22	0.025*
Breaking load – Weft	7	1572.3	56.7	0.000**
Elongation – Warp	7	7.573	5.63	0.002**
Elongation – Weft	7	9.628	24.76	0.000**
Crease Recovery angle - Total	7	887.5	19.58	0.000**
Flexural rigidity	7	0.000	14.47	0.000**
Abrasion resistance	7	844751	4.131	0.009**
Air permeability	7	1512.5	248.7	0.000**
Drape coefficient	7	20.05	1.417	0.265 NS
Bursting strength	7	13.42	47.65	0.000**
** - Significant at 1% level, * - Significant at 5% level, NS – Not significant				

Table 7: Z score analysis of dyed spun silk and void spun silk fabric characteristics produced in ring doubling process

Particulars	Fabric thickness	Cover factor	Crimp Warp	Crimp Weft	Twist Warp	Twist Warp	Crease recovery	Flexural rigidity	Abrasion resistance	Air permeability	Drape coefficiant	Bursting strength	Breaking load Warp	Breaking load Weft	Elongation Warp	Elongation Weft	Z SCORE	RANK
Control	-1.81	0.88	-1.68	-1.74	-0.84	-1.00	-1.97	-0.13	0.96	-0.52	1.02	1.50	-0.09	1.14	1.34	-1.79	-4.73	
VS 2 ply Japan	-0.77	-0.29	0.12	-0.82	-0.84	-0.90	-0.53	0.71	0.48	-0.56	0.48	1.40	-0.04	1.03	0.41	-0.60	-0.72	2
VS 4 ply Japan	-0.27	0.65	0.15	-0.50	-0.83	-0.81	-0.02	1.56	-0.42	-0.69	0.45	-1.02	0.50	0.34	0.08	0.84	0.03	1
VS 6 ply Japan	0.52	-1.64	0.12	0.96	-0.86	-0.71	0.73	-0.26	-0.86	-0.62	-0.84	-0.17	1.36	0.07	0.60	0.85	-0.76	
VS 2 ply Indian	-0.16	0.32	1.77	0.46	1.11	0.98	0.46	0.23	0.43	0.15	-0.12	-0.45	-0.93	-0.02	-0.63	-0.30	3.31	1
VS 4 ply Indian	1.54	0.70	0.15	0.48	1.20	1.38	0.38	-1.54	0.03	0.02	-0.30	-0.73	0.24	-0.72	-1.22	0.92	2.54	2
VS 6 ply Indian	0.55	-1.26	-0.63	1.15	1.06	0.98	0.95	-0.57	0.96	2.25	-0.69	-0.53	-1.02	-1.84	-0.57	0.07	0.88	

Table 8: Subjective analysis of dyed spun silk and void spun silk fabric characteristics produced in ring doubling process

Particulars	Apperance	Luster	Surface feel	Drape	Compression	Total	Rank
Control 2/40s spun silk	10.2	10.2	11.4	12.6	12.8	57.2	
Void spun silk 2 ply Japan	13.6	12.6	14.6	13.6	12.8	67.2	
Void spun silk 4 ply Japan	16.4	14.8	12.8	14.8	15.2	74	1
Void spun silk 6 ply Japan	13.6	15.4	13.6	15.8	14	72.4	2
Void spun silk 2 Ply Indian	16	12.6	15	14.4	14.2	72.2	1
Void spun silk 4 Ply Indian	14.4	15.2	15	13.6	12.8	71	2
Void spun silk 6 Ply Indian	13.8	12.4	12	15.6	14.8	68.6	

Table 9. Thermal comfort characteristics of spun silk, void spun silk fabrics in Ring doubling process.

Sl No.	Fabric samples	Q – max (W / cm^2)	Clothing insulation value (CLO)	Thermal insulation value (TIV)
1	Spun silk 2 ply	0.10 (0.002)*	0.49 (0.001)	15.31 (0.62)
2	Void spun silk 2 ply Japan	0.11 (0.002)	0.54 (0.001)	22.94 (0.49)
3	Void spun silk 4 ply Japan	0.09 (0.001)	0.55 (0.001)	34.60 (0.54)
4	Void spun silk 6 ply Japan	0.10 (0.002)	0.66 (0.001)	36.13 (0.46)
5	Void spun silk 2 ply Japan	0.09 (0.001)	0.48 (0.001)	46.38 (0.30)
6	Void spun silk 4 ply Japan	0.09 (0.002)	0.45 (0.001)	26.54 (0.46)
7	Void spun silk 6 ply Japan	0.10 (0.001)	0.45 (0.001)	21.53 (0.39)

* Values in the parenthesis are standard deviation of mean values.

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Table 10. Rotation component matrix of void spun silk fabrics produced in Ring doubling process

Characteristics	Void spun silk produced with 4 ply Japan PVA yarn		Void spun silk produced with 2 ply Indian PVA yarn	
	Component 1	Component 2	Component 1	Component 2
Fabric Thickness	0.677	-0.736		-0.845
Cover Factor		0.973		0.982
Crimp Weft	0.736	-0.676	0.845	
Twist Warp	0.996		0.729	0.684
Twist Weft	0.616	-0.788	0.971	
Breaking load – Warp	-0.643	0.766	0.958	
Breaking load – Weft	-0.815		-0.914	
Elongation – Warp		0.937	0.908	
Elongation – Weft		0.967		-0.849
Crease Recovery	0.862		-0.973	
Flexural rigidity		0.821	0.956	
Abrasion resistance		-0.995	0.931	
Air permeability	0.996		0.970	
Drape coefficient	-0.906			0.885
Bursting strength	0.906			-0.885

Extraction method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

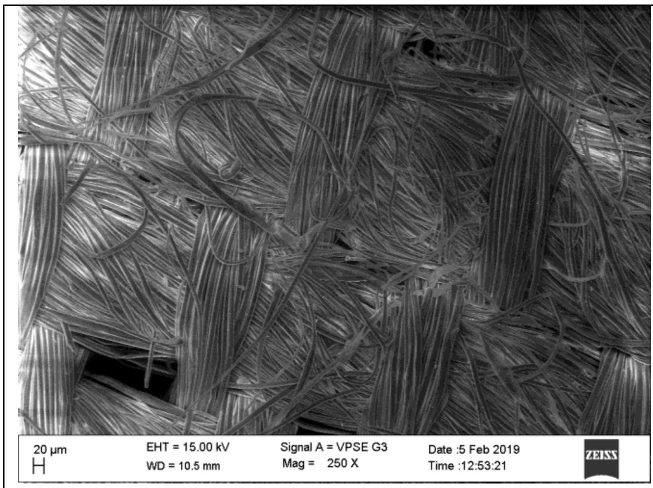

Fig 3a: Raw spun silk fabric (2/40s count) Ring Doubling

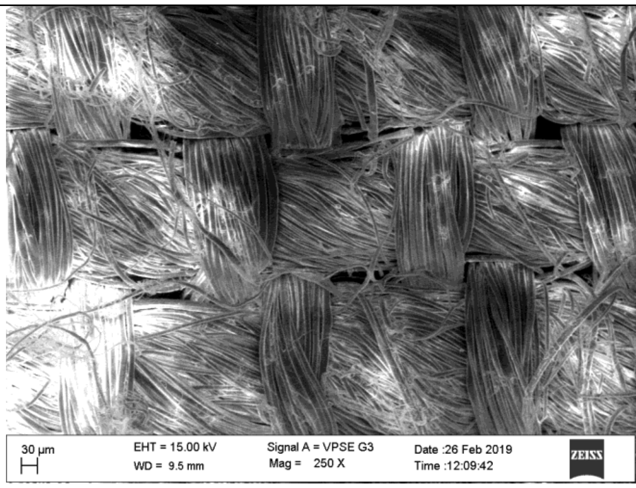

Fig 3b: Dyed spun silk fabric (2/40s count) Ring Doubling

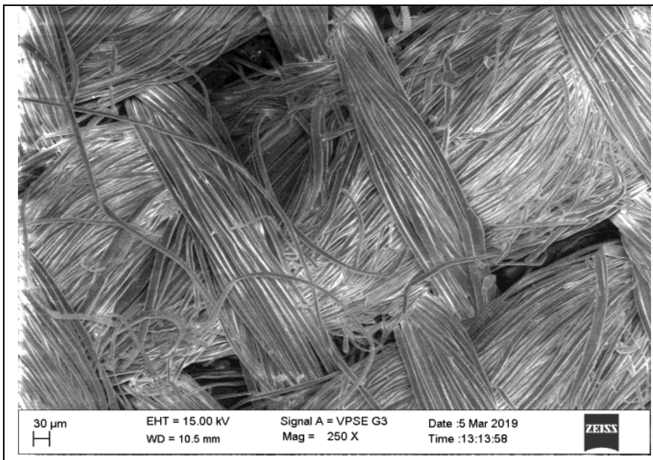

Fig 3c: Raw void spun silk fabric (Japan PVA 4 ply) Ring Doubling

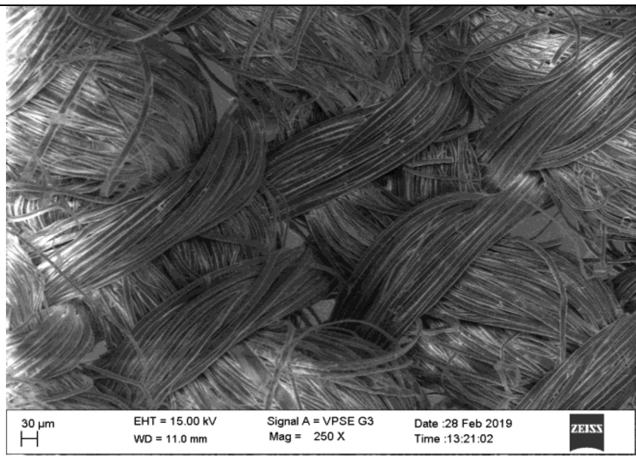

Fig 3d: Dyed void spun silk fabric (Japan PVA 4 ply) Ring Doubling

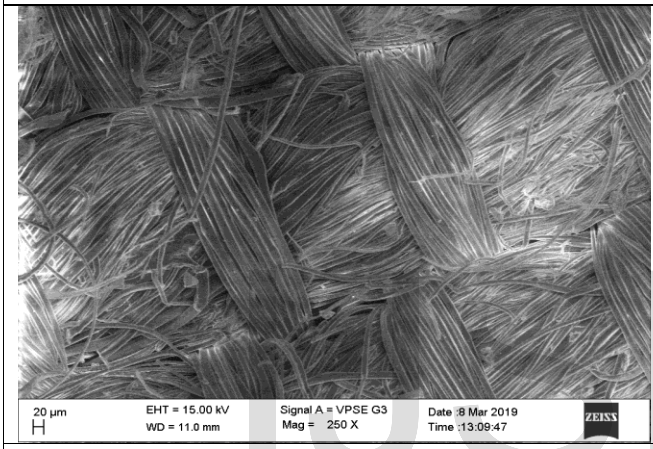

Fig 3e: Raw void spun silk fabric (Indian PVA 2 ply) Ring Doubling

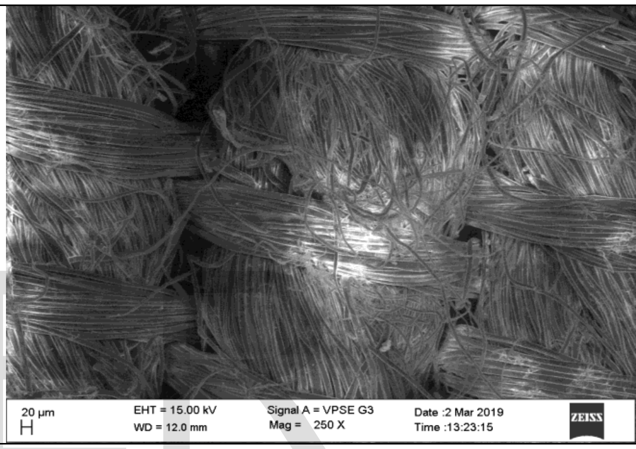

Fig 3f: Dyed void spun silk fabric (Indian PVA 2 ply) Ring Doubling

Fig. 3. SEM studies of fabrics made of ring doubled spun yarns

Fig. 4. Children dress are developed using the void spun silk fabrics.