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Studies on Hand Values of Natural Fiber-Made Union Fabrics Using Taguchi Methodology

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Abstract : Union fabrics characterize differently due to its manufacturing principle. A union fabric made of natural fibres is always the chief concern of the researchers. This study deals with the effect of three important weaving parameters like type of fibre used as weft on fixed cotton warp, fabric structure and reed count on fabric stiffness considering bending length, flexural rigidity and bending modulus. Taguchi methodology using L_9 Orthogonal Array is used in this study. Effect of factors and their levels have been studied with S/N ratio duly justified by ANOVA calculation. The best combinations of factor level which yield maximum performance have been detected and validated efficiently.

Key words - ANOVA, Fabric Stiffness, Orthogonal Array, Taguchi Methodology, Union fabric.

1. Introduction

The concern of the consumers for variety in textiles is the motivation for the textile designer to develop and design new textiles from time to time. Apparel sector of textile production is found to be the main domain of using textiles. The open width fabrics are stitched into garments. Present trends of the consumers are to purchase the textiles in the form of ready-made garments directly rather than purchasing the fabrics and converting them into garments at their own arrangements. The choice of the consumers for garment lies on so many factors like styles, colour combinations, longevity, fitness to body, comfort in wearing and draping etc. Draping or fabric fall of the garment is one of the important parameters that a consumer looks into; particularly for ladies' garments in most of the cases. Draping of the fabrics depends upon the nature of the fibres used in the yarn to make fabric and the structure of the fabrics to a large extent.

On the other hand, today's world is increasingly environment conscious and lifestyles in using natural fibre-made apparels are advancing. The inclination towards textile alternatives and the emergence of innovative fabrics is vivid. Today's growing concerns are; health, sustainability of waste management and environmental awareness which is reflecting on renewed interest in plant fibers like cotton &flax, animal fibres like silk & wool and thus having potentiality to produce a union fabric. Fabrics made of natural fibres are reported to offer comfort to the wearer, it is skin friendly and bio-degradable.

Therefore, an in-depth, scientific and systematic study on the manipulation in the arrangement of different fibres in warp & weft direction along with type of weave to explore better hand properties of the union fabrics made of natural fibres are always the topic of interest for the textile designers.

2. Review of literature

2.1. Union fabric and blended fabric

Union fabrics are the fabrics where the fibre content of warp yarn is different from that of weft yarn. Thus, a silk × cotton union fabric may have silk in warp and cotton in the weft direction. In a word, it is a traditional name for fabric made from two or more different yarns. Whereas blended fabrics are made of blended yarn which contains fibres of different composition in fixed proportion. For example, blended fabric may be made of polyester/cotton in 80:20 ratios as both warp and weft yarn.

Union fabric is reported to be durable, crease resistant, absorbent, lustrous and resilient, etc. depending upon of the characteristics of fibre used in warp and weft direction. Moreover, union fabric weaving is easy to adopt, less time consuming, easy to weave and altogether different fabrics can be prepared with the use of limited resources and technology (Arora and Sakshi 2009). Variety of fabrics thus produced can meet the demand of fashion-conscious consumers (Desai et al. 2013). In blended fabrics properties are manipulated depending upon the nature, proportion of fibres used in the constituent yarn. Economy in raw material is another chief concern for both the cases.

Existence of union fabrics is there in India since long time. Some legendary sarees like Maheshwari, Himroo, Mashru, etc. (www.craftsvilla.com) have been made mostly using silk and cotton fibre.

2.2. Properties of union fabrics

- From the definition of union fabric, it is clear that the fabric is made of two types of fibres used in two directions and differs from blended fabric where two or more types of fibres are used in either or both direction of the fabrics. A union fabric widely differs from pure fabric where only one types of fibres are used in both directions.
- Therefore, principle of manufacturing of the fabric has certainly some influence on its characteristics which can produce some difference from other two types of fabrics.
- There may be several combinations of fibre types to manufacture union fabrics. The variety in possible fibre combination may result different characteristics in the fabrics produced. Each having its own specialty. These have attracted the attention of many researchers to work with.

2.3. Available research work on union fabrics

The specialty in characteristics of union fabrics has drawn the attention of the researchers quite a few years back. Manipulation in the properties of union fabrics has become the chief concern of researchers' working in this aspect. Quite a few research works are reported to have been studied with a view to improve fabric properties using chemical treatments (Azad and Jafrin 2009, Prathibadevi et al. 2014, Samanta et al. 2007, Das et.al 2016, Manyam 2015, Ammayappan and Moses 2011, Joshi H. D et al. 2010, Desai 2012, Medar and Mahale 2018, Ammayappan 2011, Thenmozhi2010) which has explored new areas of usage of union fabrics. However, research works dealing with physical characteristics of union fabrics are also recorded in literature.

Gabur Taga and Kalita(2013) have found that, eri-acrylic and eri-viscose rayon union fabrics were better in quality in respect of mechanical & functional properties, aesthetic appearance, lustre and low weight properties than the pure eri-eri fabric. offering possibilities towards product diversification with varying weave. Researchers, Kandhavadivu and Ramachandran (2011) have tried to explore bamboo × lyocell union fabrics for medical application. They found that, presence of lyocell in higher proportion increases the strength, air permeability, water vapor permeability, wick ability, dry ability (due to its higher moisture spreading tendency) and smoothness of the union fabric. Thermal conductivity of the fabric, water absorbency increases as the presence of bamboo fibre increases, bamboo × cotton / lyocell blended union fabrics also gave same results.In their study, Efezeet etal.(2014) felt the necessity of softening process for cotton × sidarhombifolia/modal union fabric to improve fabric handle, drape coefficient, abrasion resistance and the bending length. However, OE cotton yarn yields better results that ring spun yarn.

(Kandhavadivu etal. 2014)had studied the thermoregulatory characteristics of bamboo/lyocell union fabrics where they found that, the thermal insulation value of 1/3 twill fabric is higher than that of plain and 2/2 twill woven fabric due to more float, fabric density and packing factor and itincreases with the increase of lyocell fibre. Kulloli and Sannapapamma(2014) had claimed lac dyed eri silk × natural coloured cotton (NCC) union fabricis best suitable for designer's made-ups, shirts and dress materials over NCC × NCC. Sannapapammaand Naik(2015) had an attempt to make union fabric using mulberry silk fibres from pierced cocoon as warp with polyester, cotton, art silk, filature silk as weft in order to exploit the natural unevenness of the hand spun silk yarn to enhance the aesthetic appeal of the union fabrics produced with other yarns. This was claimed to have a good market potentiality in manufacturing made-ups out of these union fabrics so developed to boost fashion world.According to Aroraet al.(2015) the abrasion resistance of silk × polyester was quite high along with tensile strength & tearing strength whereas silk × wool union fabric showed higher 'clo' value i.e., it has ability to hold heat in the fabric for longer duration. An attempt was made by Mariyam Adnan and Moses (2013) to produce UV-resist fabrics using Titanium dioxide in lyocell and silk union fabrics which showed a positive result indicating the use of UV resist silk and lyocell fabric for protecting the body against solar radiation. However, this fabric showed a marginal decrease in tensile strength, absorbency, crease recovery and air permeability. Union fabric produced from bicomponent yarns showed better Drape with lower stiffness with tremendous improvement in dye uptake as reported by Desai(2008). The tensile and tearing strength was found to be good enough to be made into sarees, dupatta, drapes, curtains, upholstery, and dress materials.

Konwar and Kaur(2015) studied the physical properties of eri ($2/60^{S}$)× cotton (2/40s) & eri × polyester (2/40s) union fabrics, using three different weaves namely; plain, twill and satin. The strength of the eri × polyester was betterthan the pure eri × eri fabrics for all the weaves in addition to improvement of some other properties as compared to pure eri × erifabrics. They concluded that eri× cotton and eri× polyester union fabrics are more crease-resistant, durable, lighter in weight and having greater drapability with unique appearance and extra lustre.

The review of literature made so far provides documentation of some mechanical and chemical aspects in regard to the properties of union fabrics. All are related mostly to powerloom fabrics and no such significant work for handloom fabrics are taken for investigation. It has explored some possibilities to carry out in-depth, scientific research work and systematic study for handloom fabrics with a view towards applicability in apparels. Extensive exploration has also revealed a possibility of producing union fabric on Handlooms as an option for conducting research.

2.4. Fabric hand

Pierce F T (1930) in his paper "The Handle of Cloth as a Measurable Quantity" has discussed in detail to measure the cloth handle quantitatively. Pierce has proposed following eight parameters for evaluating the handle of the cloth.

A. Bending length
B. Flexural Rigidity
C. Bending modulus
D. Thickness
E. Hardness or Resistance to compression
F. Compression Modulus
G. Density
H. Extensibility

In fact, 'Handle' of the cloth is judged using the sensation, such as stiffness or limpness, hardness or softness and smoothness or roughness. Here, we described the most important four parameters viz; Bending length, Flexural Rigidity, Bending modulus and Thickness to evaluate the hand of union fabrics.

2.4.1. Bending length(c)

Bending length measures the length of the fabric that will bend under its own weight to a definite extent (Booth 1979). The way in which a fabric hangs depends largely on its resistance to bending and on the weight. It is a measure of stiffness that determines draping quality. The expression is given as follows:

$C = lf_1(\theta)$

Where, $f_1(\theta) = \left(\frac{\cos\frac{\theta}{2}}{8\tan\theta}\right)^{\frac{1}{3}}$

l = length of the fabric that hangs after bending

θ = angle of deflection of the index lines in the stiffness tester

2.4.2. Flexural rigidity

Flexural rigidity is a measure of stiffness as appreciated by the fingers or it can be said that, it is a measure of stiffness associated with the handle of the fabric(Booth 1979). The flexural rigidity measures the actual forces developed during bending of the fabric; thus, two fabrics may have the same bending length but the heavier fabric will exert more resistance to bending and so will feel stiffer. The following expression gives the value.

G = $wc^3 \times 10^3\ mg.cm$

Where, w = fabric weight in gram per sq. cm.

C = bending length of the fabric in cm.

2.4.3. Bending Modulus (q)

Bending modulus can be calculated when the thickness of the fabric is known. It is independent of the dimensions of the strip tested. It is regarded as the 'Intrinsic stiffness' (Booth 1979). Peirce pointed out that, this value may be used to compare the stiffness of the material in fabric of different thickness. The expression of bending modulus is given below as;

Q = $\frac{12G\times10^{-6}}{g^3}$

Where, G = flexural rigidity in mg.cm; and

g = fabric thickness in cm.

3. Object of the present work

Based on literature review so far made it can be said that, union fabrics of various combinations are very much possible to be manufactured in both handloom and powerloom which are capable of giving favourable characteristics to be used in apparels. A few research works with union fabrics have been carried out by some researchers in a very crude way. Not much work in this field has been undertaken by the researchers in a very scientific and systematic way. Therefore, the review has opened up enough scope to carry out research in this area in most systematically in detail. Since the inherent behaviour of union fabric is different from pure and blended fabric due its principle of formation, an in-depth study is very much essential to exploit the behaviour of union fabrics (differently in two directions) for construction of apparel. Various combinations in formation of union fabrics to suite the handle of fabric can also be explored along with structural considerations. Economy in fabric formation can also be looked into.

Therefore, it has been decided to manufacture union fabrics on the basis of three factors i.e. types of fibres used in weft direction, reed count and weave with three levels of each following the Taguchi Design of Experiment methodology in order to see the effect of each factors on hand aspect of the fabrics. The hand is judged on the basis of bending length, flexural rigidity and bending modulus. This will help to find out the optimum combination of factors for which the best result of each performance characteristics; bending length, flexural rigidity and bending modulus can be achieved.

4. Experimental

4.1. Material used

The yarns used to manufacture the union fabrics are detailed in table 1.

Table 1. Particulars of yarn used

Warp		Weft	
Nature of fibre	Count (Ne)	Nature of fibre	Count (Ne)
Cotton	$2/80^S$	Flax	27.5
		Khadi	28.0
		Eri silk	28.0

4.2. Sample preparation

4.2.1. Preparation of union fabric samples

It is decided to study the effect of some important factor manipulated by three levels of each factor on some important fabric parameters like bending length, flexural rigidity and bending modulus. For this purpose, three factors and three levels for each factor within the industrially accepted range have been chosen and presented in table 2.

Table 2. Factors and levels selected

Factors	Level		
	1	2	3
Weft used (A)	Flax	Khadi	Eri
Reed count (St) (B)	56	60	64
Weave (C)	Plain	½ twill	2/2 twill

The experimental lay out as per Taguchi's design of experiment have been made and presented in table 3.

Table 3. Experimental Lay out (3^3, L_9 Design)

Sample No.	Weft (A)	Reed Count (St) (B)	Weave (C)
1	Flax	56	Plain
2	Flax	60	1/2twill
3	Flax	64	2/2twill
4	Khadi	56	1/2twill
5	Khadi	60	2/2twill
6	Khadi	64	Plain
7	Eri	56	2/2twill
8	Eri	60	Plain
9	Eri	64	1/2twill

In order to prepare the fabric samples in loom, necessary preparatory process like winding, warping, drawing (one end per eye) and denting (two ends per dent) was carried out prior to weaving. Reeds of 56^S, 60^S and 64^S stockport were used as per requirement. Necessary looming arrangement was made to weave each of plain, 1/2 & 2/2 twill fabrics. After necessary looming work, weaving was carried out to make all nine (9) fabric samples of sufficient quantity in each case according to the experimental lay out of the design of experiment (Table 3).

Thus sample no. 1 was prepared using 56^S stockport reed count, $2/80^S$ Ne warp and flax yarn of 27.5^S Ne as weft. In a similar way sample no. 2 to 9 were prepared following the combination of variables as laid down in table 3.

4.3. Test Methodology

4.3.1. Measurement of thickness of fabrics

Thickness of the fabric sample was measured following standard method of testing; ASTM D: 1777-96 (2015) with the help of Thickness tester, DIGITHICK using the following specification:

Pressure foot diameter 28.7 ± 0.02 mm, and

Applied pressure 4.14 ± 0.21 kPa

Fifty readings were taken at different places spreading over whole area of each cloth sample and the average value was taken.

4.3.2. Measurement of bending length of fabrics (warp and weft direction)

Bending length was measured with the help of Paramount make Stiffness Tester following standard method of testing; ASTM D: 1388-96 (reapproved 2002).Total 20 readings from 5 samples each for warp and weft have been taken to get the average value.

4.3.3 Measurement of fabric weight in gram per sq. m (GSM)

Mass per unit area (GSM) of fabric samples was measured following standard test method; ASTM D: 3776-96 (reapproved 2002) and with the help of a digital balance. The average weight from 20specimens have been calculated and converted in gram per sq. m.

The results obtained from 4.3.1 to 4.3.3 are presented in table 4.

5. Results and Discussion

The test results for bending length (cm), flexural rigidity (mg.cm) and bending modulus (Kg/cm^2) both warp & weft direction has been obtained and detailed in table no. 4.

Table 4. Test Results

Sample No.	Weft	Reed Count (St)	Weave	Thickness (mm)	Bending length (cm)		Weight (g/sq.cm)	Flexural rigidity (mg. cm)		Bending Modulus (kg/cm^2)	
					Warp way	Weft way		Warp way	Weft way	Warp way	Weft way
1	Flax	56	Plain	0.29	1.7	4.79	0.008163	40.107	897.170	0.197	4.414
2	Flax	60	1/2twill	0.31	1.53	3.93	0.008086	28.960	490.799	0.117	1.977
3	Flax	64	2/2twill	0.29	1.85	4.6	0.010282	65.100	1000.778	0.320	4.924
4	Khadi	56	1/2twill	0.30	2.03	1.5	0.008577	71.748	28.946	0.319	0.129
5	Khadi	60	2/2twill	0.36	2.25	1.48	0.011754	133.888	38.105	0.344	0.098
6	Khadi	64	Plain	0.27	2.35	1.7	0.009197	119.353	45.183	0.728	0.275
7	Eri	56	2/2twill	0.46	1.445	2.255	0.013123	39.596	150.482	0.049	0.186
8	Eri	60	Plain	0.36	1.55	2.55	0.011418	42.521	189.332	0.109	0.487
9	Eri	64	1/2twill	0.38	1.54	2.13	0.009455	34.532	91.369	0.076	0.200

Bending length (cm), flexural rigidity (mg.cm) and bending modulus (Kg/cm^2) both warp & weft directions of the fabric samples are considered as responses in this study. Taguchi used the signal-to-noise ratio (S/N) to measure the value of the quality characteristics of the choice (Taguchi G1986) S/N is characterized into three categories. Normal is the better; larger is the better and smaller is the better (Nassif G A 2017). In this case, the 'smaller the better' character is applied with the intention of having less bending length, less flexural rigidity and less bending modulus to obtain better handle of the fabric.

It is mentioned that, the character of S/N ratio applied in this work is 'smaller the better' type and the equation used is;

$$SNR_{Exp} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \ldots\ldots\ldots\ldots\ldots \quad (1)$$

With the help of software MINITAB version 16, the values of S/N ratio using that equation corresponding to each experimental run and each parameter are calculated and given in table 5. Taguchi's methodology is also explored to find the influence of each factor on each of the fabric parameter namely bending length (cm), flexural rigidity (mg.cm) and bending modulus (Kg/cm^2). Table 6 to 8 displays the average of each factor influencing at their different levels in relation to S/N ratio. The difference between the larger and lower values of S/N ratios is termed as delta or the gain in this ratio. Higher values of delta correspond to higher influence of that factor due to level change. In this table, optimum level corresponding to each factor is marked with an asterisk for each parameter (warp or weft direction). Optimum level can be depicted as that level where the average influence of any factor is maximum. Table 6 to 8 shows the average influence of each factor. Figure 1 to 3 depicts the plot of the main effect for S/N ratios corresponding to each parameter (response) respectively.

Table 5. S/N Ratio of responses (Lower the better type)

Sample No.	Weft (A)	Reed Count (St) (B)	Weave (C)	S/N Ration for Bending length (cm)		S/N Ration for Flexural rigidity (mg. cm)		S/N Ration for Bending Modulus (kg/cm^2)	
				Warp way	Weft way	Warp way	Weft way	Warp way	Weft way
1	Flax	56	Plain	-4.60898	-13.6067	-32.0644	-59.0575	14.1107	-12.8966
2	Flax	60	1/2twill	-3.69383	-11.8879	-29.2360	-53.8181	18.6363	-5.9201
3	Flax	64	2/2twill	-5.34343	-13.2552	-36.2716	-60.0068	9.8970	-13.8464
4	Khadi	56	1/2twill	-6.14992	-3.5218	-37.1162	-29.2318	9.9242	17.7882
5	Khadi	60	2/2twill	-7.04365	-3.4052	-42.5348	-31.6196	9.2688	20.1755
6	Khadi	64	Plain	-7.42136	-4.6090	-41.5367	-33.0995	2.7574	11.2133
7	Eri	56	2/2twill	-3.19736	-7.0629	-31.9530	-43.5497	26.1961	14.6097
8	Eri	60	Plain	-3.80663	-8.1308	-32.5721	-45.5445	19.2515	6.2494
9	Eri	64	1/2twill	-3.75041	-6.5676	-30.7644	-39.2160	22.3837	13.9794

Table 6(a). S/N Ratios at different levels and optimum condition for bending length (warp)

Control factors	Average S/N Ratios			Delta (gain)	Rank	Optimum
	Level 1	Level 2	Level 3			
Weft used (A)	-4.549	-6.872	-3.585*	3.287	1	A3
Reed count (St) (B)	-4.652*	-4.848	-5.505	0.853	2	B1
Weave (C)	-5.279	-4.531*	-5.195	0.748	3	C2

Table 6(b). S/N Ratios at different levels and optimum condition for bending length (weft)

Control factors	Average S/N Ratios			Delta (gain)	Rank	Optimum
	Level 1	Level 2	Level 3			
Weft used (A)	-12.917	-3.845*	-7.254	9.071	1	A2
Reed count (St) (B)	-8.064	-7.808*	-8.144	0.336	3	B2
Weave (C)	-8.782	-7.326*	-7.908	1.456	2	C2

Table 7(a). S/N Ratios at different levels and optimum condition for flexural rigidity (warp)

Control factors	Average S/N Ratios			Delta (gain)	Rank	Optimum
	Level 1	Level 2	Level 3			
Weft used (A)	-32.52	-40.40	-31.76*	8.63	1	A3
Reed count (St) (B)	-33.71*	-34.78	-36.19	2.48	3	B1
Weave (C)	-35.39	-32.37*	-36.92	4.55	2	C2

Table 7(b). S/N Ratios at different levels and optimum condition for flexural rigidity (weft)

Control factors	Average S/N Ratios			Delta (gain)	Rank	Optimum
	Level 1	Level 2	Level 3			
Weft used (A)	-57.63	-31.32*	-42.77	26.31	1	A2
Reed count (St) (B)	-43.95	-43.66*	-44.11	0.45	3	B2
Weave (C)	-45.90	-40.76*	-45.06	5.15	2	C2

Table 8(a). S/N Ratios at different levels and optimum condition for bending modulus (warp)

Control factors	Average S/N Ratios			Delta (gain)	Rank	Optimum
	Level 1	Level 2	Level 3			
Weft used (A)	14.215	7.317	22.610*	15.294	1	A3
Reed count (St) (B)	16.744*	15.719	11.679	5.064	2	B1
Weave (C)	12.040	16.981*	15.121	4.942	3	C2

Table 8(b). S/N Ratios at different levels and optimum condition for bending modulus (weft)

Control factors	Average S/N Ratios			Delta (gain)	Rank	Optimum
	Level 1	Level 2	Level 3			
Weft used (A)	-10.888	16.392*	11.613	27.280	1	A2
Reed count (St) (B)	6.500	6.835*	3.782	3.053	3	B2
Weave (C)	1.522	8.616*	6.980	7.094	2	C2

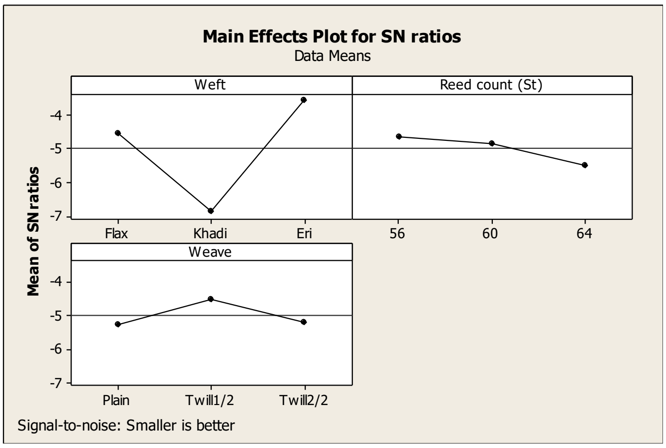

Figure 1(a). Main effect of factors on bending length (warp direction)

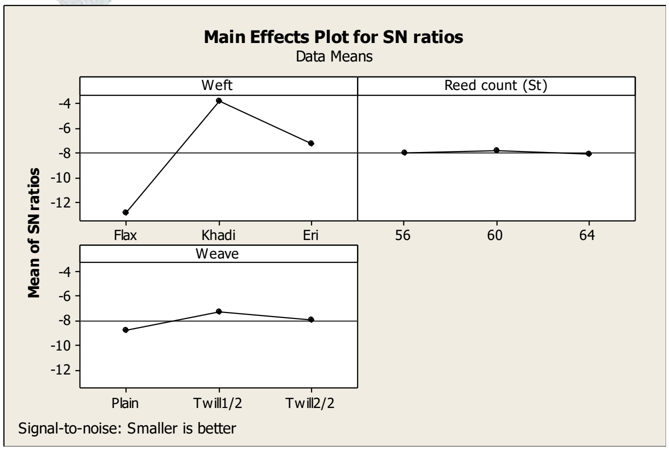

Figure 1(b). Main effect of factors on bending length (weft direction)

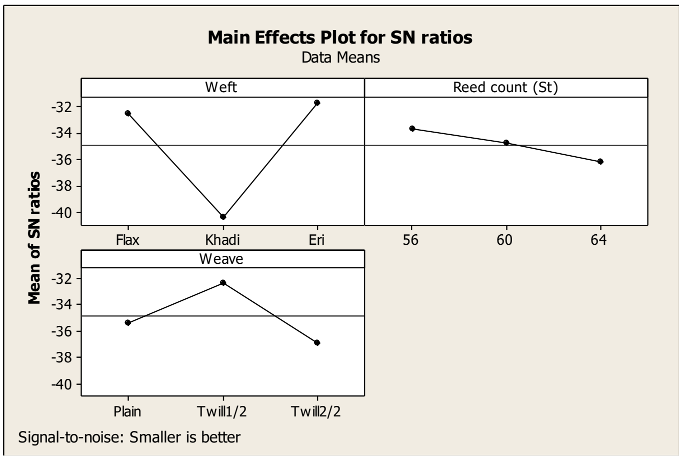

Figure 2(a). Main effect of factors on flexural rigidity (warp direction)

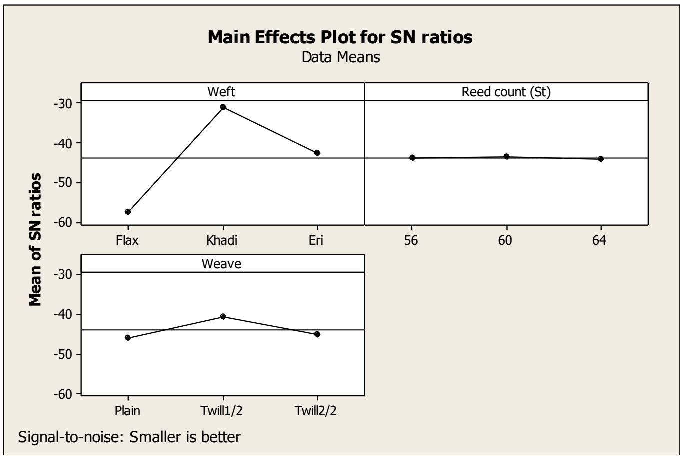

Fig. 2(b). Main effect of factors on flexural rigidity (weft direction)

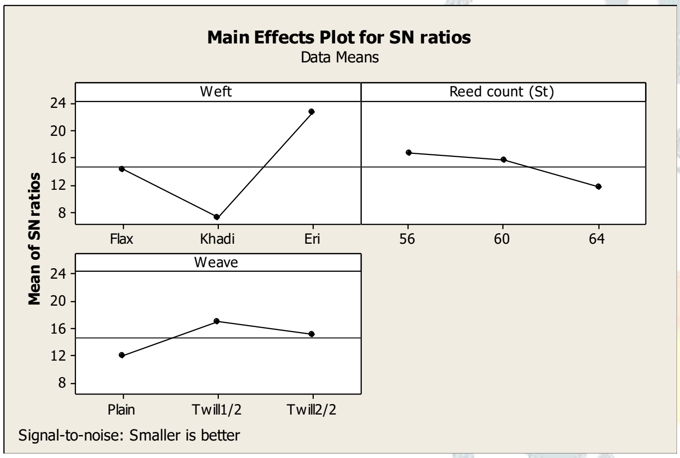

Fig. 3(a). Main effect of factors on bending modulus (warp direction)

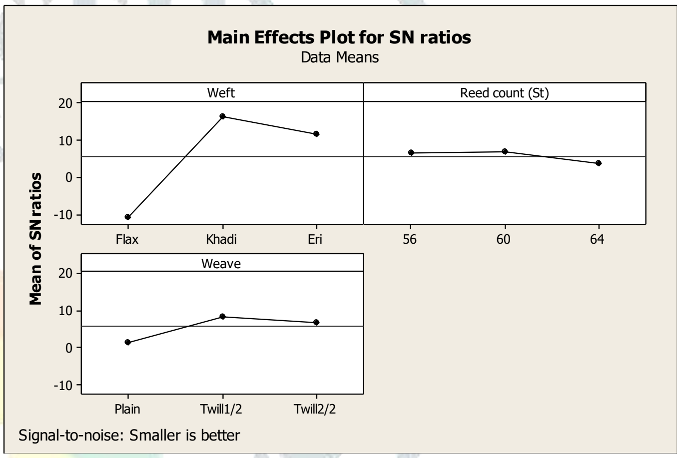

Fig. 3(b). Main effect of factors on bending modulus (weft direction)

It is observed from table 6(a) and 6(b) that, for bending length, the influence of type of weft yarn i.e., flax, khadi and eri is the most determining factor as evident from the corresponding delta value. This is also confirmed from the ANOVA results of corresponding responses in table 9(a) & 9(b). Its contribution is 87.59% for bending length in warp direction and 96.19% for weft direction. It is also found that using eri and khadi yarn as weft, the handle of the fabric increases as far as the bending length is concerned. This may be due to less rigidity of those two fibres in comparison to flax. Similar trend is followed for other two responses; flexural rigidity and bending modulus due to the fact that these parameters are derived from the corresponding values of bending length.

It is observed that, out of three factors taken under consideration, the second most governing factor is type of weave i.e., plain, 1/2 twill or 2/2 twill. Weave determines the structure of the fabric. Out of three levels of weave, it is observed that, 1/2 twill is found to give better hand value of the fabric as far as bending length, flexural rigidity, bending modulus is concerned. This may be due to a smaller number of binding points arising out of interlacement between warp & weft in twill weave as compared to plain weave. More interlacement between warp and weft makes the fabric stiffer which arises in plain weave.

It is also found that, the level in the reed count does not have much effect in the hand value of the fabric. This is also confirmed from the ANOVA results. However, further study is required to investigate the proper reason.

The optimal factor combination for bending length (warp) is found to be A3B1C2 i.e. eri as weft, 56^S reed count and 1/2 twill weave. Whereas, the same for bending length (weft) is found to be A2B2C2 i.e., Khadi as weft, 60^S reed count and 1/2 twill weave. Similar trend is followed for other two responses; flexural rigidity and bending modulus due to the fact that these parameters are derived from the corresponding values of bending length.

6. Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is calculated with the help of MINITAB 16 software for main factors against the S/N ratio value of each response i.e., bending length, flexural rigidity and bending modulus, based on 95% level of confidence (5% level of significance).

The result of ANOVA for bending length, flexural rigidity and bending modulus in both warp and weft ways for each case are presented in table 9 (a) & 9 (b), 10 (a)& 10 (b) and 11 (a) & 11 (b) respectively. As per F-ratio, the critical value for main factor, $F_{0.05, 2, 8}$ is 4.46. 'P' value, less than 0.05 for a particular parameter, indicates that it has significant effect on the response.

Table 9(a). ANOVA table for bending length (warp)(S/N ratio)

Source	DF	SS	MS	F	P	Contribution (%)
Weft	2	0.78762	0.39381	169.36	0.006	87.59
Reed count	2	0.05682	0.02841	12.22	0.076	6.32
Weave	2	0.05012	0.02506	10.78	0.085	5.57
Error	2	0.00465	0.00232			0.52
Total	8	0.89920				100.00

S = 0.0482183 R-Sq = 99.48% R-Sq(adj) = 97.93%

Table 9(b). ANOVA table for bending length (weft) (S/N ratio)

Source	DF	SS	MS	F	P	Contribution (%)
Weft	2	13.3892	6.6946	131.99	0.008	96.19
Reed count	2	0.0640	0.0320	0.63	0.613	0.46
Weave	2	0.3653	0.1827	3.60	0.217	2.62
Error	2	0.1014	0.0507			0.73
Total	8	13.9200				100.00

S = 0.225210 R-Sq = 99.27% R-Sq(adj) = 97.09%

Table 10(a). ANOVA table for Flexural rigidity (warp) (S/N ratio)

Source	DF	SS	MS	F	P	Contribution (%)
Weft	2	8902.8	4451.4	59.43	0.017	75.88
Reed count	2	850.4	425.2	5.68	0.150	7.25
Weave	2	1830.5	915.2	12.22	0.076	15.60
Error	2	149.8	74.9			1.27
Total	8	11733.5				100.00

S = 8.65455 R-Sq = 98.72% R-Sq(adj) = 94.89%

Table 10(b). ANOVA table for Flexural rigidity (weft) (S/N ratio)

Source	DF	SS	MS	F	P	Contribution (%)
Weft	2	1012922	506461	20.89	0.046	87.08
Reed count	2	34195	17097	0.71	0.586	2.94
Weave	2	67633	33816	1.39	0.418	5.81
Error	2	48489	24244			4.17
Total	8	1163238				100.00

S = 155.706   R-Sq = 95.83%   R-Sq(adj) = 83.33%

Table 11(a). ANOVA table for Bending modulus (warp) (S/N ratio)

Source	DF	SS	MS	F	P	Contribution (%)
Weft	2	0.230189	0.115094	17.98	0.50	64.29
Reed count	2	0.068825	0.034412	5.38	0.157	19.22
Weave	2	0.046214	0.023107	3.61	0.217	12.91
Error	2	0.012801	0.006400			3.58
Total	8	0.358028				100.00

S = 0.0800021   R-Sq = 96.42%   R-Sq(adj) = 85.70%

Table 11(b). ANOVA table for Bending modulus (weft) (S/N ratio)

Source	DF	SS	MS	F	P	Contribution (%)
Weft	2	25.1216	12.5608	14361	0.064	83.30
Reed count	2	1.4659	0.7330	0.85	0.540	4.86
Weave	2	1.8511	0.9255	1.08	0.482	6.14
Error	2	1.7199	0.8599			5.70
Total	8	30.1584				100.00

S = 0.927334   R-Sq = 94.30%   R-Sq(adj) = 77.19%

7. Confirmation test

The optimum factor level for bending length (warp) found in this study; eri as weft yarn, 56^S reed and 1/2 twill weave which is also same for flexural rigidity (warp) and bending modulus (warp). Whereas the optimum factor level for bending length (weft) is found to be khadi as weft yarn, 60^S reed and 1/2 twill weave which is also same for flexural rigidity (weft) and bending modulus (weft). These combinations of factors are not included in the experimental design in table no. 5. Therefore, it is decided to weave two fabrics using the optimal factor level separately and undertake the necessary testing process to obtain the values of bending length (warp) and bending length (weft). Twenty observations for each response were made to get average value of bending length (warp & weft).This is required to check the efficacy of the model. The predicted S/N ratio at optimal condition is calculated using the equation **[31]**;

$$\eta_0 = \eta_m + \sum_{i=1}^{j}(\eta_i - \eta_m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where, η_0= optimum S/N ratio,

η_m= average value of S/N ratio of the experimental runs,

j = no. of control factors, and η_i= S/N ratio corresponding to the optimum factor level

Substituting the different values in the above equation, the predicted S/N ratio for optimal condition (factor level) corresponding to the response i.e., bending length (warp) (A3B1C2) and bending length (weft) (A2B2C2) is determined and presented in table 12. From this S/N ratio, the optimum performance value (bending length) of the response is also calculated using equation no. (1). The relative error for each response is also found and given in table 12. This is found to be very encouraging.

Table 12. Results for confirmation test

Response	Optimal condition		Performance value (Experimental)	Performance value (Predicted)	Relative error (%)
	Factor	Level			
Bending length (warp)	Weft (A) Reed Count(B) Weave (C)	Eri (3) 56^S St (1) ½ twill (2)	1.41	1.32667	5.90
Bending length (weft)		Khadi (2) 60^S St (2) ½ twill (2)	1.28	1.19222	6.85

The predicted value of both the responses; bending length (warp) and bending length (weft) for the fabrics manufactured at ant factor level combinations which are not included in the L_9 design matrix can also the forecasted efficiently using Taguchi method. With the help of MINITAB 16 software, the predicted values of both the responses for each sample in the design matrix are calculated and presented in table 13alongwith their experimental result. The comparisons of experimental and predicted values can be visualized graphically in fig. 4 also. A very good correlation is observed. Therefore, it can be concluded that, Taguchi methodology is quite capable of forecasting the stiffness of the union fabrics.

Table 13. Experimental and predicted values of bending length

Sample no.	Predicted value		Experimental value	
	Bending length (Warp)	Bending length (Weft)	Bending length (Warp)	Bending length (Weft)
1	1.675	4.761	1.70	4.79
2	1.560	4.072	1.53	3.93
3	1.845	4.487	1.85	4.60
4	2.025	1.387	2.03	1.50
5	2.225	1.451	2.25	1.48
6	2.380	1.842	2.35	1.70
7	1.475	2.400	1.46	2.25
8	1.545	2.437	1.55	2.55
9	1.663	2.101	1.54	2.13

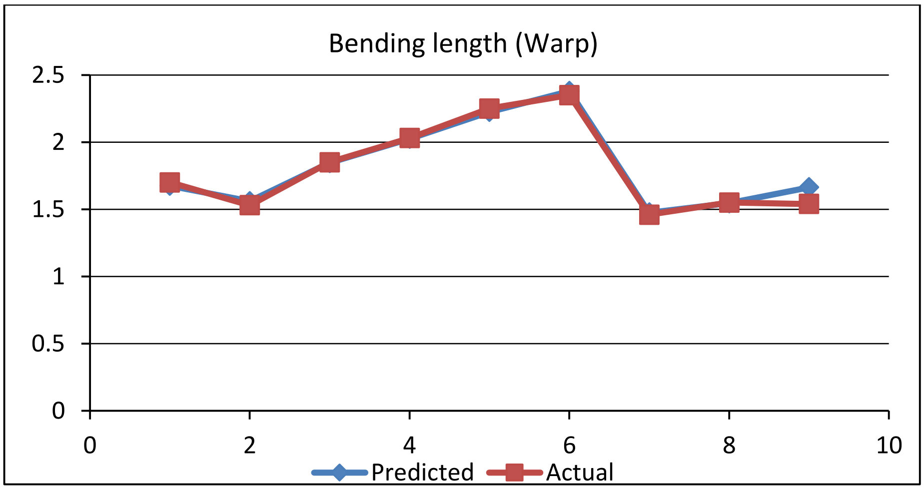

Figure 4(a). Comparison between predicted and actual value of bending length (warp)

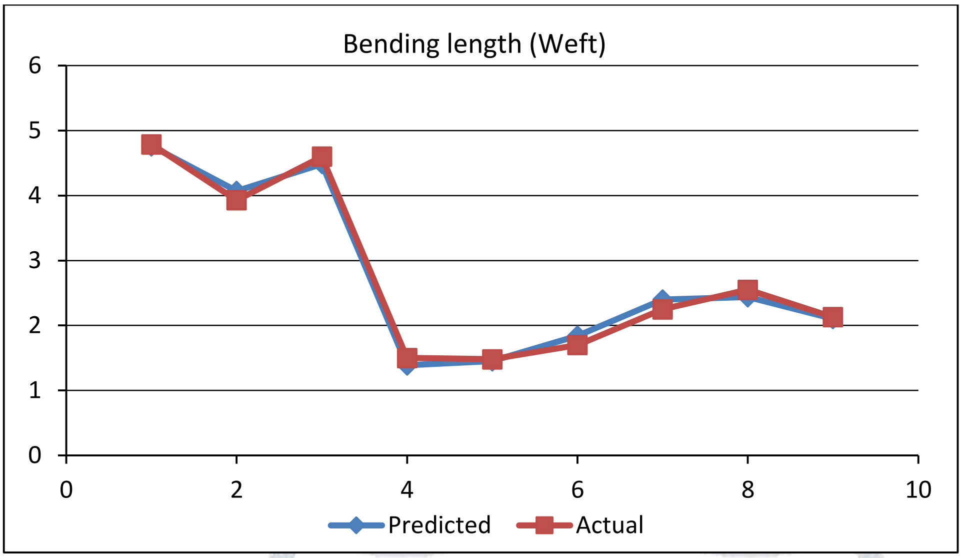

Figure 4(b). Comparison between predicted and actual value of bending length (weft)

8. Conclusion

The following conclusion can be drawn from the present study.

a. Studies on effect of the three weaving parameter like weaving structure, nature of fibre used in weft and reed count on some important hand properties viz. bending length, flexural rigidity and bending modulus of union fabrics have been successfully conducted with the help of Taguchi method using L_9 Orthogonal Array (OA). The effects of different factors and their levels on the performance characteristics can be justified very well. This is aimed to develop and design clothing meant for apparel. Study will also help to design garments particularly where gather is of importance. Selecting the right direction of fabric (warp or weft ways) to suit direction of gather or fabric fall in the garments will help to tailor the fabric accordingly.

b. The optimal level of weaving parameters (factor level) for less stiffness in warp direction was found as; 1/2 twill weave, eri yarn as weft and reed of 56^S Stockport. Whereas, the same for less stiffness in weft direction is found to be 1/2 twill weave, khadi yarn as weft and reed of 60^S Stockport. The contribution of each factor was assessed (at 95% confidence level) with their significance through ANOVA calculation.

c. The model is considered as efficient one to predict the response parameters for the union fabrics manufactured using different factor level combinations within and beyond its inclusion in the L_9Orthogonal Array (OA).

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