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A Review on Drapeability of Natural Fibre-made Fabrics

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Abstract: - Amongst the different property parameters of the produced fabric, drapeability of fabric is one of the crucial parameters with respect to end uses. It is the ability of fabric to hang freely in graceful folds when some area of it is supported over a surface and the rest is unsupported. During the application of different fabrics, both in industrial and apparel sector, it has been observed that the ability of the fabric to assume a graceful appearance of the contour is very vital conveying the significance of drapeability of the fabric. With the growing environmental concerns and eco-sustainability, the global emphasis is towards the application of eco-concordant, bio-degradable, renewable green products and this has inclined towards the natural fibre-made fabrics scoring them over their manmade counter parts and making them a natural choice for the mankind. The natural fibre-made fabrics have proven records of efficacy to prove their mettle match with manmade fabrics in different areas of application. This paper has reviewed and analyzed the various attributes of natural fibre-made fabrics such as jute, cotton, silk and wool focusing mainly on their draping behavior, determining their strengths and weakness considering the future direction of research to overcome their deficiencies.

Keywords: -*bending behavior, bending length,bending stiffness,drape,drapemeter, drape coefficient*

I. INTRODUCTION

Drape of a fabric refers to the manner in which the fabric falls, shapes, gathers or flows with gravity on the model form or on a human body, as well as on furniture and wall hangings, when only part of it is directly supported. Drape of a fabric is an important cloth property in apparel as well as in industrial uses. The ability to fold gracefully in two directions simultaneously distinguishes fabrics from other sheet materials. The folding takes a complex three-dimensional form with double curvature. The research into fabric drape dates back to the classic paper published by Pierce [1] in 1930s with the title "The Handle of Cloth as a Measurable Quantity."Chuet.al. [2] and Cusick [3] made a great contribution to the practical determination of this fabric property by measuring three-dimensional draping. In 1986, Hearle and Amirbayat [4] made a theoretical investigation on drapeability of fabric, and gained some insight into the nature of this property from a study of complex buckling using a different approach. Niwa and Seto [5] published a paper about the relationship between drapeability and mechanical properties. They derived the parameter combinations of bending rigidity, bending hysteresis, weight per unit area, shear stiffness and shear hysteresis from an analysis of bending of a fabric cantilever with hysteresis in bending and shear by applying the heavy elastic theory. Other researchers who have contributed to this area include Sudnik [6], Morooka and Niwa [7],Gaucher et.al. [8], and Collier et.al.[9], [10]. Sudnik [6] correlated fabric drapeability with bending length and in 1978, he confirmed the importance of bending length in predicting fabric drape. Peirce [1] commented that bending length from the cantilever test is strictly a measure of the draping property and simultaneously an instrument was decided to measure the angle through which a specimen of cloth drooped when a definite length was held out over an edge, based on the recognition that stiffness has a large effect on drapeability. He concluded, by means of a mathematical formula, this angle was converted into "bending length", defined as the length of fabric that will bend under its own weight to a definite extent. It is a measure of the draping quality of a sheet material. He also observed that bending length or bending rigidity is only a partial predictor of drape behavior for many fabrics.

Sudnik [6] determines that shear resistance was also a factor, although not as important as bending resistance. Morooka and Niwa [7], generated an equation to predict fabric drape using data from the Kawabata Evaluation System for Fabrics (KES-F) system and they concluded that fabric weight and bending modulus were the most important factors. They also reported that shear resistance was not a significant factor in draping behavior for the fabrics. However, research by Collier et.al. [11] indicated that shear properties are more significant predictors of fabric drape than bending properties and shear hysteresis, and that shear hysteresis is more closely related to drape coefficient. Chu et.al [2] found that in general, drapeability depends on three basic fabric parameters i.e. Young's Modulus (Y), the cross-sectional moment of inertia (I), and the weight (W). They also have generated an equation in which the drape coefficient equals to f (B/W), where the bending stiffness B = YI. In Cusick's original work, he measured the drape coefficient, bending length, and shear stiffness (the shear angle at which a fabric begins to buckle; fabrics with higher shear stiffness buckle at lower angles). Other mechanical properties such as tensile strength were not considered in his study. He also found that theoretical drape coefficients were lower than the measured values for the majority of fabrics tested, when ignoring shear stiffness. In later work, Cusick [3] used statistical evidence to prove that fabric drape involves curvature in more than one direction, and that the deformation depends on both shear stiffness and bending length. He also formulated an equation for the relationship between drape coefficient and bending length and shear angle. The bending properties of fabrics govern many aspects of fabric performance, such as hand and drape, and they are an essential part of the complex fabric deformation analysis. Peirce [1] produced a formula for calculating the stiffness of a fabric in any direction in terms of the stiffness in the warp and weft direction. This was derived from the theory for homogenous elastic material and it was found to be empirically satisfactory. It is suggested that the reason for this is that most of the fabrics which Peirce tested were made from cotton. He first introduced the bending rigidity of a fabric by applying the equation, $B = wc^3 \times 10^3$mg-cm in his classical paper, where B is the bending rigidity, w is the weight of the fabric in grams per square cm and c is the bending length. He also introduced another equation for bending rigidity in various directions which is $B_\theta = \{(\cos^2\theta/\sqrt{B_1}) + (\sin^2\theta/\sqrt{B_2})\}^{-2}$, where B_1, B_2 and B_θ are bending rigidities in warp, weft and θ directions respectively. This equation enabled the value for any direction to be obtained when the values in the warp and weft directions were known. Go et al. [12] measured the bending stiffness of fabrics using the heart loop method. They also indicated that the bending stiffness of the fabric is dependent on the bending model of the test piece. The bending stiffness of fabric having long floats on its surface was smaller in face-to-face bending than back-to-back. The effect of the crimp of the component yarn of fabric on the fabric bending stiffness was generally small. Later, Go and Shinohara [13] reported that on the polar diagram of bending stiffness there was minimum presented at 45° to the warp when the fabric was bent. Their formula neglected the restriction at the interaction of the warp and weft directions. They concluded that the stiffness of textile fabrics depended upon their bending directions and that, in general, the stiffness in bias directions was relatively small. Cooper [14] used cantilever methods to determine fabric stiffness and stated that there was no evidence to suggest that there was any appreciable shearing of the fabric caused by its own weight. He presented an equation including twist effect. The results of the twisting effect were found to be valuable in practical applications and so equation was derived $B_\theta = \{B_1 \cos4\ \theta + B_2 \sin4\ \theta + (J_1 + J_2) \cos^2\theta \sin^2 \theta\}$, where J_1 and J_2 are constants due to torsional moment. Cooper concluded that the stiffness of a fabric may vary with direction of bending in different ways, but for most practical purposes measurement along warp, weft and one other direction was sufficient to describe it. Cooper conducted a detailed study of the stiffness of fabrics in various directions and has produced polar diagrams of bending stiffness. He found that some fabrics had a distinct minimum value at an angle between the warp and weft direction while others had similar values between the warp and weft. In general, viscose rayon fabrics provided an example of the former and cotton fabrics an example of the latter. These effects were explained in terms of the fabric bending stiffness in the warp and weft direction and the resistance offered by the yarns to the torsional effects which are inseparable from bending at an angle to warp and weft. He also concluded that the resistance offered by the yarns to the torsional deformation is low when the interaction between the yarns is low and vice versa. Shinohara et.al. derived an equation empirically which is similar to the equation introduced by Peirce and analyzed the problems using three dimensional elastics. They assumed the constituent yarns of woven fabrics to be perfectly elastic, isotropic, uncrimped and circular in cross-section and to behave in a manner free from inter-fibre friction. In addition, they also presented another equation containing a parameter n which was related to V introduced by Cooper [14] in order to predict the shape of a polar diagram. In addition, although Peirce's, Shinohara et.al.'s and Cooper's models can all be applied to the prediction of polar diagrams of bending hysteresis for loose to tight plain woven fabrics, amongst these three models, Cooper's model presents the lowest deviation from the experimental results. Therefore, it can be seen that the twist and frictional effects in Cooper's model play an important role in the prediction of bending hysteresis on either loose or tight plain woven fabrics. Moreover, when comparing the bending hysteresis of loose and tight plain woven fabrics, the deviation in loose plain woven fabric is smaller than that in tight plain woven fabric. From the above analysis, we may conclude that Cooper's model is the most reliable in the prediction of bending hysteresis in both loose and tight plain woven fabrics.

Amirbayat and Hearle [15] reviewed several research works relating the simulation of fabric drape. They implied that the membrane strains are important in fabrics, observing that the uniqueness of fabric drape is the formation of double curvatures. Thus, in addition to tensile characteristics, shear rigidity and Poisson's ratio play important roles in the drape process. Amirbayat and Hearle also computed theoretical values of deformation for an isotropic material and analyzed the effects of Poisson's ratio, which is the combined effect of in-plane stiffness relative to bending stiffness and weight of the material. Bending and shear properties were confirmed as significant when measuring fabric drape and contributed to the understanding of drape to some extent. But two-dimensional drape in the cantilever cannot reflect the nature of drape because it involves three-dimensional double curvature deformations. Simultaneously, Lo et.al. [16] had developed a model for predicting the drape behavior. Chen found that Young's modulus, shear modulus, and thickness affect the extent of drape, but Poisson's ratio, in the usual range of 0.0 to 0.5, does not show any appreciable effect on drape. The shape attained by a fabric after drape is influenced by the orthotropy of fabric, but they observed that the asymmetry due to orthotropy is greatly influenced by shear modulus and thickness. It was concluded by them that the fabrics with low shear modulus do not exhibit asymmetry, even if the Young's modulus values are quite different in the warp and weft directions. Similarly, thin fabrics do not show the effect of orthotropy as much as thick fabrics.

The work of GulcanSule has been conducted to investigate drape and bending properties of gray plain woven fabrics and the effect of weft density, weft yarn count and warp tension on these properties. In his work, warp and weft yarn type, warp count and warp density were kept constant, while weft count, weft density and warp tension were varied in manufacturing the fabrics. At the end of the study, they concluded that higher values were found for bending rigidities of the fabrics woven with thicker weft yarns and at higher weft densities in the warp, weft and overall bending rigidities. It was observed that bending rigidities of the fabrics in the warp direction had increased as warp tension was increased. This increase occurred at higher levels in fabrics woven with thicker weft yarns and at higher weft densities. Considering warp crimps of these fabrics, having the same structural parameters but woven under different warp tensions as the only exception, where warp crimp had decreased as warp tension was increased. This made these yarns more resistant to bending in the fabric and thus, higher bending rigidity was achieved in the warp direction. Bending rigidity in the weft direction did not show any significant change, i.e. no increase or decrease with the change in warp tension. In the case of fabrics woven with thinner weft yarns, bending rigidity in the weft direction decreased as the warp tension increased. This decrease was explained depending on the increase in weft crimp against the increase in the warp tension in the case of fabrics woven with thinner weft yarns and/or at higher weft densities. The increase, which occurred at higher levels, in the weft crimp, reduced resistance of the weft yarns in the fabric for bending, especially in the case of fabrics woven with thinner weft yarns and/or at higher weft densities. This had caused a reduction in bending rigidity of these fabrics in the weft direction. Overall fabric bending rigidity is the geometrical mean of bending rigidity in the warp direction and bending rigidity in the weft direction. In the case of fabrics woven with thicker weft yarns, as warp tension had increased, overall fabric bending rigidity got increased. The increase in bending rigidity in the warp direction of the fabrics woven with the thinnest weft yarn, depending on the increase in the warp tension, increased at lower levels compared with the increase that had occurred in bending rigidities of the fabrics woven with other weft yarns, while bending rigidity in the weft direction did not vary significantly as the warp tension increased and therefore, overall fabric bending rigidity did not vary significantly despite a very insignificant increase. Considering drape coefficients of the fabrics, it was observed that the drape coefficient increased as the weft density increased and weft yarn became thicker. The drape coefficient did not significantly vary depending on the variations in the warp tension. This study has evidenced once more that the effect of the bending rigidity of a fabric on its drape feature is quite significant. In this study, the fabrics woven with thicker weft yarns at higher weft densities gave higher bending rigidities and drape coefficients.

Bijian Chen and Muthu Govindaraj [17] in their research work, have shown the effect of changing the thickness of the fabric while keeping the stiffness values and weight constant for the simulations. It is their observation that for a small change in thickness, there is a significant change in drape. The reason is that thickness of the fabric has a large influence on the bending stiffness of the fabric. It has been depicted in their research work that when the thickness of the fabric is of the order 0.03 cm, the corners of the fabric appear to be collapsed. This indicates that the fabric has a low stiffness. The drape also appears symmetric in spite of the differences in the warp and weft Young's modulus values. As thickness increases to 0.04cm and later to 0.05cm, the fabric takes on an asymmetric drape. This explains why thin fabrics usually assume a symmetric drape.

Bijian Chen and Muthu Govindaraj [18] have also reflected the effect of shear modulus on drapeability of fabrics in their work where they have kept Young's modulus and Poisson's ratio values constant for the different simulations. Different Young's modulus values have been chosen in the warp and weft directions to study the effect of change in shear modulus on an orthotropic fabric. Nevertheless, the effect of increasing of shear stiffness on drape can be seen from the simulations using the same Young's modulus values giving rise to occurrence of orthotropy only in combination with higher shear modulus. Jute woven fabrics usually have a low shear modulus compared to the tensile modulus, which is perhaps the reason that most fabrics assume a symmetric drape.

Chen and Llyod [18] and later on Collier et.al. concluded that Poisson's ratio has a significant effect on the drape coefficient and also found that the Poisson's ratio for fabrics is not easy, and even if some measurements can be made, the definition of Poisson's ratio may not be totally applicable to fabrics. De Jong and Postle [19] showed that theoretical and experimental values of Poisson's ratio for fabrics rarely agree. Their findings show that as Poisson's ratio increases from 0.0 to 0.5, there is no appreciable change in either extent of drape or the shape of the folds.

Weidong Yu and Zhaoqun Du studied the Bending Evaluation System of Fabric and Yarn (BES-FY) can measure the bending, weight, friction, and tensile properties of fabric and yarn through a pull-out test and delineate the relationship between the mechanical geometry and the corresponding deforming process, so as to quantify the comprehensive hand of fabrics and yarns. The bending process of the BES-FY system was mainly investigated in their study. Two bending models were developed under different conditions and the corresponding formulae for bending rigidity were also obtained. The optimum point and range for calculating the bending rigidity was acquired by experimental and analytical investigation, which involved the study of the relationship of bending rigidity-curvature. These can be divided into three sections, namely, linear, quadratic and constant function, through the comparisons between the bending rigidity of the two bending models and that of KES-FB2 and FAST-2, the better bending model was selected to characterize the bending properties of the fabrics and the yarn.

II. METHODS TO DETERMINE DRAPEABILITY OF TEXTILE FABRIC

Traditionally, the textile technologists, researchers, manufacturers and end-users assess fabric drape [20] subjectively and by practical experience. This qualitative assessment of fabric drape sometime may result in errors. Therefore, the textile researchers realized the importance of understanding the phenomenon of drape and desired to be able to measure it quantitatively and objectively. The different methods of measuring drape of a fabric improvised over the years have been included in this review.

Cantilever methods were first introduced' by Peirce (1930) [1] for the evaluation of fabric drape, his methods were based on the recognition that stiffness has large effect on drapeability. The standard tester, called flexometer which became the standard Shirley Stiffness Tester, had been described in details by Peirce. The bending / drooping angle of fabric subjected to test can be measured, when a definite length of fabric specimen droops over an edge of the instrument. The specimen is a rectangle with ratio of length to its width (6: 1). By means of a mathematical formula, the bending angle has been converted into a term called "bending length", which is a measure of fabric drapeability in two dimensions and stated as drape stiffness by Peirce. Later on with the passage of time various modifications of the method had been worked out to make the method suitable for different types of fabrics. For example, for very stiff fabrics such as starched and ironed, a weight called weighted rectangle can be added to the free-end of the specimen. Again, for a very flimsy fabric, a triangle cantilever may be used. Peirce also suggested another cantilever with wider strip of 6 in. wide.

Chu et.al. (1950) [2] and Cusick (1961) [3] made their great contribution to the measurement of fabric drape. The standard drapemeter, which is in current use, determines the drape coefficient, which is the ratio of projected area with specimen's original area. The drape coefficient can provide an objective description of the deformation. This method scores over the cantilever method because of its capability to test the three dimensional drape feature and thus can differentiate the paper web and a textile fabric.

F. R. L. Testing Machines Inc. (1980) [21] reported that the F.R.L. Cantilever Bending Tester is capable of testing thin sheet material, textiles, and other flexible materials including carpets. Kalyanaraman and Siveramakrishnan (1984) [22] designed an electronic cantilever meter based on opto-electronic principles. Their instrument has the same accuracy as the Shirley Stiffness Meter and works on measurement is objective and could easily be automated.

Clapp et.al. (1990) [23] developed an indirect method of measuring the moment-curvature relationship for fabrics.

Collier et.al. (1991) [24] designed a digital drapemeter to measure fabric drape co-efficient by using photo-voltaic cells. The drapemeter utilizes the principle of the standard experimental drapemeter and applies a bottom surface of photo-voltaic cells to determine the amount of light blocked by a fabric specimen draped on a pedestal. A digital display gives the amount of light being absorbed by the photo-voltaic cells, which is related to the amount of drape of the fabric specimen. This principle was earlier adapted by textile researchers in China.

The Fabrics Assurance by Sample Testing (FAST) system developed by CSIRO consists of a cantilever bending meter (1993). The principle for FAST 2 is very similar to that of Shirley Stiffness Tester in which the fabric bends under its own weight until its leading edge intercepts a plane at an angle of 41.5 degrees from the horizontal. Compared with Shirley Stiffness tester, the FAST 2 was designed to test a wider specimen (50mm), even though any sample width from the standard 2.45cm up to 50mm can be employed. In addition this instrument encloses totally the electronics and detection apparatus.

Russel (1994) [25] reported an alternative instrument for the measurement of the fabric bending length in contrast with the commercial Shirley Stiffness Tester and the FAST 2 bending meter.

Potluri et.al. (1996) [26] also improvised an experimental technique to verify their numerical method for the capability to compute for general situations. A laser triangulation sensor, attached to a robot arm, had been used for measuring the cantilever profile of the fabric samples. A manipulating device positions the fabric sample as a cantilever of specific length.

Stylios et al (1996) [27] developed a new type of drapemeter, which measures both static and dynamic drape in true three dimension by using CCD camera as a vision sensor. This system, called the Marilyn Monroe Meter (M3) has been used to measure real fabric drape behavior, and is being used to verify their theoretical prediction model. The drape profile of the specimen can be taken and presented on computer.

Matsudaira et.al. (2000) studied the static and dynamic drape behavior of polyester shingosen fabrics using the dynamic drape coefficient with swinging motion. The dynamic drape coefficient D_d of peach face shingosen fabric was small and that of new worsted was large. In this study the two-dimensional projection of the hanging shape of fabrics was measured by an image analysis system by Library Co. in Japan.

The image analysis method had been developed to overcome the constraints in measuring the drape coefficient of fabric. Vangheluwe and Kiekens (1993) [28], Jeong and Phillips (1998), Lo, Hu and Li (2002) have all used image analysis for the measurement of drape of fabrics. Jeong and Phillips (1998) studied the fabric drape behavior with image analysis. The effects of fabric structure and its mechanical properties on the draping characteristics of fabric had been studied with a systematically designed range of fabrics. According to Jeong and Phillips, the fabric cover factor influences the drapeability of the fabric by increasing the fabric bending rigidity. However, fabrics with different but similar cover factors showed differences in their drapeability which was due to the influence of weave structure on the thread interaction and related shear properties of the fabrics. It has been shown that the instability of fabric drape increases as the residual bending curvature and residual shear angle increases. Cover factor increased drape instability by increasing the residual bending curvature.

An automatic fabric evaluation system has been developed to analyze the structure of woven fabric and to objectively evaluate the fabric quality. Fabric images have been captured by a Charge Couple Device (CCD) camera and preprocessed by Gaussian filtering and histogram equalization. Fabric construction parameters such as count, cloth cover, yarn crimp, fabric thickness, and weight per unit area are measured automatically from planar and cross-sectional images of woven fabric with image processing and image analysis.

Lo et.al. (2002) have studied modeling of a fabric drape profile. The drape coefficient (DC %), node numbers, and node shape in the fabric drape profile can be predicted accurately with this model. Polar coordinate fitting is used to determine the constants in the drape profile model, and good agreement has been obtained between the theoretical and experimental drape profiles of thirty-five woven fabric specimens. In addition, constants in the drape profile model may also be obtained by bending and shear hysteresis using regression analysis. Good agreements are found between the calculated DC% and the experimental DC% for the fabric specimens examined in this study. Moreover better predictions of the fabric drape profile may be obtained from the mean value taken in the warp, weft and 45˚ directions than those in the warp and weft directions.

III. NATURAL FIBRES

The backdrop of growing global concern for environment concomitant with the alarming danger of carbon foot-print generation amalgamated with non-biodegradability and higher toxicity generation from the use of manmade-fibres have created an urge to come back to natural fibres, thereby opening new market opportunities. The growing disinclination to use artificial fibres and an increasing preference for natural fibres is reviving the importance of the latter like jute, cotton, silk, wool, flax, sisal, hemp, coir etc.

Jute [29], a lingo-cellulosic bast fibre belonging to botanical genus Corchorus (Family Tiliaceae) includes about 40 species available almost throughout the tropics, out of which C. capsularis linn and C. olitorius linn were found to be as economic plants and became commercially important. C. capsularis is known as ‘White’ jute and C. olitorius as ‘Tossa’ jute. Jute is grown abundantly in Bengal and adjoining areas of Indian subcontinent. Jute is widely used in production of packaging and wrapping textiles (sacking and hessian) besides its additional uses as carpet backings, decorative / furnishing fabrics, designed carry bag fabrics, geotextile fabrics, as well as for manufacture of high quality paper and composites etc. its main advantages are its renewable agro – origin, bio – degradability, high strength and high moisture regain, medium to good affinity for dyes, good heat and sound insulation properties and ready availability at low cost.

Cotton is the oldest natural fibre used for textile purpose. The cotton plant (shrubs) belongs to the family, Gossypium and the different species of this family constitutes the different varieties of cotton e.g. ordinary American Cotton is Gossypium Hirsutum, Asiatic Indian Cotton is Gossypium Herbaccum and Gosypium Arboretum, while Sea-Island, Egyptian and Peruvian Cotton are Gosypium Barbadense. The major use of cotton fibre is in making clothes in apparel sector including the areas of medical textiles, sports textiles, industrial textiles and other categories of technical textiles.

Silk is a very fine, regular and translucent, natural, protein filament. Silk filament comes from the cocoons built by 'silkworms', which are not worms at all, but silk moth pupae. The scientific name of one of the important domestic silk moth is Bombyx Mori. The silk fibre is mainly produced in China, India, Thailand, Europe, North America, Vietnam, and Malaysia in large quantity. The silk fibre may be up to 600 m long, but averages about 300 m in length. Depending upon the health, diet and state under which the silk larvae extrude the silk filaments, their diameter may be vary from 12 -30 µm. This gives a fibre length to breadth ratio well in excess of 2000:1. The beauty and softness of silk's luster is due to the triangular cross-section of the silk filament. As the silk filament is usually slightly twisted about itself, the angle of light reflection changes continuously. As a result, the intensity of the reflected light is broken, resulting in a soft, subdued luster. The silk fibre is mainly used in making clothes in apparel sector as well as in production of furnishing fabrics.

Wool is the fibre extracted from the fleece of domesticated sheep mostly. Apart from sheep, wool also comes from the angora goat, yak, llama, alpaca, and even camels. It is natural, proteinous, multicellular, staple fibre. It is largely produced in Australia, New Zealand United States and in China etc. The length of the wool fibre ranges from about 5 cm for the finest wools to 35 cm for the longest and coarsest wools. Wool fibres vary greatly in their fibre diameter, ranging from about 14 µm for the very finest wools to more than 45 µm for the coarsest wools. Fine, lightweight, pleasant handling fabrics can be manufactured from the finer wools. Fibre length to breadth ratio can be critical with wool, since the short, coarse fibres spin into less attractive yarns than do those of fine wools. In general, fibre length to breadth ratio ranges from 2500:1 for the finer, shorter wools to about 7500:1 for the coarser, longer wools. Wool fibre may vary from off-white to light cream in colour. In addition to clothing, wool has been used for blankets, horse rugs, saddle cloths, carpeting, felt, woolinsulation and upholstery. The chemical composition, physical properties and chemical properties of the natural fibres jute, cotton, silk and wool fibres have been discussed in tables 1, 2, 3 respectively. The morphological diagram of the four natural fibres is shown in the Fig. 1.

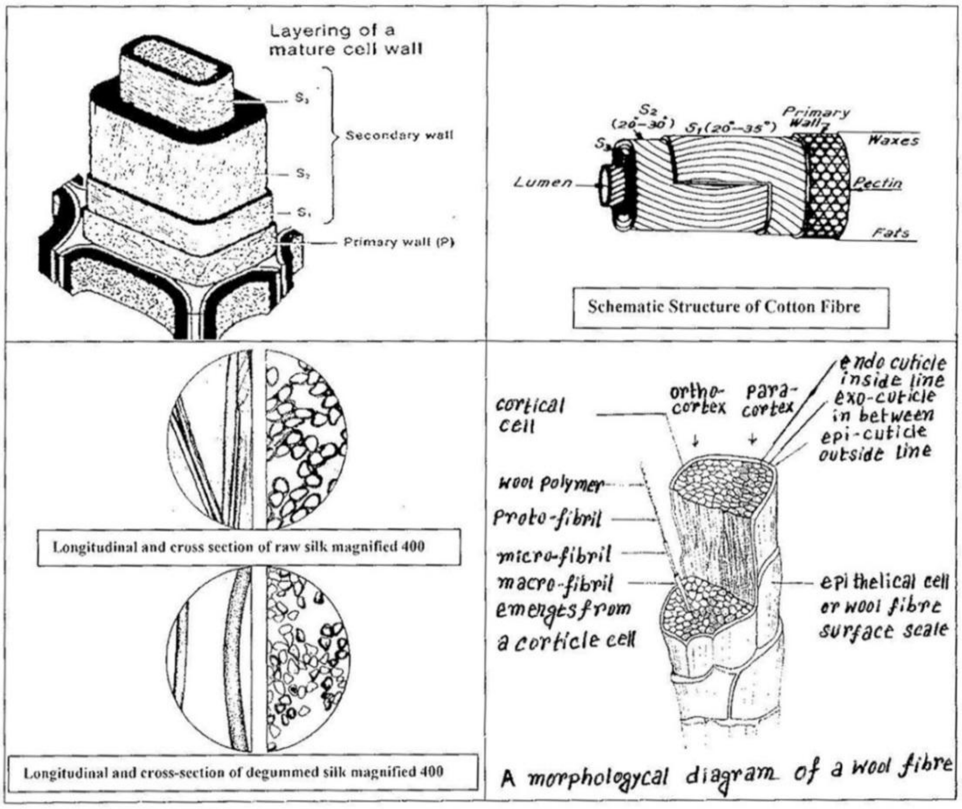

Fig.1Longitudinal and cross-sectional views of the natural fibres – jute, cotton, silk and wool

Table 1 Average chemical composition (%bone dry weight of the fibre) of jute, cotton, silk and wool fibre

Constituent	**Jute**	**Cotton**	**Silk**	**Wool**
Cellulose	60-63	95.5(94-97)	-	-
Hemi-cellulose	21-24	Nil/traces (sometimes reported to< 0.3)	-	-
Lignin	12-13	Nil	-	-
Protein or nitrogenous matter	0.8-1.87	1.1(0.3-2.5)	-	-
Pectins	0.2-0.5	0.9(0.6-1.2)	-	-
Mineral matter (Ash)	0.7-1.2	0.8(0.2-1.8)	-	-
Maleic, Citric and other organic acid residue	-	0.8(traces to 0.8)	-	-
Fat and waxes	0.4-1.0	0.4-1.6	1.5	-
Fibroin	-	-	75	-
Ash of silk fibroin	-	-	0.5	-
Sericin	-	-	22.5	-
Mineral salt	-	-	0.5	-
Keratin	-	-	-	33
Grease	-	-	-	28
Suint	-	-	-	12
Different impurities	-	-	-	26
Mineral water	-	-	-	1

Table 2 Comparison of physical properties of jute, cotton, silk and wool fibres

Fibres	**Fibre Density (g/cm^3)**	**Tenacity (g/den*)**	**Elongation at break (%)**	**Specific Gravity**	**Moisture Regain% (at 65 % RH)**	**Crystallinity (%)**
Jute	1.48	2.7 – 5.5	1.7	1.50	13.75	50 - 55
Cotton	1.55	3.5 – 3.8	5-10	1.54	8.50	60 - 65
Silk	1.34	3.33-4.56	20-25	1.25-1.34	11	65-70
Wool	1.32	1.0- 2.0	25-35	1.30-1.32	17	25-30

* cN/tex = 8.83 x (g/den);

Table 3 Comparison of chemical properties of jute, cotton, silk and wool fibres

Fibre	Jute	Cotton	Silk	Wool
Effect of acids	Easily damaged by hot dilute acids and conc. Cold acid.	Not affected by acids	Decomposed by strong acids.	Decomposed by hot conc. H_2SO_4.
Effect of alkali	Damaged by strong alkali, losses weight when heated with caustic soda.	Has excellent resistance to alkali.	Less readily damaged by alkali than wool fibre.	Strong alkaline effect on wool fibre. Dissolved in NaOH.
Effect of light	Colour changes slightly in sun light because of lignin.	Due to UV rays and infrared rays the cotton polymers degrade.	Decomposed in presence of atmospheric oxygen.	Affected by sun light.
Effect of micro-organism	Good prevention ability.	Attacked by fungi and bacteria.	Affected by mildew slightly.	Affected by mildew if remains wet for long time.
Dyeability	Easy to dye (using direct and basic dye normally).	Direct, reactive, sulphur, vat and azoic dyes is used to dye.	Acid dye is used to dye.	Could be dyed with direct, basic and acid dyes.
Solubility	Dissolved in 72% H_2SO_4.	Dissolved in Conc. 70% H_2SO_4.	Soluble in 5% NaOH (hot).	Soluble in 5% NaOH at room temperature.

IV. EMPIRICAL STUDY OF FABRIC DRAPE USING NATURAL FIBRE-MADE FABRICS

Dhingra and Postle (1980-1981) [30] investigated seam bending rigidity. They used wool woven fabric with 2/2 twill structure. It was found that a seam has a little effect on fabric shear rigidity and hysteresis, but has a significant effect on bending rigidity. When a seam is perpendicular to the axis of bending with 1 mm seam allowance, bending rigidity is 3-4 times greater than the bending rigidity with no seam. When a seam is parallel to the axis of bending with seam allowance 1 mm, there is a little effect on bending rigidity. When seam allowance is greater than 2.5 mm, bending resistance increases, but the effect is not as significant as in the perpendicular direction. Bending takes place more easily in the parallel direction than in the perpendicular direction when a seam is imposed on it. It is because more freedom area of un-sewn part is found in the former.

Hu and Chung (1998) [31] have published a paper on drape behavior of woven fabrics with seams. This paper presents a fundamental drape analysis of seamed fabrics using Cusick's drapemeter. Simple plain and twill woven fabrics with various fibres content of cotton, linen, silk, and wool and polyester are given radical and circular seams. The effects of seam allowance and seam positions are investigated experimentally. Drape behavior is determined and compared in terms of drape coefficient, node analysis, and drape profile. Investigating drape on seamed fabrics can improve apparel design and fabric end use applications. Moreover it contributes to garment drape prediction for the clothing CAD system.

Itagi and Rao (2012) [32] have highlighted an experimental investigation into the drape behavior of silk fabrics with the circular seams using Cusick's drapemeter. They have studied the effects of seam positioning on the drape behavior. Varying positions of a circular seam in the fabric specimens show varying effects on drape coefficient percentage of light and heavy weight fabrics. Fabrics of medium weight have shown gradual increase in drape coefficient percentage. Drape profiles more or less show consistency with changed seam positions for light and medium weight fabrics but heavy weight fabrics show disturbed profile. Investigations of Itagi and Rao on fabric drape value for silk apparel fabrics with seams have a significant value for both textile and garment industries because it provides a realistic drape study with respect to garment appearance. The researchers believe that their findings can be applied to computer simulations of drape in the silk apparel industries.

Hu and Chan (1998) [33] have investigated that that relation between the fabric drape coefficient and from that Cusick drapemeter and mechanical properties tested on Kawabata Evaluation System for Fabrics (KES-F) for woven fabrics. This is first attempt at determining comprehensive relationship between the fabric drape coefficient and mechanical properties. Drape coefficient is the dependent variable. Sixteen mechanical properties tested on the KES-F system and their transformed forms are independent variables. Four regression models are proposed: the multiple linear regression of the drape coefficient with KES-F original data, Niwa's model, logarithm for KES-F data and logarithm for both drape coefficient and KES-F data. Except for an initial run with Niwa's model, the mechanical properties correlated to drape coefficient are reduced to three or four by screening out inter-correlated parameters using stepwise regression. The regression results are analyzed in terms of correlation coefficients, residual and T values. The version with logarithms for mechanical properties and drape coefficient seems to be more accurate. We know that bending and shear properties are close related to drape coefficient, and this analysis shows that two other parameter-mean deviation of friction coefficient and tensile linearity – are also highly correlated with drape coefficient and may be independent.

Stylios, Powell and Cheng (2002) [34] on their paper have proposed a powerful predictive tool to determine both the drape attributes and the drape grade from the mechanical properties of a fabric. Combining this with a novel feedback system (Stylios and Cheng, in preparation), there is now the possibility of modifying the drape grade or drape attributes of a fabric to be more desirable, and then finding the changes to the material properties required to achieve them. This opens up the possibility of re-engineering fabrics to match changing fashion and market requirements. The system consists of neural networks, which predict the drape attributes from the natural logarithm of the material properties divided by the weight, and that predict the subjective drape of a fabric from the drape attributes. A comparison had been made between these neural networks with linear regression models and discriminate analysis. The drape coefficient was found to be a principal factor in the prediction of the subjective drape. However, the incorporation of the drape attributes allows quantities that relate directly to the aesthetic qualities of a fabric's drape to be related to the mechanical properties of the fabric.

Shyr, Wang and Cheng (2007) [35]have investigated the comparison of the key property parameters affecting the dynamic and static drape co-efficient of four natural-fibre woven fabrics (cotton, linen, silk and wool fabrics) by a newly devised dynamic drape automatic measuring system integrating Cusick's drapemeter principle with the image analysis technique. The relationship for four natural-fibre woven fabrics between the fabric drape coefficient and sixteen physical property parameters, based on the Kawabata Evaluation System for Fabrics (KES-F), have been investigated. Results show that the experimental data of the dynamic drape coefficient versus the rotating speed can be well fitted to a Boltzman function. The correlation coefficient analysis showed that the static drape coefficient and the dynamic drape coefficients of these four natural-fibre woven fabrics, at 100 and125 r.p.m. did not have a very good correlation, apart from the wool fabric. The key parameters for the static drape coefficient and dynamic drape coefficient at 100 r.p.m. of each natural-fibre fabric were selected from sixteen physical properties using a stepwise regression method. Results showed that the selected key parameters of different natural-fibre fabrics were not entirely the same, and that the static drape coefficient of a fabric could not show dynamic performance. However, the bending and shearing blocked properties were found to be most closely associated with the static and dynamic drape coefficient for the test fabrics.

Fathy and Ebrahim (2011) [36] have made a paper on prediction of garment drapeability based on fabric properties. The drape coefficient alone is not sufficient information about a fabric, so the number of folds, their wavelength, distribution and amplitude is specified as well. In case of cloths the position compared to the projection and warp line is also specified for these data. The investigation of the drape properties of 100% cotton fabrics has shown high correlation between various fabric structure parameters and the fabric drape. The drape coefficient values for most of the sample varies from 29.77 to 56.86% which is expected value for the woven fabric for outerwear women's tailored clothing. The sample that has much greater drape value has also much higher bending stiffness (length & rigidity), warp formability, shear rigidity, and weight. The highest correlation has been found between the fabric drape and stiffness and the parameters which indicate fabric tightness.

GülcanSüle (2012) [37] has made an investigation of bending and drape properties of woven fabrics and the effects of fabric constructional parameters and warp tension on these properties. This study was conducted to investigate drape and bending properties of grey plain woven fabrics and the effect of weft density, weft yarn count and warp tension on these properties. The particular of warp yarns like type, count, density and weft yarn type have been kept constant while weft count, weft density and warp tension were varied in manufacturing of the fabrics. At the conclusion, higher values had been observed for bending rigidities of the fabrics woven with thicker weft yarns. It was seen that bending rigidities of the fabrics in the warp direction increased as warp tension increased. Considering warp crimps of these fabrics, having the same structural parameters but woven under different warp tensions as the only exception, warp crimp decreased as warp tension increased. This made these yarns more resistant to bending in the fabric and, thus, higher bending rigidity was achieved in the warp direction. Bending rigidity in the weft direction did not show any significant change. In the case of fabrics woven with thinner weft yarns at a weft density of 26 threads/cm, bending rigidity in the weft direction decreased as the warp tension had increased. This decrease was explained depending on the increase in weft crimp versus the increase in the warp tension in the case of fabrics woven with thinner weft yarns. Overall fabric bending rigidity is the geometrical mean of bending rigidity in the warp direction and bending rigidity in the weft direction. Considering drape coefficients of the fabrics, it had been observed that the drape coefficient increases as the weft density increases and weft yarn becomes thicker. The drape coefficient did not significantly vary depending on the variations in the warp tension. This study has evidenced once more that the effect of the bending rigidity of a fabric on its drape feature is quite significant.

El-Sabbagh and Taha (2013) [38] have investigated the draping behavior of jute woven fabric to study the feasibility of using natural fabrics in place of synthetic glass-fibre fabrics. Draping behavior describes the in-mould deformation of fabrics, which is vital for the end appearance and performance of polymer composites. The draping coefficient was determined with a common drapemeter for fabrics with densities of 228–765 gsm and thread counts under different humidity and static dynamic conditions. The results were compared with that of glass-fibre fabrics with close areal densities. Characterization of the jute fabrics was carried out to fill the knowledge gap about natural fibre-made fabrics and to ease their modeling. The tensile and bending stiffness and the shear coupling have been also characterized for a plain woven jute fabric with a tensile machine, Shirley bending tester, and a picture frame respectively. As a case study, the draping and resin-transfer moulding of the jute fabric over a complex asymmetric form was performed to measure the geometrical conformance. The adoption of natural fibres as a substitute for synthetic fibres, where the strength requirements are satisfied, would thus require no special considerations for tool design or common practices. However, the use of natural fibres would lead to weight and cost reductions.

Ghosh et.al. (2014) [39] have studied on the evaluation of the drapeability of the jute fabrics. They have tested some conventional jute woven and nonwoven fabrics, jute geotextile fabrics along with some woven and nonwoven synthetic fabrics. After performing the tests for the physical properties along with drapeability related properties of the different supplied fabric specimens and analyzing their test results, they have observed that the drapeability of the double warp woven jute geotextile specimen of area density 805 gsm (having a drape co-efficient value of 0.882) was more than that of the double warp woven jute geotextile fabric specimen of area density 627 gsm amongst the three jute geotextile specimens. It was also found that among the conventional jute woven fabric specimens hessian fabric specimen has the superior draping phenomena (having a minimum drape co-efficient value of 0.928).Comparing the conventional jute woven fabric specimens with the jute woven geotextile specimens with respect to the drape co-efficient value, it had been observed that the jute woven geotextile specimens have comparatively high drapeability than that of the conventional jute woven fabric specimens. The property parameters of the supplied fabric specimens some jute nonwoven fabric specimens along with some synthetic nonwoven fabric specimens, namely, polyester and polypropylene fabrics, had been also tested. During testing the different mechanical property parameters (such as bending length, flexural rigidity, bending modulus) of the different selected fabric specimens it had been observed that most of the property parameters were showing their responses beyond the range of the measuring capacity of the testing instruments which were used to carry out the testing of the property parameters of the different supplied fabric specimens in their study. Test results of the different supplied jute woven fabric specimens and synthetic woven fabric specimens as well as jute and synthetic nonwoven fabric specimens reveal the fact that woven jute geotextile specimens, having comparatively high area density in terms of gsm as compared to that of the conventional jute and synthetic woven fabrics and the jute and synthetic nonwoven fabric specimens show superior drapeability than the rest of the supplied fabric specimens.

Robson and Long (2000) [40], in their study investigated the application of an imaging system to the detailed objective measurement of the drape profiles of a range of wool fabrics, captured from a traditional drape tester. Image processing and software techniques are successfully implemented to enable, by the measurement of number of key parameters, a full and automatic characterization of the drape profiles reflecting visual impression. Drape coefficient values gathered via the instrumental technique correlate strongly with those established using the traditional cut and weigh approach. Strong parameter relationships are identified, and it is established that a three parameters combination of drape coefficient, numbers of nodes and variation in node severity would be required to enable good discrimination between the drape profiles of the fabric range under study.

Chen, Hu, and Ten (2001) [41] have authored a paper, dealing with the formulation of a "finite-volume method for contact drape simulations of woven fabrics and garments”. A simple and easily achievable approach for handling the contact process between a fabric sheet and a rigid object has been proposed. A number of numerical examples demonstrating the capability of the method for various drape problems and different fabric materials (cotton, wool and polyester) have been given. Based on the results and discussions presented in that paper, they proposed that the conclusions may be drawn as the validity and accuracy of the present finite-volume method together with the proposed contact determination algorithm have been demonstrated through numerical comparisons with available numerical and experimental results; among the three different fabric materials studied, the numerical simulations have shown that the wool fabric has a better drapeability than the polyester or the cotton fabric; a drape simulation of fabric sheets or garments using the present method can be easily achieved on a computer within a reasonably short period of time, which demonstrates the efficiency of the proposed method. The computer time required for the drape simulation of the softer wool fabric is generally less than that for the stiffer polyester or cotton fabric; the proposed method is not only capable of accurate and efficient simulations of contact drape deformations of simple fabric sheets but also provide realistic predictions for the drape behavior of garments such as skirts in contact with body forms.

Abdin, Taha, El-Sabbagh and Ebeid (2012) [42] have published a paper on description of draping behavior of woven fabrics over single curvatures by image processing and simulation techniques. The conclusions that they have made is about the draping ability of woven fabrics like jute and glass fibre-made fabrics which is found to improve with decreased fabric cover factor. This is reflected in low drape coefficient and high Drape Distance Ratio (DDR) values. Although the current study evidences no clear relationship between the cover factor and the number of folds created when fabric is draped, the depth of each fold, in terms of the Fold Depth Index (FDI), is observed to decrease with increasing cover factor. Experimental observations can be easily predicted with finite element tools, like PamForm2G software.

In another paper (2012) [43] Taha, Abdin and Ebeid have made a paper on the prediction of draping behavior of woven fabrics over double-curvature moulds using finite element techniques. Increased cover factor (implying increased areal density and fabric tightness) results in increased shear resistance, and hence poor draping qualities. In addition to shear behavior, out-of-plane bending properties additionally contribute to final draping. Thus, to avoid wrinkling of reinforcement fabrics in moulding operations, fabrics of low in-plane shear and high bending resistance are to be favored. Whenever possible, acute angles and large edge curvatures should be avoided in mould design. The interaction of different mould geometries is also to be avoided. Simulation techniques for the optimization of mould design and material selection have been proven to be a successful tool.
Wang and Cheng (2011) [44] have published a paper on dynamic drape property evaluation of natural fibre woven fabrics using a novel automatic drape-measuring system. In this study, static and dynamic drapeability testing values of spring/summer natural fibre woven fabrics are analyzed. The weights of the tested fabrics range from 11.0 to 18.3 mg/cm2. The ‘Four-in-One’ Automatic Measuring System for dynamic drape is used to measure fabric drapeability. The drape-testing instrument is employed with forward rotation, reciprocating motion, and swinging motion, simulating the changes in the dynamic drape of fabric when people walk at different speeds. The results of this study indicate that the dynamic drape coefficient (D_c) and dynamic drape

coefficient of fabric in forward rotation (D_{cr}) can be used to determine the dynamic drape liveliness of four types of natural fibre woven fabrics in forward rotation, the dynamic drape coefficient with reciprocating motion (D_d) can be used to determine the dynamic drape liveliness of the four fabrics in reciprocating motion, and the dynamic drape coefficient with swinging motion (D_{sr}) can be used to determine the dynamic drape liveliness of the four fabrics in swinging motion.

Lin, Wang and Shyr (2008) [45] on their investigation compared and prepared model of the dynamic drape of four natural fibre-made (cotton, linen, silk and wool) fabrics. They have primarily analyzed the dynamic drape coefficient of four natural-fibre fabrics at speeds of 0–450 rpm. A tangent partition method was used to divide the drape coefficient curve into four regions, characterized as drape coefficient increment initial growth, fast growth, slow growth and dynamic stable regions. The ANOVA test was used for validation. The dynamic drape coefficients of these four natural fibre-made fabrics were then compared. The order of the drape coefficient of these fabrics changed three times in the fast growth region and then remained unchanged throughout the slow growth and dynamic stable regions. The order of the static drape coefficient of fabrics could not represent the drape coefficient of fabrics in dynamic performance. Therefore, a linear model, a growth model and a nonlinear logistic model were used to analyze the dynamic drape coefficient curve. The results showed that the nonlinear logistic function could be used to fit the drape coefficient curves throughout the static state and the dynamic stable region.

V. COMPARATIVE ANALYSIS OF THE DRAPING BEHAVIOR OF DIFFERENT NATURAL FIBRE-MADE FABRICS

The review work shows that the draping property of fabric is an important phenomenon to satisfy the end-use requirement of the fabric both in industrial and apparel sectors and to understand their suitability as per the specific end uses. This review work shows the different methods of measuring drape of a fabric improvised over the years starting from the Peirce Cantilever Method to the modern Image Analysis Technique. These modern instruments help to reduced error to evaluate drape of fabric both qualitatively as well as quantitatively. The drapeability of natural fibre-made fabric has made them unique in their own sectors, depending on their end-use requirements. It has been observed that the drape coefficient of jute fabrics is comparatively high than the other natural fibre-made fabrics like cotton, silk and wool considering the effective property parameters of fabrics and this makes the fabrics suitable in the field of geotextile applications such as road construction, river embankment, soil erosion control in the hill slope etc. as well as in agrotextile applications like mulching, weed management etc. While, cotton, wool and silk fabrics having a comparatively low drape coefficient value than that of the jute fabric, are much more drapeable, due to which the former are very much suitable to be used in apparel sector. Again, amongst cotton, silk and wool fabrics, the later are suitable to be used as winter garments while silk fabrics are suitable in producing furnishing products along with dress wear.

VI. CONCLUSION

The results of comprehensive review shows shortcomings and constraints that have been encountered during the performance of the experiments to evaluate the drape and related property parameters of certain natural fibre-made fabrics such as jute nonwoven fabrics. It has been observed that the bending phenomenon of those fabric specimens is occurring in a region beyond the scope of measurable zone of the existing instrument, disabling to record the readings of bending property parameters of the fabric specimens. So, there lies a possibility to design and develop an instrument for precisely evaluating the draping related property parameters of jute or alike natural fibre-made fabrics. Again, during evaluation of drape and its related property parameters of coarser fibre-made fabrics, using a standard stiffness tester and drapemeter, it has been found that the number of yarns per unit length of the fabric specimen in the width direction of the instrument template is not sufficient to give a satisfactory reading due to very small size of the template width as compared to its length, which is generally 1:6 in a standard stiffness tester. Hence, it is very difficult to analyze and assess the bending behavior related to draping behavior of the fabrics within the scope of such instruments. Therefore, an instrument is required to be engineered so that true draping behavior can be evaluated for such fabrics.

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