TEKSTİL VE KONFEKSİYON

VOL: 33, NO. 3
DOI: 10.32710/tekstilvekonfeksiyon.983438

Poisson's Ratio of Non-Woven Spun Bonded Fabric for Medical Apparel

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ABSTRACT

An investigation of Poisson's ratio of a series of spun bonded non-woven fabrics, differing in areal density, number of layers, testing directions and finishes, is reported. The Poisson's ratio value is found to be higher with increase in the number of layers of spun bonded fabric assembly of fabrics of same Grams per Square Metre (GSM). The contraction in cross direction is higher than in the machine direction. Since spun bonded non-woven fabrics are anisotropic in nature, the Poisson's ratio values range from 0 to 0.728 for the various extension levels that have been considered depending on the direction of action of the tensile force in the machine (MD) and cross directions (CD). The relationship between Young's modulus & bending rigidity is poor. Flexural rigidity and Young's modulus in machine direction are higher than in cross direction.

ARTICLE HISTORY
Received: 17.08.2021
Accepted: 24.01.2023

KEYWORDS

Non-woven, Anisotropy, Flexural rigidity, Poisson's ratio, Uni-axial test

1. INTRODUCTION

Poisson's ratio is the ratio of lateral contraction strain to longitudinal extension strain in the direction of stretching force. Poisson's ratio is one of the fundamental properties of any engineering material and can be used to express the mechanical behavior of fabrics. Poisson's ratio is the elastic constant to decide the fabric tensile deformation behavior. It has been considered in the theoretical treatment of yarn and fabric mechanics. During the uni-axial extension or compression of a solid fabric material, besides the deformation in the direction of the applied force, a certain amount of lateral contraction or expansion, perpendicular to the direction of the applied stress occurs. This observable fact is called the Poisson's effect. Tensile deformation is considered positive and compressive deformation is considered negative. Poisson's ratio is the unit less scalar quantity.

Greaves, Greer, Lakes and Rouxel [1] state that the numerical metric that Poisson's ratio provides will be advantageous in researching and developing new materials, marrying the mechanical response of diverse components, from the nano to the macro scale through variable changes in shape and volume.

The Poisson's ratio is an important physical quantity in the mechanics of solids, arguably second only in significance to the Young's modulus. It is named after the French mathematician, Simeon Denis Poisson (1781-1840), who quantified the relationship of strains in the multiple directions of objects under load. The ratio of transverse contraction strain $\epsilon_{transverse}$ to longitudinal or axial strain ϵ_{axial} in the direction of the applied load force is defined as the Poisson's ratio:

$$v = \frac{-\epsilon_{trans}}{\epsilon_{axial}} = \frac{-\epsilon_y}{\epsilon_x} \qquad (1)$$

In Equation (1) the minus sign indicates that the traverse strain has a sense opposite to that of the longitudinal strain.

Tadeja Penko & Jelka Gersak [2] studied the test method on the longitudinal and transverse deformation of specimens and determination of Poisson's ratio with strip quadratic method using KES - FBI measuring device for up to 1% of tensile deformation. On the analysis, they found

To cite this article: Ramamurthy P, Paranthaman S. 2023. Poisson's ratio of non-woven spun bonded fabric for medical apparel. *Tekstil ve Konfeksiyon,* 33(3), 219-228.

deformations by the strip biaxial method, when tensile force was applied in the longitudinal direction the response of the test specimens on tensile loading is different along each specimen. They introduced the strip quadratic method for determining the Poisson's ratio. On the basis of the obtained results they concluded that the strip quadratic method was found to be effective than biaxial method.

Lloyd & Hearle [3] in their study of fabric Poisson's ratio, using wide-jaw test method, where they have considered only one width, have reported that a large width to length ratio of specimen dimensions would be required in order overcome the errors in uni-axial testing.

Kilby [4] was one of the earliest to define Poisson's ratio and explained the dependence of the modulus of elasticity of fabric in relation to the directions of action of the tensile forces. The method for evaluating the anisotropic tensile behavior using the "uni-axial test method" was investigated by other researchers during their study of the mechanical properties of fabrics [5-7].

Nazanin Ezaz Shahabi [8] studied the effect of fabric structure and weft density on the Poisson's ratio of the worsted woven fabrics. They observed that the higher weft density had higher Poisson's ratio and also concluded that higher the structural firmness of the fabric higher the Poisson's ratio. They reported that a higher linear correlation exists between crimp interchange and Poisson's ratio. They have also reviewed the subject of Poisson's ratio of fabrics recently [9].

Huiyu Sun & Ning Pan [10] developed a mechanical model for a woven fabric made of extensible yarns to predict Poisson's ratios. The Poisson's ratio depends on the properties of the yarns and structural geometry of the fabrics. Their investigations show that the increase in Young's modulus ratio increases the Poisson's ratio. The increase in diameter ratio between warp and weft yarns also increased the Poisson's ratio. The effects of structural parameters of fabrics are more pronounced than the yarn mechanical parameters.

Hearle & Ozsanlav [11] studied adhesive–bonded non-woven fabrics for Poisson's ratio using Instron tester. They reported that the rate of contraction was initially low but after 5-10% extension it tends to increase. The lateral contraction varied with the direction of the fabric. The fabrics contracted more in machine direction than the cross laid ones.

Hursa, Rolich & Ercegovic Razic [12] measured Poisson's ratio for three cotton woven fabric samples that were exposed to tensile loading of 1% strain on a tensile test machine. Testing was simultaneous with recording done on a digital video camera. These video recordings were afterwards processed in the MATLAB program and pseudo Poisson's ratio was determined according to the displacement in the x and y directions. For woven plain weave fabric pseudo Poisson's ratio was of higher value than that of twill weave.

Goswami [13] compared uni-axial and biaxial tests in terms of their efficiency and accuracy in determining Poisson's ratio for thermally bonded non-woven fabrics. The binder fibre film characteristics tend to dominate the effect on changes in dimensions during uni-axial straining. The biaxial test was tedious and consumed much time but it gave a better estimate of Poisson's ratio for non-woven fabrics.

Snjezana Brnada [14] studied the Poisson's ratio and shear modulus of complex, nonlinear elastic material, such as woven fabric. They found that at higher extensions, the common methodology becomes unsuitable because of woven fabric buckling. A mechanical model was developed to calculate Poisson's ratio throughout the fabric stress-strain curve.

Zeljko Penava [15] analysed the values of elastic constants of woven fabrics for different angles of extension direction. They tested the Poisson's ratio for four types of fabric samples in seven directions with a 15° increment with respect to weft direction. They concluded that the measurements are to be undertaken when tensile force is acting only in the warp, weft and at an angle of 45°. Giroud [16] analysed the Poisson's ratio of non-woven geo-membranes and found theoretical equations for calculating Poisson's ratio as a function of strain. Collier [17] experimented on the simulation of fabric drape using finite element analysis. They opined that Poisson's ratio affects the fabric drape.

Jinyun [18] found that there is a significant Poisson's effect for knitted fabric under tensile deformation. They proposed a method for testing the Poisson's ratio and tensile modulus for elastic knitted fabric based on orthotropic theory and strip biaxial tensile test.

Recently, Leucker & Schubert [19] have analyzed the influence of size and fraction of bonding points onto the mechanical behavior of Polypropylene spun bond non-wovens. They investigated the influence of bonding point fraction, bonding point size and spacing on the tensile properties of non-wovens. In addition to that, fiber orientation and cloudiness on the strength were also evaluated. It has been demonstrated that an increase in the bonding fraction leads to an increase in stiffness, whereas an increase in the distance between the bonding points leads to a reduction in the Young's modulus. Although the strength increases with increasing bonding point content, more transitions between bonding points and free fiber matrix are introduced when the bonding point size is kept constant, which leads to an additional damage and thus to a reduction in strength.

Leaf [20] had summarized the mechanical equations previously derived relating the mechanical properties of plain woven fabrics and their geometrical parameters and also derived relationships among the mechanical properties. The shear modulus and fabric bending rigidity relationships were discussed.

Zhang, Ghita and Evans [21] investigated the Poisson's ratio behavior of a further development of the HAY (Helical Auxetic Yarn), needed for many practical applications. The 3-component auxetic yarn is based on a stiff wrap fibre (the first component) helically wound around an elastomeric core fibre (the second component) coated by a sheath.

Miller, Hook and Smith [22] present the use of double helix yarn that is shown to be auxetic and the Poisson's ratio of auxetic composite made from the yarn in a woven yarn.

Sloan, Wright and Evans [23] studied the range of helical auxetic yarn with varying geometric properties of structures and the effect of the auxetic behavior of these with the Poisson's ratio of the yarn.

Ali, Zeeshan and Ahmed [24], studied the knitted Auxetic Fabrics (AF), the AF structures is seen to improve the comfort properties of the fabrics with different fabric geometry and utilizing the differential shrinkage properties of different structures.

Tiritoğlu, Tezel and Kavuşturan [25] used Universal tensile tester for estimation of the Poisson's ratio of the fabric is studied.

Chen and Govindaraj [26], studied that bending rigidity should influence conformability and intimacy of contact between two bodies.

Penava, Simic and Knezic [27], have reported that the shape of the Poisson's ratio curve of the woven fabric is the result of the internal interactions in the fabric.

Rawal [28], in an investigation of bending rigidity (BR) of the non-woven fabric concluded that bending rigidity decreases with an increase in the test direction, revealing the anisotropic characteristics in bending properties. The combined effects of fibre volume fraction/fibre modulus and anisotropy constant have significant effect on the bending rigidity of thermally bonded non-woven structures.

In a review paper by Yilmaz, Sabuncuoglu, Yildirim and Silberschmidt [29], they have reported that in coupled experimental and numerical studies revealed that self-bonded non-woven fabrics could withstand higher bending stresses with superior extensibility in both tension and compression.

Poisson's ratio is primarily used by engineers to identify how much a material can be stretched or compressed before it fails. This is commonly used in the design of new structures because it allows considering the expected dimensional changes of a given material when under load.

Aim of the Study

A medical protective garment like surgical gown is used to protect the operating room personnel from transfer of micro-organisms, body fluids and particulate material. The performance related mechanical behavior influences the scope of its end use, as they are subjected to stress and strain during wearing. The relevance of Poisson's ratio could be envisaged to the made-up garment characteristics for effective performance.

As Poisson's ratio is an elastic constant which is very much applicable to engineering materials, few studies are available concerning investigation of textile material like woven fabrics but are scanty with reference to non-woven used for medical apparel. This coefficient determines the important mechanical characteristics of fabrics in many applications where textiles are used as a structural element.

Fabrics are subjected to various levels of loading (tension, bending, shear loads & compression) in their real-time use as an article of clothing [16] .Hence, this study has been taken up on spun bonded non-woven fabric with a view to quantifying the variables that influence the Poisson's ratio and the fabric's mechanical behavior under a lower stress in the linear part with reference to the elastic model of Hooke's law.. The effects of areal density and thickness on Poisson's ratio have been also been examined in this study.

2. MATERIALS

An experimental design for study of quantitative variables was adopted, taking into account the parameters of fabric Grams per Square Metre (GSM), number of sandwich layers and thickness, The materials studied comprise 12 commercial samples, details of which are given in Table 1.

Table 1. Details of the samples studied

Variety	GSM	Sample ID
SMS (Spunbond-Meltblown-Spunbond)	35	SMS1
SMS (Spunbond-Meltblown-Spunbond)	35	SMS2
SMS (Spunbond-Meltblown-Spunbond)	50	SMS3
Antistatic SMS (Spunbond-Meltblown-Spunbond)	35	ASMS1
Antistatic SMS (Spunbond-Meltblown-Spunbond)	50	ASMS2
Alcohol Repellent and Antistatic SMS (Spunbond-Meltblown-Spunbond)	35	ARASMS1
Alcohol Repellent and Antistatic SMS (Spunbond-Meltblown-Spunbond)	45	ARASMS2
SMMS (Spunbond-Meltblown-Meltblown-Spunbond)	35	SMMS
SSMMS (Spunbond-Spunbond-Meltblown-Meltblown-Spunbond)	35	SSMMS1
SSMMS (Spunbond-Spunbond-Meltblown-Meltblown-Spunbond)	43	SSMMS2
SSMMS (Spunbond-Spunbond-Meltblown-Meltblown-Spunbond)	50	SSMMS3
BVB (Breathable Viral Barrier)	70	BVB

Table 2. Physical characteristics of the spun bonded fabric studied

Sample code	Direction	Thickness (mm)	GSM	Tensile Strength (N)	Young's Modulus (MPa)	Elongation (%)	Flexural Rigidity (gm*mm/rad)
SMS1	MD	0.25	35	90.45	26.1	52.08	104.3
	CD			40.45	13.7	56.37	36.4
SMS2	MD	0.30	35	107.30	32.5	53.64	196.2
	CD			51.98	11.2	56.41	69.1
SMS3	MD	0.31	50	95.53	26.2	54.50	62.0
	CD			51.19	10.0	57.32	29.8
ASMS1	MD	0.26	35	75.65	31.1	50.32	189.4
	CD			40.75	10.1	65.42	92.1
ASMS2	MD	0.33	50	123.56	21.5	52.41	161.9
	CD			56.57	8.99	50.56	51.1
ARASMS1	MD	0.23	35	71.70	41.5	41.55	50.0
	CD			32.32	13.8	51.10	38.8
ARASMS2	MD	0.28	45	100.74	35.1	35.98	54.7
	CD			42.75	10.1	48.42	20.2
SMMS	MD	0.23	35	76.77	45.3	38.11	50.8
	CD			36.95	17.2	42.34	12.7
SSMMS1	MD	0.26	35	89.21	27.2	56.36	180.3
	CD			41.14	9.5	63.64	112.8
SSMMS2	MD	0.31	43	110.52	25.5	51.74	183.1
	CD			52.73	9.06	59.11	62.1
SSMMS3	MD	0.35	50	112.34	21.7	52.31	318.1
	CD			52.04	10.6	59.50	111.6
BVB	MD	0.38	70	113.91	27.9	39.13	125.5
	CD			57.93	5.18	55.08	47.3

*MD – Machine Direction, CD – Cross Direction

Table 2 represents the thickness, GSM, Young's modulus, elongation and flexural rigidity of the spun bonded non-woven surgical gown fabrics analyzed in both MD & CD. The elongation values for all the spun bonded materials are higher in the case of cross direction when compared to machine direction. This is in agreement with the findings of other researchers [18].

The value of flexural rigidity is higher in the MD than in the CD for all the samples. The value of flexural rigidity is found to be less for alcohol repellent and antistatic finished fabrics when compared to ordinary SMS fabric of the same GSM. As the number of layers (like SSMMS) increases, the flexural rigidity also increases for the same GSM. Very low flexural rigidity value was observed in sample no.8 at the cross direction.

3. METHODS

Testing of Samples

Tensile tester Zwick Roell UTM was used for measuring Poisson's ratio and for investigating the effects of gauge length and areal density of the spun bonded non-woven fabric. Fabric samples were prepared with dimensions of 200 x 50 mm with 5 specimens each in machine direction (MD) and cross direction (CD). The sample size adopted was based on the research on strip quadratic method done by Tadeja Penko & Jelka Gersak [1]. The speed of extension was maintained at 10mm/min. The spun bonded fabric was subjected to a uni-axial strain and Poisson's ratio calculated for both the machine and cross directions. The uni-axial strain was applied in 10 steps (viz. 2.5%,5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5% & 25%) and the fabric contraction was measured to evaluate the Poisson's ratio at all extension levels given above.

The cyclic test (program) allows the test to be conducted at various extension levels and provide time lag (30 sec) to measure the contraction on the fabric at the desired extension. A pre-tension of 0.5N was maintained and the gauge length used was 50mm. The fabric samples were marked at the centre so as to make the contraction measurement at the midline. The fabric was marked with lines as shown in the Figure 2. Lines 'A' & 'B' indicate clamping lines and line 'C' represents the midline.

A delay time of 30sec was set to measure the contraction. The values were recorded and Poisson's ratio was calculated. Statistical analysis of the data was done using Microsoft Excel.

The fabric areal density was determined as per ISO 9073-1; the tensile strength was evaluated as per ISO 9073-3 in both the machine and cross directions. The thickness of the non-woven fabrics was measured as per ISO 9073-2. The flexural rigidity of the non-woven fabrics was evaluated on the FTT (Fabric Touch Tester from SDL) as per M293 manufacturer's protocol. The flexural rigidity is measured in terms of force needed to bend the fabric per radian.

Figure 1. Experimental set-up on Zwick Roell equipment

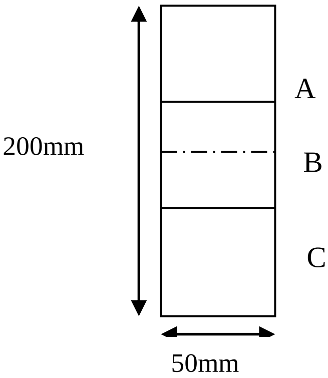

Figure 2. Diagrammatic representation

4. RESULTS AND DISCUSSION

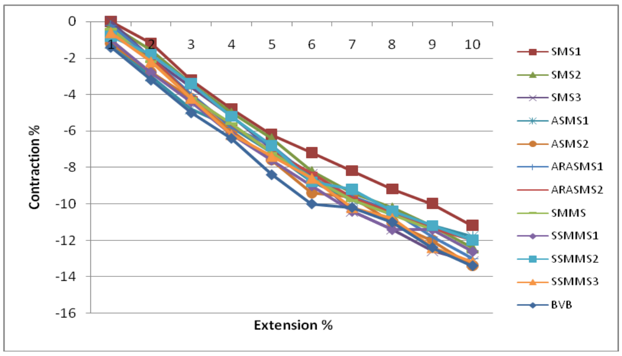

Figure 3. Spatial deformation of the fabric in the machine direction

Figures 3 & 4 represent the spatial deformation of the fabric sample with extension. It is evident that fabric contractions are small at the beginning of stretching. With increase in extension or strain & fabric stretching the values of fabric contraction also increase.

The Regression value (R^2) between relative contraction vs. relative extension shows that a higher linearity is observed in the cross direction when compared with the analysis in the machine direction (Table 3). The correlation between the mechanical parameters is shown in Table 4, where the flexural rigidity is lower with increasing elongation and has the least correlation and is inversely related.

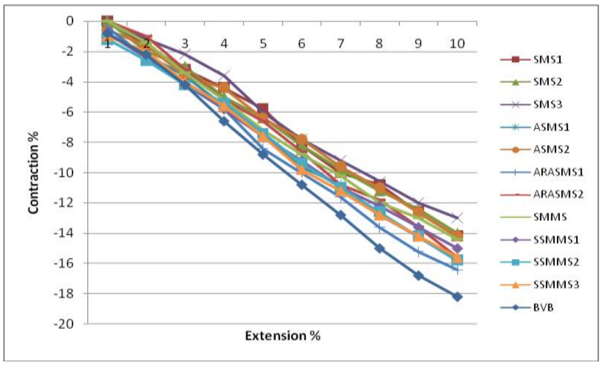

Figure 4. Spatial deformation of the fabric in the Cross Direction

Table 3. Regression value of Contraction Vs Extension

Sample Id	Machine Direction	Cross Direction
SMS1	0.9831	0.9962
SMS2	0.9886	0.9978
SMS3	0.9887	0.9925
ASMS1	0.9730	0.9970
ASMS2	0.9864	0.9975
ARASMS1	0.9861	0.9968
ARASMS2	0.9769	0.9971
SMMS	0.9806	0.9949
SSMMS1	0.9708	0.9974
SSMMS2	0.9783	0.9982
SSMMS3	0.9853	0.9960
BVB	0.9731	0.9976

Table 4. Correlation between Flexural Rigidity and Tensile strength, Young's Modulus, Elongation

Correlation between	Flexural Rigidity
Tensile strength	0.6631
Young's Modulus	0.2628
Elongation	0.1601

It could be inferred that correlation coefficients whose magnitudes are between 0.5 and 0.7 indicate variables which can be considered moderately correlated. Correlation coefficients whose magnitudes are between 0.3 and 0.5 indicate variables which have a low correlation at 0.05% level of significance.

It was found that the classical equation (2) for bending rigidity (BR) is inapplicable for these spun bonded non-woven materials considered.

$$BR = \frac{Et^3}{12(1-\nu^2)} \qquad (2)$$

Where, 'BR' is the Bending Rigidity
'E' is the Young's Modulus
't' is the fabric thickness &
'v' is the Poisson' Ratio (PR)

Table 5. Poisson's ratio at Different Extension Levels – MD

Extension %	SMS1	SMS2	SMS3	ASMS1	ASMS2	ARASMS 1	ARASMS 2	SMMS	SSMMS 1	SSMMS2	SSMMS 3	BVB
2.5	0.000	0.080	0.000	0.350	0.480	0.080	0.267	0.160	0.400	0.320	0.240	0.560
5	0.240	0.320	0.400	0.450	0.560	0.400	0.400	0.440	0.560	0.360	0.440	0.640
7.5	0.427	0.453	0.480	0.520	0.580	0.533	0.556	0.560	0.587	0.453	0.560	0.667
10	0.480	0.500	0.520	0.580	0.600	0.580	0.567	0.560	0.620	0.520	0.580	0.665
12.5	0.496	0.512	0.560	0.576	0.608	0.544	0.573	0.576	0.608	0.544	0.592	0.672
15	0.480	0.547	0.560	0.587	0.600	0.573	0.556	0.573	0.600	0.587	0.573	0.667
17.5	0.469	0.537	0.594	0.560	0.590	0.549	0.552	0.560	0.594	0.526	0.583	0.583
20	0.460	0.510	0.570	0.530	0.550	0.520	0.525	0.530	0.570	0.520	0.540	0.550
22.5	0.444	0.498	0.560	0.498	0.533	0.524	0.504	0.507	0.507	0.498	0.551	0.551
25	0.448	0.496	0.528	0.472	0.536	0.520	0.480	0.504	0.504	0.480	0.528	0.536

Table 6 — Poisson's ratio at Different Extension Levels - CD

Extension %	SMS1	SMS2	SMS3	ASMS1	ASMS2	ARASMS1	ARASMS2	SMMS	SSMMS1	SSMMS2	SSMMS3	BVB
2.5	0.000	0.000	0.000	0.320	0.240	0.160	0.000	0.000	0.320	0.480	0.400	0.320
5	0.320	0.300	0.240	0.440	0.320	0.480	0.200	0.280	0.480	0.520	0.400	0.440
7.5	0.427	0.400	0.293	0.480	0.400	0.560	0.427	0.453	0.533	0.560	0.533	0.560
10	0.440	0.500	0.360	0.560	0.440	0.580	0.520	0.520	0.580	0.540	0.560	0.660
12.5	0.464	0.512	0.480	0.608	0.512	0.672	0.528	0.576	0.608	0.592	0.608	0.704
15	0.547	0.547	0.520	0.640	0.530	0.667	0.573	0.587	0.613	0.627	0.653	0.720
17.5	0.571	0.560	0.526	0.617	0.549	0.663	0.617	0.583	0.629	0.629	0.640	0.731
20	0.540	0.560	0.530	0.640	0.550	0.680	0.590	0.600	0.610	0.630	0.640	0.750
22.5	0.560	0.551	0.533	0.631	0.560	0.676	0.604	0.578	0.604	0.631	0.631	0.747
25	0.568	0.560	0.520	0.632	0.568	0.656	0.624	0.576	0.600	0.632	0.624	0.728

Tables 5 & 6 give the experimental values of Poisson's ratio for the various fabrics studied at specified extension % in the machine and cross directions.

From Figure 5, it is also observed that the trend of Poisson's ratio curve is found to be almost similar for all the samples at various extension levels in the machine direction. It is seen that the Poisson's ratio increases initially (till 15%) and then decreases as the extension is increased (up to 25%) in the machine direction.

From Figure 6 it may be seen that, in cross direction the plot flattens above 15-20% extension for all the fabric varieties studied. The Poisson's ratio increases non-linearly and after having reached the peak value, it decreases. These two zones represent the two different processes in the deformation of the fabric. The first zone represents the way of the lateral contraction because of the longitudinal stretching. The second zone shows the termination of the lateral contraction of the fabric and the fabric is stretching without any further contraction. The plot flattens above 15% for all the fabric varieties studied.

From Table 6, it is apparent that the correlation between GSM and PR is found to be more prominent than the correlation between thickness and PR.

Poisson's ratio of fabrics with identical GSM and Multiple layers

A comparison of the Poisson's ratio was made for identical GSM fabrics but with similar multiple layers. From the plots as shown in Figures 7-10, it is seen that the value of Poisson's ratio is higher for the SSMMS samples and lower for SMS samples. It is inferred that as the number of layers increase for spun bonded fabric, the value of Poisson's ratio also increase. The trend remains the same for 35 GSM as well as for 50 GSM.

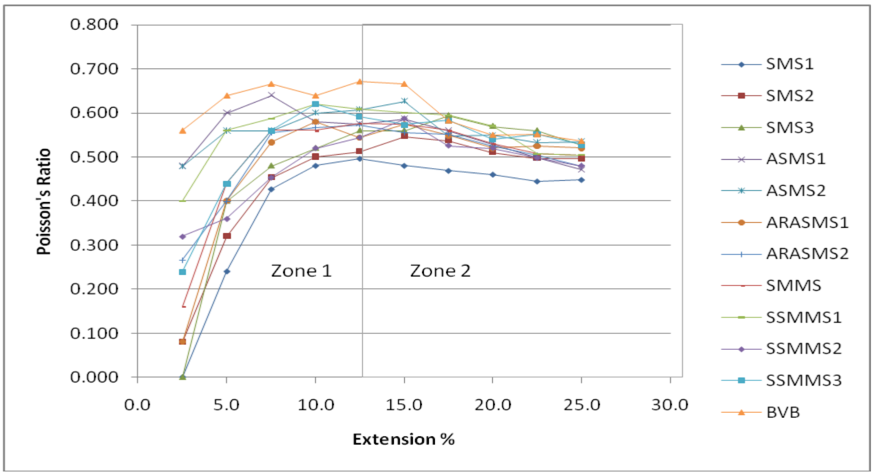

Figure 5. Poisson's ratio values of the non-woven fabrics in Machine Direction

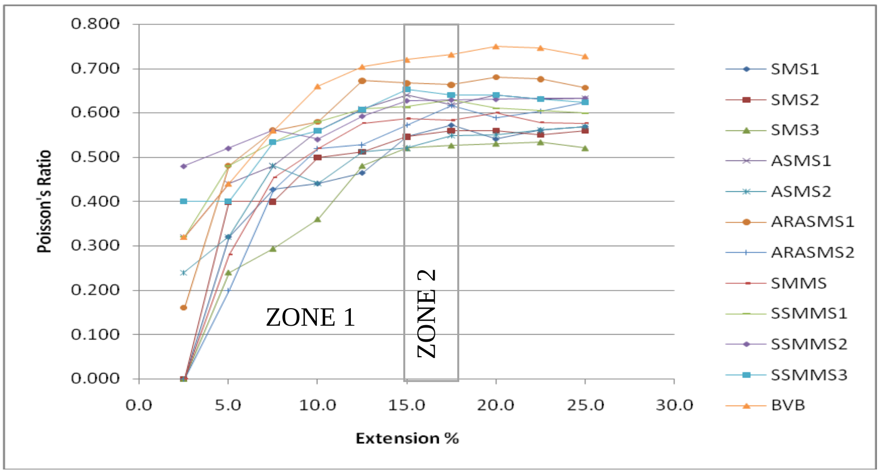

Figure 6. Poisson's ratio values of the non-woven fabrics in Cross Direction

Table 6. Correlation between Poisson's ratio and Thickness & Poisson's ratio and GSM

S. No	Correlation at different extension Levels	Thickness Vs. PR	GSM Vs. PR
1	5%	0.35	0.59
2	10%	0.23	0.53
3	15%	0.42	0.63
4	20%	0.39	0.43

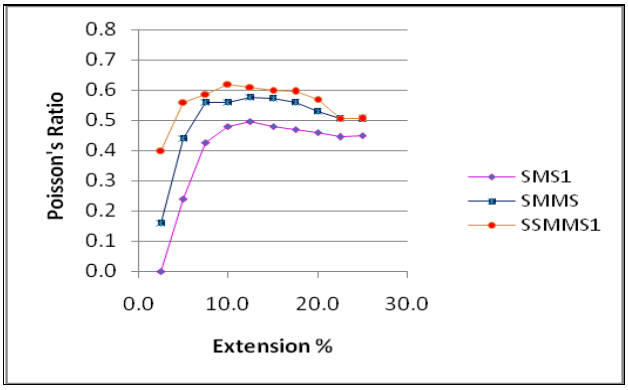

Figure 7 - MD

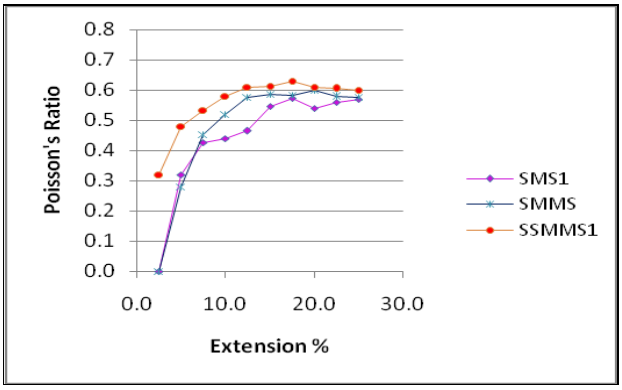

Figure 8 - CD

Figures 7 & 8. Comparison of SMS, SMMS and SSMMS fabrics of 35 GSM

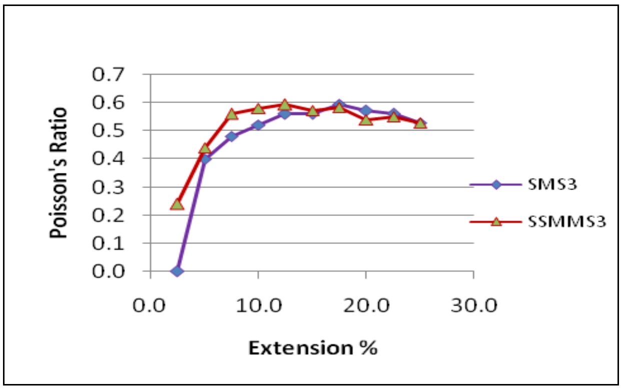

Figure 9 - MD

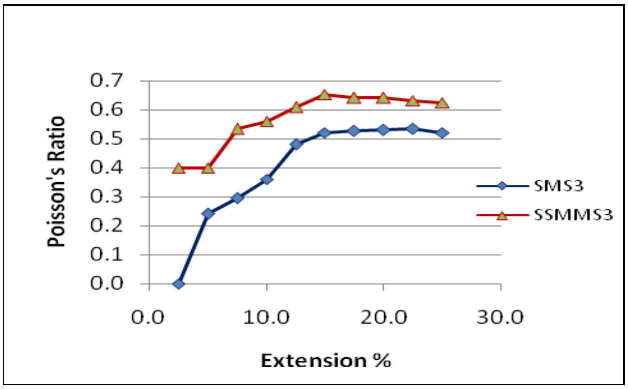

Figure 10 - CD

Figures 9 & 10. Comparison of SMS and SSMMS fabrics of 50 GSM

Table 7. Regression between Poisson's ratio and Extension %

Sample Code	Machine Direction			Cross Direction		
	Linear Equation	m	R^2	Linear Equation	m	R^2
1	Y= -0.0168X+0.1783	-0.017	0.4875	Y= 0.019X+0.1825	0.0190	0.6691
2	Y= 0.0131X+0.2647	0.0131	0.4811	Y= 0.0189X+0.1886	0.0172	0.5701
3	Y= 0.0159X+0.2591	0.6036	0.462	Y= 0.0205X+0.1184	0.0205	0.7619
4	Y= 0.0035X+0.4645	0.0035	0.1273	Y= 0.0125X+0.3852	0.0125	0.7515
5	Y= 0.0003X+0.5594	0.0003	0.0035	Y= 0.0139X+0.276	0.0139	0.8510
6	Y= 0.0114X+0.3257	0.0114	0.3315	Y= 0.0162X+0.3568	0.0162	0.5759
7	Y= 0.0059X+0.4168	0.0059	0.213	Y= 0.0233X+0.1483	0.0233	0.7161
8	Y= 0.0083X+0.3833	0.0083	0.2481	Y= 0.0199X+0.2019	0.0199	0.6051
9	Y= 0.001X+0.5418	0.0010	0.0115	Y= 0.0095X+0.4269	0.0095	0.5766
10	Y= 0.0068X+0.3875	0.0068	0.3839	Y= 0.0068X+0.4908	0.0068	0.8481
11	Y= 0.0079X+0.4101	0.0079	0.3114	Y= 0.0108X+0.4206	0.0108	0.7145
12	Y= -0.0041X+0.6648	-0.004	0.2832	Y= 0.017X+0.4027	0.0170	0.7455

Y – Poisson's ratio, X – Extension %, m – slope of the regression line, R^2 – regression value

Table 7 gives the values of the linear equation between Poisson's ratio and extension%, as well as the slope value and linear regression value. The slope 'm' of the linear equation of the plot of Poisson's ratio and extension levels is lower when tested in the machine direction compared to values for cross direction of the fabric, which means that the contraction level of the fabric in the cross direction is higher than that of the machine direction. This characteristic is in line with the work done by Hearle & Ozsanlav [9].

The R^2 value is found to be higher for cross direction than machine direction in the strain vs. Poisson's ratio plot in spite of the relationship between the variables 'X' and 'Y' being quite low and statistically insignificant.. A comparatively higher value of R^2 would mean that a higher percent of variation in the Poisson's ratio is due to the variation in the extension levels in cross direction.

5. Conclusion

The flexural rigidity in machine direction is higher than in cross direction for all the spun bonded fabric samples, while, the elongation % showed a reverse trend. With multiple layers, the flexural rigidity increases for the same GSM. It was observed that the Poisson's ratio increases initially and then decreases slightly as the extension is increased in machine direction for all fabrics studied.

The graph flattens for cross direction after 15% extension for all the fabrics studied. It is inferred that as the number of layers increases for spun bonded fabric, the value of Poisson's ratio also increases when compared with fabrics of same GSM which can be related to the structural integrity of the component layers. The contraction level in machine direction is higher than in the cross direction. In the machine direction, the extension contributes much lesser and there may be other factors like binder film, melt structure, degree of orientation of fibrils, etc., influencing the Poisson's ratio.

Since spun bonded non-woven fabrics are anisotropic in nature, the Poisson's ratio values range from 0 to 0.728 for the various extension levels considered depending on the direction of action of the tensile stress (Machine Direction & Cross Direction).

The correlation between GSM and Poisson's ratio is found to be moderate (0.5-0.7), whereas the correlation between the thickness and Poisson's ratio is lower (0.2-0.4). The regression plot between contractions vs. extension reveals the values for CD shows more linearity when compared to MD.

The correlation between Young's modulus and flexural rigidity is poor although the trend followed is similar in both machine and cross directions. The classical formula is found to be inapplicable for predicting the Poisson's ratio.

For certain applications, due to high Poisson's ratio of the fabric material used, the machine width is over-designed or process conditions are compromised in order to control the width-loss. This problem also extends into finishing operations causing issues of sheet control and overcompensating machine conditions or product dimensions.

Recommendations based on this study would be

Since the elongation values are higher and higher contraction (higher Poisson's ratio) is found in cross direction, the manufacture of surgical gown may be patterned accordingly to provide more comfort and stability during use for the medical personnel. With the current COVID 19 pandemic, this study could offer a critical insight into the various aspects to be considered in manufacturing coverall/bodysuits for physicians and patients.

Medical apparel manufacturers need to go in for a fabric with better elongation behavior, low to medium flexural rigidity and higher Poisson's ratio. It is suggested to use right fabric direction for various garment panels like yoke & shoulder rounds.

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