RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

Textiles are utilized for its functional and aesthetical parameters amongst which one of the factors is protection against hazardous pollution – UV rays, Sound absorbers, etc. Unfortunately, our non-renewable resources are used in the manufacturing such products which causes deterioration in our resources and in addition to it the processing method creates the environmental pollution. The present study highlights the sustainability of sustainable material like sisal and ramie for sound resistance materials. The fiber was processed, finished and converted into woven fabrics. The fabrics were analyzed for its sound resistance and factors affecting has been discussed.

The results have been given and discussed under the following subsection:

4.1. Characterization of fibers

4.2. Optimization of softening treatment

4.3. Analysis of the untreated and treated fiber

a. Chemical analysis
b. Structural analysis
c. Element analysis
d. Physical properties

4.4. Analysis of yarn properties

a. Yarn fineness and twist
b. Yarn strength

4.5. Analysis of the structural properties of the fabrics

4.6. Factors affecting the sound absorption properties of different fabrics

a. Effect of distance between sound source and sample
b. Effect of frequency on different types of fabrics
c. Effect of number of layers

4.7. Analysis of fabric properties of selected fabrics

a. Comparative analysis of unfinished and resin finished fabrics
b. Performance analysis

4.8. SWOC analysis

4.1. Characterization of fibers

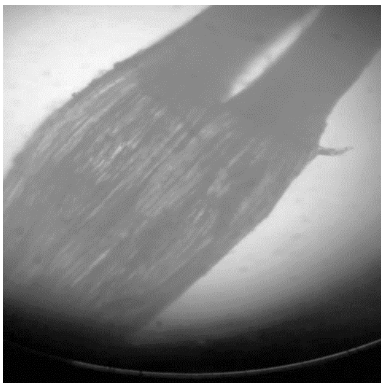
The two different lignocellulosic minor fibers – sisal and ramie were selected for manufacturing different sound absorbing fabrics. The inherent characteristic and the hollow structure make this fiber suitable for sound absorbing materials. The characterization of the fiber was done for its physical and structural property. The preliminary data of the fibers were accessed and the details are mention in Table 4.1.

Table 4.1: Preliminary data of fibres.

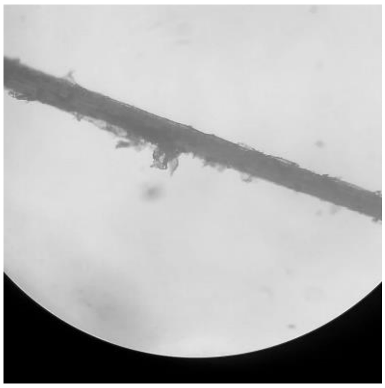
Type of Fibre	Length (cm)	Diameter (µm)	Denier
Sisal (Sr)	70	179	198
Ramie (Rr)	48	79	739

The creamy white sisal fibers have been derived from the leaf of the plant Agave Sisalana. According to Guerrero, B. et.al. (2016) each individual fiber has multicellular bundle of polygonal hollow sub fibers and the characterization of the fiber has been done. The length of the fiber was found 70 cm so it is characterized as filament fiber. The average diameter and the denier measured between 179 µm and 198 respectively. The sisal fiber seems stiffer and less cohesive in nature but has good strength.

The longitudinal view of the fibers was observed under the compound microscope with the magnification of 10X power to identify inner structure of the fibers. Sisal under the microscope showed straight striations with clear lined structure. Plate 4.1 (a), which reveals that it is more crystalline in nature. However, the fibers being smooth consists of multicellular sub fibers, thus considered as bundled fiber. Each single fiber seems to be stiff as they are very straight with pointed edges, while little unevenness on the surface could be due to impurities.



(a) Sisal fibre



(b) Ramie fibre

Plate 4.1 Microscopic view of the fibers

The ramie a lignocellulosic fiber of brown colour and derived from bast of the plant Boehmeria Nivea. A filament fiber was found to be of 48 cm in length and each bundle of fiber consists of many sub fibers. The average diameter and denier measured between 79 µm and 739 respectively. The fiber is known for its good tensile strength and absorbent characteristics owing to its inherent hollow structure. Additionally, the fibers are lustrous, ability to hold the shape and reduce shrinkage as stated by Du, Xuan., et.al. (2013).

While, the Plate 4.1 (b) of Ramie fiber shows nodes at various intervals when the fibers were observed under the microscope. The roughness on the surface can be the impurities as well as the small protruding sub-fibers. On separating the sub fibers, they are very smooth and soft similar to cotton fibers.

4.2. Optimization of softening treatment

The single fiber strength and feel test of all the fiber samples were conducted to identify two best treated fiber samples which will be pliable and useful for creating sustainable products from each fiber category (Table 3.3). The optimized recipe used for the treatment has given in the table 4.2.

Table 4.2: Optimised recipe of enzyme treatment on the fibers

Sr. No.	Treatment sequence	% Concentration	Time
1.	Beating	-	10 mins
2.	Combing	Combing of the fibers in small bundles	
3.	Pectinase	2%	15 mins
4.	Laccase	10%	30 mins
5.	Cellulase	7%	45 mins
6.	Hemicellulase	5%	60 mins
7.	Oil emulsion (water + Rice brain oil + Non-ionic detergent)	Oil – 5% Detergent – 25%	10 mins
8.	Batching	-	Over night
9.	Combing	Combing of the fibers in small bundles	

The recipe has been standardized and the process was conducted on Infracolor and Launder-O-Meter machines in the Laboratory to analyze the possible bulk and commercial treatment method. The two treated fibers using Launder-O-Meter machine from each category - Sisal-High % concentrated-Combing-Beating-Combing (*Shcbc*), Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water) (*Shcbc4*), Ramie-High % concentrated-Combing-Beating-Combing (*Rhcbc*) and Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water) (*Rhcbc4*) were finalized based on the analyses. Hence the optimized recipe with launder-o-meter process giving best results with less processing time and possible bulk quantity treatment was further tested for its chemical, structural and physical analysis keeping raw fibers as standard.

4.3. Analysis of the untreated and treated fiber

One of major factor in selecting both these fibers was its natural beauty in terms of colour. As the created fabrics will be installed as interiors for sound absorption, the fabrics need to be eco-friendly with the elements of aesthetics. Thus, utilizing natural hue of sisal (cream) and ramie (brown) for interiors was experimented. So, whiteness index was checked of untreated and treated fibers to identify the change in colour after the treatment.

Whiteness index of the untreated and treated fibers was observed from the test results. The more of whiteness was achieved by both the Shcbc4 and Rhcbc4 – enzyme treatment without changing water. While negligible difference was observed in the yellowness of both the fibers, which could be because of cellulase and laccase enzymes. The details of the whiteness index are mentioned in Table 4.3.

Table 4.3: Whiteness and yellowness index of raw and treated fibers

Sr. No.	Sample	Whiteness	Yellowness
1.	Sr (Raw Sisal)	71.49	27.07
2.	Shcbc	69.16	27.35
3.	Shcbc4	68.92	29.37
4.	Rr (Raw Ramie)	45.13	52.59
5.	Rhcbc	49.72	52.88
6.	Rhcbc4	53.91	41.02

Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water), Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water).

The lignocellulosic fibers are composed of cellulose, hemicellulose, lignin, pectin and waxes. Hence to understand the reaction and effect of the softening process using enzymes on both the fibers certain tests has been done to check its chemical and structural properties of untreated and treated fibers.

a. Chemical analysis

The untreated and treated fibers have been analyzed for its chemical composition using Fourier Transform Infrared Spectroscopy (FTIR). This analysis highlights the change in the active molecular functional groups in the fiber constituents. Sisal fibers – untreated (Sr) and treated (Shcbc and Shcbc4) were analyzed and frequency ranges representing the changes in the bonds are given in Table 4.4.

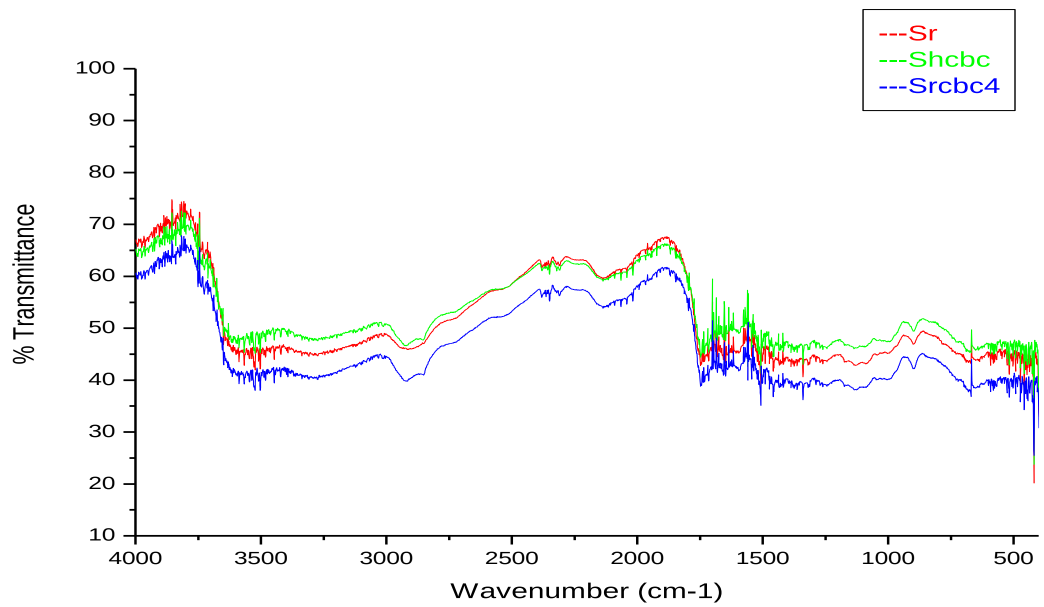
Table 4.4: FTIR absorbance band of untreated and treated sisal fiber samples

Frequency Range	Absorption (cm^{-1})	Group	Sr	Shcbc	Shcbc4
4000-3000cm^{-1}	3550-3200	O-H stretching	3502.85 3451.73	3566.50 3523.10 3502.85	3562.64 3502.85
3000-2500cm^{-1}	3000-2840	C-H stretching	2936.72 2902.00	2934.79	2922.25
2400-2000cm^{-1}	2140-2100	C=C stretching	2136.23		2139.13
2000-1650cm^{-1}	1750-1735	C=O stretching	1747.57 1743.71	1746.60 1742.74 1737.92	1747.57
	1730-1715	C=O stretching		1715.74	
1600-1300cm^{-1}	1550-1500	N-O stretching		1507.42	1516.10
1400-1000cm^{-1}	1440-1395	O-H bending	1433.16 1423.51		
	1420-1330	O-H bending	1417.73		1362.75
	1390-1310	O-H bending	1378.18 1374.33 1339.61 1319.35		
	1275-1200	C-O stretching	1271.13 1260.52		
	1210-1163	C-O stretching	1173.72 1166.97		

	1205-1124	C-O stretching	1126.47		1126.47
	1124-1087	C-O stretching	1120.68 1112.96 1106.21		1121.64

The Graph 4.1 shows significant differences in infrared spectra. The four different enzymes used in the treatment works on the individual components of the fiber i.e. pectin, cellulose, hemicellulose and lignin. As sisal being the stiffer fiber, it was important to break the lignin content for achieving cohesiveness and thereby success in spinning of the fibers.

The FTIR spectra of the fibers indicate that the intensity of the absorption band of O-H stretching of hydrogen bond ranging between 3400-3600 cm^{-1} increases in Shcbc, while it decreased slightly after Shcbc4 treatment. This is likely due to the breaking of hydrogen bonds between O-H groups of cellulose and hemicellulose molecules according to Saha. et al. 2010. The range around 2900 cm^{-1}, associated with C-H stretching of lignin were observed to be almost same in sample Sr and Shcbc. While, a change and broader peak was observed in the Shcbc4 which could be due to the continuous activated laccase enzyme throughout the process which has weaken the lignin content.



Graph 4.1: FTIR graph of untreated and treated sisal fibers with different process

Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water).

The absorption peak around 1700cm^{-1} associated to carbonyl (C=O) stretching of acetyl groups of hemicellulose structure of fiber. A dropping peak nearby the range could be said that bonds have become weaker in sample Shcbc4 compare to Sr and Shcbc. C-H deformation of the lignin was also observed in the range of 1400-1500cm^{-1} of sample Shcbc4 compare to Sr and Shcbc, which again indicates that lignin structure has broken and deteriorated. Overall, the curve is similar but much of variation in intensity with sample Shcbc4.

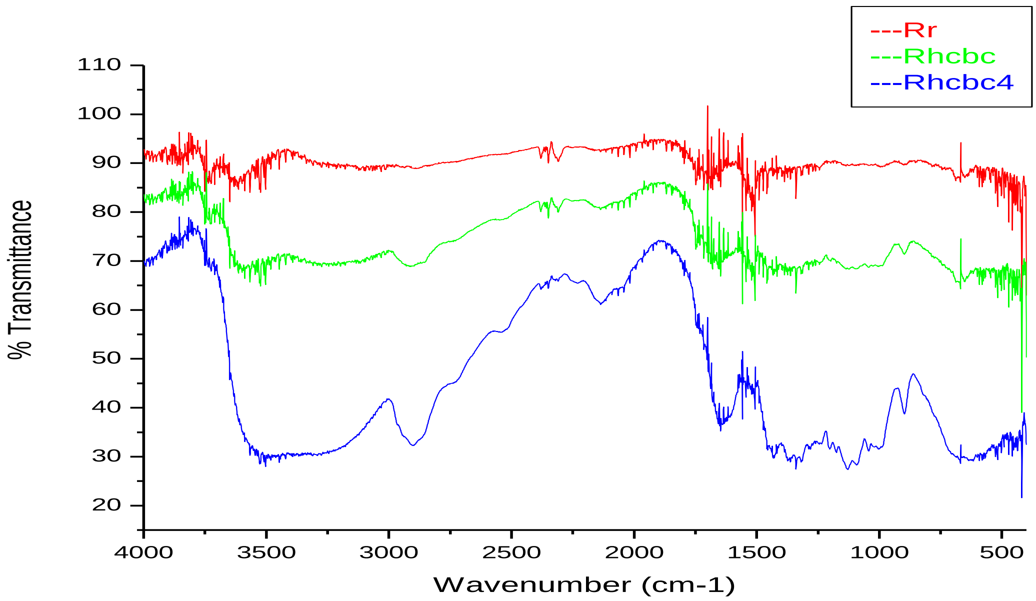
Similarly, the difference in the untreated and treated ramie fibers was observed and the difference at various frequency ranges are mentioned in Table 4.5.

Table 4.5: FTIR absorbance band of untreated and treated ramie fiber samples

Frequency Range	Absorption (cm^{-1})	Group	Rr	Rhcbc	Rhcbc4
4000-3000cm^{-1}	3700-3584	O-H stretching	3648.48 3631.12 3587.72		
	3550-3200	O-H stretching			3545.28 3509.60 3495.13 3487.42 3481.63 3473.91 3453.66 3437.26 3421.83 3384.22 3335.03
3000-2500cm^{-1}	3333-3267	C-H stretching			3310.92 3291.63 3276.20
	3000-2840	C-H stretching			2903.93
2000-1650cm^{-1}	1725-1705	C=O stretching	1715.74		
	1710-1680	C=O stretching	1680.05		
	1710-1685	C=O stretching	1697.41 1687.77		
1670-1600cm^{-1}	1650-1600	C=C stretching			1642.44 1626.05
1600-1300cm^{-1}	1550-1500	N-O stretching	1544.07 1520.92		
1400-1000cm^{-1}	1440-1395	O-H bending			1432.19 1428.34

	1420-1330	O-H bending		1417.73	
	1390-1310	O-H bending	1339.61	1374.33 1319.35, 1361.79	1374.33 1355.04 1317.43 1313.57
	1205-1124	C-O stretching			1128.39
	1124-1087	C-O stretching			1118.75 1091.75

The Graph 4.2 shows the FTIR images of untreated and enzyme treated ramie fibers. The spectrum of treated ramie fibers i.e. Rhcbc showed a weak peak around 3500cm^{-1} while broader and deep peak was observed in sample Rhcbc4 which arranges from 3200 - 3500 cm^{-1} due to the bonded O-H group. While the other uneven peaks were observed in the range of 1300-1600 cm^{-1}, which are of C=O stretching, C-H deformation and stretching and C-O deformation bonds. However, in the case of Rhcbc4 a peak was observed nearby 1100 cm^{-1}, which might be due to stretching and deformation of C-O and C-H bonds. All the mentioned ranges were associated with the lignin; hence it could be said that the treatment and process had an impact on the softening of the fiber.



Graph 4.2: FTIR graph of untreated and treated ramie fibers with different process

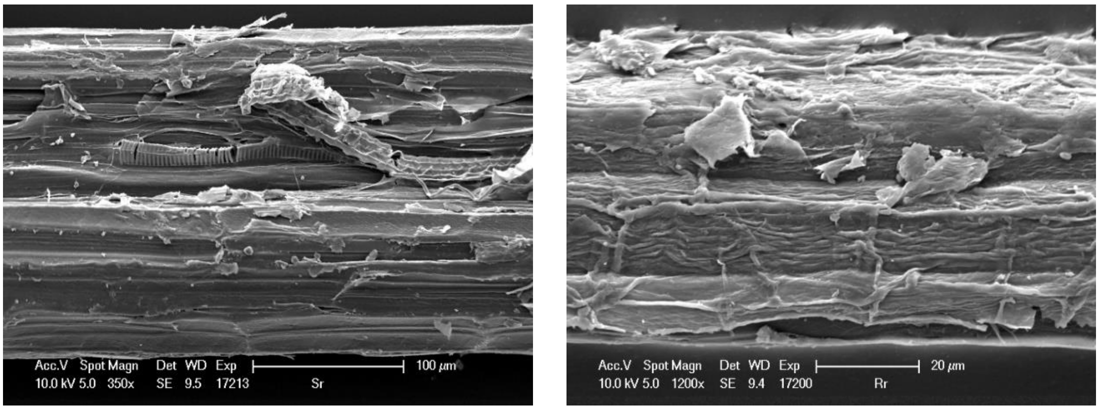
Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water).

However, the peaks detected in the Shcbc4 and Rhcbc4 are weak, this weakening indicates the removal of the lignin after the treatment. The results also show that the treatment remarkably decreases certain components, such as cellulose, hemicellulose and lignin. The change in the components leads to the change in other properties, surface area and crystallinity of the fiber. Thus, further tests were also done on the samples.

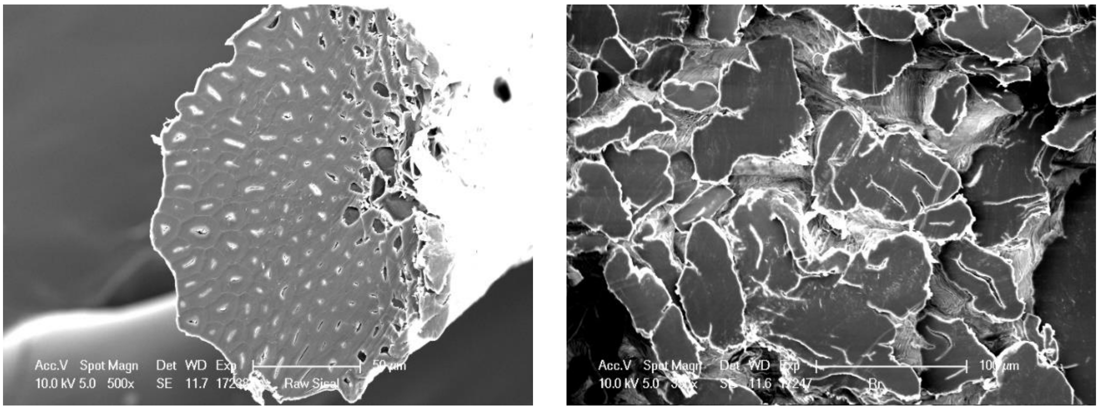
b. Structural analysis

The structural analyses have been done using Scanning Electronic Microscopy (SEM). This analysis has been done to identify the changes taking place due to the enzyme treatment. The SEM analysis has been done to identify the surface characteristics and morphological structure of fibers.

The morphological surface structure of the untreated and treated fibers was studied with the help of SEM. Three selected samples of each fiber on the basis of feel and strength were analyzed to identify the smoothness, roughness and clear visibility of fiber strands. Modification of the untreated and treated with different process of sisal and ramie fibers are mentioned.



Longitudinal View



Cross sectional view

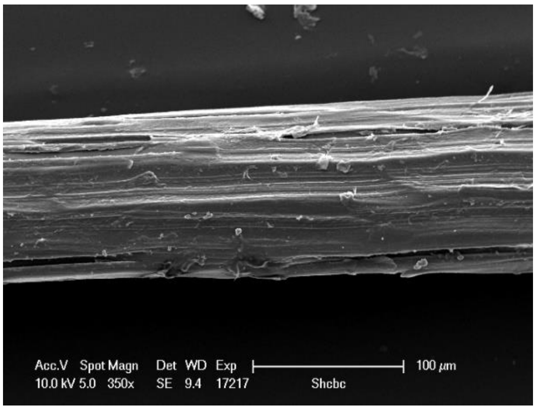
Sr (Sisal raw) **Rr (Ramie raw)**

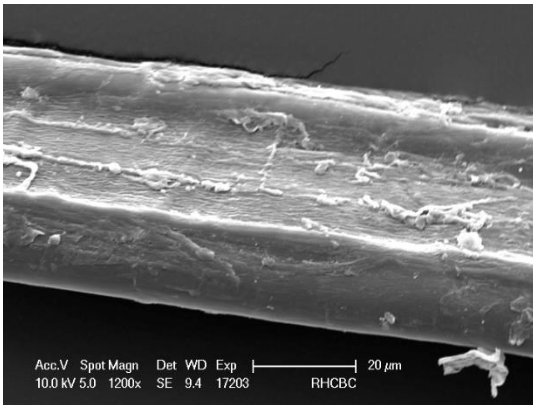
Plate 4.2: Longitudinal and Cross-sectional SEM images of untreated fibres

The raw sisal fiber is built up of about 100 fiber cells which can be corelated with the cross-sectional view of the fiber in Plate 4.2 image. Each strand consists of multiple fibers of different shapes and a lumen which was clearly visible. The compact fiber structure is composed of lumen surround by the parallel fibrillar, which is composed of micro-fibrillae cellulose molecular chain and hence the fibers are stiff.

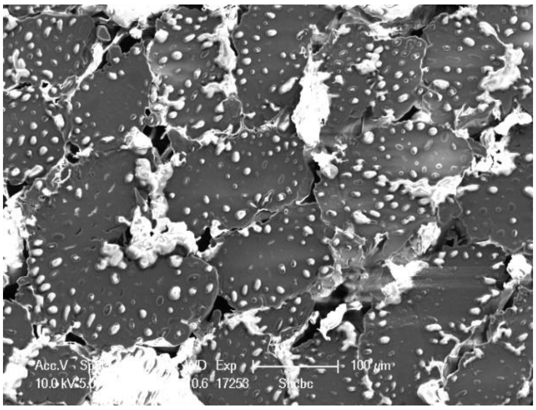
While raw ramie fiber is comparatively less dense with space in between the fibers, oval shape and variation in the size of the fibers were observed along with the lumen in the cross-sectional view of Plate 4.2. Thus, the fiber is more porous in structure compare to sisal and so are soft.

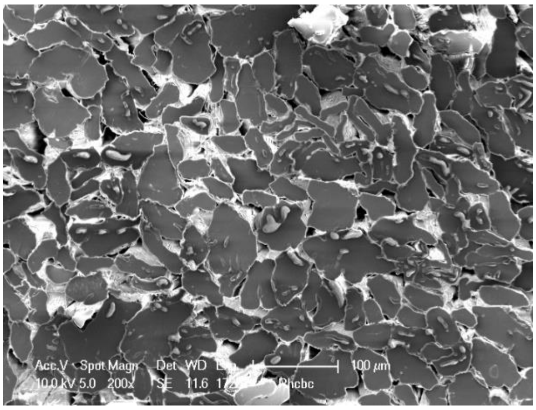
The fibers are more aligned and visible after the treatment, the pithy materials were comparatively removed by the enzymes (recipe - Table 3.4 & 3.5). It has also created space between the sisal fibers which can be observed in longitudinal view of Plate 4.3.





Longitudinal View





Cross sectional view

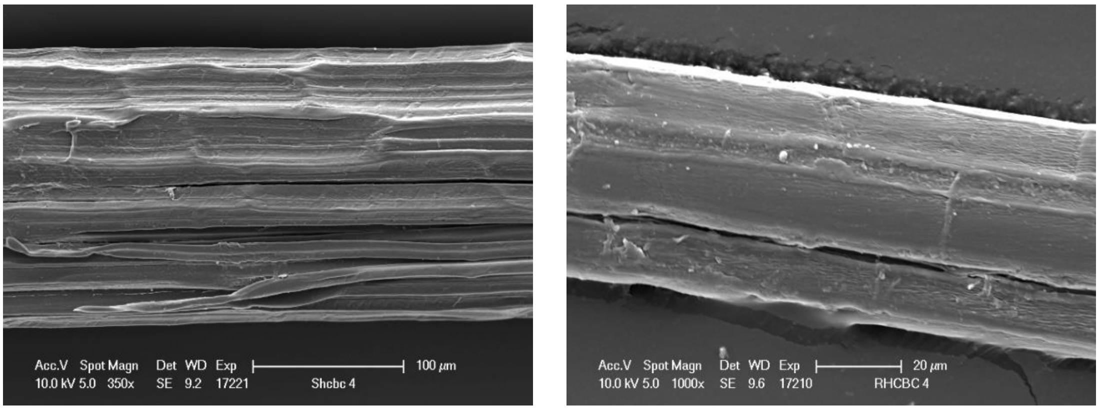
Shcbc **Rhcbc**

Plate 4.3: Longitudinal and Cross-section SEM images of enzyme treated fibers

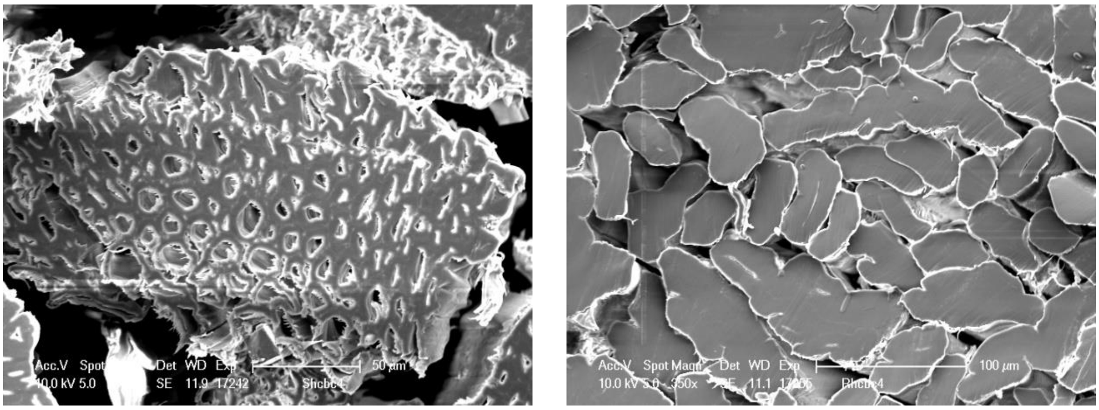
Sisal-High % concentrated-Combing-Beating-Combing, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing

The cross-sectional view (Plate 4.3) of the treated fibers clearly indicates that the pores of the fibers are swollen and has increased the cohesion between the fibers. It has also improved the surface characteristics; hence the surface has become more even and soft compare to untreated fibers.

It was observed from the longitudinal view of Plate 4.4, that the Shcbc4 fibers are smooth, more aligned and even and pithy materials were removed. Each strand was parallel to each other, which might be because of the changes in the inner structure that got converted into more crystalline region due to effect of enzyme treatment. Hence the treated fibers were softer compare to Shcbc. Similarly, effect was seen in Rhcbc4 sample also.



Longitudinal View



Cross sectional view

Shcbc4 **Rhcbc4**

Plate 4.4: Longitudinal and Cross-section SEM images of enzyme treated fibers with variation in process

Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water), Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)

By using combine enzyme treatment (Recipe Table 3.4 and 3.5) it has been observed from cross-sectional view in Plate 4.4 that the porous structure has improved which will increase the absorbency, hence Shcbc4 is more effective compare to Shcbc. While, Rhcbc4 sample showed changes in lumen part, the fiber structure was clear and the space between the fibers was visible.

Hence based on the observation and need of the present study sample Shcbc4 and Rhcbc4 were carried further for yarn conversion to develop woven sound resistant materials. The sound that will penetrate into the fibers will be trapped into the lumen or gaps within the fibers and to some extent the scattering of sound will also play a major role in sound resistance.

c. Element analysis

The micro structure/element analyses have been done to see the change in crystallinity and the addition of element and deformation of bond using X-Ray Diffraction (XRD) and Energy-dispersive X-ray spectroscopy (EDS). The XRD has been analyzed mainly to identify the crystallinity phases present in material to get composition information. The EDS has been used mainly for micro structural analysis, to identify the elemental composition of the material to understand the addition of elements or deformation of bonds in product.

X-Ray Diffraction (XRD)

The research studies show removal of surface impurities (waxy layer and oils) surrounding the fibers, swelling of the crystalline regions, and disruption of the hydrogen bonds takes place in the natural fiber with the effect of the treatment. During cellulose swelling, the cellulase penetrates into the amorphous regions located between crystallites and the cellulosic fibers and breaks the hydrogen bonds built between the macromolecules in the fiber cell wall. This leads to the destruction of the cellulose supramolecular structure and separation of the cellulose chains in the primary wall. Thus, swelling increases the disorder of the microfibril networks (i.e., more amorphous cellulose is generated) with the decrease of the overall CI and crystal size. At the same time, the inter fibrillar regions are likely to become less dense and less rigid and thereby make the cellulose microfibrils more capable of rearranging and packing themselves (preferably along the direction of tensile deformation). However, better packing and stress relaxation of cellulose chains increase the crystal sizes. When fibers stretch, such rearrangements amongst the microfibrils may result in better load sharing by them, and hence higher stress development in the fiber according to Gonzalez, B.,el.al. (2015).

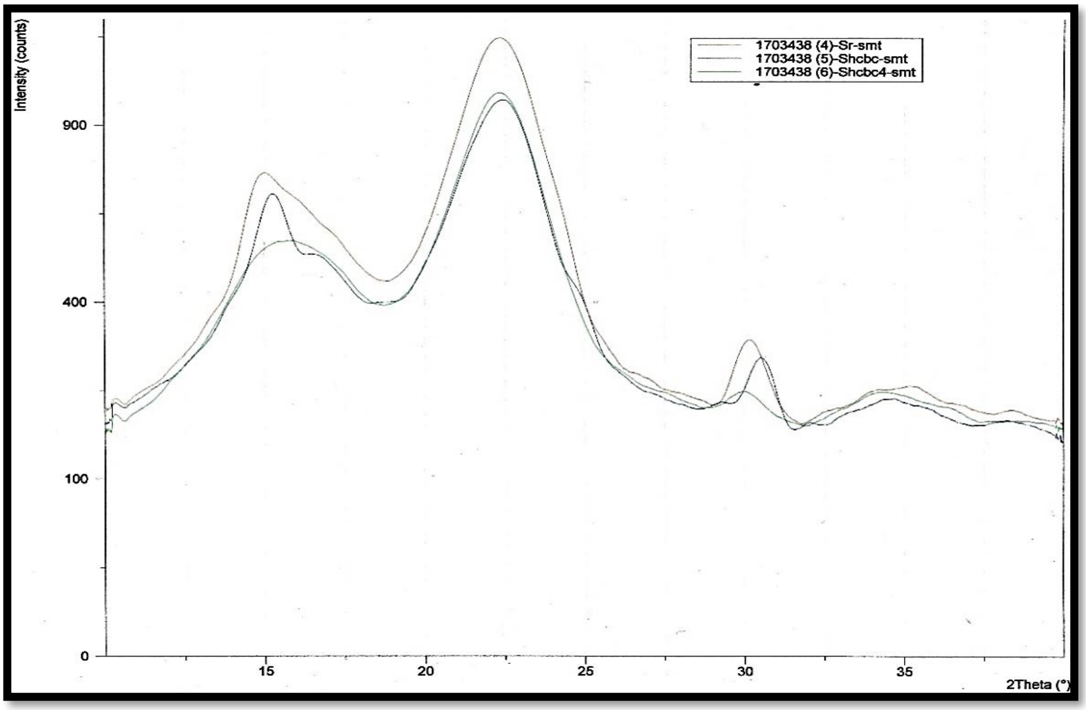
As per the mentioned results of the percentage crystallinity, crystalline size and orientation angle at 2θ in Table 4.6, it was observed that there is decrease in the percentage crystallinity in both the treated fibers compare to the untreated. The increase in crystalline size could be because of the enzyme activity which has created swelling in the chains and it is also evident in the SEM cross section view.

Table 4.6: XRD of bundle fibers scanned in Transmission mode 10-40°

Sample Code	**Crystallinity (%)**	**Orientation angle at 2θ (°)**	**Crystallite Size (°A)**
Sr (Raw Sisal)	70.79	18.50	22.39
Shcbc	69.66	32.38	23.16
Shcbc4	67.39	31.96	25.09
Rr (Raw Ramie)	81.77	14.3	32.42
Rhcbc	85.59	11.56	34.06
Rhcbc4	84.90	13.46	32.44

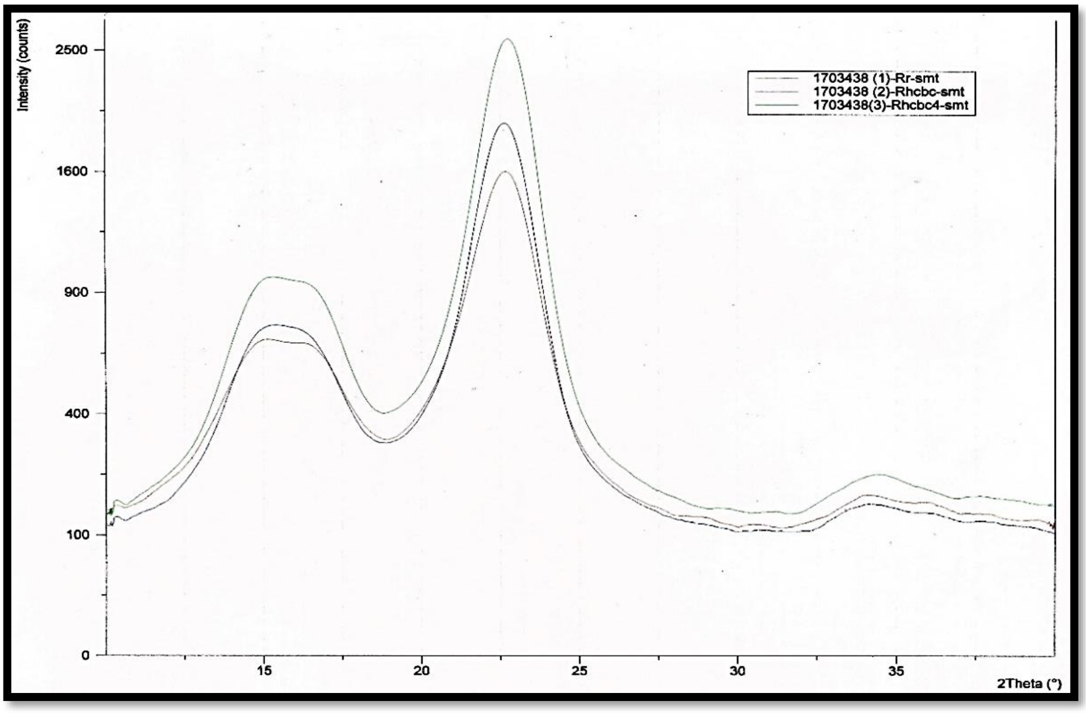
Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water), Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)

Thus, from the data of Table 4.6 it seems destruction in the chains has an impact on crystallinity, crystalline size and orientation angle at 2θ, in case of both the treated fibers compare to untreated fibers. The highest crystalline size was in sample Rhcbc which could be because of swelling in the chains due to enzyme activity which is evident in the SEM cross section view. Moreover, the surface modification has increased the pliability and this change in the property might assist in sound absorption also. Thus, because of the removal of non-cellulosic compounds, crystallinity has increased and softness of the fiber was the resultant.



Graph 4.3: X-ray diffraction of untreated and enzyme treated sisal fibers

Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)



Graph 4.4: X-ray diffraction of untreated and enzyme treated ramie fibers

Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)

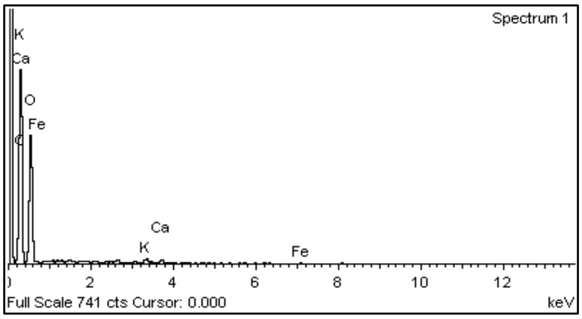
The crystallinity of sisal untreated (Sr) and enzyme treated (Shcbc and Shcbc4) fibers were analyzed and the Graph 4.3 indicates major peak differences at 2θ diffraction angles of 15°, 22.5° and 30°, according to Li, Y. (2009) it indicates the presence of Type I cellulose.

The X-ray diffraction of untreated (Rr) and treated ramie (Rhcbc & Rhcbc4) fibers are shown in Graph 4.4. The rising peaks of both the Rhcbc4 and Rhcbc compare to Rr at 16° and 22°, according to Li, Y. (2009) it indicates the presence of Type I cellulose. Another important observation is at peak 16°, where the intensity of the peak has increased compare to the other samples as well as uneven broader width suggesting the destruction in the amorphous region.

Energy-dispersive X-ray spectroscopy (EDS)

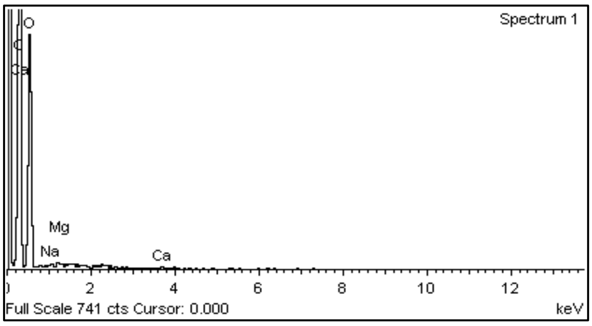
The EDS analysis was undertaken for the study to identify the modification in elements of the fibers after the enzyme treatment with different process in comparison to the untreated fibers. Carbon and Oxygen are the main elements of the cellulosic fiber for the formation or deformation of the bonds after any kind of treatment or finishes.

Element	Weight%	Atomic%
C K	27.18	33.26
K K	0.14	0.05
Ca K	0.15	0.05
Fe K	0.04	0.01
O	72.50	66.62
Totals	100.00	



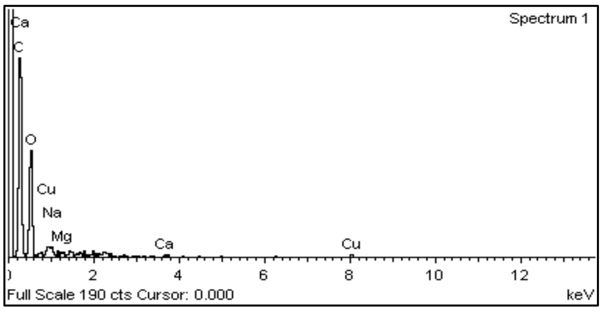
Sample : Sr

Element	Weight%	Atomic%
C K	27.24	33.29
Na K	0.06	0.04
Mg K	0.04	0.03
Ca K	0.04	0.01
O	72.62	66.63
Totals	100.00	



Sample : Shcbc

Element	Weight%	Atomic%
C K	26.70	32.95
Na K	0.39	0.25
Mg K	0.18	0.11
Ca K	0.16	0.06
Cu K	0.90	0.21
O	71.67	66.41
Totals	100.00	



Sample : Shcbc4

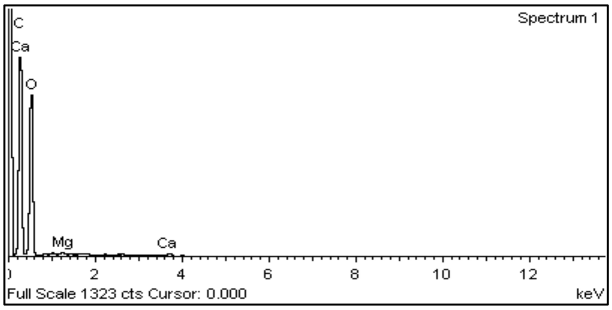
Graph4.5: EDS of untreated and treated sisal fibers

Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)

Sisal untreated fibers is composed of Carbon (C K), Potassium (K K), Calcium (Ca K), Iron (Fe K) and Oxygen (O). From the Graph 4.5, negligible difference has been observed in carbon and oxygen, whereas reduction in calcium element - which plays role of cell development was seen in sample Shcbc. Thus, formation or structure of cell wall must have been weakened in this particular sample compare to Sr and Shcbc4.

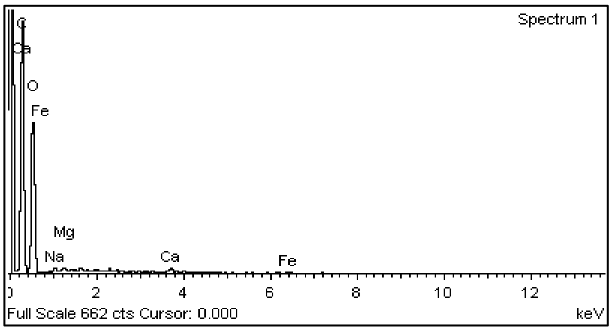
Presence of Sodium is due to the use of Soda ash in the scouring recipe, which is in permissible limit. Addition of Magnesium and Copper which are again in permissible limits might be due to the containers or instrument in which the treatment was carried out. While the removal of Potassium and Iron was also observed.

Element	Weight%	Atomic%
C K	27.21	33.27
Mg K	0.07	0.04
Ca K	0.15	0.05
O	72.58	66.64
Totals	100.00	



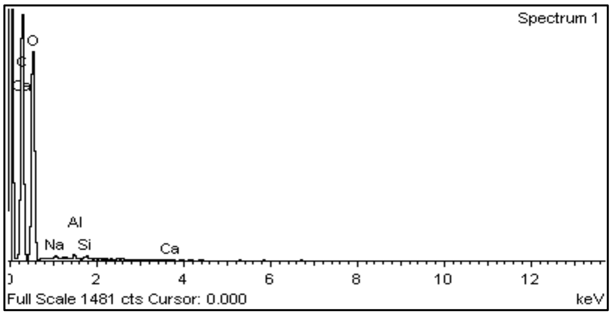
Sample : Rr

Element	Weight%	Atomic%
C K	27.07	33.17
Na K	0.20	0.13
Mg K	0.09	0.05
Ca K	0.16	0.06
Fe K	0.12	0.03
O	72.35	66.55
Totals	100.00	



Sample : Rhcbc

Element	Weight%	Atomic%
C K	27.13	33.19
Na K	0.21	0.13
Al K	0.08	0.05
Si K	0.05	0.03
Ca K	0.04	0.02
O	72.49	66.59
Totals	100.00	



Sample : Rhcbc4

Graph 4.6: EDS of untreated and treated ramie fibers

Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)

The elements present in the Ramie untreated fibers are Carbon (C K), Magnesium (Mg K), Calcium (Ca K) and Oxygen (O). Insignificant difference in the Carbon and Oxygen elements has been observed from the Graph 4.6. Reduction in Calcium element was seen in both the treated sample – Rhcbc and Rhcbc4. Presence of Sodium is due to the use of Soda ash in the scouring recipe, which is in permissible limit. While addition of other elements like Magnesium and Iron and Aluminum and Silicon in the sample Rhcbc and Rhcbc4 respectively could be the result of reaction of enzymes with the metal body of the instrument or containers used during the enzymatic process.

Hence it was seen that all the changes and addition of elements were in permissible limits. So, the treatment recipe was effective for the softening of both the fibers and are harmless to the ecology and environment.

d. Physical properties

The bundle fiber strength test was conducted for both the fibers to identify the effect of enzyme treatment in terms of strength and elongation. Variation in breaking strength and elongation had an impact on softness and pliability of the fibers. The details of tensile strength analyses are given in Table 4.7.

The lignin component of the sisal fiber was important to reduce, to bring little flexibility in the fiber and thereby to increase the spinnability of the fiber. The penetration of each enzyme removes the impurities and creates the space within the cells and between the cell walls, as well as changes in the bonds were also observed. Such changes might be the cause of reduction in strength of sisal fiber, but for the spinnability the strength of treated fibers was appropriate to form an even yarn structure.

Table 4.7: Average tensile strength of untreated and treated fibers

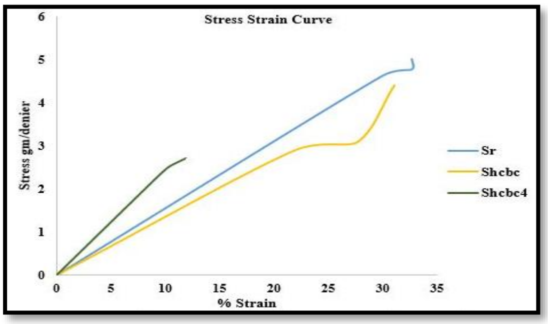
Fiber Code	Denier	Maximum Load (gf)	Extension at max. (mm)	Stress (gm/den)	Strain (%)
Sr	988	4868	0.98	5.03	32.73
Shcbc	918	3816	0.93	4.42	31.07
Shcbc4	965	2685	0.36	2.72	11.93
Rr	2178	5407	0.39	2.46	12.87
Rhcbc	1379	3167	0.69	2.44	23.13
Rhcbc4	1321	3626	0.48	2.80	16

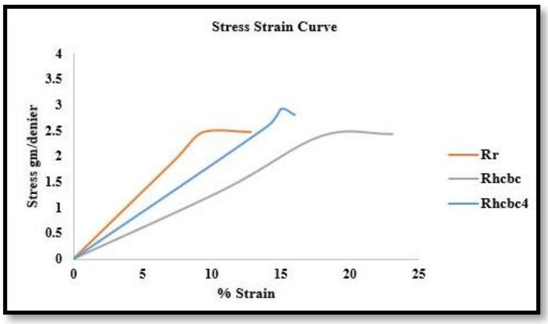
Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water), Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water)

Ramie fibers are soft and surrounded by the rigid cellulose component. This cellulose structure is crystalline and porous but the removal of impurities was needed for smooth surface and good spinnability. Thus, the enzyme treatment given to the fibers might have removed the impurities and thereby the bonds have been aligned, which has converted the enzyme treated fibers stronger than the raw ramie.

The stress stain curve of untreated and treated fibers in Graph 4.7 shows that, after the enzyme treatment the softness and cohesiveness of the fiber has increased, also the change in stiffness could be evident. The change in stiffness can be correlated with the previous chemical and structural analysis i.e. reduction in lignin. The reduction of lignin component has an impact on strength. It was found that Shcbc could withstand the stress approximately till 3gm/denier. That means stress bearing capacity has been reduced in Shcbc4 compare to Shcbc and Sr, which shows that the stiffness has decreases. Any finishes applied to the substance will reduce the strength and the same was observed in the Shcbc4. Another observation was that the elongation reduced and so with reduced strength, elongation and stress it might be difficult to machine spun the treated fibers.

Similarly, the stickiness as well as the impurities were removed from the ramie fiber after the treatment. Thereby a softer and comparatively straighter fibers was observed. The strength of the fiber has reduced after the treatment, which could be due to the changes in the nodes or maybe it is the impact of process during the treatment. The stress bearing capacity of the treated fiber Rhcbc4 has increased and thereby %strain increased compare to raw. The elongation being an important factor for spinnability has also increased in Rhcbc4 compare to raw. Overall, with the stress, strain and elongation it could be said the Rhcbc4 has good physical properties for yarn conversion.



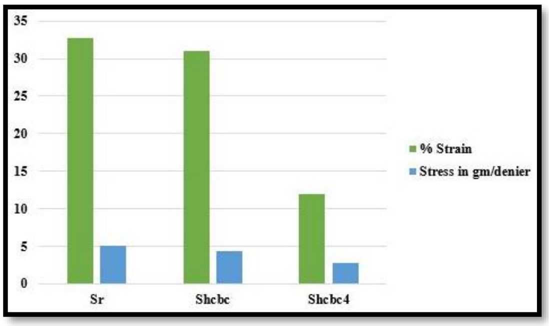


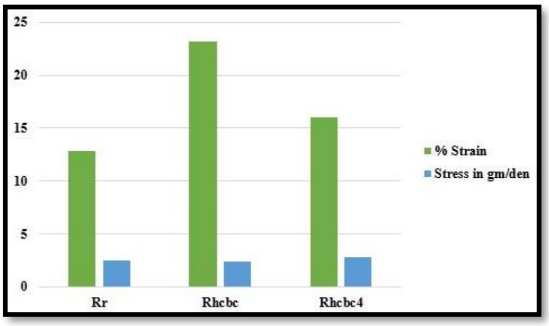
Sisal fibres **Ramie fibers**

Graph 4.7: Stress strain curve of raw and treated fibers

Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water), Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water).

While, the bar graph (Graph 4.8) of both the fibers show high percent strain. The alignment of the bonds must have taken place due to which they are able to resist the force applied onto it. While both Shcbc4 and Rhcbc4 shows lower percent strain and stress, but for coarser yarn both the fibers have appropriate strength, thereby the strength of the product would be good. Hence based on strength analysis, enzyme treated fibers without changing the water i.e Shcbc4 and Rhcbc4 were selected for yarn preparation.





Sisal fibres **Ramie fibres**

Graph 4.8: Stress and strain bar graph of raw and treated fibers

Sr: Sisal Raw, Shcbc: Sisal-High % concentrated-Combing-Beating-Combing, Shcbc4: Sisal-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water), Rr: Ramie Raw, Rhcbc: Ramie-High % concentrated-Combing-Beating-Combing, Rhcbc4: Ramie-High % concentrated-Combing-Beating-Combing (4hrs treatment without changing water).

4.4. Analysis of yarn properties

The conversion of fibers into yarns was based on the fiber characteristics, twist holding capacity and end use. The handspun yarns were developed from untreated sisal and ramie as well as from treated sisal. While from treated ramie machine spun yarn was developed using rove technique. The three different physical properties of the yarns were analyzed and they were yarn fineness, twist and strength.

a. Yarn fineness and twist

Fineness of the fabric depends on the yarn quality, but owing to fiber properties and need of the research coarser yarns using two different suitable techniques were applied for developing 100% sisal and 100% ramie yarns. Fineness and twist of each yarn were analyzed to understand its effect on fabric thickness and structure. Fineness of the yarn was evaluated from the denier of the yarn - higher the denier higher the yarn thickness and heavier the yarn.

Amongst the yarn samples in Table 4.8, only RTR was machine spun. The denier of untreated fiber yarns - SUT and RUT were more compared to treated fiber yarns - STH and RTR. The difference in denier might be due to the nature of the raw fiber (rough, less cohesive and stiff) and spinning technique.

Table 4.8: Fineness of the sisal and ramie yarns

Yarn sample Code	Denier	Twist per Inch (TPI)	Twist Direction
SUT	855	2.8	S
STH	607	2.4	S
RUT	1492	3.8	S
RTR	939	0.4	S

SUT: Sisal-Untreated-Traditional spinning technique, STH: Sisal-Treated-Hand spinning technique, RUT: Ramie- Untreated-Traditional spinning technique, RTR: Ramie-Treated-Rove spinning technique

Hand spinning with untreated sisal and ramie fibers were difficult and an unfinished rough textured yarn were the outcome with protruding fibers from the yarn. Thus, based on spinners feedback (difficult to handle and twisting of the fibers) and final appearance of the yarn, the untreated yarns were purposively eliminated for the study.

Twist per inch (TPI) and twist direction was also analyzed, it is said that higher the twist, finer the yarn and with the increase of twist amount hairiness reduces. The TPI of the untreated sisal yarn (SUT) seems to be higher than the treated (STH) and the same was observed in ramie yarns i.e untreated ramie yarn (RUT) shows higher TPI than treated (RTR).

Based on the studies and need of the research, coarser yarns were purposively developed from treated fibers. “S” twist direction was followed for all the samples, to have better strength and reduction in hairiness. Thus, based on the yarn properties STH and RTR yarns were used as weft yarns.

b. Yarn strength

Sisal fibers being stronger, stiffer and less cohesive compare to ramie. The fiber after the treatment showed reduction in lignin content but was still stiff and with less of elongation, stress and strain it was difficult to develop machine spun yarns. So, both the untreated and treated fibers were handspun with unique fiber locking system to have continuous length of 100% sisal yarn. In case of ramie, the fibers after the treatment became too softer and with less of resiliency it was difficult to hand spun, thus 100% machine spun using rove technique was purposively selected based on the hollow yarn structure for sound absorb. While, from untreated fibers 100% ramie yarn was prepared using handspun technique only. All the coarser yarns were analyzed for tensile strength using Instron tensile strength tester and the details are mentioned in the Table 4.9.

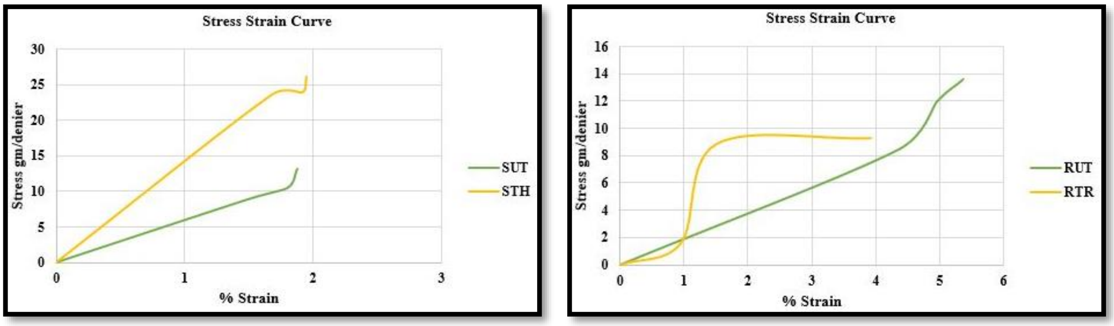
Table 4.9: Average tensile strength of untreated and treated yarns

Yarn Sample	Denier	Maximum Load (gf)	Extension at Max (mm)	Stress in (gm/den)	Strain (%)
SUT	855	10334	1.88	13.22	1.88
STH	607	15541	1.95	26.14	1.95
RUT	1492	20654	5.37	13.59	5.37
RTR	939	9761	3.93	9.24	3.93

SUT: Sisal-Untreated-Traditional spinning technique, STH: Sisal-Treated-Hand spinning technique, RUT: Ramie- Untreated-Traditional spinning technique, RTR: Ramie-Treated-Rove spinning technique

The denier of both the treated fiber yarns has reduced, but it was observed that the yarns are still coarser with the reduction in thickness and weight. Further, to understand the impact of treatment and yarn conversion process, stress strain curve of all the yarns was plotted.

It was observed from the Graph 4.9, that the sisal treated yarns showed good strength compare to untreated with negligible difference of breaking point. The stress strain curve graph of sisal shows that the difference of breaking point is negligible whereas increase in the stress holding capacity was observed in treated yarn (26.14gm/den). The increase in strength and stress could be due to treatment as well as impact of bundled fibers twisted together for yarn conversion. While, twist per inch of treated yarn was less and yet it could withstand the load which might be because of the increase in cohesiveness of the bundled fibers.

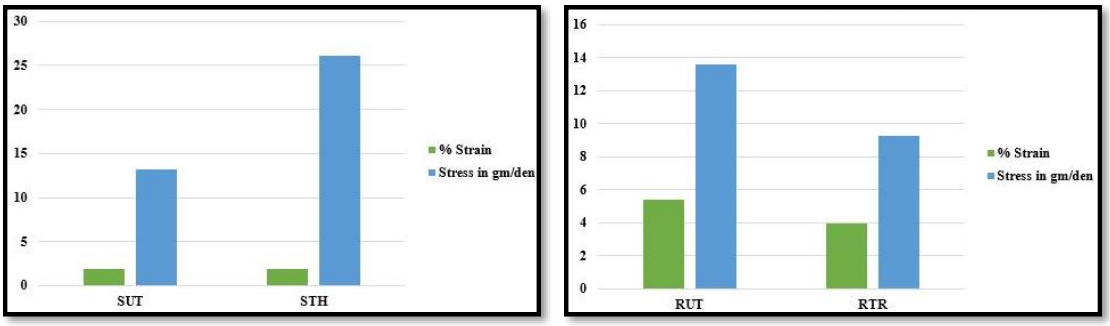


Sisal yarns **Ramie yarns**

Graph 4.9: Stress strain curve of untreated and treated yarns

SUT: Sisal-Untreated-Traditional spinning technique, STH: Sisal-Treated-Hand spinning technique, RUT: Ramie- Untreated-Traditional spinning technique, RTR: Ramie-Treated-Rove spinning technique

While in ramie the elongation increased initially and breaks at certain point of load. The breaking point of treated ramie was observed at 9.24gm/den which is low compare to untreated yarns (13.59gm/den). The treated yarns were developed using the rove technique having hollow structure for absorption and with negligible twist, thus strength to hold the load was found to be less. But, based on the absorption and aesthetics factors the treated yarns were considered for the study.



Sisal yarns **Ramie yarns**

Graph 4.10: Stress and strain bar graph of untreated and treated yarns

SUT: Sisal-Untreated-Traditional spinning technique, STH: Sisal-Treated-Hand spinning technique, RUT: Ramie- Untreated-Traditional spinning technique, RTR: Ramie-Treated-Rove spinning technique

Further, from the bar Graph 4.10 it was observed that sisal showed increase in stress with negligible difference in per cent strain, while reduction in stress as well as % strain was found in ramie treated yarns. It means that the sisal treated yarn had better strength after the treatment and the strength of ramie treated yarns had reduced due to rove technique. Yet, both the yarns comparatively had good strength for this particular study where absorption of sound was the main motto. Hence, both the treated yarns with “S” twist possess better strength and even structure due to fineness of yarn were considered further for fabric development.

4.5. Analysis of the structural properties of the fabrics

The three different weaves like Plain, broken twill and double cloth weave were taken to study the sound absorption behavior of different fabrics made from different types of fiber strands/yarns using same weave. The three needle punch nonwoven fabrics of 620, 814 and 919 GSM has been also prepared. The nonwoven fabric has been mainly used for backup material. All the single layer fabrics has been checked for its physical properties like fabric count, thickness, GSM, air permeability and cover factor.

Fabrics from fiber strands

The three different plain weave samples using fiber strands as weft were developed at pilot stage, to understand the feel, texture and aesthetics of the final fabrics. The samples were developed using sisal, ramie and combination of both the fiber strands. While mercerized cotton as warp of 7’s count of 4ply yarn was taken and keeping 4 ends per/inch as constant. The details of the fabrics are mentioned in Table 4.10.

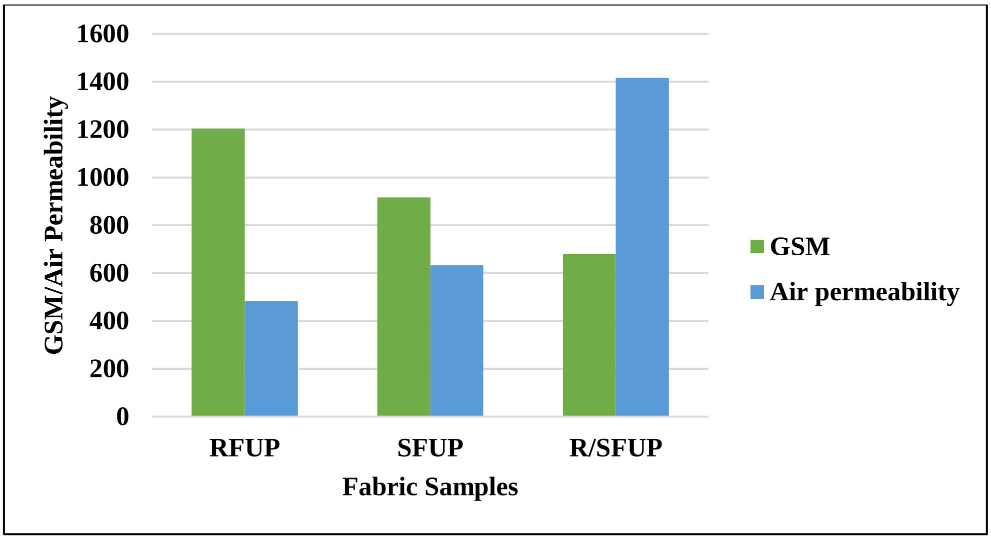
The physical property like thickness, GSM and air permeability are main factors which has an impact on the sound absorption property of fabric. The fabric samples which are manufactured having average thickness of 2.6 mm and GSM varies from 680 to 1204 gm/m^2. It clearly indicates from Graph 4.11, that GSM value have a direct effect on air permeability of the fabric. The trend shows as GSM value increases the air permeability decreases and fabric becomes more compact. Also, it is observed that due to the fiber strand, the fiber density can be increased but the cohesion between fiber is less and also the placement of the fiber are uneven which makes the structure coarser.

Table 4.10: Specification of the fabric constructed using untreated fiber strands

Sr. No.	Fabric codes	Thickness (mm)	GSM (g/m^2)	Air permeability (cm^3/cm^2/s)	Fabric Count (Ends/inch * picks/inch)	Fabric Sample
1	RFUP	2.7	1204	483.33	4X22	
2	SFUP	2.6	916	633.33	4X32	
3	R/SFUP	2.4	680	1416.67	4X28	

RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave

The fabric cover factor is difficult to calculate due to fiber strand insertion. The subjective analysis of three samples, shows better cover, good appearance and also the stable structure in fabric R FUP. Due to the stiffness of sisal S FUP shows the protruding fibers on surface which gives harsh feel. The problem with the blend sample R/SFUP due to the mixing of two strands, difference in the thickness of the fiber and uneven distribution within the strand gives unbalanced porous structure. The air permeability of this sample is clear evidence of it. Even by increasing the weft density no much change in permeability was found.



RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave

Graph 4.11: GSM and air permeability of fabric with fiber strands

Fabrics from sisal yarns

The three different fabrics were constructed using untreated and treated handspun yarns. The fabric from untreated yarn with plain weave has been compared with treated yarn plain weave and broken twill fabric. The details of the fabrics are mentioned in Table 4.11.

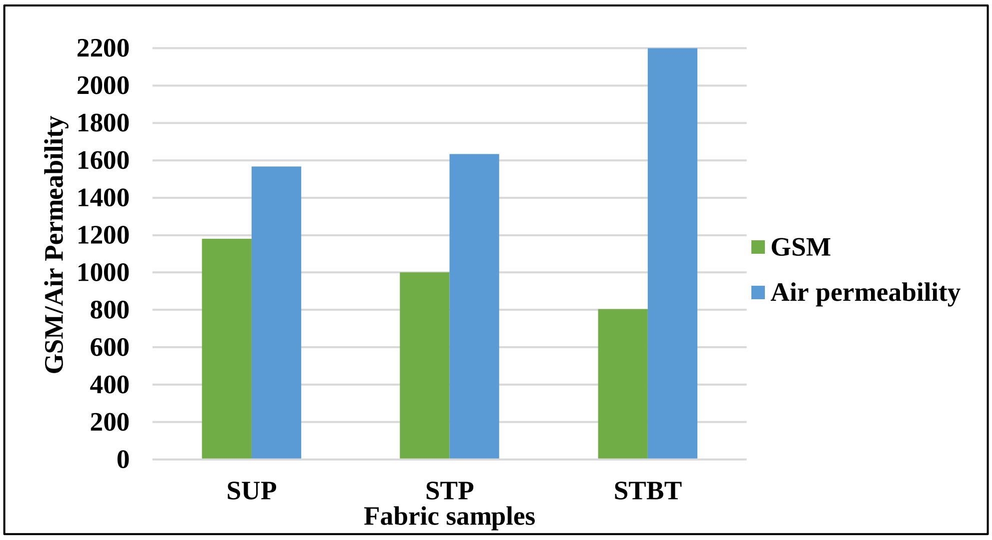
The SUP and STP fabrics were developed with plain weave structure. On comparing the parameters of both the fabrics it shows that with the similar fabric count and cover factor, the thickness and GSM is higher and air permeability is lower in SUP fabric. It might be because of the effect of treated fiber yarn that creates the comparatively thinner and little open structured fabric.

In case STBT the number of warps were increased based on the weave structure. Here, all the parameters decreased except air permeability. It was corelated with the visual and feel of the fabric that with the change in thickness and effect of weave of the sample, it was little more porous compare to SUP and STP. Thus, from the Graph 4.12 it can be analyzed that SUP might absorb sound better because of rough texture and protruding fibers which will scatter and hinder sound to pass completely through the fabric.

Table 4.11: Specification of the fabrics constructed using sisal yarns

Sr. No.	Fabric Codes	Thickness (mm)	GSM (g/m^2)	Air permeability ($cm^3/cm^2/s$)	Fabric Count (Ends/inch * picks/inch)	Cover Factor	Fabric sample
1	SUP	3.5	1180	1566.67	4X24	24.57	
2	STP	3.0	1000	1633.33	4X24	24.57	
3	STBT	2.6	804	2200	8X20	22.29	

SUP: Sisal-Untreated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave



SUP: Sisal-Untreated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave

Graph 4.12: GSM and air permeability of sisal fabrics

Fabrics from ramie yarns

Ramie yarns were prepared using two different techniques – handspun yarns using untreated fibers and rove yarns using treated fibers. Further, two samples of plain weave fabrics were developed using both the yarns separately, while broken twill weave sample were only developed using the rove yarns. The details of the fabrics are mentioned in the Table 4.12.

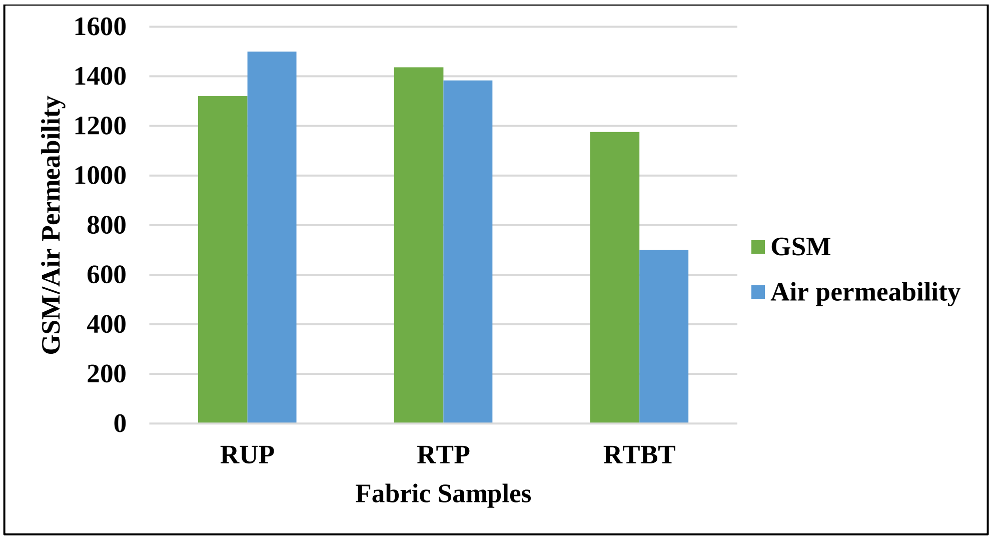
On comparing the plain weave samples, it was observed that thickness has decreased but the GSM increased. It might be due to yarn preparation technique, RTP fabric was developed by inserting more number of rove yarn as weft per inch compare to RUP for creating similar kind of compact fabrics. Another observation was that being the untreated fiber fabric it seems RUP will able to absorb less sound based on air permeability results. The reason could be the nature of the bast fiber having the nodes like structure at intervals as well as the unevenness of the fiber due to the impurities.

Table 4.12: Specification of the fabrics constructed using ramie yarns

Sr. No.	Fabric Codes	Thickness (mm)	GSM (g/m^2)	Air permeability ($cm^3/cm^2/s$)	Fabric Count (Ends/inch * picks/inch)	Cover Factor	Fabric sample
1	RUP	3.4	1320	1500	4X18	19.43	
2	RTP	3.0	1436	1383.33	4X28	28.00	
3	RTBT	3.0	1176	700	8X16	19.43	

RUP: Ramie-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave

While comparing the entire data it was also observed that RTBT can absorb more of sound due to less of air permeability as well as the weave structure. Owing to the fabric count and cover factor it seems that RTP could give best results. For further analyses, the graph was plotted using GSM and air permeability data.



RUP: Ramie-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave

Graph 4.13: GSM and air permeability of ramie fabrics

It was observed from the Graph 4.13, that the GSM and air permeability having negligible different in RTP fabric. While, lowest GSM and air permeability has been observed in RTBT fabric. Hence, based on the properties and other factors both the RTP as well as RTBT might absorb better sound.

While comparing the details of both sisal and ramie plain weave fabrics on the basis of air permeability RTP was found to be the lowest. Though the weave is same, but because of the rove yarn technique the fabric shows lowest air permeability. While amongst all the six fabrics RTBT shows lowest reading. Hence RTP and RTBT might absorb sound better.

Fabrics from sisal and ramie (R/S) of yarns

The sound wave when hits to the uneven/irregular fabric surface, it gets scattered and travels through the medium in smaller parts. Based on this concept, double cloth weave structure was studied further using both the sisal and ramie treated yarns alternately in a fabric. The three different fabrics – Double cloth without stuffing (R/STDC), Double cloth with stuffing (R/STDCs) and tubular cloth with stuffing

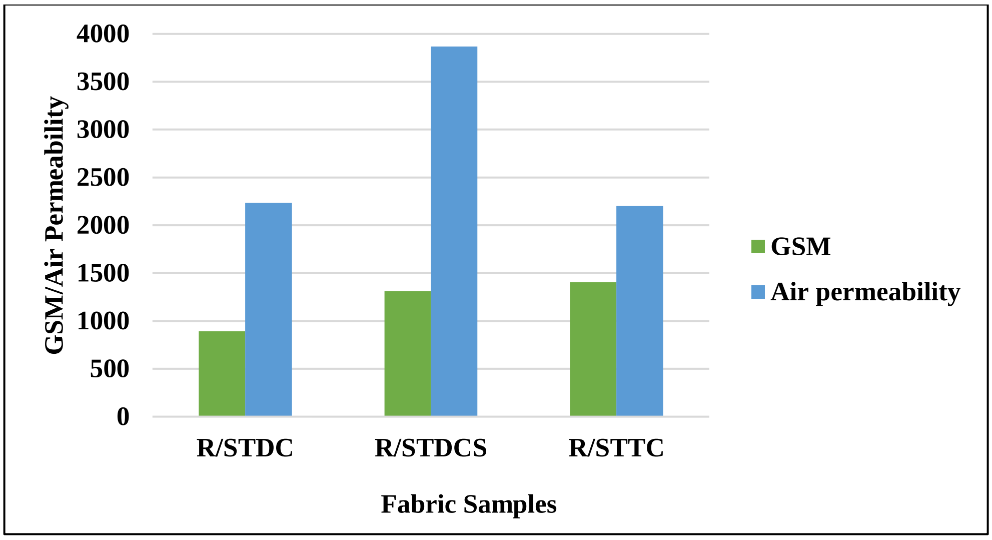
(R/STTC) were developed on table loom. All the samples were further evaluated for basic fabric properties and the details are mentioned in the Table 4.13.

With the increase in GSM, negligible difference was observed in air permeability within the sample R/STDC and R/STTC in the Graph 4.14. Sample R/STDCs showed highest air permeability with almost similar GSM of R/STTC. Further the samples were physically analyzed and it was observed that by using two different yarn thickness, the samples were having little open structure specially at the intersection points. Thus, based on the higher air permeability readings the samples were excluded but sound absorption test was conducted to corelate its result with air permeability.

Table 4.13: Specification of the fabrics constructed using sisal and ramie yarns

Sr. No.	Fabric Codes	Thickness (mm)	GSM (g/m^2)	Air permeability ($cm^3/cm^2/s$)	Fabric Count (Ends/inch * picks/inch)	Fabric sample
1	R/STDC	3.1	892	2233.33	12X20	
2	R/STDCS	7.8	1312	3866.67	12X14	
3	R/STTC	5.5	1404	2200	12X16	

R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing



R/S TDC: Ramie and Sisal-Treated Yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated Yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated Yarn-Tubular Cloth weave with stuffing

Graph 4.14: GSM and air permeability of fabrics using sisal and ramie yarns

Nonwoven fabrics

The nonwoven fabrics were developed as backing material. Sisal being stiffer fiber compare to ramie even after the treatment was eliminated. From the previous research it was observed that using needle punch technique the sisal nonwoven fabrics were difficult to handle i.e the fibers starts separating and the structure gets spoiled. The same feedback was given by the NIRJAFT experts. Hence, three different needle punch nonwoven fabric samples of different GSM were developed from scoured ramie fibers.

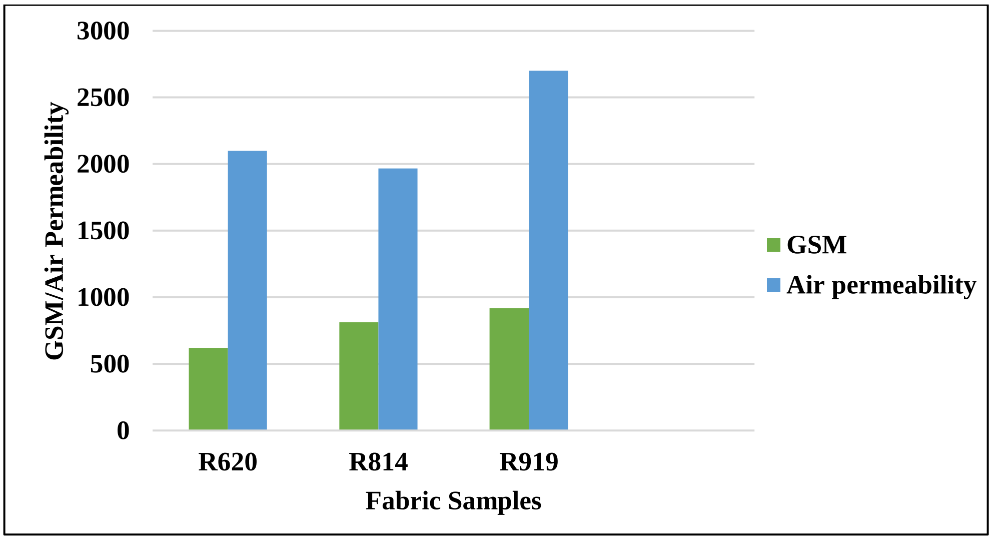
The air permeability of the nonwoven fabrics using needle punch technique depends on fiber density, arrangement and layering of the fibers as well as punching density. Considering these factors three fabrics were prepared between 620 to 920 GSM. A major drawback of these fabrics is uneven fiber thickness and layering of such fiber creates uneven or clusters due to which accurate readings of air permeability or sound absorption is difficult.

The basic fabric properties for sound resistance were evaluated and mentioned in Table 4.14. Based on which further Graph 4.15 were plotted using GSM and air permeability data. From the graph it seems that as the GSM increases the air permeability increases except for R814. Backing material should be stronger and thicker as it will be the base of the final product and with highest thickness attachment of less layers could be possible, thereby bulkiness of the product can be reduced. Hence, R919 was considered as the final backing material for the study.

Table 4.14: Specification of the ramie nonwoven fabrics

Sr. No.	Fabric Codes	Thickness (mm)	GSM (g/m^2)	Air permeability ($cm^3/cm^2/s$)	Fabric sample
1	R620	3.4	620	2100	
2	R814	4.4	814	1967	
3	R919	5.3	919	2700	

R614: Ramie needle punch of 614 GSM, R814: Ramie needle punch of 814 GSM, R919: Ramie needle punch of 919 GSM



R614: Ramie needle punch of 614 GSM, R814: Ramie needle punch of 814 GSM, R919: Ramie needle punch of 919 GSM

Graph 4.15: GSM and air permeability of ramie nonwoven fabrics

4.6. Factors affecting the sound absorption properties of different fabrics

The analysis of all the developed fabric samples was based on three parameters – change in distance, frequency and number of layers. For optimization of testing process all the samples were tested in the fabricated sound absorbing instrument.

a. Effect of distance between sound source and sample

The first and foremost important parameter to be optimize was the distance between the sound source and sample. The 100cm length of the tube was used for testing. The samples were initially tested next to the speaker i.e. at 0cm distance and then the distance was increased with increment of 20cm. The noise reduction coefficient was measured at 1200Hz frequency and the data are mentioned in Table 4.15.

Table 4.15: Effect of distance between sound source and fabric sample

Sr. No.	Fabric Code	Noise Reduction Coefficient (NRC)				
		0	20	40	60	80
Plain weave using fiber strands						
1	R FUP	0.55	0.60	0.60	0.55	0.72
2	S FUP	0.55	0.68	0.68	0.68	0.75
3	R/S FUP	0.55	0.50	0.50	0.44	0.55
Untreated Plain Weave						
4	RUP	0.44	0.44	0.44	0.50	0.50
5	SUP	0.50	0.44	0.50	0.50	0.50
Treated Plain weave						
6	RTP	0.80	0.72	0.72	0.60	0.68
7	STP	0.21	0.37	0.29	0.37	0.44
Broken Twill weave						
8	RTBT	0.55	0.44	0.50	0.44	0.50
9	STBT	0.75	0.21	0.3	0.21	0.29
Double Cloth variations						
10	R/S TDC	0.29	0.44	0.29	0.37	0.50
11	R/S TDC_S	0.29	0.44	0.29	0.37	0.44
12	R/S TTC	0.44	0.50	0.37	0.44	0.44
Nonwovens						
13	R620	0.44	0.50	0.50	0.50	0.44
14	R814	0.37	0.44	0.37	0.37	0.50
15	R919	0.44	0.50	0.44	0.44	0.44

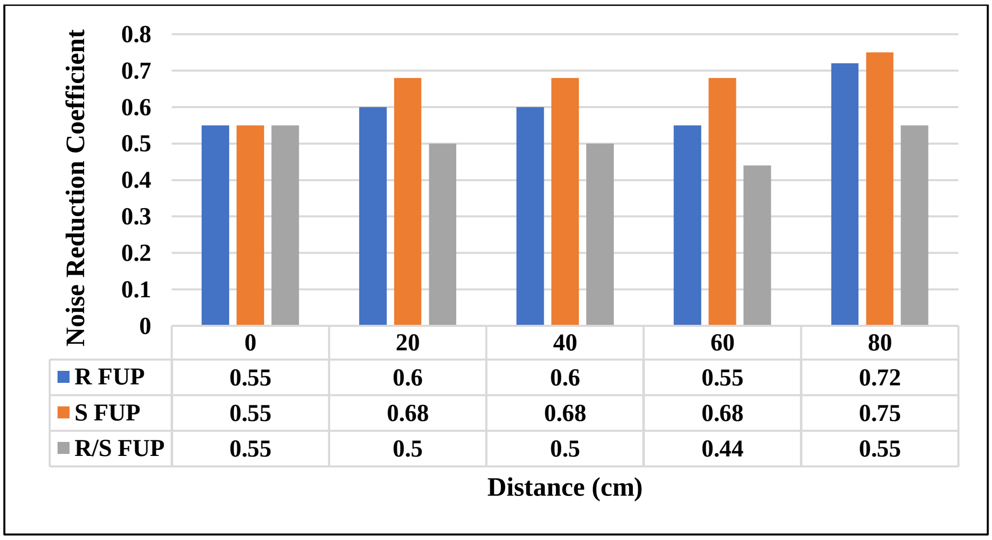
RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave, RUP: Ramie-Untreated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave, R/S TDC: Ramie and Sisal-Treated *yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing, R614: Ramie needle punch of 614 GSM, R814: Ramie needle punch of 814 GSM, R919: Ramie needle punch of 919 GSM*

From the mentioned data various comparison based on fiber or yarn content as weft and fabric structure were plotted on graph for further clarity to optimize the distance for the study.

Plain weave fabrics using fiber strands

The noise reduction coefficient of three different woven samples using untreated fibers as weft has been represented in Graph no. 4.16. It was observed that per cent reduction ranges from 0.44 to 0.75 at various distances (0 to 80 cm) at 1200Hz frequency as constant. At 0 cm i.e. next to the source all three samples showed absorption coefficient 0.55 i.e. there was approximately 50 per cent absorption. With gradual increase in distance variation in absorption was marked. From 20 cm to 60 cm the absorption is almost the same, while little increase was observed at 80 cm.

Sisal and ramie combination sample showed negligible difference, may be due to the fabric structure and two minor fibers incorporated in a sample. Thickness of the fiber also varies hence when inserted as bundled fibers the open structure samples were created. Wherein both the fiber having opposite texture might also be affecting the absorption.



	0	20	40	60	80
R FUP	0.55	0.6	0.6	0.55	0.72
S FUP	0.55	0.68	0.68	0.68	0.75
R/S FUP	0.55	0.5	0.5	0.44	0.55

RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave

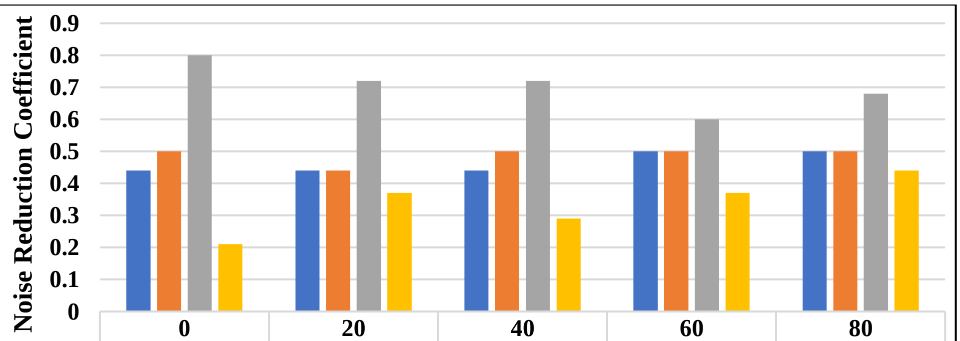
Graph 4.16: Analysis of plain weave fabric using fiber strands

While amongst the two woven samples R FUP and S FUP, sisal untreated plain (S FUP) weave sample absorbed more compare to ramie untreated plain (R FUP) weave sample. It could be because of the number of inherent pores of the fibers which plays major role in absorption. Hence through the SEM (Cross section Plate no. 4.4), it was clearly visible that untreated sisal fibers showed more porous structure compared to ramie. Further sisal fibers were more aligned; having smooth surface gives more cohesion when used as bundle fibers for weaving.

Plain weave fabrics

The sound absorption behavior is mainly governed by fiber, yarn and fabric structure. For a given fiber and yarn structure, the fabric structure can be altered in terms of its pick density and cover factor. The plain weave structure is one of the stable structures where by means of any type of yarn can be converted into the woven fabric. Thus, porous interlocking structure can be manipulated by changing the material parameters.

The effect of sound behavior of sisal and ramie plain weave fabric parameters has been studied using untreated and treated fiber in yarn form. As the analysis shows in Graph 4.17, it gives the idea of change in sound absorbency with change in distance. It clearly indicates that the treated fiber in form of yarn gives better results in ramie fabrics. Thus, with the increase in softness, bulkiness and swelling of the fiber during the softening treatment had an impact on the final fabric.



	0	20	40	60	80
RUP	0.44	0.44	0.44	0.5	0.5
SUP	0.5	0.44	0.5	0.5	0.5
RTP	0.8	0.72	0.72	0.6	0.68
STP	0.21	0.37	0.29	0.37	0.44

Distance (cm)

RUP: Ramie-Untreated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave

Graph 4.17: Analysis of plain weave fabrics

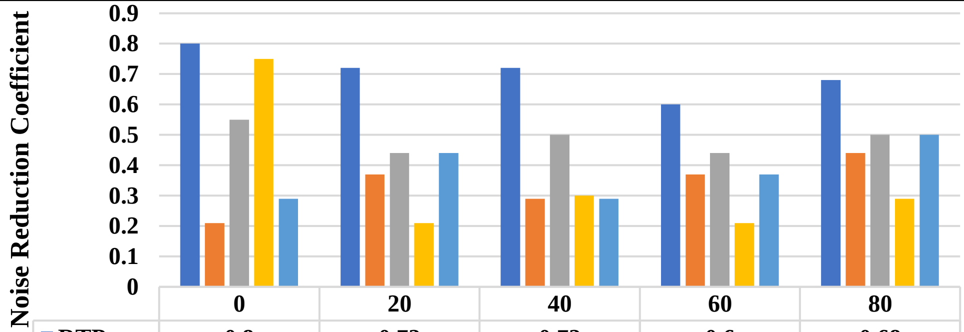
While in case of sisal, little reduction in absorbency at all distance has been observed due to increase in the crystalline structure which was also observed in the fiber XRD results. The effect of variance in sound absorption at different distance shows no significant change at all distance in both RUP and SUP. Having similar structure of yarn and fabric certain change has been observed within and between the samples due to treated fiber and change in yarn property for a same fabric structure. Even at the different distance the better results have been shown between 20 to 60cm. It can be concluded that the plain weave fabric parameter can be optimized to get the best sound absorption properties.

Different weaves of the fabrics

The fabric structure of the different weave is changing based on its way of interlacement and the alignment of the intersecting point. In plain weave generally having a simple square structure which can be changed by changing weave like twill, broken twill, zig-zag twill, satin, etc. changes the surface characteristic, appearance, lustre and strength of fabric. Here in the study three weave has been taken – plain, broken twill and double cloth weave. As studied earlier the plain weaved RTP sample gives good results of sound absorption. The further two sample of the broken twill RTBT and STBT has been also studied and it clearly indicates from the Graph 4.18 that NRC value of RTBT reduces little compare to RTP. That reduction is mainly due to the surface structure of broken twill which scattered the sound waves. Similar trend has been observed in STP and STBT.

Another structure of the fabric with double cloth weave has been taken but not expected result has been found. The general consideration that the double cloth fabric due to its thickness and pockets in between it will give more sound absorption property, which is true in case of double cloth fabrics but in case of ramie and sisal yarns the structured formed is not as compact as normal cloth and at interchanging point more gapping was created during weaving. Hence, the fabric is not trapping any air in the pocket and so it was not found an effective structure for sound resistant material. Also, during the study plain weave structure found to be more suitable specially when minor fibers are used.

At the distance 40cm optimum and an average result has been observed. Due to the little uneven structure of the fabrics certain uniform trend cannot be traced out. This is one of the limitations of fabrics manufactured from the minor fibers.



	0	20	40	60	80
RTP	0.8	0.72	0.72	0.6	0.68
STP	0.21	0.37	0.29	0.37	0.44
RTBT	0.55	0.44	0.5	0.44	0.5
STBT	0.75	0.21	0.3	0.21	0.29
R/S TDC	0.29	0.44	0.29	0.37	0.5

Distance (cm)

RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave, R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing

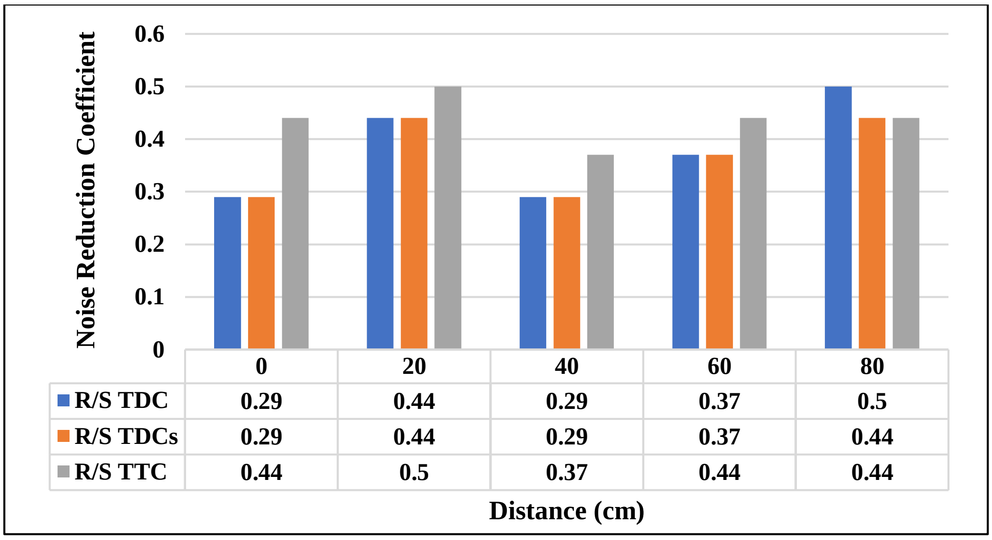
Graph 4.18: Analysis of different weave fabrics

Double Cloth weave fabrics

The double cloth structure is created in such a way that it forms two layers of fabric with interlocking points which creates pockets. As the number of layers increases, sound absorption increases hence this weave was considered for analysis of noise reduction coefficient. Further, based on basic structure of double cloth – double cloth weave without stuffing and double cloth weave with stuffing were analyzed depending upon fabric surface characteristics i.e. flat and wavy surface.

While comparing the Graph 4.19, NRC values of both the fabrics showed similar absorption at all distance except on 80cm. Though R/S TDC having a greater number of picks compare to R/S TDCs and comparatively less gapping at interlocking point it showed similar result only. This might be due to the alignment of the ramie and sisal yarns alternately used for the fabric construction. The sound wave when strikes the fabric was partially passing through the gapping at the intersecting points.

Another fabric structure R/S TDCs was developed based on its bulky and wavy structure at the surface which might absorb sound. But the results showed no difference, due to the stuffing material, the combination of weft and warp yarns and the gapping at the interlocking points.



R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing

Graph 4.19: Analysis of various double cloth weave fabrics

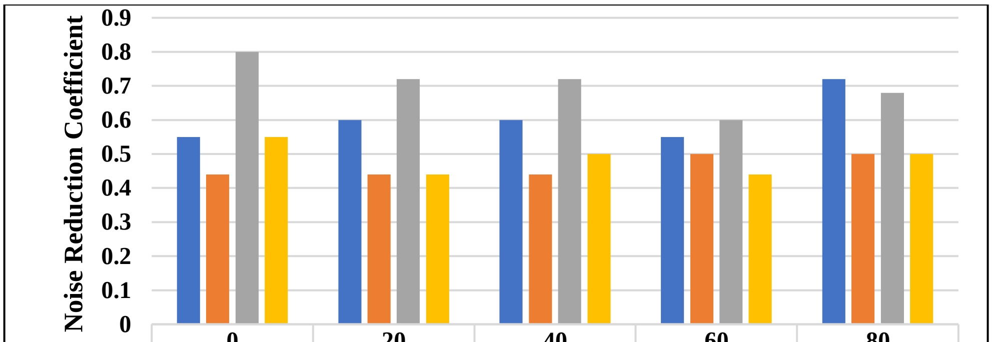
Further, a variation of double cloth weave i.e Tubular cloth weave was created to check its impact on sound absorption. This particular weave showed better absorbency compare to R/S TDC and R/S TDCs, the reason could be piping like structure creating horizontal lines and vertical wavy structure. Additionally, for the stuffing fiber strands were used and at the interlocking very small gapping was found. Thus, amongst the three R/S TDCs showed better results, but as all the three samples showed below 0.50 NRC values, they were excluded.

Owing to the fiber and fabric characteristics the absorption at different distance showed unusual trend till 60cm and increase at 80cm only. Hence, optimization of distance for this particular sets of fabrics were difficult to predict.

Different weaves in ramie fabrics

The fibers inherent property and fabric structure are the two major factors for sound absorption. The four different fabrics developed using fiber strand, untreated fiber yarn and treated fiber yarn for two different weaves were compared in Graph 4.20.

Amongst the fabrics of untreated fibers, it seems that R FUP gives better result compare to RUP. Amount of fibers utilized for creating fabric and its wavy structure having impurities at the fiber surface might be the reason of sound absorption. Despite of having more thickness, RUP could not absorb good amount of sound which could be due to coarser yarn structure creating porous fabric structure.



	0	20	40	60	80
R FUP	0.55	0.6	0.6	0.55	0.72
RUP	0.44	0.44	0.44	0.5	0.5
RTP	0.8	0.72	0.72	0.6	0.68
RTBT	0.55	0.44	0.5	0.44	0.5

R FUP: Ramie-Fiber-Untreated-Plain weave, RUP: Ramie-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave

Graph 4.20: Analysis of different weave ramie fabrics

While comparing two fabrics of different weaves, RTP shows better absorption. Hence, as discussed earlier the plain weave fabrics of minor fibers has better impact on sound absorption. While RTBT fabric ranging between 0.44 to 0.55 NRC is only because of the low cover factor. Another point over here is that RTP texture shows ramie weft yarn only while RTBT shows both ramie and cotton yarn almost of equal proportion at the surface and hence the reduction in NRC value has been observed.

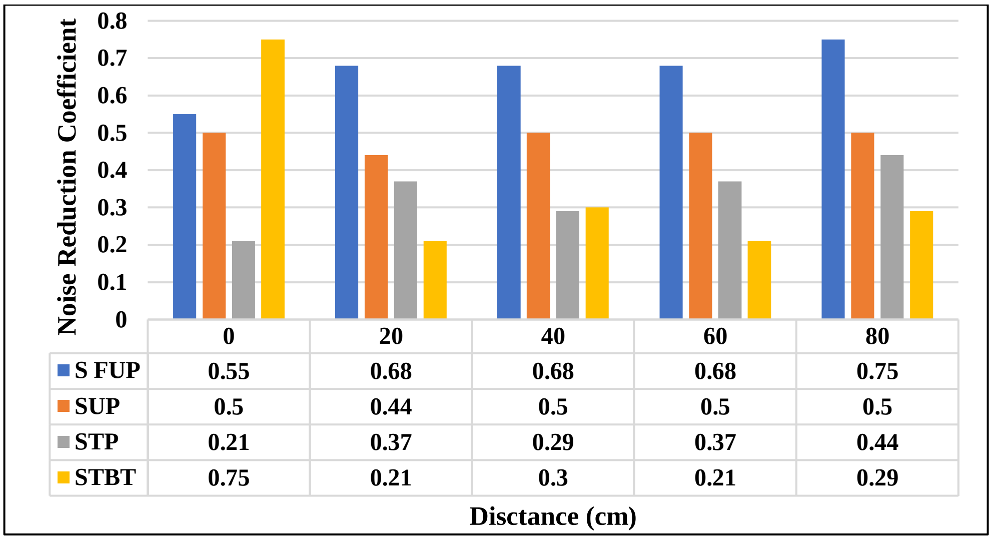
Hence, amongst the four samples RTP shows the best result and constant NRC value has been observed at 40 cm distance for all the samples.

Different weaves in sisal fabrics

Sisal a less cohesive and stiff fiber were treated to soften the fibers for developing various woven fabrics. The inherent properties and effect of weave will have an impact on sound absorption; hence four different fabrics were analyzed from the Graph 4.21.

A similar trend was also observed in sisal fabrics of untreated fibers i.e. S FUP shows better absorption compare to SUP. The amount of fiber strand, number of picks and the uneven rough surface of S FUP might be the reason of better sound absorption.

Another comparison between different weave using treated fiber yarn shows that STP absorbs sound much better than STBT. Here it could be because of the improvement in the crystalline structure of the fiber as well as the alignment of the yarn as per the weave. While comparing both the fabric more of warp yarns were observed in STBT, thus due to mercerized cotton warp yarn creating thinner structure in between the weft yarns might be the reason of less NRC value.



SFUP: Sisal- Fiber-Untreated-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave,

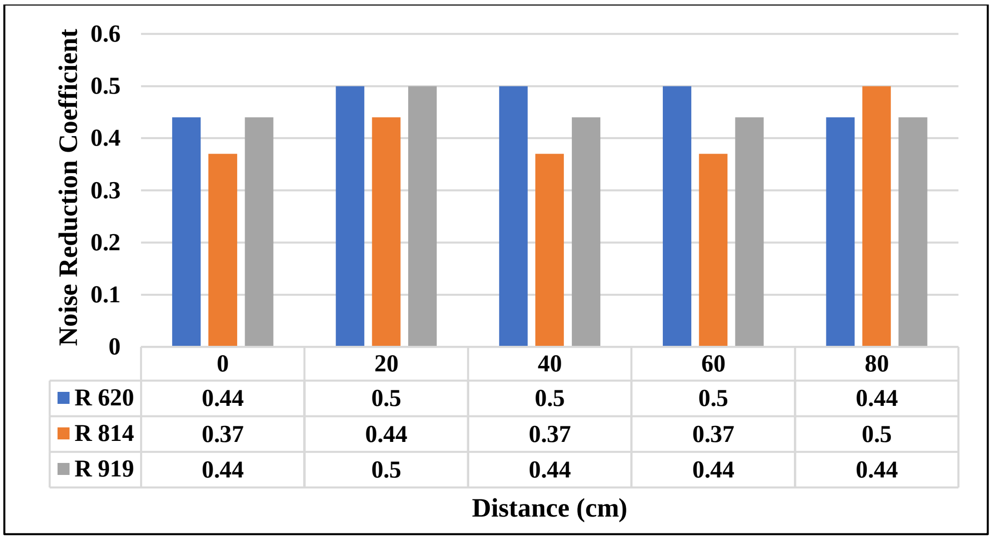
Graph 4.21: Analysis of different weave sisal fabrics

While, amongst the four samples S FUP and SUP show good sound absorption results. At 20 and 60cm distance almost the NRC values of all samples are showing similar results.

Nonwoven fabrics

The sound absorption parameters for nonwoven fabrics are fiber density, layering of fibers and needle punching technique. The three different fabrics of different GSM were manufactured hence the major change amongst the three are quantity of fiber and its density. As the amount of fiber and its density increases thickness also increases, which is an important factor for sound absorption.

The impact of different GSM based nonwovens on sound absorption was shown in Graph 4.20. As the thickness increases, sound absorption increases. Similar trend has been observed but with little variance in NRC values of all the three samples. Thus, major reason of such negligible difference could be because of uneven fiber distribution and fabric surface. The fibers got cluster due to cohesive nature of the fibers and hence uneven fabric surface was observed.



R614: Ramie needle punch of 614 GSM, R814: Ramie needle punch of 814 GSM, R919: Ramie needle punch of 919 GSM

Graph 4.22: Analysis of various nonwoven fabrics

Thus, based on thickness and almost a constant NRC value at all distance R 919 nonwoven was selected for the study as backing material. While in case of distance major difference was found at 0 and 60cm distance. Hence, 40cm distance was optimized for the study as majority of fabrics showed better results.

b. Effect of frequency on different types of fabrics

Another parameter is to optimize the frequency for the sound absorbing testing of the developed samples at 40cm distance. As per the end use and the capacity of the fabricated tube, mid frequency range from 1000Hz to 2200Hz were taken for the testing. The test results are mentioned in Table 4.16. From the mentioned data various comparison based on frequency and fabric structure were plotted on graph for further clarity to optimize the frequency for the study.

Table 4.16: Sound resistance of different fabrics at various distance.

Sr. No.	Fabric Code	Noise Reduction Coefficient (NRC)				
		1000Hz	1200Hz	1400Hz	1800Hz	2200Hz
Plain weave using fiber strands						
1	R FUP	0.78	0.60	0.72	0.86	0.72
2	S FUP	0.72	0.68	0.68	0.86	0.78
3	R/S FUP	0.55	0.50	0.55	0.65	0.55

Untreated Plain Weave						
4	RUP	0.37	0.44	0.55	0.68	0.60
5	SUP	0.44	0.50	0.55	0.68	0.55
Treated Plain Weave						
6	RTP	0.72	0.72	0.67	0.89	0.75
7	STP	0.37	0.37	0.50	0.21	0.37
Broken Twill Weave						
8	RTBT	0.75	0.44	0.68	0.80	0.60
9	STBT	0.37	0.21	0.45	0.21	0.37
Double Cloth Variations						
10	R/S TDC	0.50	0.44	0.37	0.29	0.37
11	R/S TDCs	0.50	0.44	0.37	0.44	0.44
12	R/S TTCs	0.50	0.50	0.59	0.60	0.50
Nonwoven						
13	R620	0.37	0.50	0.75	0.50	0.21
14	R814	0.37	0.44	0.78	0.50	0.29
15	R919	0.37	0.50	0.86	0.60	0.29

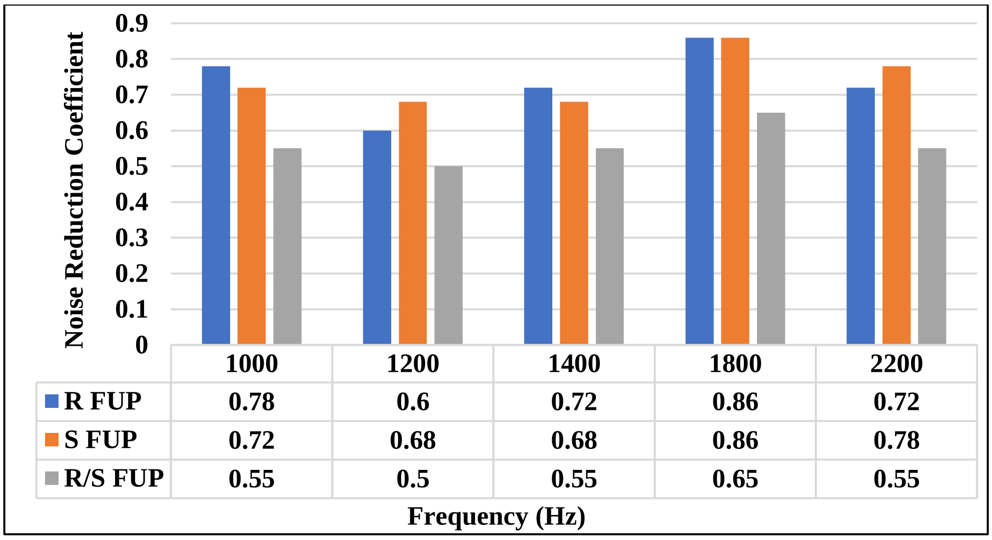
RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave, RUP: Ramie-Untreated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave, R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing, R620: Ramie needle punch of 620 GSM, R814: Ramie needle punch of 814 GSM, R919: Ramie needle punch of 919 GSM

Plain weave fabrics using fiber strands

The fiber count, weave structure, fabric count and thickness have an impact on sound absorption. As the pick density increases, the absorption increases. Being a plain weave structure, the variation in the pick density was due to the effect of fiber i.e fiber thickness and number of the strand inserted as weft.

The effect of sound absorption of three different fabrics of untreated fibers showed difference in absorption at various frequency. Earlier, based on distance it was observed that SFUP absorbed sound better than RFUP. Amongst the three fabrics from

Graph 4.23, R FUP having lowest fabric count (4X22) and highest thickness (2.7) shows better absorption. Hence, apart from the thickness it could be the fiber structure i.e. untreated ramie having rough and rigid structure could have scattered the sound wave. Another factor could be that ramie fiber strands are bundle of small fibers that protrude at the surface of the fabric which must have scattered or trapped the sound better compare to SFUP.



RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave

Graph 4.23: Analysis of various plain weave fabrics using fiber strands

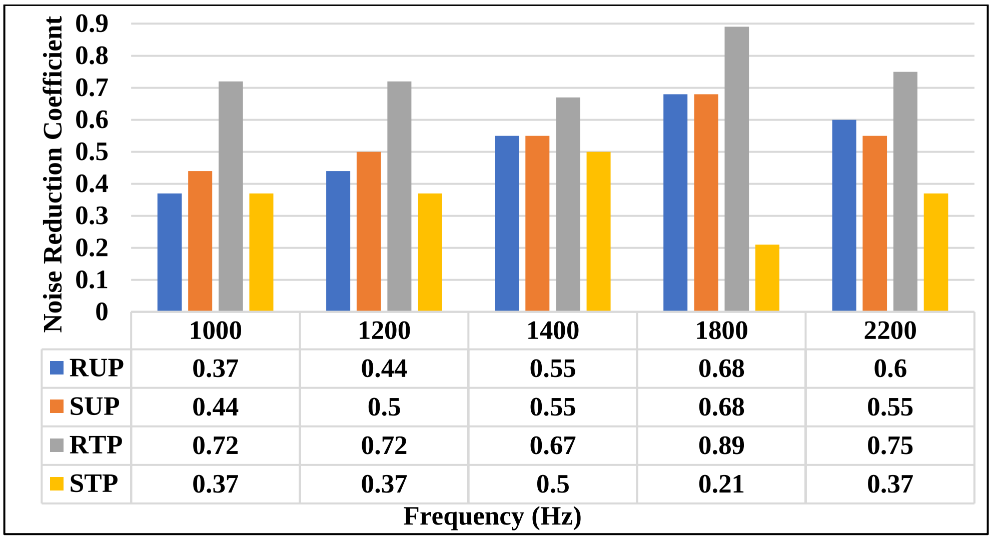
Based on the sound mechanism the sound absorbs better with less porous and fibrous material and at high frequency it shows moderate to high absorption. The concept was observed in sample R FUP followed by S FUP and R/S FUP. While on 1400Hz frequency almost all the samples showed an appropriate absorption followed by 1000, 1800 and 2200 Hz and lowest at 1200Hz frequency.

Plain weave fabrics

The four different plain weave fabrics using untreated and treated fiber yarns of ramie and sisal were developed. The untreated yarns were of coarser structure compare to the treated yarns. While amongst the treated yarns, ramie yarns were fluffy and coarser compare to sisal.

The two fabric properties i.e. cover factor and thickness also have an impact on the sound absorption. The sound absorption coefficient of all the samples plotted in Graph 4.24, ranged between 0.21 to 0.89. It seems that fiber property, pick density and yarn structure must have played an important role in sound absorption by RTP fabric.

Though fabrics SUP and RUP had higher thickness with negligible absorption coefficient were lower than RTP. The reason over here could be porous structure due to untreated fiber insertion.



	1000	1200	1400	1800	2200
RUP	0.37	0.44	0.55	0.68	0.6
SUP	0.44	0.5	0.55	0.68	0.55
RTP	0.72	0.72	0.67	0.89	0.75
STP	0.37	0.37	0.5	0.21	0.37

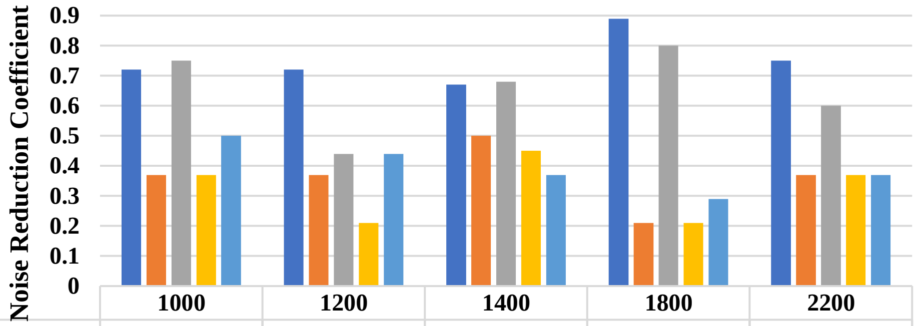
RUP: Ramie-Untreated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave

Graph 4.24: Analysis of various plain weave fabrics

Overall, at all frequency the RTP fabric showed good absorption followed by SUP, RUP and STP. While the highest coefficient was observed in RTP at 1800Hz and at 1400Hz it seems that absorption coefficient reduces or increases on either side. Hence it can be said that at 1400Hz an average reading was observed.

Different weaves of the fabrics

The different weave structure of similar denier yarn of ramie and sisal were analyzed for sound absorption based on Graph 4.25. On comparing two plain weave fabrics, the highest absorption at all frequency were observed in RTP. The pick density was high with less of pores and fluffy surface which might have scattered and absorbed the sound. While in case of STP due to the fiber thickness, the yarn structure was uneven and hence having gapping in between might be the reason of less absorption. Hence, this can be correlated with the concept that scattering/absorption of sound depends on porous structure, yarn density and fabric surface.



	1000	1200	1400	1800	2200
RTP	0.72	0.72	0.67	0.89	0.75
STP	0.37	0.37	0.5	0.21	0.37
RTBT	0.75	0.44	0.68	0.8	0.6
STBT	0.37	0.21	0.45	0.21	0.37
R/S TDC	0.5	0.44	0.37	0.29	0.37

Frequency (Hz)

RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave, R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing

Graph 4.25: Analysis of different weave fabrics

While in case of broken twill weave fabrics also RTBT showed better absorption except at 1200Hz frequency. Inspite of good results when compared with plain and broken twill fabrics, reduction in sound absorption was observed. The major reason could be the warp and weft yarn thickness which created uneven surface but with clear visible warp yarns having minute pores from which sound waves must have passed through.

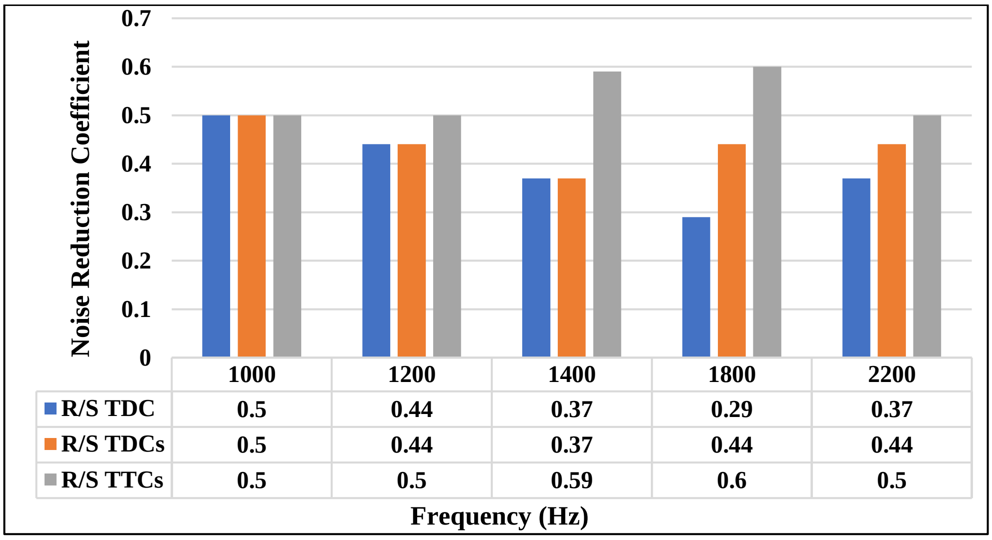
The R/S TDC fabric was developed using both ramie and sisal yarns alternately. The coefficient of this particular sample showed variation between 0.29 to 0.50 absorption i.e. hardly 50 percent. The lowest absorption might be due to the three different fiber and yarns properties and little open structure at interlocking areas of the fabric.

Hence, amongst all the fabrics RTP followed by RTBT showed good absorption majorly at all frequency. While from the trend it is clearly visible that before and after 1400Hz frequency the absorption have changed i.e. increased/decreased.

Double Cloth weave fabrics

The number of layers and the uneven fabric surface has an impact on sound absorption. With this concept, three double cloth weave fabrics were developed using ramie and sisal yarns alternately. The basic double cloth weave fabric with and without stuffing showed negligible difference, especially at 1800Hz and 2200Hz frequency.

Amongst the two R/S TTCs (Tubular Cloth with stuffing) showed better results at higher frequency. It could be because of the stuffing which created uneven surface and that scattered the sound of higher frequency, thereby absorption was observed.



	1000	1200	1400	1800	2200
R/S TDC	0.5	0.44	0.37	0.29	0.37
R/S TDCs	0.5	0.44	0.37	0.44	0.44
R/S TTCs	0.5	0.5	0.59	0.6	0.5

R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing

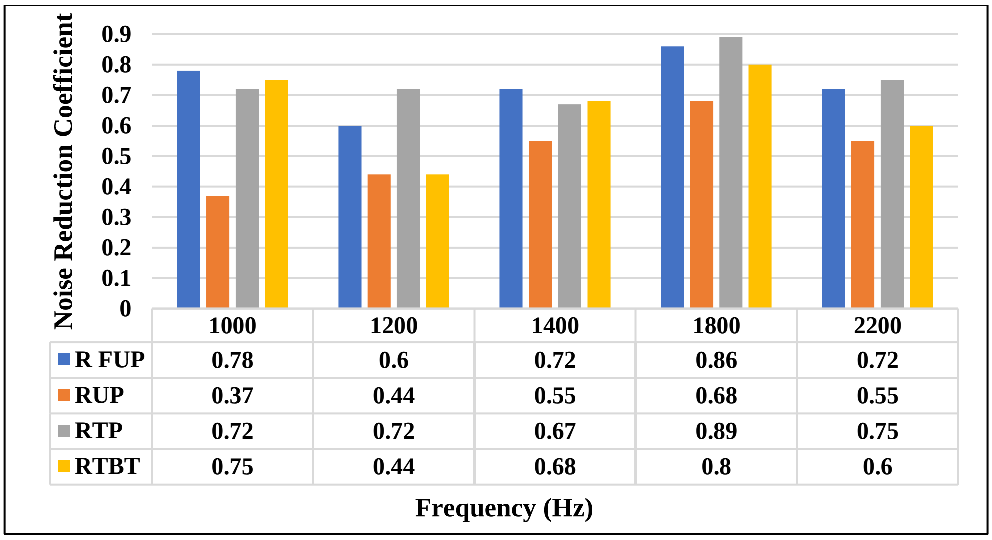
Graph 4.26: Analysis of different double cloth weave fabrics

While comparing all the fabrics in Graph 4.26, R/S TTCs showed absorption value of 0.5 to 0.6 from 1000 to 1800Hz after which it reduced till 0.5. The best result of R/S TTCs could be due to the stuffing of untreated ramie fiber strand and comparatively less of space between two tubular lines. Also, the gapping was very little compare to R/S TDCs and R/S TDC. Overall, at 1400Hz the fabrics showed increased absorption value and then reduced at 1800Hz and 2200Hz.

Different weaves in ramie fabrics

The absorption coefficient of all the different ramie fabrics ranged between 0.37 to 0.89 at different frequency. All the fabrics analyzed from Graph 4.27, to get a clarity of which fabric at which frequency gives best absorption.

The fabric RTP followed by R FUP gives overall better results, in the former one the weave with less pores alongwith the fluffy yarn structure might be the reason for better sound absorption. While R FUP as discussed earlier has better absorption which may be due to its fiber structure and uneven surface might be the cause of absorption.



RFUP: Ramie-Fiber-Untreated-Plain weave, RUP: Ramie-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave

Graph 4.27: Analysis of different weave ramie fabrics

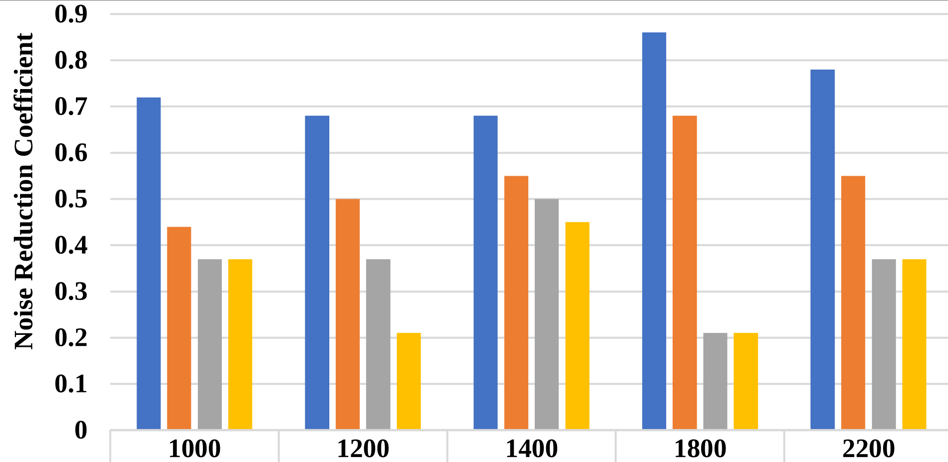
The RTBT fabric being compact but due to its weave structure the fabric thickness and different yarn properties must have created a compressed fabric, hence showing second lowest absorption amongst all the fabrics at all frequency. While RUP fabric of coarser untreated fiber yarn was little stiff and rough which created gapping in between the weft as well as at the intersecting points, from which the sound must be passing through.

Hence, at 1800Hz frequency all the samples showed highest absorption followed by 1400, 2200, 1000 and 1200 Hz. While, over here it was also observed that absorption values after and before 1400 Hz was increase and decrease in all the fabrics.

Different weaves in sisal fabrics

The fabric developed using untreated fiber strands showed more absorption comparatively than the untreated and treated fiber yarn fabrics. It might be because of the fiber being stiff and less cohesive which must have covered the pores of the fabrics very well. The weave structure and higher number of weft insertion and the protruding fibers at the fabric surface must have also played role in sound absorption.

Despite of having similar fabric count and cover factor SUP shows better absorption than STP from Graph 4.28, which is owing to the fact that with the increase in thickness and yarn denier and the inherent fiber structure all together must have an impact on absorption. Having negligible thickness difference STP showed less absorption because of the bulky yarn structure when inserted as weft was compressed it created tiny pores owing to its stiffness at the intersection points.



	1000	1200	1400	1800	2200
S FUP	0.72	0.68	0.68	0.86	0.78
SUP	0.44	0.5	0.55	0.68	0.55
STP	0.37	0.37	0.5	0.21	0.37
STBT	0.37	0.21	0.45	0.21	0.37

SFUP: Sisal- Fiber-Untreated-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave

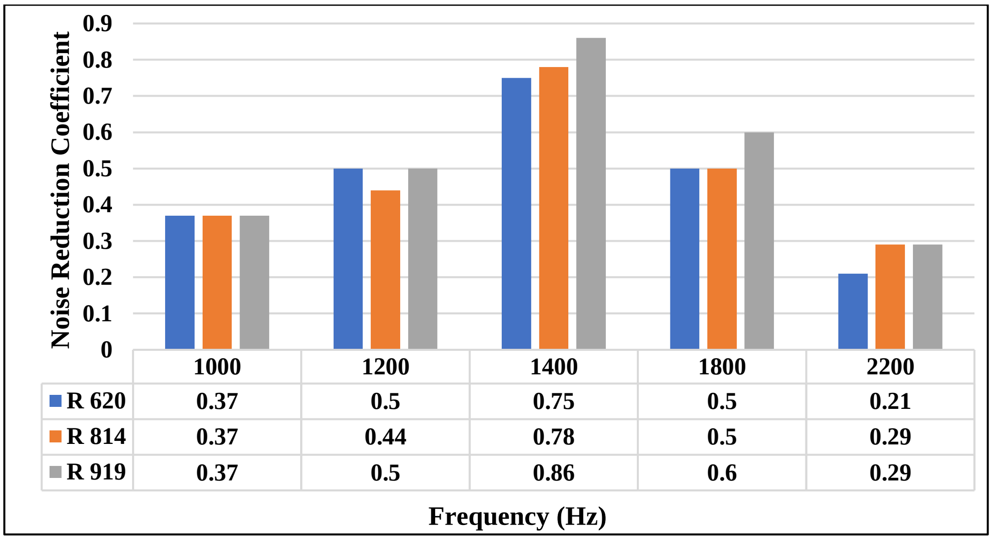
Graph 4.28: Analysis of different weave sisal fabrics

While, broken twill fabric STBT showed lowest absorption same as RTBT, due to the lowest fabric count, cover factor and thickness. Both the sisal and cotton yarns were equally visible at the surface, but as the cotton yarn was comparatively finer than that of sisal the unevenness and pores have showed less absorption.

The highest absorption was observed at 1800Hz and 1400Hz frequency for all fabrics. The major factor for this could be the thickness and level of compactness to resist the sound wave of particular frequency.

Nonwoven fabrics

The three nonwoven fabrics of different GSM were developed for backing material. As discussed earlier the fiber density, thickness and needle punching affects the sound absorption of the fabrics. The trend of R919 fabric in Graph 4.29 shows, increase in absorption as frequency increases till 1400Hz after which gradual absorption went down at different frequency. Hence, it is clear that the absorption increases with the increase of thickness. The maximum absorption at all frequency was by R919 followed by R814 and R620.



	1000	1200	1400	1800	2200
R 620	0.37	0.5	0.75	0.5	0.21
R 814	0.37	0.44	0.78	0.5	0.29
R 919	0.37	0.5	0.86	0.6	0.29

R620: Ramie needle punch of 620 GSM, R814: Ramie needle punch of 814 GSM, R919: Ramie needle punch of 919 GSM

Graph 4.29: Analysis of various nonwoven fabrics

c. Effect of number of layers

The sound absorption panel composition is made up of number of layers. The top layer is considered as an aesthetic as well as absorption layer. This layer allows sound wave to penetrate and scatter as per the surface characteristics. The second layers are thicker comparing to top layer and generally it is made up of fiber compositions inform of fiber sheet like glass wool or nonwoven. In this work the backup material was taken of ramie nonwovens. This composition of material is mounted on the ply to create the panel either by increasing the thickness of the backup material or the combination of backup with air gaps. The Table 4.17, indicates different NRC values of single layer fabric with nonwoven and the combination of air gap and ply. Main motto was to have maximum absorption with less layers in order to decrease the bulk of final product. Hence three different possible combinations were analyzed at 40cm distance with 1400Hz frequency.

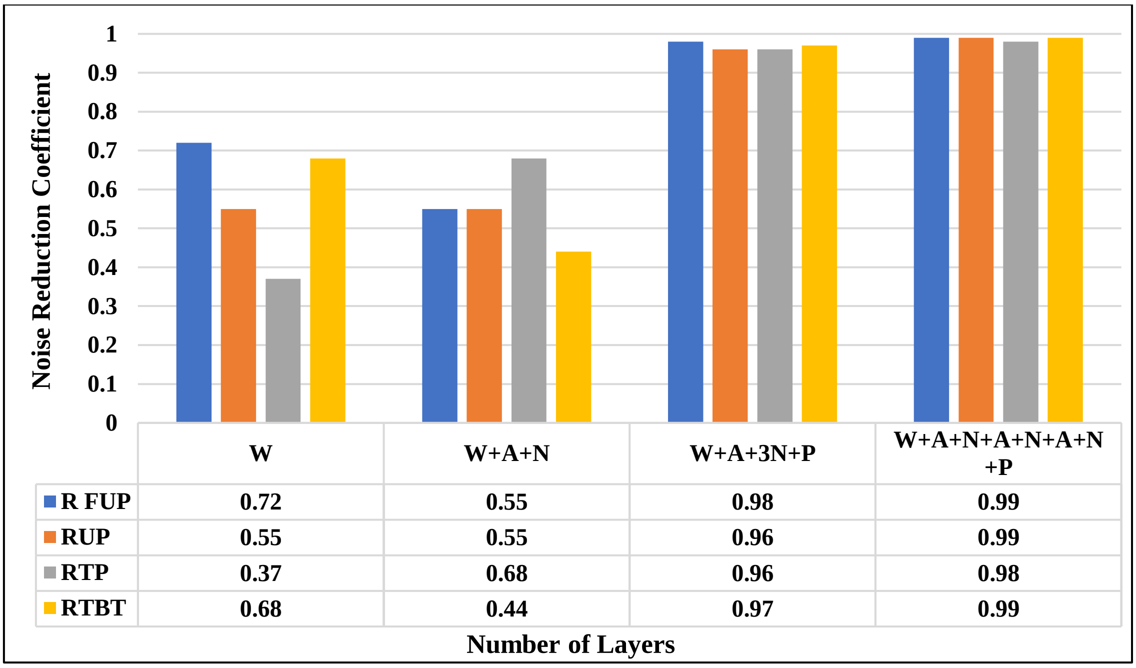
Table 4.17: Sound resistance properties of different fabrics in combination

Sr. No.	Sample Code	Noise Reduction Coefficient (NRC)			
		W	W+A+N	W+A+3N+P	W+A+N+A+ N+A+N+P
Plain weave using fiber strands					
1	R FUP	0.72	0.55	0.98	0.99
2	S FUP	0.68	0.55	0.97	0.99
3	R/S FUP	0.55	0.68	0.96	0.99
Untreated Plain weave					
4	RUP	0.55	0.55	0.96	0.99
5	SUP	0.55	0.60	0.96	0.99
Treated Plain weave					
6	RTP	0.37	0.68	0.96	0.98
7	STP	0.50	0.50	0.93	0.98
Broken Twill Weave					
8	RTBT	0.68	0.44	0.97	0.99
9	STBT	0.45	0.29	0.96	0.98
Double Cloth variation					
10	RS TDC	0.37	0.44	0.96	0.99
11	RS TDCs	0.37	0.37	0.96	0.98
12	RS TTCs	0.59	0.37	0.96	0.99

RFUP: Ramie-Fiber-Untreated-Plain weave, SFUP: Sisal- Fiber-Untreated-Plain weave, R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave, RUP: Ramie-Untreated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave, R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTC: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing

Different weaves in ramie fabrics

The single layer fabric absorption was discussed earlier, to understand the surface properties and its impact on sound absorption. With the data of single layer and increasing the number of layers further its impact on sound was analyzed with Graph 4.30.



	W	W+A+N	W+A+3N+P	W+A+N+A+N+A+N +P
R FUP	0.72	0.55	0.98	0.99
RUP	0.55	0.55	0.96	0.99
RTP	0.37	0.68	0.96	0.98
RTBT	0.68	0.44	0.97	0.99

RFUP: Ramie-Fiber-Untreated-Plain weave, RUP: Ramie-Untreated handspun yarn-Plain weave, RTP: Ramie-Treated handspun yarn-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, W: Woven fabric, A: Air gap, N: Nonwoven fabric, P: Ply

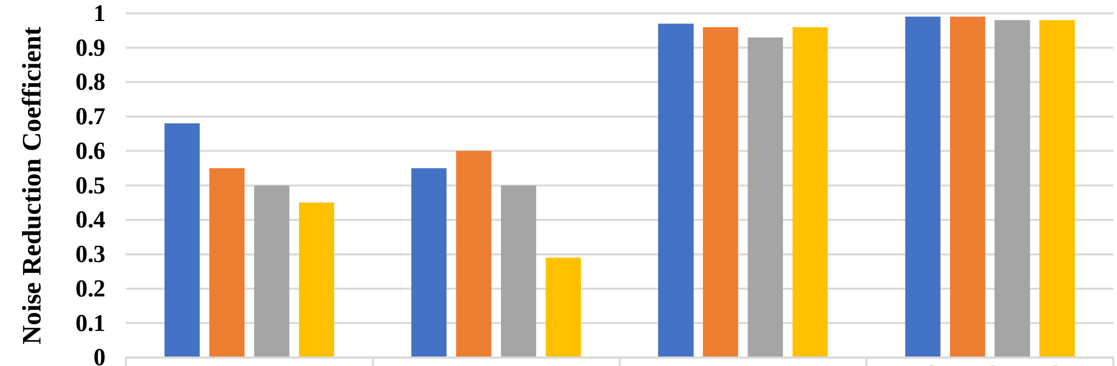
Graph 4.30: Analysis of different weave ramie fabrics

Amongst the plain weave fabrics, highest absorption was observed in RUP followed by RTP and R FUP. The rough and unbalanced fabric surface are the main factors of absorption. While, by adding the layers it was found the all the three samples absorption increases but the highest was by fabric RTP. The fabric of treated fiber yarn had fluffy structure from which sound wave passed but by adding air gap and nonwoven the absorption increased due combination of two differently oriented fabric structure as well as the gap within which the change of energy must have reduced the frequency of sound and thereby the absorption was good.

While comparing all the four fabrics, RTBT shows better absorption as single layer. By adding layer and air gap reduction of was observed which might be because of the sound wave which passed though the fabric must have trapped it less owing to the fabric properties of the nonwoven. Overall, the trend of absorption increased with the number of layers as well as air gap and by adding a ply.

Different weaves in sisal fabrics

The sisal fabrics are little stiffer compare to ramie, owing to its fiber properties. After the treatment it improves in terms of smooth and lustrous surface apart from pliability. The Graph 4.31, shows comparative analyses of different sisal woven fabrics developed using untreated fiber strands, untreated and treated fiber yarn.



	W	W+A+N	W+A+3N+P	W+A+N+A+N+A+N +P
S FUP	0.68	0.55	0.97	0.99
SUP	0.55	0.6	0.96	0.99
STP	0.5	0.5	0.93	0.98
STBT	0.45	0.29	0.96	0.98

SFUP: Sisal- Fiber-Untreated-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, STP: Sisal-Treated handspun yarn-Plain weave, STBT: Sisal-Treated handspun yarn-Broken Twill weave, W: Woven fabric, A: Air gap, N: Nonwoven fabric, P: Ply

Graph 4.31: Analysis of different weave sisal fabrics

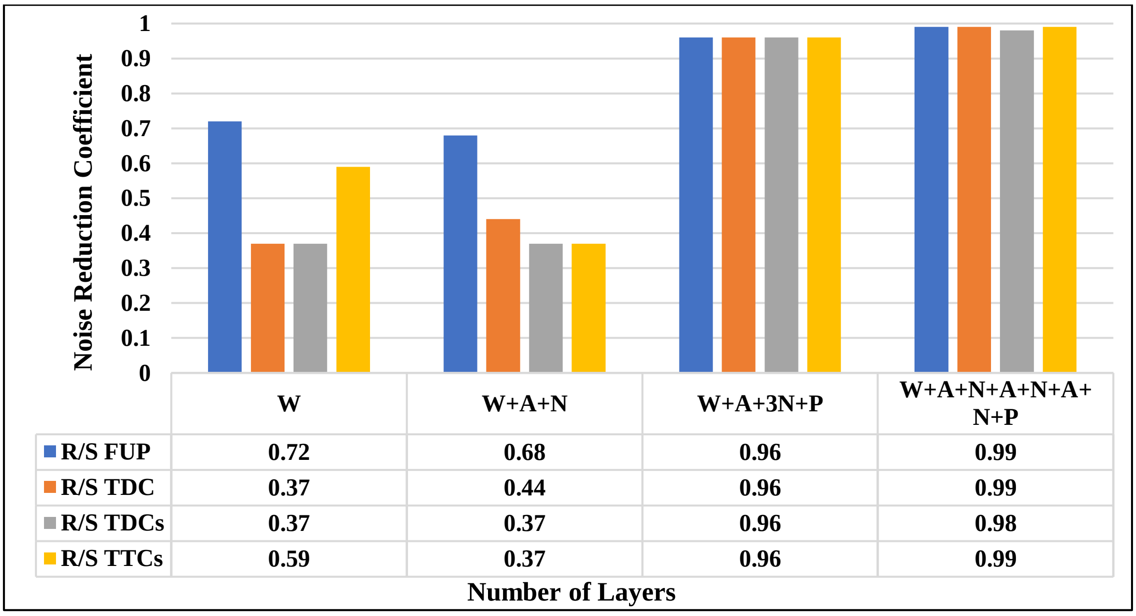
Amongst the plain weave sisal fabrics, the highest absorption was found in S FUP followed by STP and SUP, as single layer. With the addition of a layer and air gap the sequence changed i.e. SUP followed by S FUP and STP. The reason over here could be the rough texture of untreated fiber yarn which might have scattered sound and after penetration further it must have absorbed more by nonwoven. Again, the orientation of the fabric structure as front and backing layers plays an important factor in sound absorption. Thus, the uneven surface of nonwoven backing fabric must have made the difference.

The sample STBT shows reduction by adding a layer and air gap. The sound wave passing through the asymmetric fabric surface must have scattered in multiple direction and that wave passing through nonwoven could not absorb further owing to its fabric properties. Hence, with a layer and air gap it showed reduction. Further, with addition of number of layers, air gaps and a ply the 0.98 and 0.99 has found.

Combination of ramie and sisal

The combination of ramie and sisal fiber strand fabric and three different double cloth weave fabrics were analyzed from Graph 4.32, as single layer and by adding number of layers.

Earlier at the different distance and frequency R/S FUP gave better results, while double cloth fabrics gave poor results as single layer. The same trend has been observed by adding a layer of nonwoven and air gap. It might be due to the pore areas and the uneven fabric surface through which sound passes easily.



	W	W+A+N	W+A+3N+P	W+A+N+A+N+A+N+P
R/S FUP	0.72	0.68	0.96	0.99
R/S TDC	0.37	0.44	0.96	0.99
R/S TDCs	0.37	0.37	0.96	0.98
R/S TTCs	0.59	0.37	0.96	0.99

R/SFUP: Ramie and Sisal-Fiber-Untreated-Plain weave, R/S TDC: Ramie and Sisal-Treated yarn-Double Cloth weave without stuffing, R/S TDCs: Ramie and Sisal-Treated yarn-Double Cloth weave with stuffing, R/STTCs: Ramie and Sisal-Treated yarn-Tubular Cloth weave with stuffing, W: Woven fabric, A: Air gap, N: Nonwoven fabric, P: Ply

Graph 4.32: Analysis of ramie and sisal combination fabrics

As the number of layers increases absorption will be high, with this concept and for aesthetic reasons double cloth fabrics were developed using two different weft yarns. As single layer they gave poor results, when these fabrics having number of nonwoven layers, air gaps and a ply as backing material the absorption increased drastically. Here the reason could be the scattering at front layer gets absorbed partially by each layer and finally by the ply which trapped the sound. Hence based on the kind of demand these fabrics could also be a part of collection.

4.7. Analysis of fabric properties of selected samples

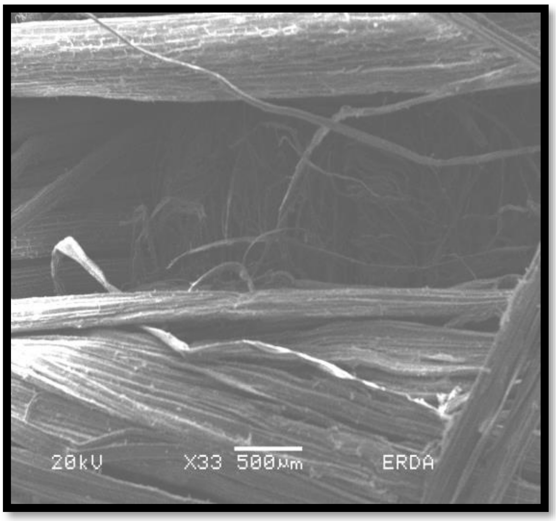
The sound absorption fabrics developed showed difference in absorption as single layer and also had little rough surface owing to the fiber and yarn properties. As the woven samples will be utilized as the front layer and to increase its surface characteristics, resin was applied onto the selected samples. Those samples having the more rough and open structure amongst the basic weaves were only selected. The tests to identify its effect on fabric surface as well as sound absorption and comparative analysis were done on the unfinished and resin finished fabrics.

a. Comparative analysis of unfinished and resin finished fabric

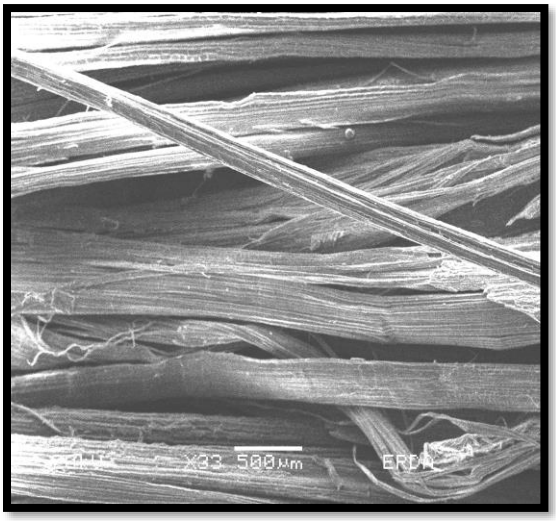
The three different fabrics based on raw material content were selected for resin finish. Along with the aesthetic purpose sound absorption was also important. Hence, structural analysis and sound absorbing test were done to identify the effect of resin on the fabric surface and porous areas of the fabric as well as to understand its impact on the sound absorption.

Scanning Electronic Microscopy (SEM)

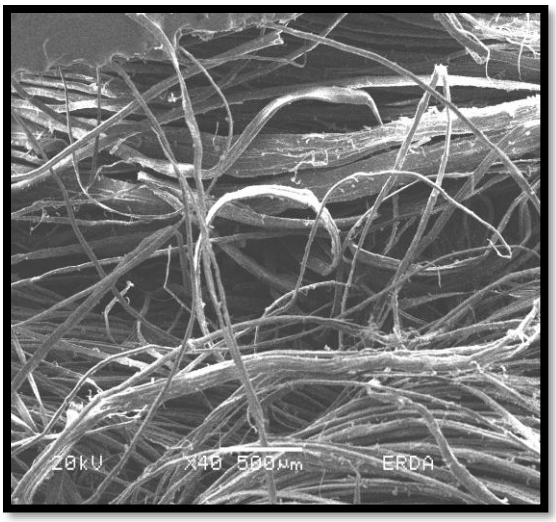
Natural resin was applied on the selected fabrics. It was observed from the Plate 4.5, that the resin had penetrated into fabric instead of creating a layer on the surface of the fabrics. Due to the penetration the feel of the fabric was improved, reduction in protruding fiber on the surface on the fabrics as the application process was done using padding mangle technique as well as aesthetics were also improved. Thus, further the sound absorption tests were done at the optimized standards.



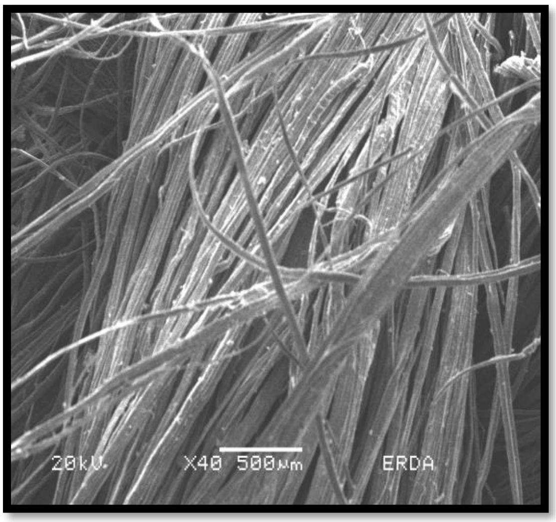
R/S FUP



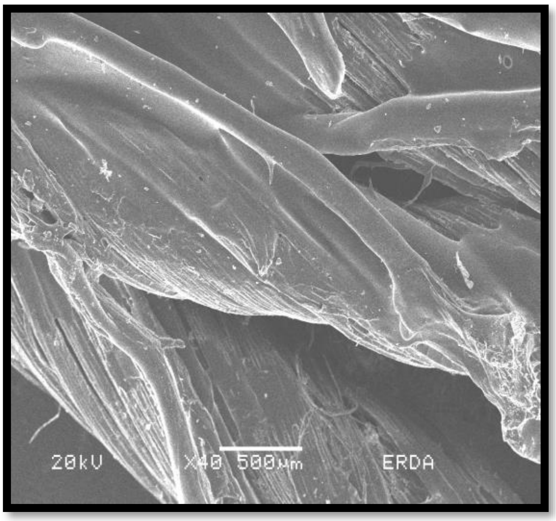
R/S FUP (R)



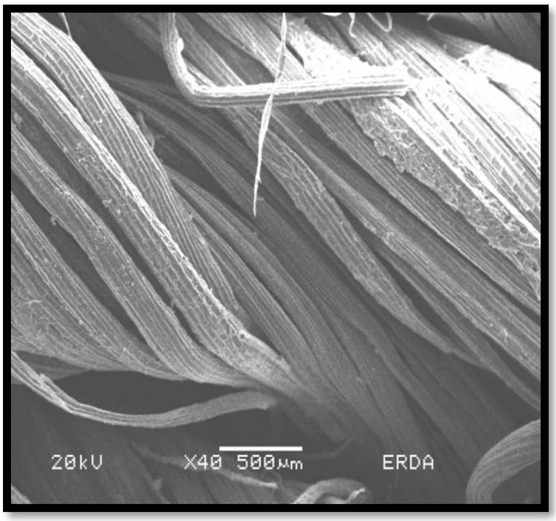
RTBT



RTBT (R)



SUP



SUP(R)

Plate 4.5: SEM image of un-finished and resin finished fabric samples

R/S FUP: Ramie and Sisal-Fiber-Untreated-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, SUP: Sisal-Untreated handspun yarn-Plain weave, (R): Resin finished fabrics

Sound absorbing properties:

The resin finished woven fabrics were analyzed for sound absorbing materials as a single layer and compared with unfinished woven fabrics. Testing details are mentioned in Table no. 4.18.

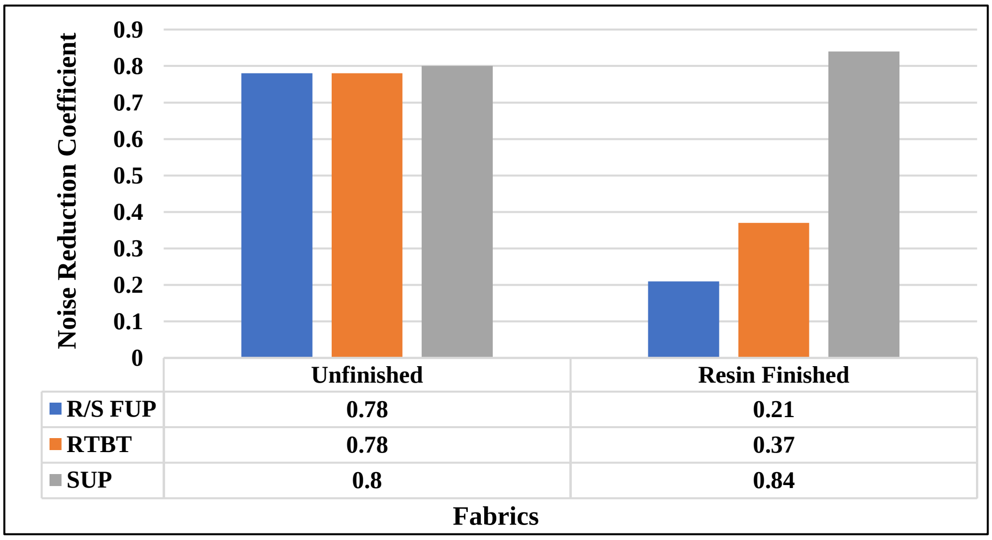
From the data graph was plotted for comparative analysis. It was observed from the Graph 4.31, that the unfinished fabrics showed more absorption compared to resin finished fabrics. As analyzed from SEM (Plate no. 4.5), the resin penetrated from the fabric which might have blocked the pores. Even fabric surface was also seen after the resin treatment. Thus, sound absorption by resin finished fabrics was less compared with unfinished. While negligible difference was observed in SUP sample after the finish. Hence, for sound absorption study unfinished fabric was considered.

Table 4.18: Sound resistance properties of unfinished and resin finished fabrics

Fabric Codes	Noise Reduction Coefficient (NRC)	Fabric sample
Unfinished		
R/S FUP	0.78	
RTBT	0.78	
SUP	0.80	

Resin finished		
R/S FUP$_R$	0.21	
RTBT$_R$	0.37	
SUP$_R$	0.84	

R/S FUP: Ramie and Sisal-Fiber-Untreated-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, SUP: Sisal-Untreated handspun yarn-Plain weave, (R): Resin finished fabrics



R/S FUP: Ramie and Sisal-Fiber-Untreated-Plain weave, RTBT: Ramie-Treated handspun yarn-Broken Twill weave, SUP: Sisal-Untreated handspun yarn-Plain weave

Graph 4.33: Comparison between unfinished and resin finished fabric samples

b. Performance analysis

The ramie and sisal are lignocellulosic fibers having good inherent properties for sound absorption. The fabrics developed from these fibers can be utilized as residential or office interiors as eco-friendly products. In interiors moisture and flammability are the two major factors. Based on which the utility, durability and maintenance depends on it. Hence, three samples were purposively selected for these tests to identify their additional properties and its potentiality towards natural atmosphere.

Antimicrobial properties

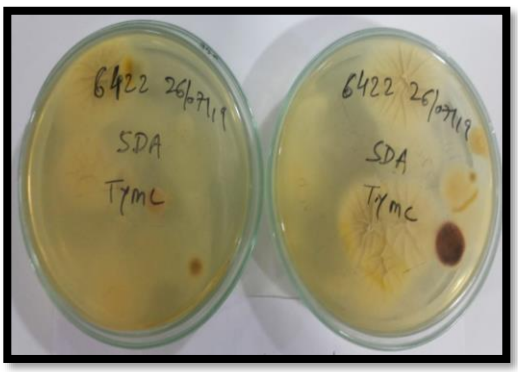
The test was conducted to identify the total bacterial count and total yeast & mould count of the samples; details are mentioned in Table 4.18.

Table 4.19: Details of antimicrobial and anti-fungal properties of samples

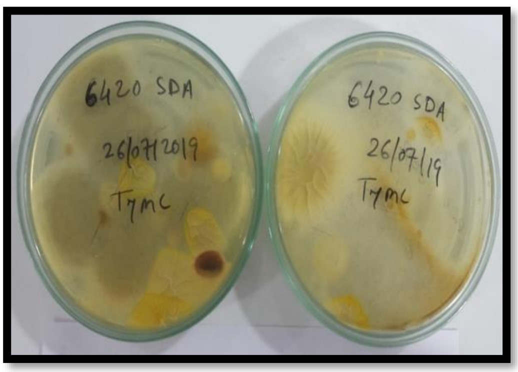
Fabric Code	Total bacterial count (cfu/gm)	Total Yeast & mould count (cfu/gm)
RTP	390	240
SUP	130	170
R 919	780	270

RTP: Ramie-Treated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, R919: Ramie needle punch of 919 GSM

From data, it was observed that number of colonies forming units (cfu) as well as bacterial counts is more in R 919 followed by RTP and SUP. Thus, the untreated sample shows lowest counts compare to scoured and enzyme treated samples. The growth might be because of the residues of scouring and enzyme treatment on the samples which attracts microorganisms. While comparing two ramie samples – RTP and R 919, the growth is more on scoured sample i.e R919. Which means due to the enzyme treatment reduction in the growth rate of microorganisms were observed.



RTP



SUP

R919

RTP: Ramie-Treated handspun yarn-Plain weave, SUP: Sisal-Untreated handspun yarn-Plain weave, R919: Ramie needle punch of 919 GSM

Plate 4.6: Microbial activity on the fabric samples

Flammability test

The flammability of plant fibers depends on the factors like chemical composition, crystallinity, degree of polymerization and fibrillar orientation. Fibers tend to me more flammable with an increase of cellulose, hemicellulose and lignin content. The decomposition of lignin contributes to char formation more than cellulose and hemicellulose. Hence for plant fibers, higher the content of lignin, the more flammable are the fibers.

It is said that both ramie and sisal fibers are good resistant to flammability. Hence, to identify its resistance after the treatment two enzyme treated samples i.e. RTP and SUP and a nonwoven fabric R919 were tested for flame retardancy using 45° Flammability test method (ASTM D 1230-45).

All the three samples were non-flammable even after exposing the samples for 15 seconds. Thus, both the minor cellulosic fibers – Sisal and Ramie are naturally flame resistance which will be an additional feature of the sound resistant product.

End application for acoustic panel:

With all the different variables of sound absorption materials and its results, depending upon the required amount of sound to be absorbed and kind of aesthetics needed different combination can be done. The twelve different woven samples and three different nonwoven fabrics are presented below in Plate 4.7.

Plate 4.7: Collection of constructed fabrics

The top/front layer of woven fabric for aesthetic and sound absorption will be having further attachments of air gap, nonwoven fabric/s and ply, which all together will be a complete set of a product. Depending upon the level of absorption needed the changes in backing material could be done. The schematic combination of product will be as Plate 4.8 and the application based product will be as shown in Plate 4.9

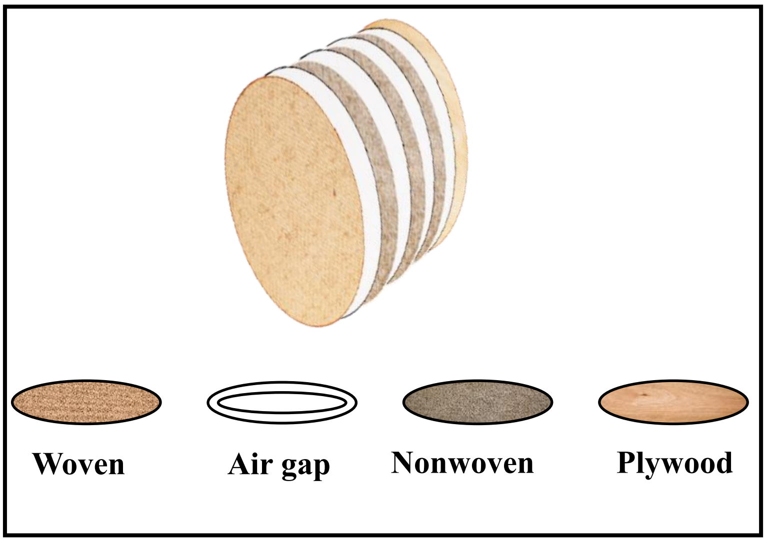


Plate 4.8: Schematic presentation of final product

Plate 4.9: Acoustic panel of R FUP fabric

4.8. SWOC analysis

Strength:

- The world is moving towards sustainable approach which increases the demand of Natural fiber product and eco-friendly process. Amongst the natural fibers sisal and ramie has inherent properties to develop suitable products.
- Sisal (Agave Sisalana) and ramie (Boehmeria Nivea) plants are available in plenty and are biodegradable.
- Both the fibers have good strength and hollow structure. While ramie is lustrous as well as holds the shape thus can be utilized for technical textile applications where aesthetics is also needed.
- These natural cellulosic fibers having natural aesthetics could be utilized to protect against hazardous noise pollution thus various products could be developed based on the application.

- These fibers have additional inherent characteristics of anti-microbial and flame retardancy thus have vast scope of applications. Additionally, with different weaves the fabrics looks good aesthetically and are appropriate for interiors.

Weakness:

- The natural fibers are not available in standard quality as the process depends on maturity of the plant, soil, as well as extraction process which is a lengthy process for manufacturing commercial products. Also, the product development process has not been commercialized.
- As the fibers are not ready to be used, it has to be scoured for the removal of foreign materials, softening treatment need to remove the impurities and make it pliable, then are used as a fiber or converted into yarn as per fiber characteristics and finally depending upon the product fabrics are developed. Additionally, finishing treatment might be needed as per the end use. Hence fiber to fabric manufacturing process is too tedious.
- Sisal fibers are less cohesive; hence treatment is needed to reduce its stiffness. Thus, it becomes a lengthy process to develop the yarn and utility product.
- After the treatment they are pliable but still pose stiffness. Thus, treated fiber yarn has little stiffness which makes the weaving process time consuming as well as the protruding fibers are seen on the surface of the developed fabrics.

Opportunities:

- Global warming has increased the demand of eco-friendly products; thus, these fibers will have commendable application and market.
- Both the fibers were essentially grown for non-textile purposes. Utilization of these fibers for wide textile applications will create more income for farmers. In addition, it shall generate employment opportunities in the process plants for making fabric from fibers.
- Sisal and ramie fibers have some of the potential characteristics like strength, hollow structure and natural colour. Owing to this, the utilization of both the fibers will increase. Thus, to soften the fibers enzyme treatment plant needs to be set up which will assist further in constructing / manufacturing various end products.
- Spinnability of the fibers will assists further in developing more varieties of woven fabrics which can absorb sound of different levels.

- Enzyme treatment and the modification in the process softens the fibers by breaking the lignin structure of the fiber, increases pliability, apart from its capability of reducing environmental pollution. After the treatment, the stress bearing capacity of the sisal fiber remains almost the same as that of raw fibers, hence these fibers can be utilized for the products which need good stress bearing capacity.

Challenges:

- Lack of available expertise for channelizing the process of commercializing the manufacturing process to convert the minor fiber i.e. fiber to fabric.
- The treatment showed that the fibers have weakened after the treatment. Further research is still needed to reduce the stiffness of the sisal fibers to an extent that it could be machine spun.
- Mass production of fabric and other products, at a reasonable cost, so as to be able to compete with synthetic fibers on cost and wide range of utility.