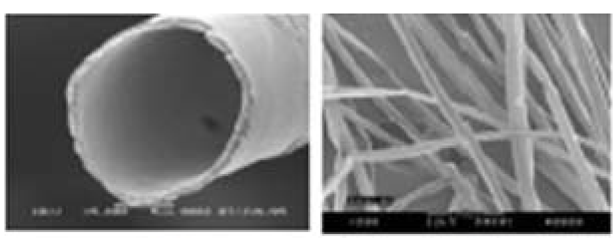
Chapter 3

Experimental Work

3.1 Material and Methodology

3.1.1 Fibre Collection

The present research is concerned with the study of acoustic properties of unconventional natural fibres like kapok and milkweed, which could serve as an alternative for other commonly used sound absorbing materials. Kapok and milkweed fibres are types of natural cellulosic fibres with the unique hollow tubular structure as shown in figures 3.1 and 3.2. The hollowness of fibres makes it possess high surface area, excellent moisture



(i) (ii)

Figure 3.1: SEM of kapok fibre. (i) Kapok fibre cross-section (ii) Kapok fibre surface

absorption, and thermal insulation capability. The kapok and milkweed fibres used in this study are collected from different parts of Gujarat state of India. To collect the kapok fibre first, the seedpod of kapok fibre collected from the kapok tree, and then the Kapok fibre is extracted from seedpod. Figure 3.3 shows the different stages of kapok fibre during the collection period.

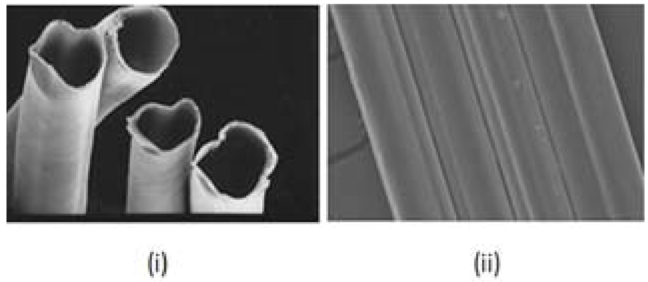


Figure 3.2: SEM of milkweed fibre (i) Milkweed fibre cross-section (ii) Milkweed fibre surface

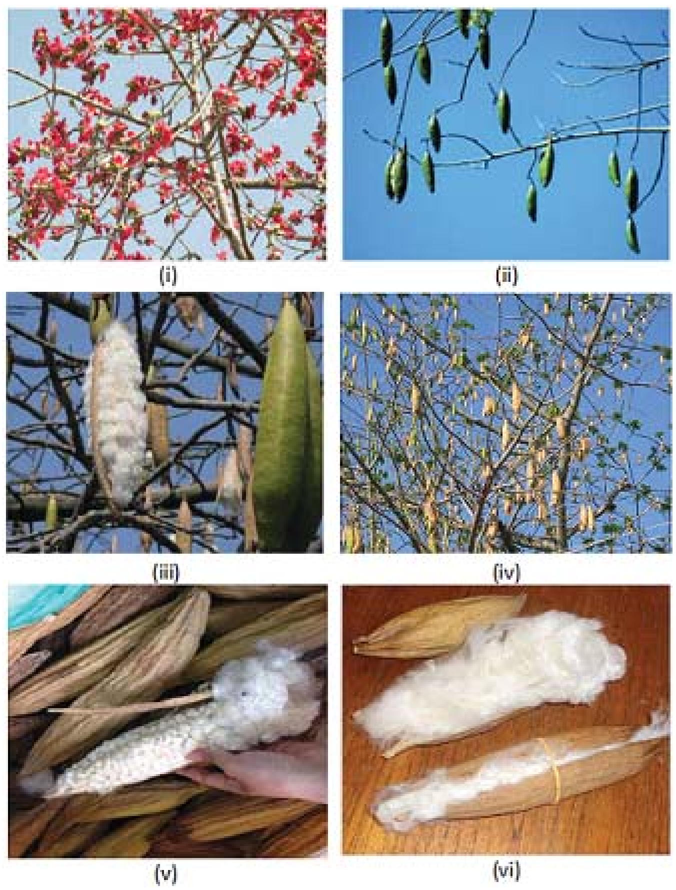


Figure 3.3: Different stages of kapok fibre

Milkweed fibre is also collected from different parts of the Gujarat state of India. Collection of the milkweed (Estabragh fibre) is one of the biggest challenges in this study because as shown in figure 3.4, when the fibre seedpod open, the fibre are flown in the air. Fibre may be collected by collecting a green seedpod as suggested in many research studies, but in this method ripening of the fibre is again a question mark. So after several trials at last, small nets bags are used to collect the milkweed fibre to fully exploit fibre properties without affecting its natural ripening process. Small PP nets are tied with cotton thread on seedpod as shown in figure 3.5 and awaiting still the fibre seedpod fully open naturally. Due to net fibres remained into the nets after seedpod burst. Now, the net bags are collected from the plant and fibre are extracted from it for further process.

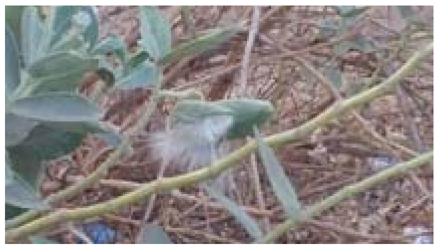
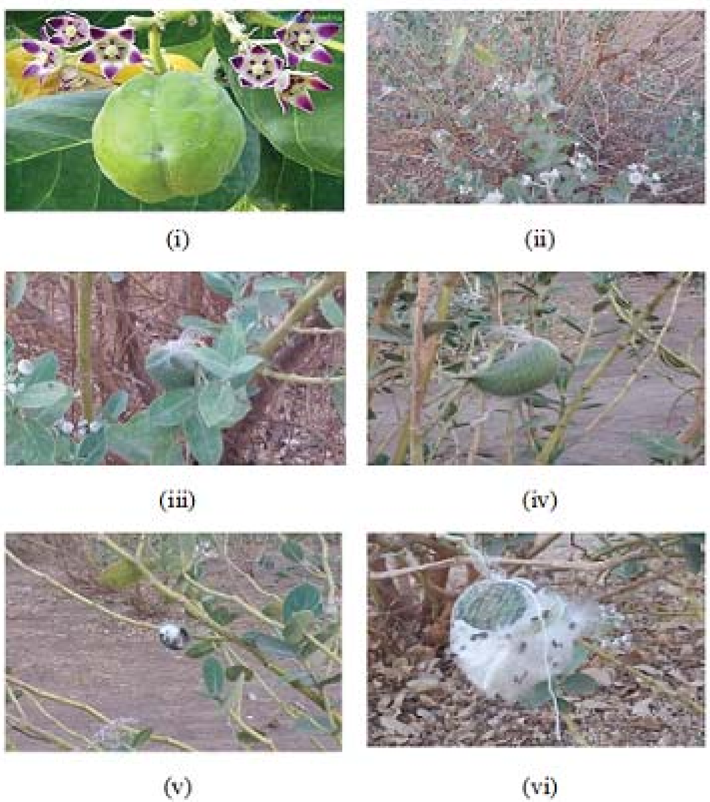


Figure 3.4: Open pod of milkweed fibre



(i) (ii)
(iii) (iv)
(v) (vi)

Figure 3.5: Different stages of milkweed fibre collection

All dust, seed, seed fragments, lumps, and other impurities are removed manually from the fibre before the kapok and milkweed fibres are used for further process. Several pre trails had been conducted before the actual trials to produce carding web of kapok and milkweed fibre. The difficulty of producing carded web from kapok and milkweed fibres is noticed as the surface of both these fibres had very little inter fibre cohesion due to its smooth surface. This will create a problem during the further process of fibres, particularly during the carding process. In this study, modal fibres are blended with kapok and milkweed fibre and used as carrier fibre to enhance the performance of kapok and milkweed fibre during the carding process. Kapok and milkweed fibres are blended with modal fibres in different proportions by weight. The reason for blending viscose-modal is, it is also known as carrier fiber and able to enhance the process performance during web formation, final fabric formation and also the structural integrity of the final fabrics. Some of the physical properties of kapok, milkweed and modal fibre are given in table 3.1.

Table 3.1: Kapok & Milkweed fibres properties

Fibre	**Length (mm)**	**Fineness (dTex)**
Kapok	16 -27mm (Average length =21mm)	0.625
Milkweed	20-30m (Average length = 27mm)	1.15
Modal	38 mm	1

3.1.2 Experiments Plan

In this study, experiment work is planned using RSM-CCD methodology with the help of Minitab 18 software, which is commonly used software for planning the design of experiments and statistical analysis. Sound absorbing material composed of a blend of natural hollow fibres kapok and modal, milkweed and modal fibres are used to produce needle-punched nonwoven samples. Sixty-two different samples are produced by varying blend ratio, carded web mass per unit area, needle stroke frequency, and needle depth. Sound Absorption Coefficient (α) of the samples is evaluated using the impedance test method for different frequencies of the incident sound [117]. After conducting several pre-trial, designs of the experiment is finalized using the response surface methodology - central composite design (RSM-CCD) method.

The central composite design method is used to define the number of experiments to be evaluated for the optimization of the variables and response. The minimum, intermediate, and maximum values of each variable are termed as -1, 0, and +1, respectively. Blend ratio, web mass per unit area (GSM), depth of needle penetration, and stroke frequency are varied at three levels. Table 3.2 and Table 3.3 shows the actual values of these three levels.

Table 3.2: Kapok fibre - Experimental range and levels of the independent variables

Variables	**Factor**	**Range and levels**				
		-α	**-1**	**0**	**+1**	**+α**
Kapok fibre blend %	X_1	30	40	50	60	70
Carded web mass (g/m^2)	X_2	200	300	400	500	600
Stroke frequency (/min)	X_3	150	200	250	300	350
Needle depth (mm)	X_4	5	7.5	10	12.5	15

In the design of the experiment plan for kapok fibre, the frequency of sound waves is considered as categorical factors X_5 and its values are varied at nine level. The actual values of these nine levels are 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz, 5000 Hz, and 6300 Hz.

Table 3.3: Milkweed fibre - Experimental range and levels of the independent variables

Variables	**Factor**	**Range and levels**				
		-α	**-1**	**0**	**+1**	**+α**
Milkweed fibre Blend %	Y_1	30	40	50	60	70
Carded web mass (g/m^2)	Y_2	200	300	400	500	600
Stroke frequency (/min)	Y_3	150	200	250	300	350
Needle depth (mm)	Y_4	5	7.5	10	12.5	15

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As per the design of the experiment planned using the RSM-CCD method, 31 samples of kapok fibre and 31 samples of milkweed fibres are produced by varying fibre blend %, carded web mass, stroke frequency, and needle depth. Table 3.4 and Table 3.5 show the design of the experiment planned for kapok fibre and milkweed fibre according to the RSM- CCD method along with variables and levels.

Table 3.4: Kapok fibre - Central composite design experiments

Experimental trial	**Experimental design**				**Sample code**	**Experimental plan**			
	X_1	X_2	X_3	X_4		**Kapok fibre %**	**Carded web mass (g/m^2)**	**Stroke frequency (/min)**	**Needle depth (mm)**
1	0	0	- α	0	K1	50	400	150	10
2	-1	-1	-1	-1	K2	40	300	200	7.5
3	-1	+1	-1	-1	K3	40	500	200	7.5
4	+1	-1	-1	-1	K4	60	300	200	7.5
5	+1	+1	-1	-1	K5	60	500	200	7.5
6	-1	-1	-1	+1	K6	40	300	200	12.5
7	-1	+1	-1	+1	K7	40	500	200	12.5
8	+1	-1	-1	+1	K8	60	300	200	12.5
9	+1	+1	-1	+1	K9	60	500	200	12.5
10	0	0	0	- α	K10	50	400	250	5
11	- α	0	0	0	K11	30	400	250	10
12	0	- α	0	0	K12	50	200	250	10
13	0	0	0	0	K13	50	400	250	10
14	0	0	0	0	K14	50	400	250	10
15	0	0	0	0	K15	50	400	250	10
16	0	0	0	0	K16	50	400	250	10
17	0	0	0	0	K17	50	400	250	10
18	0	0	0	0	K18	50	400	250	10
19	0	0	0	0	K19	50	400	250	10
20	0	+ α	0	0	K20	50	600	250	10
21	+ α	0	0	0	K21	70	400	250	10
22	0	0	0	+ α	K22	50	400	250	15

Experimental trial	Experimental design				Sample code	Experimental plan			
	X_1	X_2	X_3	X_4		Kapok fibre %	Carded web mass (g/m^2)	Stroke frequency (/min)	Needle depth (mm)
23	-1	-1	+1	-1	K23	40	300	300	7.5
24	-1	+1	+1	-1	K24	40	500	300	7.5
25	+1	-1	+1	-1	K25	60	300	300	7.5
26	+1	+1	+1	-1	K26	60	500	300	7.5
27	-1	-1	+1	+1	K27	40	300	300	12.5
28	-1	+1	+1	+1	K28	40	500	300	12.5
29	+1	-1	+1	+1	K29	60	300	300	12.5
30	+1	+1	+1	+1	K30	60	500	300	12.5
31	0	0	+ α	0	K31	50	400	350	10

Table 3.5: Milkweed fibre - Central composite design experiments

Experimental trial	Experimental design				Sample code	Experimental plan			
	Y_1	Y_2	Y_3	Y_4		Milkweed fibre%	Carded web mass (g/m^2)	Stroke frequency (/min)	Needle depth (mm)
1	0	0	- α	0	M1	50	400	150	10
2	-1	-1	-1	-1	M2	40	300	200	7.5
3	-1	+1	-1	-1	M3	40	500	200	7.5
4	+1	-1	-1	-1	M4	60	300	200	7.5
5	+1	+1	-1	-1	M5	60	500	200	7.5
6	-1	-1	-1	+1	M6	40	300	200	12.5
7	-1	+1	-1	+1	M7	40	500	200	12.5
8	+1	-1	-1	+1	M8	60	300	200	12.5
9	+1	+1	-1	+1	M9	60	500	200	12.5
10	0	0	0	- α	M10	50	400	250	5

Experimental trial	Experimental design				Sample code	Experimental plan			
	Y_1	Y_2	Y_3	Y_4		Milkweed fibre%	Carded web mass (g/m^2)	Stroke frequency (/min)	Needle depth (mm)
11	- α	0	0	0	M11	30	400	250	10
12	0	- α	0	0	M12	50	200	250	10
13	0	0	0	0	M13	50	400	250	10
14	0	0	0	0	M14	50	400	250	10
15	0	0	0	0	M15	50	400	250	10
16	0	0	0	0	M16	50	400	250	10
17	0	0	0	0	M17	50	400	250	10
18	0	0	0	0	M18	50	400	250	10
19	0	0	0	0	M19	50	400	250	10
20	0	+ α	0	0	M20	50	600	250	10
21	+ α	0	0	0	M21	70	400	250	10
22	0	0	0	+ α	M22	50	400	250	15
23	-1	-1	+1	-1	M23	40	300	300	7.5
24	-1	+1	+1	-1	M24	40	500	300	7.5
25	+1	-1	+1	-1	M25	60	300	300	7.5
26	+1	+1	+1	-1	M26	60	500	300	7.5
27	-1	-1	+1	+1	M27	40	300	300	12.5
28	-1	+1	+1	+1	M28	40	500	300	12.5
29	+1	-1	+1	+1	M29	60	300	300	12.5
30	+1	+1	+1	+1	M30	60	500	300	12.5
31	0	0	+ α	0	M31	50	400	350	10

In the present study, all the samples are developed using Response surface Methodology – Central Composite Design (RSM-CCD). After the planning of the design of the experiment, the first step is to prepare a carded web.

3.1.3 Carded Web Preparation

Kapok and milkweed fibres are manually cleaned and passed through the blow room line generally used for viscose fibre and commercial carding machines at the textile research and development center (TRADC), Kharach, Gujarat.

The first modal fibre web is prepared as shown in figure 3.6, using a miniature card machine having machine width 100 cm, feeding roller diameter 57 mm, licker-in diameter 133 mm, cylinder diameter 245 mm, doffer diameter 183 mm, stripping roller diameter 66 mm, crush roller diameter 38 mm, take up drum diameter 240 mm, feeding roller circumferential speed 89.49 mm/min, licker-in circumferential speed 87700 mm/min, cylinder circumferential speed 384650 mm/min, doffer circumferential speed 5746 mm/min and total draft 105.45. Figure 3.7 shows the miniature carding used to produce the carded web.

Figure 3.6: Modal fibre carded web

Then from the produced web, a thin layer of the web is separated and over it, kapok fibre is layered. These procedures repeated four times and a sandwich like a web structure is prepared for kapok fibre as shown in figure 3.8.

The same process is also repeated for milkweed fibre. Now, this sandwich type of web once again is passed through a miniature carding machine as shown in figure 3.9, to get the intimate blend and it also helped in the web formation process of kapok and milkweed fibers.

Figure 3.7: Miniature carding machine

Figure 3.9: Image of sandwich web passed through a miniature carding machine

Sandwich web structure preparation for kapok and milkweed fibre and final web formation is done using miniature carding machine having machine width 100cm, feeding roller diameter 5cm, cylinder diameter 40cm, doffer roller diameter 27cm, feeding roller linear speed 0.28cm/s and take-up roller linear speed 3.97cm/s in the textile technology department at The M. S. University.

3.1.4 Production of Nonwoven Fabric

All the samples are produced using needle punching methods, which involve the formation of a web by a miniature carding machine followed by a layering of fibre to produce a web.

Figure 3.8: Sandwich web preparation

To produce a nonwoven fabric sample as per the RSM-CCD design of the experiment, the carded web produced using a miniature carding machine is passed through a needle punching machine. Needle punch machine inlet speed and outlet speed kept 0.80 m/min, and other machine parameters are varied as per the design of the experiment mentioned in Tables 3.4 and Table 3.5. Needle punched nonwoven fabrics are prepared at Man-Made Textiles Research Association (MANTRA), Surat, Gujarat. Figures 3.10 & 3.11 Indicate web feeding in the needle punch machine and its setting on the display screen respectively.

Punching (rpm) : As per DOE (150, 200, 250, 300, 350).

Material inlet speed(m/min): 0.8

Material outlet speed(m/min): 0.8

Needle density: $50/cm^2$

Needle depth (mm): As per DOE (5, 7.5, 10, 12.5, 15)

The developed nonwoven fabric sample is shown in figure 3.12.

Figure 3.10: Image of web feeding in needle punch machine

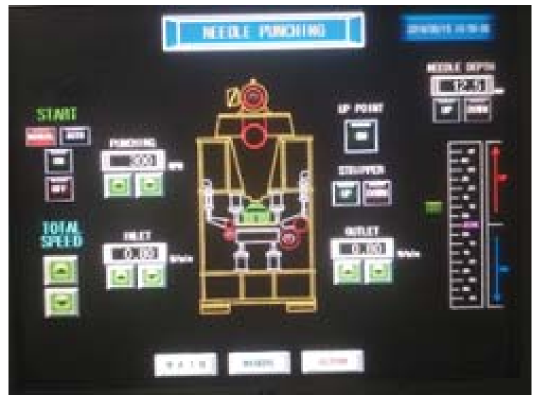

Figure 3.11: Image of machine setting display screen

Figure 3.12: Image of produced nonwoven fabric

3.2 Sample Testing

All samples are tested for physical properties of fabric like thickness, GSM, air permeability, porosity and sound absorption coefficient (α) using customized impedance tube according to the standard testing methods. Fabric samples are tested to evaluate and optimize its acoustic properties by performing the following tests.

3.2.1 Fabric Thickness

Fabric thickness is extremely important physical properties of nonwoven fabric which affect the sound absorption properties of the fabric. The thickness of all samples is tested according to the standard ASTM D5729-97. Fabric thickness is determined by measuring the perpendicular distance between the upper and lower side of the fabric under a standard load. A digital fabric thickness gauge is used to measure the thickness of the fabric. Fabric is placed on a flat anvil and a circular pressure foot, and pressure is applied on it from the top under the standard fix load. Then the thickness of the fabric is measured in mm by directly taking a reading from the dial indicator. Five readings are taken for each sample, and the average fabric thickness of the sample is calculated.

Range of measurement: 0 – 10mm

Accuracy of least: 0.01 mm

Diameter of anvil: 60 mm

Diameter of pressure foot: 10 mm

Pressure on pressure foot: 2 kPa

3.2.2 Fabric GSM

GSM means mass per unit area of fabric, which is generally measured in terms of grams per square meter. In the present study to measure the fabric GSM, all the fabric samples are cut in 10 x 10 cm, the weight of each sample is measured using weighing balance as per D 5261 ASTM test methods. Five tests perform for each sample and an average of five samples are taken into consideration to calculate grams per square meter of fabric.

3.2.3 Air permeability

The air permeability of fabric is a measure of how well fabric allows the air to pass through it. It is a very important physical characteristic of fabric used for industrial filters, tents, sailcloths, parachutes, raincoat materials, shirtings, airbags, and sound absorption material.

The air permeability of nonwoven fabrics is measured on Metefem air permeability tester, shown in figure 3.13. Air permeability is defined as the volume of air measured in cubic centimeters passed in one second through 1 cm^2 of the fabric at a pressure of 1 cm head of water. In this test fabric sample is first clamped over the air inlet of the apparatus, and the air is passed through the fabric at 100 Pa water pressure. The pressure difference between the two surfaces of the fabric, as indicated by the monometer is measured by liters/hours. The testing is carried out as per the ASTM D 737 test method. The result of the test measured in m^3/m^2/h.

Figure 3.13: Air permeability tester

3.2.4 Porosity

Porosity is the percentage of open space per unit volume of fabric. The Porosity of fabric is defined as the ratio of open space to the total volume of porous material. Air permeability and porosity are very closely related properties, although the relationship is not simple. In the present study, the porosity of the nonwoven fabric is calculated from the measured fabric thickness, fabric GSM, and fibre density using the equation 2.10.

3.2.5 Sound absorption coefficient (α)

All the samples are tested for acoustic properties to measure the sound absorption coefficient at a different frequencies (250-6300 Hz) for each sample. The normal incidence sound absorption coefficient (α) is measured according to the ISO 10534-2, standard test methods for the sound absorption coefficient using transfer function methods [117]. A custom build impedance tube with 100 mm and 30 mm diameters are used to measure the sound absorption coefficient with open-source software visual analyzer and MATLAB software. These tubes support the frequency range of 171 – 6631Hz. Four reading are taken randomly from each sample to measure the acoustic property of the sample.

The apparatus is developed and validated by presenting the paper at the conference of Institution of Engineers (India), held on February 9-10, 2020 at Kolkata and also by computing the results of the samples, obtained from PSGTECHS COE INDUTECH LABORATORY, Coimbatore with newly developed apparatus.

The next chapter deals with this instrument.