# Acoustic Properties of Kapok Fibre

**S. S. Bhattacharya, D. V. Bihola**

***Abstract*: Noise pollution has become an important burning issue in today's modern industrial era after Air and Water pollution. Noise adversely affects human health and decrease productivity in various environments. The present study tries to study the acoustic properties of natural hollow fiber-kapok to develop a cost-effective and eco-friendly sound absorbing material as an alternative of conventional sound absorbing material which is harmful to the environment. Therefore, sound absorbing material consist of a blend of Natural hollow fibres Kapok and Modal were used to produced needle-punched nonwoven fabrics. A nonwoven needle punch method to produce fabrics was selected due to its technical merits and low production cost. Different nonwoven needle punched samples were produced by varying blend ratio, web mass per unit area, needle stroke and needle depth. After conducting several pre-trial, designs of the experiment was plan using Response surface methodology - Central composite design (RSM-CCD) method. Sound absorption coefficients of the sample were measured at a different frequency of incident sound using impedance tube test method ISO 10534-2. It was observed that sample with a higher percentage of kapok fiber showed higher sound absorbency at higher Frequency of 2000 to 6000 HZ. It was also found sound absorption coefficient increased with the increased in mass per unit area, needle stocks and needle depth.***

***Keywords*: sound absorption, kapok, Natural hollow fibre, nonwoven, sound absorption coefficient.**

## I. INTRODUCTION

In today's era of the continuing development of new technologies, the use of more powerful machinery and an increase in the number of vehicles leads to increase the noise pollution. Its impact on the environment and human health is a matter of concern. Sound pollution is increasing public health problem according to the World Health Organization's (WHO) "Guidelines for Community Noise". Noise can have adverse health effects: hearing loss, sleep disturbance, feeling tiredness, cardiovascular and psycho physiologic problem, performance reduction, annoyance response, and adverse social behavior. Noise also significantly decreases productivity in various environments. Therefore, it is very important to control or reduce noise. Use of natural fiber in the field of acoustics application increased drastically, as the synthetics fibre is harmful to the environment. Most of the synthetic fibres are non-biodegradable in nature and now in many county rules and regulations related to environmental pollution are very stringent. Natural fibre has a huge potential to replace synthetics fibres in the field of acoustic textile. Kapok fibre was selected for the present study due to its unique natural hollow structure. Sound absorption properties of material increased if hollow fibre is used to produce acoustic material. Hollow fibre has a higher surface area in comparison to the normal fibre, which leads to an increase in the sound absorption properties of the material. Kapok being natural hollow fibre has a huge potential to be used in the field of acoustic. Considering this unique property of kapok fibre, it was decided to select Kapok fibre for the present study. Textiles are widely used as sound insulators. Among the spectrum of textiles, nonwoven fabrics due to their technical merits and low cost used to produce sound absorption material. Considering all these facts, needle punch nonwoven fabrics were produced using kapok fibre, due to its structural advantages and cost-effectiveness. Some of the natural fibre used for acoustic application are flax, hemp, kenaf, jute, agave, bamboo, coir, and wool [1].

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## II. LITERATURE REVIEW

Xiang et al. [2] investigate the sound absorption properties of kapok fibre with different bulk density, thickness, fibre length and orientation for kapok fibrous assemblies. They found that thickness, bulk density, and arrangement of fibre significantly affect the acoustic properties of the fibrous assembly.

Hassani et at. [3] investigated the sound absorption coefficient of Estabragh/polypropylene nonwoven. They also studied the effect of areal density (g/m$^2$), blend ratio and needle punch density on the sound the acoustic properties of nonwoven fabric. They found that the sound absorption property of the sample increased with an increase in the proportion of Estabragh fibers. They also stated that areal density and higher needle density leads to an increase in the sound absorption property of nonwoven samples.

Mvubu et al. [1] Studied the process parameters of needle punched nonwoven produced using flax, hemp and agave fibres with PET fibre in 50/50 blend ratio. They concluded that when multiple factors were acting simultaneously during production stages, fibre type played the least dominant role in determining sound absorption properties. In another study, the acoustic properties of natural fibre nonwoven made from bamboo, banana and jute fibres blended with polypropylene fibres in 50/50 blend ratio [4]. They obtained NAC value 0.20, 0.13 and 0.17 for bamboo/ polypropylene, banana/polypropylene and jute/polypropylene blended samples respectively at 1250 Hz frequency.

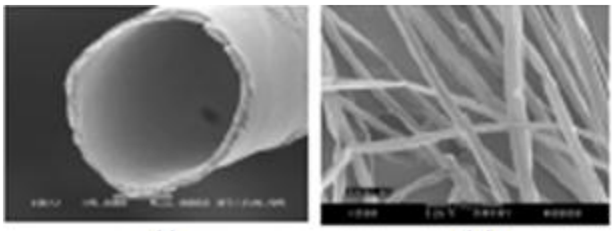
Tascan M and Vaughn EA [5]investigate the effect of various fibre shape on sound absorption properties. It was observed that nonwoven fabric produced using trilobal and 4DG showed better sound absorption properties as compared to round shape fibre. 4DG fibre showed better sound insulation properties due to its octalobal cross-sectional shape, which provide higher surface area.

They also found that total surface area and fabric density positively affect the sound absorption properties of nonwoven fabrics.

Various researchers [6]–[8] studied the effect of the fineness and cross-sectional shape of the fibre on sound absorption properties. It was observed that finer fibre gives better sound absorption properties. Use of finer fibre provides a larger surface area and more tortuous path in nonwoven fabric leads to better sound absorption on properties. Up to now, few very research works were done to study the acoustic properties of kapok fibres, due to its surface characterizes which hinder the process of kapok fibre during spinning. In the present study, kapok fibre was selected for study because kapok fibre has high potential for excellent sound absorption properties due to its natural hollow structure. This study systematically evaluated kapok fibre for its sound absorbency properties.

## III. METHODOLOGY

Kapok fibre is a type of natural cellulosic fibre with unique hollow tubular structure with 80-90% void as shown in figure 1. The high hollowness of fibre makes it possess surface area, excellent moisture absorption, and thermal insulation capability. The kapok fibre used in this study was collected from different part of Gujarat state of India. Before the kapok fibres were used for further process, all dust, seed, and lumps had been removed. Kapok fibre surface had very less inter fibre cohesion due to its smooth surface. This will crease problem during the further process of fibre, particularly during the carding process. In this study, modal fibres were blended with kapok fibre and used as carrier fibre to enhance the performance of kapok fibre during the carding process. some of the physical properties of kapok and modal fibre were given in table 1.



(i) (ii)

**Figure 1. SEM of kapok fibre. (i) Kapok fibre Cross-section (ii) Kapok fibre surface**

**Table 1. Fibre properties**

| Fibre | Length (Mm) | Fineness (dTex) |
|---|---|---|
| Kapok | 16 -27mm (Average length =21mm) | 0.625 |
| Modal | 38 mm | 1 |

All the samples were 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. First modal fibre web was prepared using a miniature card with 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. Then from the produced web, a thin layer of the web was separated and over it kapok fibre was layered. This procedure repeated four times and a sandwich like a web structure was prepared. Now, this sandwich type of web again passed through a miniature carding machine to get the intimate blend and it also helped in web formation process of kapok fiber. The web was passed through a needle punching machine. Kapok fibres were blended with modal fibres in different proportion by weight. The reason for blending Viscose-modal is, it 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.

Kapok fibres were manually cleaned and passed through the blow room lined generally used for viscose fibre and commercial carding machine at the textile research and development center (TRADC), Kharach, Gujarat. Modal and kapok fibre webs were separately prepared at TRADC. Sandwich web structure preparation and final web formation were done at textile technology department at The M. S. University. Needle punched nonwoven fabric was prepared at Man Made Textiles Research Institute (MANTRA), Surat, Gujarat.

Blend ratio, web mass per unit area (GSM), depth of needle penetration and stroke frequency were varied at three levels. Table 2 shows the actual values of these three levels. A total of 31 samples, were produced using RSM-CCD method.

**Table 2. Parameters levels for the design of the experiment.**

| Parameters | Levels | | |
|---|---|---|---|
| | **-1** | **0** | **1** |
| Kapok fibre Blend % | 40 | 50 | 60 |
| Carded Web Mass (g/m$^2$) | 300 | 400 | 500 |
| Stroke frequency (/Min) | 200 | 250 | 300 |
| Needle Depth (mm) | 7.5 | 10 | 12.5 |

All the samples were tested for acoustic properties. The normal incidence sound absorption coefficient (α) was measured according to the ISO 10534-2 standard test methods for sound absorption coefficient using transfer function methods [9]. A costume build impedance tube with 100 mm and 30 mm diameters were used to measure the sound absorption coefficient. These tubes support the frequency range of 171 – 6631Hz. Four reading were taken randomly from each sample to measure the acoustic property of the sample.

Following equations were used to find out the sound absorption coefficient (α). The normal incidence reflection factor can be calculated using the formula[9].

$$r = |r|\, e^{j\phi_r} = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk_0 x_1} \qquad (1)$$

Where:

r is a reflection factor of normal incidence;

$x_1$ is the distance between the sample and the further microphone location;

j is the square root of minus one

k is $2\pi f/c$ (m$^{-1}$)

$\phi_r$ is the phase angle of the normal incidence reflection factor;

$H_{12}$ is the transfer function from microphone one to two, defined by the complex ratio $p_2/p_1 = S_{12} / S_{21}$;
$H_R$ and $H_I$ are the real and imaginary part of $H_{12}$;
α is Sound absorption coefficient;
The sound absorption coefficient can be calculated as [9]:

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2 \qquad (2)$$

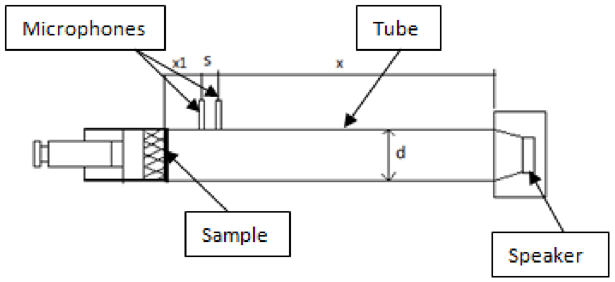



**Figure 2 Impedance tube**

Where,
X1 is the distance between a sample and furthest microphone;
S is the distance between two microphones;
X is the distance between a sound source and first microphone;
d is the diameter of the impedance tube.
The sound absorption coefficient measured at a different frequency (250-6300 Hz) for each sample. Design of experiment planned using RSM-CCD method and a total of 31 samples were produced by varying kapok fibre blend%, Carded web mass, stroke frequency and Needle depth as shown in table 3.

**Table 3. Design of experiments according to RSM- CCD method along with parameters**

| Sample Code | Kapok fibre Blend % | Carded Web Mass (g/m2) | Stroke Frequency (/Min) | Needle Depth (mm) |
|---|---|---|---|---|
| B1 | 50 | 400 | 150 | 10 |
| A2 | 40 | 300 | 200 | 7.5 |
| A3 | 40 | 500 | 200 | 7.5 |
| C4 | 60 | 300 | 200 | 7.5 |
| C5 | 60 | 500 | 200 | 7.5 |
| A6 | 40 | 300 | 200 | 12.5 |
| A7 | 40 | 500 | 200 | 12.5 |
| C8 | 60 | 300 | 200 | 12.5 |
| C9 | 60 | 500 | 200 | 12.5 |
| B10 | 50 | 400 | 250 | 5 |
| D11 | 30 | 400 | 250 | 10 |
| B12 | 50 | 200 | 250 | 10 |
| B13 | 50 | 400 | 250 | 10 |
| B14 | 50 | 400 | 250 | 10 |
| B15 | 50 | 400 | 250 | 10 |
| B16 | 50 | 400 | 250 | 10 |
| B17 | 50 | 400 | 250 | 10 |
| B18 | 50 | 400 | 250 | 10 |
| B19 | 50 | 400 | 250 | 10 |
| B20 | 50 | 600 | 250 | 10 |
| E21 | 70 | 400 | 250 | 10 |
| B22 | 50 | 400 | 250 | 15 |
| A23 | 40 | 300 | 300 | 7.5 |
| A24 | 40 | 500 | 300 | 7.5 |
| C25 | 60 | 300 | 300 | 7.5 |
| C26 | 60 | 500 | 300 | 7.5 |
| A27 | 40 | 300 | 300 | 12.5 |
| A28 | 40 | 500 | 300 | 12.5 |
| C29 | 60 | 300 | 300 | 12.5 |
| C30 | 60 | 500 | 300 | 12.5 |
| B31 | 50 | 400 | 350 | 10 |

## IV. RESULTS AND DISCUSSION

Sound absorption coefficient results obtained for different controllable parameters at a different frequency. ANOVA analysis was applied to examine the effect of different controllable parameters on the response sound absorption coefficient. Table 4 presents the ANOVA results of the sound absorption coefficient of the samples (6300 Hz). In the table, DF is the degree of freedom, and SS and MS are the sums of squares and the mean sum of squares due to the source respectively. Results indicate that the effect of all considered parameters is statistically significant except Needle depth. This is due to the fact that their corresponding p-value is less than 0.05.

Table 4 Statistical Analysis of variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Kapok fiber Blend % | 2 | 0.079 | 0.079 | 103.74 | 0 |
| Carded Web Mass (g/m2) | 2 | 0.043 | 0.043 | 56.68 | 0 |
| Stroke Frequency (/Min) | 2 | 0.008 | 0.008 | 10.55 | 0.005 |
| Needle Depth (mm) | 2 | 0.002 | 0.002 | 3.14 | 0.096* |
| Residual error | 22 | 0.012 | 0.001 | | |
| Total | 30 | 0.160 | | | |

***The P-value >0.05 is not significant.**

### 4.1. Effect of proportion of Kapok in the blend on sound absorption coefficient.

The natural hollow structure of kapok fibres leads to an increase in the surface area of the fibre. Larger fibre surface area influences the boundaries faced by the sound wave which in turn leads to an increase in the sound absorption ability of the nonwoven fabric. Narang [10] stated in his research work, increase friction between fibre and air and its effect on sound absorption performance.

Hollow fibre due to entrapment of air in their hollow lumen is expected to increase the sound absorption properties of the material by a twofold.

Therefore, an increment in the Kapok proportion of the blends leads to more frictional losses and higher sound absorption coefficient. Figure 3. Shows the results obtained for a different proportion of the blend. From the graph, it is clear that with a higher proportion of kapok fibre at sound absorbency of nonwoven fabric increased at high frequencies.

Previous research work [11], has also stated the importance of fibre diameter and fineness on sound absorption properties of the material. Kapok fibre due to in low density and fineness, a nonwoven fabric made out of kapok fibre has a higher number of fibre. This leads to an increase in the surface area of fibre in fabric and leads to higher sound absorbency. This explains the excellent sound absorption properties of the sample composed of a higher proportion of kapok fibre.

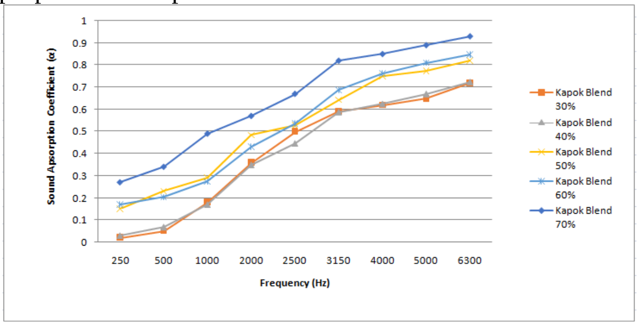



**Figure 3. Sound Absorption coefficient interaction with Kapok blend %.**

### 4.2. Effect of carded web mass on sound absorption coefficient.

Figure 4. Shows the effect of the carded web mass on sound absorption. It was found that the sound absorption coefficient of nonwoven needle punches fabric increase linearly with an increase in the mass of carded web. This also supported by the earlier research work done by Tascan and Vaughn [5]. The increase in the carded web mass leads to an increase in the higher number of fibre within the material which will increase the air/fibre boundaries within nonwoven needle punch fabric. This will offer higher resistance to the incident sound wave by nonwoven material and leads to increase the sound absorbency.

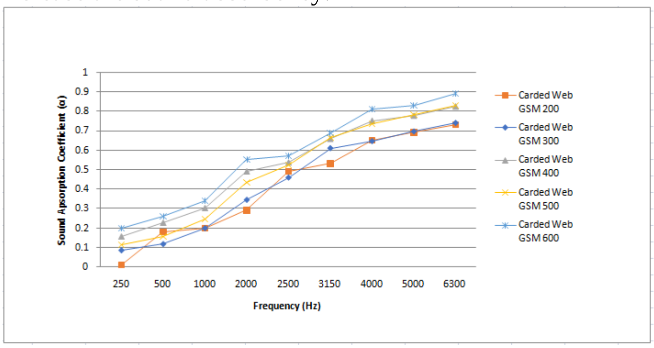



**Figure 4. Sound absorption Coefficient interaction with carded web mass (g/m$^2$).**

### 4.3. Effect of Stroke frequency on sound absorption coefficient.

Figure 5 depicts the effect of stroke frequency of the sound absorption coefficient. It shows almost linear increasing trends of the sound absorption coefficient of nonwoven needle punched samples with an increase in stroke frequency. Arrangement of fibre in the structure is important to increase the fibre to fibre contact within the nonwoven structure. The number of fibre to fibre contact in the nonwoven structure; affect the sound absorbency of nonwoven fabric. Interaction of incident sound wave depends on the fibre to the fibre contact point. Increase in stroke frequency can lead to creating smaller pores in the nonwoven fabric. Increase the stroke frequency in the range of 150-350/min, leads to an increase in a number of pores which entrap the sound waves in the structure. This will help to increase the sound absorption properties of the material.

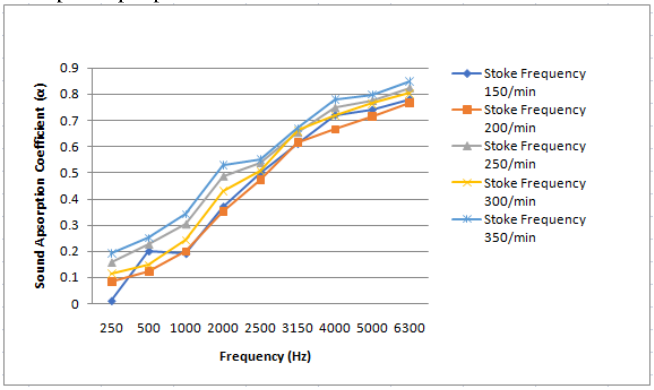



**Figure 5. Sound absorption coefficient interaction with Stroke frequency (/min).**

### 4.4. Effect of Needle depth on sound absorption coefficient.

Figure 6 shows the results obtained of needle penetration depth on the sound absorption coefficient. Increase of needle depth from 7.5mm to 12.5mm and 5 to 10mm leads to an increase in the sound absorption properties of the material. It was found the change in needle depth from 5mm to 7.5mm and 7.5 mm to 10 mm does not affect the sound absorbency property of the material significantly. But when the needle penetration depth increases from 12.5mm to 15mm it leads to increase the sound insulation properties of the nonwoven material. Increase in the needle depth results into intense fibre entanglement, which results in the formation of numbers of small pores which entrap the sound wave in the structure. This will increase the frictional resistance to sound wave and dissipation of more energy and increase the sound absorption coefficient [10].

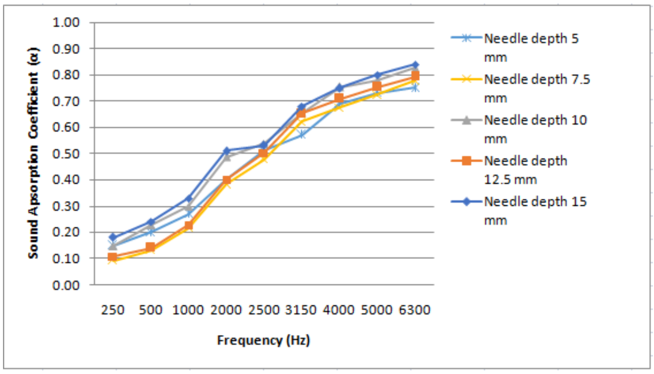



**Figure 6. Sound absorption Coefficient interaction with Needle depth (mm).**

## V. CONCLUSION

The sound absorption coefficient of nonwoven needle punched fabric was investigated in relation to variables such as proportion kapok bled, carded web mass, stroke frequency, and needle depth. Results of ANOVA test indicated that controllable parameters like the proportion of kapok fibre in the blend, carded web mass and stroke frequency increase the sound absorption coefficient of nonwoven fabric. Results also showed that the sound absorbency of material increased at higher frequencies. Increased in needle depth also increases the sound absorption of material, but its effect is not significant. The findings revealed that there is a significant effect of percentage of kapok fibre in the blend, carded web and stroke frequency on sound absorption property of the nonwoven fabric.

## REFERENCES

1. M. Mvubu, A. Patnaik, and R. D. Anandjiwala, "Process Parameters Optimization of Needle-punched Nonwovens for Sound Absorption Application," *J. Eng. Fiber. Fabr.*, vol. 10, no. 4, p. 155892501501000, 2018.
2. H. F. Xiang, D. Wang, H. C. Liua, N. Zhao, and J. Xu, "Investigation on sound absorption properties of kapok fibers," *Chinese J. Polym. Sci. (English Ed.*, vol. 31, no. 3, pp. 521–529, 2013.
3. S. Hassanzadeh, H. Hasani, and M. Zarrebini, "Analysis and prediction of the noise reduction coefficient of lightly-needled Estabragh/polypropylene nonwovens using simplex lattice design," *J. Text. Inst.*, vol. 105, no. 3, pp. 256–263, 2014.
4. G. Thilagavathi, E. Pradeep, T. Kannaian, and L. Sasikala, "Development of Natural Fiber Nonwovens for Application as Car Interiors for Noise Control," 2010.
5. M. Tascan and E. A. Vaughn, "Effects of Total Surface Area and Fabric Density on the Acoustical Behavior of Needlepunched Nonwoven Fabrics," 2008.
6. M. Tascan, D. Ph, E. A. Vaughn, and D. Ph, "Effects of Fiber Denier , Fiber Cross-Sectional Shape and Fabric Density on Acoustical Behavior of Vertically Lapped Nonwoven Fabrics," pp. 32–38.
7. Y. na, J. Lancaster, J. Casali, and G. Cho, "Sound Absorption Coefficients of Micro-fiber Fabrics by Reverberation Room Method," *Text. Res. J.*, vol. 77, no. 5, pp. 330–335, 2007.
8. N. Voronina, "Acoustic properties of fibrous materials," *Appl. Acoust.*, vol. 42, no. 2, pp. 165–174, 1994.
9. Acoustics, *Determination of sound absorption coefficient in impedance tubes - Part 2: Transfer- function Method , ISO 10534-2*. 1998.
10. P. P. Narang, "Material Parameter Selection in Polyester Fibre Insulation for Sound Transmission and Absorption," vol. 45, pp. 335–358, 1995.
11. H. S. Seddeq and N. M. Aly, "Investigation on sound absorption properties for recycled fibrous materials," 2013.