REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Literature is an essential part of the study based on research subject, so the chapter consists of crux relevant to theoretical literature and researches which were studied. The literature was collected by the investigator from various libraries like NIRJAFT (National Institute of Research on Jute and Allied Fibre Technology), Kolkata; CIRCOT (Central Institute for Research on Cotton Technology); Smt. Hansa Mehta Library and the department library of The Maharaja Sayajirao University of Baroda, Vadodara. Online search and correspondence were another important source of literature collection.

The review of literature collected was categorized and discussed under the following subsections:

2.1 Theoretical Review

2.1.1 Minor cellulosic fibers

a. Sisal fibers
b. Ramie fibers
c. Enzyme treatment

2.1.2 Sound absorbing system

a. Sound wave concept and its mechanism
b. Causes of sound and its effects on human beings
c. Factors affecting sound absorption
d. Various sound absorbing materials
e. Testing methods

2.2 **Research Review**

2.2.1 Morphological analysis of minor fibers

2.2.2 Sound absorbing materials

2.1 Theoretical Review

2.1.1 Minor cellulosic fibers

India being an agriculture land, many varieties of plants are cultivated for various purposes. One of the category is the natural minor cellulosic fibers, they are those fibers which are less cultivated, less known and explored and has less production as well as end use. Cellulose is a fibrous material obtained from the different part of the plants that are leaves, stem and seed. Some of these fibers are for the manufacturing of the textiles and/or non-textile products. Few of the minor cellulosic fibers to be listed are – Kapok, flax, nettle, kenaf, ramie, hemp, sisal, abaca, banana, pineapple, coir and so on.

Lignocellulosic fiber is a scientific name that refers to natural fibers/minor cellulosic fibers, as all plant fibers are constructed by millions of macrofibril, while a macrofibril is framed by microfibril that consists of cellulose, hemicellulose, and lignin which was described by **Sapuan., et.al. (2018)**. Most of the plant fibers contain 50-70% of cellulose as shown in Table. 2.1

Table 2.1: Chemical content of natural fibers

Fiber	Cellulose	Hemicellulose	Lignin	Pectin	Wax	Moisture Content
Jute	64.4	12.0	11.8	0.2	0.5	10
Flax	64.1	16.7	2.0	1.8	1.5	10
Hemp	67.0	16.1	3.3	0.8	0.7	10
Ramie	38.6	13.1	0.6	1.9	0.3	10
Kenaf	63.5±0.5	17.6±1.4	12.7±1.5	-	-	-
Sisal	65.8	12.0	9.9	0.8	0.3	10
Nettle	54	10	9.4	4.1	4.2	-
Banana	61.5	20.3	15	-	-	-
PALF	69.5	17.8	4.4	1.1	3.3	-
Coir	45.84	0.25	43.44	3.3	-	-
Natural Bamboo	73.83	12.49	10.15	0.37	-	-

Source: Jain, A., et.al. (2016)

The structure, micro fibrillar angle, cell dimensions, defects, and chemical composition of the fibers are the most important variables that determine the overall properties of the fibers. Tensile strength and Young's modulus of the fibers increase with increasing cellulose content, while micro fibrillar angle determines the stiffness of the fibers. If the micro fibrils are oriented parallel to the fiber axis, the fibers will be rigid, inflexible and have high tensile strength (Table. 2.2). Lignin/hemicellulose matrix provides nature's protection against microbial invasion, also renders the material water resistant and inaccessible to chemical reagents as reported by **Jain, A., et.al. (2016)**.

Table 2.2: Physical properties of natural fibers

Fiber	**Fiber Denier**	**Tenacity (g/d)**	**Breaking Elongation (%)**	**Moisture Regain (%)**
Jute	5-25	2.0-6.3	1.0-2.0	10.08
Flax	12-30	2.6-8.0	1.5-5	8.205
Hemp	16-50	3.0-7.0	1.5-5	8.0
Ramie	16-125	4.5-8.8	1.5-5	6.60
Kenaf	14-33	2.4-3.33	1.6	10-20
Sisal	100-400	6.46	3.02	10.57
Nettle	20-80	5.65	1.2	5-8
Banana	17	29.98	6.54	12
PALF	22-50	3.41-4.53	2.4-3.4	11
Coir	16	1.1	30	10.5
Natural Bamboo	23.22	5.43	3.59	10.14

Source: Jain, A., et.al. (2016).

To decide the end use of the fiber, physical properties are major factors based on which potential utility can be decided. Thus, for the study two different minor cellulosic fibers – sisal and ramie were explored aiming to its distinctive features and to develop eco-friendly product for the consumption of niche market, thereby to increase it consumption rate which will have an impact standard of living of the workers as well as economic growth of our country.

a. Sisal fibers

Sisal fiber extracted from leaves Agave Sisalana plant belongs to the Agave family. The name "Sisal" comes from a harbor town in Yucatan, Mexico and the native Mexican people used it for centuries. It is native of Central America and its origin can be traced back to the centuries. The industry was built up in tropical regions of Africa, Central and South Asia and Asia. Production process is set in many of the poor areas of the world where, it is the only source of income and economic activity. Goa was the first place in India where the Agave plant was fetched by the Portuguese in the fifteenth century. Later the cultivation was carried out in Orissa and was found throughout the country.

Sisal occupies 6th place among fiber plants, representing 2% of the world's production of plant fibers and contributes nearly 85% of the total sisal fiber production of the world. The total annual production of sisal fiber varies depending on demand, climatic conditions and cultivation. Approximately, 428.1 thousand ha area in the world is utilized for growing sisal, while in India it is estimated that around 1800 to 2400 ha area of land is for growing sisal out of which about 1080-1440 tons fiber are produced.

Various species available in India are A. Sisalana, A. Americana, A.Cantala, A. Mexicana and A.Veracruz, amongst which A. Sisalana commonly known as sisal. It is a xerophyte plant which can survive on poor soils in drought prone tropical regions. The cultivation on sisal is done in many arid and semi-arid regions of India like Madhya Pradesh, Chhattisgarh, Orissa, Uttar Pradesh, Rajasthan, Andhra Pradesh, Tamilnadu, Karnataka, Maharashtra, Bihar and West Bengal. It was primarily used by the tribes/villagers to provide fence or hedges and they even extracted the fibers through laborious process for producing mats, ropes, etc. which was reported in the research on sisal and its potentiality for employment generation by **Srinivasakumar, P., et.al. (2013).**

The fibers are very commonly used in the shipping industry for mooring small craft, lashing and handling cargo, also found on embankments, bunds and roadside serving the purpose of soil conservation and protection as hedge plantation. It is also utilized for the conventional purposes like ropes, anchors, cordage and handicrafts. Yet, an optimal utilization and commercially exploited with respect to their abundant availability, superior characteristics/quality and wide applicability needs an eye.

Besides, it has several other domestic to industrial uses including high strength requiring long-lasting geo textiles and specialty composites. Sisal is also an excellent CDM (Clean Development Mechanism) crop for bioethanol as well as for afforestation over poor quality arid lands giving both permanent carbon credits of forestry for carbon sequestration.

According to the Global Production of sisal fiber 2007 reported by **Asokan, P. (2011)**, the global production of sisal was aroung 240 thousand tons, amongst which the highest sisal producer in the world is Brazil (1,30,000ton) followed by Mexico (45,000ton), China (40,000ton), Tanzania (37,000ton), Kenya (27,000ton), Madagascar (15,000ton) and Venezuela (10,500tons). While other small quantity producers are South Africa, Mozambique, Haiti, Angola, Uganda, Malawi, Jamaica, Puerto, Rico, France, Indonesia, Cuba and India. All over the world fiber quality standards are different, whereas India follows BIS standard for grading and marking of sisal fibers. Due to less of sisal production in India it is imported to other countries to meet the overall requirement.

In India, the fiber is cultivated under the unorganized sector, for the employment and income generation. It provides additional opportunities to the tribal people during off-season. The marginal and dry land giving less than Rs. 2500/- profit per hectare annually can safely be brought under sisal cultivation. Dry fibre yield of sisal plant varies between 2.5 to 4.0 ton/ha depending upon the plant population and management practices. As stated by **Patel, F. (2010)**, in 1985 a high yielding sisal hybrid plant known as Leela was developed at Sisal Research Station, Bamra. Later, the District Rural Development Agency (DRDA), Koraput, Orissa started a programme under Jawahar Rojgar Yojana (JRY) in the year 1995 and titled it as “Sisal plantation, Fiber extraction and Rope making”. As one of the world's important natural fibers, sisal is covered by activities of the International Year of Natural Fibres 2009.

Sisal a monocarp and semi-perennial plant has a small stalk of 3feet height and 15inches in diameter, which produces around 200-250 leaves during its life span of 10-12years. The sword shaped leaves arranged spirally are known as sessile of length 1-1.5m or more with a diameter of 20 cm. After 2.5years and having around 100 leaves on the plant, the leaves are cut. The lance shaped leaves are thick, fleshy, rigid, with dark green colour and often covered with waxy layer, typical characteristics of xerophytic plants.

Extraction of fiber from the sisal leaf (Plate 2.1) as mentioned by **Shroff, A. (2014)**, it is done either by manual process of retting, scraping or retting followed by scaping or by mechanical process i.e. decortication using Raspador machine. In decortication process to separate the fibers, the leaves are crushed by rotating wheel and beaten by blunt knives. Then the degummed fibers are washed thoroughly and sun dried or by blowing the hot air. And the lustrous strands of creamy white colour with an average of 80 to 120 cm in length and 0.2-0.5 mm in diameter are the fibers ready to be use. Moist content plays an important role to have better grade of sisal fiber hence drying process needs to be done properly. The extracted fibers are only 4% out of the total weight.

Sisal Plant

Sisal Harvesting

Fiber extraction using Raspador Machine

Fiber washing process

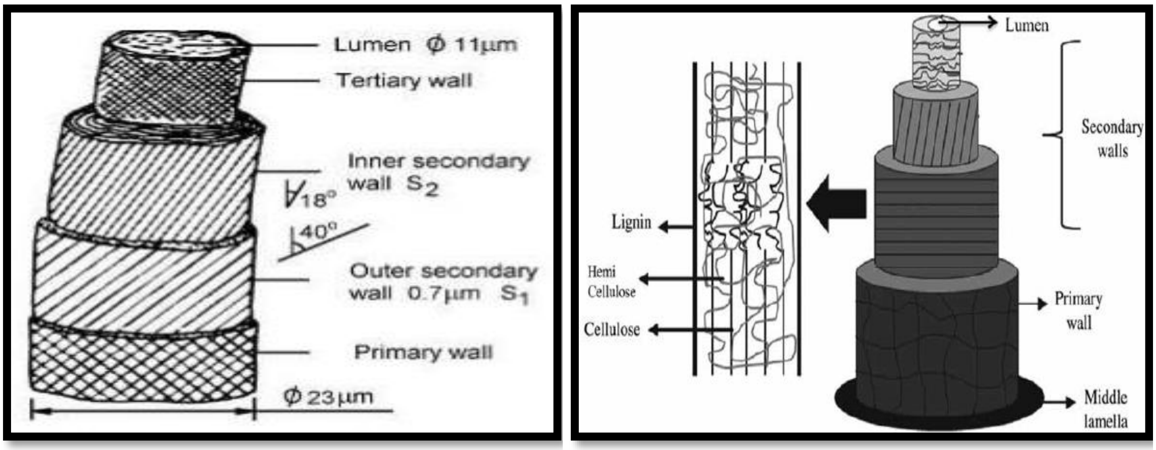
Degummed fibers

Sisal fiber products

Plate 2.1: Sisal Plant to Product process steps

Source: http://jafexpert.crijaf.icar.gov.in/sisal_info/sisal.aspx#

According to **Asokan, P. (2011)** the chemical composition of the fiber is 55-65% cellulose, 10-20% lignin, 10-15% hemicellulose, 2-4% pectin, 1-4% water soluble materials, 2-3% fats and waxes and 1% ash. Variation in the contain chances the quality of the fiber which depends on various factors like cultivation process, soil, climate, maturity of plant and extraction process. The fiber in cross section is built up of about 100 fiber cells and composition is present in each fiber cell which are divided into four main parts – the primary wall, secondary wall, tertiary wall and the lumen (Figure 2.1). The microstructures consist of parallel cells and a cuticle interface in the form of a continuous network around each cell. Sisal plant can withstand temperatures upto 40-50°C and low annual rainfall of 40-300 cm as well as can thrive in prolonged drought conditions.



a) Schematic sketch of fiber cell b) Chemical composition in macrofibril

Figure 2.1: Sisal fiber cell

Source: a) Shroff, A. (2014) & b) Maya, M.G., George, S.C., & et.al. (2017)

The fibers are recyclable, biodegradable, durable, needs less maintenance with minimal wear and tear. Other distinct features mentioned by **Bhoj, R. (2016)**, are anti-static, resistant to moisture, water and dust, takes up due easily due to its fine texture, good sound absorbing and fire-resistant properties. They have good strength but are stiffer and less cohesive, as individual cells are cemented with hemicellulose and lignin to form a complex fiber and thus to spun fine denier yarn, weaving and manufacturing of nonwovens are difficult. Another reason of having less of research work with these fibers globally are they are non- traditional food crop, research on sisal is not very exhaustive not only in India but globally also.

b. Ramie fibers

Ramie a bast fiber producing plant which is known as Boehmeria Nivea of the nettle family *Urticaceae*. As mentioned by **Mitra, S., Saha, S., & et.al. (2013)**, it is one of the oldest, strongest and fine fiber also known as ‘China grass’, ‘Grass linen’ or ‘China linen’. In ancient times, ramie clothes were only used by the Royal families of Egypt or for Mummies. It is said that the fiber was originated in China, most of the species are also observed and were grown for centuries together till the cotton entered in 1300 AD. Ramie of various species has be traced in various parts of India like Meghalaya, Assam, Arunachal Pradesh, Manipur and Sikkim in North Eastern, at Western Ghats as well as Northern parts of West Bengal and Uttarankhand.

In Indian ancient literature, around 400 AD Kalidas mentioned about the fiber in his drama “Shakuntala” as well as in “Ramayana” as stated by **Singh, D. ()**. While it is also said that ramie fiber clothing was worn in ancient times, at least before 600 BC. Ramie cultivation was traced back in 1960 by George Eberhard Rumph, who found that the ramie plantation was done in East Indies and name it *Ramium Majus*. Later from 19^{th} Century the seeds and plants were planted and supplied to various parts of the world, were the cultivation is still going on today.

Major ramie producing country is China, it was cultivated in 72,934 ha area and contributes 96.3% of the global production. The other countries where ramie is grown are Brazil, Indonesia, Philippines, Korea, Vietnam, Japan, India and other South Asian countries. While in India the cultivation is majorly in Assam and North Bengal covering small area of around 100 ha only. Ministry of Agriculture, Govt. of India has laid major emphasis on expansion of area under this crop. CRIJAF, has therefore, taken a lead for the area expansion of ramie in the tribal areas of Assam utilizing the budget of Tribal Sub Plan (TSP) to uplift their socio-economic conditions.

Less of research and development has been done, because of certain characteristics of ramie. The fibers being strong and lustrous are adapted limited because of tedious extraction process, limited progress in area expansion and genetic improvement has been hardheaded. Hence few attempts are been practiced to maintain various species at Ramie Research Station, Sorbhog, Assam which is the National Active Germplasm Site of ramie.

Ramie grows in large number of straight slender stalks with the length upto 150-200 cm and diameter of 12 to 20 cm, depending upon the climatic situation. The heart shaped of 5 to 15 cm long and width of 4 to 10 cm, are grown alternatively on the upper part of the stalks. As the fibers are extracted (Plate 2.2) from the stalks they are known as bast fibers. Approximately fibers 35-45kg fibers are extracted from 800-1000kg fresh green stalks using decorticating machine which removes the outer bark, crushes the stalk to remove the woody material and to some extent gum and waxes also. Then the fibers are washes to remove gum and wax followed by sun dried for 2 to 3days. Further, to remove the gummy substances the fibers are degummed by either of degumming process – Microbial degumming or Chemical degumming using alkali to increase the spinnability of the fiber.

Mitra, S., Saha, S., & et.al. (2013) mentioned in their paper that ramie is a longest filament fiber amongst the bast fiber category provides the fiber of length 3 to 30 cm, width ranging between 40-100µm and length to width of the fiber cell varies from 3000 to 3500. It is the longest and strongest plant cell having unicellular fiber structure, while the fiber cell is oval shaped having a wide lumen and a large cross section.

The lustrous, silky, white ramie fiber consists 76.2% cellulose, 14.6% hemicellulose, 0.7% lignin, 2.1% pectin, 0.3% wax and 6.1% others as mentioned by given by **Shroff, A. (2014)**. The fiber is so strong that its tensile strength times is eight times higher than silk, also the strength increases when the fibers are in wet condition and are durable. The fiber tenacity is 6-7 g/tex. The additional features of the fiber are resistant to bacteria, mildew, alkalis, rotting, light, insect attack and not harmed by mild acids. It has excellent thermal conductivity, ventilation function, coolness, moisture absorption and dye uptake.

Degummed ramie fibers produce stronger and excellent yarn compare to cotton when spun on jute spinning system. The fine and strong ramie yarn are found to be even better than viscose yarns. The ramie spinning can also be conducted on cotton spinning system but will not give finer yarns like cotton. With proper combing process the fibers become softer and fluffier. However, the moisture content should be properly controlled for better results as per the research by **Singh, D. ().**

Ramie plant

Ramie decortication process

Chemical degumming process

Impregation of ramie into the degumming tank

Washing of the fibers

Open air/sunlight drying of the fibers

Decorted and degummed fibers

Hand and machine spinning process

Ramie blended yarns

Ramie woven samples

Plate 2.2: Ramie plant to product process steps
Source: Biswas. D., Chakrabarti. S., et.al. (2012)

Good rainfall and warm moist climate are suitable for the proper growth of the ramie plants. Sandy loam or loamy, fertile with organic matter soil with no water logging is preferred for the cultivation process. During summers temperature ranging from 25° to 31° C and rainfall of 1500 to 3000mm throughout the year is considered to be suitable for the growth of the crop. Harvesting is normally done two to three times per year, while under good conditions it can be harvested six times per year.

Owing to the fiber features, they are used for making apparels, curtains, draperies, upholsteries, towels, canvass, filter cloth, twines, threads, pully belts, ropes and cordages, fishing nets, fire hoses, water carrying bags, industrial packing, canvas, furnishing materials, shoe sewing threads, etc. Composites for aviation, car and railway interiors are also made using ramie fiber. The currency notes and cigarette papers can be manufactured from waste fibers, while several bio-degradable products like ply wood, particle boards, fiber boards, etc can be manufactured from the woody portions.

Dyeing and finishing with modern technologies will improve the comfort properties for creating a high-quality product using ramie fibers. In recent years many research and developments are going on to improve the quality of the fiber as well as cultivation processes. The fiber has such a huge potential that it will have good demand after cotton and jute, thus will be considered as a major fiber yielding crop all over the world. They are also used fodder and medicinal purposes.

c. Enzyme treatment

Enzymes are naturally occurring biological products produced by living organisms like animal tissue, plants and microbes. It is composed of complex three-dimensional globular protein molecules formed by long linear chains of about 200 to 250 amino acids lined by peptide bonds. They act as biocatalyst in chemical reactions and by their mere presence and without being consumed in the process, enzymes can speed up chemical processes that would otherwise run very slowly. After completion of reaction, the enzyme is released again to start another reaction.

As stated by **Nagaje, V. & Hulle, A. (2014)**, in 19th century, Louis Pasteur studied the fermentation process and conclude that it was a catalyzed by a material called ferments. The word enzyme was derived in 1877 by German physiologist Wilhelm Kuhne which means 'in (en) yeast (zyme)'. Though the process and its uses were known since long, the actual importance were understood recently and gaining global recognition because of their non-toxic eco-friendly characteristics.

Each molecule of the enzyme has active site in the form of three-dimensional structures as fissures, holes, pockets and cavities or hollows which combines with the substrate. The active site per molecule are very small, generally only one. The chemical bonds of the substrate weaken as soon as it interacts with the molecules of the enzyme. Thereby, modification takes place in the substrate and the enzymes retain its original shape and starts functioning again in the same manner as per the researcher **Mal, P. & Ganguly, D. (2013)**.

Enzymes catalyze the reaction by lowering the activation energy of the reaction (Figure 2.2). The reaction between the enzyme molecule and the substrate has been very well explained by lock and key fashion (Figure 2.3) of Emil Fischer with a hypothesis. The enzymes do not change during the reaction but it will be reabsorbed by the other part of the substrate or react on another substrate. It is a continuous process till the molecular enzymes gets affected by the chemical reactions or inactivated by extremes of temperature, pH or by any environmental condition during the process. The three main sources of enzymes are:

- Vegetable source – Malt extract is made from germinated barley. These are particularly used in desizing.
- Bacterial source – Enzymes can be commercially produced by growing cultures of certain microorganisms e.g. proteases, catalase.
- Animal Source – These enzymes obtained from slaughterhouse wastes such as pancreas, clotted blood, liver, etc.

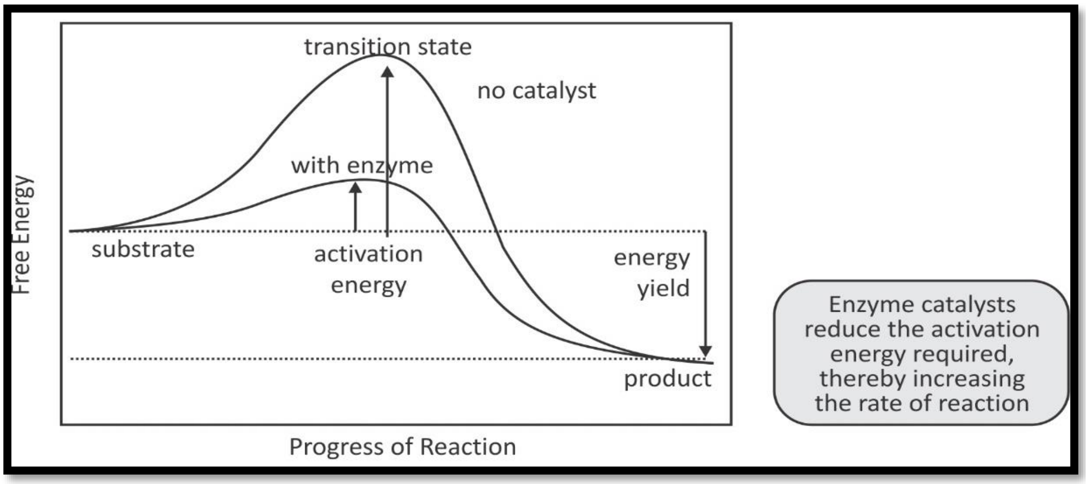


Figure 2.2: Activation energy vs rate of reaction

Source: https://www.google.com/search?q=lock+and+key+model+of+enzyme+reaction&sxsrf=ALeKk00vanYK6mfX2DX1APUEdtNaNSPMFA:1600180746360&source=lnms&tbm=isch&sa=X&ved=2ahUKEwilhtrnsevrAhWgzjgGHTw3DecQ_AUoAXoECA4QAw&biw=1366&bih=635#imgrc=vhElviOKBOC9xM

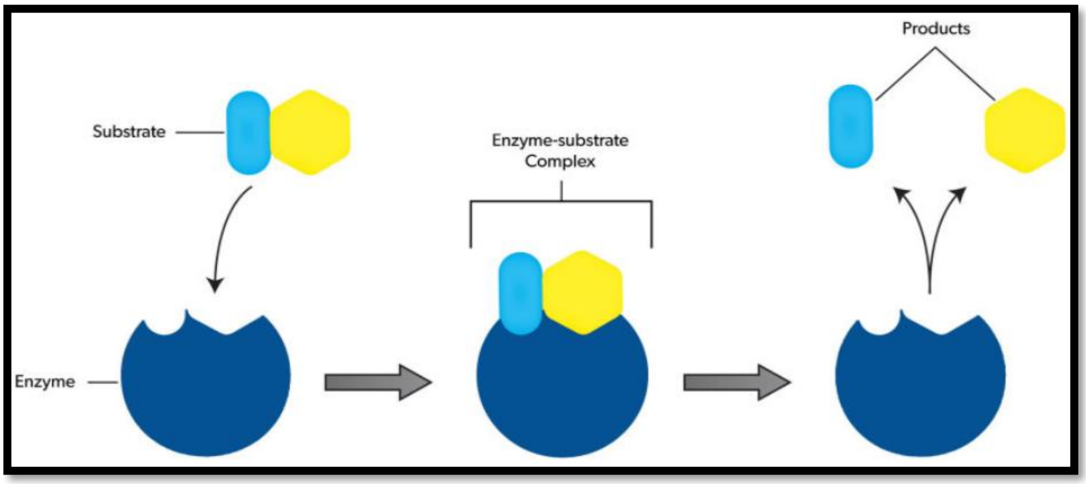


Figure 2.3: Lock and Key fashion

Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fhaygot.s3.amazonaws.com%2Fquestions%2F732470_663355_ans_18e5c2f9909b4041bd5474399fd4c81e.PNG&imgrefurl=https%3A%2F%2Fwww.toppr.com%2Fask%2Fquestion%2Flock-and-key-model-of-enzyme-action-illustrates-that-a-particular-enzyme-molecule%2F&tbnid=DtYEGNmTpht0RM&vet=12ahUKEwjr56mJsuvrAhXWBLcAHfU3BdMQMygDegUIARCnAQ..i&docid=noUvXJy8x2DrBM&w=945&h=488&q=lock%20and%20key%20model%20of%20enzyme%20reaction&ved=2ahUKEwjr56mJsuvrAhXWBLcAHfU3BdMQMygDegUIARCnAQ

In textile industry, the enzymes are used for various process like scouring, bleach clean-up, desizing, denim abrasion and polishing. The benefits of it are specific use with fast action, with the use of small quantity of enzyme cost of raw materials, chemicals as well as consumption of energy and water reduces. It has a positive impact on economy as well as on environment. Thus, gaining more and more importance with increasing awareness of sustainable development and climate change. At the same technological upgradation is needed to have an assembly line and thereby to meet the demand was mentioned by **Shroff, A. (2014)** in the paper.

Enzymes are categorized according to the compounds they act upon, some of the common ones are – proteases which break down proteins, cellulases which break down cellulose, lipases which split fats into glycerol and fatty acids, amylases which break down starch into simple sugars. **Araujo, R., et.al. (2008)** explaines about the four different enzymes used for the pre-treatment of lignocellulosic fibers are cellulase, hemicellulase, laccases and pectinases.

Cellulase Enzyme:

Cellulases are hydrolytic enzymes that catalyse the breakdown of cellulose to smaller oligosaccharides and finally glucose. Cellulase activity refers to a multicomponent enzyme system combining at least three types of cellulase working synergistically. Endoglucanases or endo cellulases cleave bonds along the length of cellulose chains in the middle of the amorphous region. Cellobiohydrolases or exo-cellulases start their action from the crystalline ends of cellulose chains, producing primarily cellobiose. Cellobiohydrolases act synergistically with each other and with endoglucanases, thus mixtures of all these types of enzymes have greater activity than the sum of activities of each individual enzyme alone. Cellobiose and soluble oligosaccharides, produced by exo cellulases, are finally converted to glucose by b-4-glucosidase. These enzymes are commonly produced by soil welling fungi and bacteria, the most important being Trichoderma, Penicillium and Fusarium. Many of the fungal cellulases are modular proteins consisting of a catalytic domain, a carbohydrate-binding domain (CBD) and a connecting linker. The role of CBD is to mediate the binding of the enzyme to the insoluble cellulose substrate. Cellulases are active in a temperature range from 30 to 60°C. Based on their sensitivity to pH, they are classified as acid stable (pH 4.5_5.5), neutral (pH 6.6_7) or alkali stable (pH 9_10). The application of cellulases in textile processing started in the late 1980s with denim Application of enzymes for textile fibers processing finishing. Currently, in addition to bio stoning, cellulases are also used to process cotton and other cellulose-based fibres.

Hemicellulase Enzyme:

Hemicellulase are a group of enzymes that are defined and classified according to their substrate hemicellulose. The hemicelluloses are polymers of xylose, galactose, mannose, arabinose, other sugars and their uronic acids. The terms “hemicellulases” or hemicellulose-degrading enzymes refer to those enzymes that specifically degrade only hemicelluloses, and are also frequently capable of hydrolyzing the short-chain or monosaccharide appendages from the main, backbone chain of hemicelluloses. Most hemicelluloses however, occur as heteroglycans containing different types of sugar residues, often as short appendages linked to the main, backbone chain. These are usually classified according to the sugar residue present, for example, as L-arabinanases, D-galactanases, D-mannanases, and D-xylanases. They are xylan degrading enzymes and ranks second to the cellulase. Xylan consists of a homopolymeric backbone of 1,4- ß-D- xylopyranose units. Hemicellulase enzymes contain endo and exo activities. Endo- enzymes attack the xylan in random manner, giving a decrease in degree of polymerisation. L-Arabinans are often associated with the pectic polysaccharides from a number of plant sources, but are usually included in the hemicellulose group.

Laccases Enzyme:

Laccases are extracellular, multicopper enzymes that use molecular oxygen to oxidize phenols, and various aromatic and non-aromatic compounds by a radical-catalysed reaction mechanism. They belong to a larger group of enzymes termed the blue-multicopper oxidase family. Laccases have been found in plants, insect, bacteria, but are most predominant in fungi. Laccase activity has been demonstrated in more than 60 fungal strains. Typical fungal laccase is a protein of approximately 60_70 KDa with a pH optimum in the acidic pH range, and optimal temperature range between 50 and 70°C. The range of substrates with which laccases can react is very broad, showing a remarkable lack of specificity towards their reducing substrate. Laccases are widely researched for the decolourization of textile effluents and also been studied for textile bleaching. Laccases can improve whiteness of cotton by oxidation of flavonoids. The substitution or combination of chemical bleaching with an enzymatic bleaching system leads not only to less fibre damage, but also to significant water economy.

Pectinases Enzyme:

Pectin and other pectic substances are complex polysaccharides present in plant cell walls as a part of the middle lamella. Pectinases are a complex group of enzymes involved in the degradation of pectic substances. They are primarily produced in nature by saprophytes and plant pathogens (bacteria and fungi) for degradation of plant cell walls. There are three major classes of pectin degrading enzymes: pectin esterases (PEs), polygalacturonases (PGs) and polygalacturonate lyases (PGLs). Pectin esterases are mainly produced in plants such as banana, citrus fruits and tomato, but also by bacteria and fungi. They catalyze hydrolysis of pectin methyl esters, forming pectic acid. The optimum pH for activity varies between 4.0 and 7.0. The exception is PE from Erwinia with an optimum pH in the alkaline region. The optimum temperature ranges between 40 and 60°C. Polygalacturonate lyase cleaves polygalacturonate or pectin chains via b-elimination that results in the formation of a double bond between C4 and C5 at the non-reducing end and elimination of CO2.

To have an effective enzymatic treatment on the substrate certain factors are important and they are:

Substrate concentration:

The rate of enzyme reaction increases with increase in substrate concentration initially afterwards a point is reached where for very large increase in substrate concentration the enzyme activity increases very little. This enzyme activity is called as maximum enzyme activity and is denoted by Vmax.

pH value:

Optimum pH of enzymes is 4 to 9, beyond this limit the denaturation of enzymes takes place.

Temperature:

If the temperature is increased by 10, the rate of most of chemical reactions doubles. The rate of reaction increases due to the thermal energy increase. However, in the range of 40°C-60°C there is loss of enzyme activity because denaturation of proteins occurs at this temperature.

Time:

The time for reaction is inversely proportional to the concentration of the enzyme i.e. more is the enzyme concentration less will be the time required for particular reaction and vice versa.

Activator:

Many chemical compounds activate the catalytic activity of enzyme presence of certain bivalent metallic carbons. These metals stabilize the structure of enzyme substrate complex or sensitive the substrate to attack of the enzyme.

Inhibitor:

Certain compounds combine with an enzyme but do not serve as a substrate. They thus block catalysis by the enzyme and function as inhibitor. The inhibition may be competitive or non- competitive inhibition. In competitive inhibition substrate and inhibitor molecule both compete for binding with the enzyme. Whereas in non-competitive inhibition inhibitor reacts with various functional group of enzymes and thus prevents the normal reaction.

2.1.2 Sound absorbing system

a. Sound wave concept and its mechanism

Concept

Sound can be considered as a wave phenomenon. A sound wave is a longitudinal wave where particles of the medium are temporarily displaced in a direction parallel to energy transport and then return to their original position. The vibration in a medium produces alternating waves of relatively dense and sparse particles – compression and rarefaction respectively.

Kherdekara, G., Basuk, M. & Behera, J. (2011), explains about the resultant variation to normal ambient pressure is translated by the ear and perceived as sound. A simple sound wave can be described in terms of variables like – Amplitude, Frequency, Wavelength, Period and Intensity (Figure 2.4).

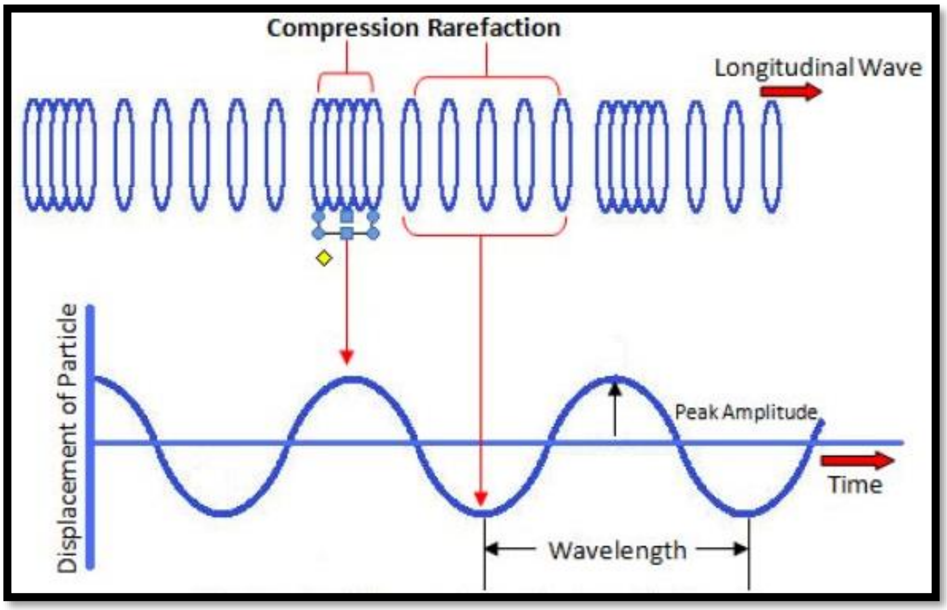


Figure 2.4: Diagram of a sound wave
Source: Mohan, V. (2011)

Mechanism

The sound absorption is due to dissipation of acoustic energy to heat. Air molecules oscillate within the pores due to sound pressure when it enters into the porous materials. This oscillation results in frictional losses.

A change in the flow direction of sound waves, together with expansion and contraction phenomenon of flow through irregular pores, results in a loss of momentum. Thus, sound with air molecules in the pores undergo periodic compression and relaxation and so change of temperature is the result. Because of long time, large surface to volume ratios and high heat conductivity of fibers, heat exchange takes place isothermally at low frequencies and at high frequency compression takes place adiabatically. In the frequency region between these isothermal and adiabatic compression, the heat exchange results in loss of sound energy. So, because of frictional, momentum and temperature losses altogether contribute in absorbing the sound as mentioned by **Mistry, P. (2013)** in the research work.

Padhye, R. & Nayak, R. (2016) explains about the sound that might be absorbed, reflected, transmitted, refracted or diffracted depending upon the material or object surface which it strikes with. These phenomena are explained with the figure 2.5 and 2.6.

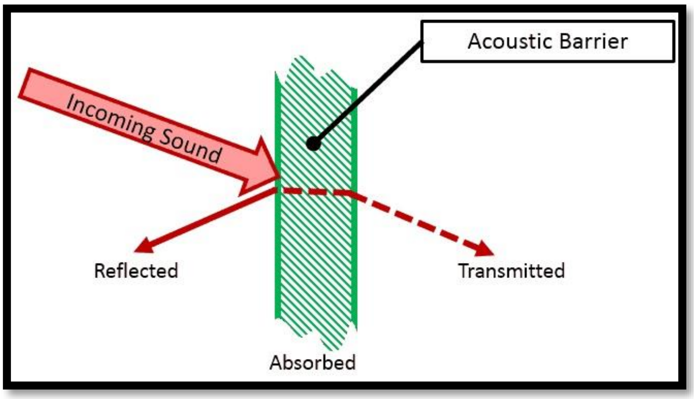


Figure 2.5: Sound absorption mechanism

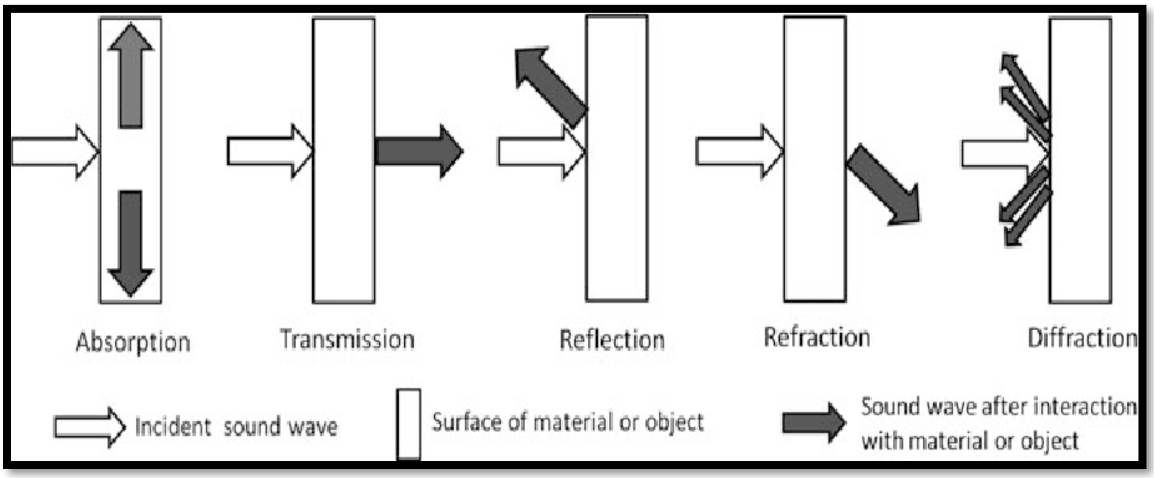


Figure. 2.6: Sound wave interaction with the surface material or object

Source (2.5 & 2.6): Padhye, R. & Nayak, R. (2016)

Absorption

Sound absorption is an important phenomenon as far as sound insulation is concerned. There are two types of sound absorbers – porous absorbents or resonant type. Fibrous materials and open celled foams are the porous absorbents. The acoustic energy is converted into heat energy when waves impinge the fibrous materials, while in case of foam sound wave displacement occurs through a narrow passage of foam and causes heat loss. Resonance absorbents are of mechanical type, where there is a solid plate with a tight air space behind.

Transmission

Sound waves from the source propagate through the medium, which reaches to the receiver without being absorbed or reflected due to no frequency loss.

Reflection

When sound waves impinge on hard or smooth surface, they may reflect back with their full energy without altering their characteristics. Echo is a simple example of sound reflection phenomenon, which can be heard when the sound wave, perpendicular to the sound source, hits a flat and smooth surface.

Refraction

It occurs when sound waves transmit through the surface and bent away from the straight line of travel. Sound refraction depends on factors like speed of sound, angle between sound propagation and wind direction and atmospheric conditions such as temperature and relative humidity.

Diffraction

It involves a change in the direction of sound waves as it strikes through a surface. Sound waves when impact on a partial barrier, some of them get reflected, some propagate without any disturbance and some bent or diffract over the top of the barrier.

Thus, there are certain factors associated with the raw material, surface treatment and the application area based on which the impact and absorption of sound depending upon.

b. Causes of sound and its effects on human beings

Sources of noise are poor urban town planning where the industrial and residential areas are nearby, too many family members in a small house, lack of infrastructure and all. Another source is industrialization to meet the demand and supply of the consumers the production is carried out using heavy machines and equipment like compressor, generators, exhaust fans, grinding mills, etc and thus to minimize the effect of noise the workers wear the ear plugs. Social events and gatherings like weddings, parties, pubs, etc. has huge gatherings and creates noise which harms the people leaving in nearby areas. Traffic of huge and large number of vehicles on roads, pickup and landing of the plane, metro and underground trains not only generates noise but also vibration that leads to disturbance and losses hearing capacity. Construction sites like high-rise buildings, dams, flyovers, etc. is good for the development of city but takes long time to build up and increases the noise pollution. Other technological developments are also the major factors which makes are work easier but creates noise pollution in day to day life, i.e. electrical appliances like TV and music systems, public address systems, mixer, washing machine, Vacuum cleaner, dryer, cooler and electricity generating sets. Thus, the people associated with the metropolitan cities or big towns and working in factories are more susceptible to the adverse effects of noise. Excessive sound vibrations in urbanized settings also leads to structural damage and so value of the property goes down.

Annoying sound that our ears cannot filter can cause problems within the body (Figure 2.7). If continuously exposed to the noise of jackhammers, horns, machinery, airplanes and even vehicles (Figure 2.8) can damage our ear drums and loss of hearing or reduction in sensitivity to sounds can be resultant. Prolonged engagement in working areas where noise pollution is there like offices, construction sites, bars or polluted residential areas has an impact on psychological health. According to various studies it is said that aggressive behavior, sleep disturbance, constant stress, fatigue and hypertension are the results of excessive noise levels. Thus, causes one’s performance in the work environment as well as leads to severe and chronic health issues later.

Studies also reveals that blood pressure, cardiovascular diseases and stress related heart problems are increasing and will only be manageable by understanding the noise level and by finding ways of reducing the noise pollution. High decibel noise will not only harm the health but also disturbs the communication, which leads to misunderstanding. Association with sharp noise creates severe headache as well as disturbs emotional balance also.

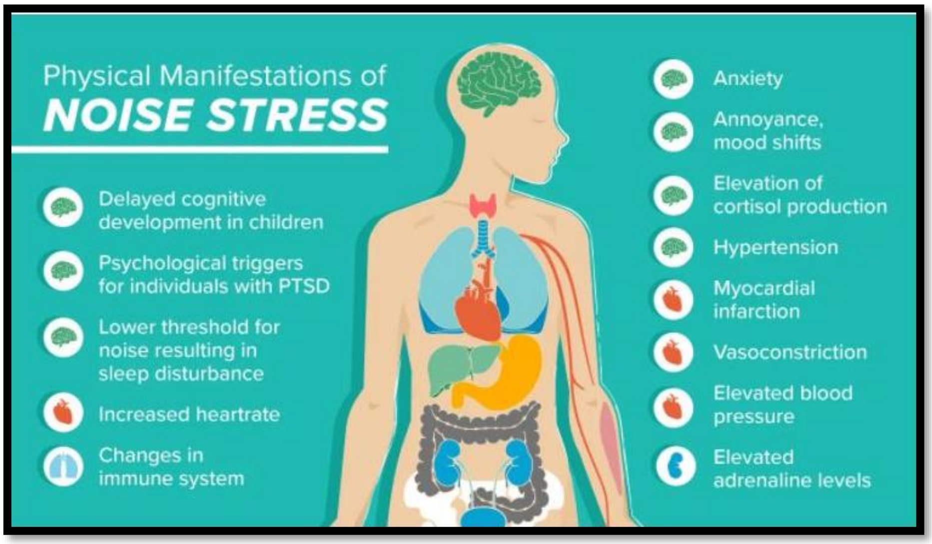


Figure 2.7: Impact of noise on human body

Source: https://www.healthline.com/health-news/loud-noises-bad-for-your-health#Your-immune-system-weakens

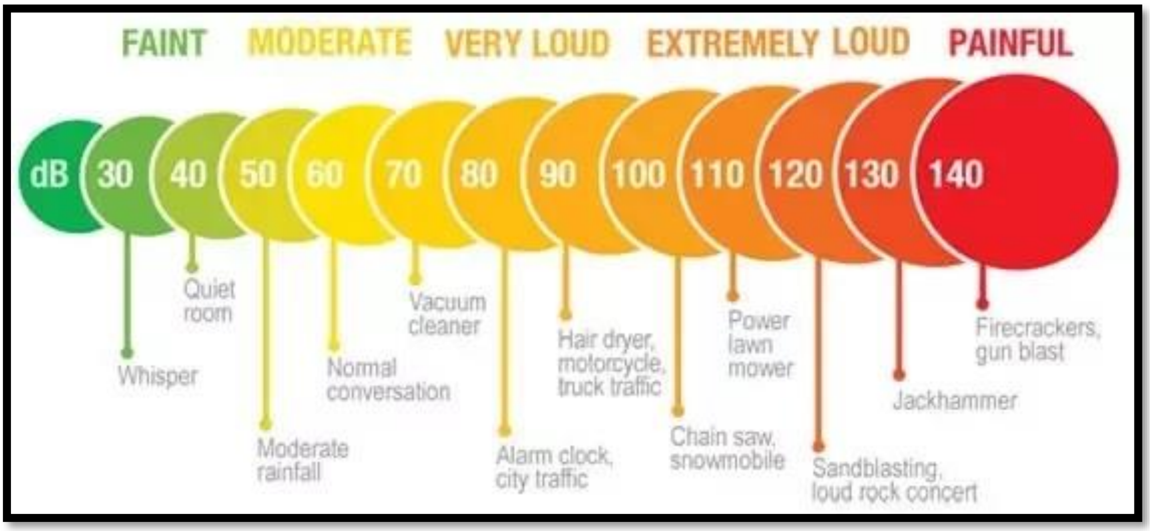


Figure 2.8: Chart representing various noise level that can cause damage.
Source: https://www.quora.com/Will-air-shows-affect-your-hearing

Wildlife is dependent on sound thus it is more harmful to them rather than human beings. They have a better sense of hearing and their survival depends on it. Hunting efficiency reduces, also disturbing the balance of the eco-system. **Pantawane, R., Maske, K. & Kawade, N. (2017)** stated that due to manmade noise those species that depend on mating calls to reproduce are often unable to hear these calls. The pets at home who are connected to noise will have ill effects like will be more aggressive, become disoriented more easily, face many behavioral problems, hearing loss, which makes them easy prey and leads to dwindling populations. Others require sound waves to echo-locate and find their way when migrating.

Unwanted noise leads to pollution and prolonged engagement causes health issues. It creates imbalance in the eco system as well as environment. By replacing the synthetic materials with agricultural waste, reduction in petroleum consumption as well as in global warming due to emission of carbon dioxide will have positive impact on our economy and environment. Thus, for all the mentioned benefits an ambience to avoid the noise needs attention and so it is essential to know the affecting factors of sound absorption.

c. Factors affecting Sound absorption

The parameters that influence the sound absorption properties of fibrous materials was studied and classified (Figure 2.9) by **Seddeq, H. (2009)** and details are mentioned as follows:

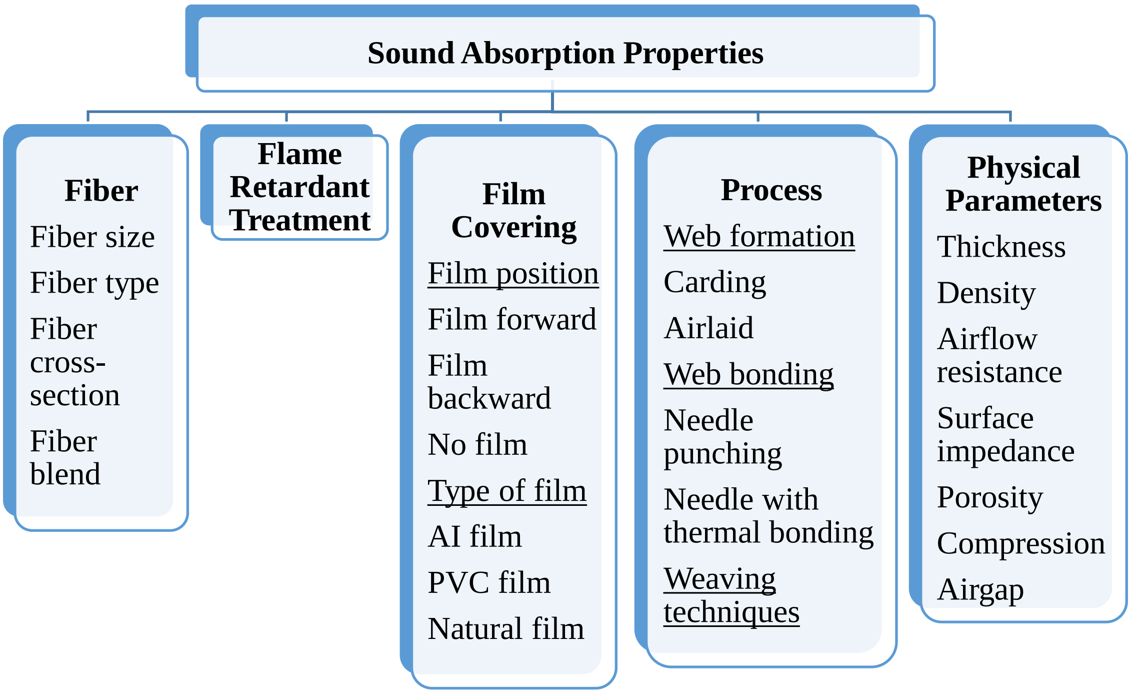


Figure 2.9: Sound absorption properties

Fiber size

Sound absorption coefficient increases with the decrease in the fiber diameter, as due to the sound waves the thin fibers can move easily rather than thick fibers. Also, more amount of fibers is required in case of fine denier fibers that will increase the volume density, thus more tortuous path and higher airflow resistance will be resultant. The fine fiber content increases NAC values, due to an increase in airflow resistance by means of friction of viscosity through the vibration of the air. The study also concludes that fine denier fibers ranging from 1.5 – 6 denier/filament (dpf) gives best results than the coarser denier fibers, moreover the micro denier fiber (less than 1dpf) increases the acoustical performance.

Fiber surface area

The sound absorption and fiber surface area have a direct correlation i.e. as the friction between fibers and air increases with fiber surface area resulting in a higher sound absorption. Porous material absorbs sound more due to the viscosity of air pressure in the pores or the friction of pore wall. Moreover, in the frequency range 1125 Hz – 5000 Hz, fibers with serrated cross sections absorbs more sound compared to the round cross-sectional area.

Airflow resistance

An important quality that influence the sound absorbing characteristics of a material, it describes the acoustical properties of porous materials that are governed to a great extent by flow resistance of the material. When sound enters in the material its amplitude is decreased by friction as the waves try to move through the tortuous passages, thus the acoustic energy gets converted into heat energy.

Porosity

Sound dissipation by friction happens when the sound wave enters the porous material. Thus, number, size and type are the important factors of sound absorption mechanism in porous materials. The material should have enough pores on the surface for the sound to pass through and get dampened. The porosity of a porous material is defined as the ratio of the volume of the voids in the material to its total volume.

Tortuosity

It is a measure of elongation of the passage way through the pores, compare to the thickness of the sample. It is an influence of the internal structure of a material on its acoustical properties. Tortuosity mainly affects the location of the quarter wavelength peaks, whereas porosity and flow resistivity affect the height and width of the peaks. While, the value of tortuosity determines the high frequency behavior of sound absorbing porous materials.

Thickness

It is said that low frequency sound absorption has direct relationship with thickness, while at higher frequencies thickness has insignificant effect on sound absorption. The thumb rule is that the effective sound absorption of a porous absorber is achieved when the material thickness is about one-tenth of the wavelength of the incident sound. If there is air space inside and behind the material, the maximum value of the sound absorption coefficient moves from the high to the low frequency range.

Density

Density governs the sound absorption behavior of the material i.e the sound absorption value increase in the middle and higher frequencies as the density of the material increases. Thus, the number of fibers increases per unit area and so it affects directly to the cost of an acoustical material. Energy loss increases as the surface friction increases, thus the sound absorption coefficient increases. Less dense and more open structure absorbs sound of low frequencies (500 Hz). Denser structure performs better for frequencies above than 2000 Hz.

Compression

From the various studies it was concluded that compression decreases the thickness, porosity and thermal characteristic length (shape factor), while increases the tortuosity and airflow resistivity. Having such physical parameters in the compressed material, the drop in the sound absorption value is mainly due to the decrease in sample thickness. The influence of compression on sound absorption can play an important role in the field of automotive acoustics.

Surface Treatments

Acoustical materials are used inside building, so they are coated with paints or some finishes to have good aesthetics and so on. Thus, such surface coatings on the sound materials for its absorptive behavior need to be analyzed. Fibrous materials are covered with film in order to improve the sound absorption properties at low frequencies by the phenomenon of surface vibration of film.

Placement / Position of Sound Absorptive Materials

Sound absorption of a material depends also on the position and placement of that material. Thus, if several types of absorbers are used it is desirable to place some of each type on ends, sides and ceilings so that all 3 axial modes (longitudinal, transverse and vertical) will come under their influence. Material applied to the lower portions of high walls can be as much as twice as effective as the same material placed elsewhere. Moreover, it is recommended that untreated surfaces should never face each other.

Surface Impedance

The surface impedance of the layer increases with resistivity, due to the greater amount of reflections on the surface layer, giving a lower absorptivity capability. Additionally, the whole process is frequency dependent, so that for lower frequency bands the necessary layer thickness increases as resistivity decreases. Thus, sound absorptive materials are chosen according to the spectrum of sound being emitted. For example, thicker materials capable of absorbing lower frequencies are used for door panels and carpet backing. Thus, it is essential to know the range of frequencies that need to be controlled in order to have effective use of sound absorptive materials.

d. Various Sound absorbing materials

The increase noise level at residential as well as office areas has elevated the need acoustic materials to be used by the civil engineers, architectures and interior designers. So, the use of such materials which can reduce the acoustic energy of sound wave as it passes through it by the phenomenon of absorption are called sound absorptive materials.

Absorptive materials are mostly used with some kind of barriers to restrict the passage of noise from the porous absorptive materials. An absorber, when backed by a barrier reduces the energy in a sound wave by converting the mechanical motion of the air particles into low grade heat. It prevents a buildup of sound in enclosed space and reduces the strength of reflected noise.

A wide range of textile materials like nonwoven, composites, knitted and woven fabrics can be used for the acoustic purposes. These products provide some degree of absorption nearly at all frequencies and performance at low frequencies increases with increasing the material thickness. Amongst all the fabrics nonwovens are widely used owing to its light weight, low production cost and lower impact on environment.

The fiber interlocking system of nonwovens act as frictional elements and thus resists the acoustic wave motion. When sound enters the material, its amplitude is decreased by friction as the waves tries to move through the tortuous passages. Thus, the acoustic energy is converted into heat.

Composites of various raw materials are also explored for the sound absorption. Amongst which results shows that composites with activated nonwoven carbon fiber as a surface layer provides good absorption coefficient at both low (100-1600 Hz) and high (1600-6400 Hz) frequencies rather than the glass fiber composite with nonwoven. As activated carbon materials has exceptional absorptive capacity due to their high specific area and micro-pore volume and are lighter in weight.

While the recycled polyester nonwovens have more advantages compare to the conventional nonwovens like glass wool and rock wool due to its low-cost process, good handling and environmental protection. Additionally, the fabric can be opened and reconstructed again, as well as materials can be remelted and used to make fibers again using chemical process. But the entire process needs the chemicals for processing.

Reasonable processing temperatures, low cost and recyclability are the major factors for the growth of such thermoplastic materials compare to thermosets. Arranging the structure of the fibers and consolidating the structure is the main step for manufacturing these kinds of materials. Heat is the main element which is need to melt the thermoplastic material or start the reaction of this thermosetting materials, when phenolic resin is used.

To overcome the use of chemicals and heat, knitted and woven fabrics are the best option as it creates good textured surface which gives an aesthetically pleasing appearance. A geometrically organized structured fabric will absorb the sound as well as gives a beautiful look to the interiors. Knitted fabrics are majorly used for headliner, carpets, seats, door panels and other interior parts. Smaller pore size and reduced porosity gives good noise absorption. For automobile smaller pore size with increased thickness provides suitable absorption.

Incase of woven fabrics, rock wool is majorly used for noise reduction and decorative materials as absorbers. The transmission loss of a sound wave of a given frequency depends mainly on cover factor followed by fabric weight and thickness. The parameters that affect sound absorption properties of woven fabrics are the frequency of impinging sound wave, fiber content, yarn count, cover factor and airgap behind the fabric. At the high frequency the absorption increases after a certain cover factor of fabric as it gets denser, while as the airgap increases the absorption coefficient shows uncertain trend till some level after that it increases.

Selection of the particular sound absorptive fabric depends upon the infrastructure, acoustic requirements, availability of the materials and possible manufacturing process that can save our environment are the major factors which are gaining attention. Thus, certain exploration using the sound absorption testing methods can provide best solution for healthier environment as researched by **Pal S., Pal S. and Jajpura L. (2015)**.

e. Testing Methods

Various measurement techniques can be used to compute the sound absorbing behavior of the material. Additionally, one of the properties is identified to quantify the absorption and they are – Sound absorption coefficient, noise reduction coefficient, reflection coefficient or surface impedance. The description of the measuring techniques and properties are given below:

The three different detailed measuring techniques was mentioned by **Deshpande, S. & Rao, M. (2014)** in the research paper and the techniques are – Reverberant Field Method, Impedance Tube Method and Steady State Method.

Reverberant Field Method

In reverberation field method the material is exposed to a randomly incident sound wave, which technically occurs when the material is in diffusive field. To create a diffusive sound field, it requires a large and costly reverberation room and still difficult to get accurate results. Thus, value of complex impedance cannot be derived only from the absorption coefficient. As the sound strike from all the directions on to the material, random incidence sound absorption coefficient can determine the absorption. Reverberation field method (Figure 2.10) is also known as reverberation room or chamber technique and anechoic chamber technique was sound absorbing testing.

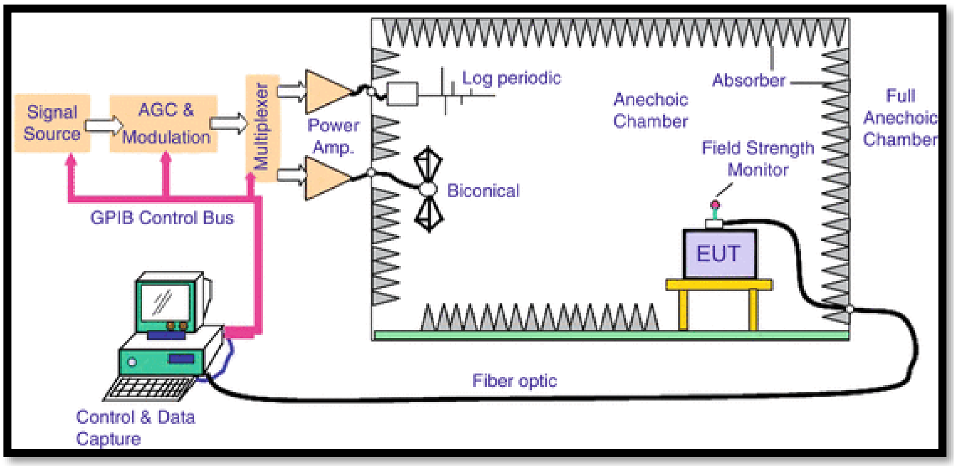
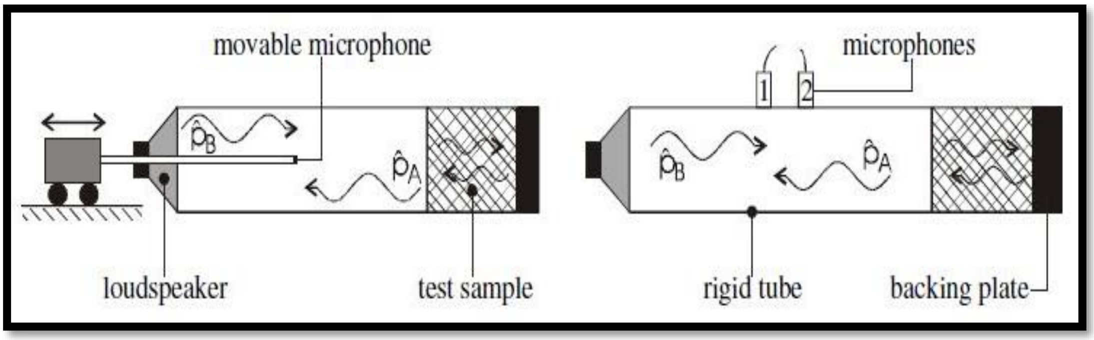


Figure 2.10: Reverberation Method

Source: https://link.springer.com/referenceworkentry/10.1007%2F978-981-4560-75-7_81-1

Impedance Tube Method:

Impedance tube method uses plane sound waves that strike the material straight and so the sound absorption coefficient is called normal incidence sound absorption coefficient (NAC). It is a faster method, which requires small sample of 35 or 100mm diameter (according to the type of the impedance tube). The sound waves are confined within the tube and thus the size of the sample should be large enough to fill the cross section of the tube. There are two ways to conduct the test i.e. Movable microphone and Two fixed microphone impedance tube test (Figure 2.11).



a) Movable microphone b) Two microphone technique

Figure 2.11: Schematic diagram of Impedance Tube method

Source: pcfarina.eng.unipr.it/Public/Standing-Wave/ebook_6_impedance.pdf

Movable microphone test is based on ASTM C 384, which is based on standing wave ratio principle and uses the audio frequency spectrometer to measure the absorption coefficient at various center frequencies of the third octave bands. The measuring method is little tedious as frequency at each distance of the sound field is calculated. While, two fixed microphone test or transfer function method is based on ASTM E 1050. A broadband random signal is used as a sound source. The normal incidence absorption coefficients and the impedance ratios of the test materials can be measured much faster and easier compared with the first technique. Two microphones at different locations and a digital frequency analysis system for the determination of normal incidence sound absorption coefficient (NAC) and normal specific acoustic impedance ratios of materials. In both the sound source is at one end and on other end the samples are mounted, but basically the measuring techniques are different.

Steady State Method

Steady state method is based on ASTM E 336-71, it measures the transmission coefficient of the materials using a third or even a second pair of microphones which is placed behind the test sample in a second impedance tube. This method is mostly applied as last possible option.

2.2 Research Review

This section discusses about the natural cellulosic fiber, morphological changes due to chemical/enzyme treatment and natural woven fabrics for sound resistance.

2.2.1 Morphological analysis of minor fiber

Natural properties

Zheng, Y., et.al. (2015) studied various researches related to the structure and properties of kapok fiber and explorations which can increase its utilization. It was found that the fiber has unique features like thin cell wall, large lumen, low density and hydrophobic-oleophilic properties. Owing to the waxy layer on the surface of the fiber, it has excellent opportunities to be utilized for the manufacturing of oil absorbing materials. Through the optical microscopy and SEM tests it was found that the fiber is cylindrical in shape, non-textured surface, thickening groins at ends, while the cross-section shows that the fiber is oval in shape with hollow structure can be explored for the insulation against the sound and heat. As they are brittle having low cohesivity and strength, it is difficult to spun but can be blended with other fibers. Thus, the fibers need the pre-treatments to increase its efficiency as well as to have more end uses.

He, J., et.al. (2007) examined the morphological characteristics of extracted bamboo fibers using both chemicals and enzyme. Fiber structure was identified by SEM which showed that it has long cylindrical with tapered end and uniform in size, thicker lumen and nodes, however the length of the fiber is less. Similar to ramie it also has long crystallinity and crystalline size, orientation and structure having lower intensity peaks at 3580 and 3560 cm^{-1} i.e. free hydroxyl groups in cellulose which was observed using FTIR and X-ray diffraction tests. Thus, amongst the natural cellulosic fibers this fiber also has potential application in composites apart from converting it into pulp, using it in constructions and artworks.

Thilagavathi, G., et.al. (2010) developed needle-punched nonwoven fabrics using three different natural fibers – Banana, Bamboo and Jute and blended individually with polypropylene. It was tested for sound absorption by ASTM E 1050. Amongst the three combinations banana/polypropylene having compact structure, higher tensile strength, higher stiffness, lower elongation, lower thermal conductivity, lower air permeability and higher absorption coefficient (0.2) was suggested for the application of automotive interiors. Moreover, it has good thermal insulation property hence could be used as acoustic wall covering for auditoriums, theatres, generator room and floor mats.

Potential use of sisal residue was identified by conducting SEM, FTIR analysis after treating to understand the changes occurring. **Peng, L., et.al. (2014)** also draws the attention on sisal fiber residue having smaller diameter, lower mechanical strength with holes and rupture of the lateral wall of the fiber. The SEM and FTIR observation were after the treatment with 20 wet-dry cycles the reduction in volume of lumen and presence of micro-cracks on the fiber cells and the sidewall while no chemical change in FTIR. Thus, the fiber has potential to be used as cement reinforced material.

Modified fiber properties

To improve the physical properties of Jute fiber **Hossen, J., et.al. (2018)** experimented combined scouring and bleaching process for fiber surface modification, to develop composites by blending it with unsaturated polyester. The fiber were treated with alkali and hydrogen peroxide to remove the impurities – wax, oil, fat and lignin so as to increase the adhesion with polymer matrix. Using ASTM specification, the fiber were tested for tensile strength, bending length, thermal and water absorbency test, while SEM was conducted to analyse the untreated and treated fibers. Change colour of jute from brown to slivery white was observed due to di-lignification, while certain amount of hemicellulose, pectin and waxes was also removed which increased the penetration of chemicals. The thermal behaviour of the composites improved which may have implications of the materials in the field of heat insulation and sound barrier.

Mamtaz, H., et.al. (2016) stated that pretreatment of natural fiber causes the removal of moisture contents which results in the decrease of its acoustic absorption, hence found that incorporation of granular in the materials balance it. It was explained that absorption in the material is controlled by the inter and within fiber voids. The pores of granular material absorb the sound due to viscosity. Some of the examples of granular are clay, sands, gravel, limestone chips and soil, which are perfect for controlling outdoor sound propagation. For highest overall sound absorption each component of fibro granular composite helps in optimizing the acoustic properties of other material to absorb sound of desired frequency. Reduction is due to porosity, tortuosity and flow resistivity of the material, thus if the sample will be compact it will reflect sound instead of absorbing. Other factors and sound absorption tests were also conducted to corelated the findings.

Morphological analysis alongwith physical and sound absorbing analysis conducted by **Sari, N., et.al. (2016)** emphasized that special structure of lumen and its distribution are the main reasons of acoustical absorptivity. The scanning electron micrographs of untreated and treated corn husk fibers shows difference. The raw fiber contains impurities and shallow grooves, with cross section dense hollow structure inside the fiber bundles were also observed. With NaOH treatment hemicellulose and lignin was removed and fibrillation caused by rougher surfaces enhanced the mechanical and acoustical properties. Reduction in the size of lumen and the number of micropores in the porous structure of a single fiber bundle has great impact. The sound wave impinges on the porous structure of the fibrous panel, the air motion and compression in the lumina caused by sound vibration can cause friction on the lumen. Due to friction and viscous forces, a considerable amount of sound is converted into heat, which attenuates the acoustic energy. Thus, the random distribution of the fibers in the panel plays important role for acoustical absorption.

Sisal fibers structural and chemical characteristics were studied by **Guerrero, B. et.al. (2016)** after using three different pretreatments – mechanical grinding, cryogenic grinding and hot water washing. Its impact was determined by the SEM, XRD and FTIR analysis. The defibration of sisal fibers was observed in case of mechanical grinded fibers, while cryogenic grinding produced breakage and flattened the fibers causing amorphization of the cellulose in different degrees. Washing in hot water for 2 hours at 75°C produced partial solubilization of minerals. After the extraction increase in moisture absorbed by fiber due to exposure of hydrophilic groups and increase in crystallinity index was observed.

Shroff, A. (2014) experimented softening process using three different enzymes namely hemicellulase, cellulase and pectinase on natural fibers – banana, ramie and sisal. To optimize the best treatment process, various per cent concentration and treatment hours were conducted. All the fibers were treated with enzymes individually and in combinations to identify its impact, which was tested by touch and feel method followed by strength loss and SEM. In case of banana and ramie pectinase and cellulase enzymes removed major impurities while hemicellulase and cellulase enzymes removed impurities from sisal fiber. 12% concentration and 12 hours treatment gave the best results. It was also observed that the cellulosic and non-cellulosic impurities were effectively and evenly removed by the combination of enzyme treatments on all the three fibers. Which also had an impact on the morphological structure of the fibers, strength and whiteness index also.

A comparative study to understand the impact of chemical and enzyme treatment on sisal fiber was conducted by **Bhoj, R. & Karolia, A. (2016)**. Laccase, cellulase, hemicellulase and pectinase were the enzymes, while sodium hydroxide, hydrogen peroxide and sodium hypochlorite are the chemicals used for the treatments. The comparative study reveals that enzyme treatment reduces the strength, increases the elongation, the fibers were swollen and are softer, decrease in whiteness and brightness index and yellowness index was increased. While the chemically treated fibers strength was maintained after the treatment, no elongation and swelling, fibers less smooth and flexible with more fibril, whiteness index increased due to bleaching and brightness was increased but reduced the yellowness. The yarns were prepared from untreated, enzyme treated and chemically treated fibers amongst which the finest was untreated fiber yarn followed by chemically and enzyme treated ones. Plain weave fabrics were also developed and the enzyme treated fibers were rough with uneven textures as the fibers were protruding on the surface of the fabric which gives it rough surface.

Plant fibers are hydrophilic in nature. **Kalia, S., et.al. (2013)** compiled various researches on surface modifications of plant fibers using various pre-treatment methods. One of the treatment methods was enzyme treatment and its effects on the properties of the plant fiber and reinforced polymer composites. Most commonly used enzymes for polymer modification from the class hydrolase: glycosidases, proteases and lipases and from the class of oxidoreductases: tyrosinase, laccase and peroxidase. Enzymes degrades cellulose in the fiber wall structure which then initiates wall stripping, generates fine fibrils and leaves the fibers less hydrophilic. Advantages of using enzymes were also emphasized like milder reaction conditions, non-destructive transformations on the surface of polymer, environmentally friendly but needs technological ways for commercial application and thereby it will also be cost effective.

Merdan, N., et.al. (2012) experimented enzyme treatment on Luffa fibers using three different processes and two different chemicals. Luffa cylindrical fibers are lignocellulosic fiber, contains lignin and other wastes which was carried out using cellulase enzyme. The conventional, ultrasonic and microwave method were analysed by various test - % weight loss, SEM and FTIR. Weight loss was around 3-6%, but it was considered an outstanding result with the success of riding the impurities. After the treatment it was observed under SEM that the fiber reveals the macro fibers on the surface in conventional method, while by means of microwave the outer layers of parenchyma cells have been removed to expose the inner fibers. The treated fibers confirms that cellulase enzyme reaction and formyl group reaction were effective. The partial substitution of the -OH groups on the fibers are interesting, since its hydrophilic character were reduced. Thus, the enzyme treated modified the fiber as well as consumption of water, energy and time was reduced.

2.2.2 Sound absorbing materials

Fabric construction/Surface orientation process

Xiang, H., et.al. (2013) investigated relationship between the physical and acoustical characteristics of Kapok fiber for acoustic properties. After examining the fiber properties, they were assembled with different bulk density, thickness, fiber length and orientation to manufacture the fabric and evaluate their acoustical performance. The fabric was compared with commercial glass wool for sound absorption coefficients by employing modified Delany and Bazley's empirical equation. The outcomes of the research were – a) the large and straight hollow structure increases the friction, thereby energy dispersion of the waves takes place, b) the unique fiber structure transfers the vibrations easily, as a result, it converts the acoustical energy into the mechanical energy more efficiently, c) air compression and expansion of the sound waves might occur within the fiber tubes and so the acoustical energy dissipates due to the thermal diffusion, d) the more of entanglements due to random packing of the fibers that increases the possibility for sound waves to dissipate acoustical energy than that of oriented fibers. Thus, the fiber has a potential application in noise reduction as a light and environment-friendly acoustical damping material.

Mundkur, S. (2016), collected used clothes from various sources, which were sorted as per the fiber content and recycled it to create different product. Amongst which sound absorbing materials was one of the products. The recycled fibers were cotton, polyester and viscose rayon which were blended in various proportions to create six different composite nonwoven samples. As the fiber content was different, thickness of samples varied. Thickness, weight per square meter, air permeability, sound absorbing coefficient (SAC) and noise reduction coefficient (NRC) were analyzed. For calculating SAC and NRC the samples were tested using impedance tube using two microphones at a distance and at 21 different frequency levels including - low, medium and high frequency. From the experiment work following points were concluded – a) the nonwoven with higher content of filament fibers like polyester and viscose rayon are the most effective in reducing noise at high frequencies, b) Average NRC value measured at 21 frequencies was not different between 6 samples, c) Nonwovens of 280g/m2 with higher percentage of filament fibers such as polyester and viscose rayon content had higher air permeability and higher sound reduction at higher frequencies, d) for medium frequencies the nonwoven created from recycled T-shirt and polyester dress materials showed higher NRC, while at higher frequencies cotton/polyester T shirts showed best absorbency. Thus, further studies can be done to create more efficient and methods to achieve more uniform nonwovens from discarded materials.

Wool and polyester fiber blended composite fabrics were created and investigated by **Peng L. et. al., (2014)** based on the fact that polyester fibers are widely used as it possesses good sound absorbing characteristics. The chemical process in producing polyester fibers has high impact on environment and they are costly also. Thus, wool fiber as a partial substitute of polyester fiber for sound absorbing composite materials was experimented. The microstructure of the material was analyzed to know the mechanism of the sound absorption using scanning electronic microscopy, further tested with impedance tube method. Sound absorption coefficient increased with the decrease in the airflow. When there were cavities behind the composite material, the sound absorbing peak value moved to lower frequencies. Thus, as the thickness of the cavities increased, sound absorption coefficient increased at low frequency.

Acoustic absorption coefficient of the nonwovens using two different types of micro porous natural fibers – date palm fiber and coconut coir fiber was experimented by **Alrahman, et.al. (2013)**. From the analysis it was determined that both the fibers have potential to replace common synthetic fibrous materials such as glass wool, rock wool and asbestos. The fiber size plays an important role in the acoustic absorption and that was proved by these fibers. Size of date palm fiber is smaller than coconut coir fiber and so the absorption was more by the former one. Secondly, as the thickness of the fabrics increased the absorption increased. Thus, results demonstrated that more strategically designed layers and configurations of natural fibers increases the acoustic absorption.

Jayamani E., and Hamdan S., (2013) studied Sound Absorption coefficients of Natural Fibre Reinforced Composites. Two different set of sample preparation using different techniques of composite manufacturing was experimented. Each set consists of two different kenaf fiber lengths. The results showed unclear effect of fiber length on to the sound absorption, while the thermoplastic (Polypropylene) showed high sound absorption coefficient compared to the thermoset plastic (Urea-formaldehyde). By introducing the composite materials from natural fiber reinforced polymeric materials, the resulting materials showed good potential to be an environmentally friendly product with additional benefits of low cost and light weight compare to glass fiber and mineral based synthetic fiber.

Teli, Adivarekar and Pal., (2004) studied the application of Textile and Polymeric Surfaces for Acoustic Properties. Five different materials polyester, viscose, cotton, thermocol and commercial samples were considered for the experiment and various surface textures were also created. The absorption test was conducted at various distance ranging from 50 to 300 cm and at frequency from 250 – 8000 Hz. Finally, the layers of commercial samples and theromocol sheet had good reduction at 8000 Hz. Thus, nature of the fiber, thickness, number of layers, surface modification, and changes in morphology enhances the effect of sound absorption.

Soltani, P. and Mohammad, Z., (2013) conducted the research on Acoustic Performance of Woven Fabrics in Relation to Structural Parameters and Air Permeability. The sound absorption coefficient of plain weave fabric using polyester yarn was analyzed using Texsonicmeter maintaining airspace of 4 cm at the back of the sample. Also, air permeability at 100Pa was performed to evaluate the porous structure of the fabric. The results for lower sound absorption of the woven fabrics were compared with the nonwoven samples; it was observed that woven fabrics were less appropriate in terms of both technical and economically for certain applications. With additional airspace provided at the back of woven fabrics were more effective for sound absorption. Thus, six layered samples were analyzed for sound absorption including other parameters like pick density, fabric thickness and yarn twist. Hence it was observed that all the mentioned parameters for woven fabrics plays important role in absorption, low twist yarns and higher pick density absorbs sound well and it was confirmed with the lower air permeability of the woven fabrics.

Mankodi H. and Mistry P., (2014) conducted a research on Woven fabrics combination for acoustics of building interior had selected various fabrics like velvet, denim, jacquard, etc. based on the characteristics and method of manufacturing the fabrics from the market. The GSM and thickness of woven and polyester needle punched nonwoven fabrics were analyzed. Also, an experimental setup was created based on Steady State Method as per ASTM E336-71to evaluate the sound reduction of the fabrics. It was concluded that amongst the parameters like nature of the fabric, air permeability, thickness, GSM, distance and level of sound. Air permeability had a negative impact on the sound absorbing capacity. In case of cover fabric i.e. in woven fabrics the sound absorption properties and air permeability depend on the compactness and design of the fabric as well as surface finishes applied on it. The variation of distance was 5 cm to 20 cm from which 20 cm distance gave the best results and one-sided laminated fabric in combination with backing material showed sound reduction between 10 to 15dB.

Acoustic textile: A new era of noise control by **Pal S., et.al. (2015)** discussed various factors such as noise control, method of noise control, sound absorptive materials, mechanism of sound absorption in fibrous materials, factors influencing sound absorption by nonwoven, woven and knitted fabrics and placement and application of sound absorptive materials. Majorly all materials were created using synthetic fibers and future needs were analysed by the researcher. Apart from the testing parameters and various applications of the products, a need for various fabrics manufacturing technique such as woven and knitted fabrics using different fiber type, size, shape and structure was felt. Also, acoustic quality attention was felt for aesthetic look. Hence, an intensive research need was felt for economical fabric having aesthetics.

The sound absorption characteristics of woven materials to be used as carpet and curtains were analyzed in a case study for auditorium restoration. **Ricciardi, P. & Lenti, M. (2010)** studied the acoustic behavior of the auditorium to understand the need and accordingly the materials were developed. The samples were analyzed for sound absorption coefficient using Kundt’s impedance tube method and the results were correlated with the thickness of the material, fiber compositions and layering system.

Results showed that with the increasing thickness the absorption increasing but it was suggested to undergo reverberation test method as the material will be used for the hall and this method will give more accurate effect of the material on acoustical behavior.

Three different paintings on canvas and cotton tapestry art work done by the students was analyzed by **Martellotta F. and Castiglione M., (2011)** for sound absorption coefficient. Cotton canvas of two different GSM was finished by oil painting and embroidery with silkscreen paintings as covering of polyester fiber panel of 5 cm and 10 cm thickness. As well as jute canvas was painting with special fabric colours were used as the cover of polyester fiber panel of 10 cm thickness. All the three painted samples were investigated for sound absorption coefficient at various frequencies from 125 Hz to 4 kHz. The large cotton tapestry of 9m2 was hung straight to a movable frame and tested in reverberation room varying in distance from 5 cm to 100 cm, to know the effect of distance on sound absorption. While, the pores of the canvas were blocked by the paintings and embroidery, but sound could pass through the embroidered sample thus able to absorb sound at low frequencies. The lightweight tapestry gave better absorption simply by changing the distance from the wall. Thus, a proper solution can create an effective sound absorption in the buildings.

A good thermal and sound absorptive material which are non-hazardous, available in large quantities, made up of natural fiber and so eco-friendly i.e. sheep wool panels for room acoustic applications were examined by **Berardi, U., et.al. (2016)**. Two different types of sheep wool – Industrial and raw wool were used to develop tapestries and were mounted at the variable distance (5 cm and 10 cm) from the rigid termination of the impedance tube. Kundt’s method was used for the analyses. Raw wool with 10 cm thickness showed higher absorption coefficients (0.95-0.98 range between 630-2000 Hz) than industrial wool (0.82-0.92 range between 630-2000 Hz), probably due to the more interwoven fibers that allow an increased energy dissipation and thus greater absorption.

Memon, H., et.al. (2015) has compiled the outcomes of various researches related to designing of acoustic home textiles - right from fiber content to the manufacturing process till product installation ways and its impact on acoustic absorption. The process parameters of woven fabrics were one of the objectives, which mentions factors like weave type, fabric density, pile height and pile density that can affect the final acoustical, physical as well as aesthetical properties. The best absorption in each parameter are as follows:

- Amongst the plain, twill, rips and satin woven fabrics the noise reduction coefficient decreased in the respective order. The open structure absorbs less while one sided laminated fabric shows highest absorption.
- Impact of pile density of the tufted carpet has an impact on sound absorption coefficient rather than pile height.
- Other parameters like air permeability, fabric thickness and fabric GSM also has an impact while analysing the acoustical properties.

Further, amongst the three types of backing material – fabric backing (multiple layers), lamination and resistive layer. The analysis depicts that it depends on the installation area as well as frequency of sound. If fabric backing is considered then needle punched nonwoven is the best option, in case of lamination thermo bonded aluminium foil laminated nonwoven is best and an upstream resistive layer (perforated plate) are appropriate to use.

Bendixen, C. (2010) experimented with textiles for to know how sound can be shaped by textile and vice versa. The physics of sound, acoustic properties of the textile and important outcomes of the experiment for architectures and designers were suggested. Textiles can be arranged in many ways as per the need of absorption and area of installation – a) distance of textile from the wall, b) the quantity of textiles in the room, c) the position of the textile in relation to walls, windows, doors, etc. and in relation to the sound source, d) draping and folding of the textiles and e) the number of textile layers. Further some of the rules were also given i.e. an optimal absorption is achieved by placing the textiles min. 50 cm from the wall, the unfold and flat textiles will more efficiently absorb sound, the absorb by textiles also depends on the sound tones and complexity if the sound, while how to achieve shapes depends on the design technique used and how shapes appear depends on the subjective evaluation. The work also focused on the algorithmically derived cuts between the layers, constraints of the lased cutting technique and material properties.

The acoustic performance not only depends on absorption coefficient but also on the textile properties, drapery fullness as well as backing conditions. **Pieren, R., Schaffer, B., et.al. (2018)** experimented draping variation using polyester woven fabrics with and without backing materials. The four different models developed for the experimented were – a) flat curtain in front of rigid wall, b) freely hanging flat curtain (without wall), c) folded curtain in front of a rigid wall, and d) freely hanging folded curtain (without wall). Each fabric consist of three-five different types of yarns with linear mass densities of 24-1200 dtex. The warp and weft densities are 50-65 yarns per cm. The fabrics covered a broad range of light weight textiles.

The models were compared with the existing ones using reverberation method and compared with commercially software's available for sound absorption coefficient. Specific airflow resistance (R_s) and Pieren's proposed method of calculating cut-off frequency (f_c) – a parameter to characterize the effect of vibration of the textile were also determined. While the model absorbs frequency range from 100 Hz to 8 KHz for all fabrics. The other major observations were – a) the woven textiles even the light weight and single layer do absorb sound of certain frequency, b) folded fabrics do reduces interference patterns, thus at high frequencies folding results in somewhat higher values compared to flat curtains, c) changing the configuration of the curtains and increasing the average air cavity has an impact on sound absorption coefficient and d) the reverberation methods performs better than commercial software's and can be a viable alternative to experimentally measured values, which are prone to uncertainties of similar magnitude. Thus, the models are applicable to textile development as well as to room acoustical planning purpose.

Acoustic material which can be as decorative material was developed by **Alcaraz. P., et.al. (2018).** Polyester woven fabrics of 2, 3 and 4-ply plain weave with different ends/cm (15,20,30) and picks/cm (15,30,45) were used to create. The aim was to show how to improve the acoustic characteristics of a simple woven fabric can achieve values near to 1 with an appropriate combination of warp and weft count. Better absorption can be achieved even without any kind of treatment and finishes. For this the acoustic testing was carried out using Impedance tube with two microphone method, additionally airflow resistivity and cover factor was also determined. Single layer of the fabric and with nonwoven backing material with various thickness – 15mm, 30mm and 45mm were considered for the analysis. The results with the increasing density absorption increase due to the reduction in the size and number of pores in the fabric. While the unequal densities in warp and weft causes the formation of slits instead of square shape pores. Amongst these small strips when sound penetrates the vibration takes place especially when the floats are long which converts the energy and thereby absorption takes place. Hence the structural parameter of the textile fabric could improve the sound absorption efficiency.

Testing of materials

Karuppiah, T. & Karuppiah, R. (2017) analyzed five different materials – Jute, Styrofoam, bubble wrap, gypsum and foam of 1 cm thickness for soundproofing. According to their observation the natural fiber in the material: when sound waves collide with the air space, the waves are trapped. Additionally, the rough surface of the jute fiber reflects the sound waves several times thus, weakens it. Bubble wrap diffuses the sound by the lots of bumps caused by the air pockets. Styrofoam has several holes which are slightly uneven and foam has small soft bumps that diffuses and absorbs the sound. A test box of carboard material with dimensions – 22.5 cm height, 30.5 cm length and 21.5 cm width were used and was covered by the materials individually. At all the frequencies (200 to 1500 Hz) jute fiber material showed best results.

The effect of three physical properties of the fibers – thickness, diameter and compressed fiber on the sound absorption coefficient was study by **Zunaidi, N., et.al. (2017).** Based on ISO standard 10534-2 transfer function method, the impedance tube was fabricated and frequency range was 60-1800 Hz. 40 mm and 60 mm thickness of fiber was analysed and it was found that as the thickness increases and diameter reduces the absorption increases. The absorption more is due to the porous structure and more amount of the fiber that will create friction between the sound wave and the fiber thereby decreases the sound wave energy. While in case of compress the porous structure will become smaller and packed, thus contributes to the increase of frictional force and increase in sound absorption coefficient. Comparing the efficiency of both the fiber the kenaf fiber absorbs than rice straw fiber. Thus, fiber size and diameter directly affects the sound absorption coefficient of the material.

Nonwoven fabric was developed using different bread of sheep wool (33-36µm) and PET (33 µm) fibers under the study by **Rey R., Uris A., et al. (2017)** with an aim to make efficient sustainable material for acoustic applications. Seven sheep wool samples having different compositions and densities were studied. The blended fabrics having 80 per cent sheep wool and 20 per cent PET fiber were analyzed for airflow resistance and sound absorption coefficient using different measurements – Impedance tube, reverberation chamber and empirical model. Airflow resistance analysis of the samples showed little variance between all the samples, as there was minute difference in the density and diameter of all the fibers. An empirical model by Delany-Bazley for calculating coefficient statistically revealed that the samples absorbed good amount of sound. Hence, all the samples absorbed sound at mid and high frequencies depending upon the thickness of the material.

Tiuc, A., Vermesan, H., Gabor, T. & Vasile, O. (2015) tested the samples of polyurethane mixed with textile waste for sound absorption using two-microphone (transfer function method) of ISO 10534-2, an international standard for testing sensitive materials. To measure acoustic parameters for frequency range of 100 to 3200 Hz, Brüel & Kjaer kit of type 4206 was used as an impedance tube. Two microphones of 4187 Brüel & Kjaer, to generate acoustic signal one analyser PULSE 3560-B-030, an amplifier of 2716 Brüel & Kjaer and a PC for entire process and recoding was connected to Brüel & Kjaer PULSE interface. And further the Noise Reduction Coefficient values were calculated of all the samples.

Berardi, U. & Iannace, G. (2015) performed sound absorption measurements using Impedance tube method (ISO 10534-2). The Kundt's tube method with 10 cm as internal diameter for the higher frequency of 2000 Hz, length of 56 cm which was mounted with two ¼" microphones initially at 5 cm (for measuring 250 Hz and above) and later at 10cm distance (for below 250 Hz). The testing was carried out at 125, 250, 500, 1000, 2000 and 4000 Hz and calculated NRC values to identify the best acoustic material. The sample thickness was ranging from 0.03 – 0.10 mm. Density, thickness and airflow resistance test was also conducted. The highest NRC value was noted in sheep wool (0.55) and coconut (0.45), followed by Kenaf (0.45), cardboard (0.40), cane (0.25), Hemp (0.25) and wood (0.25). Further it was recommended that comparisons among different sound absorbing materials will be based using functional unit the material mass that allows a given sound absorption effect, as it could represented by the absorption based on the synthetic NRC values.

Sandoshkarthika, N., Muthukumar, N. & Thilagavathi, G. (2015), explains about the sound wave and absorption mechanism. It is said that Impedance tube method is the faster and reproducible test method. This method determines normal incident sound, normal specific acoustic impedance ratios as well as absorption coefficient of all the nonwoven samples. The data can be derived using smaller size samples of 35 or

100mm diameter (as per the dimensions of tube for the testing). At one end the loudspeaker was attached and at the other end test samples was mounted. Random sound waves generated from loudspeaker when hits to the samples as plane wave, partially it is absorbed and partially reflected. For testing frequency range of 100 Hz-5000 Hz a single tube with fixed microphone spacing was used to measure and plotted the results on graphs showing absorption coefficient of sample at various frequencies.

Izhar, T., et.al. (2014) focused on the sound reduction wall surface material rather than available techniques and used natural fibers like coconut coir fiber, rice husk and sawdust to develop indoor panels. Six combination were prepared using the fibers and two different binders i.e polyester resin with hardening catalyst and cement with sand. The testing parameters used to determine NRC and sound transmission are the frequency, speaker intensity and the distance from the speaker. The samples were tested at various distance – 50 cm, 100 cm, 120 cm, 170 cm and 220 cm and with various combination of frequency and intensity. It was found that NRC increases with increasing of the sample distance from speaker and frequency and speaker intensity.

An estimation of nonwoven fabrics for sound absorption properties with rigid wall was tested **Alrahman, et.al. (2013)**. An experimental setup was developed to identify acoustic absorption and impedance measurements using two-microphone transfer method based was ISO 10534-2 and ASTM E1050-98. The impedance tube was made of two steel tubes of 100mm and 28mm diameter for high frequency. The ¼” microphone was calibrated and was performed with a noise generator and using loudspeaker. The sample was mounted onto the holder and SCS 8100 software was used to record the data. The acoustic coefficient range between 0-1 which represents the amount of sound energy absorbed by the material.

One microphone impedance tube was fabricated by **Mistry, P. (2013)** using an acrylic box for creating an enclosed environment. The standard setup was prepared based on ASTM E33671. On the one side the source was fixed and at another end the receiver was fixed. 50 cm x 10 cm x 14 cm were the dimensions of the box wherein the sample was mounted between the wooden holders. For mounting and adjusting the distance the top lid was kept as adjustable box. While, for sound reduction measurement of the fabric, the Steady State Method of ASTM E336 71 was followed. Wherein initially the testing was conducted without the sample to identify the sound level and after that with sample to calculate sound reduction. The sound reduction testing variables were difference between the sound source and fabric and sound receiver and fabric of all fabric as single layer and with combination of layers.

Veerakumar, A. & Selvakumar, N. (2012) developed the nonwoven materials using kapok and polypropylene. Sound absorbing testing was conducted using movable microphone impedance tube test and its effectives was supported by fabric thickness and porosity. SAC and NRC values were calculated of both the uncompressed and compressed composites with and without air at frequency ranging from 250 Hz to 2000 Hz. The uncomposed nonwoven composite of 30:70 blend ratio having bulk density, low porosity and air space gave better absorption. It might be because of the tortuosity and the air space which converted the sound wave into the heat energy, thus less of sound transferred and reflected.

Lefebvre, A., Scavone, G., Abel, J and Smith, A. (2007) had conducted a comparative analyses of testing technique using impedance method with two microphone and one microphone and developed a setup. The former technique i.e. Two-Microphone Transfer Function Technique (TMTF), having compact apparatus can measure high frequency sound level. The wave travelling within the instrument will be measured by the two microphones, for which calibration of the microphones was essential to have accurate data. While, in another method i.e. Time-Delay Spectrometry (TDS) only one microphone was used at the opposite end of the loudspeaker. This method is simpler, less time consuming and no calibration of microphone needed but a long tube is must to fix the microphone at the center. A major drawback it reduces the measurement efficiency with the increase in distance. Finally, a setup based on TDS method was developed for the testing.

According to a study by **Parikh, D., Chen, Y., and Sun, L. (2006)** had experimented for floor covering system of automobiles. Natural fibers which are itself noise absorbing materials, are renewable and biodegradable were converted into nonwovens using needle punch technique. Also, blended with polypropylene and polyester and underpad coverings were made out of re-bonded polyurethane foam or soft cotton. All the natural fiber-based floor coverings individually and with combination of underpad were evaluated by ASTM E-1050 in the frequency range of 100 to 3200 Hz. As a result, all the natural fiber-based nonwovens gave good reduction coefficients and the most reduction was observed with kenaf and polyurethane pad at 3.2 KHz were – 1.0, compare to soft cotton underpad i.e. 0.81. The floor covering system thickness ranged between 8 to 10 mm including the cotton underpad, but due to less density (998g/m2) little difference was observed in comparison to polyurethane underpad. Hence, floor covering system with natural fiber nonwovens and rebounded polyurethane provided better noise absorption as well as reduced overall sound level and can be utilized for quiet passenger compartments.

Teli, M., Roy, D. & Karthikeyan, N. (2006) had developed composites using non-conventional fibers and epoxy resin. Five samples of each different fiber (jute, banana, sisal and ramie) using fiber length of 3, 6 and 9mm was converted into composites. The thickness, density and air permeability tests along with sound absorption were conducted. A tube setup with the facility of variation of angle of incidence was used, frequency range for testing was 1000 Hz to 8000 Hz and mean sound absorption was calculated. Air permeability should be moderate, not too high or low for best sound absorption. While shorter the fiber length lower will be the total sphere of influence of the vibrating nuclei and the epoxy resin matrix that efficiently dissipate sound energy. Thus, the nature of the fiber, thickness of the composite, density, air permeability, fiber length and frequency of the sound wave all has its impact on the absorption coefficient. While based on the efficiency of the fiber reinforced composite as a sound absorber showed highest in jute followed by ramie, banana and sisal.

Hence, from the literature it was concluded that majorly synthetic fibers, nonwoven or composite materials and hazardous processing technique has been explored and are used currently. Thicker and bulky layered sound absorbing products are available and are manufactured using hazardous process. Due to the changes in eco-system, the trend is moving towards the utilization of natural fibers. Need of eco-friendly and aesthetically appealing fabrics are in demand. Thus, there is a scope of exploring and increase the utilization of minor natural fibers. Amongst these fibers few has inherent properties which can absorb sound. The sustainable conversion process of fiber to fabric can bring the newer range of products in the market. Also, with the exploration of fabric manufacturing techniques aesthetics can be incorporated along with sound absorption properties. Further, more exploration with these fibers can provide additional benefits like flame retardancy, anti-microbial, moisture resistant, etc. Hence, the research is focused on developing woven sound resistant fabrics using minor fiber for interiors.