Acoustical Absorptive Properties of Cotton, Polylactic Acid Batts and Fabrics

W.O Ogunbowale
Chemistry Department
Federal University of Technology
Minna – Nigeria.

P. Banks-lee
College of Textiles, North Carolina State University
Raleigh – U.S.A.

K.A Bello
Dept. of Textile Science and Techn.
Ahmadu Bello University
Zaria - Nigeria

S.Maiwada
Dept. of Industrial Design
Ahmadu Bello University
Zaria – Nigeria.

E.G.Kolawole
Dept. of Textile Science and Techn.
Ahmadu Bello University
Zaria - Nigeria

Abstract

This study investigated the absorptive properties of nonwoven cotton and Polylactic acid batts and fabrics. Fibrous nonwoven materials convert sound that passes through them to heat energy. The nonwoven samples used in this study were made from 100 percent cotton and 100 percent polylactic acid fibers, which are all natural fibers that are degradable and are environmentally friendly. The method used for measuring the acoustical properties of the batts and fabrics used in this research is the impedance tube method, whereby; sound absorption coefficient is determined at each frequency in accordance with the ASTM 1050 - 08 standards. The results of this study shows that physical elements such as; fibre type, fibre size, layering order, fibre cross section, material thickness, density, airflow resistance and porosity are important factors in determining the absorption behavior of nonwovens materials. The results of the acoustical data show that eight (8) layers cotton batts absorbs better than cotton fabric and Polylactic acid batts and fabric. It is recommended that these fibres (cotton and PLA) which are environmentally friendly and cost effective be adopted as good alternatives to petroleum based fibres which are currently in use since they are effective sound insulator.

Introduction

In the present age, noise is an ever-increasing problem everywhere in the world, especially in the developing countries where the Government regulation is not been enforced against public disturbance, sources of noise are now on the increase and they are steadily growing louder. Noise pollution was once termed an irritating but harmless nuisance but it has now become a major threat to health and well-being. Noise is public nuisances which causes undue distractions, contributes to health problems, stress and eventually lower productivity.

This explains why most people love quiet environment and are willing to pay for it. In places such as homes, hospitals, concert halls, schools and learning environment where one expects to be quiet are not exempted from noise pollution in some places. Sound is a physical disturbance in a medium (in a gas, liquid, or solid) that is capable of being detected by the human ear. It is a series of longitudinal or compression waves that move through air or other materials which must have mass and elasticity. It is a mechanical vibration that travels through matter as a waveform. Sound does not travel in a vacuum or in outer space (Harris C.M., 1991). Sound is a mechanical energy; which will always find the path of least resistance from the source to the outside world.

Stacy (1959) defined sound absorption as a measure of the propagation of sound energy falling on a surface and is not reflected, and it is expressed as a coefficient or percentage of the incident energy; which could be 0.5 or 50 percent absorbency. Noise absorbing material absorb unwanted sound by dissipating sound wave energy when it pass through, and also convert some of the energy into heat. Absorption coefficient is the amount of the original energy less the remaining unabsorbed energy.

Sound proofing and acoustic materials are used to attenuate, deaden, or control sound and noise levels from machinery and other sources for environmental amelioration and regulatory compliance. Sound absorptive or acoustic materials can be either noise reduction or noise absorption. A noise absorption material suppresses echoes, resonance reverberation and reflection, while a noise reduction reduces the energy of sound waves as they pass through. Important specifications for noise reduction and noise absorption products include noise attenuation and noise reduction coefficient. Noise attenuation is the reduction in sound pressure level (SPL) that an acoustic product provides. It is measured in decibels (dB). Noise reduction coefficient (NRC) is the average of an acoustic material's absorption coefficients at a specified set of frequencies, typically 250 Hz, 512Hz, 1024 Hz and 2048 Hz in accordance with the type of tube and acoustic measuring instrument use for tests. Absorption coefficients range between 0 and 1 and are often evaluated at many frequencies in the audible range in order to create a performance curve for the material throughout the audio spectrum.

One of the most important design issues today for the building and automotive industries is sound insulation. Textile materials are effective in converting the mechanical motion of the air particles in sound waves into low-grade heat. Almost all materials have some kind of acoustical property. However, materials that absorb a majority of the sound impinging upon them rather than reflecting the sound are termed "acoustical material". Sound absorbing materials are attracting much attention as a solution to the ambient noise impact on people's lives and they are performing greatly (Allampalayam K., 2005). Nonwoven fabrics have been in use as acoustic absorptive materials and are still in use for acoustic ceilings in vehicles, wall claddings and acoustic barriers in buildings. Although, the conventional fibers mostly used are glass-fibers and polyurethane foams which are neither biodegradable nor recyclable. Nonwoven fabrics are ideal materials for use as acoustical insulation products because they have high total surface.

Eneh , (2010); sited a remarkable example with the case of the University of Lagos, Akoka Theatre, Lagos, Nigeria, where acoustical textile materials were used to divide multiple classrooms at the Department of Architecture to provided sound-proof environments, even when lectures go on at adjacent rooms simultaneously.

The purpose of this study is to establish the effectiveness of cotton and Polylatic acid (PLA) nonwoven batts and fabrics in absorbing sound. In this study; multilayered batts were compared to single layers, batts were also compared to needle-punched fabric.

Materials and Methods

The experiment was designed to produce both PLA and Cotton batts and fabrics. It also carried out various investigations to characterize the fibres used before they were processed into batts and fabrics. The batts and fabrics were also tested in-order to establish their characteristics.

Seventeen (17) fabric samples were produced for use in this study. Six (6) fabric samples were assembled with single fibre type and eleven (11) fabric samples were assembled by varying the order of assembling layers of PLA and cotton batts. Three (3) out of the (11) samples have the front surfaces assembled with different fibre type from the back surface. Two fabric samples were produced using the needlepunch technology each with 12mm needle penetration. A total of 13samples were made by assembling eight (4) layers of 200 g/m^2 batts together using 15mm depth tacking with 2 boards top and bottom having 4 needle in a square centimeter on a Truetzschler Tuft Feeder Scanfeed machine.

Web Formation

Polylactic Acid fibers and Ultra-clean Cotton fibers were converted into three-dimensional fibrous structure batts and Nonwoven fabrics with the Truetzschler Tuft Feeder Scanfeed Machine at the Short Staple Fiber Laboratory of the North Carolina State University, Raleigh United States. These major operation set-up parameters used are Opening, Roller Top Card, Crosslapper and preneedling.

Web Bonding

The mechanical method of bonding; which is tacking and needle-punch were used to impact sufficient frictional force to the web.

Procedure

The bale was opened and mixed using a Fine Opener 2; and transport Fan 2. The Doffer was set for 23.8 meters per minute; the workers were set for 15, 12 and 10 RPM; the cylinder was set for 224 RPM; while the feed roll was 4.1 RPM, and the main convey was set to run for 24 meters per minute. With the above specifications, samples of 100% cotton batts of 100 grams per square meter (g/m^2) were produced along side with 100% PLA batts of 100 grams per square meter (g/m^2). The batts were tacked together on the scanfeed needle-punch machine in the following layering arrangement, which resulted into an assembly 800g/m^2 batts respectively.

Table1. Layering Arrangement of Samples

50/50 COTTON/PLA

SAMPLE (1)	SAMPLE (2)	SAMPLE (3)	SAMPLE (4)	SAMPLE (5)
PLA	PLA	COTTON	PLA	COTTON
PLA	PLA	PLA	PLA	COTTON
PLA	COTTON	COTTON	COTTON	PLA
PLA	COTTON	PLA	COTTON	PLA
COTTON	PLA	COTTON	COTTON	PLA
COTTON	PLA	PLA	COTTON	PLA
COTTON	COTTON	COTTON	PLA	COTTON
COTTON	COTTON	PLA	PLA	COTTON

75/25 PLA/COTTON

SAMPLE (6)	SAMPLE (7)	SAMPLE (8)
PLA	COTTON	PLA
PLA	PLA	PLA
PLA	PLA	COTTON
COTTON	PLA	PLA
COTTON	PLA	PLA
PLA	PLA	COTTON
PLA	PLA	PLA
PLA	COTTON	PLA

75/25 COTTON/PLA

SAMPLE (9)	SAMPLE (10)	SAMPLE (11)
COTTON	PLA	COTTON
COTTON	COTTON	COTTON
COTTON	COTTON	PLA
PLA	COTTON	COTTON
PLA	COTTON	COTTON
COTTON	COTTON	PLA
COTTON	COTTON	COTTON
COTTON	PLA	COTTON

100g/m^2 EACH LAYER.
PLA 100g/m^2 X (2) = **SAMPLE 12**
COTTON 100g/m^2 X (2) = **SAMPLE 13**
NEEDLE-PUNCH COTTON FABRIC = SAMPLE **14**
PLA 100g/m^2 X (8) LAYERS BATT = **SAMPLE 15**
COTTON 100g/m^2 X (8) LAYERS BATT= **SAMPLE 16**
NEEDLE-PUNCH PLA FABRIC = **SAMPLE 17**

75% PLA / 25% COTTON Layering Arrangements:
SAMPLE 6 = three layers PLA 100g/m^2 tacked to two layers COTTON 100g/m^2 and tacked to other three layers PLA 100g/m^2
SAMPLE 7 = one COTTON of 100g/m^2 tacked to six layers PLA 100g/m^2 and tacked to another layer of 100g/m^2 COTTON.
SAMPLE 8 = two layers PLA tacked to a layer COTTON and tacked to two layers PLA and to a layer COTTON and two layer PLA

25% PLA / 75% COTTON Layering Arrangements:
SAMPLE 9 = three layers COTTON 100g/m^2 tacked to two layers PLA 100g/m^2 and tacked to other three layers COTTON
SAMPLE 10 = two layers PLA tacked to a layer COTTON and tacked to two layers PLA and to a layer COTTON and two layer PLA
SAMPLE 11 = two layers COTTON tacked to a layer PLA and to two layers of COTTON and to a layer of PLA and to two layers COTTON of 100g/m^2 each.

(100)% PLA and COTTON (100) %
SAMPLE 12 = PLA of 100g/m^2 tacked to another layer of PLA of 100g/m^2
SAMPLE 13 = COTTON layer of 100g/m^2 tacked to another layer of COTTON of 100g/m^2
SAMPLE 14 = NEEDLE-PUNCH COTTTON FABRIC
SAMPLE 15 = 8 layers of PLA batts 100g/m^2
SAMPLE 16 = 8 layers of COTTON batts 100g/m^2
SAMPLE 17 = NEEDLE-PUNCH PLA FABR
KEY TO TABLE 1:
50% PLA / 50% COTTON Layering Arrangements:
SAMPLE 1 = four layers PLA 100g/m^2 tacked to four layers COTTON 100g/m^2
SAMPLE 2 = four layers COTTON 100g/m^2 tacked to four layers PLA 100g/m^2
SAMPLE 3 = one layer COTTON 100g/m^2 tacked to one layer PLA 100g/m^2 four times.
SAMPLE 4 = two layers PLA 100g/m^2 tacked to four layers COTTON 100g/m^2 and tacked to other two layers PLA 100g/m^2
SAMPLE 5 = two layers Cotton 100g/m^2 tacked to four layers PLA 100g/m^2 and tacked to other two layers COTTON 100g/m^2

After the batts were produced, the above layering orders were used in tacking them together on the scanfeed needle-punch machine. This was done in-order to achieve the desired effect of having cotton/polylactic sandwich; which resulted into an assembly 800g/m^2 batts

Sound Absorption Test

The acoustical properties of fabrics and webs were measured using the impedance tube method (ASTM E 1050-08 Standard Test Method for Impedance and Absorption of Acoustical Materials; using a tube, Two Microphones and A Digital Frequency Analysis. In this method; broadband signal from a noise source plane waves are generated in the tube. A stationary sound wave pattern is formed in the tube. This sound wave pattern includes the incident sound and the fraction of the sound that has been reflected back and not absorbed by the specimen.

The small test sample that gives fast and accurate measurements of frequency range from: 500Hz – 6.4 kHz, and other parameters such as; sound absorption coefficient, reflection coefficient, acoustic impedance, acoustic admittance and transmission loss coefficient was used.

Normal-incidence sound absorption coefficient (NAC) was measured according to ASTM E 1050-08 Standard Test Method for Impedance and Absorption of Acoustical Materials; using a tube, Two Microphones and A Digital Frequency Analysis.

The samples for acoustic tests were prepared by using a 29 mm diameter circle die punch to cut all samples to 29mm diameter, which fits the small sample tube used for the test. Five specimens were cut from each sample in accordance with the test standard.

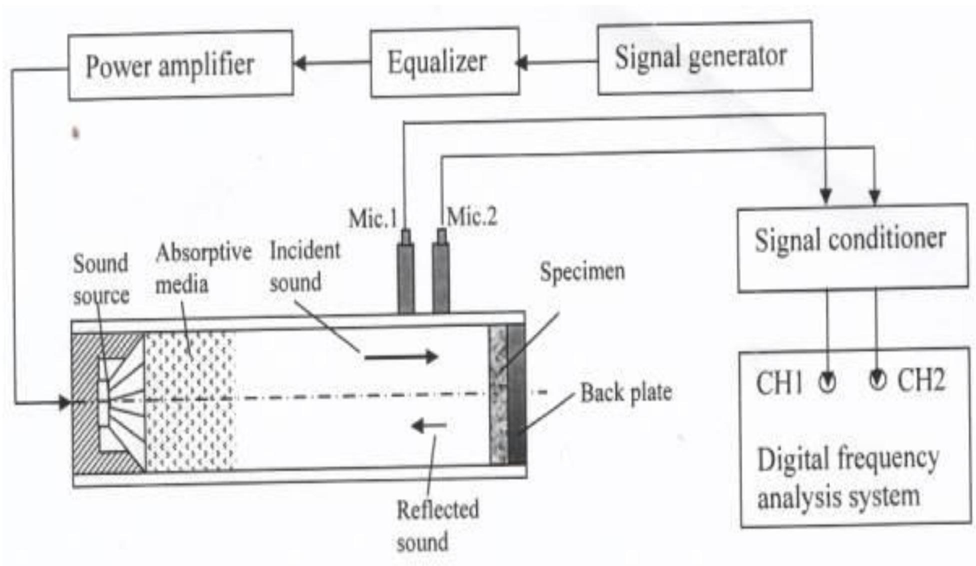

Fig. 1: Schematic diagram of acoustical material testing system. This is adapted from ASTM E 1050-08 and Bruel & Kjaer, (2009

Fig. 2: Bruel & Kjaer two-microphone impedance tube type 4206 (Bruel & Kjaer 2009), used for this experiement.

The impedance tube is a hollow cylinder with a sound source at one end and a test sample holder at the other. Microphone ports are mounted at two locations along the wall of the tube as shown in Figs. 1 and 2 above. For data acquisition and processing, a two-channel digital frequency analysis system is used. The signal processing equipment includes two matched microphones, two identical analog signal conditioners and a two-channel Fast Fourier Transform (FFT) analyzer. An individual channel of the analyzer is connected to the signal from each microphone system. A desktop computer is used for determining the acoustic absorption coefficient from the measured transfer function data (ASTM E 1050-80).

Normal Incidence Sound Absorption Coefficient

The effectiveness of the samples in absorbing sound energy was investigated; beginning with single-fibre web and fabric materials, followed by the investigation on the effect of layer sequencing of web. The Digital Frequency Analysis of the two-microphone transfer-function presented each specimen's result by frequency range. The frequency ranges from 500Hz – 6.4 kHz, and results for parameters such as; sound absorption coefficient, reflection coefficient, acoustic impedance, acoustic admittance and transmission loss coefficient were displayed.
Five specimens were tested from each sample batt and fabrics, for each frequency range, the summation of the data generated were averaged. The average data sets were imported into the SAS statistical data analysis software for processing and analysis.

Procedures of Processing Data Acquired:

The Statistical Analysis System; SAS was used to analyse the data acquired from the different tests conducted. Many models were developed in order to ascertain the model that would give the best result when used.

The general linear models (GLM Procedure); Duncan's Multiple Range Test and t-test (LSD); and the ANOVA were all test before adopting general linear, the Pearson Correlation Coefficients and the backward regression models, this decision is as a result of the unequal replication of test carried out. Statistical test results and the graph curves were also used to determine and compare the effectiveness of the materials in absorbing sound.
As NAC values of each specimen were measured repeatedly at different sound frequencies, a repeated-measures model has been adopted. Repeated measures methodology is mostly used in the area of human psychology (Littell, 2006). Each specimen has been taken as a subject, which is measured repeatedly for different frequencies. The covariance structure was assumed a heterogeneous symmetry compound. Mixed model is used because it is a procedure widely used for longitudinal data analyses; whereby repeated measurements are analysed in agreement with (Liu et al., 2007).

Results and Discussion

Sound absorption (*α)*, ranges from zero (0) (i.e. no absorption) to one (1) (total absorption), R-square values which are closest to one (1) are taken as excellent absorption. Results show that the R-square values of all parameters having great influence on the sound absorption ability of the samples gave resultant value closer to one (1).

Also the general linear model (GLM) was used to determine the batts and fabric which absorbs best in order of efficiency.

A total of 20 samples were evaluated for each of the eleven frequency range used. Five specimens were tested from each sample at all the frequency ranges tests were imported into the statistical analysis software (SAS). The general linear model (GLM) was adopted for the analysis.

In this model absorption is the dependent variable and the total number of observations read for cotton was 1100, with the results of 0.984 (R-Square), 9.695 (Coefficient Variance) and (Absorption mean) 0.790 values.

The R-Square value of 0.983 at this level is considered good for experimental textile data, since there is a relative variability in the raw materials used. Moreover; complete absorption is one (1) for normal incidence sound absorption coefficient in acoustic material. Therefore, an R-square value of 0.984 is an excellent absorption, so it could be concluded that the material tested performed excellently in absorbing sound.

Weight of batts and fabrics were normalized for the purpose of analysis; samples were assumed to be of equal thickness and weight for a fair comparison in acoustic characterization.

Seventeen (17) samples used with the addition of 3-flips; (i.e samples having one side of it surface different from the other) as a result of layering arrangements; making a total of twenty (20) samples. Data sets acquired from test was processed for analysis in the order of the highest to the least in sound absorption and in interaction with other variable of great influence on absorption.

The results show that polylactic acid fibre is a good absorber when in composite with cotton. It is interesting to note that cotton always display greater strength once it is placed in the front close to the microphone the percentage notwithstanding. In comparison, polylactic acid fibre batts layered with 25%, 50% and 75% cotton all performed better than 100% polylactic acid batts. The fine diameters of cotton, its convolution and spiral shape provides a good surface area and propagation towards sound waves.

The first sample on the table is sample (16) which is cotton batts of $800g/m^2$. The sample exhibited an excellent absorption capacity of 0.790 dB and the variable with great influence is porosity which is 0.952. Porosity is the amount, size and types of voids in the sample which in turn dictates the air-flow resistivity of the sample. The amount, size and type of pores in a porous material are a function of the fibre size and type. Pores are important factors in sound absorption mechanism. For sound dissipation by friction, sound wave has to enter the porous material.

Fibre interlocking in nonwovens is the frictional elements that provide resistance to acoustic wave motion and it greatly depends on fibre size. When sound enters the material, its amplitude is decreased by friction as the waves try to move through the tortuous passages and as a result, the acoustic energy is converted into heat.

It could be observed from the results that sample no. 16 which is cotton batts, absorb sound better than needle-punched cotton fabrics. It is also observed that cotton batts and fabric absorb sound better than ploylactic acid batts and fabric. cotton batts exhibited the absorption mean is 0.790; whereas PLA batts exhibited absorption value of 0.489 which placed it on level (12) in the sample level of absorption where cotton batts is placed on level one (1) . Although polylactic acid batts exhibited good absorption in 50 - 50 layering sequence with cotton as demonstrated by samples 1a, 5, and 3a.

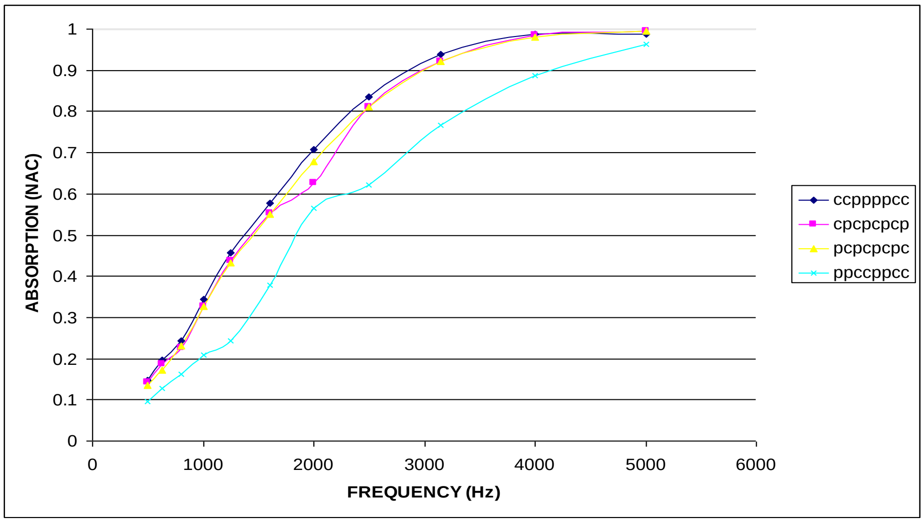

Fig. 3 Comparing 50% Cotton and 50% PLA layering order: A flip of front and back of samples 2 and 3 batt.

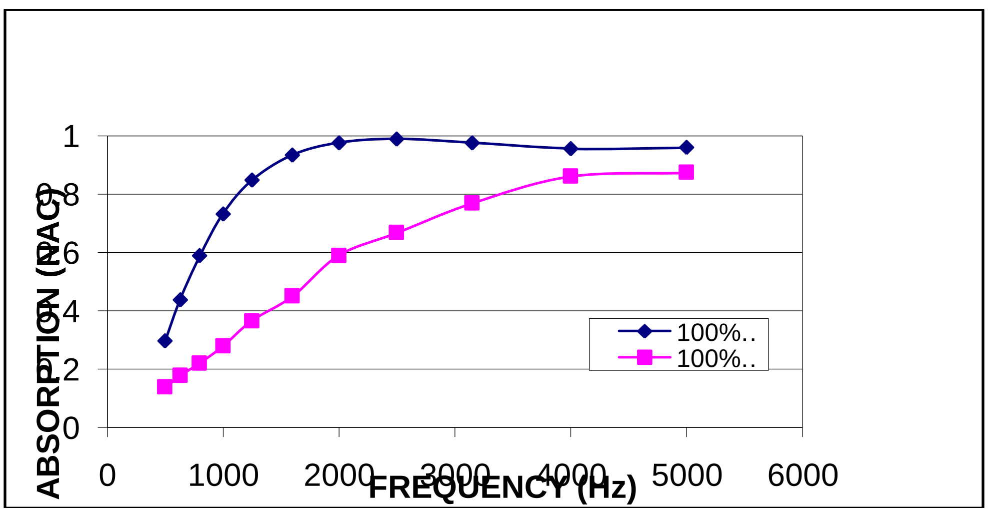

Fig. 4: Comparing NAC curve of (8) layers 100% Cotton and (8) layers 100% PLA Batt.

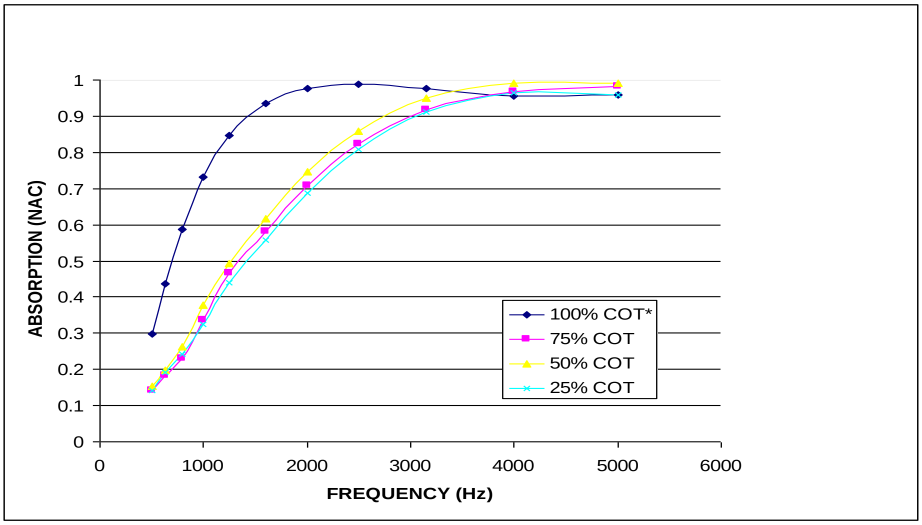

Fig. 5: NAC curves Comparing the level of absorption of Cotton/PLA batt at 100%, 75%, 50% and 25% respectively.

It is observed in NAC curve in fig. 3 that in layering arrangements where the interface is less, sound wave can flow easily at a relatively constant frequency as the case is with the first two samples plotted on the graph which are samples 3.1 and 3.2 respectively. But with the third sample with a double layer of PLA facing the microphone, sound would propagate at lower frequency, since the wave length is longer and higher therefore; thickness rather than fibre size is the determining factor at this level. But where there is an interface, there is a change in sound absorption especially in the region of mid and high frequency. It can be seen that there was an easy propagation at lower frequency and at 2000Hz absorption rose to 5.8 owing to double layer of cotton (25%) interface before the next double layer of PLA (25%) interface.

Conclusion

The R-square value obtained from the model used which is (0.856) is a level considered to be good values for experimental textile data, where there is relatively large variability in the raw materials.

In conclusion results from the evaluations carried out on the acoustical properties of cotton and polylactic acid fibre webs and fabrics have established that the materials are effective because the fibres used are good in absorbing sound.

Interestingly, it was discovered that an appreciable increase in normal absorption coefficient, NAC, values were obtained by using the impedance material in web form instead of bonding. Therefore; it can be concluded that this research has succeeded not only in introducing new acoustic materials, but in establishing that webs could be used behind panels or in places where finishing is not required. Needle-punched samples absorbed sound energy, nevertheless; webs performed 2.5 times better. Moreover, the innovative aspect of these materials from the natural source is their light weight coupled with low cost which is a great asset to the automotive and aircraft industry, since automobile production is now focused on a drastic weight reduction to cut down on energy consumption.

It was observed that multi-layer absorbers achieve higher sound absorption than the mono-layer absorbers with the same thickness. Layers of nonwoven made from the two fibre types used were varied in order of arrangements and the effect of positioning to the microphone was evaluated.

References

American Society for Testing and Materials, ASTM E 1050-08 Standard Test Method for Impedance and Absorption of Acoustical Materials using a Tube, Two Microphones and a Digital Frequency Analysis System, 2008.

American Society for Testing and Materials, ASTM C 522-03 Standard Test Method for Airflow Resistance of Acoustical Materials, 2008.

American Society for Testing and Materials, ASTM C 634-08 Standard Terminology Relating to Building and Environmental Acoustics, 2008.

Eneh A.E.O., (2010); the relevance of industrial design to the building industry; a paper presented at the conference of 3rd decade of industrial design education in Nigeria.

Harris C.M , (1991); Handbook of Acoustic measurement and Noise control (R.R. Donnelly and Sons Company) U.S.A.

Stacy E.F, 1959 Sound Insulation in Buildings. Building Research Station, Department of Scientific and Industrial Research (The Journal of Royal Society for the Promotion of Health; 78; 789

INDA, (2008). (Association of the nonwoven fabrics industry), "about nonwovens,"

Bies D.A and Hansen C.H ; (1996), Engineering Noise Control Theory and Practice, 3rd Edition, London; New York: Spon Press.

Jayaraman, K. A. Banks-Lee, P. and Jones, M. (2005) in Joint INDA-TAPPI Conference - INTC: *International Nonwovens Technical Conference* 403-411. *Proceedings* (Association of Nonwoven Fabrics Industry, St. Louis, MO., 2005)

Littell R. C. (2006) SAS for Mixed Models, 2nd ed (SAS Institute, Cary, N.C.). pp. 814

Lee, F. C. and Chen, W. H. (2004). "On the acoustic absorption of multi-layer absorbers with different inner structures*." J. Sound Vib. 259 (4), 761-777".*