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Adhesive Bonded Nonwovens from Mattress Foam and Cotton Fabric Waste for Sound Absorption

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Abstract: Textile composite mills generate waste during the production process and amongst this waste, fabric waste is most common. Hence recycling was carried out to convert the saleable fabric waste to useable value-added products and also to avoid environmental pollution. To reduce the noise level and to improve the sound absorbency, a three-layer sound absorbing material was produced in this research, by using PVA (polyvinyl acetate) treated base fabric, non-woven material in the middle with combination of cotton fabric waste and mattress foam and top fabric treated with fire retardant finish. Thirteen different nonwoven product combinations are prepared with different proportions of cotton fabric waste and mattress foam percentages by using Box Behnken experimental design. Properties such as thickness, areal density, air permeability and thermal conductivity and their relation with sound absorbent coefficient at different frequency ranges are measured using standard methods. The increase in thickness results in increase in sound absorption properties of non-woven product. The sample comprising of 79% mattress foam and 21% cotton fabric waste with 45mm thickness resulted in the optimum sound absorption coefficient in the mid-to-high frequency ranges. In order to improve the performance of non-woven product, the base fabric was treated with PVA and top fabric with fire retardant finish. The properties like tensile strength, water repellency, air permeability, extensibility, fabric stiffness was also tested for base fabric and it was found that 75% PVA treated base fabric gives good results and is more suitable for acoustic purposes.

Keywords: Sound Absorption Coefficient, Mattress Foam, Fabric Waste, Fabric Thickness

1. Introduction

The classical solution to the problem has been the elimination of noise at source. But usually it is impossible to treat most of the noise problems this way. Therefore, the reduction of noise emission is usually accomplished by noise isolation methods [1].

In audio record work, the audio recorder spends their time in a single room and the sound is easily reflected inside in the enclosed space so that a noise appears to be repeated and the quality of recorded sound is low. On the other side the reflected sound will result in health hazard to the recorder impairing hearing and heart problems. To make better sound quality it is mandatory to give acoustic treatment and mostly nonwoven fabrics manufactured by needle punching, stitch bonding and adhesive bonding techniques proves to be an ideal acoustic solution due to their high volume-to-mass ratio.

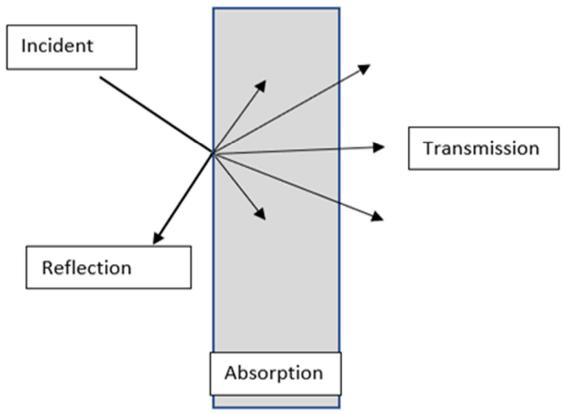

Figure 1. *Schematic of sound absorption process for porous materials.*

Leitao et al. (2018) has tried in his research to treat the sound inside the room in porous material under the principle of absorption, reflection and transmission of sound [2]. The above figure 1, the reasons for the acoustic energy loss when sound is passed through sound absorbing materials are due to: Fractional losses owing to sound pressure, air molecules oscillate in the interstices of the porous materials with the frequency of the exciting sound wave, this oscillation results in frictional losses. The other reason being momentum losses in the flow direction of sound waves, together with expansion and contraction phenomenon of flow through irregular pores, resulting in temperature fluctuation owing to exciting of sound. Sound vibrations travel through air or water and can be heard when they reach a human for the human ear, the hearing range starts about 16 Hz to 20000Hz and the sensitive range is within 1000 – 3000 Hz.

Sound absorption is measured as sound absorption coefficient alpha (α), which has a value between 0 and 1.00. Zero represents no absorption (total reflection), and 1.00 represents total absorption of the incident sound. To enable comparison between acoustic materials, it was classed on a scale from A to E, with A-rated products having the highest rated sound absorption performance. First, a material is tested to obtain absorption coefficient values over a range of standard test frequencies, according to BS EN ISO 354. These are then plotted on a graph to produce an absorption curve. The sound absorption class is attained by comparing these values against a reference curve, resulting in an A weighted sound absorption coefficient (αw) calculated in accordance with BS EN ISO 11654.

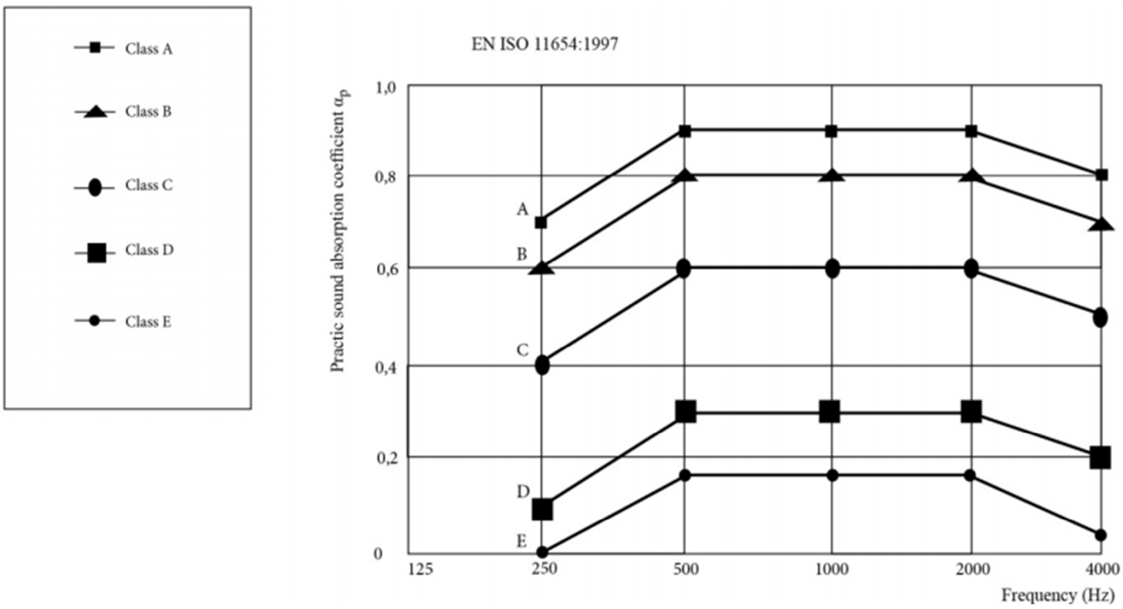

Figure 1. *Reference curves limiting with different sound absorption classes[3]*

The following table 1 describes the sound absorption coefficient class with their rated sound absorption coefficient (αw) and its explanation.

Table 1. *Sound absorption class description and values (Wintzell, 2013).*

Sound absorption class	Rated sound absorption coefficient (αw)	Absorption class description
A	0.9, 0.95, 1	Extremely absorbing
B	0.8, 0.85	Extremely absorbing
C	0.6, 0.65, 0.70, 0.75	Highly absorbing
D	0.3, 0.35, 0.4, 0.45, 0.5, 0.55	Absorbing
E	0.15, 0.2, 0.25	Hardly absorbing
F	0.00, 0.005, 0.01	Reflecting

The performance of non-woven textile fabric and its influence on sound absorption is affected by fiber parameter, fabric physical parameter; method of manufacturing and other factors. Non-woven made of acrylic and cotton fibers perform better compared to those made of polyester fibers in the medium and high frequency range, i.e. above 1000Hz [4]. Küçük and Korkmaz (2012) studied on the effect of physical parameters on sound absorption properties of natural fiber mixed with non-woven composite by changing the fiber type and method of manufacturing [1]. The result proved that the samples including 70% cotton and 30% polyester resulted in the better sound absorption coefficient in the mid-to-high frequency ranges. On the other hand, the addition of acrylic and polypropylene into a cotton and polyester fiber mixture increased the sound absorption properties of the composite in the low and mid-frequency ranges also.

Temesggen Feleke (2018) reported on manufacture of reclaimed fiber non-woven’s and sound absorption are influenced by fabric thickness, areal density, air permeability and thermal conductivity [5]. The study shows that as the thickness increases the sound absorbing performance also increases. Low frequency sound absorption has direct relationship with thickness but at higher frequencies thickness has insignificant effect on sound absorption. Less dense and more open structure absorbs sound of low frequencies. The high-density material due to mass increase it increases the sound absorption. Furthermore, thick sound absorber absorbed more sound energy at lower frequency region while thin samples are more suitable for higher frequency application. Most of the results indicated that, denser materials tend to have higher sound absorption value compared to less dense materials.

Porosity of the materials also happened to be a related factor and the material configuration involving the volume of the voids/holes to the total volume needs to be measured. There are different types of voids present in the material such as containing pores, granular, fibrous or cellular types. The open pore with continuous channels prevails better sound absorbing, because of the multiple reactions between the sound wave and the walls of the pores [6]

2. Materials and Methods

2.1. Materials

The materials used are crushed mattress foam, shredded cotton fabric waste, PVA, binders (printing binder and MDI), boric acid, padding machine, sample preparation box and various measuring instruments. The product produced has three-layers with bottom and top as cotton fabric (PVA coated base fabric and fire retardant treated top covering fabric), sand witching the middle adhesive bonded non-woven porous absorber which is made from shredded cotton fabric waste and crushed mattress foam.

Table 2. *Experimental measurements and their standard for adhesive non-woven product.*

Test parameters		Standard method	Instrument
Physical properties for base fabric	Water repellency test	AATCC method 35	Spray rating tester
	Fabric extensibility test	BS 4294-1968.	Fryma fabric extensometer
	Fabric stiffness test	ASTM D1388-2007	Shirley stiffness tester
	Fabric tensile strength test	ASTM D5035	TENSOLAB strength tester
	Fabric air permeability test	ASTM-D737	Fx3300 air permeability tester
Physical properties for sound absorbent fabric	Air permeability test	UNI EN ISO 9237.	AIRTONIC TYPE 3240 Air Permeability Tester
	Sound absorption coefficient	Standing wave method ISO 10534-1 (1996)	Standing wave apparatus
	Thermal conductivity test	ASTM C177	GuntWL374 thermal conductivity in solid
	Fabric density test	ASTM D 3776	Balance
	Fabric thickness test	ASTM D 1777	Thickness
Flammability test for fire retardant top covering fabric	Vertical flammability test horizontal flammability test	ASTM D 6413	Fabric flammability tester

2.2. Methods

The research uses fabric waste generated at garment section from Bahirdar Textile Share Company, Ethiopia and recycled foam waste from AMAGA FOAM FACTORY Ethiopia. The foam factories after the production of original foam does cutting as per market desired size and it result in cutting foam waste which was used.

2.2.1. Preparation of Base Fabric

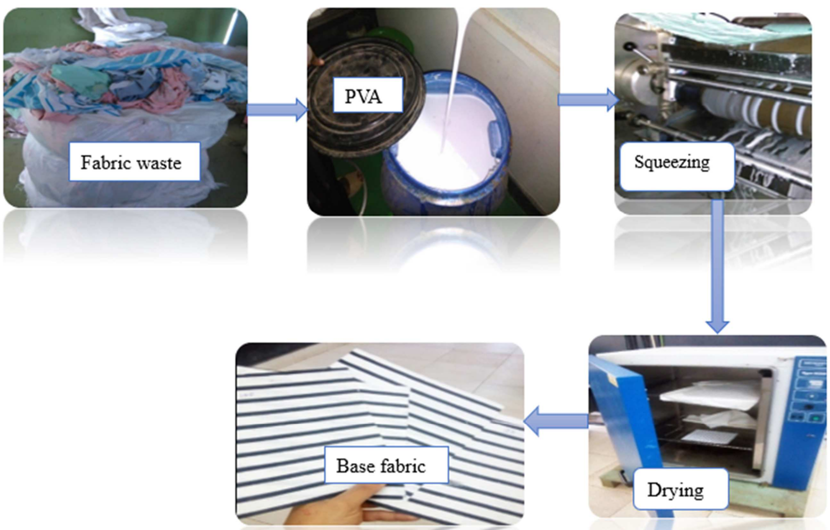

Figure 3. *Preparation of PVA treated base fabric.*

Preparation of base fabric -From the cotton fabric rag wastes width about (10cm -50cm) was taken and cleaned and cut to the required width. PVAc with different concentration (100% PVA, 75% PVA, 50% PVA and 25% PVA with 5% printing binder that of PVA in each concentration was prepared and the sample fabric is immersed in the prepared solution on the beaker. Padding is done at a speed of 1.5 m/min, 2.8 bar squeezing pressure and dried using dryer at 100°C for 10 min and cured at 150°C for 3 min.

2.2.2. Preparation of Adhesive Non-Woven Product

To develop sound absorbent material with cotton fabric waste and mattress foam BOX Behnken design expert software package was used and to estimate the minimum and the maximum value for the factors. In this study three factors were considered and their effect on the performance of sound absorption coefficient, air permeability, density and thermal conductivity of the adhesive bonded non-woven product. Shredded mattress foam and cotton fabric waste are mixed by mass based on the design expert ratio given. 6% of adhesive on the total mass was added and mixed for 2 minutes. 40% water is added on the adhesive mass and mixed for 3 minutes. Using the sample preparation box required thickness is achieved by pressing till 7% of the input thickness reduces. Conditioned for 2-4 hours at room temperature and then removed from the sample preparation box.

Table 3. *Sound absorbing product experimental plan DOE parameter setting.*

Run	Factor 1 A: Thickness Mm	Factor 2 B: Cotton fabric waste (%)	Factor 3 C: Foam (%)	Response 1 Average Sound absorption coefficient (α)	Response 2 Air permeability (mm/s)	Response 3 Density (g/m²)	Response 4 Thermal conductivity (W/mK)
1	30	21	79				
2	45	23.5	76.5				
3	15	39	61				
4	15	43.5	56.5				
5	30	40	60				
6	15	32	68				
7	15	23.5	76.5				
8	30	48	52				
9	45	39	61				
10	30	35	65				
11	45	43.5	56.5				
12	45	32	68				
13	30	27	73				

Based on the above DOE parameter setting prepare the adhesive non-woven product form mattress foam and waste cotton fabric for sound absorption the process flow presented the following Figure 4.

Figure 4. *Development of adhesive bonded non-woven.*

2.2.3. Preparation of Fire-Retardant Treated Fabric

Preparation of fire-retardant top fabric - Boron is colorless, highly fire resistant, soluble in water, and can melt after heating with melting temperature of 2300°C [7]. The chemicals used are boric acid 20-40% gpl, with MLR ratio 1:10. Fire retardant finish is given to the top fabric by padding the fabric in the padding beaker. The sample is immersed and pick up of 70-80% is ensured. Then the fabric is dried in dryer at 100°C for 5 min and subsequent curing at 150°C for 3 min is maintained.

2.2.4. Sound Absorption Coefficient Testing

The result of for this test was taken after assembling the three part of the developed sound absorbing product. The instrument consists of loudspeaker, amplifier, impedance tube, microphone probe, oscilloscope and wave form generator as show the Figures 5 and 6 below.

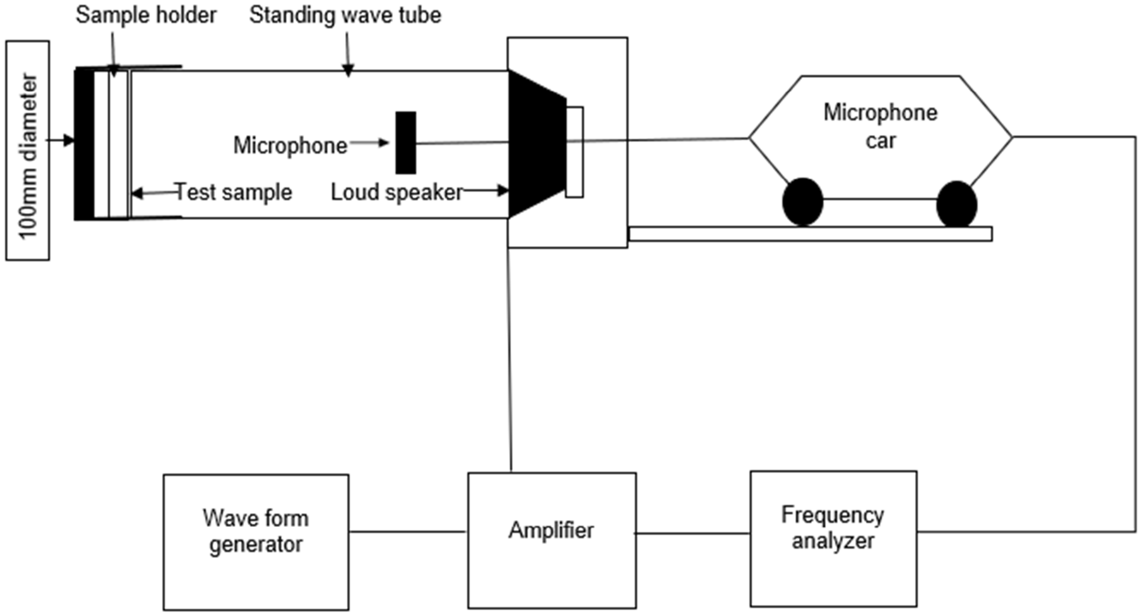

Figure 5. Standing wave apparatus.

The loud speaker produces an acoustic wave which travels down the pipe and reflected from the test sample. The phase interfaces between the wave in the pipe which are incident upon and reflected from the test sample result in the formation of standing wave pattern in the pipe.

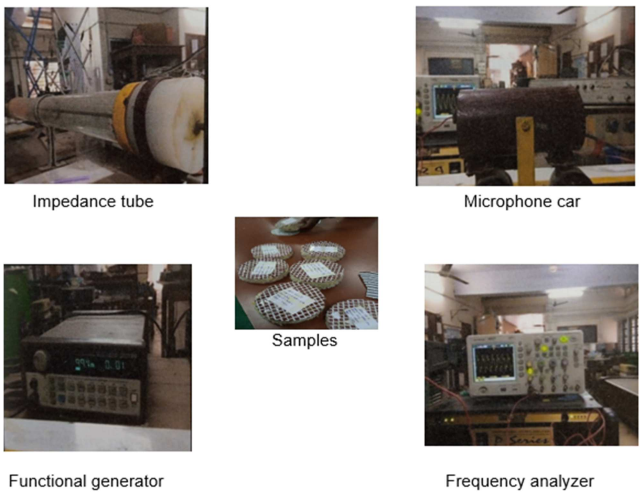

Figure 6. *Standing wave apparatus (Source: Indian Institute of Technology Chennai).*

The required frequency is generated using wave form generator; the microphone attached to the microphone car was moved back and forth to measure the minimum and maximum sound pressure level. If 100% of the incident wave is reflected in the incident and the reflected waves have the same amplitude the node in the pipe have zero pressure and the anti-node have double the pressure. If some of the incident sound energy is absorbed by the sample, then the incident and reflected wave have different amplitude; the node in the pipe no longer have zero pressure. The pressure amplitude at node and antinode are measured use microphone probe attached to a car which slide along graduated ruler. The ratio of the pressure maximum (antinode) to the pressure minimum node is called standing wave ratio (SWR).

The sound absorption coefficient can be defined as (α) can Be defined as the ratio of energy absorbed material to the energy to incident up on its surface [8].

$$SWR=(A+B)/(A-B) \quad (1)$$

Where A+B = Pressure maximum

A-B= pressure minimum

The reflection coefficient R defined by

$$R=B/A= (SWR-1)/(SWR+1) \quad (2)$$

Finally, the sound absorption coefficient

$$\alpha = 1- \mid R \mid^2 \quad (3)$$

3. Result and Discussion

3.1. PVA (Polyvinyl Acetate) Treated Base Fabric

To improve the durability of sound absorbent material, it required backing fabric in this research use PVA (polyvinyl acetate) treated fabric as backing fabric and test some required parameter like strength, air permeability, stiffness, water absorbency and extensibility the obtained result discussed as follows.

3.1.1. Fabric Tensile Strength

The below graph Figure 7, shows that the increase in polyvinyl acetate (PVA) concentration improves the tensile strength of fabric. So, 100% PVA treated fabric has better strength than others in warp as well as weft direction.

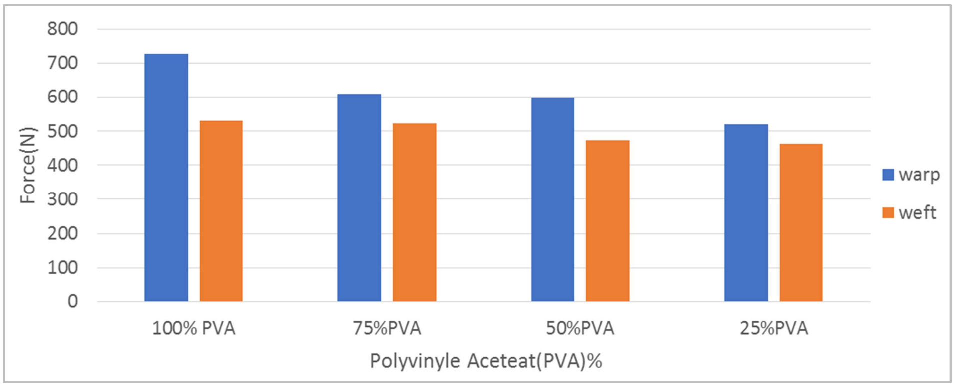

Figure 7. *PVA treated base fabric tensile strength.*

3.1.2. Fabric Stiffness

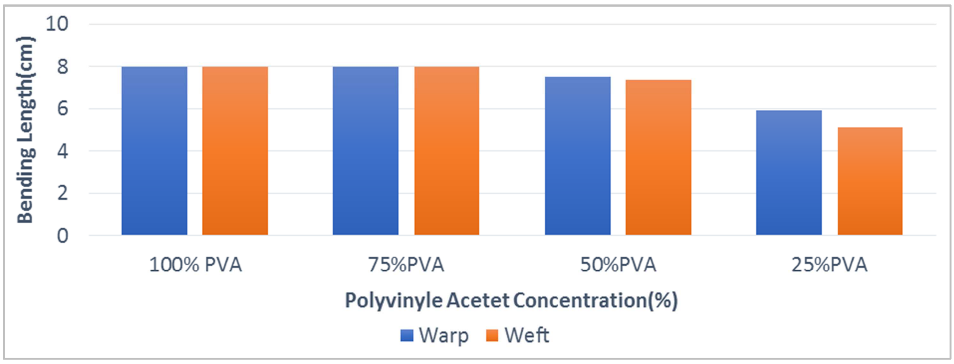

Figure 8. *PVA treated base fabric stiffness.*

The above graph in figure 8, demonstrate the bending length of polyvinyl acetate treated fabric the increase in concentration of the Polyvinyl acetate (PVA) increase the fabric stiffness properties both fabric which have 100% and 75% PVA concentration observed equal bending length in the weft as well as warp direction.

3.1.3. Air Permeability

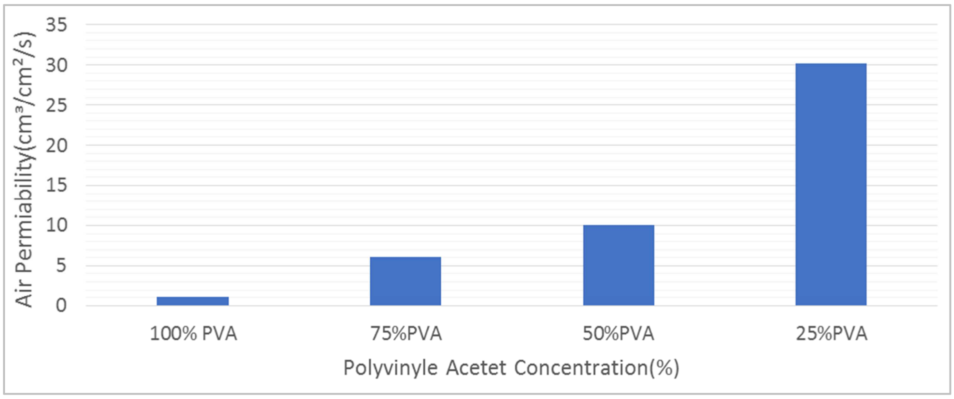

Figure 9. *PVA treated base fabric Air permeability.*

The increase in polyvinyl acetate (PVA) decrease the air permeability performance of fabric from the above figure 9, illustrate 100% PVA treated fabric it is nearly non-Air permeable.

3.1.4. Fabric Extensibility Test

The extensibility test was measure by mechanical extensibility tester for all (100% PVA, 75% PVA, 50% PVA, and 25% PVA) solution treated fabric the result observed that all the Polyvinyl acetate (PVA) treated fabric have no any extensibility property due to the improve in stiffness level and strength of the fabric comparatively with untreated fabric. when testing the extensibility of untreated fabric results on average 4.5% in weft direction and 3% in the warp direction. The PVA solution treated base fabric have no any extensibility in any direction.

Figure 10. *PVA treated fabric extension.*

3.1.5. Fabric Water Repellency

The polyvinyl acetate treated fabric the result was evaluated by photographic standard as shown in figure 11 it results 100 (ISO 5) which means no wetting of and no adherence of small drops to the sprayed surface for all PVA concentration (100%PVA, 75%PVA, 50%PVA and 25% PVA) solution treated base fabric. The polyvinyl acetate (PVA) treatment results covering the fabric surface as film like structure due to this the water cannot absorbed by the fabric this help to prevent the base fabric from wetting.

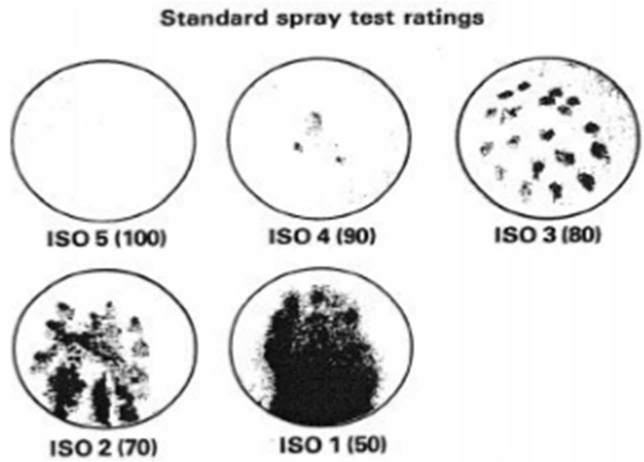

Figure 11. *AATCC standard spray test ratings.*

3.1.6. Selection Criteria for Base Fabric

The required parameter for selection of PVA solution base fabric is better stability (stiffness), low air permeability, less extensibility and better water repellency properties. 75% PVA treated fabric is considered better than 50% and 25% PVA treated fabric. Since PVA treated fabric has no extensibility properties it helps to increase the durability of the sound absorbing product as the fabric suspended in the wall never fails due to load and gravity. Audio studio may expose to humid environment and due to the presence of printing binder and curing process for drying the base fabric does not lose its stability. The PVA treated fabric has no wetting and adhering of water from is surface. Tensile strength test gave the better durability performs the better strength. So by considering the above reasons the fabric treated with 75% PVA solution treated base fabric is selected.

3.2. The Physical Properties of Sound Absorbent Adhesive Bonded Non-woven Material

Table 4. *Physical properties of adhesive bonded non-woven sound absorbent.*

No	Composition (%)		Thickness (mm)	Density (g/m²)	Air Permeabiliy (mm/s)	Thermal conductivity (W/mK)	Sound absorption cofficent (α)				Avarage Sound Absorption Cofficent (α)
	Cotton fabric waste (%)	Foam (%)					250 Hz	500 Hz	750 Hz	1000 Hz	
1	21	79	30	2588	639.3	0.33	0.16	0.3	0.37	0.47	0.325
2	23.5	76.5	45	3150	535.9	0.108	0.38	0.46	0.53	0.55	0.48
3	39	61	15	1740	709.5	0.88	0.13	0.21	0.29	0.45	0.27
4	43.5	56.5	15	1980	700	0.98	0.12	0.2	0.28	0.43	0.2575
5	40	60	30	2870	577.3	0.41	0.2	0.22	0.44	0.46	0.33
6	32	68	15	1660	715.3	0.8	0.12	0.22	0.44	0.46	0.31
7	23.5	76.5	15	1585	725.5	0.6	0.13	0.25	0.3	0.41	0.2725
8	48	52	30	2950	550	0.46	0.2	0.23	0.41	0.43	0.3175
9	39	61	45	3573	497	0.25	0.41	0.43	0.47	0.49	0.45
10	35	65	30	2800	600	0.38	0.22	0.25	0.45	0.47	0.3475
11	43.5	56.5	45	3850	440	0.29	0.35	0.42	0.46	0.47	0.425
12	32	68	45	3360	500	0.156	0.39	0.53	0.6	0.67	0.55
13	27	73	30	2688	605	0.36	0.22	0.23	0.47	0.49	0.3525

3.2.1. Influence of Thickness on Sound Absorption (α)

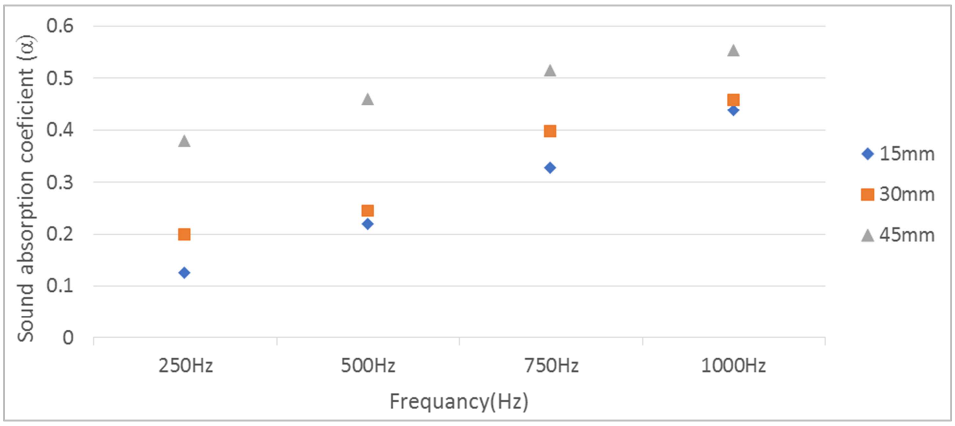

Figure 12. *Influence of thickness on sound absorption coefficient.*

The effect of thickness on sound absorption performance of adhesive bonded non-woven shown in the above figure 12. The result indicates that the increase in thickness have significant effect on sound absorption performance of adhesive bonded non-woven product among thirteen samples there are four 15mm, five 30mm and four 45mm thickness level samples was made based on the experimental design and the above figure 12, describe the average value of each sound absorption coefficient at different thickness level with in the given frequency at (250Hz, 500Hz, 750Hz and 1000Hz). The average sound absorption coefficient for 15 mm, 30mm and 45mm thickness specimen was observed (α=0.27) and (α=0.32) and (α=0.47) respectively. As thickness of specimen increase from 15mm to 45mm thickness the sound absorption coefficient performance was improved. The average sound absorption coefficient of the specimen which have 45mm thickness approximately two times greater than absorption performance of 15mm thickness as well as three times greater than 15mm thickness specially at single low frequency (250Hz) this indicates thickness have significant effect on sound absorption performance in the average sound absorption performance besides in single low frequency level. Therefore, low frequency sound absorption coefficients are improved compared to 15mm thickness this is supported by [9].

3.2.2. Influence of Density on Sound Absorption (α)

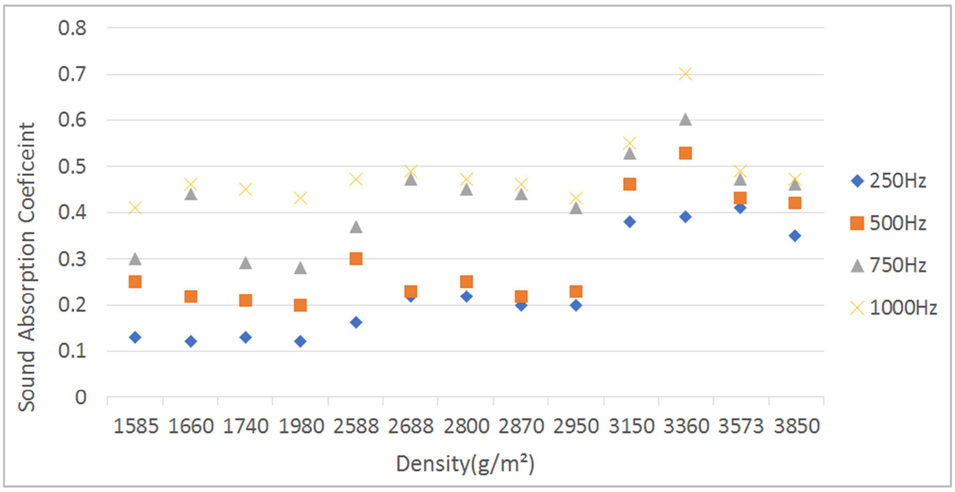

Figure 13. *Influence of Density on Sound absorption coefficient.*

The influence of density on sound absorption was presented on the above figure 13, sound absorption increases with increase in density as a result of the energy loss of sound waves occur because of surface friction. From the above figure 12, the product specimen thickness about 30mm and the sample have 2688g/m² density observed better sound absorption performance than the sample have 2588 g/m² density with same thickness level the sound absorption coefficient was detected (α=0.3525) and (α=0.325) respectively this indicate density have their own effect on sound absorption. On the other hand, the above graph also shows the increase in density decrease the sound absorption performance of adhesive bonded non-woven product which is made from cotton fabric waste and mattress foam at certain point for instance both samples have same level of thickness about 15mm density was 1740g/m² and 1660g/m² the average sound absorption performance was observed (α= 0.27) and (α= 0.31) respectively. Therefore, from this experimental result the density of the materials basically affected by the amount of the cotton fabric waste and foam percentage which is available in the product with same thickness. If the percentage of cotton fabric is more in the given sample comparatively with others as the same thickness level the density of the product was increase but, the amount is beyond optimum level at certain point it reduces the sound absorption performance with increase in density of adhesive bonded non-woven product for the given frequency range.

3.2.3. Influence of Air Permeability on Sound Absorption (α)

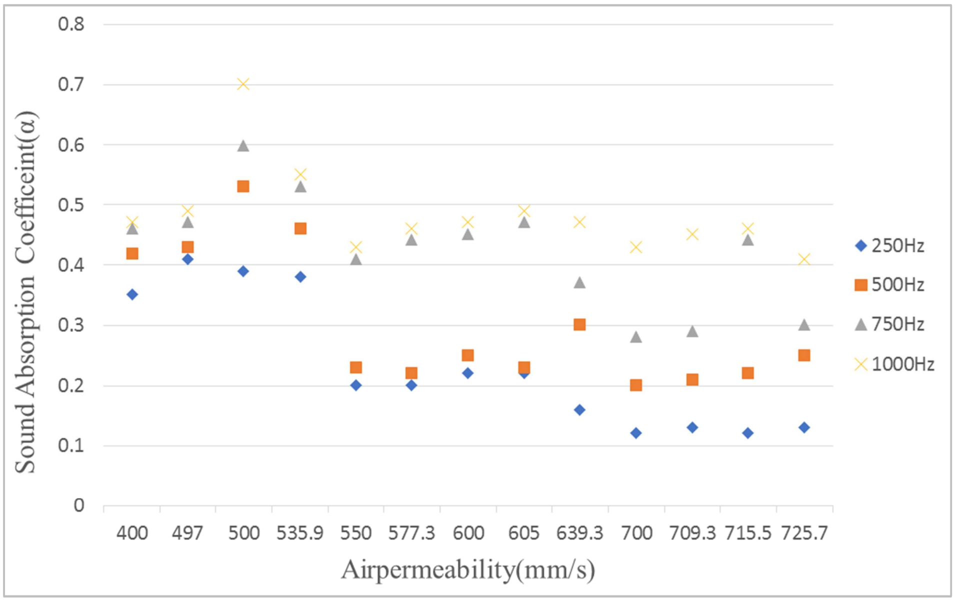

Figure 14. *Influence of Air permeability on sound absorption coefficient.*

The above figure 14, shows the relationship between air permeability and sound absorption coefficient. The increase in air permeability results the decrease in sound absorption due to the decrease in density as well as the decrease in thickness of the adhesive non-woven product. From the above graph the materials observed higher sound absorption at 500mm/s the absorption coefficient was (α= 0.55) with 45mm product thickness. The lower air permeability is reduce sound absorption performance of adhesive bonded non-woven product made from cotton fabric waste and mattress foam at certain point with in the given frequency range for instance, the specimen has same thickness about 15mm and its air permeability was observed about 709 mm/s and 715.3mm/s with the sound absorption coefficient (α= 0.27) and (α=0.31) respectively. Basically, the air permeability of the product influenced by the non-woven product thickness and cotton fabric waste percentage with in the non-woven product therefor, there is optimum level of air permeability for this developed adhesive bonded non-woven made from mattress foam and cotton fabric waste for sound absorption.

3.2.4. Influence of Thermal Conductivity on Sound Absorption (α)

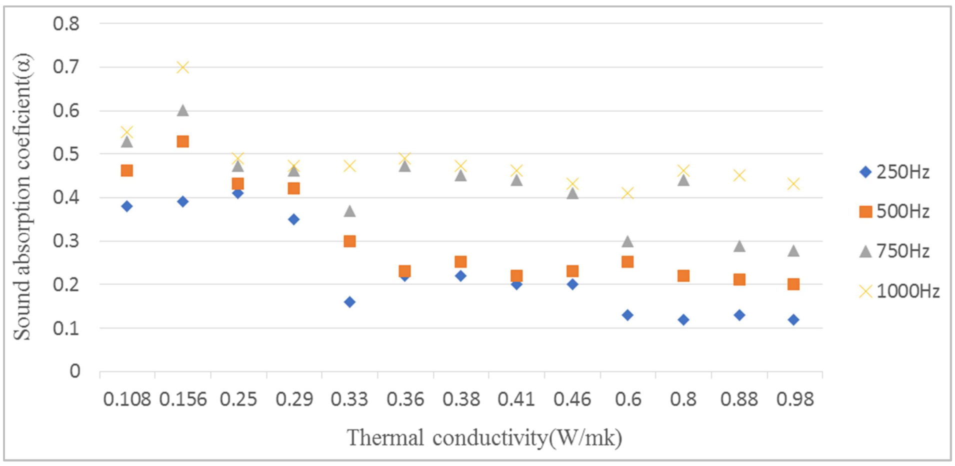

Figure 15. *Influence of Thermal conductivity on sound absorption coefficient.*

The above figure 15, demonstrates the influence of thermal conductivity on sound absorption coefficient. The thermal conductivity of the adhesive bonded non-woven can be affected the density or compactness, air permeability, thickness and type of the material. The adhesive bonded non-woven product made from mattress foam and cotton fabric waste has low thermal conductivity due to its open internal structure. Generally, as the thermal conductivity of the product decreases the sound absorption performance was increased due to the increase in thickness and decrease in compactness with in required level. From above figure 15 the thermal conductivity of samples was presented among thirteen samples the first four samples have 45mm thickness, the second five samples 30mm thickness and the last four samples have 15mm thickness from those samples the better sound absorption coefficient is observed the specimens with 45mm thickness with low thermal conductivity compared to others and its sound absorption coefficient (α) is observed form the range of (0.42 - 0.55) and its thermal conductivity is observed from the range of (0.108W/mK - 0.29W/mK) which means it have better acoustic performance as well as thermal resistance properties compared to the product have 30mm and 15mm thickness. additionally thermal conductivity of adhesive bonded non-woven material increase as material density increase this idea supported by Tao Yang et al. (2016) and S. Sair et al. (2018) [10, 11]

Table 5. *ANOVA statistical analysis for sound absorption coefficient.*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	0.0834	3	0.0278	17.51	0.0004	Significant
A-Thickness	0.0800	1	0.0800	50.41	< 0.0001	
B-Cotton fabric waste	0.0013	1	0.0013	0.7877	0.3979	
C-Foam	0.0021	1	0.0021	1.33	0.2783	
Residual	0.0143	9	0.0016			
Cor Total	0.0976	12				

3.3. Statistical Significance Effect of Different Factors on Responses

3.3.1. Sound Absorption Coefficient

P-values less than 0.0500 indicate model terms are significant. In this case A is a significant model term. From the above table 5 and figure 16 below describe thickness have significant effect on sound absorption performance of adhesive non-woven fabric when the thickness goes up from 15mm to 45mm the absorption performance increase significantly therefore, from ANOVA statistical analysis thickness has great effect compared to other factors like cotton fabric waste and foam percentage.

3.3.2. Air Permeability

P-values less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. From the below table 6 and figure 16 below describe both thickness and cotton fabric wastes have significant effect on air permeability because when the increase in cotton fabric waste percentage in the product results the increases density then it, reduce the air permeability of non-woven product due to cotton fabric have high mass to volume ratio compared to foam. On the other hand, the increase in thickness also result increase density then decrease the air permeability of the adhesive bonded non-woven sound absorbing product.

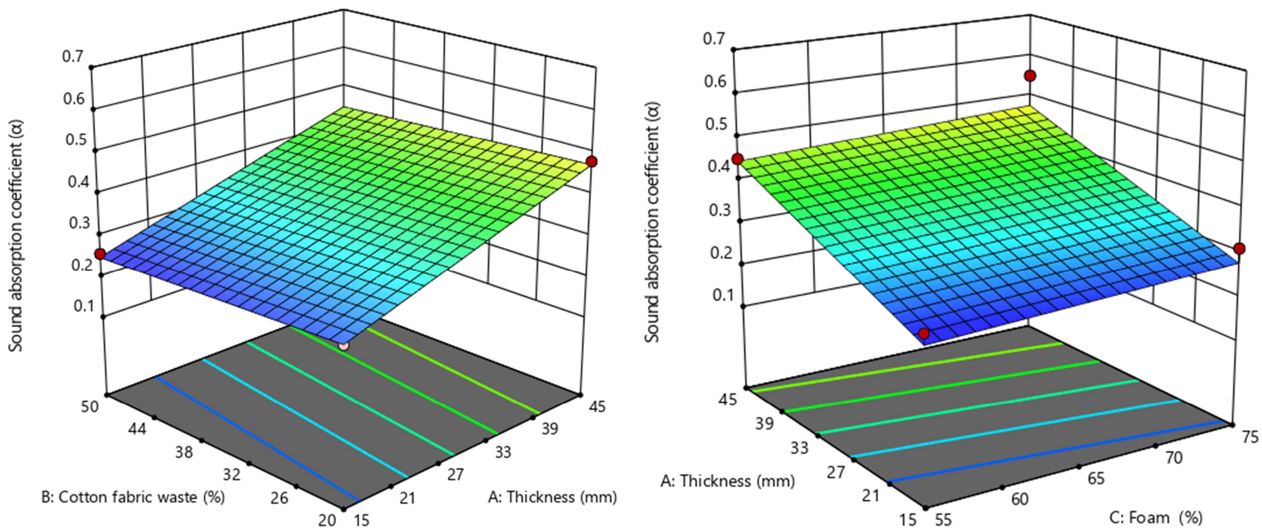

Figure 16. *Significant effect of thickness on Sound Absorption Coefficient.*

Table 6. *ANOVA statistical analysis for Air permeability.*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	1.040E+05	3	34650.90	157.31	< 0.0001	Significant
A-Thickness	96228.85	1	96228.85	436.87	< 0.0001	
B-Cotton fabric waste	7104.32	1	7104.32	32.25	0.0003	
C-Foam	619.52	1	619.52	2.81	0.1278	
Residual	1982.41	9	220.27			
Cor Total	1.059E+05	12				

3.3.3. Density

Table 7. *ANOVA statistical analysis for Density.*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	6.433E+06	3	2.144E+06	119.46	< 0.0001	Significant
A-Thickness	6.069E+06	1	6.069E+06	338.10	< 0.0001	
B-Cotton fabric waste	3.358E+05	1	3.358E+05	18.71	0.0019	
C-Foam	27966.13	1	27966.13	1.56	0.2435	
Residual	1.616E+05	9	17950.55			
Cor Total	6.594E+06	12				

P-values less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. From the above table 7 and below figure 17 shows both thickness and cotton fabric waste have significant effect on density of adhesive bonded non-woven sound absorbent product. When the increase in thickness from 15mm to 45mm the mass of the material at specified area was also increase so, the density of product similarly increases additionally cotton fabric waste have high mass to volume ratio compared to foam. As, the percentage of the cotton fabric in the product increases the compactness of material increase that results the increase in density of the adhesive bonded non-woven product made from cotton fabric waste and mattress foam for sound absorption. Therefore, cotton fabric waste and thickness have statically significant effect on density of sound absorbing non-woven product.

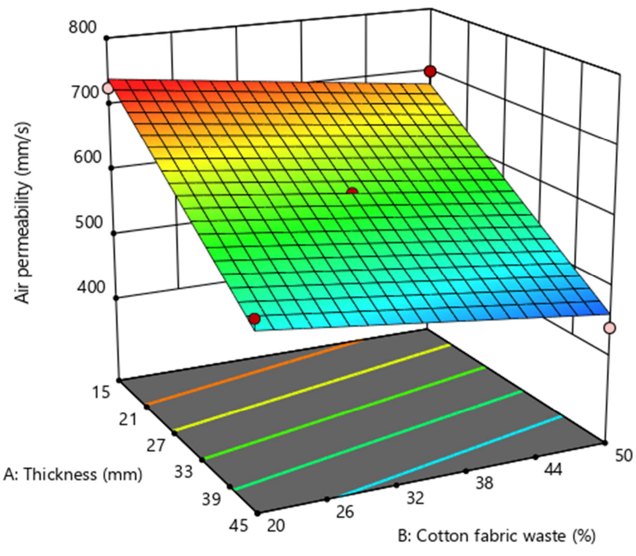

Figure 17. *Significant effect of thickness and cotton fabric waste on Air permeability.*

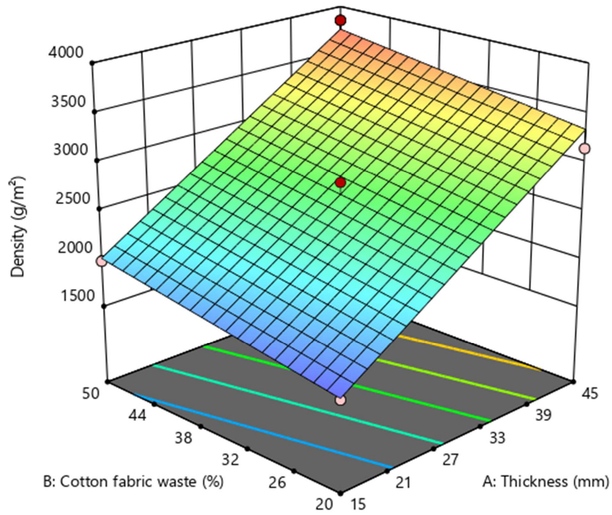

Figure 18. *Significant effect of Thickness and cotton fabric waste on Density.*

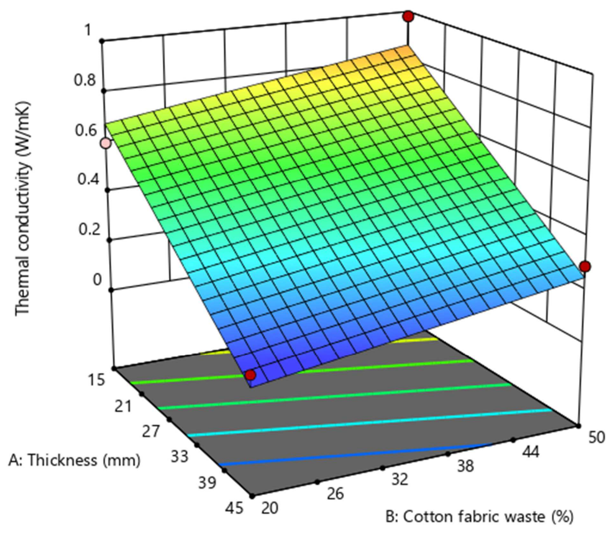

Figure 19 *Significant effect of Thickness and Cotton Fabric waste on Thermal conductivity.*

3.3.4. Thermal Conductivity

Table 8. *ANOVA statistical analysis for Thermal conductivity.*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	0.8309	3	0.2770	32.71	< 0.0001	Significant
A-Thickness	0.7540	1	0.7540	89.06	< 0.0001	
B-Cotton fabric waste	0.0688	1	0.0688	8.13	0.0191	
C-Foam	0.0081	1	0.0081	0.9525	0.3546	
Residual	0.0762	9	0.0085			
Cor Total	0.9071	12				

P-values less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. From the above table 8 and the figure 18 designates the thermal conductivity of adhesive non-woven product basically affected by the cotton fabric waste and the thickness of the product. The increase in cotton fabric waste results the increase in thermal conductivity due to the increase in compactness of adhesive non-woven product. On the contraries the increase in thickness results decrease the thermal conductivity due to the presence of high air gap with the sound absorbing product. So, cotton fabric waste and thickness have statistically significant effect on thermal conductivity of non-woven product.

3.3.5. Fire Retardant Properties of Top Covering Fabric

Fire retardant test was conducted as per ASTMD 6413 on the treated cover fabric both in horizontal and vertical flame spreading test. The test result indicates in the figure 20 below, the material spreading time was below 5 seconds. The finish given over the fabric enhances charring and formation of surface barriers and hence forth the horizontal flammability direction is better than with vertical flammability test.

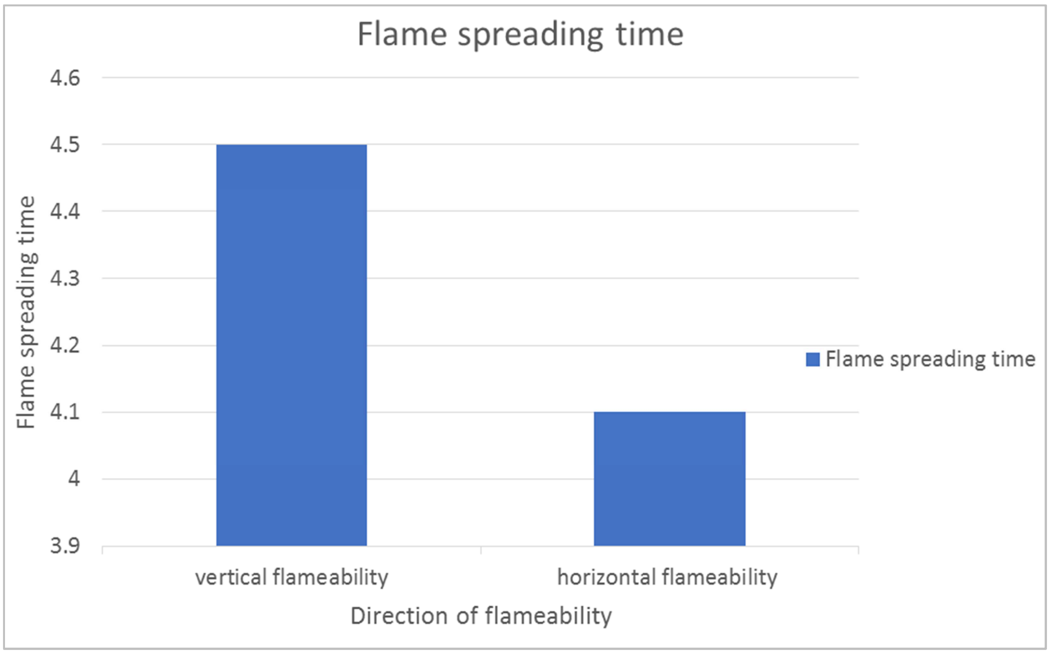

Figure 20. *Fire retardant treated fabric flame spreading time.*

Boron compounds are environmentally friendly when used as flame retardants. They do not cause toxic gas release and have low volatility value. Boron flame retardants cause the formation of a glass protection layer that acts as a barrier for polymer chain oxidation. They cover the burning material, cut off the contact with oxygen and repress the burning, as well [12].

3.4. Optimizing the Proportion of Ingredients

The optimization done in two methods in order to recognize the optimum adhesive bonded nonwoven product made from cotton fabric waste and mattress foam for acoustic purpose.

3.4.1. First Method

The first method is by using the average sound absorption coefficient at different frequency such as (250Hz, 500Hz, 750 Hz and 1000Hz). The following table 9 shows the optimized proportion of ingredients among thirteen samples for adhesive bonded non-woven sound absorbent materials made from cotton fabric waste and mattress foam. The optimum sound absorption coefficient (SAC) obtained by

21% cotton fabric waste and 79% foam with 45mm thickness. The following table 9 show optimum sound absorption coefficient with different physical parameters.

Table 9. *Optimized proportion of the ingredient.*

Cotton fabric waste (%)	Mattress foam (%)	Thickness (mm)	Average sound absorption coefficient (α)	Density g/m²	Air permeability (mm/s)	Thermal conductivity (W/km)
21	79	45	0.48	3283.46	528.5	0.0303

3.4.2. Second Method

The second method is very important in order to recognize the sound absorption class of any product performance based on ISO 11654:1997. This method based on the selective octave band center frequency and calculating their rated sound absorption coefficient (αw). In this research select 500Hz center third frequency based on ISO standard and calculate the average sound absorption coefficient at center third (500Hz), bottom third (400Hz) and upper third (630Hz) and take its average value then obtain single figure rated sound absorption coefficient (αw). Therefore, based on experimental design the optimized result shown as follows in the following table 10. In this method also the optimized sound absorption is the same as the first method that means the optimum sound absorbing product achieved in the proportion of 21% cotton fabric waste and 79% mattress foam with 45mm product thickness and its desirability about 0.894 from the experimental design.

Table 10. *Rated sound absorption coefficient for optimized ingredient.*

No	Thickness (mm)	Cotton fabric waste (%)	Foam (%)	Rated sound absorption coefficient (αw)	Frequency (Hz)			Desirability
					(bottom third 400Hz)	(center third 500Hz)	(upper third 630Hz)	
1	45. 00	21.000	79.000	0.456	0.375	0.466	0.518	0.894

The above two method are important for optimization in this research work in both method optimum sound absorption product achieve at 21% cotton fabric waste and 79% foam with 45mm thickness.

4. Conclusion

The development of adhesive bonded non-woven product made from cotton fabric waste and mattress foam confirmed their potentiality in replacing common sound absorbing materials applicable for acoustic purpose for radio broadcasting station and audio recorder. Study on the influence of thickness, air permeability, thermal conductivity and density on sound absorption performance of adhesive non-woven product was also done. The product thickness has statically significant effect on sound absorption performance of adhesive bonded non-woven product made from cotton fabric waste and foam. The increase in the non-woven product thickness increases the absorption coefficient especially at low frequency ranges indicating very high absorption performance. The product is average sound absorption performance ranges from (0.257-0.55) with in different thickness and varying cotton fabric waste and foam percentage in the product. The optimum sound absorption product based on Box Behnken experimental design was 79% foam and 21% cotton fabric waste with 45mm thickness through average sound absorption coefficient of (α= 0.489). The adhesive bonded non-woven product has equivalent competitive performance with the existing sound absorbing materials. This product falls under class D (ISO 11654:1997) and is similar to the existing product used in Radio Stations in Ethiopia for acoustic purpose.

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