J. Basic. Appl. Sci. Res., 6(10)9-18, 2016
© 2016, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Effect of Fibers Types on the Properties of Acoustic and Thermal Nonwoven Fabrics Used in Cars

Dr. Nahla Fawzy Ahmed

Assistant professor spinning and weaving dept.,
Faculty of Applied Arts / Helwan University, Egypt

Received: June 11, 2016
Accepted: August 31, 2016

ABSTRACT

Textile of different structure and properties are widely used in automotive for different function. These textiles are called as technical textile or automotive textile. Automotive textiles are produced from synthetic, natural and recycled fibers to provide both comfort and an aesthetic appearance to automotive in trios. Also these materials have potential to reduce interior noise and heat in automotive due the textile structure and diameter size of fiber porous as a sound absorbing and thermal insulation material. This research aims to produce nonwoven fabrics used for the acoustical and thermal insulation application in automotive.
The samples were produced with cross-laid nonwoven technique and bonded using needle punching method using three types of textile materials: glass wool, jute and waste. Samples of glass wool made of glass wool fibers count 2 den. Where a layer of nonwoven polyester fabric (300 g/m^2) was put on both surfaces of nonwoven glass wool fabric for easy usage. Samples of jute made of jute fibers count 20 den. where a layer of nonwoven polyester fabrics (150 g/m^2) was put on one surface of nonwoven jute fabrics. Samples of waste made of (jute, cotton, polyester and polypropylene) with different count and length of fibers. Tests are carried out to evaluate the samples produced under study. The obtained test results are presented and discussed.
KEYWORDS: Acoustic properties – sound absorption coefficient – porous materials – thermal insulator value – waste fibers – glass wool fibers.

1. INTRODUCTION

Noise has become a serious environmental problem. Noise can cause general types of negative impacts. And it is an increasing public health problem according to the world health organization's "Guide lines for community noise". Noise can have the following adverse health impacts: hearing loss, auditory health impact, impact on sleep, communication interference and impact on domestic animals and wild life [1]. So noise control was one of the major requirements to improve the living environment.

Also acoustics is defined as the scientific study of sound, which includes the effect of reflection, refraction, absorption, diffraction and interference.

1.1. Noise in cars:

Car noise is basically caused by the unit sound, the exhaust system noise, air-suction noise, rolling and wind noises. While the major part of the sound energy is spread outwards, some of it reaches the car interior by the body and the running gear or directly. The airborne-noise transmissions or those transmitted by the car interior appear in diverse ways, which partly affect each other. Both noise-reducing measures at the sound sources as well as specific interference the sound transmission mechanisms are important considerations in the achievement of low car noise levels.

Within a car the acoustic materials can be used in structures such as: door panels, headliners, luggage compartment, under bonnet/hood liner, floor carpet underlay mat [2].

1.2. Acoustic material:

Noise control issues and the emergence of sound quality is becoming vital in an automotive product design, acoustic material is increasingly relevant to engineers, designers and manufacturers from a broad image of industries. Sound absorptive materials are generally used to resist the undesirable impacts of sound reflection by hard, rigid and interior surfaces and thus help to reduce the reverberant noise levels [3].

High-density materials are capable of insulate sound efficiently. However, their rigid nature prevents the sound waves to get through so they reflect a majority of sound waves back into the environment. The use of the rigid structures as insulators is not practical because of their high weights and high cost; limit their use in automotive applications [4]. When the sound meets with material, some of the waves are reflected back, some of the waves are transmitted through the boundary, and some of the waves are absorbed by the material. The energy of the absorbed sound waves changes into vibration and heat energy that are dissipated to the environment. If the

Corresponding Author: Dr. Nahla Fawzy Ahmed, Assistant professor spinning and weaving dept., Faculty of Applied Arts / Helwan University, Egypt.

material is fibrous, then the number of boundaries of the structure will be directly proportional to the number of fibers in the fibrous material [5].

1.3. Sound absorption:

The proportion of sound absorbed by the surface is called the sound absorption coefficient. The absorption coefficient α is $\alpha = 1-(B/A)^2$. The coefficient can be viewed as a percentage of sound being absorbed, where 1.00 is complete absorption (100%) and 0.01 are minimal (1%). A and B are the amplitudes [6], [7].

1.4. Porous materials:

Porous materials are used in noise control engineering to absorb sound energy. They have low stiffness and so prevent mechanical compression during carrying, so their absorption features change but they do not exhibit deformation and this investigation examines the absorption coefficient of a compressed porous material. Many studies have applied acoustic field theory to porous materials.

Number, size and type of pores are the essential factors that one should consider while studying sound absorption mechanism in porous materials. To allow sound dissipation by friction, the sound wave has to enter the porous material. This means, there should be enough pores on the surface of the materials 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 [8].

1.5. Textiles in automotive:

Textile of different structures and properties are used in automotive for different functions. These textiles are called as Technical Textiles or Automotive Textiles. Automotive textiles are produced from synthetic, natural and recycled fibers.

This material has ability to reduce interior noise in automotive due to the textile structure and diameter size of fiber porous as a sound insulating and sound absorbing material [9]. The property of textile is lightweight and less expensive as compared to material like steel and additionally environmental- friendly materials ,was enhances highest consumption in interior part of automotive industry.

Sound absorption of textile materials were design such as porosity was increased along the propagation of the sound wave and porosity should be maximum value in the middle of material. Sound absorbing materials absorb most of the sound energy striking them and making them very beneficial for the control of noise [10].

1.6. Thermo-insulation properties:

Heat transfer can take place by means of conduction, convection or radiation across the barrier from the hot side to the cooler side. In conduction, heat passes from a hotter to a cooler region along the static material (as in textile barriers). Convection is the transfer of heat by a flow of gases or liquids of different temperatures. In radiation, thermal energy is transmitted as electromagnetic waves [11].

Thermal insulation materials are specifically designed to reduce the heat flow by limiting heat conduction, convection, radiation or all three while performing one or more of the following functions: conserving energy by reducing heat loss or gain Controlling surface temperatures for personnel protection and comfort Facilitating vapor flow and water condensation of a process Increasing operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power system found in commercial and industrial installations [12].

1.7. Thermal insulation value:

Thermal insulation value (TIV) represents the efficiency of the textile fabric as an insulator. It is defined as the percentage reduction in heat loss from a hot surface maintained at a given temperature. The TIV increases to 100% when a perfect insulator is obtained. It is expressed as a percentage which represents the reduction in the rate of heat loss due to the insulation, relative to the heat loss from the surface.

TIV can be measured based on the insulation factor (R). (R_{si}) can be described in the relation $R_{si} = d/\lambda$.

Where:

- λ: It represents the heat flow in watts (W) through a 1 m^2 surface and 1 m thick flat layer of a material when the temperature difference between the two surfaces in the direction of heat flow amounts to 1 kelvin (K). The unit of measurement for thermal conductivity (λ) is W/(m.k).
- d: thickness of the samples [13].

1.8. Thermal insulation properties of fabrics:

The thermal insulation properties of textile fabrics depend on their thermal conductivity, density, thickness and weight. The efficiency of thermal insulating materials generally depends on the amount of dead air space present within. The insulative materials are bulky as air entrapped helps in increasing the insulation properties of the fabric [14].

Batting and nonwovens are used widely for thermal insulation applications otherwise apparel. As nonwoven fabrics have the advantage of containing many dead air spaces (micro-spaces) present within the material that give the fabric its insulation abilities. Compound structures with more than one layer of different materials are also effective in certain applications [15], [16].

1.9. Fibers used in this research:

Glass wool: Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties.

Jute: Jute is a versatile fiber, a key feature of jute is its ability to be used either independently or blended with a range of other fibers and materials. Advantages of jute include good insulating and antistatic properties, as well as having low thermal conductivity and moderate moisture retention.

Wastes: Textile wastes can be classified as either pre-consumer or post-consumer wastes as recycling removes the waste from the waste stream and recycle it back into the market. Pre-consumer waste consists of by-product materials from the textile, fiber and cotton industries that are remanufactured for the automotive, home building, furniture, mattress, paper, apparel and other industries. [17].

2. Experimental work:

2.1. Materials and methods:

2.1.1. Specification of samples under study:

The present research is concerned with the nonwoven fabrics which are suitable for using as sound absorption and thermal insulation inside cars.

Nine samples were produced with cross-laid nonwoven technique and bonded using needle punching method using three types of textile materials: glass wool, jute and waste.

Nonwoven glass wool fabrics made of glass wool fibers count 2 den. where a layer of nonwoven polyester fabric (300 gm/m^2) was put on both surface of nonwoven glass wool fabrics for easy usage. Table (1) shows the specification of nonwoven glass wool fabrics.

Nonwoven jute fabrics made of jute fibers count 20 den where a layer of nonwoven polyester fabrics (150 gm/m^2) was put on both surface of nonwoven jute fabrics. Table (2) and (3) show the specification of nonwoven jute fabrics and nonwoven polyester fabrics.

Nonwoven waste fabrics made of (40% jute + 20% cotton + 40% polyester and polypropylene) with different count and length of fibers. Table (4) shows the specification of nonwoven waste fabrics.

Table (1): Specification of nonwoven glass wool fabrics under study

No.	Property	Specification
1	Type of fiber	Glass wool fibers
2	Fiber length	30 mm
3	Fiber count	2 den.
4	Fabric weight (gm/m2)	2000 gm/m2
5	Web formation	C. L. (cross – laid)
6	Web bonding	Needle punching
7	Number of beats/min	500
8	Puncture depth	9, 11 and 13 mm

Table (2): Specification of nonwoven jute fabrics under study

No.	Property	Specification
1	Type of fiber	Jute
2	Fiber length	35 mm
3	Fiber count	20 den.
4	Fabric weight (gm/m^2)	1800 gm/m^2
5	Web formation	C. L. (cross – laid)
6	Web bonding	Needle punching
7	Number of beats/min	500
8	Puncture depth	9, 11 and 13 mm

Table (3): Specification of nonwoven polyester fabrics under study

No.	Property	Specification
1	Type of fiber	Polyester
2	Fiber length	80 mm
3	Fiber count	6 den.
4	Fabric weight (gm/m^2)	150, 300 gm/m^2
5	Web formation	C. L. (cross – laid)
6	Web bonding	Needle punching
7	Number of beats/min	500
8	Puncture depth	9, 11 and 13 mm

Table (4): Specification of nonwoven waste fabrics under study

No.	Property	Specification
1	Type of fiber	Waste(40% jute + 20% cotton + 40%polyester and polypropylene)
2	Fiber length	20, 30 and 40 mm
3	Fiber count	3, 6, 15 and 25 den.
4	Fabric weight (gm/m^2)	1500 gm/m^2
5	Web formation	C. L. (cross – laid)
6	Web bonding	Needle punching
7	Number of beats/min	250
8	Puncture depth	9, 11 and 13 mm

2.1.2. Tests applied to samples under study

Several tests were carried out in order to evaluate the produced fabrics, these tests are:

1. Sound absorption coefficient [18].
2. Thermal insulation of fabrics [19].
3. Air permeability [20].
4. Fabric thickness [21].

3. RESULTS AND DISCUSSIONS

Results of experimental tests carried out on the produced samples were presented in the following tables and charts. Results were also statistically analyzed for the date listed and relationships between variables were obtained.

3.1. Fabric sound absorption coefficient:

Table (5): Sound absorption coefficient of nonwoven glass wool fabric measurements results

		Sound absorption coefficient of fabric %																		
Frequency (Hz)		100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
Puncture depth (mm)	9	0.006	0.007	0.017	0.032	0.049	0.074	0.12	0.21	0.34	0.51	0.75	0.89	0.98	0.97	0.96	0.92	0.83	0.72	0.76
	11	0.003	0.005	0.012	0.026	0.041	0.063	0.098	0.17	0.28	0.42	0.64	0.85	0.94	0.93	0.91	0.86	0.77	0.67	0.70
	13	0.001	0.002	0.009	0.021	0.034	0.059	0.089	0.15	0.24	0.36	0.55	0.79	0.88	0.87	0.85	0.82	0.73	0.63	0.66

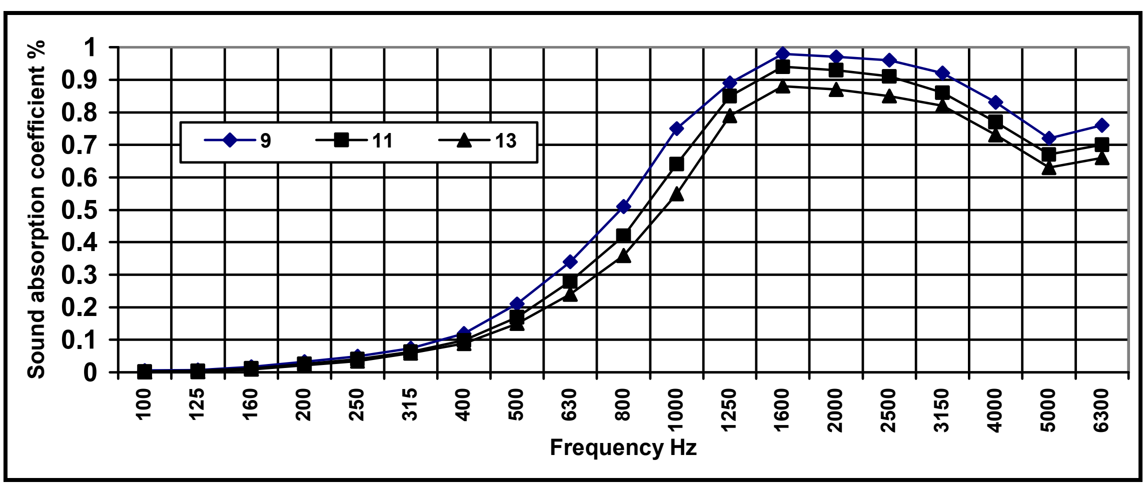

Fig. (1)
Effect of needle penetration depth(mm) on the Sound absorption coefficient of glass wool at weight 2000 gm/m^2

Table (6)
Regression equation and correlation coefficient for the effect of the needle penetration depth (mm) on the Sound absorption coefficient of glass wool at weight **2000** gm/m^2

Puncture depth	Regression equation	Correlation coefficient
9 mm	Y = 0.11X3 – 0.20X2 + 0.22X + 0.48	0.662555
11 mm	Y = 0.10X3 – 0.19X2 + 0.21X + 0.44	0.662428
13 mm	Y = 0.09X3 – 0.17X2 + 0.21X + 0.41	0.674779

Table(7) : Sound absorption coefficient of nonwoven jute fabric measurements results

Sound absorption coefficient of fabric %																				
Frequency (Hz)		100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
Puncture depth (mm)	9	0.15	0.21	0.056	0.09	0.11	0.071	0.08	0.084	0.12	0.16	0.19	0.28	0.39	0.42	0.47	0.65	0.85	0.97	0.99
	11	0.13	0.19	0.047	0.061	0.09	0.061	0.072	0.078	0.1	0.14	0.17	0.25	0.35	0.38	0.44	0.61	0.8	0.94	0.98
	13	0.11	0.18	0.04	0.07	0.08	0.05	0.06	0.07	0.09	0.12	0.15	0.22	0.31	0.35	0.41	0.57	0.75	0.9	0.97

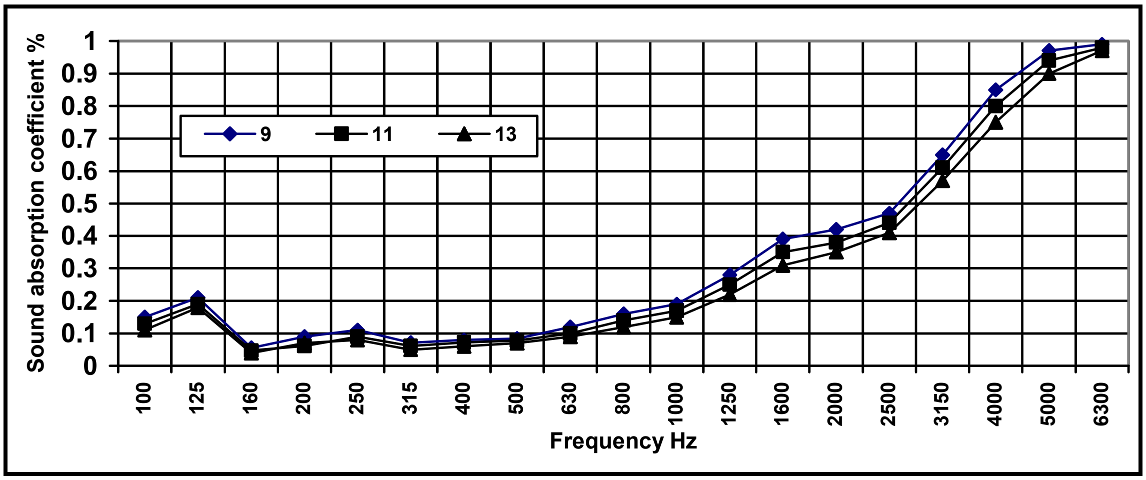

Fig. (2)
Effect of needle penetration depth(mm) on the Sound absorption coefficient of nonwoven jute fabric at weight**1800** gm/m^2

Table (8)
Regression equation and correlation coefficient for the effect of the needle penetration depth (mm) on the Sound absorption coefficient of nonwoven jute fabric at weight**1800** gm/m^2

Puncture depth	Regression equation	Correlation coefficient
9 mm	$Y = -0.03X^3 – 0.02X^2 + 0.26X + 0.33$	**0.977564**
11 mm	$Y = -0.03X^3 – 0.01X^2 + 0.26X + 0.31$	**0.981989**
13 mm	$\mathbf{Y = -0.03X^3 – 0.01X^2 + 0.25X + 0.29}$	**0.984963**

Table (9): Sound absorption coefficient of nonwoven waste fabric measurements results

Sound absorption coefficient of fabric %																				
Frequency (Hz)		100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
Puncture depth (mm)	9	0.034	0.14	0.062	0.073	0.084	0.075	0.095	0.1	0.15	0.17	0.39	0.45	0.58	0.69	0.72	0.91	0.96	0.97	0.98
	11	0.026	0.11	0.048	0.061	0.072	0.064	0.083	0.091	0.13	0.14	0.26	0.38	0.49	0.51	0.63	0.81	0.92	0.95	0.96
	13	0.021	0.09	0.04	0.05	0.06	0.053	0.07	0.08	0.11	0.12	0.21	0.31	0.41	0.43	0.54	0.72	0.86	0.93	0.94

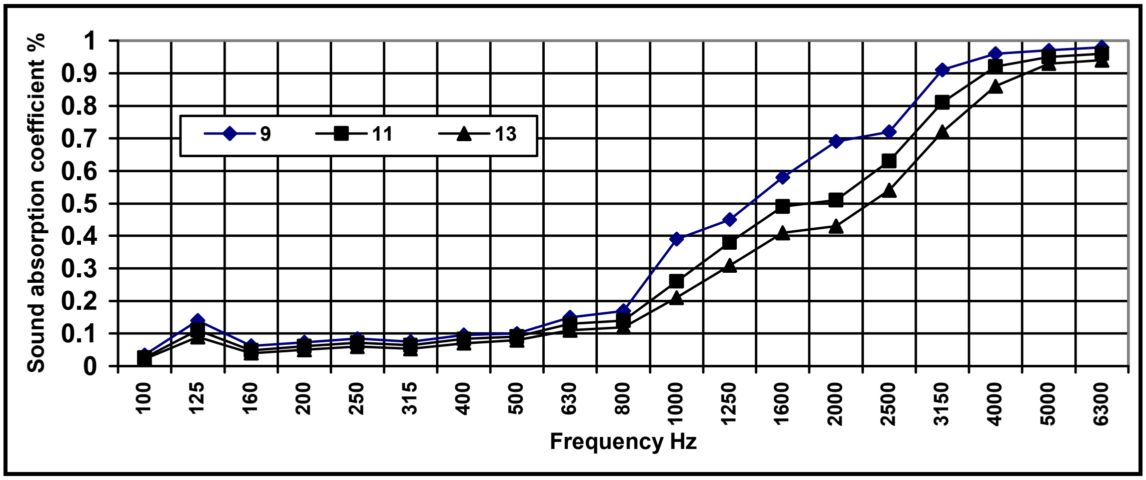

Fig. (3)
Effect of needle penetration depth (mm) on the Sound absorption coefficient of waste fabric at weight 1500 g/m²

Table (10)
Regression equation and correlation coefficient for the effect of the needle penetration depth (mm) on the Sound absorption coefficient of nonwoven waste fabric at weight1500 gm/m²

Puncture depth	Regression equation	Correlation coefficient
9 mm	$Y = 0.001X^3 - 0.10X^2 + 0.29X + 0.40$	0.92727
11 mm	$Y = -0.01X^3 - 0.07X^2 + 0.28X + 0.35$	0.95654
13 mm	$Y = -0.02X^3 - 0.05X^2 + 0.27X + 0.32$	0.97278

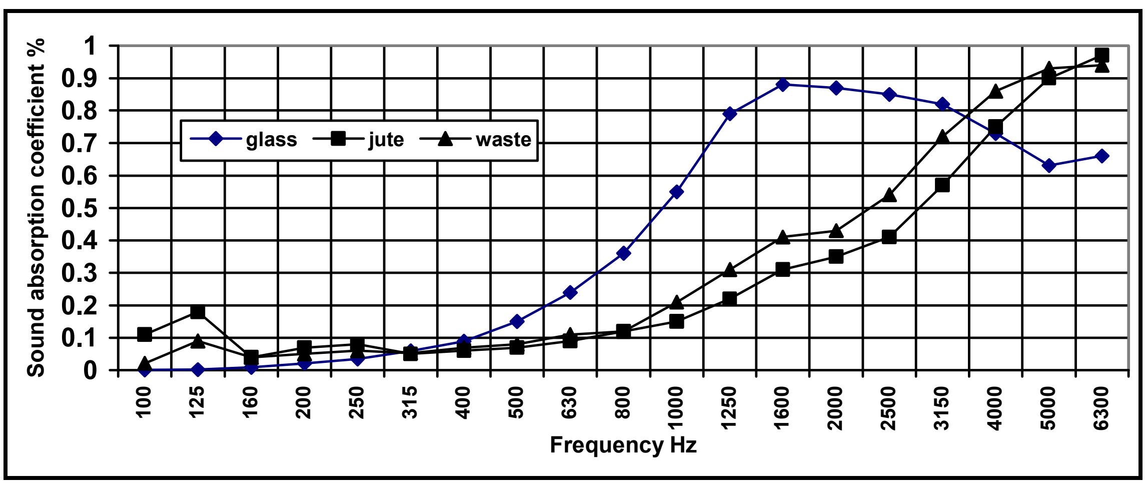

Fig. (4)
Effect of the fabric type on the Sound absorption coefficient at needle puncture depth (13) mm

3.1.1. Effect of the fabric type on the sound absorption efficiency:

From tables (5,7,9) and figs. (1,2,3,4) it can be seen that the samples of jute have recorded the highest sound absorption coefficient compared to samples of waste whereas the samples of glass wool have recoded the lowest sound absorption coefficient at the frequency range from 100 : 250 Hz. Whereas the samples of glass wool recorded the highest sound absorption coefficient compared to samples of waste whereas the samples of jute recorded the lowest sound absorption coefficient at the frequency range from 315 : 3150 Hz. Then the samples of jute recorded the high score again in sound absorption coefficient then the samples of waste whereas the samples of glass wool recoded the low score at the frequency range from 4000: 6300 Hz.

3.1.2. Effect of the needles penetration depth on the sound absorption coefficient:

Tables (5,7,9) and figs. (1,2,3,4) signify that there is an inverse relation between the puncture depth and the sound absorption coefficient. This due to that by increasing puncture depth the fabric becomes more compacted as a sequence decreases space between fibers hence decreases its ability to absorb sound waves between the spaces of fibers.

3.2. Fabric thermal insulation factor (R):

Table (11): Thermal insulation factor (R) of fabric measurements results

Thermal insulation factor (R) of fabric (m^2 k/w)				
Type of fiber		Glass wool	Jute	Waste
Weight gm/m^2		2000 gm/m^2	1800 gm/m^2	1500 gm/m^2
Puncture depth (mm)	9	91.82	50.61	42.02
	11	93.36	52.98	45.12
	13	96.43	55.12	47.75

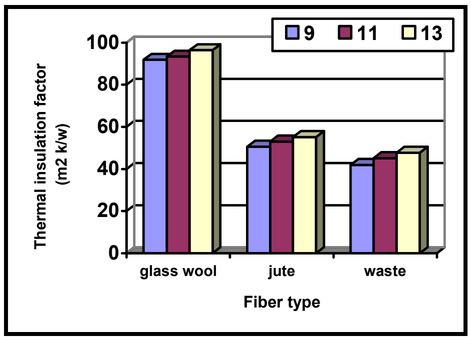

Fig. (5)
Effect of the fabric type and needle penetration depth (mm) on the thermal insulation factor(R)

3.2.1. Effect of the fabric type on the thermal insulation factor (R):

It is obvious from table (11) and fig. (5) That the nonwoven glass wool fabrics have recorded the highest thermal insulation factor compared to samples of jute whereas the samples of waste have recorded the lowest thermal insulation factor. This is due to the structure of glass wool fibers which contain many small pockets result in high thermal insulation followed by the sample of jute which including a good insulation low thermal conductivity and moderate moisture regain, then the sample of waste which recorded the lowest weight and density. Thus the glass wool used as thermal insulation for engine compartments.

3.2.2. Effect of the needles penetration depth on the thermal insulation factor (R):

It is obvious from table (11) and fig. (5) That there is direct relationship between the puncture depth and the thermal insulation factor. This is due to that by increasing puncture depth the fabric becomes more compacted and create pores of dead air that cause the entrapment of heat and minimize heat transfer thus increase fabrics thermal insulation properties.

3.3. Fabric air permeability:

Table (12): Fabric air permeability measurements results

Fabric air permeability (cm^3/cm^2/sec)				
Type of fiber		Glass wool	Jute	Waste
Weight gm/m^2		2000 gm/m^2	1800 gm/m^2	1500 gm/m^2
Puncture depth (mm)	9	20.39	16.85	28.04
	11	18.78	15.68	26.83
	13	16.88	14.58	25.31

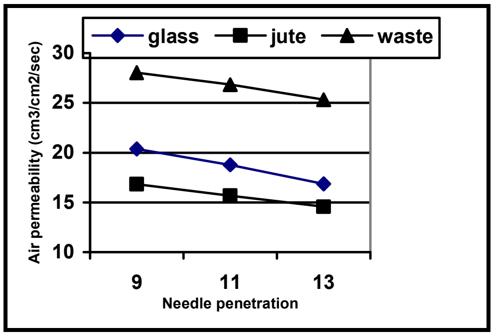

Fig. (6)
Effect of the fabric type and needle penetration depth (mm) on the air permeability measurements results

Table (13)
Regression equation and correlation coefficient for the
Effect of the fabric type and needle penetration depth (mm) on the air permeability measurements results

Layer type	Regression equation	Correlation coefficient
Glass wool	Y = -0.8775 * X + 28.3358	-0.99886
Jute	Y = -0.5675 * X + 21.9458	-0.99984
Waste	Y = -0.6825 * X + 34.2342	-0.99786

3.3.1. Effect of the types of fabric on the air permeability:

It is obvious from table (12) and fig. (6) That the samples of waste have recorded the highest air permeability compared to the samples of glass wool whereas the samples of jute have scored the lowest air permeability. This can be explained that the samples of waste have lowest weight and higher thickness than the jute samples which means the decrease in number of fibers per unit area which leads to increase the spaces between the fibers which allows the largest amount of air through them. Also the jute samples recorded the lowest amount of air permeability due to the increased weight and decreased thickness compared to the waste samples which mean increasing in number of fibers per unit area and thus decrease the spaces between the fibers hence the little amount of air through them also which means the increase in fabric density the decrease in air permeability.

3.3.2. Effect of the needles penetration depth on the air permeability:

It can be seen from table (12) and fig. (6) That there is an inversely proportional relation between the needles penetration depth and the fabric air permeability. This can be attributed to the increase in needles penetration depth cause increasing fabric compactness and decreases the spaces between fibers leading to the decrease of fabric air permeability.

3.4. Fabric thickness:

Table (14): Fabric thickness measurements results

				Fabric thickness (mm)
Type of fiber		Glass wool	Jute	Waste
Weight gm/m2		2000 gm/m2	1800 gm/m2	1500 gm/m2
Puncture depth (mm)	9	16.17	10.3	15.12
	11	15.06	9.8	14.38
	13	14.16	9.2	13.52

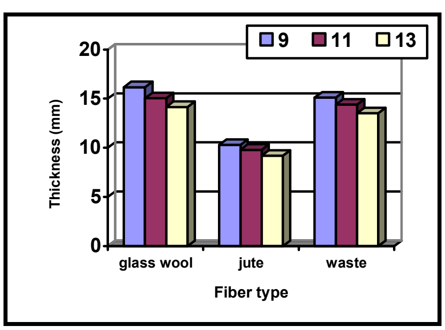

Fig. (6)
Effect of the fiber type and needle penetration depth (mm) on the Fabric thickness measurements results

3.4.1. Effect of fabric type on the thickness of fabric:

It is clear from table (14) and fig. (7) That the nonwoven glass wool fabric has higher thickness than the nonwoven waste fabric whereas the nonwoven jute fabric has the lowest thickness. This can be explained as the difference between properties of material and the method of structure for every type of fabric.

3.4.2. Effect of the needles penetration depth on the fabric thickness:

It is clear from table (14) and fig. (7) That there is an inversely proportional relation between the needles penetration depth and the fabric thickness. This can be attributed to the increase in needles penetration cause fibers to be reoriented and so increasing the contact between the horizontal and vertical level structure increasing fabric compactness and decreases the space between fibers leading to decrease of fabric thickness.

3.5. Density of fabric:

Density is a characteristic property of a substance. The density of a substance is the relationship between the mass of the substance and how much space it takes up (volume). Density equals to the mass of the substance divided by its volume. $D = M/V$.

Table (15): Fabric density measurements results

Fabric density (gm/cm^3)				
Type of fiber		Glass wool	Jute	Waste
Weight gm/m^2		2000 gm/m^2	1800 gm/m^2	1500 gm/m^2
Puncture depth (mm)	9	0.1236858	0.1747573	0.0992063
	11	0.1328021	0.1836735	0.1043115
	13	0.1412429	0.195622	0.1109467

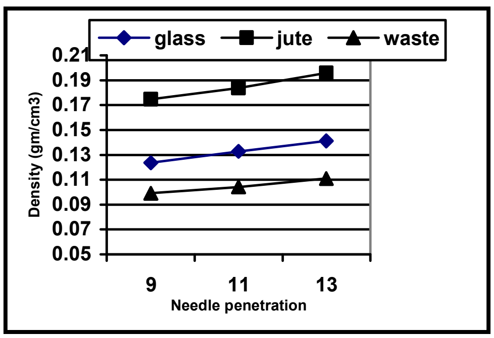

Fig. (8)
Effect of the fiber type and needle penetration depth (mm) on the Fabric density measurements results

Table (16)
Regression equation and correlation coefficient for the
Effect of the fiber type and needle penetration depth (mm) on the Fabric density measurements results

Layer type	Regression equation	Correlation coefficient
Glass wool	Y = 0.00438928 * X + 0.0842949	**0.999753**
Jute	Y = 0.00521617 * X + 0.127306	**0.996498**
Waste	**Y = 0.0029351 * X + 0.0725354**	**0.997181**

It is clear from table (15) and fig. (8) That the samples of jute have recorded the highest density compared to samples of glass wool whereas the samples of waste have recorded the lowest density of fabric. It can also be seen from the results that there is a direct relationship between fabric density and puncture depth this is due to that by increasing puncture depth the thickness will be decreased with constancy of weight which leads to increased density of fabric.

4. Conclusion:

In this study, samples of non woven fabrics were produced for sound absorption and thermal insulation in cars by using three types of materials. Many results were reached for example.

- The types of materials and weight have great impacts on the sound absorption coefficient, thermal insulation and air permeability.
- The samples of jute have recorded the highest sound absorption then the samples of waste then the glass wool samples at the frequency range from 100: 250 Hz and 4000: 6300 Hz.

- The samples of glass wool recorded the highest sound absorption then the waste samples then the jute samples at the frequency range from 315: 3150 Hz.
- The Samples of glass wool have recorded the highest thermal insulation factor then the jute sample whereas the waste samples have recorded the lowest thermal insulation factor.
- The samples of waste have recorded the highest air permeability then the glass wool samples whereas the jute samples have recorded the lowest air permeability.
- There is a direct relationship between the needle penetration depth and thermal insulation factor and the density.
- There is inversely proportional relation between the sound absorption coefficient, air permeability and thickness. Which means, increasing of thickness, leads to decreasing of sound absorption coefficient and air permeability.

5. REFERENCES

[1] Francesco D'Alessandroa, Giulio Pispolab, "Sound absorption properties of sustainable fibrous materials in an enhanced reverberation room", inter-noise 2005.

[2] D. V Parikh, Y. Chen and L. Sun. Reducing Automotive interior Noise with Natural Fiber Nonwoven Floor Covering System. Textile Research Journal. Vol. 76 (2006), pp 813-820.

[3] Hoda S. Seddeq, "Factors influencing Acoustic Performance of Sound Absorptive Materials", Australian Journal of Basic and Applied Sciences, 2009.

[4] M. Tascan, E. A. Vaughn, K. A. Stevens and P. J. Brown, "Effects of total surface area and fabric density on the acoustical behavior of traditional thermal-bonded high loft nonwoven fabrics" Journal of the Textile Institute, Vol. 12, Issue 9, 2011.

[5] Shoshani, Y., Yakubov, Y., "Numerical Assessment of Maximal Absorption Coefficients for Nonwoven Fiber webs", Appl. Acoust. 59, 77-87 (2000).

[6] A. Izewska, "Measurement uncertainty of the sound absorption coefficient", Acoustics 2008 Paris, 3979-3983.

[7] Arenas, J. P., and Crocker, M. J. "Recent trends in porous sound absorbing materials", sound and vibration 2010, 44 (7), 12-18.

[8] Chao-Nan Wang, Yan-Min Kuo, Shih-Kai Chen, "Effects of compression on the sound absorption of porous materials with an elastic frame", J. Applied acoustics 2008, Vol. 69, issue 1, PP. 31-39.

[9] Mevlut Tascan and Edward A. Vaughn, "Effect of total surface area and fabric density on the acoustical behavior of needle punched nonwoven fabric", Textile Research Journal. Vol. 78, (2008), PP. 289.

[10] Merve Kucukali, Banu Uygun Nergis, Cevza Candan, "A study of the influences of fabric structure on sound absorption behavior of spacer knitted structure", 7th international conference TEXSCI (2010).

[11] X. Tao, "Smart fibers, Fabrics and clothing" The textile Institute, Woodhead Publishing Ltd., 2001.

[12] Jirsak, O., "Thermo-insulating properties of perpendicular-laid versus cross-laid lofty nonwoven fabrics", Textile Res. J., Vol. 20, No. 2, PP. 121-128, 2000.

[13] Y. L. Bozec, S. Kaang, and others, "The thermal expansion behavior of hot compacted polypropylene and polyethylene composites", Composites Science and Technology, 60 (2), 2000, 333-344.

[14] Z. S. Abdel-Rahim, M. M. Saad, and Others, "Textile fabrics as thermal insulators", AUTEX Research Journal, 6 (3), 2006, 148-161.

[15] E. Payne, B. T. Perry, and Others, "Thermal barriers for buildings appliances and textiles, U. S. Patent, no. 5532039, July, 1996, 4.

[16] S. Adanur, Wellington sears Handbook of industrial Textiles (Technomic Publishing Company Inc., Lancaster, Pennsylvania, 1995).

[17] G. Dziworska, and J. Bilska, "Comparative analysis of the thermal insulation properties of fabrics made of natural and man-made cellulose fibers", Fabrics and Textiles in Eastern Europe, Dec., 2002, 40-44.

[18] ASTM–E 1050-1982, "Standard test method for measuring sound absorption coefficient ".

[19] ASTM-D 1518, "Standard test method for measuring thermal transmittance of textile materials".

[20] ASTM-D 4491-92, "Standard test method for measuring air permeability ".

[21] ASTM-D 17777,"Standard test method for measuring fabric thickness".