"Application of Nonwoven Fabrics Produced from Textile Waste and Hollow Fibers as Thermal Insulation in Automotative Industry"

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Abstract

In this research an attempt was made to produce nonwoven fabrics to be used as thermal insulation in automotive industry. The produced fabrics were placed between the motor and the driver cabin. Three kinds of textile waste materials were used namely, polyacrylic, polypropylene and polyester hollow fibers. Two blends were formed from these textile waste, namely, polypropylene/polyacrylic (50/50 %) (waste blend 1) and polyester hollow fibers/polypropylene/polyacrylic (35/15/50 %) (waste blend 2). These two blends were used to produce different nonwoven samples having different construction. Monitoring the samples for thermal insulation and thickness were carried out. Results obtained showed that all samples showed different degree of insulation, depending on fiber type, puncture depth, number of beats/min and fabrics weight. Moreover, the sample produced from waste blend 2 and having puncture depth 20 mm, 950 beats/min as well as 2500 g/m^2 gave the best results.

Introduction

Nonwovens in automotive industry

The automotive industry has become so competitive that manufactures are reluctant to divulge precise details of their process for fear that it could be helpful to their competitors. Industrial textiles are widely used in transportation vehicles and systems including cars, trains, buses, airplanes and marine vehicle [(1)] Automotive textiles are very growing market in terms of quantity, quality, and product variety [(2)]

Over the last decades, the field of non-conventional textiles has been witnessing a material revolution, which has resulted in improved and economical products. [(3)]

The motor vehicle remains an important means for individual transport worldwide and the interior of transportation vehicles is receiving more attention these days. Acoustical insulation products are frequently used in automotive interiors to reduce heat levels [(4)] they are also used to cover vehicle interior cladding materials. Interior décor textiles have a considerable predominantly stylistic function, as they give the vehicle an interior pleasant cosy feeling [(5)]

Nonwovens are fabrics made by bonding webs of fibers through mechanical, chemical or physical means [(6)]. There is a very wide scope of utilization of various types of nonwoven textiles in different fields of industry [(7)]. Nonwoven have become a major importance in all types of industries, they have grown to such importance, that we hardly can live without. The use of nonwoven structures in automobiles today, as well as in all transportation industries, is very large and quite diverse and its use is not limited to certain area of the vehicle.

Automotive uses of nonwoven fabrics were introduced in the early 1950 s, when needlepunched waste fibers were adapted for thermal insulation.

Nonwoven is employed as fabrics for different kinds of interior applications such as seat covers, door and side panels, roof substrate and headlining, they are also used for floor covering such as car pelts and as lining in the trunk compartment, and as sound and thermal insulation materials[(8)]. In general applications of nonwoven in cars can be classified into functional or aesthetic uses but there is a third category- that of substitutes for other materials.

Nonwoven can be made in a wide range of densities and different forms, the use of nonwoven is increasing because of their versatility their and low cost, so they can be used as substitutes for more expensive materials, in addition they are easy to work with, retain their shape when molded and are easily recycled [1]

Use of textiles in thermal insulation

Thermal resistance is the ability of the fabric to remain relatively unchanged when exposed to radiant, conductive and connective heat. [9] The performance of thermal fabrics depends on its ability to insulate and to maintain structural integrity when exposed to high heat assault [10]

The influence of heat on the properties of fibers is of paramount importance with respect to textile processing as well as use .The materials most frequently utilized in thermal insulation are polypropylene, polyester and polyacrylic, in this research waste and hollow fibers are used [9]

Blended waste

The necessity and importance of protecting our environment is evident in this time and the high-developed industrial nations are responsible in the first position. [11] In recent years waste management has become an important issue along with the stricter environmental protection regulations for reducing these waste at the source of origin, and so recycling has been advocated to be possible solution to the ever growing waste problems at both processor and consumer levels. [12] The concept and practice of recycling have been a well – established part of textile industry since the first industrial revolution and even today ,[13] as garbage dumps of our industrial society are getting higher every day. When producing and processing industrial products of all kinds, the formation of waste materials cannot be avoided –this also applies to the textile and nonwoven industry ,[14] as textile industry is considered one of those industries that creates a whole series of environmental risks. Textile waste are not only produced during the processing ,finishing and making –up of textile, but also after the consumers and industrial sectors have finished with the textile products .[15] Textile waste resulting from production and used textiles are today largely disposed ,dumped or burnt . [16] Because of the increasing of price and growing shortages of raw materials and costs, the textile industry has the assignment of integrating textile waste into its technological and commercial thinking .It is therefore the tasks of machinery manufacturers to indicate applications ,processes ,and means in which textile waste can be used for optimum recycling . Recycling is the most viable approach for reducing solid waste stream after source reduction, as the main goal of textile recycling efforts is to reprocess the textiles and fibers , so they can be recycled back into the original stream or into useful end products. This also means that plans for waste recycling must offer extremely flexible production possibility [17]

Waste sources

Synthetic fiber production, blow room in spinning process ,weaving ,knitting ,garment making ,machine made carpets ,re-claimed textile product and nonwoven manufacture [18]

Typical nonwoven products made from recycled textiles are as follow :

Automobile industry it includes sound and thermal insulating webs, hard pressed parks for floors, side and seat lining, trunk compartment, luggage dump …etc , bottom felts for carpeting ,stitch –bonded nonwoven (maliwatt, malivlies)

Furniture it includes mattress covers, mattress web ,bottom webs for seating furniture ,upholstery materials ,wadding materials wiping cloths and needled webs.

Carpet industry it includes bottom felts for carpeting ,building industry ,sound and thermal insulting webs ,filter products ,nonwoven coating , substrates ,footfall sound insulation ,textile shreds as filling materials for insulating webs [19]

Hollow fibers

The technology behind hollow fibers was discovered in the late 1980s. it wasn't until the mid –1990s that this technology was successfully applied in fibers . In 1980s and early 1990s, hollow fibers worked to find way to use materials often found in aerospace applications and combine them with textile fibers. [20]

For a number of years now , melt –spinning and wet spinning process have been used to produce hollow fibers . [21] Hollow fibers are made of a sheath of fiber material with a hollow space at the center , this hollow may be formed in a number of different ways .the fiber may be made with a core of one material and a sheath of another , and then the central material is dissolved out . or by using an inert gas that may be added to the solution from which the fiber is formed ,with the gas bubbles creating a hollow area in the fiber .

Hollow fibers provide greater bulk with less weight,. they are therefore ,often used to make insulated fabrics .[22]

II .The experimental work

Two kinds of textile waste. materials were used in this research, polyester hollow fibers and polypropylene polyacrylic fibers. Non woven construction was used for producing all samples, it depended on using random- laid web with needle punching process for web bonding.

Table (1) specifications of the machine used for producing all samples

No	Property	Specifications
1	Model	180
2	Type	59 TOYKCOING
3	Company name	ELBUF
4	Year of manufacture	1983
5	The manufacture country	Austria
6	Width of the machine	2 m

Table (2) specifications of samples produced in this research.

No	Property	Specifications
1	Type of fiber	Waste blended of polypropylene 50% and polyacrylic 50 % (waste blend 1) - Waste blended of polypropylene15%, polyacrylic 50% and polyester hollow fibers 35 %. (waste blend 2)
4	Web formation	Random –laid
5	Web bonding	Needle punching
6	Weight (g/m^2)	1000,1500, 2000 and 2500 (g/m^2)
7	Number of beats /min	600 ,800 and 950 beats /min
8	Puncture depth	12, 16 and 20 mm

Tests

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

Thermal insulation of fabrics, this test was carried out according to the (ASTM-D 1682) where the samples were exposed to 130 ^{0} C and its well known that cooling in car motor begins at 80 ^{0} C [23]

Fabric thickness, this test was carried out according to the ISO 2094 & BS 4052 [24]

III-Results and Discussion

Results of experimental tests carried out on the produced samples were presented in the following tables and graphs. And were statically analyzed for statistically

Through this research, it was reached to the following results

1- It is obvious from the statistical analysis of thermal insulation results and diagrams from 1 to 12 beside of figure 14 that there are direct relationship between weight/m^2 and thermal insulation. I can state that the increase of fibers in unit area, due to the increase in fabric weight, causing spaces in the fabric to be decreased but air sinuses are increased, and so quantity of lost heat is decreased, causing an increase in thermal insulation

2- It can be seen from table (3) and figures from (1) to (10) that the more number of beats/min and puncture depth, the higher thermal insulation the samples become. I can report that the increase in puncture depth and number of beats /min cause fabrics compaction due to the decrease in fabrics thickness, cause the produced samples to be compacted, so air spaces in the fabrics will be decreased but air antrum are increased, and so quantity of lost heat is decreased, causing an increase in thermal insulation

3-It is also clear from table (3) and diagrams from (11) to (13) that samples produced with waste blend 2 had recorded the highest rates of thermal insulation, whereas samples produced waste blend 1 have recorded the lowest rates. I can report that samples produced with waste blend 2 contain hollow fibers, which contain air sinuses and so quantity of lost heat is decreased, leading to an increase in thermal insulation

4- It is obvious from the statistical analysis of thermal insulation results that there are direct relationship between product density and thermal insulation. I can state that the increase in density produced, cause the produced samples to be compacted, cause to a decrease air spaces in the fabrics but air sinuses are increasing, and so quantity of lost heat is decreased, causing to an increase in thermal insulation

5- It is obvious from the statistical analysis of thermal insulation results in table (3) and diagrams from (14) to (16) that there is an inverse relationship between exposure time and thermal insulation. I can state that the increase in exposure time, cause a decrease in heat resistance , so quantity of lost heat is increased, causing decrease in thermal insulation

6- Tables from (21) to (28) show critical F- test and tabulate F- test for the effect of weight /$m^{2,}$ and puncture depth, weight /m^2 and fiber type, weight /m^2 and number of beats /min on thermal insulation and the interaction between them ,from theses tables it is clear that there is a highly significant effect of weight /$m^{2,}$ and fiber type and interaction between them ,also number of beats /min and weight /m^2 on thermal insulation ,and interaction between them for samples produced with waste blend 2 , whereas there is a highly significant effect of weight /$m^{2,}$ and number of beats/min and interaction between them for samples produced with waste blend 1. Also there is a highly significant effect of puncture depth and fiber type, puncture depth and number of beats /min on thermal insulation and interaction between them, besides there is a highly significant effect of puncture depth and weight /$m^{2,}$ on thermal insulation , whereas interaction between them is significant. Also there is a highly significant effect of number of beats /min and fiber type on thermal insulation, whereas the interaction between them is significant .

7-It is also clear from table (3) and diagrams (18, 20 and 23) that there is an direct relationship between, number of beats /min and the decrease in fabric thickness, I can report that the increase in number of beats / min causes the fabric to be more compacted which cause the decrease in fabric thickness under load.

8- It is obvious from the statistical analysis and diagrams (17,18.19 and 21) thickness results that there are direct relationship between weight /m^2 and fabric thickness .I can state that the increase of fibers in unit area, cause an increase in fabric thickness

9-It is also clear from table (4) and diagrams (17,20 and 22) that there is an inverse relationship between puncture depth and fabric thickness, I can report that the increase in puncture depth cause the fabric to be more compacted which cause the decrease in fabric thickness .

10-It is also clear from tables (36) to (41) of critical F- test and tabulate F- test that there is a highly significant effect of weight /$m^{2,}$ and number of beats /min , weight /$m^{2,}$ and fibers type on thickness ,whereas the interaction between them is significant, also there is a highly significant effect of weight /m^2 and puncture depth on thickness and interaction between them ,besides of there is a highly significant effect of number of beats /min and fiber type on thickness, whereas the interaction between them is significant,. Also there is a highly significant effect of puncture depth and fiber type, puncture depth and number of beats /min on thickness and interaction between them is significant

11-It is also clear from figure (24) that samples produced waste blend 2, puncture depth 20, 950 beats/min and 2500 g/m^2 has achieved the best results by Radar analysis (samples no 36),where has achieved thermal insulation 83 %

12-Table (4) shows F test for all variables used in this research (number of beats /min, weight /m^2, puncture depth, fibers type). It is clear from this table that all variables had a highly significant effect on fabrics properties, as shown from α 1 to α 32 (α=>0.01).

Table (4) F test for the effect of all variables used in this research on the properties of the produced samples

No	F test	No	F test	No	F test
α 1	0.00295584	**α 12**	0.000003899	**α 22**	0.00000743
α 2	0.00202430	**α 13**	0.000002033	**α 23**	0.00000009
α 3	0.00104053	**α 14**	0.000008232	**α 24**	0.00000043
α 4	0.00098722	**α 15**	0.000000833	**α 25**	0.00000025
α 5	0.00124167	**α 16**	0.000000933	**α 26**	0.00000123
α 6	0.00214167	**α 17**	0.000000373	**α 27**	0.00000693
α 7	0.00000389	**α 18**	0.000000699	**α 28**	0.00000159
α 8	0.00000723	**α 19**	0.000000001	**α 29**	0.00000063
α 9	0.00000929	**α 20**	0.000000036	**α 30**	0.00000159
α 10	0.00000823	**α 20**	0.000000017	**α 31**	0.00000176
α 11	0.00000823	**α 21**	0.000000018	**α 32**	0.00000153

Table (5) multi regression equation for the effect of weight /m^2 and puncture depth on thermal insulation, at 800 beats /min and exposure time 150 minute, for samples produced waste blend 1.

Multi regression equation
$Z= 42.692X +0.563X+0.002Y-0.02X^2-1.333e-6Y^2$

Table (6) regression equation and correlation coefficient for the effect of weight /m^2 and puncture depth on thermal insulation, at 600 beats /min and exposure time 90 minute, using waste blend 2.

Puncture depth	**Regression equation**	**Correlation coefficient**
12	Y = -0.0025 X+52.3333	-0.993399
16	Y = -0.0025 X+50.16667	-0.993399
20	Y = -0.004 X+51.5	-1

Table (7) regression equation and correlation coefficient for the effect of weight /m^2 and puncture depth on thermal insulation, at 600 beats /min and exposure time 180 minute, using waste blend 1.

Puncture depth	**Regression equation**	**Correlation coefficient**
12	Y = -0.0037 X+49.85	−0.992278
16	Y = -0.0034 X+51.7	-0.98778
20	Y = -0.0037 X+36.6	-0.997816

Table (8) regression equation and correlation coefficient for the effect of weight /m^2 and puncture depth on thermal insulation, at 800 beats /min and exposure time 150 minute, using waste blend 2 .

Puncture depth	Regression equation	Correlation coefficient
12	Y = -0.003 X+47.16667	-0.981981
16	Y = -0.006X+45.3333	-0.981981
20	Y = -0.0025 X+34.5	-0.944011

Table (9) multi regression equation for the effect of weight /m^2 and puncture depth on thermal insulation, at 950 beats /min and exposure time 60 minute, using waste blend 2.

Multi regression equation
$Z= 37.358X +0.544X+0.004X^2-1.333e\text{-}6Y^2$

Table (10) regression equation and correlation coefficient for the effect of weight /m^2 and number of beats / min on thermal insulation, at puncture depth 12 mm and exposure time 30 minute, using waste blend 1 .

Number of beats /min	Regression equation	Correlation coefficient
600	Y = -0.0018 X+46.15	-0.858116
800	Y = -0.0064 X+48.7	-0.943629
950	Y = 0.0037 X+36.6	-0.983611

Table (11) regression equation and correlation coefficient for the effect of weight g/m2 and number of beats /min on thermal insulation, at puncture depth 12 mm and exposure time 30 minute, using waste blend 2.

Number of beats /min	Regression equation	Correlation coefficient
600	Y = -0.75 X+49.16667	-0.901127
800	Y = -0.75X+43.66667	-0.981981
950	Y = -0. 25 X+32	-1

Table (12) multi regression equation for the effect of weight /m^2 and number of beats/min on thermal insulation, at puncture depth 20 mm and exposure time 90 minute, using waste blend 2.

Multi regression equation
$Z= 29.557X +0.03X+0.002Y+2.459e\text{-}6XY-1.833e\text{-}6Y^2$

Table (13) multi regression equation for the effect of weight /m^2 and number of beats /min on thermal insulation, at puncture depth 16 mm and exposure time 120 minute, using waste blend 2 .

Multi regression equation
$Z= 42.297X +0.025X+0.007Y-5.459e\text{-}6XY-2.333e\text{-}6Y^2$

Table (14) regression equation and correlation coefficient for the effect of number of beats /min and weight /m^2 on thermal insulation, at puncture depth 20 mm and exposure time 60 minute, using waste blend 1

Number of beats /min	Regression equation	Correlation coefficient
600	Y = -0.0078 X+55.9	-0.955779
800	Y = -0.0074X+50.95	-0.985354
950	Y = -0.0029X+38.45	-0.991779

Table (15) regression equation and correlation coefficient for the effect of weight /m^2 and fibers type on thermal insulation, at puncture depth 20 mm and 950 beats /min and exposure time 30 minute

Fibers type	Regression equation	Correlation coefficient
Waste blend 2	Y = -0.0035 X+35	-0.972598
Waste blend 1	Y = -0.0021X+31.55	-0.984495

Table (16) regression equation and correlation coefficient for the effect of weight g/m2 and fibers type on thermal insulation, at puncture depth 12 mm, 800 beats /min , 1500 g/ m^2 and exposure time 30 minute

Fibers type	Regression equation	Correlation coefficient
Waste blend 2	Y = -0.002 X+34.75	-0.830455
Waste blend 1	Y = -0.0022X+33.1	-0.98387

Table (17) regression equation and correlation coefficient for effect of number of beats and fibers type on thermal insulation, at puncture depth 20 mm, 1000 g/m2 and exposure time 60 minute

Fibers type	Regression equation	Correlation coefficient
Waste blend 2	Y = -0.01919 X+35	-0.931553
Waste blend 1	Y = -0.03073X+55.17162	-0.960964

Table (18) multi regression equation and correlation coefficient for the effect of weight /m^2 and exposure time on thermal insulation, at puncture depth 12 mm and 800 beats /min, using waste blend 1 .

Multi regression equation	Correlation coefficient
Z= -0.00593X +0.035863 Y+46.27232	-0.932928

Table (19) multi regression equation and correlation coefficient for the effect of product density and exposure time on thermal insulation ,at puncture depth 16 mm and 950 beats /min ,using blend 1 .

Multi regression equation	Correlation coefficient
Z= -39.695X +0.037054 Y+39.30178	-0.954704

Table (20) multi regression equation and correlation coefficient for the effect of product density and exposure time on thermal insulation, at puncture depth 20 mm and 800 beats /min, using waste blend 2.

Multi regression equation	Correlation coefficient
Z= -19.4136X +0.023056 Y+37.16822	-0.961359

Table (21) tabulate F-test and critical F-test for the effect of puncture depth and weight /m^2 on thermal insulation, at 950 beats /min and exposure time 60 minute, using waste blend 2.

The variables	P-value	Tabulate F-test	Critical F-test
Weight /m^2	0.0000	77.81248	3.008786
Puncture depth	0.0000	44.25259	3.402832
Interaction	0.010064	3.661886	2.508187

Table (22) tabulate F-test and critical F-test for the effect of number of beats /min and weight /m^2 on thermal insulation, at puncture depth 12 mm and exposure time 120 minute, using waste blend 1.

The variables	P-value	Tabulate F-test	Critical F-test
Number of beats /min	0.0000	355.8042	3.008786
Weight /m^2	0.0000	1526.708	3.402832
Interaction	0.0000	21.89103	2.508187

Table (23) tabulate F-test and critical F-test for the effect of weight /m^2 and fibers type on thermal insulation, at 950 beats /min and exposure time 30 minute

The variables	P-value	Tabulate F-test	Critical F-test

weight /m^2	0.0000	3.238887	69.29154
fibers type	0.0000	4.493998	30.721
Interaction	0.000118	13.53396	3.238867

Table (24) tabulate F-test and critical F-test for the effect of number of beats /min and puncture depth on thermal insulation, at 1000 g/m^2 and exposure time 90 minute , using waste blend 1.

The variables	P-value	Tabulate F-test	Critical F-test
Number of beats /min	0.0000	49.73451	3.554561
Puncture depth	0.0000	413.5278	3.554561
Interaction	0.0009345	4.65438	2.927749

Table (25) tabulate F-test and critical F-test for the effect of number of beats /min and puncture depth on thermal insulation, at 1500 g/m^2 and exposure time 30 minute , using waste blend 2.

The variables	P-value	Tabulate F-test	Critical F-test
Puncture depth	0.00000	185.1337	3.554561
Number of beats /min	0.00000	726.1324	3.554561
Interaction	0.00000	25.91803	2.927749

Table (26) tabulate F-test and critical F-test critical for the effect of puncture depth and fibers type on thermal insulation, at 800 beats /min and exposure time 60 minute.

The variables	P-value	Tabulate F-test	Critical F-test
Fibers type	0.00000	247.6802	3.238867
Puncture depth	0.00000	3127.683	4.493998
Interaction	0.00000	24.44526	3.238867

Table (27) tabulate F-test and critical F-test for the effect of number of beats /min and weight /m^2 on thermal insulation, at puncture depth 20 mm and exposure time 90 minute, using waste blend 2 .

The variables	P-value	Tabulate F-test	Critical F-test
Number of beats /min	0.00000	21.16988	3.008786
Weight g/m^2	0.00000	36.70623	3.402832
Interaction	0.01542379	1.742379	2.508187

Table (28) tabulate F-test and critical F-test for the effect of number of beats /min and fibers type on thermal insulation, at puncture depth 20 mm and exposure time 60 minute and 2000 g /m^2.

The variables	P-value	Tabulate F-test	Critical F-test
Number of beats /min	0.00000	509.3805	3.88529
Fibers type	0.00000	132.5976	4.747221
Interaction	0.00000	23.95817	3.88529

Table (29) regression equation and correlation coefficient for the effect of weight /m^2 and puncture depth on thickness, at 600 beats /min, using waste blend 1, without loud.

Puncture depth	Regression equation	Correlation coefficient
12	Y = -0.00042 X+7.816667	-0.998492
16	Y = -0.00039 X+7.673333	-0.99674
20	Y = -0.0004 X+7.486667	-0.980188

Table (30) regression equation and correlation coefficient for the effect of weight /m^2 and number of beats /min, on thickness, at puncture depth 12 mm /min using waste blend 2 , under loud.

Number of beats /min	Regression equation	Correlation coefficient
600	Y = -0.0005 X+6.115	-0.993504
800	Y = -0.000548 X+5.841	-0.988455
950	Y = -0.000412 X+5.889	-0.995279

Table (31) multi regression equation for the effect of weight /m^2 and number of beats / min on thickness, at puncture depth 16 mm , using waste blend 2, under loud .

Multi regression equation
$Z= 3.804X +0.005X-3.607e-6X^2-1.778e-6XY-7e-8Y^2$

Table (32) regression equation and correlation coefficient for the effect of puncture depth and number of beats /min on thickness, at 2500 g /m^2 ,using with waste blend 2 ,without loud .

Puncture depth	Regression equation	Correlation coefficient
12	Y = -0.00179 X+9.873649	−0.80955
16	Y =- 0.00179 X+9.427973	-0.986768
20	Y = -0.00191 X+9.428919	-0.984839

Table (33) regression equation and correlation coefficient for the effect of fibers type and weight /m^2, on thickness, at 800 beats /min and puncture depth 20 mm, under loud

Fibers type	Regression equation	Correlation coefficient
Waste blend 2	Y = 0.000576 X+5.312	0.997741
Waste blend 1	Y = 0.000586 X+5.492	0.96929

Table (34) regression equation and correlation coefficient for the effect of fibers type and puncture depth on thickness, at 950 beats /min and 2000 g/ m^2, using waste blend 2, without loud.

Fibers type	Regression equation	Correlation coefficient
Waste blend 2	Y = - 0.02375 X+7.886667	−0.999539
Waste blend 1	Y = -0.02125 X+7.95	−0.99485

Table (35) regression equation and correlation coefficient for the effect of fibers type and number of beats /min on thickness, at puncture depth 12 mm and 1500 g/ m^2, under loud

Fibers type	Regression equation	Correlation coefficient
Waste blend 2	Y = -0.00128 X+7.54473	−0.980316
Waste blend 1	Y = -0.00122 X+7621498	−0.98275

Table (36) tabulate F-test and critical F-test for the effect of weight /m^2 and number of beats /min on thickness, at 950 beats/min, and 1500 g/ m^2, using waste blend 2, under load .

The variables	P-value	Tabulate F-test	Critical F-test
weight /m^2	0.0000	517.9852	3.554561
Puncture depth	0.0000	234.6396	3.554561
Interaction	0.0000	88.13307	2.927749

Table (37) tabulate F-test and critical F-test for the effect of weight /m^2 and number of beats /min on thickness, at puncture depth 16 mm , under load ,using with waste blend 2

The variables	P-value	Tabulate F-test	Critical F-test
weight /m²	0.0000	59.49945	3.008768
Number of beats /min	0.0000	22.84102	3.402832
Interaction	0.0144053	1.788699	2.508187

Table (38) F tabulate F-test and critical F-test l for the effect of puncture depth and number of beats /min on thickness, at 1000 g/m^2 , without load ,using waste blend 2

. The variables	P-value	Tabulate F-test	Critical F-test
Puncture depth	0.0000	1.007595	3.008768
Number of beats /min	0.0000	1.007928	3.402832
Interaction	0.00448114	88.13307	2.9277749

Table (39) tabulate F-test and critical F-test for the effect of puncture depth and fibers type on thickness, at 950 beats / min , and 2000 g/ m^2 ,without load

The variables	P-value	Tabulate F-test	Critical F-test
Puncture depth	0.0000	53.11197	3.88529
Fibers type	0.0000	36.32775	4.747221
Interaction	0.00204817	1.814903	3.88529

Table (40) tabulate F-test and critical F-test for the effect of weight /m^2 and fibers type thickness, at puncture depth 20 mm , and 800 beats /min ,under load

The variables	P-value	Tabulate F-test	Critical F-test
weight /m²	0.0422292	0.990478	3.238867
Fibers type	0.0331856	1.001448	4.493998
Interaction	0.0417699	1.001273	3.238867

Table (41) tabulate F-test and critical F-test for the effect of number of beats /min and fibers type on thickness, at puncture depth 12 mm, and 1500 g/ m^2 ,under load

The variables	P-value	Tabulate F-test	Critical F-test
Number of beats /min	0.00000	211.5798	3.88529
Fibers type	0.00000	46.32775	4.747221
Interaction	0.020215	5.495798	3.88529

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