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THERMO-INSULATION PROPERTIES OF CROSS-LAID NONWOVEN FABRICS MADE OF PET AND PP WASTE FIBERS

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ABSTRACT

Thermal properties are among the most important features of textiles that are used for personal protection and protection of objects. This research deals with thermal insulation properties of cross-laid nonwoven fabrics made of waste fibers (polyester and polypropylene fibers). In this research 72 samples were produced with cross-laid nonwoven technique and bonded using needle punching method using two groups of waste fibers ,waste blend (1) composed of polypropylene / polyester waste fibers of 50/50 blend and the waste blend (2) composed of polypropylene / polyester /polyester hollow waste fibers of 15/50/35 blend. Four fabric weights were produced 300, 600, 900 and 1200 g/ m^2 with three number of beats 600, 800 and 950 beats/min. and three puncture depths 12, 16 and 20 mm. Different parameters including fiber type, puncture depth, fabric weight and number of beats per unit area were studied and their influence on the performance of the end-use fabrics were also studied. The results demonstrated that thermal insulation properties of fabrics are increased by adding hollow fibers and increasing fabrics weight and both puncture depth and number of beats/min.

***Keywords*: *Nonwoven Fabrics, Solid Waste Management, Recycling Of Textile Wastes, Technical Textiles, Thermal Protective Fabrics, Thermal Insulation Properties Of Textiles, Waste Fibers*.**

I. INTRODUCTION

The rate of growth in consumption of fibers designed for technical applications , however , is now faster than those going to traditional clothing and furnishing sectors. Much of this growth will depend on greater realization of technological and functional benefits that fiber-based structures could bring to the traditional and unyielding sectors of engineering. [1] The increasing emphasis on human protection and the continued introduction of health , safety and environmental legislation means that the technical textiles market continues to be buoyant and thrive. [2]

Protective and safety textiles are technical textiles with high-tech character in many cases, as it includes protection against cuts, abrasion, ballistic and other types of severe impact, fire and extreme heat, hazardous dust and particles, biological and chemical hazards, extreme cold, static electricity, etc. [2]& [3]

Issues such as environment, recycling and biodegradability, which are increasingly subjects of concern for the public, will further encourage and benefit the growth and use of technical textiles. [1] Thus this paper aims at effective usage of waste polyester and polypropylene fibers into useful nonwoven products used in thermal insulation applications .

1.1 Thermal Insulation Properties of Fabrics

It is a major cause of death in areas where there is a severe climate especially in high temperatures work areas, which is the main concern of this research, so fabrics with good thermal insulation must reduce heat transfer to weather to achieve comfort for the user or give adequate time for escape before burn damage occurs. [4] Fabrics for thermal insulation purposes are also used in walls and ceiling of buildings , walls of home appliances and other applications to prevent heat from being conducted either into or out from an enclosed environment so that a desired temperatures can be maintained inside. [5] So safety and protective materials used in thermal protective textiles must often withstand the effects of multiple harsh environments without decomposition and without losing its major physical properties. [3]

1.2 Factors Affecting Thermal Insulation Properties of Fabrics

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 colder 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[6]
The thermal insulation properties of textile fabrics depend on their thermal conductivity, density, thickness and weight. [7]

The efficiency of thermal insulating materials generally depends on the amount of dead air space present within the insulative materials. Because of this, many of the commonly used insulative materials are bulky as air entrapped helps in increasing the insulation properties of the fabric. [5]

1.3 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 represent the reduction in the rate of heat loss due to the insulation, relative to the heat loss from the surface. [8]

1.4 Structure of thermal insulation fabrics

In general, fabrics made for high temperature insulation fabrics have a weight range of 2-50 ounce per square yard but for apparel fabrics being in the 6-8 oz range. [3] will and sateen weave designs are common structures for thermal insulation woven fabrics . Batting and nonwovens are used extensively 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. [3] & [5] Compound structures with more than one layer of different materials are also effective in certain applications. [3]

1.5 Fibers used in thermal insulation applications

Synthetic fibers with improved thermal stability up to 190 ^{0}C are available and are being used successfully alone or in blends for insulation applications, [1] as normally for a textile fiber to be industrially useful in heat insulation field it should not become tacky or soften bellow 300 oF . Natural fibers and regenerated cellulosic and protein fibers are not preferable as thermoplastic, they do not soften with heat, but instead char and decompose, so thermoplastic fibers are more preferable. [3]

Hollow fibers are type of core-sheath heterofil in which the core is composed of air. [9] Hollow fibers are well suited to this end use as the air entrapped in the hollow cores adds significantly to their insulation properties. [10]

1.6 Solid Waste Management

Solid wastes present challenges and opportunities to societies regardless of their sustainability awareness and technological advances. [11]

Health and safety have been the major concerns in waste management, as waste must be managed in a way that minimizes risk to human health. The first objective of waste management is to reduce the amount of waste generated and the second objective is to manage the waste in a sustainable way, by minimizing the overall environmental burden associated with the waste management system. [12]

Traditionally solid waste management has evolved as mainly the removal of municipal wastes by hauling them out of the city boundaries and dumping them there. However, with the ever increasing tonnage of refuse due to expansion of urban centers, which implies increased collection, transportation and disposal costs, recycling solid waste management. [13]

1.7 Recycling in Textiles

The textile industry suffers a great deal of material waste which is in evitable due to the variable nature of fibers, fiber-machine interaction, and the lack of purity of the raw material. [3]

Textile wastes can be classified as either pre-consumer and post-consumer wastes as recycling removes the waste from the waste stream and recycles it back into the market. [14] 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. Post-consumer waste is defined as any type of garment or household article made from manufactured textiles that the owner no longer needs and decides to discard. [3]& [4]

Unlike most recycling, a high proportion of textile reclamation takes the form of reuse of textile raw material and therefore does not involve resource intensive reprocessing. [12] Now, the textile recycling industry is now able to process 93% of the waste without the production of any new hazardous waste or harmful products. [14]

A considerable amount of reclaimed fibers is used in nonwovens. Recycled nonwoven products range from middle and lower grade to functional and industrial grades and the variation in type, fineness, length, and color of recycled fibers may causehigh variability in the properties of the finished products. [3]

II. EXPERIMENTAL WORK

2.1 Materials and Methods

In this research 72 samples were produced with cross-laid nonwoven technique and bonded using needle punching method using two groups of waste fibers , the first blend group was polypropylene / polyester waste fibers of 50/50 blend and the second blend group was polypropylene / polyester /polyester hollow waste fibers of 15/50/35 blend ,as polyester hollow fibers were added to increase fabrics insulative properties. Four fabric weights were produced 300, 600, 900 and 1200 g/ m2 with three number of beats 600, 800 and 950 beats/min and three puncture depths 12, 16 and 20 mm.

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As waste fibers were allowed to stand for 12 hours to condition the material and then thoroughly mixed in the desired proportions to get homogenous blend of fibers. Later, the mix was sprayed with an antistatic agent to reduce the static problem, by further conditioning for an additional hour. Pre-opening of the material was carried out using bale opener then the material was taken to super fine opener where further opening was carried out. Material delivered was fed through a feeder box to roller and cleaner card with increasing speed cylinders. The delivered webs were cross laid using lappers and fed to needling loom. The weight of web was adjusted by laying several layers to get weight of 300 g/ m2 . The cross laid web was then fed to the needling loom. After pre needling , several layers were again combined and re-fed to needling loom to get the final fabrics of desired weights of 300 , 600, 900 and 1200 g/ m2 .

Samples under study were subjected and exposed to 130 ^{0}C for graduated time 30, 60,90, 120 and 180 min. and readings were taken as in the following tables.

Table (1) specifications of samples under study

No	Property	Specifications
1	Type of fiber	Waste blend(1) of polypropylene / polyester waste fibers of 50-50% Waste blend (2) of polypropylene / polyester /polyester hollow waste fibers of 15-50-35%
2	Web formation	cross –laid
3	Web bonding	Needle punching
4	Weight (g /m2)	300,600, 9000 and 1200 (g /m2)
5	Number of beats /min	600 ,800 and 950 beats /min
6	Puncture depth	12, 16 and 20 mm

2.2 Tests applied to samples under study

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

1- 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 readings were taken after periods 30, 60, 90, 120, 150 and 180 minutes. [15]

2-Fabric thickness and this test was carried out according to the ISO 2094 & BS 4052 [16]

III. RESULTS AND DISCUSSION

Results of the experimental tests carried out on samples under study are presented in the following tables and graphs. Results were also statistically analyzed for data listed and relationships between variables were obtained.

Table (2) results of tests applied to samples under study produced with waste blend 1 , 600 beats /min and puncture depth 12 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1204819	8.3	6.58	44	46.5	48	49	49.5	49.5
600	0.1777251	8.44	6.91	43.5	44.5	45.5	46	47.5	48.5
900	0.233372	8.67	7.13	43.5	44	45	46	46.5	47.5
1200	0.280184	8.86	7.34	41	41.5	42.5	43	44.5	46

Table (3) results of tests applied to samples under study produced with waste blend 1 , 600 beats /min and puncture depth 12 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1231627	8.12	6.17	43.5	45	46.5	48	48.5	49
600	0.181378	8.27	6.71	42	42.5	44	45	46.5	46.5
900	0.2372497	8.43	7.98	41	42	43	44.5	44.5	45
1200	0.288683	8.66	7.22	40.5	41	42	43.5	43.5	44

Table (4) results of tests applied on samples under study produced with waste blend 1 , 600 beats /min and puncture depth 20 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.125	8.00	6.10	42.5	43	44.5	45.5	46	47
600	0.1849568	8.11	6.50	38.5	39.5	42.5	44	44.5	45.5
900	0.2427184	8.24	7.71	37.5	38	41.5	42	42.5	43.5
1200	0.293772	8.51	7.11	36.5	37.5	39.5	39.5	40.5	41.5

Table (5) results of tests applied on samples under study produced with waste blend 1 , 800 beats /min and puncture depth 12 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1282051	7.8	6.41	41	42.5	43	44	44	44.5
600	0.1886792	7.96	6.60	40.5	41	42	42.5	43	43.5
900	0.2469135	8.1	7.00	37	39.5	40.5	41	41.5	42
1200	0.304136	8.22	7.19	31.5	32.5	33	34.5	35	37.5

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Table (6) results of tests applied on samples under study produced with waste blend 1 , 800 beats /min and puncture depth 16 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1307189	7.65	6.23	40	42	43.5	44	44.5	45
600	0.1905972	7.87	6.47	36	36.5	37.5	39	39.5	40.5
900	0.2526265	7.98	6.84	35	35.5	37	38	39	39.5
1200	0.3082614	8.11	7.12	30.5	30.5	32.5	34	35.5	36.5

Table (7) resultsof tests applied on samples under study produced with waste blend 1 , 800 beats /min and puncture depth 20

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1351351	7.40	6.00	38.5	40.5	41	42.5	43.5	43.5
600	0.1984127	7.56	6.15	33	35.5	36	38	38.5	39
900	0.2560819	7.81	6.62	32	34	34	36.5	37	37.5
1200	0.3125	8.00	6.94	28	28.5	30	31.5	32	32.5

Table (8) resultsof tests applied on samples under study produced with waste blend 1 , 950 beats /min and puncture depth 12

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.131406	7.61	6.30	35	35.5	37	38.5	38.5	40.5
600	0.194552	7.72	6.49	33	34.5	35.5	37	37.5	39
900	0.258064	7.80	6.75	32	32.5	34	34.5	35.5	36.5
1200	0.3140703	7.96	6.9	27.5	28	28.5	30	31.5	32.5

Table (9) results of tests applied on samples under study produced with waste blend 1 , 950 beats /min and puncture depth 16

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1340482	7.46	6.10	32.5	34	35	36	36.5	36.5
600	0.1976284	7.59	6.18	31.5	32.5	32.5	34	35	35.5
900	0.259704	7.70	6.55	29.5	30.5	31	31.5	32.5	34
1200	0.3125	8.00	6.79	27	27.5	29.5	31	31.5	32

Table (10) results of tests applied on samples under study produced with waste blend 1 , 950 beats /min and puncture depth 20

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m^2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.137741	7.26	5.85	31	31.5	32	33.5	34	34
600	0.2024291	7.41	6.00	29.5	30.5	30.5	30.5	32.5	33.5
900	0.2656042	7.53	6.24	27.5	29.5	30	31	31.5	32.5
1200	0.3221649	7.76	6.63	26.5	27	28	30	31	31.5

Table (11)results of tests applied on samples under study produced with waste blend 2 , 600 beats /min and puncture depth 12 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1234567	8.10	6.5	42	44.5	46	47	47.5	47.5
600	0.18226	8.23	6.80	41	43	44.5	45.5	46	46
900	0.2389486	8.37	7.00	34	35.5	36.5	38	38.5	40.5
1200	0.2893518	8.64	7.21	33	34	34.5	36	37	38.5

Table (12) results of tests applied on samples under study produced with waste blend 2 , 600 beats /min and puncture depth 16 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1257861	7.95	6.10	36.5	37.5	39	40	40.5	40.5
600	0.1875	8.00	6.54	35.5	36.5	37.5	38	38.5	38.5
900	0.24242	8.25	6.81	33	33.5	35	35.5	36.5	37.5
1200	0.297265	8.41	7.00	31.5	32	32.5	34	35.5	36.5

Table (13) results of tests applied on samples under study produced with waste blend 2 , 600 beats /min and puncture depth 20 mm.

Tests	Density	Thickness (mm)		Thermal insulation (%)					
weight (g/m2)	(kg/m3)	Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.126903	7.88	5.9	35.5	36	36.5	37.5	38	38
600	0.185185	8.10	6.35	35.5	36	36.5	37	37	37.5
900	0.2444981	8.18	6.54	33	33.5	34.5	35.5	36	37
1200	0.3008423	8.31	7.00	32.5	32.5	33	33.5	34.5	35.5

Table (14) results of tests applied on samples under study produced with waste blend 2 , 800 beats /min and puncture depth 12 mm.

Tests weight (g/m2)	Density (kg/m3)	Thickness (mm)		Thermal insulation (%)					
		Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1315789	7.60	6.28	39	40.5	42	42	43	43.5
600	0.1920614	7.81	6.47	37.5	39	40	40.5	41	41.5
900	0.2518891	8.94	6.89	35.5	37	38.5	39	35.5	40.5
1200	0.3086419	8.10	7.10	29.5	30	31	32	32.5	35.5

Table (17) resultsof tests applied on samples under study produced with waste blend 2 , 950 beats /min and puncture depth 12 mm.

Tests weight (g/m^2)	Density (kg/m3)	Thickness (mm)		Thermal insulation (%)					
		Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1347708	7.42	6.18	31	32	32.5	34	35.5	36
600	0.1986754	7.55	6.36	29	31	31.5	32	34	34.5
900	0.2631578	7.60	6.61	28	30.5	31	32	33	33.5
1200	0.3063725	7.76	6.75	27	27.5	28	29	31	32

Table (18) resultsof tests applied on samples under study produced with waste blend 2 , 950 beats /min and puncture depth 16 mm.

Tests weight (g/m^2)	Density (kg/m3)	Thickness (mm)		Thermal insulation (%)					
		Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1373626	7.28	5.85	29.5	30.5	31.5	33	35	35
600	0.2013422	7.45	6.00	28.5	30	31	31.5	32	33.5
900	0.262812	7.61	6.34	27	29	29.5	30	31	32
1200	0.3201024	7.81	6.61	26.5	27	28.5	29	30	30.5

Table (19) results of tests applied on samples under study produced with waste blend 2 , 950 beats /min and puncture depth 20 mm.

Tests weight (g/m^2)	Density (kg/m3)	Thickness (mm)		Thermal insulation (%)					
		Without load	Under load	30 min.	60 min.	90 min.	120 min.	150 min.	180 min.
300	0.1402524	7.13	5.70	28	29.5	30	31	32.5	33.5
600	0.2063273	7.27	5.88	27	29	29	29.5	30.5	31.5
900	0.2699055	7.41	6.11	26	27.5	28.5	29	30	30.5
1200	0.3267973	7.65	6.49	25	26.5	27	27.5	29.5	30

3.1 Effect of Research Variables on Fabrics Thickness

It is obvious from tables and fig. (1) that waste blend 1 had higher thickness compared to waste blend 2 but differences between both waste blend samples are insignificant.

It is clear from the results and fig. (1),(2) and (4) that, there is a direct relationship between fabrics weight and its thickness. This is for the sake of that, the increase in weight means increase in number of fibers per unit area leading to the increase in fabrics thickness.

Results illustrated in tables and tables (3) and (4) show that, there is an inverse relationship between number of beats/min and fabric thickness as by increasing number of beats/min the thickness of fabric decreases . This is due to that punching technique decreases spaces between fibers leading to fabric to be more compacted and decrease its thickness.

It can also be seen from the results and fig. (2) and (3) that, samples of 20 mm. puncture depth have scored the lowest thickness followed by samples of 16 and 12 mm.puncture depth. This is due to that by increasing puncture depth the fiber entanglement increase and fabric become more compacted and its thickness will be decreased.

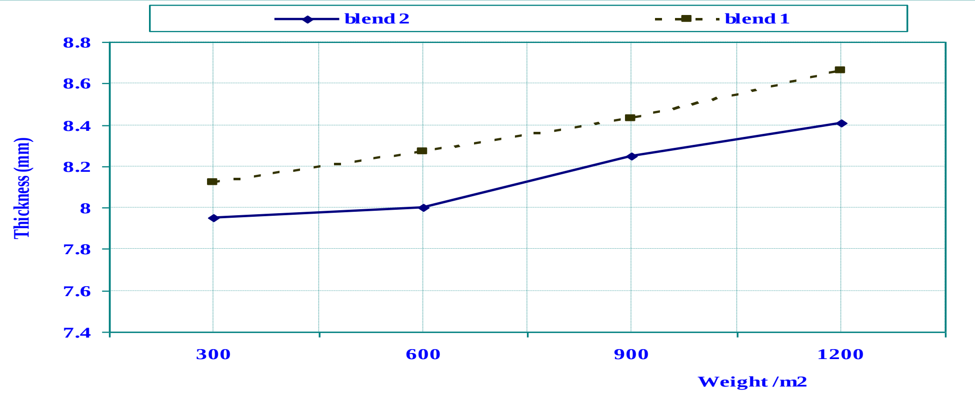

Fig .(1) Comparison between effect of blend 1 and blend 2 on thickness , at puncture depth 16 mm , 600 beats / min , without load.

Table (20) regression equation and correlation coefficient for the effect of blend 1 and blend 2 on thickness, at 12 puncture depth without load

Fibers type	Régression équation	Corrélation coefficient
Waste blend 1	Y = 0.000683X+7.868333	0.948683
Waste blend 2	Y = 0.00065X+7.65	0.994674

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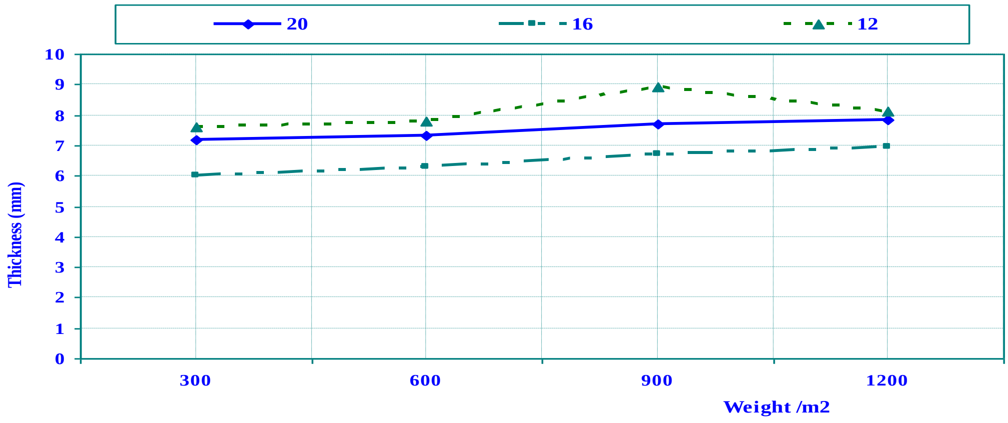

Fig .(2) effect of weight /m2 and and puncture depth on thickness , at 800 beats /min , weithout load , using waste blend 2

Table (21) regression equation and correlation coefficient for the effect of weight g/m2 and puncture depth on thickness, 800 beats/min, without load ,using waste blend 2.

Puncture depth /mm	Régression équation	Corrélation coefficient
12	Y = 0.000683X+7.868333	0.95294
16	Y = 0.001033X+5.716667	0.989082
20	Y = 0.000483X+7.848333	0.847067

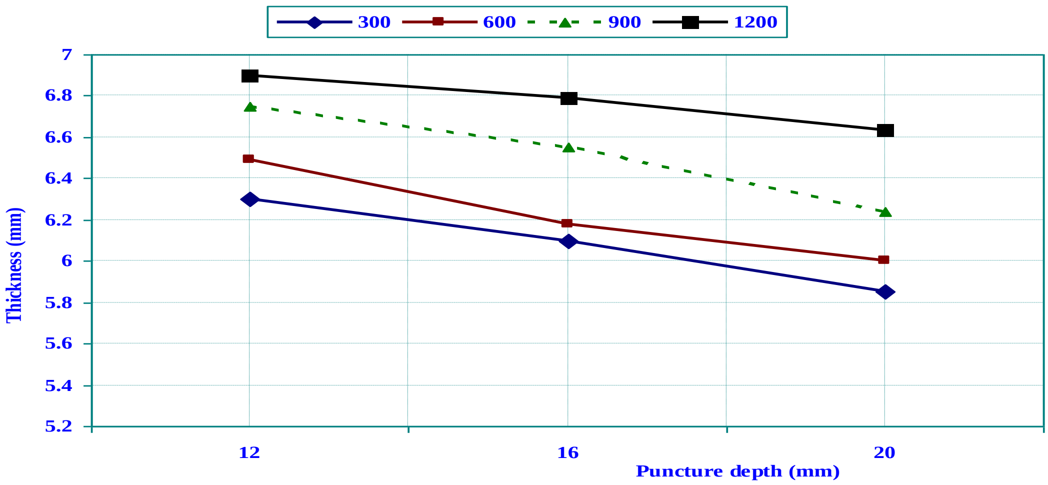

Fig .(3) effect of weight /m2 and and puncture depth on thickness , at 950 beats /min , under load , using waste blend 1

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Table (22) regression equation and correlation coefficient for the effect of weight g/m2 and puncture depth on thickness, at 950 beats/min under load,using waste blend 1.

Puncture depth /mm	Régression équation	Corrélation coefficient
12	Y = 0.000683X+7.868333	0.988215
16	Y = 0.00107 X+5.591667	0.9921515
20	Y = 0.00105X+5.345	0.990684

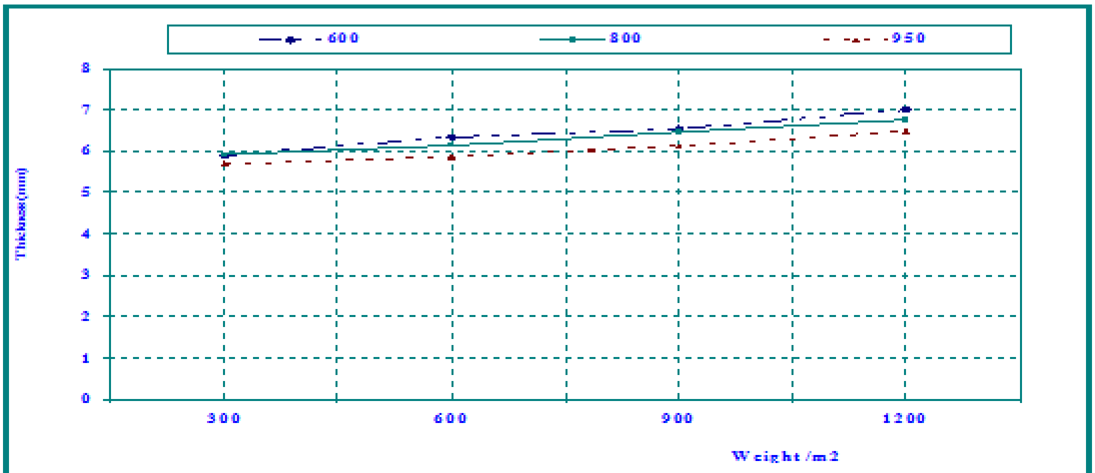

Fig .(4) effect of weight /m2 and and number of beats /min. on thickness , at 20 punctur depth , under load , using waste blend 2

Table (23) regression equation and correlation coefficient for the effect of weight /m2 and number of beats/min. on thickness, at 20 puncture depth ,under load

Number of beats /min.	Régression équation	Corrélation coefficient
600	Y = 0.001083X+5.656	0.972426
800	Y = 0.001033X+5.526667	0.999307
950	Y = 0.00107X+5.245	0.990072

3.2 Effect of Research Variables on Thermal Insulation Properties of Fabrics

It is obvious from tables and fig. (7) and (8) that samples of waste blend (2) have scored the highest rates of thermal insulation compared to samples of waste blend (1) .This is mainly due to presence of polyester hollow fibers in waste blend (2) where the entrapped air in the structure of these fibers contribute to the total thermal insulation , as air is considered one of the lowest thermal insulators besides this polyester fibers have the advantage of having higher thermal resistance compared to polypropylene and polyacrylic fibers.

From the results obtained in table and fig. from (5) to (9), it was found that there is a direct relationship between fabrics weight and its thermal insulation (the percentage reduction in heat loss) as samples of 1200 g/m2 weight have scored the highest values of thermal insulation followed by 900, 600 and 300 g/m2 weight

,this may be because the increase in weight means increase in number of fibers per unit area leading to the increase in fabrics thickness and also its thermal insulation.

When testing the influence of number of beats/min on samples thermal insulation property, it can be noted that its influence is noticeable as by increasing number of beats /min thermal insulation increases as shown in fig. (6) and (11). This is due to that the increase of number of beats cause the produced fabric to be more compacted as when the needles descend into the bat the barbs catch some fibers and pull them through the other fibers. When the needles return upwards, the loops of fiber formed on the down stroke tend to remain in position, because they are released by the barbs. This downward pressure repeated many times makes the bat much denser and then thermal insulation will also be increased .

It can be seen from the results and fig. (5), (10) and (11) that, samples of 20 mm. puncture depth have scored the highest rates of thermal insulation followed by 16 and 12mm. puncture depth. This is due to that by increasing puncture depth the fabric become more compacted and create pores of dead air that cause the entrapment of heat and minimize heat transfer thus increase fabrics thermal insulation properties.

From the results obtained and fig. (8) and (9), it was found that by increasing time of heat exposure , heat insulation values decrease but the differences are very low.

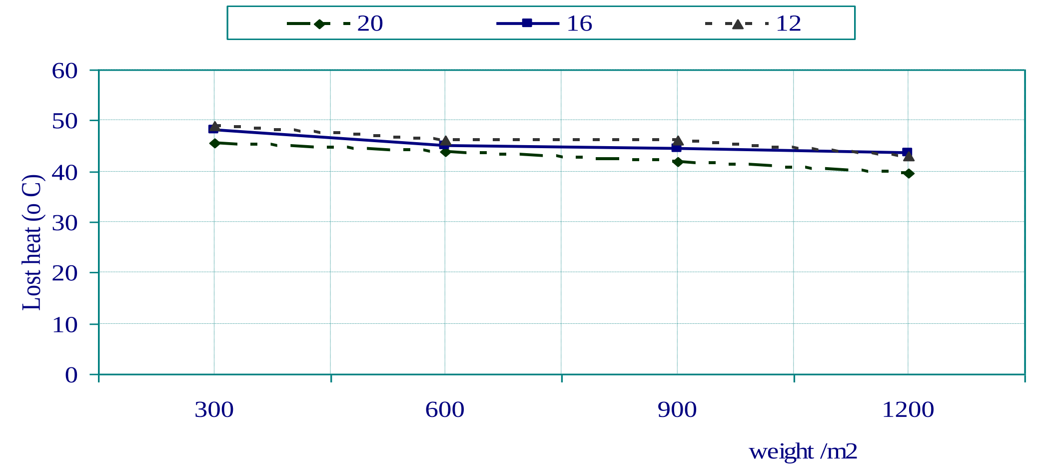

Fig .(5) ffect of weight /m2 and puncture depth on thermal insulation, at 600 beats /min and exposure time 120 minute, using waste blend 1

Table (24) regression equation and correlation coefficient for the effect of blend 1 and blend 2 on thermal insulation, at 12 puncture depth and exposure time 60 minute

Puncture depth /mm	Régression équation	Corrélation coefficient
12	Y = -0.006 X+50.50	-0.948683
16	Y = -0.00467X+48.75	-0.933333
20	Y = -0. 00667 X+47.75	-0.993808

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Table (25) regression equation and correlation coefficient for the effect of weight g/m2 and number of beats /cm on thermal insulation, at 20 puncture depth (exposure time 180 minute) ,using waste blend 1.

Number of beats /min	Régression équation	Corrélation coefficient
600	Y = -0.00617 X+49	-0.997816
800	Y = -0.0115X+46.75	-0.982213
950	Y = -0.005 X+38.25	-0.989071

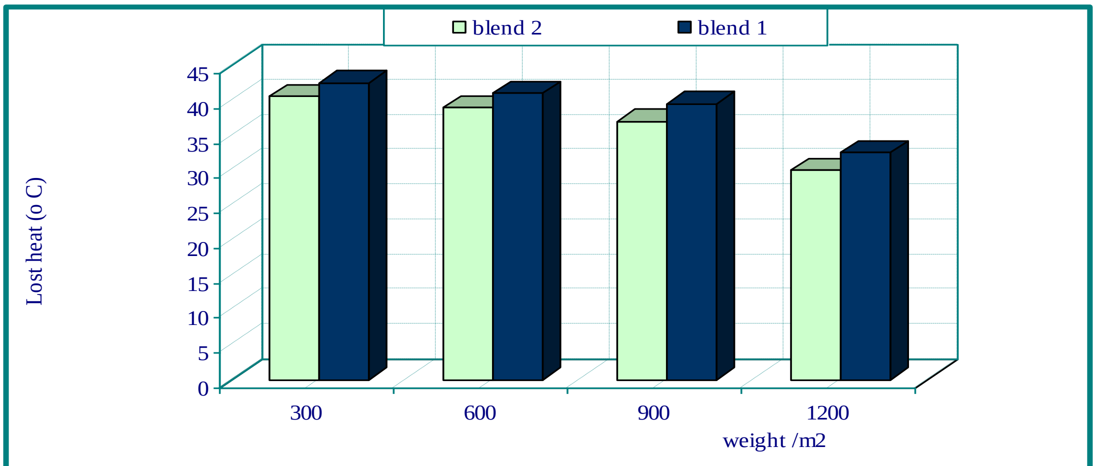

Fig .(7) Comparison between effect of blend 1 and blend 2 on thermal insulation, at puncture depth 12 mm , 800 beats / min and exposure time 60 minute.

Table (26) regression equation and correlation coefficient for the effect of blend 1 and blend 2 on thermal insulation, at 12 puncture depth and exposure time 60 minute

Fibers type	Régression équation	Corrélation coefficient
Waste blend 1	Y = -0.0105X+46.75	-0.919439
Waste blend 2	Y = -0.01117X+45	-0.931364

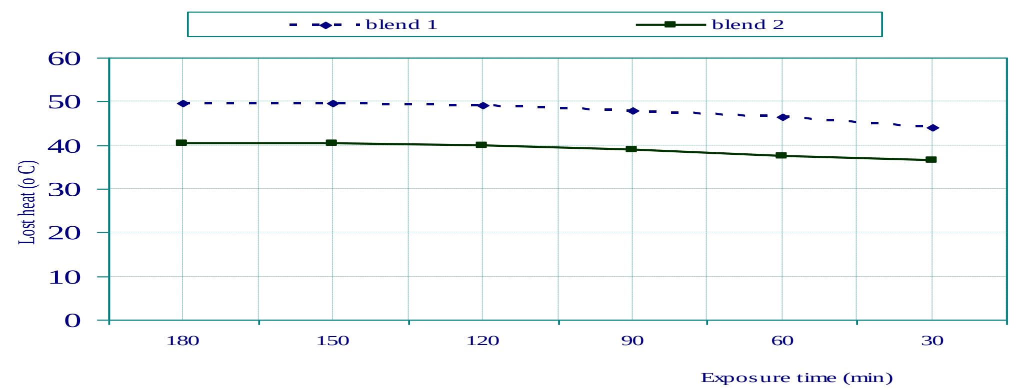

Fig .(8) Comparison between effect of blend 1 and blend 2 on thermal insulation, at puncture depth 12 mm , 800 beats / min and exposure time 60 minute.

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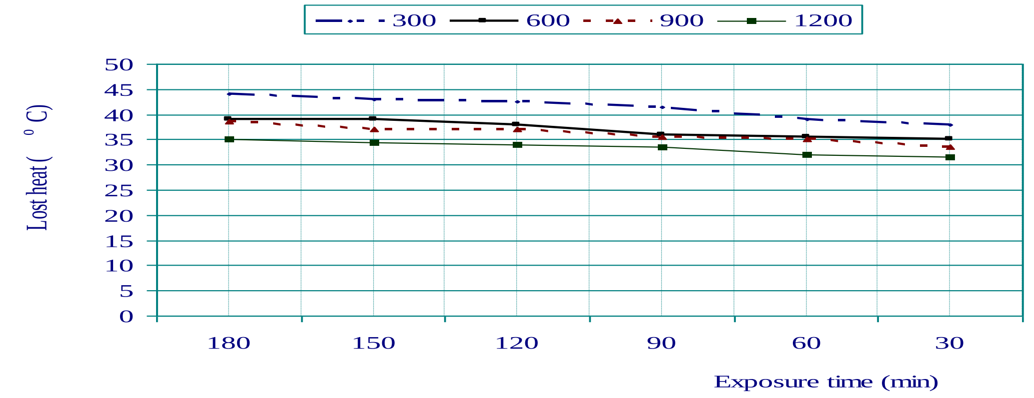

Fig .(9) effect of weight /m2 and exposure time on thermal insulation, at 800 beats /min , and 16 puncture depth , using waste blend 2

Table (27)regression equation and correlation coefficient of the effect of weight and exposure time on thermal insulation, at16 puncture depth ,800 beats /min. using waste blend 2.

Exposure time (min.)	Régression équation	Corrélation coefficient
30	Y = -0.00583 X+38.58333	-0.9296616
60	Y = -0.00583 X+39.41667	-0.924493
90	Y = -0.00417 X+38.75	-0.944911
120	Y = -0.00667 X+42.3333	-0.960769
150	Y = -0.0075 X+43.583333	-0.997949
180	Y = -0.00667 X+43	-0.917663

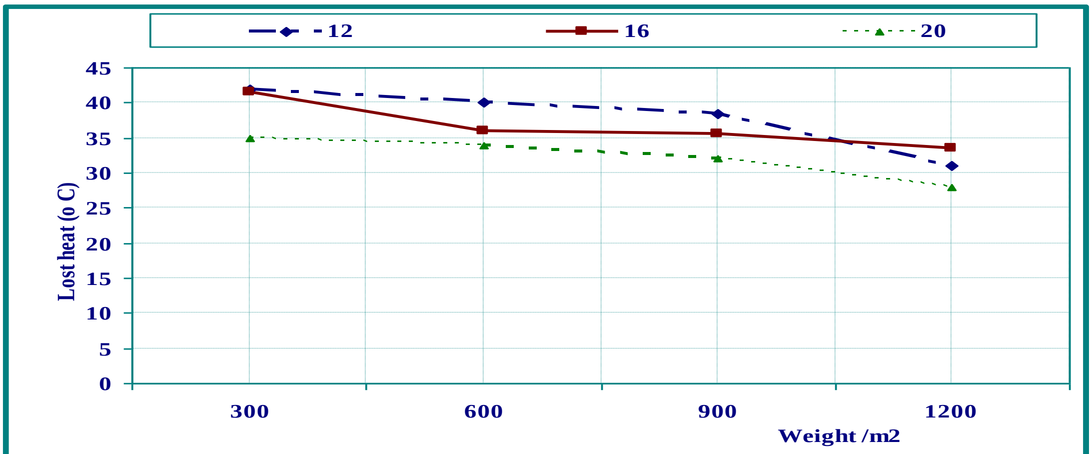

Fig .(10) effect of weight /m2 and puncture depth on thermal insulation, at and exposure time 90 minute , 800 beats /min , and 16 puncture depth , using waste blend 2 .

Table (28) regression equation and correlation coefficient for the effect of weight g/m2 and puncture depth on thermal insulation, at 800 beats /min. and exposure time 90 minute ,using waste blend 1.

Puncture depth (mm)	Régression équation	Corrélation coefficient
12	Y = -0.015 X+50	-0.933257
16	Y = -0.00417X+38.75	-0.944911
20	Y = -0.01 X+40.3333	-0.981981

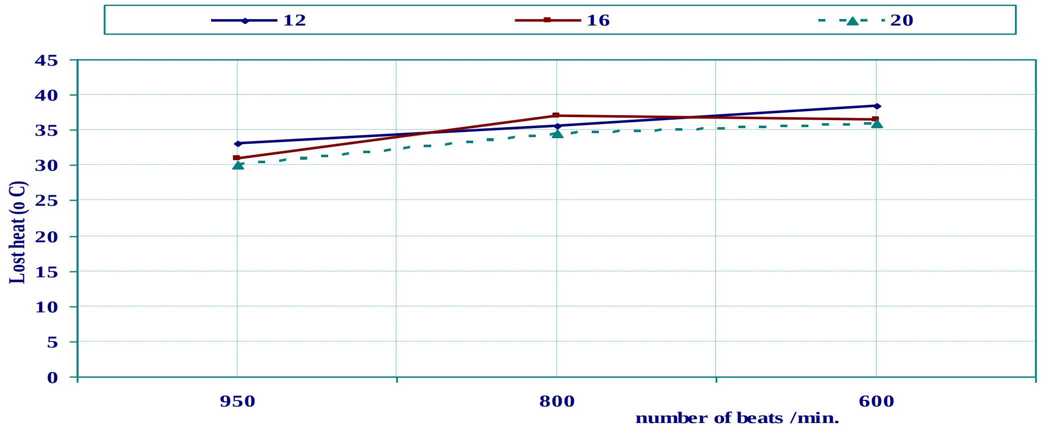

Fig .(11) effect of number of beats /min.and puncture depth on thermal insulation, at exposure time 150 minute , 900 g/m2 , using waste blend 2 .

Table (29) regression equation and correlation coefficient for the effect of puncture depth and number of beats /cm on thermal insulation, at 900 g/m2 and exposure time 150 minute ,using waste blend 2.

Number of beats /min	Régression équation	Corrélation coefficient
600	Y = -0.0125 X+38.5	1
800	Y = -0. 625X+47	1
950	Y = -0.25 X+35	1

IV. CONCLUSIONS

The aim of this work was to investigate the thermal insulation properties of cross-laid nonwoven fabrics of waste fibers. Based on the previously calculated and experimental results of samples under study producedas heat insulators, the researcher concluded the following points:

1- The study concludes that, the selected fabrics have high thermal performance as insulator in high temperatures till 130 ^{0} C.
2- Hollow fibers have significant effect on fabrics thermal insulation performance where waste blend (2) showed obvious in heat insulation compared to waste blend (1).
3- The effect of fabric thickness on fabrics thermal insulation properties is obvious as higher thickness means good thermal insulation.
4- The exposure time of fabrics to heat affects its thermal insulation as by increasing the exposure time, thermal insulation decrease but the change is very low.
5- By increasing fabric weight, its thermal insulation increases.
6- Construction factors of fabrics have significant effect on its thermal insulation properties as by increasing number of beats/min and puncture depth, fabrics thermal insulation also increases.

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