UTILIZATION OF TEXTILE WASTES IN NONWOVENS

Part II: New Approach to Preneedling, Drawing, and Hydroentanglement Technology.

الاستفادة من العوادم النسيجية فى انتاج الاقمشة الغير منسوجه ميكانيكيا

الجزء الثانى : مدخل جديد لتكنولوجيا تصنيع الاقمشة الغير منسوجة عن طريق التغريــز الاولى ـ السحب ـ التغريز النهائى .

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الخلاصـــه :

تحسنت خاصية الايزوتروبيا (تســـاوى متانــة الشد فى الاتجاهات المختلفة) لاقمشة حشو الملابس الجاهزة المصنعة من عوادم الفســـكوز عن طريق تغريز ابتدائى ٨ ـ ١٢ ابرة/سم٢ يليه سحب (٢) وأخيرا التغريز باستخدام تيار من الماء المضغوط (٤، ٨، ١٢، ١٦ بار) حيث يعمل التغريز الابتدائى على تشابك الشعيرات القصيرة بدرجة يمكن معها السيطرة على شاشة الشعيرات ولايعوق عمليات التغريز التالية، أما السحب فهو بغـــرض تكوين محاور التفاف تدور حولها الشعيرات واخيرا التغريز النهائى لاعطاء المتانه المطلوبه.

قورنت النتائج التى تم الحصول عليها بهذه الطريقة بنتائج متانة الشد لعينات مماثله غـــرزت ميكانيكيا بكثافة تغريـــز ٢٩ أبـــــره/ ســـم٢ وثبت زيادة متانة الشد بمقـــــدار يتراوح ما بين ٢٫٥ الى ٦٫٧ من المرات.

قورنت ايضا الخواص التالية: سمك القماش، كتلة المتر المربع، معامل التعبئـــــــة، استطاله الشد، صلابه الاقمشة، الطول القاطع، نفازية الهواء واخيرا خاصية عدم تساوى الخواص الانيزوتروبيا (Anisotropy).

الأقمشة الغير منسوجة بهذه الطريقه تعد مناسبه للحشو فى صناعتى الملابس الجاهزة وصناعة الاحذيه وكذا فرش الارضيات والسيارات وغيرها.

ABSTRACT

The technology of preneedling, drawing and final double side hydroentanglement of short fibre webs achieves a good approximation to anisotropic conditions of tensile strength. The ultimate tensile properties have been determined for tested nonwoven before and after hydroentanglement. Generally speaking, the tensile strength of tested nonwoven interlining rose when a higher hydroentanglement energy was used. This technology is not confined to the manufacture of interlining only, but can also be applied to geotextiles, the production of coating materials, bitumen roofings and mouldable lining for the interior of automobiles. This study explores the feasibility of using hydroentanglement technique to produce nonwoven interlining from textile wastes.

INTRODUCTION

Nonwovens now are involved in many industry sectors and on a worldwide basis with products ranging from disposable single use items to significant highly technical materials in aerospace and the medical industries. It has been estimated that some 20 billion process combinations are available today. In USA some 200 billion pounds of fibre is used per year. There are 200 or more Nonwoven companies in the world with a total annual consumption of perhaps more than 450 billion pounds. It is little wonder that our nonwoven industry attracts a great deal of attention.

The importance of interlining to the garment industry cannot be overstressed. Consider these two facts: woven and knitted fabrics now account for less than 88% of world production. The bulk of the remainder have lining and interlining. The interlining for garment industry represents an important and growing market for textile materials. Tnterlining can clearly affeet garment comfort in much the same way as upper materials and therefore the earlier comments regarding desirable characteristics for comfort also apply to interlining.

For the near future Wood (8) considers that there will be extensive developments needed in three important areas:

1) Melt-Spun products and processes,
2) Composite structure, and
3) Apertured membranes.

Our major objective in this study was to evaluate the nonwoven interlining out of textile wastes performance before and after hydroentanglement procedure. The hydraulic entanglement of fibrous structures is not a nonwoven process as we usually consider it but rather a binding method where hydrualic forces move individual fibres to entangle with each other holding together with inter-fibre friction.

The hydroentanglement unit may be combined with the dry laid process, and will be situated just after the web formation sections and provide a way to increase bulk, softness and drapability to otherwise nonwoven structures. This above mintioned process either produces a fabric with a large geometric pattern or where the pattern is so small that fabric resembles a lightly woven material without any visual apertures.

The aerodynamic method of web production is most effective with short fibres, some of which are orientated vertically, making such webs bulkier and less compact. Most of the fibres lie in the direction of the material flow, which can give rise to an irreversible anisotropism in strength (longitudinal/transverse strength 1.2 to 1.4: 1) (2).

In this paper we developed a special hydroentanglement procedure, which includes a drafting operation to re-orientate the fibres and produce practically isotropic conditions. The process can be divided into three stages.

1- Preneedling:

The object of preneedling is to:

a) make the web suitable for drawing by reduction and consolidation of its volume,
b) produce pivot points for rotation of the short fibres, and
c) preserve homogeneity of the web and orientation of the fibres.

2- Drawing:

The object of drawing may be mentioned at this point:

Controlled reorientation of the fibres, retaining as far as possible the levelness of the web. During drafting the batt increases in length, shortens in width and the maas per unit area is reduced. In several successive stages of drafting, the fibres protruding in bunches from the punched holes rotate with increasing effect until the required ratio between longitudinal and transverae strength has been reached. To attain uniformity of the batt, it is important that preneedling precedes the drafting operation. The points of penetration serve as pivots around which the fibres rotate and can also bridge thin placea in the web.

3- Final Hydroentanglement:

As previously mentioned, the fibres in an area around each water nozzle are drawn radially into the centre of the punched hole, which partially disturbs their predominently lateral alignment in the batt plane (1).

Test assemblies were subjected to 10, 20, 30 and 40 passes of the hydroentanglement (spray nozzle). Thus the nominal external pressure level was 4, 8, 12 and 16 bar. Note that in laboratory spray process, the fabrics are held at a fixed angle to the spray nozzle, that is the fabrics are "passive" without stress or movement during the hydroentanglement procedure.

TEST MATERIALS AND METHODS

In earlier papers in this series (4, 5, 6, and 7), we demonstrated the utility of nonwovens out of textile wastes in various end uses. This investigation presents the feasibility of using hydroentanglement technique to produce nonwoven interlining. We selected for analysis two nonwoven interlining fabrics out of textile wastes one subjected to hydroentanglement procedure and the other was free.

The theory of suggested procedure is given in Figure 1.

Preneedling	+	Drawing	+	Double side—hydroentanglement	+	Drying	→	Nonwovens
(8–12 S.P.C^2)		(draft = doubling)		(4, 8, 12 and 16 bar)		(90^{o}C)		(for various end uses).

Fig. 1: Shows the principles of preneedling, drawing, and hydroentanglement procedure.

The batt is placed on a screen for hydroentanglement and high pressure, high-speed water jets displace and entangle the fibres to turn the batt into a stronger nonwoven as shown in Figure 2.

1- Hydroentanglement gun,
2- Batt.of fibres,
3-Screen,
4-Wood frame, and
5- Return water.

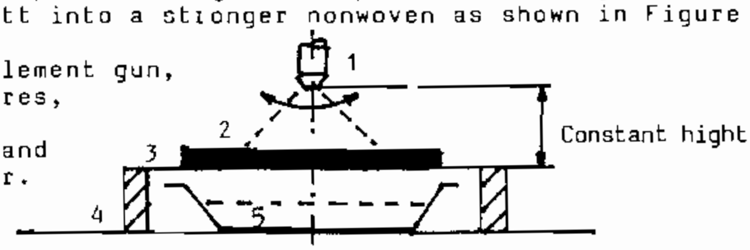


Fig. 2: The Prenciples of Laboratory Hydroentanglement unit.

The physical test methods used during nonwoven characterisation were as follows:

Basis weight :	BS 3432 (1980),
Thickness :	BS 4817 (1972),
Tensile Strength:	BS 4415 (1986),
Stiffness :	EDANA method for bending length.
Air-permeability:	According to ČSN 800817
Packing Density :	According to Ref. (3)
Anisotropy :	According to Ref. (4)

Ths data has been normalised with respect to basis weight and plotted using the following parameters:

$$\text{Break length (1)} = \frac{\text{tensile strength (N/15 mm)}}{\text{basis weight } (g/m^2)} \times 6.796 \text{ (Km)} \quad .....(1)$$

$$\text{Anisotropy} = \frac{\text{max. tenacity} - \text{min. tenacity}}{\text{max. tenacity} + \text{min. tenacity}} \quad .....(2)$$

RESULTS AND DISCUSSION

The products were studied using light microscope at 35 x magnification to establish the surface structure of hydroentanglement nonwoven. The effect of energy is presented in Figure 3, which shows that high energy leads to greater fibre density and entanglement than low energy.

Nonwoven Physical Properties:

The main properties of tested nonwoven interlining are shown in Tables 1a and 1b. The ranges in values of fabric stiffness ($N.m^2 \times 10^{-8}$), packing density coefficient (10^{-3}) and breaking length are 28 - 140, 8 - 21.1, 1.01 - 185.38 respectively as indicated in this tables.

From the previous tables, the following results could be made:

Table 1: Properties of nonwoven interlining.

Sample Code	Pressure x no. of passes	Thickness (mm) ↑	Thickness (mm) ⊥	Surface mass (g/m^2) ↑	Surface mass (g/m^2) ⊥	Packing density $\times 10^{-3}$ ↑	Packing density $\times 10^{-3}$ ⊥	Tenacity (mN/tex) ↑	Tenacity (mN/tex) ⊥	Elongation (%) ↑	Elongation (%) ⊥	Stiffness $(N.m^2)\times10^{-8}$ ↑	Stiffness $(N.m^2)\times10^{-8}$ ⊥	Air-pre $m^3 m^{-2}.s^{-1}$	Anisotropy	Breaking length (Km)	
a) $(0.100\ Kg/m^2$, 4 bar and variable no. of passes)																	
A_1	0	4.2	4.2	58	51	9.0	8.0	3.9	0.2	68	146	30.3	41.0	2.9	0.90	3.91	1.01
A_2	40	4.0	4.0	57	67	9.5	11.0	8.0	1.7	63	132	28.0	52.0	3.2	0.72	4.51	1.66
A_3	80	3.4	3.4	55	60	10.9	11.7	6.8	2.1	72	146	46.0	45.0	3.6	0.52	32.06	11.91
A_4	120	3.4	3.4	64	65	12.6	12.8	9.5	2.6	56	126	36.7	38.2	3.0	0.65	66.95	19.67
A_5	160	3.2	3.2	66	64	13.7	13.0	9.9	2.8	56	125	33.4	46.4	1.9	0.55	68.77	20.59
b) $(0.200\ Kg/m^2$, 10 passes, and variable pressure)																	
B_1	10	7.0	7.0	133	139	12.6	13.2	1.8	0.6	66	150	69	80	1.6	0.5	27.14	8.95
B_2	40	5.6	5.6	160	120	19.4	14.4	7.4	1.2	69	130	134	140	1.5	0.7	139.84	18.01
B_3	80	4.9	4.9	150	154	20.4	21.1	10.2	2.5	53	105	68	75	1.3	0.6	185.38	44.85
B_4	120	4.3	4.3	117	118	18.1	18.3	4.6	3.0	48	127	49	79	1.1	0.2	60.49	40.25
B_5	160	4.4	4.4	107	120	16.3	18.3	13.8	3.6	49	127.4	56	93	1.2	0.5	170.89	49.91

The following aerodynamic webs and energies were used in the hydroentenglement traials:

- Single web, needle punched 29.10^4 $s.p.m^2$ (marked A_1), $0.100\ Kg/m^2$, and No. of passages is zero,
- Single web, high energy (4 bar) marked A_2, $0.100\ Kg/m^2$, and No. of passes is 10,
- Single web, high energy (4 bar), marked A_3, and No. of passages is 20,
- Single web, high energy (4 bar), marked A_4, and No. of passes is 30, and
- Single web, high energy (4 bar), marked A_5, and No. of passages is 40.

* double web, needle punched 29×10^4 $s.p.m^2$, $0.200\ Kg/m^2$, and No. of passages is zero, mared B_1, and
* double web, high energies from 4 bar to 16 bar marked from B_2 to B_4 and No. of passes is 10.

1) It was evident from experimental results that the high values of packing density coefficient are associated with the high values of tested nonwoven interlining tenacities, fabric stiffness, and breaking length, and with low values of fabric elongation, fabric air permeability and tensile properties anisotropies.

2) Hydroentangleling consolidation between 10 - 40 impart the tested nonwoven interlining sufficient strength and volume is reduced considerable. The genersl trend obtained is that fabric strength tends to increase after hydroentangling. The increase in strength relative to that measured for needle punched interlining fabric, ranges between 154% and 667%, and/or 500% snd 1300% in machine direction and cross direction respectively.

3) With respect to fabric breaking length, it was calculated using equ. 1. The values of breaking length ranges between 1.01 and 185.38 Km. Therefore one would expect the breaking length to be high for press and/or out of virgin fibres and low for deformable fabric.

4) In the above tables perhaps the most important factor is the tensile anisotropy of tested nonwoven interlining out of textile wastes. As the degree of consolidation increased the tensile anisotropy tended to decrease (improve) and vice versa. For degree of consolidation, parameters like pressure in injectors (like depth of needle penetration in needle punched fabric), and hydroentangling passages (like intensity of needling, are determining factors.

5) Another important factor was fabric stiffness. It was found that as the intensity of hydroentangling increased the fabric stiffness increased also. The reason for this phenomenon may be that high energy leads to great fibre density. Generally speaking, in the measurement of bending length it was observed that the stiffness rises as the weight increases. The fabric stiffness is greater in cross direction than in the machine direction.

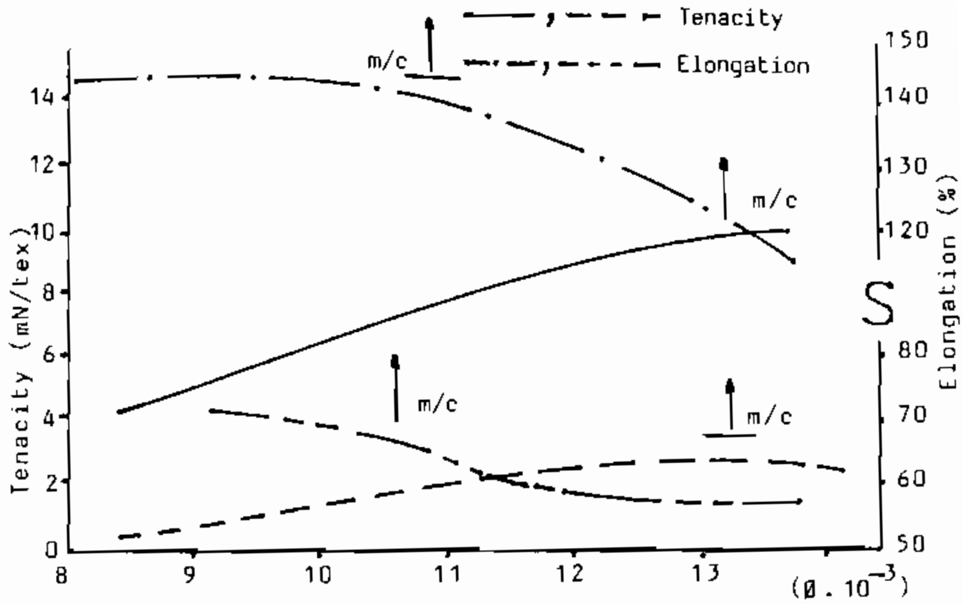
6) As expected, the air permeability readings tends to decreased as intensity of hydroentangling increased. The reason for the decrease in air permeability with the increased of energy may be that there are more fibres punched and the degree of entanglement increased. The effect of hydroentaglement energy is visible not only in airpermeability readings but also in the thickness, packing density, and strength measurements, namely that the best results were obtained with 40 - 60 hydroentangling intensity.

(a) High-energy (35 x) (b) Low-energy (35 x)

Fig. 3: Effect of energy on surface structure.

Figure 4 presents the tensile strength (mN/tex) and elongation results of the testing.

The extension is greater in the cross direction than in the machine direction.



Packing Density Coefficient

Fig. 4: Shows tenacity and/or elongation versus packing density coefficient of tested nonwoven interlining (for 0.100 kg/m^2)

Plotted in Fig. 5 the values of packing density coefficient versus the degree of consolidation. It is evident from the figure that high values of Ø are associated with high degree of consolidation at the first half of the curve and vice—versa in the second half of diagram. Since Ø is well related to reinforced conditions, hence one would expect a strong relationship between them.

A vast literature (3) dealing with the relationship between punching density and packing density coefficient tests to the simplicity of using (Ø) as a structure parameter. It was found that the behaviour of packing density coefficient and hydro-entengling intensity is the same as the behaviour of packing density and punching intensity in needle punched nonwovens.

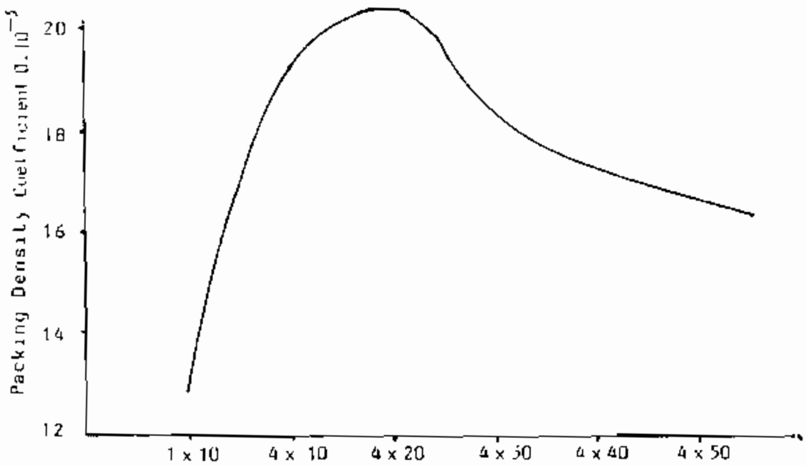


Fig. 5: Packing Density Coefficient (Ø) versus the Degree of Consolidation (Product of pressure in injectors and hydroentangling passages), 0.200 Kg.m^{-2}.

CONCLUSIONS

Hydroentanglement is one of the fastest growing technologies for the production of nonwovens. The softness, drape, handle and good strength characteristics of preneedling-drawing-hydroentangled nonwoven make them unique products in this calss.

External pressure in injectors causes increase in fabric tenacity by 2.5 or 6.7 times of original tenacities and thus must be carefully analyzed in future work. It was found that nonwoven out of textile wastes (V_s, 0.4 tex, 12-48 mm) gives good results owing to its high degree of flexibility and produces a soft nonwoven. Hydroentangled nonwoven made from wastes are used as bandaging material and clothing interlining for garment industry, and footwear production.

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WARMTH PROPERTY OF CLOTHING ASSEMBLY

Part II: Design of Components of Clothing Assembly

خاصية الدفء لأقشة الطبوسات

الجزء الثاني: تصميم مكونات اقشة الملبوسات

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الخلاصه :

فى هذا البحث وجد أن بلوفرات التريكو والفانلات الداخليه واقشه البدل على الترتيب تساهم بأعلى قدر من المقاومه الحراريه (العزل الحرارى) بالمقارنه بالمكونات الأخرى لأقمشه الملبوسات . أيضا امكن تقييم وترتيب خمس حالات لبس من حيث كفاءة الدفء مستعملا المتوسط الهندسى والداله الأسيه لكل من المقاومه الحراريه ومقاومه نفاذيه الهواء، ووجد أن أحسن حاله لبس هى الحاله الرابعه التى تحتوى على فانله داخليه (جيل)وقميص (بوبلين كفر الدوار) وبلوفر خارجى (ذو تركيب نصف كارديجان) وقماش بطانه (فسكوز) وقماش حشو (قماش ذو سطح لاصق عند استخدام المكواه) وقماش بدل (صوف ١٠٠٪)٠ ايضا أمكن حساب نمرة خيط التريكو المطلوبه لانتاج بلوفر خارجى بمقاومه حراريه معينه وذلك عند ثبات نوع الغرزه وعدد الصفوف الرأسيه والصفوف الافقيه فى وحده الطول . ايضا اجريت محاوله للتعديل فى التركيب الانشائى لأحد الاقمشه الصوفيه التى تصنع منها البدل الشتويه وذلك بغرض زيادة مقدرتها على الدفء. هذا التعديل امكن تحقيقه عن طريق معرفه العوامل الانشائيه المثاليه للقماش مثل الماده الخام المستعمله فى خيوط اللحمه ونمرة خيوط اللحمه وكثافه الحدفات فى وحدة القياس. الخواص التى تم دراستها للأقمشه الصوفيه هى المقاومه الحراريه ومقاومة نفاذيه الهواء ، والموديلات الرياضيه التى تصف هذه الخواص امكن الحصول عليها باستخدام طريقه تصميم التجارب . وباستعمال الطريقه البيانيه وجد أن التركيب الانشائى الأمثل يوصى بأن يحتوى على خيوط نمرة ٢/٥٠ مترى مخلوط من الصوف والبوليستر بنسبة ٣٠٪ : ٧٠٪ مع استخدام ٤٨ حدفه فى البوصه وذلك مع استعمال مواصفات السداء للصنف ٦٥٦ .

ABSTRACT - In this research, it was found that knitted outer wear, under wear and suit fabrics respectively have the highest values of percentage share of thermal resistance compared to the other components of clothing assembly. Five wearing cases could be assessed and ranked with respect to warmth parameters using the geometric mean and the exponential function, and it was found that the best wearing case of clothing assembly was the fourth one, containing under wear (Jil), shirt fabric (poplin of Kafr El-Dawar), knitted outer wear (half cardigan), lining fabric (Viscose), gasket fabric (Sticking fabric) and suit fabric (100% wool). Also the needed yarn count for knitting could be calculated for obtaining the desired thermal resistance of the knitted outer wear at constancy the type of structure, number of wales and coarses per unit length. Also an attempt has been made to modify the construction of one type of fabrics which are used to make suit clothes in order to increase its thermal insulation. This modification could be achieved by means of knowing the optimum constructional factors of fabrics such as material used for weft yarns, weft yarn linear density and pick density. The investigated warmth properties that correlated with the end use performance of suit clothes are thermal resistance and air resistance.

Mathematical models describing these properties could be obtained, by using factorial design method, for predicting the warmth behaviour of suit fabrics. By using the graphical method, it was found that the optimum fabric construction to make suit cloth is recommended to be contained weft blended yarns (30% wool / 70% polyester) of 50/2 Nm at 48 picks per inch with using 1/1 plain weave design and with using warp specificatios of article No. 656.

1. INTRODUCTION

According to the different atmospheric conditions in our country in the north and the south in winter season, it is necessary to design the eomponents of clothing assembly such as knitted and woven fabrics to protect the human body against the atmospheric conditions.

Rate of cooling of the human body during the work results in decreasing the activity of the person. Cool feeling can be achieved when thermal insulation properties of the clothing assembly are not enough [1].

Because elothing is basically concerned with minimizing the thermal stresses, warm or cold, imposed on man by the environment, there is good reason to measure the thermal insulation of single layers of clothing materials as well as multiple layers assembled more or less as in clothing during use [2].

Design of components of clothing assembly for protecting the human body against the eold wheather is a difficult seentific problem, because these clothing assemblies must be fulfiled the necessary requirements such as minimum weight, maximum thermal insulation properties, minimum air permeability and an enough moisture conductivity to insure moisture exchange of the person with the surrounding medium.

The purpose of this study was to evaluate the warmth performance of the various clothing assemblies used in winter season in Egypt and to design the eomponents of elothing assembly.

2- COMPARISON BETWEEN DIFFERENT WEARING CASES OF CLOTHING ASSEMBLY

As a result of the data obtained in part (I) of this series, the warmth property of the best wearing cases of clothing assemblyhas been compared regarding the thermal resistance and the air resistance. The best components for eaeh wearing case of elothing assembly and their percentage share of total thermal resistanee are shown in Table (1). Table (2) shows the warmth parameters for the different wearing cases of clothing assembly.

From Table (2), it could be deduced that the best wearing case of clothing assembly was the fourth one, containing jil (under wear), poplin of kafr El-Dawar (Shirt fabric), half cardigan (Knitted outer wear), viscose (Lining fabric), sticking fabric (Gasket fabric) and 100% wool (Suit fabric).

3- DESIGN OF COMPONENTS OF CLOTHING ASSEMBLY

From observation the result in Table (1), it is seen that knitted outer wear, under wear and suit fabric have the highest values of percentage share of thermal resistance compared to the other components. Thus, it is necessary to design knitted and suit fabrics for obtaining maximum thermal insulation.

In this paper, the problem of designing the knitted and woven components could be solved as follows:

Table (1): The Best Components of Wearing Cases of Clothing Assembly and Percentage Share of Total Thermal Resistance.

Components	1 st Case		2nd Case		3 rd Case		4 th Case		5 th Case	
	Type	Share,%	Type	Share,%	Type	Share,%	Type	Share,%	Type	Share,%
Under wear	Tricona	15.14	Jil	18.25	Jil	6.27	Jil	10.32	Jil	5.23
Shirt fabric	Poplin of Kafr El-Dawar	10.34	Poplin of Kafr El-Dawar	14.74	Poplin of Kafr El-Dawar	5.06	Poplin of Kafr El-Dawar	8.33	Poplin of Kafr El-Dawar	4.23
Knitted outer wear	Half cardigan	49.30	-	-	-	-	Half cardigan	39.71	Double jersey	17.62
Lining fabric	-	-	Polyester	13.16	Polyester	4.52	Viscosse	6.12	Viscose	3.10
Gasket fabric	-	-	With stick.	16.26	0.5 cm Air spacing	76.37	With stick	9.19	1.5 cm Air spacing	65.11
Suit fabric	-	-	100% Wool	22.65	100% Wool	7.78	100% Wool	12.80	50% Wool	4.71

Table (2): Comparison Between the warmth Property of the Best Wearing Cases of Clothing Assembly.

Wearing Case No.	Warmth Parameters		Relative Values		Quality Parameters		Rank
	Thermal Resistance, $10^4.(m^2c^o)/watt$	Air Resistance, $(N.sec)/m^3$	q_1	q_2	Geometric Mean (G)	Exponential Function (E)	
1	385.11	1222.86	0.4086	0.3544	0.3805	0.0344	5
2	270.23	3450.42	0.2867	1	0.5354	0.4705	3
3	786.67	503.58	0.8347	0.1459	0.3490	0.0514	4
4	478.04	3029.63	0.5072	0.8780	0.6673	0.9052	1
5	942.48	1472.88	1	0.4269	0.6534	0.8542	2

3.1 Design of knitted Outer Wear Fabrics

Thermal resistanee of knitted outer wear fabrics (R_k) depends on the properties of the used yarn and the construction of the knitted fabric and it can be calculated by the following equation [3]:

$$R_k = \frac{d_y}{e.k_y} \qquad \ldots (1)$$

where $e = 26.10^{-2}$ - emperical coefficient ;
d_y - calculated yarn diameter, m ; and
k_y - thermal conductivity of yarn , watt/(m.c°).

Linear density of yarn (tex) can be expressed as follows:

$$Tex = (m_y.1000)/L = (V.\rho_y.1000)/L.$$

i.e.

$$Tex = 250\ \pi\ d_y^2 .\rho_y \qquad \ldots (2)$$

where ρ_y - yarn density , g/cm^3.

By substituting in E_q. (2) from E_q. (1),

$$Tex = 250\ \pi\ (R_k.\ e.\ K_y)^2.\ \rho y \qquad \ldots (3)$$

Thermal resistance of yarn (K_y) can be calculated [4] from the following equation:

$$K_y = K_d\ [\ c + \frac{2(1-c)}{c} - I\ (1-c)^2\ ]\ , \qquad \ldots (4)$$

where K_d = 0.049 watt/(m.c°) - average thermal conductivity of the different textile fibres in the dry state [5];

$C = \cos(\phi/3)-0.143$;
$\phi = \text{arc}\ \cos(1-m_2)$;
$m_2 = (1-m_1)$ - ratio of air to yarn volume;
m_1 = ratio of yarn to fibres density ; and
I = 12.65 - ratio of water to dry fibres thermal conductivity.

Thus, the actual yarn thermal conductivity (K_y) can be calculated from E_q.(4) by finding the average fibre density and yarn density using the hlend ratio.

Total thermal resistance of clothing assembly composed of under wear (U), shirt fabric(S) and knitted outer wear (K) can be calculated as follows:

$$R_t = R_a + R_m + R_o \quad \ldots (5)$$

where R_a - thermal resistance of the air layers, $(m^2.c^o)/watt$;
R_m - thermal resistance of the textile material layers, $(m^2.c^o)/watt$; and
R_o - thermal resistance of the outside air film, $(m^2.c^o)/watt$.

By neglecting thermal resistance of the outside air film (R_o), E_q.(5) can be rewritten as follows:

$$R_t = R_a + (R_u + R_s) + R_k \qquad (Ra = 0.0074 \text{ experimentaly}) \quad \ldots (6)$$

From knowledge the values of R_t, R_a, and the total thermal resistanee of the clothing assembly without knitted outer wear ($R_u + R_s$), the thermal resistance of the knitted outer wear, R_k, can be easily calculated from E_q.(6)

$$R_k = R_t - (0.0074 + R_u + R_s)$$

By substituting in E_q.(3), the linear density of the knitted yarn (Tex) can be known for obtaining the desired thermal resistance of the knitted outer wear (Half Cardigan).

3.2 Design of Suit Fabric

There are many fabrics which can be used as a suit fabric. Therefore, an attempt has been made to design a good suit fabric with respect to the thermal resistance and air resistance. Thus, experimental design method (fractional factorial design) [6] was chosen to investigate the important constructional factors in weft direction of a certain suit fabric (article 656) such as X_1 (% wool /polyester), X_2 (weft yarn count, N_m) and X_3 (picks/inch) with constancy the specifications in warp direction such as 30/70 wool/polyester blend %, 50/2 N_m warp count and 20 ends/inch for a plain fabric. The factors and motrix of experimental design are given in Tables (3,4).

Table (3): Aetual Levels of Studied Factors

Factor	Level			Interval
	- 1	0	+ 1	
X_1 = Wool (%)	30	50	70	20
X_2 = Weft yarn count (N_m)	36/2	43/2	50/2	7/2
X_3 = Picks / ineh	40	45	50	5

Table (4): Experimental Design of Thermal Resistance and Air Resistance of Suit Fabric.

No.	Level of Factors X_1	X_2	X_3	Thermal Resistance, $10^4.(m^2.c^o)/watt$	Air Resistance, $(N.Sec)/m^3$	Relative Values q_1	q_2	Quality Parameters Geometric Mean (G)	Exponential Mean (E)	Rank
1	-	+	+	56.10	1150.24	0.9388	0.7824	0.8570	1.8690	3
2	+	+	-	59.76	380.44	1	0.7824	0.8570	1.8690	7
3	+	-	+	57.78	1470.15	0.9669	1	0.9833	4.0846	1
4	+	-	-	50.75	811.80	0.8492	0.5522	0.6848	0.9711	5
5	-	+	+	57.78	951.83	0.9669	0.6477	0.7912	1.4515	4
6	-	+	-	49.98	380.46	0.8363	0.2588	0.4652	0.2676	8
7	-	-	+	47.07	1460.51	0.7877	0.9934	0.8846	2.0986	2
8	-	-	-	59.26	558.28	0.9916	0.3797	0.6136	0.7166	6

The results of warmth property were analyzed using the computer. The regression coefficients were determined and the response-surface equations for both thermal resistance and air resistance are given in Table (5) with the correlation coefficients between the experimental values and the calculated values obtained from the response-surface equations. The response surfaces agree fairly well with the experimental results, as can be observed from the high correlation coefficients.

Table (5): Response-surface Equations

Property	Response-surface Equation	r
Y_1 = Thermal resistance, $10^4.(m^2.c^o)/watt$	$Y_1=54.81+1.29X_1+1.09X_2-0.13X_3+0.74X_1X_2+0.97X_1X_3+1.16X_2X_3$	0.9999
Y_2 = Air resistance, $(N.sec)/m^3$	$Y_2=895.96+58.19X_1-160.22X_2+363.22X_3-8.60X_1X_2-5.18X_1X_3-27.93X_2X_3$	0.9868

Figures (1,2) show the effect of yarn count (N_m) and picks/inch on both thermal resistance and air resistanee respeetively. The response surface is easily influenced by the variables X_1, X_2 and X_3. There is a large increase in thermal resistance when X_1 and X_2 at the highest level. But there is a large increase in air resistance when X_1 and X_3 are at the highest level.

The highest values of both thermal resistance and air resistance of suit fabrics could be aehieved by doubllcating the figures (1,2) together for the level+1 of variable X_1 (wool%) as shown in Fig.(3). As can be observed from Fig.(3), the oplimum constructional factors (X_2,X_3) would be found in the optimum zone which X_2 (weft yarn eount) is equal to 50/2 N_m and X_3 (picks/inch) is equal to 48. Thus it is preferable to design suit fabrics with the following specifications: to protect human body against the atmospheric conditions.

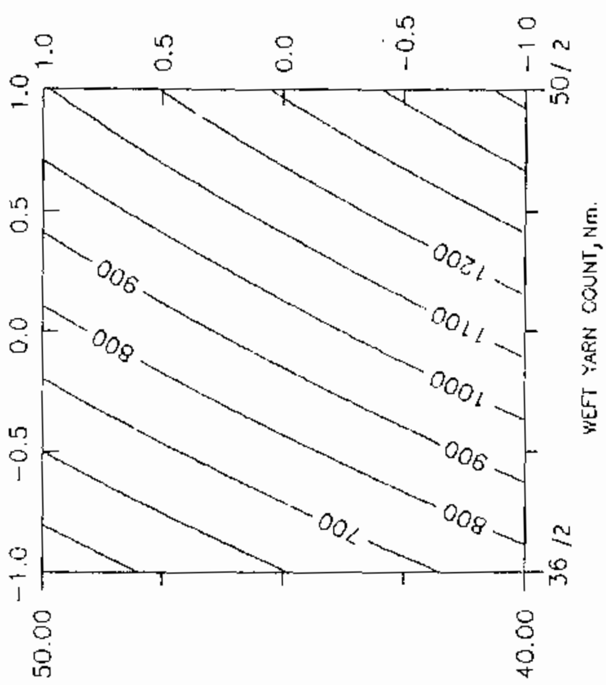

FIG. (2) CONTOURS FOR AIR RESISTANCE OF SUIT FABRIC FOR +1 LEVEL OF VARIABLE X_1 (70% Wool).

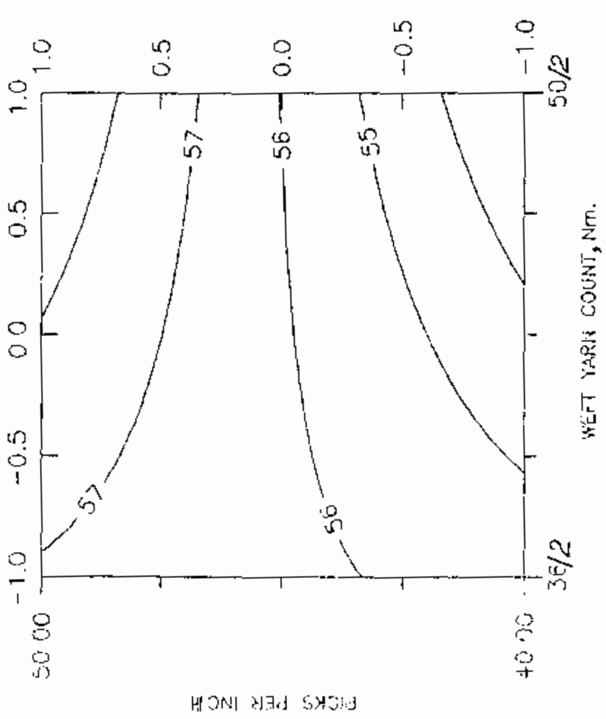

FIG. (1) CONTOURS FOR THERMAL RESISTANCE OF SUIT FABRIC FOR +1 LEVEL OF VARIABLE X_1 (70% Wool).

Characteristics of Suit Fabric:

Ends/inch	: 20
Picks/inch	: 48
Warp count, N_m	: 50/2
Weft count, N_m	: 50/2
Wool/polyester blend (%) in warp	: 30/70
Wool/polyester blend (%) in weft	: 70/30
Weave design	: plain

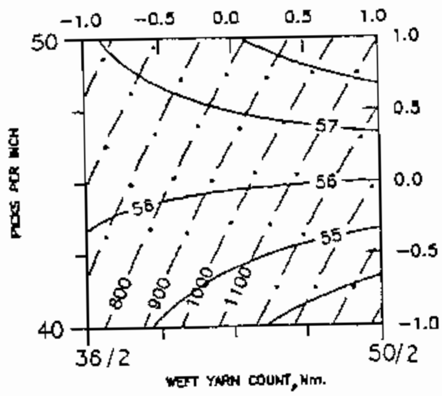

FIG.(3) THE DUPLEX CONTOURS OF WARMTH PROPERTIES FOR SUIT FABRICS.
— Thermal resistance at R_1 = +1 (100% Wool)
-.- Air resistance at R_1=+1 (100% wool)

4. CONCLUSIONS

From the work described in this paper, the following conclusions have been deduced:

1- Knitted outer wear, under wear and suit fabrics have the highest values of percentage share of thermal resistance respectively compared to the other components of clothing assembly.

2- Five wearing cases could be assessed and ranked with respect to warmth efficiency using the geometric mean and the exponential function.

3- The best wearing case of clothing assembly was the fourth one, containing Jil (under wear), poplin of Kafer El-Dawar (Shirt fabric), half cardigan (Knitted outer wear), viscose (Lining fabric), Sticking fabric (Gasket fabric) and 100% wool (Suit fabric).

4- The needed linear density of knitted yarn (Tex) could be calculated for obtaining the desired thermal resistance of the knitted outer wear at constancy type of structure, number of wales and number of coarses per unit length.

5- The optimum values of the constructional factors in weft direction of a certain suit fabric such as wool/polyester ratio, weft yarn count and picks per inch could be determined to design a new suit fabric with a high warmth efficiency, which wool/polyester was 70% / 30%, weft yarn count was 50/2 Nm and picks per inch was 48.

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