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STRUCTURE OF NON-WOVEN FABRICS

Part. IV Compressional Properties of Needle Punched Non-Woven Fabrics.

By

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خلاصة ـ الخواص الانضغاطيه للأقمشه الغير منسوجة ميكانيكيا يمكن التنبأ بها من دراسة العلاقه بين السمك والضغط للقماش المختبر . ثبت أن معادلة سلوفيف لقياس العلاقه بين الضغط والسمك والخاصة بالاقمشة المنسوجة صالحة أيضا للتطبيق على الاقمشة الغير منسوجة فى حدود ٢ر٠-٢ر١٠٤ جم/سم٢ أثبت البحث أن معامل B ، والمعامل b فى معادلتى سلوفيف وبوجاتى ترتبط بصلابة القماش H . معادلة قياس السمك للقماش الغير منسوج عند ضغط صفر على صوره ت صفر = ١٦٧ر١ ت ٦ر٠ - ١٦٧ر٠ ت ٢ر١٠٤ أعطيت فى هذا البحث لاول مرة . كما ثبت أن كل من طراوة القماش وانضغاطيته ترتبطان كل منهما بالاخر.

ABSTRACT

The compressional properties of needle punched non-woven fabric could be predicted from the thickness-pressure relationship. The thickness-pressure equations found by Bogaty and Solove'ev for woven fabrics. were also found suitable for needle punched non-woven fabrics, for pressure ranges between 0.2 and 104.2 g/cm^2. The final incompressibility coefficient B and the compression energy coefficient b obtained from Solove'e's and Bogaty's equations are well related to fabric hardness. A new equation in the form of; $t_o = 1.167\ t_{0.6} - 0.167\ t_{104.2}$ could be used to calculate the thickness at zero pressure. Also it was found that fabric softness and fabric compressibility are well related to each other.

Key-Words: y, b_p, t and a = fabric thickness (mm), P and X = pressure (g/cm^2), A = fabric initial resistance at pressure less than 1 g/cm^2, (g/cm^2/mm)$_2$, B = fabric final incompressibility at pressure above 1 g/cm^2, (mm^{-1}), b = compression energy coefficient, H = fabric hardeness, (g/cm^2/mm), R = fabric resilience (%).

1. INTRODUCTION

The purpose of the present investigation is to examine the compressional properties of needle punched non-woven fabric, through the study of the thickness-pressure relationship of the fabric.

The literature of physical and mechanical properties of non-woven fabrics show that the use of the thickness-pressure relationship for assessing the compressional properties of the fabric, has not been examined in details, and the measurment of thickness for any particular purpose[1,2,3,4 and 5] has been carried out at arbitrarly pressure. In addition to this no information are available in the literature to calculate the thickness of non-woven fabric at zero pressure, which was found to be important in the studies of the structure of non-woven fabric[1].

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In the present investigation, the equations of thickness proposed by Bogaty[6] and Solove'ev[7] for woven fabrics have been selected and examined for non-woven fabrics.

2. Measurment of Thickness

The thickness of non-woven fabric was measured by the "Shirley Thickness Gauge"[2] at pressure ranges between 0.2 and 104.2 g/cm^2, using a foot of 50 cm^2.

3. Specifications of Fabrics

The specifications of fabrics are given in the Appendix.

4. Thickness-Pressure Relationship

Plotted in Fig. 1 examples of the relationship between thickness and pressure. Generally for all fabrics this form of curves is obtained, i.e. thickness tends to decrease as pressure increases, and that the decrease in thickness is large at the begining then at lower rate as pressure increases. This may be attributed to the collapse of the protruding hairs at low pressures, then to fabric flattening at high pressures.

To examine the suitability of Solove'evs equation, i.e. y = bp + P-X/A+BX, the procedure described by Solove'ev has been followed and the coefficients A and B were determined, but a slight modification has been made in these coefficients so that the differences between the measured and calculated thickness are within ± 10% and better. Given in Table 1 the values of A and B in the loading and recovery cycles. The equation is also valid in the recovery cycle, but with different A and B values.

Table 1: Values of A and B in the Loading and Recovery Cycles.

Fabric	Loading Cycle		Recovery Cycle	
	A	B	A	B
Wool Waste	1.299	0.263	1.383	0.440
100% Wool	0.808	0.577	1.343	0.980
Polyproplyene (POP)	0.968	0.210	1.020	0.308
Polyacrylic	2.126	0.295	3.143	0.508
Polyester (undyed)	2.685	0.311	4.895	0.601
Polyester (PES)	1.294	0.256	1.839	0.428

With respect to Bogaty's equation; i.e. t = a+b/p+c the limiting thickness "a" was measured at the maximum pressure available in the thickness gauge meter, i.e. 104.2 g/cm^2, and trials have been made to select the suitable value for the pressure correction parameter C. According to Bogaty C accounts for the fact that the fabric does not become thicker without limit (i.e. thickness will be infinite at zero pressure, which is not real) as the pressure decreases. A single C-value of 3.6 g/cm^2 was choosen for all tested fabrics.

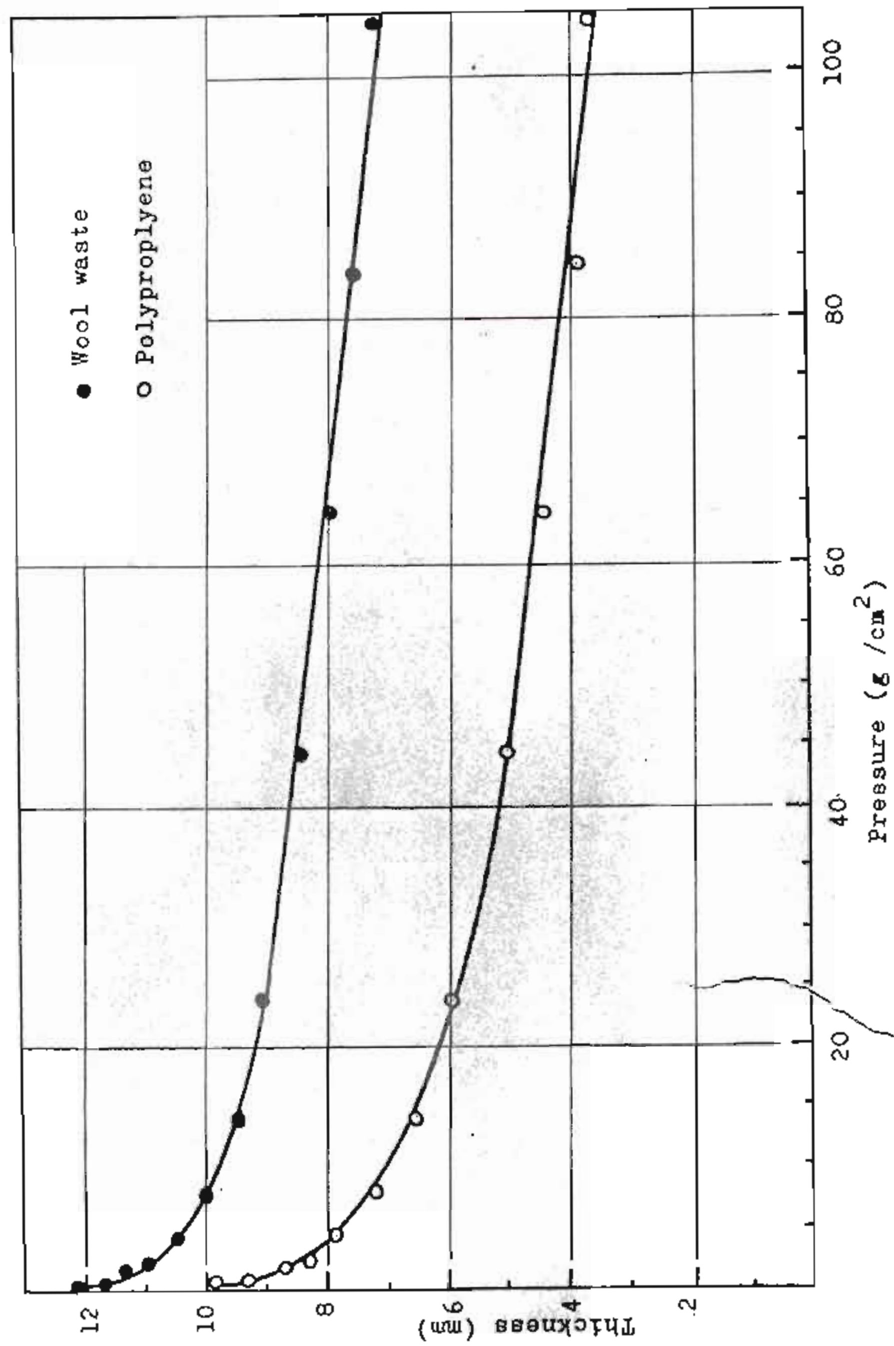

Fig.1 Thickness Versus Pressure

When the value of b was calculated at each pressure it was not constant, but fairly constant between pressures 0.2 and 8.2 g/cm^2. But since we are looking for a single b- value for each fabric, a slight alteration in the limiting thickness "a" was considered, so that the differences between the calculated and measured thickness are within ± 10% and better. The average b-value obtained at low pressures, i.e. up to 4.2 g/cm^2 was very close to the b- value calculated at pressure 0.6 g/cm^2. This value could be used directly in any comparisons between fabrics. Given in Table 2 the b- values in the loading and recovery cycles and at 0.6 g/cm^2.

Table 2: Value of the Coefficient b in the Loading and Recovery Cycles.

Fabric	b-loading	b-recovery	b-loading (at pressure = 0.6 g/cm^2)
Wool Waste	19.30	12.18	19.11
100% Wool	12.66	5.88	12.60
Polypropylene (POP)	24.04	17.22	23.94
Polyacrylic	16.70	10.50	16.38
Polyester (undyed)	14.63	9.07	14.32
Polyester (PES)	20.77	12.60	20.58

From the table one may observe the large drop in the b-value in the recovery cycle. According to Bogaty this value could be used to represent the hairiness or fuzziness of the surface of the fabric, or as an energy absorption coefficient, since from it's definition it represents an area under the thickness-pressure curve. In Section 9 we have shown that the ratio between b- value obtained in the recovery cycle and loading cycle expressed in percentage is well related to fabric resilience.

When the b- values obtained in the loading and recovery cycles were ranked, it was interesting as may be seen from Table 3 that each fabric maintains it's position.

Table 3: Ranking of b- Values.

	Fabric					
	Wool waste	100% Wool	Polyproplyene	Polyacrylic	Polyester	Polyester(PES)
b-loading	3	6	1	4	5	2
b-recovery	3	6	1	4	5	2

The rank correlation coefficient R = 1 and highly significant at the 1% level.

These results indicated that the information obtained from the thickness-pressure relationship in the recovery-cycle would reflect the original nature of the fabrics and that the original differences in structure between fabrics would remain after compression, and fabrics will rank in the same order.

The above trends in the coefficients A, B and b in the loading and recovery cycles for non-woven fabrics are similar to that obtained for a wide variety of knitted structures[8]. In a future publication we are going to show how the coefficients A and B could be used to calculate the compression moduli of textile structures.

5. Thickness at Zero Pressure

From the equations given in Sec. 4, using the A, B and b values, the thickness at zero pressure "t_o" was calculated for each fabric. Given in Table 4 the values of t_o.

Table 4: Thickness at Zero Pressure.

Fabric	Thickness at Zero Pressure (t_o) (mm)	
	According to Solove'ev's Equ.	According to Bogaty's Equ.
Wool Waste	12.20	12.51
100% Wool	8.43	8.61
Polyproplyene	10.22	10.30
Polyacrylic	10.96	11.34
Polyester (undyed)	8.64	9.00
Polyester (PES)	10.80	11.70

It is interesting to find that the differences obtained in t_o-values are practically of insignificant value, hence both equations could be used equally to calculate the thickness at zero pressure. This in fact showed that the determination of the coefficients A, B and b was successful.

6. Relationship between Coefficients B and b and Fabric Hardness (H)

Plotted in Figs. 2 and 3 the values of B and b versus fabric hardness (H). The hardness is calculated according to Peirce's[9] equation:

$$H = \frac{P_{104.2} - P_{0.2}}{t_{0.2} - t_{104.2}} \ g/cm^2/mm \qquad \ldots\ldots(1)$$

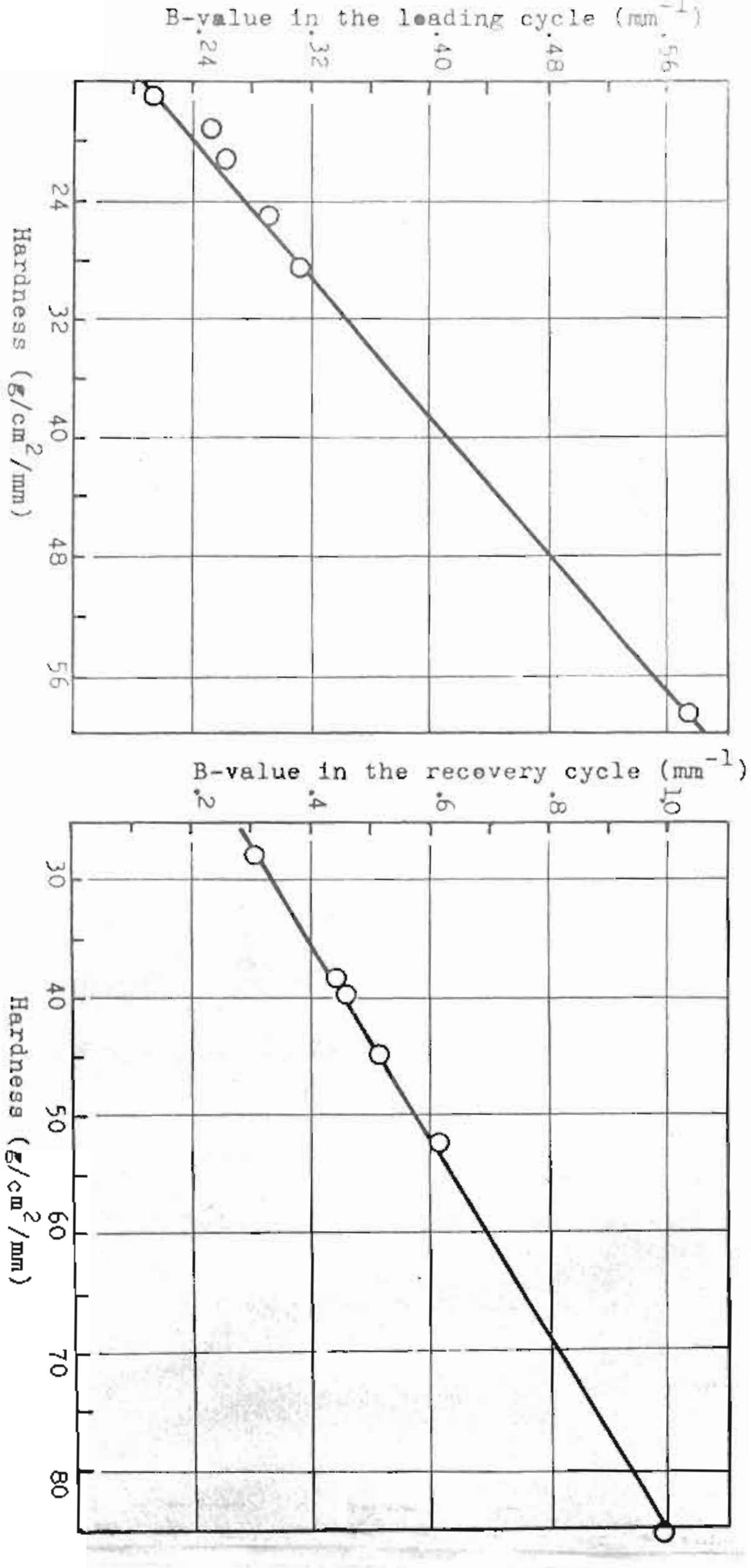

Fig.2 Fabric Final Incompressibility Coefficient(B) Versus Fabric Hardness (H)

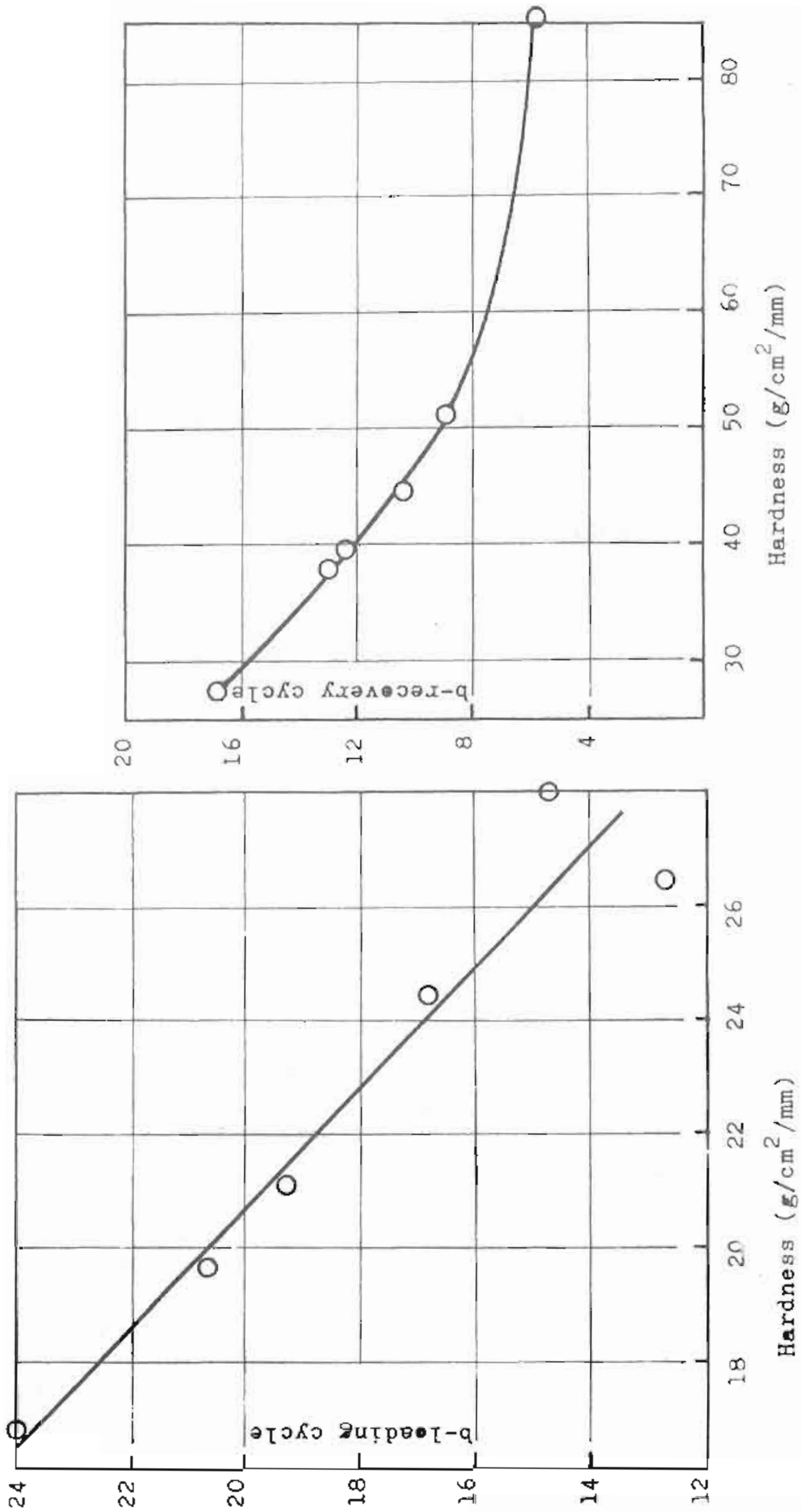

Fig.3 Compression Energy Coefficient (b) Versus Fabric Hardness (H)

where $t_{0.2}$ and $t_{104.2}$ are the thickness measured at pressures 0.2 and 104.2 g/cm^2 respectively.

It is interesting to observe from the figures that B tends to be high for hard to press fabrics, while b follows an opposite trend. This means that the final incompressibility of the fabric at pressures above 1 g/cm^2 (represented by B) will be less for hard fabrics and vice-versa. And that the hard to press fabrics will absorp less energy in compression (represented by b-value) than soft fabrics. Hence both coefficients b and B could be used equally to assess the ability of the fabric to absorp compression energy, and the same to be said about hardness. Therefore any of the three coefficients B, b and H could be used equally to assess the compressional properties of the fabric.

7. Relationship between Fabric Softness (M), Fabric Compressibility (b/c) and Fabric Hardness (H)

Solove'ev[7] proposed the use of his equation to calculate the thickness at zero pressure (t_o), and from this value and the thickness value at high pressure, i.e. t_c, fabric softness (M) could be determined. According to Solove'ev;

$$M = t_o - t_c \text{ mm} \quad \text{.....(2)}$$

In the present work t_c was measured at the maximum pressure available in the thickness-tester, i.e. 104.2 g/cm^2.

From Bogaty's equation, i.e. $t = a + b/p+c$, one can also calculate the thickness at zero pressure (Bogaty never used his equation for this purpose), hence "t_o" will be:

$$t_o = a + \frac{b}{c} \quad \text{.....(3)}$$

and since a is measured at 104.2 g/cm^2, then $a = t_c$ hence equ. 3 becomes:

$$t_o - t_c = \frac{b}{c} \quad \text{....(4)}$$

Therefore from equs. (2) and (4) one can write;

$$M = b/c \quad \text{.....(5)}$$

Since M in equ. 2 and b/c in equ. 4 represent the amount by which the thickness is compressed from zero pressure to the maximum pressure used, one would expect these values to be equall if the coefficients A, B, b and c were determined correctly. Given in Table 5 the values of M and b/c for various fabrics.

Table 5: Values of Fabric Softness (M) and Fabric Compressibility (b/c).

Fabric	M (mm)	b/c (mm)
Wool Waste	5.05	5.36
100% wool	3.34	3.52
Polypropylene (POP)	6.62	6.68
Polyacrylic	4.26	4.64
Polyester (undyed)	3.70	4.06
Polyester (PES)	5.40	5.77

Although the b/c_{values} are slightly higher than the M values but the differences are practically of insignificant value, and have no influence on fabric ranking. Both M and b/c rank the fabrics in the same order. The rank correlation coefficient R = 1 and highly significant at the 5% level.

Plotted in Fig. 4 the values of M and b/c versus fabric hardness (H) in the loading cycle. Also shown in the figure the b-value for each fabric.

It is clear from the figure that both M and b/c are well related to fabric hardness, generally hard to press fabrics show less softenss or compressibility and vice-versa. Also that hard to press fabrics show lower b-values than soft fabrics. Here again it is evident that the three parameters M, b/c and H would describe the fabric compressibility equally and that fabrics will generally rank in the same order if any of the three parameters was used.

8. New Equation to Calculate the Thickness at Zero Pressure

In Sec. 7 we have proved that;

$$M = b/c \qquad .....(6)$$

and since

$$M = t_o - t_c \qquad .....(7)$$

then

$$t_o - t_c = b/c \qquad .....(8)$$

$$\therefore t_o = t_c + b/c \qquad .....(9)$$

But we have proved in Sec. 4 (Table 2) that the b-value could be directly calculated with high accuracy at pressure 0.6 g/cm^2, and that the suitable c-value is 3.6, hence equ. 9 could be written as:

$$t_o = t_c + \frac{(t_{0.6}-t_c)(p + c)}{c} \qquad .....(10)$$

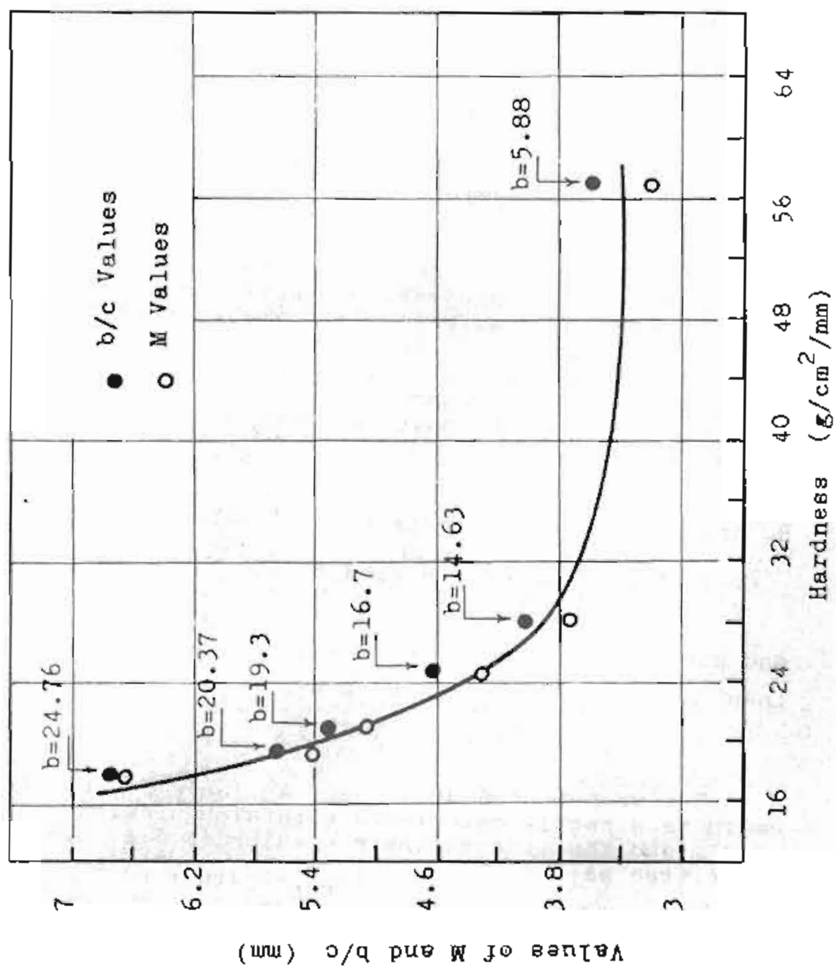

Fig.4 Values of Hardness Versus Softness and Compressibility (Loading Cycle)

and by arranging this equation, the thickness at zero pressure will be:-

$$t_o = 1.167\ t_{0.6} - 0.167\ t_c \qquad .....(11)$$

where $t_{0.6}$ = thickness measured at 0.6 g/cm^2,
and t_c = thickness measured at 104.2 g/cm^2.

Given in Table 6 the values of thickness at zero pressure as calculated from Bogaty's, Solove'ev's and the present work equations.

Table 6: Values of Thickness at Zero Pressure.

Fabric	Thickness (t_o) (mm)			c.v.%
	Solove'ev's Equ.	Bogaty's Equ.	Present Work's Equ.	
Wool Waste (I)	12.20	12.51	12.47	1.11
100% wool (II)	8.43	8.61	8.60	0.01
Polyproplyene(POP)(III)	10.22	10.30	10.25	0.32
Polyacrylic (IV)	10.96	11.34	11.25	4.50
Polyester (undyed)(V)	8.64	9.00	8.92	1.74
Polyester (PES) (VI)	10.80	11.70	11.12	3.34

9. Fabric Resilience

The thickness measurments for non-woven fabrics could be used to calculate the resilience (%) of the fabric. The value of resilience is used generally to assess the suitability of the fabric when exposed to compression.

The following equation was used to calculate the resilience:-

$$\text{Resilience (\%)} = \frac{Z - Y}{X - Y} \times 100 \qquad .....(12)$$

where X = original thickness (in our case measured at 0.6 g/cm^2).
Z = recovered thickness (in our case measured at 0.6 g/cm^2).
Y = compressed thickness (in our case measured at 104.2 g/cm^2).

For the present fabrics the resilience ranges between 46.7% (for 100% wool fabric) to 71.9% (for polyproplyene fabric). It is known that the higher the percentage the better is the recovery from compression.

It was thought of using the compression energy coefficient (b) as determined according to Sec. 4 in the loading and recovery cycles to describe the resilience of the fabric. Since from the definition of this

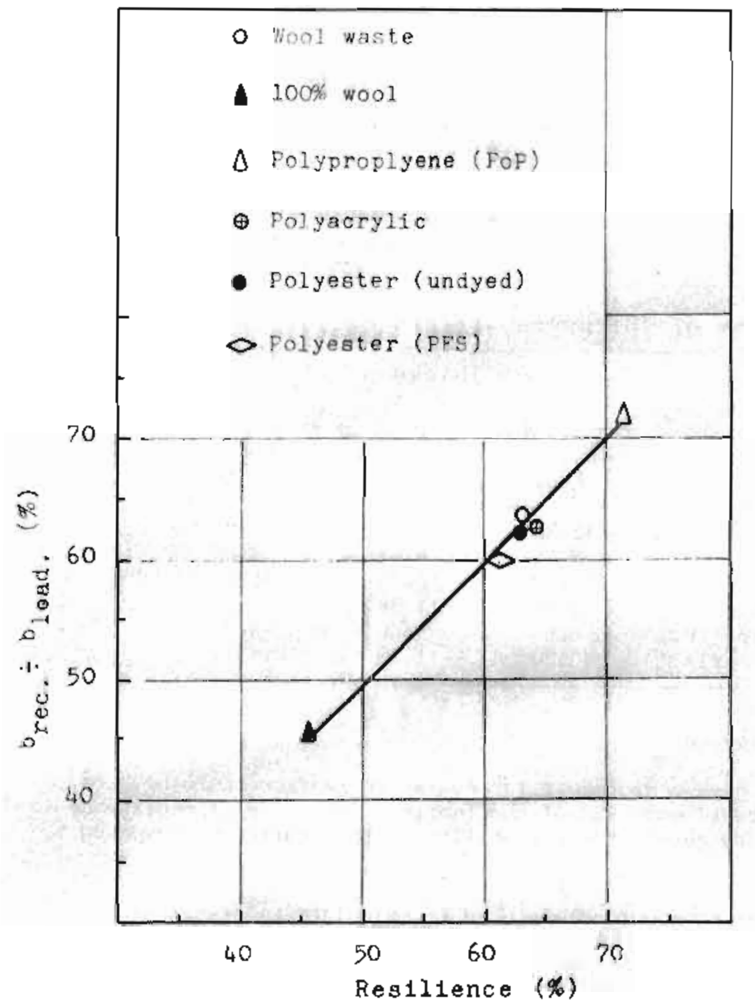

Fig.5 Values of $b_{rec.}/b_{load.}$ Versus Resilience

coefficient, it represents an area under the thickness-pressure curve, therefore the ratio of $b_{recovery}$ and $b_{loading}$ expressed in percentage was calculated for each fabric. It was found that the values obtained are very close to those obtained for resilience, and the fabrics rank in the same order. Plotted in Fig. 5 the values of the resilience (%) and the ratio $b_{rec.}/b_{Load.}$ x 100. It is evident from the plot that the two values are positively correlated and that fabric of high resilience has also high b-rec./b-load. ratio and vice-versa. This result indicated that the b-value in the loading and recovery cycles as calculated at 0.6 g/cm^2 is a very good indication to fabric resilience. Therefore no need to measure the whole area under the thickness-pressure curve to assess fabric resilience in compression.

CONCLUSIONS

1- The equations proposed by Bogaty and Solove'ev to relate thickness to pressure, are equally suitable to relate the thickness of needle punched non-woven fabric to pressure, when the thickness is measured at pressure ranges between 0.20 and 104.2 g/cm^2. Also applicable when the pressure is reduced over the compressed area.

2- The coefficient of final incompressibility B is well related to fabric hardness, B tends to increase as fabric hardness increases.

3- The compression energy coefficient b is well related to fabric hardness, as fabric hardness increases the compression energy coefficient decreases, and that the compression energy coefficient in the recovery cycle is less than that of the loading cycle.

4- The fabric softness as proposed by Solove'ev and the compressibility as determined from Bogaty's equation are approximately equall, and both tend to decrease with the increase of fabric hardness.

5- The thickness at Zero pressure (t_o) could be calculated from the equation:-

$$t_o = 1.167\ t_{0.6} - 0.167\ t_{104.2}$$

where $t_{0.6}$ and $t_{104.2}$ are thickness at the pressures 0.60 and 104.2 g/cm^2 respectively.

6- Fabric resilience is well related to the ratio of the compression energy coefficient as determined from the recovery and loading cycles, expressed in percentage. Fabric showing high resilience also shows high b-ratio.

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APPENDIX

Specifications of Fabrics.

Commerical Needle-Punched Fabrics.

Code	I	II	III	IV	V	VI
Type	Random-laid					
Fibre	Waste wool	Wool 100%	POP_s	PAN_s	PES_s (undyed)	PES_s (dyed)
Weight (g/m^2)	690	600	360	600	480	600
Punching Density (stitches/cm^2)	60	60	100	60	60	100