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PILLING OF TEXTILE FABRICS

BY

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1- INTRODUCTION:

The textile fabric (woven, non-woven and knitted) during its use is subjected to various types of strains, i.e. tensile, bending, shear and surface friction. These strains may act individually or together on the individuall elements of the fabric, i.e. fibres and causes damage.
When a textile fabric comes into contact with itself or with a dissimilar fabric or with a foreign surface (metallic or non-metallic) and forced to move, friction is generated[1]. The friction force generated may act directly on the individuall elements to cause wear of fibre material or indirectly to cause tension, bending, shear, torsion and/or slippage[2,3]. During abrasion action fibre bend and when its length becomes suitable it entangles with other fibres and form a pill.

With the introduction of man-made and synthetic fibres and with their wide use in the manufacture of fabrics many proplems have appeared. Among these proplems is the proplem of pilling. Pilling does not only deteriorates garment appearance but also creates discomfort in undearwear that are in contact with the skin.

The literature of pilling show that Richard[4] examined the case of pilling of weft knitted structures and namely plain and 1x1 rib under arbitary light pressure. The fabrics were knitted from 64^s tops and tested for pilling tendency by W.I.R.A. abrasion testing machine. In this machine both sample and abradant rotate in the same direction. The assessement of pilling was carried out by removing the pills from the fabric and weighting it. The weight per unit area was used as estimation of pilling. Richard[4] also carried out wear trials for

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garments produced at the same conditions and at various cover factors. These garments and their corresponding fabrics were tested after dry relaxation. The following results were found:-

1) pilling decreased as stitch length was reduced.
2) wet relaxed fabrics pilled more than dry relaxed fabrics.
3) pilling increased as yarn had become finer.

Baird and Morris[5] examined pilling tendency of nylon and nylon blended woven fabrics. Their investigation considered the influence of nylon content, fibre length and denier, yarn twist, doubling yarns, ends and picks, type of weave, milling, heat setting, dyeing, wetting and flexing. They found the following:-

1) at low twist factor the number of pills is high and as the twist multiplier increased the number of pills droped drastically.
2) fibre staple length had no effect on pilling.
3) fabric weave has a remarkable effect on pilling. Plain fabrics show high number of pills than a 2 x 2 twill fabric woven from the same yarn.
4) wetting increases pilling.
5) flexing of fabric has no effect on pilling.

In the above mentioned investigations no attempt was made to explain the mechanism of pilling of a fabric. Conti and Tassinari[6] put a simplified kinetic model for the mechanism of pilling. Brand and Bohmfalk[7] considered the fabric as an infinite source of fuzz. The process begins with the formation of fuzz, then entanglement of fuzz and finally the formation of pill. The pill may take many rubs untill it breaks or seperated from the body of the fabric. Also in their investigation they examined the number of fibres included in the pill and made a distribution for this number.

In the present investigation the effect of various factors (which have not been considered in previous investigations) on pilling of fabric, such as pressure, cover factor (in the case of knitted fabric), speed of rubbing, type of motion of both fabric and abradant and type of abradant has been examined. The investigation included the study of pilling of knitted and woven fabrics when the fabric is rubbed against itself or against a standard worsted fabric.

2- Apparatus Used for Studying Pilling of Fabrics:

The apparatus used in the present investigation for studying pilling of fabrics is the pill-o-meter. In this appararus rubbing is produced by the relative displacement of two clamp heads placed on one another with their flat surfaces and pressed together by a definite force. The lower clamp hold the test specimen and the upper head carries the abradant. The abradant may be a standard abrading cloth, or may be the same fabric under consideration, or some other abrading material. The table which carry the specimen to be tested can move in "x" or "y" direction as shown in Figs. 1 and 2. The x-movement is an alternating movement of constant speed, changes in the speed occuring only at the two extreme dead points at which the movement is reversed. The "y" movement is a simple harmonic/sinusoidal movement. The number of combinations by the two alternating movement in "x" and "y" directions is 25. This combination number can be varied by making the top head to stop or to rotate, therefore 49 movement combination can be obtained by the apparatus.

3- Testing Procedure:

The sample and the abradant are fixed in their places in the lower and upper clamps respectively. The apparatus was adjusted to stop automatically every 1/2 hr. to follow the changes which may occur on the surface of the fabric as a

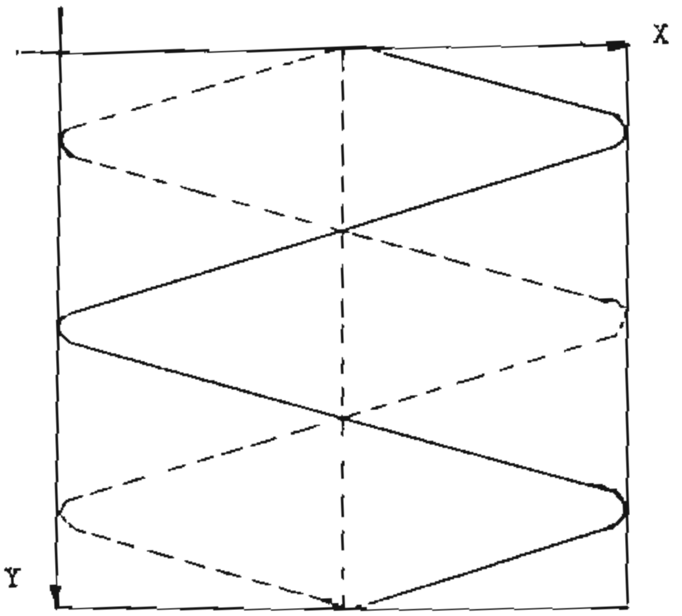

Fig.1.

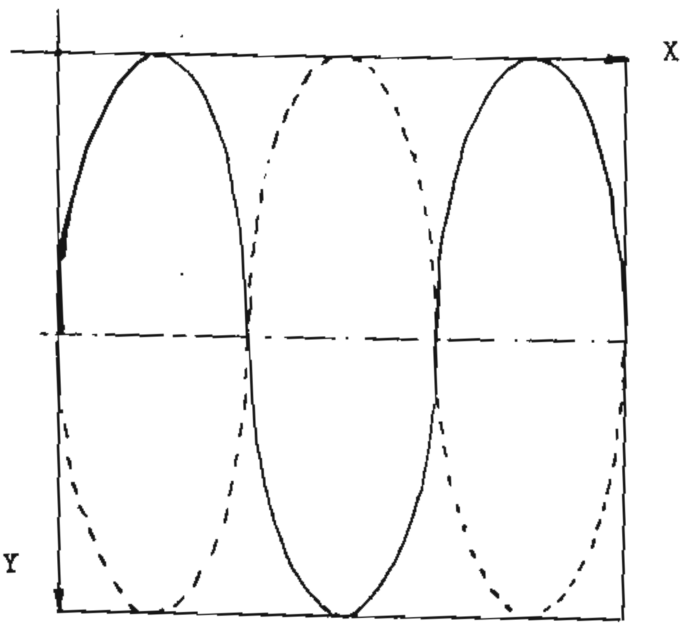

Fig.2.

result of rubbing. The abradant (which is a standard worsted fabric and the fabric itself) is removed and replaced by a fresh one every four hours. At the end of each 1/2 hr the number of pills are counted using a special template.

4- Results:

4-1. Pilling of Knitted Fabrics:

The tendency of pilling of some weft knitted fabrics produced at various cover factor and that of a warp knitted fabric has been examined in the dry state using the pill-O-meter. The weft knitted fabrics were produced on a flat v-bed knitting machine usingacrylic yarn and a wool/nylon yarn of 242 tex and 281 tex respectively. The acrylic fabrics were knitted at four cover factors ranging between 15.3 and 10.4 $tex^{1/2}. cm^{-1}$. The pilling test was carried out using a standard worsted abradant fabric and the pressure applied between fabric and abradant ranging between 10 and 25 g/cm^2. The rubbing time reaches to four hours. The upper head which is carrying the abradant rotates at 1 r.p.m. (clock-wise), while the specimen is moving at 40 cycles/min and supported by soft packing (sponge).

Given in Table 1 the number of pills formed after various periods of rubbing. From the table one may observe the following:-

1) at a pressure of 10 g/cm^2 and over the range of cover factors used no pills were formed.

2) when pressures higher than 10 g/cm^2 were used pilling occured, and generally as the time of rubbing went on the number of pills increased and reaches a maximum then fell down. After four hours of rubbing all pills were removed leaving the surface of the fabric clean and clear. The effect of cover factor on pilling is the not the same for the range of pressures used, while pilling tends to decrese as the cover

factor decreases for pressures 12.5 and 15 g/cm^2, the trend is reversed at maximum pressure (provided by the pilling apparatus used) i.e. 25 g/cm^2.

Given in Table 2 the number of pills formed in a plain weft knitted wool/nylon fabric produced at four oover factors ranging between 11.2 and 16.5 tex^{½}. cm^{-1}. Rubbing action took place at conditions similar to that used in the case of plain weft knitted acrylic fabric, except that hard packing was used to support the fabric. The support surface is prespex material. The following was found:-

Table (1): Number of pills formed in a plain weft knitted acrylic fabric rubbed against a standard worsted fabric.

Cover factor $\sqrt{tex}/L$	Pressure g/cm^2.	Time of rubbing (hr). ½	1	1½	2	2½	3	3½	4
15.3	10	-	-	-	-	-	-	-	-
13.0		-	-	-	-	-	-	-	-
11.5		-	-	-	-	-	-	-	-
10.4		-	-	-	-	-	-	-	-
15.3	12.5	3	3	2	2	1	-	-	-
13.0		1	1	2	2	2	2	-	-
11.5		1	2	2	2	2	2	-	-
10.4		2	3	3	3	2	2	-	-
15.3	15	6	6	4	4	3	2	-	-
13.0		4	4	3	3	3	2	-	-
11.5		3	2	2	2	2	2	-	-
10.4		2	1	1	1	1	1	-	-
15.3	25	4	4	4	3	3	3	-	-
13.0		2	3	2	2	2	2	2	-
11.5		3	5	5	4	4	4	-	-
10.4		4	6	6	7	7	7	-	-

Table (2): Number of pills formed in a plain weft knitted wool/nylon fabric rubbed against a standard worsted fabric.

Cover factor $\sqrt{tex}/L$	Pressure g/cm^2	Time of rubbing (hr.) ½	1	1½	2	2½	3	4
16.5	2.5	4	2	1	1	1	0	0
14.0		0	0	2	1	1	1	0
12.4		0	0	0	0	0	0	0
11.2		0	0	0	0	0	0	0
16.5	10	2	1	0	0	0	0	0
14.0		0	0	0	0	0	0	0
12.4		0	0	0	0	0	0	0
11.2		0	0	0	0	0	0	0
16.5	12.5	0	0	1	1	2	2	0
14.0		0	1	1	1	1	1	0
12.4		0	1	1	0	0	0	0
11.2		0	0	0	0	0	0	0
16.5	15	11	8	6	5	5	5	0
14.0		6	5	4	2	2	2	0
12.4		3	1	1	1	1	0	0
11.0		0	0	0	0	0	0	0

Table (3): Number of pills formed in a plain warp knitted acrylic fabric rubbed against a standard worsted abradant fabric.

Pressure g/cm^2	Time of rubbing (hr.) ½	1	1½	2	2½	3	4
10	22	35	48	50	25	13	0
20	20	32	35	12	7	6	0

1) the number of pills at any cover factor increases as pressure applied between fabric and abradant increases. This was quite apparent at cover factors of 16.5 $tex^{1/2}. cm^{-1}$ and at a pressure of 15 g/cm^2.
2) at all pressures used, fabrics with low cover factor showed no tendency for pilling. This was quite apparent with conditions of low pressures, i.e. 2.5 and 10 g/cm^2.

In addition to the previous experiment on pilling of knitted fabrics the tendency of pilling of a plain warp knitted fabric rubbed against a standard worsted abradant fabric, has been carried out applying pressures of 10 and 20 g/cm^2 between fabric and abradant. Given in table 3 the number of pills formed in the fabric at various periods of rubbing at these pressures. In this experiment the fabric was given "x" - "y" movement at a speed of 40 cycles/min, and the abradant was rotating at 1 r.p.m. A hard packing was used to support the fabric.

From Table 3 and Fig. 3 one may observe that under the pressures used, the number of pills increases as the time of rubbing goes on and reaches a maximum then falls down. After four hours of rubbing the pills were removed entirely. Also from Table 3 one can observe that with high pressure, i.e. 20 g/cm^2 the number of pills formed in the pill-building part of the pill-time curve are less than that obtained when lower pressure was used, i.e. 10 g/cm^2. In addition to that mentioned the rate of pill removal in the wear-off part of the pill-time curve is high at pressures used.

4-2. Pilling of Plain Cotton/Polyester Woven Fabric Rubbed Against Itself and Against a Standard Worsted Fabric.

Given in Table 4 the number of pills formed in a plain cotton/polyester fabric rubbed against a standard worsted fabric and against itself. The fabric was given "x" movement only at a speed of 40 cycles/min. Soft packing was used.

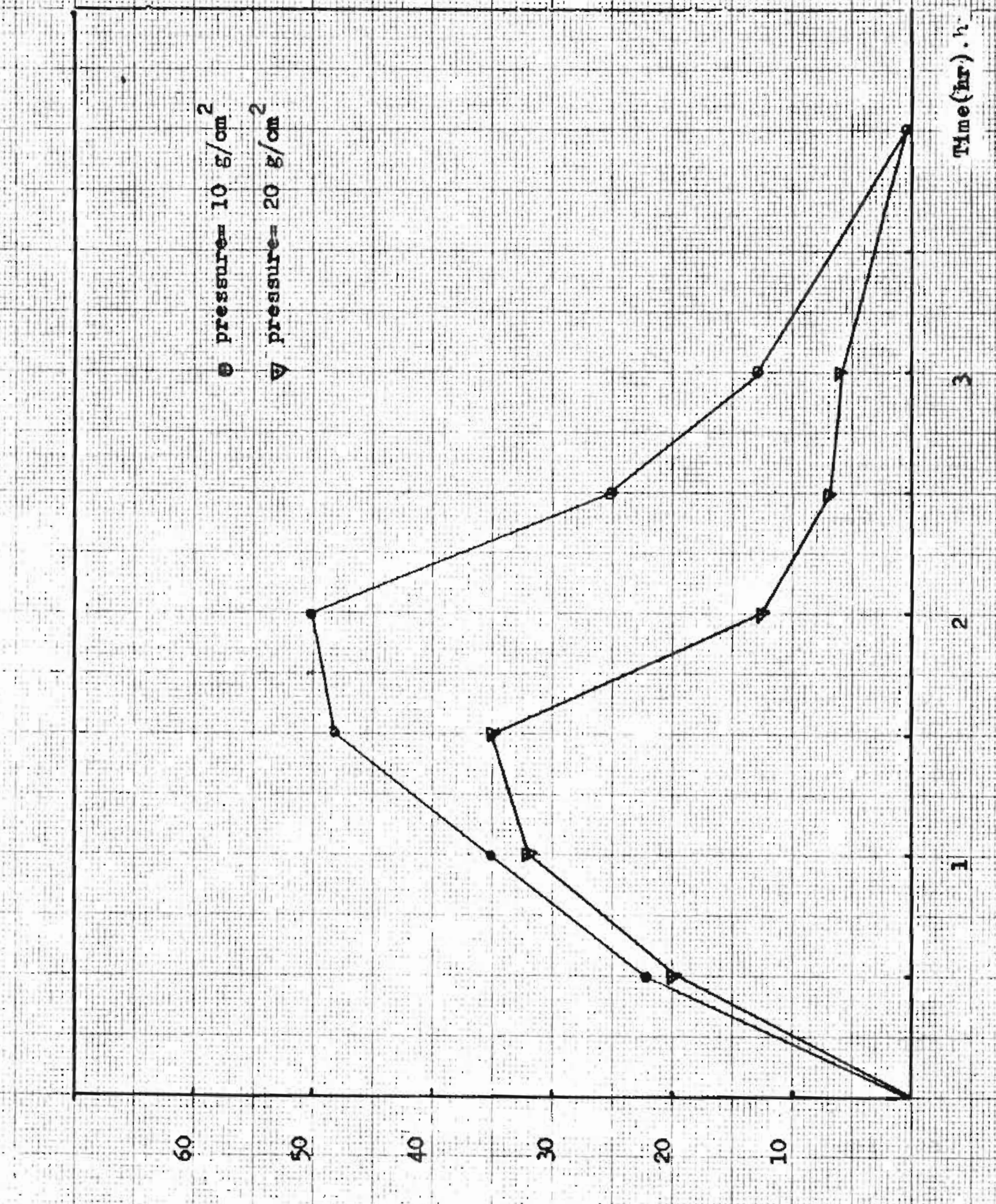
pressure= 10 g/cm2
pressure= 20 g/cm2
Time(hr).h
number of pills
60
50
40
30
20
10
1
2
3

Fig.3.

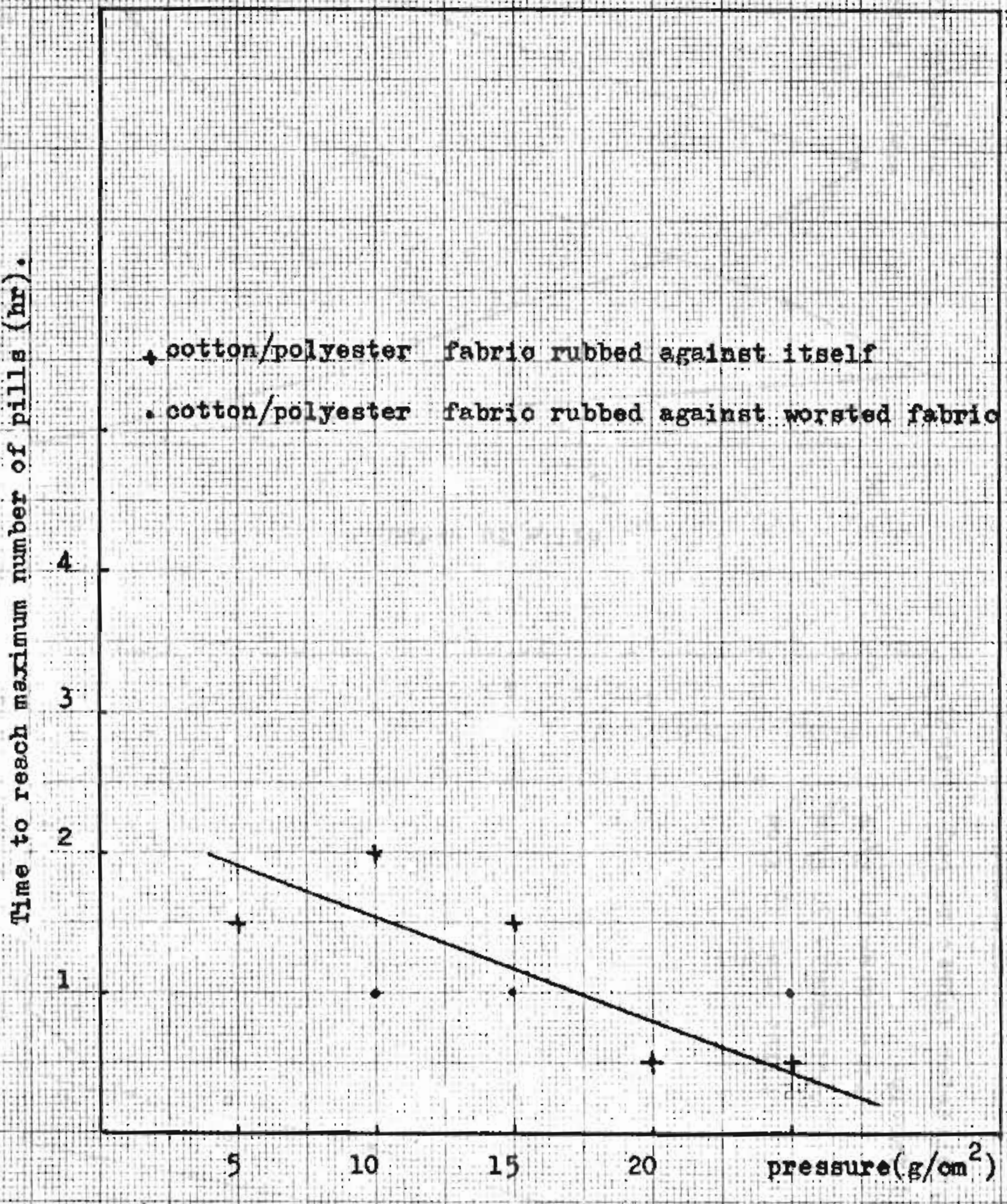
+ cotton/polyester fabric rubbed against itself
• cotton/polyester fabric rubbed against worsted fabric
Time to reach maximum number of pills (hr).
1
2
3
4
5
10
15
20
pressure(g/cm²)

Fig.5.

Plotted in Fig. 5 the relationship between pressure applied between fabric and abradant and the time to reach a maximum number of pills for plain woven cotton/polyester fabric rubbed against a standard worsted fabric. Statisticall analysis using the least square method has shown that the correlation coefficient is high (r = -0.93) and highly significant at the 5% level. As pressure increases the time to reach a maximum number of pills on the surface of the fabric decreases and vice-versa.

4-3. Effect of Speed of Rubbing on Pilling of Cotton/Polyester Woven Fabric Rubbed Against Itself.

Given in Table 5 the number of pills formed in a plain cotton/polyester woven fabric rubbed against itself under four pressures namely 10, 15, 20 and 25 g/cm^2. Four rubbing speeds were used namely 10, 20, 30 and 40 cycles/min. The abradant is rotating at 1 r.p.m. clock-wise, and the fabric to be abraded is supported by soft packing.

Examples of the number of pills-time of rubbing curve for cotton/polyester fabric rubbed against itself at the above conditions are shown in Figs. 6and 7. From the plots it is evident as was evident before in the case knitted fabrics rubbed against a standard worsted fabric that the number of pills increases as the time of rubbing goes on and reaches a maxium then falls down. Also it is evident from the plots that the number of pills increases as the speed of rubbing increases. For example at a pressure of 10 g/cm^2 and after 1 hr. of rubbing the number of pills had increased 133% when the speed of rubbing increased from 10 to 40 cycles/min. At pressure higher than this, i.e. 25 g/cm^2 the number of pills increased by about 6 times when the rubbing speed had been increased from 10 to 40 cycles/min.

Plotted in Fig. 8 the relationship between speed and time to reach a maximum number of pills on the surface of cotton/polyester fabric when rubbed against itself under various pressure and speed.

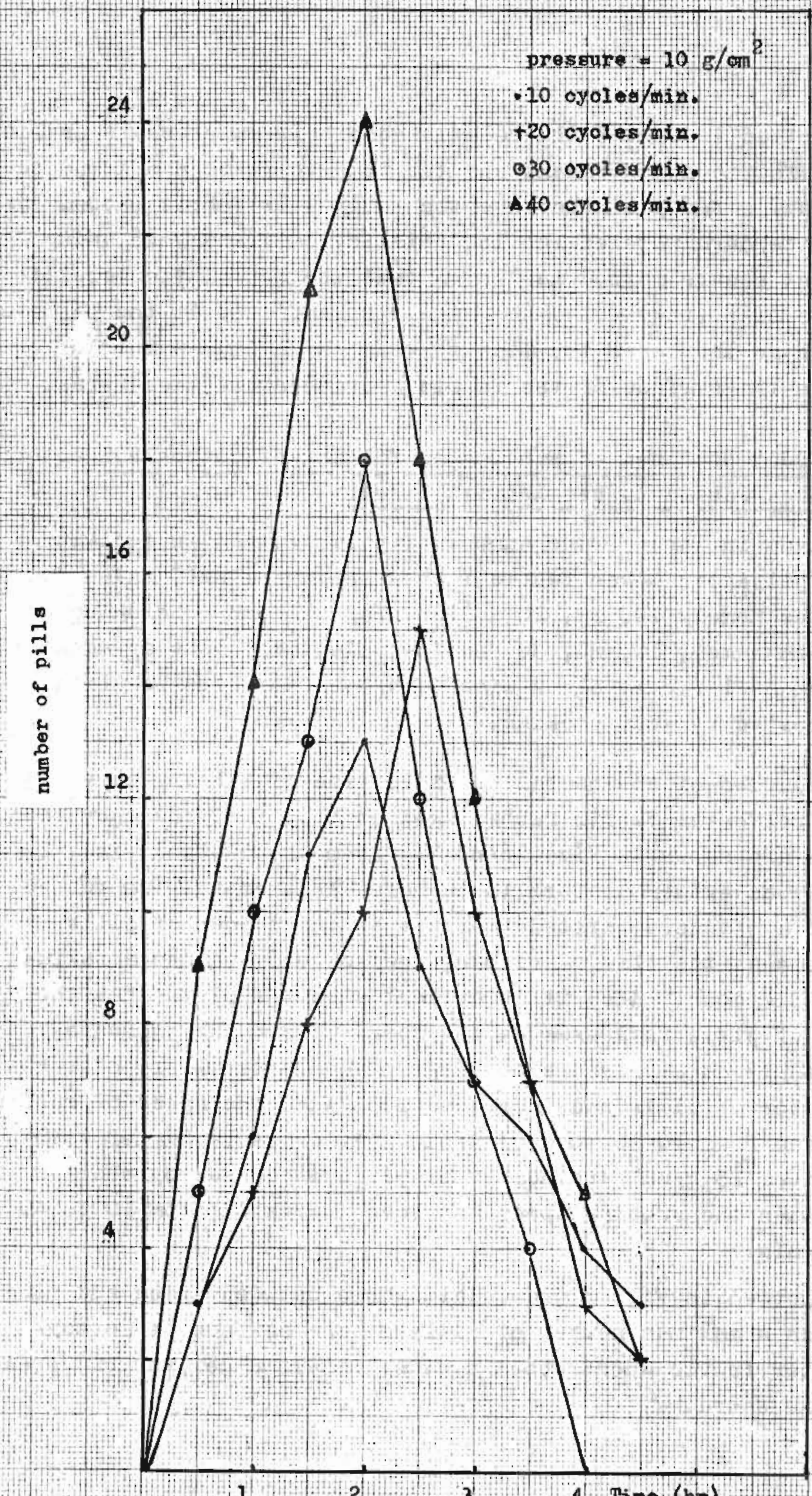
pressure = 10 g/cm²
•10 cycles/min.
+20 cycles/min.
⊙30 cycles/min.
▲40 cycles/min.
24
20
16
12
8
4
number of pills
1
2
3
4
Time (hr).

Fig.6.

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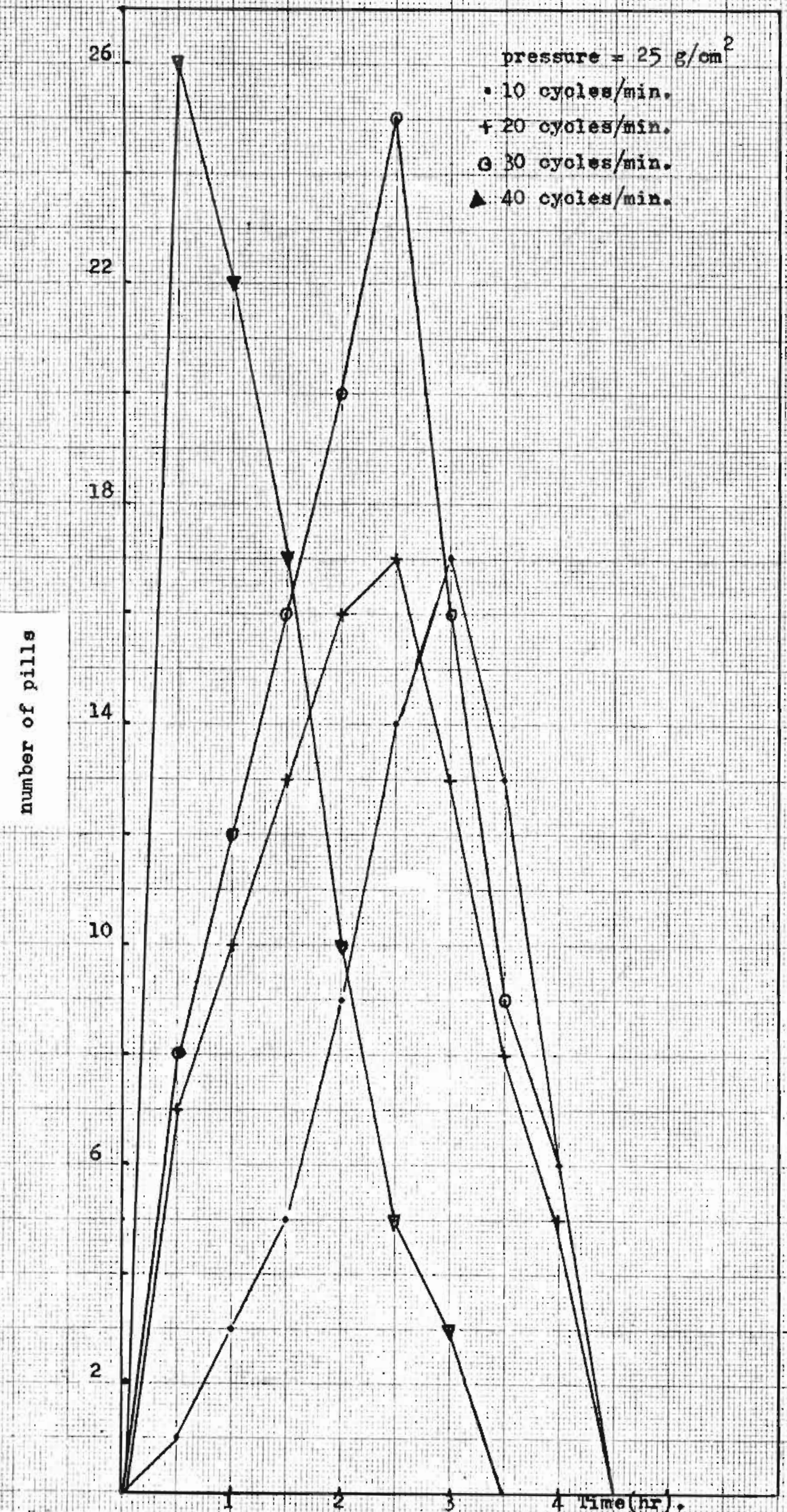

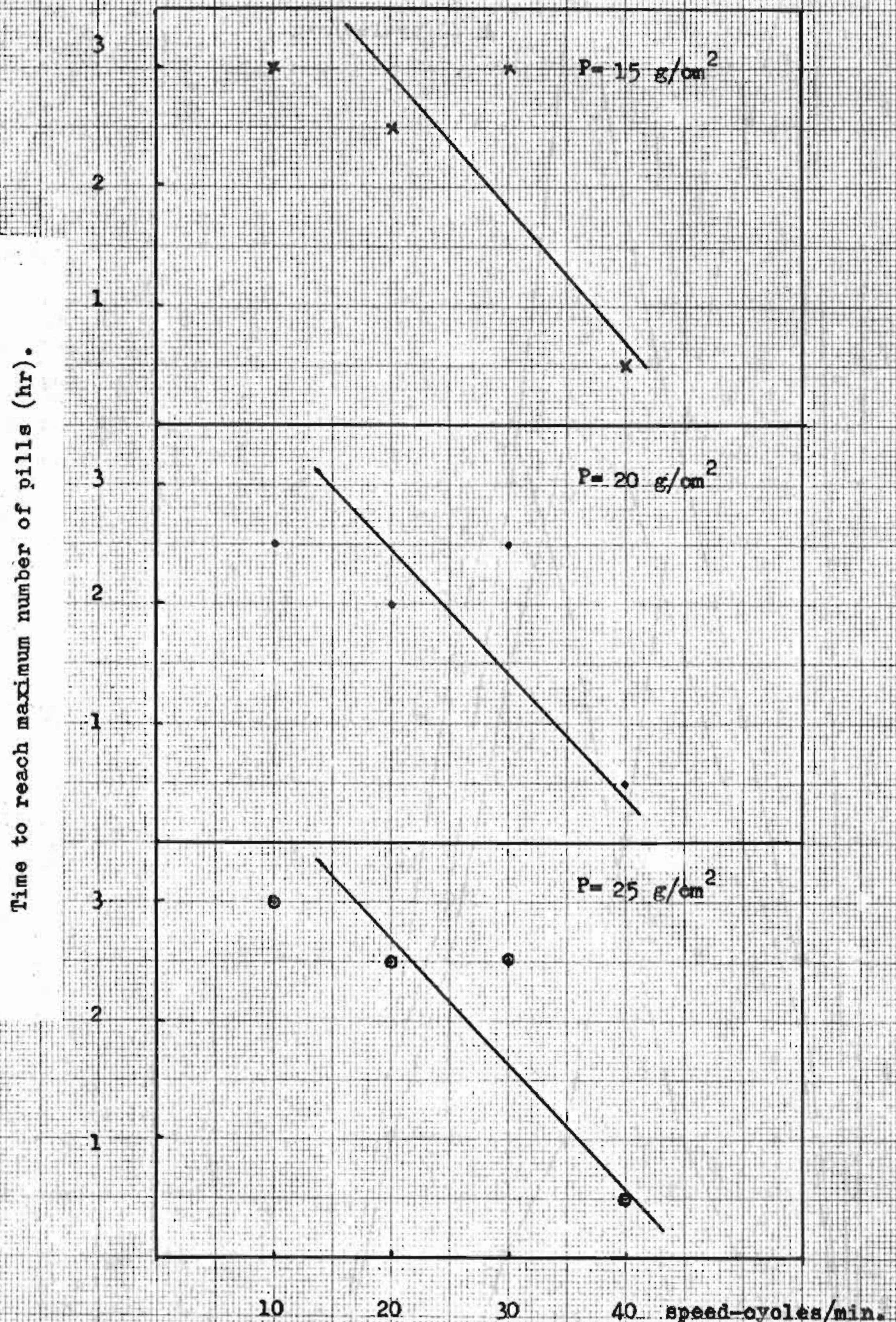

Time to reach maximum number of pills (hr).
3
2
1
P= 15 g/cm²
3
2
1
P= 20 g/cm²
3
2
1
P= 25 g/cm²
10
20
30
40
speed-cycles/min.

Fig.8.

Table (5): Number of pills formed in a plain cotton/polyester woven fabric rubbed against itself.

Pressure g/cm^2	Speed cycles/min	Time of rubbing (hr.) ½	1	1½	2	2½	3	3½	4	4½
10	10	3	6	11	13	9	7	7	4	3
	20	3	5	8	10	15	10	7	3	2
	30	5	10	13	18	12	7	4	-	-
	40	9	14	21	24	18	12	7	5	2
15	10	3	6	8	11	14	18	12	7	3
	20	6	8	11	18	23	18	15	8	4
	30	1	4	8	11	14	19	13	6	3
	40	9	16	20	11	6	3	-	-	-
20	10	4	9	14	18	20	18	13	5	-
	20	5	9	14	19	16	11	11	6	-
	30	5	9	17	21	26	15	11	5	3
	40	12	10	6	6	6	2	-	-	-
25	10	1	3	5	9	14	17	13	6	-
	20	7	10	13	16	17	13	8	5	-
	30	8	12	16	20	25	16	9	6	-
	40	26	22	17	10	5	3	-	-	-

From the plot one may observe that in general the time to reach a maximum number of pills (when pressure is fixed) decreases as the speed of rubbing increases. For example at a pressure of 15 g/cm^2 it was found that by increasing the speed of rubbing from 10 to 40 cycles/min the time required to reach a maximum number of pills droped about 50%, while at a pressure of 25g/cm^2 the drop reached to about 83%.

5- Effect of Type of Rubbing Motion on Pilling of Acrylic Warp Knitted Fabric.

The textile fabric during its use as in apparell fabrics and coverings (bed sheets, cushion covers....etc. of these uses) is exposed to various types of rubbing motions depending on the nature and habits of the user. The same to be said when the fabric is washed mechanically. Each type of washing machines has its own characteristics and each propeller produces different type of motion. This in turn will give the fabric various types of movement.

The apparatus used in the present investigation for studying pilling provides 49 types of motion, in which the abradant may be kept fixed or moving at a speed of 1 r.p.m. The fabric may be given the types of motion described in section 2.

Given in Table 6 the number of pills formed in a plain warp knitted acrylic fabric rubbed against a standard worsted abradant fabric. The fabric to be abraded was given x-y movement and the abradant was fixed once and left to rotate in another. The pressure applied between fabric and abradant is 25 g/cm^2. From Table 6 one may observe, that:- when the speed of rubbing in the x-direction was kept fixed at 40 cycles/min and that in y-direction had been doubled the number of pills increased by 420%, and when the abradant was prevented from rotating (having the speed in x and y directions) a drop of about 16% occured in the number of pills formed on the surface of the fabric. It was interesting to observe that x-y movement creates pills of large size compared with that obtained when fabric is given a reciprocating movement in x or y direction only.

Table (6): Number of pills formed in a plain warp knitted acrylic fabric rubbed against a standard worsted fabric.

Pressure g/cm^2	Movement and speed of fabric	State of abradant	No. of pills
25	x-y, 40-40 cycles/min	fixed	26
25	x-y, 40-40 cycles/min	rotating	31
25	x-y, 40-20 cycles/min	rotating	5

Time of rubbing = ½ hr.

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6- General Discussion:

Given in sections 4 and 5 the results of a study concerning pilling tendency of textile fabrics (woven and knitted). This study considered the effect of various following parameters on pilling:-

1) fabric structure
2) type of abradant
3) speed of rubbing
4) pressure
5) type of motion of both fabric and abradant.

The results obtained have shown that pilling occurs on the surface of the fabric when a certain normal pressure is applied between fabric and abradant. With respect to the build-up and wear-off pills, it was found for all combinations formed from the fabric and the abradant used, that the number of pills increases as the time of rubbing goes on and reaches a maximum then falls down. Over the range of rubbing speeds used in the present investigation it was found that all pills formed as a result of rubbing by any of the used abradants, were completely removed after a period of rubbing ranging between 3 and 4½ hrs., irrespective of fabric structure (in the case of knitted fabric), type of abradant, pressure and type of motion of both fabric and abradant.

The formation of pill is attributed to a complex mechanism which begins with the formation of fuzz, then entanglement of fuzz and finally formation of pill. Also from the results obtained it was found that for cotton/polyester woven fabric rubbed against itself at various rubbing speed and under various pressure, both cover and speed have remarkable effect on the time required to reach a maximum number of pills on the surface of the fabric. Generally this time becomes less when pressure applied between fabric and abradant and speed of rubbing increases (Figs. 7 and 8). Also it was found for this fabric that the number of pills increases as pressure and speed of rubbing increases.

In fact the above trends concerning pilling of fabric could be explained in the light of the frictional properties of both fabric and abradant. In a previous investigation carried out by the author[1] on the frictional properties of a wide range of textile fabrics it was found that the frictional force is well related to pressure by a relationship in the form of; Log F = m + n Log P, where m and n are constants. Both m and n are well related to fabric physical and mechanical properties. Fabrics with hairy surfaces have high m values. During rubbing (in pilling test) friction force is generated between fabric and abradant, its magnitude depends as shown above on normal pressure (P) and the compressional properties of the fabrics in contact, and also on the speed of rubbing. The frictional force generated on the individual elements of the fabric, i.e. fibres is transilated to tensile, torsional and bending forces. The magnitude of each depends on the original firctional force. If the tensile (or pulling) force generated on the fibre is not able to over-come internal friction between fibres in the yarn, pilling would not occur since the length of fibre protruding from the body of yarn will not be sufficient to cause fibre entanglement. This seems to be the case with plain weft knitted acrylic fabric rubbed against a standard worsted fabric under a normal pressure of 10 g/cm^2. At that pressure and at all cover factors used no pilling occured. It was interseting to find that the fibres seperated during rubbing are short in length (between 2 and 3 mm). Their rupture seems to be due reasons similar to that mentioned in previous studies carried out by the author on the mechanisms of attrition of fibres due to abrasion action 2,3. Also this seems to be the case of wool/nylon fabric rubbed by the same abradant under pressures of 10 and 12.5 g/cm^2. At these pressures the cover factor of the fabric was found to be of neglicible effect on pilling, but at a pressure of 15 g/cm^2 the cover factor was found to be of a remarkable effect on pilling. Generally the number of pills formed has decreased by the decrease in the cover factor of the fabric and vice-versa. It was interesting to find that at the low cover factor 11.2 $tex^{1/2}.cm^{-1}$ many long fibres have been thrown out during rubbing. This indicated that the friction force and hence the pulling force is high and aided by the openess of the structure have led to that found. With high cover factor the stitch density (the product of courses/cm and wales/cm) is large than with low cover factor; Accordingly the number of hairs involved in the contact (or rubbing) zone will be large. This as been mentioned before will affect the magnitude of the frictional force and hence the pulling force. When the pulling force is high and inter fibre to fibre friction is low then fibre would tend to slip.

The results of pilling of cotton/polyester fabric when rubbed against itself at various rubbing speeds (Table 5) have shown that pilling is greatly affected by speed of rubbing. Generally at a fixed pressure, the number of pills formed had increased as the speed of rubbing increased. This is again could be explained in the light of the frictional interaction and frictional properties of the combination of fabric and abradant. Friction force (hence pulling force) is expected to increase with rubbing speed. With cotton/polyester woven fabric it is propable that with the fabric containing thermoplastic fibre high frictional heat is generated due to rubbing when the fabric is rubbed against itself rather than against the standard worsted fabric. Heat will cause fibre softening, hence the fibre will deform more under pressure providing large area of contact between fabric and abradant. As a result of this the friction force and hence the pulling force will increase.

With respect to the effect of the type of motion of both fabric and abradant on pilling of fabric it was found that when the fabric was given a reciprocting movement in the x-y direction and the abradant has been kept fixed or moving, the size and number of pills have been affected. With movable abradant (in the present work the abradant rotates at 1 r.p.m. clockwise) the number and the size of pills increased than when was kept fixed. By moving the abradant more yarn movement is attained and hence more fibres will be involved in the rubbing (or contact) zone. This will be reflected on the magnitude of the frictional force (hence the pulling force) as mentioned previously. Therefore more length of fibre will be drawn which would give large size pill. This seems to be the case with warp knitted acrylic fabric rubbed against a standard worsted fabric (Table 6).

7- CONCLUSIONS:

1. When a textile fabric is rubbed against itself or against a standard worsted fabric the number of pills increases and reaches a maximum then fall down.
2. Pilling occurs when certain normal pressure is applied between fabric and abradant.
3. At a certain pressure the number of pills formed in a plain wool/nylon knitted fabric increases as cover factor increases and vice-versa.
4. Both speed of rubbing and pressure have a remarkable effect on pilling of fabric. Generally the number of pills increases as speed and pressure increases.
5. The time to reach a maximum number of pills becomes less when high pressure and high speed is used.
6. By reciprocating the fabric in x-y direction and keeping the abradant stationary or moving the size and number of pills are affected. The number of pills increases when the abradant is moving (rotating).
7. Increasing the speed of rubbing in x or y direction has led to a considerable increase in the number of pills.
8. x-y movement of fabric produces large size pills.
9. The type of abradant affects the number of pills formed in the fabric rubbed against it.

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