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FRICTIONAL AND TACTILE COMPRESSION OF SOME POLYMERIC FABRICS

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Abstract

One of the first concerns of this study was the meaningful way in which friction could be characterized in fibrous polymers which behave differently from materials in which classical law apply.

The frictional behavior of some polymeric fabrics was analyzed using a structural model and experimental method which provided reproducible results of frictional values. The friction parameters used in this study were the average coefficient of friction μ, and the friction indices a and n. The structural model applied is based on the estimation of the true area of contact from the generalized pressure-area curve of the asperities when tests were performed on samples of various types of structures.

***Key words**: Fibrous polymers, fabrics, friction, compression, true contact area, friction coefficient.*

Résumé

L'un des principaux objectifs de cette étude a été de comprendre la nature de la friction dans les polymères fibreux dont le comportement en friction a toujours été interprété comme une déviation par rapport aux lois classiques établies pour les matériaux homogènes.

A cet effet, un dispositif original permettant des mesures de friction sur des surfaces de polymères, à différents types de contact, a été réalisé. Le modèle structural, utilisé pour décrire le comportement de ces matériaux, est basé sur l'estimation de l'aire de contact réelle à partir des courbes pression–aire de contact des aspérités. Les paramètres de friction utilisés dans cette étude sont le coefficient de frottement moyen μ et les indices de friction a et n.

***Mots clés**: Polymères fibreux, friction, compression, coefficient de frottement, aire de contact.*

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ملخص

إن أهم أهداف هذا البحث هو مفهوم طرق تمييز الاحتكاك في المواد الليفية التي لا توافق القوانين الاتباعية.

سيرة الدعك لبعض المكثفات الليفية حللت بواسطة نموذج تركيبي و منهج اختباري مالحا نتائج مكررة لقيمة الاحتكاك ثابتات.

الدعك المستعملة في هذا البحث هي: معامل الاحتكاك المتوسط (μ) و علامة الاحتكاك (a) و (n).

النموذج المستعمل مبني على تقدير المساحة الحقيقية للاتصال بدا من الدالة المعممة: (إنضغاط - مساحة الاتصال) للمكثفات.

لما تحققت الاختبارات في مكثفات من أنواع و هياكل مختلفة يكون هذا النموذج قاعدة لمفهوم التغيرات في قيمة العلامة (a) و (n) و معامل الاحتكاك المتوسط.

***الكلمات المفتاحية**: المكثفات الليفية، الاحتكاك، الضغط، معامل احتكاك، مساحة الاحتكاك.*

Friction on polymer materials has been the subject of various studies. When referring to friction, there is a tendency to speak about the coefficient of friction tied to Amonton's law:

$$F = \mu N \tag{1}$$

where F is the frictional force, N the normal load and μ the friction coefficient.

The review of literature has indicated that this classical law of friction was not obeyed by most of the fibrous materials [1-4]. A research for an alternative expression relating the frictional force to the normal load has been a major part of the effort in most of the previous investigations concerning fiber friction. The most acceptable equation which has been fitted with a high degree of correlation is of the following form:

$$F = a N^n \tag{2}$$

where a and n are constants.

The validity of this equation to fibrous materials has been shown by Bowden and Tabor on the basis of the adhesion theory of friction [5, 6]. The adhesion theory of friction interprets the frictional force between two bodies as the force necessary to shear the junctions at the interface:

$$F = A\ S \tag{3}$$

where A is the true area of contact and S the specific shear strength of the junctions.

The theoretical treatments developed by several authors differed from each other in terms of the assumed arrangement of the asperities and the method of calculating the true contact area [7-9]. All of these treatments were specific, they applied only to materials deforming elastically. The

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availability of a more general treatment is essential to understand and rationalize the nature of friction in fibrous materials which do not generally deform either purely elastically or plastically, but deform in a manner which is a combination of the two.

An attempt is made here to formulate a generalized equation of frictional force in terms of the deformational parameters which govern such force. With the help of the above equation, a general relation between the true area of contact and the normal force is derived. This relation leads to a clearer understanding of the meaning of the parameters μ, *a* and *n* and the factors affecting their values.

STRUCTURAL MODEL OF FRICTION IN FIBROUS POLYMERIC MATERIALS

The pressure-area deformation curve of figure 1 may be expressed by the following general equation:

$$P = K\,A^{\alpha} \tag{4}$$

where P is the pressure, A is the area of contact, K and α are constants which together define the shape of the curve. If $\alpha = 0$, therefore $P = K$ which is the yield pressure; if $\alpha = 1$, then the P-A curve is a straight line with K representing the slope of the curve.

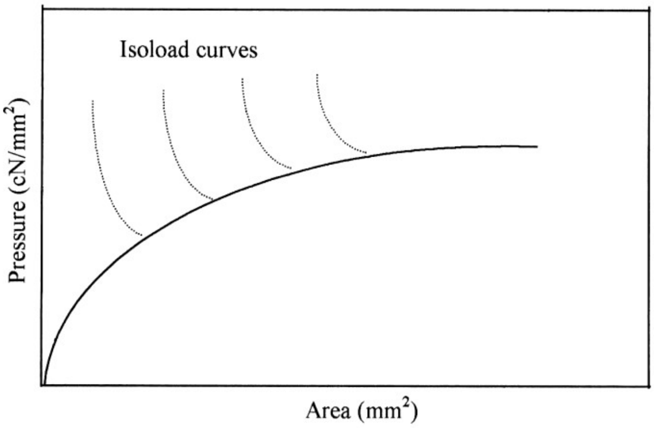

Figure 1: Generalized Pressure-Area Deformation Curve.

It is clear that the value of K represents in some scale the stiffness or the hardness of the material, whereas the value of α is more directly related to the shape of the curve and, thus, to the viscoelastic nature of the material in compression.

Referring back to the Figure1 an asperity i supporting a load w_i undergoes a deformation represented by an isoload curve characterized by:

$$W_i = P_i\,A_i \tag{5}$$

From equations 4 and 5:

$$W_i = P_i \,.\, A_i = K.\,A_i^{\alpha}\,.\,A_i = K\,A_i^{(\alpha+1)} \tag{6}$$

Or:

$$A_i = \left(\frac{1}{K}\right)^{\gamma} w_i^{\gamma} \tag{7}$$

with $\gamma = (1+\alpha)^{-1}$.

Equation 7 represents the dependence of the area of contact of an asperity on the external load w_i and the mechanical behavior of the asperity given by the values of the constants K and α. The total true area of contact between two bodies is then equal to the sum of the areas of contact of the individual asperities. Therefore: $A = \sum_1^m A_i$,

and:

$$A = \left(\frac{1}{K}\right)^{\gamma} \sum_1^m w_i^{\gamma} \tag{8}$$

where m is the total number of asperities making contact.

If all asperities were identical, one could expect the load to be uniformly distributed over the junctions. In this case the total load will be equal to the sum of loads supported by the individual asperities: $N = m.w$ and:

$$\sum_1^m w_i^{\gamma} = m^{1-\gamma} N^{\gamma} \tag{9}$$

Substitution of equation 9 in equation 8 gives the total area of true contact:

$$A = \left(\frac{1}{K}\right)^{\gamma} m^{1-\gamma} N^{\gamma} \tag{10}$$

Equation 10 represents the solution for a generalized case of load distribution, it reveals, however, some of the important factors which influence the true area of contact. These factors are the number of asperities, m, the normal load, N, and the mechanical behavior of the junctions in compression represented by the constants K and γ.

According to the adhesion theory of friction, the frictional force F is given by the product of the true area of contact A and the specific shear strength of the junctions as shown by equation 3. By substituting A from equation 10 into equation 3 yields the relationship between the frictional force F and normal load N:

$$F = S\left(\frac{1}{K}\right)^{\gamma} m^{1-\gamma} N^{\gamma} \tag{11}$$

Comparison of equations 2 and 11 provides the following forms for the values of the friction constants n and a:

$$\mathrm{n} = \gamma \tag{12}$$

$$a = SK^{-n} m^{1-n} \tag{13}$$

A summary of fundamental friction equations is given below:

$$A = K^{-n} m^{1-n} N^{n} \tag{14}$$

$$F = SK^{-n} m^{1-n} N^{n} \tag{15}$$

$$\mu = SK^{-n} m^{1-n} N^{n-1} \tag{16}$$

MEASUREMENT TECHNIQUE OF POLYMER FRICTION

The objectives of this study have been to understand the nature of friction in fibrous materials and to examine the effect of a number of structural factors on its values. To fulfil these objectives, test method was developed [10], which allowed friction measurements of several fibrous surfaces at various contact types.

The friction is generated between different cylindrical rubbers of Aluminum, Steel, Poly(methyl Metacrylate) and some specimen of fibrous polymeric surfaces such a woven canvas of a fabric (cotton-polyester); a knitted pattern of a cloth (cotton-elasthan); an open framework of technical filament (polyamide); a Nonwoven veil structure of polypropylene and a sheet structure of poly(vinyl chloride). All used samples are a raw materials, they did not undergo any particular surface treatment.

The characterization of surface friction was carried out using an original model device derived from the method originated earlier by Bowden [11]. This method does not differ a lot from that used in the Kawabata's Evaluation System for fabrics [12].

A normal load is applied to the sample and the friction parameter is measured on a plate set between a swing arm and a chuck, which maintains the sample at one end. At the other end, the movement of the specimen, at a 1.04 mm/sec of speed, is obtained from a reverse roll-up drum. The resistance to sliding is transmitted by a piano wire to a force pick-up, the amplified signal corresponding to the friction is then recorded on an oscilloscope.

A new specimen were used for each test, the measurements are being taken in identical and standard atmospheric conditions.

RESULTS AND DISCUSSIONS

The friction parameters used in this study were the average coefficient of friction μ_a and the friction indices *a* and *n* in the general equation $F = a.N^n$. In materials deforming plastically, such as metals, the friction index *n* assumes a value of unity and the constant *a* becomes identical with the classical coefficient of friction μ. In materials deforming elastically or viscoelastically, the constant *n* exhibits values less than unity and *a* exhibits values different from μ. The values of these constants were determined by the method given below:

- for each different sample, friction measurements were made at several different values of normal load.
- at each value of normal load, the value of μ was calculated by the classical equation 1.
- a linear regression model was fitted on the data, and the values of the constants *a* and *n* were determined.

These parameters are given in table 1 for the fabric canvas, the knitted cloth and the nonwoven veil at various contact types, and in table 2 for the polyamide open framework and the PVC sheet at the same contacts.

These results generally indicate that the values of the *n* index showed no significant difference whereas values of the constant *a* varies greatly as a function of the material in contact. In the contact between same surfaces (woven fabric and knitted pattern), the static friction is significantly higher than the kinetic one; whereas this difference is lowest and no significant for the other materials (open framework, veil and sheet).

These effects of a stick-slip phenomenon in fabric friction agree with those of H.N. Yoon and *al.* for various Cotton-polyester fabrics [13].

Nature of contact	Coefficient of friction μ_a	a	n
Woven fabric (Cotton-polyester)			
Aluminum on Fabric	0.348 (0.016)*	0.79	0.83
PMMA on Fabric	0.397 (0.018)	1.01	0.81
Steel on Fabric	0.467 (0.010)	1.46	0.79
Fabric on Fabric -Static	0.766 (0.013)	3.18	0.74
- Kinetic	0.586 (0.016)	1.87	0.76
	* Standard deviation		
Knitted pattern (Cotton-elasthan)			
Aluminum on pattern	0.412 (0.017)	0.86	0.85
PMMA on pattern	0.391 (0.014)	0.65	0.89
Steel on pattern	0.524 (0.010)	1.22	0.83
Pattern on pattern - Static	0.736 (0.022)	2.51	0.77
- Kinetic	0.615 (0.016)	1.86	0.79
Nonwoven veil of Polypropylene			
Aluminum on Nonwoven	0.395 (0.015)	0.74	0.87
PMMA on Nonwoven	0.388 (0.016)	0.75	0.86
Steel on Nonwoven	0.488 (0.021)	1.37	0.79
Nonwoven on Nonwoven	0.496 (0.017)	0.94	0.87

Table 1: Values of the friction parameters of the woven fabric, knitted pattern and Nonwoven surfaces at various contact types.

Nature of contact	Coefficient of friction μ_a	a	n
Polyvinyl Chloride Sheet			
Aluminum on PVC Sheet	0.343 (0.012)*	0.48	0.93
PMMA on PVC Sheet	0.429 (0.013)	0.58	0.94
Steel on PVC Sheet	0.479 (0.014)	0.69	0.92
Sheet on Sheet	0.799 (0.013)	0.97	0.96
	* Standard deviation		
Polyamide open framework			
Aluminum on framework	0.231 (0.013)	0.56	0.83
PMMA on PA framework	0.194 (0.012)	0.47	0.83
Steel on PA framework	0.379 (0.014)	0.83	0.85

Table 2: Values of the friction parameters of the filament open framework and PVC sheet surfaces at various contact types.

It seems that both PVC sheet and polyamide framework possess the same behavior: the deformation remains equivalent for all of the contacts considered. In the two cases, the small values of the constant *a*, involves an weak adhesion at the surfaces.

This finding is consistent with a simple physical picture of the variation of the number of contacts with the normal load:

- with the polyamide open framework and the PVC sheet at low pressure, contact will occur only at a few raised points in the surface of the element. As the load is increased, the number of contact points will increase rapidly as the material structure spreads under the load.
- with the woven canvas, the knitted pattern and the nonwoven veil, there will be a large number of contacts at low pressure due to the projecting surface fibers. As the normal load is increased, the number of contacts increases but not rapidly as a smooth surface.

If however, one compares the average values of the constants a, n and μ_a of the various components, one finds that the material sliding against itself consistently has higher values of these parameters. This clearly shows that the yarn arrangement in the materials also affected the values of these parameters. The changes would arise from the differences in the shear strengths of the junctions, the deformational behavior of the junctions (pressure-area curves) and the nature of contact between the bodies (chemical constitution and physical structure).

These results indicate that the true area of contact between samples sliding against rubbers is expected to be generally less than between two same components. Larger true area of contact should lead to a value of the coefficient of friction which is higher in fabrics sliding against itself and in fabrics sliding against steel.

The predicted pressure-area curves of the various materials are shown in figure 2 for the aluminum-materials contact; in figure 3 for the poly(methyl metacrylate)-materials contact, and in figure 4 for the contact steel-materials.

In any cases, the curves can be classified into three groups: woven fabric and filament open framework; then nonwoven veil and knitted pattern items and finally sheet sample of PVC.

Both structures, nonwoven and knitted pattern, when placed on a plane surface have their spun fibers arranged in a relative disorder. Woven fabrics are better structured, but far less than the PVC sheet. These results agree with those obtained in a previous work on the mechanical and tactile compression of fabrics [14]. Therefore, true area of contact between the polymers and the rubbers is affected by the fibers arrangement and surface geometry, it is generally large in the steel-polymers contact (Fig. 4). This larger true area of contact should lead to a value of the constant K which is higher in polymers sliding against steel. This constant is a function of the ultimate shearing modulus of the weakest material. The above mentioned curves leads to a logical results: steel with its high shearing modulus gives the highest friction force. This force is evidently function of the geometry of the contact polymer - rubber, the binding of threads intervenes also.

Accordingly, the prediction of the pressure-area curves of the polymer materials should give a reasonable basis for rationalizing the expected differences in the frictional behaviors. These curves indicate that the true area of contact between the fibrous polymers sliding against metallic or plastic rubbers is expected to be generally lower than that between polymers sliding against themselves.

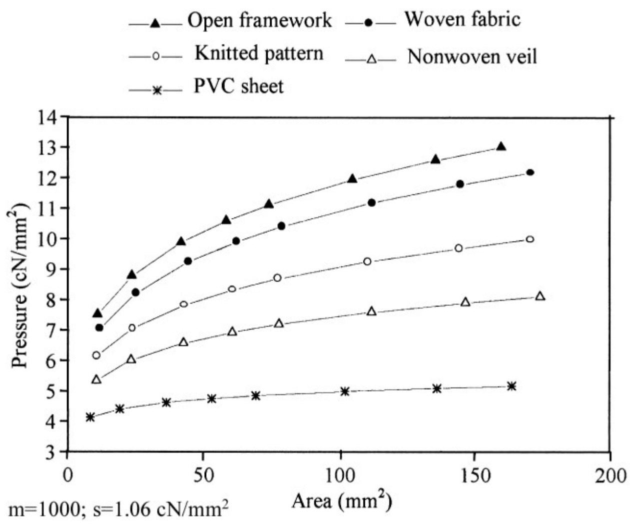

Figure 2: P-A curve predicted from the Aluminium-Polymers contact.

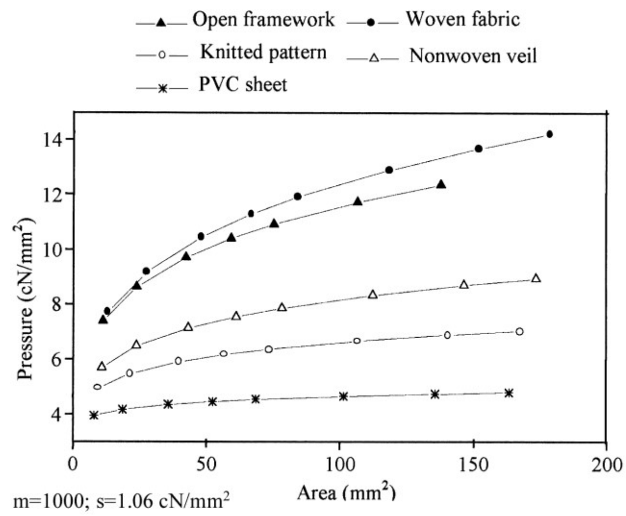

Figure 3: P-A curve predicted from the Poly(methyl Metacrylate)-Polymers contact.

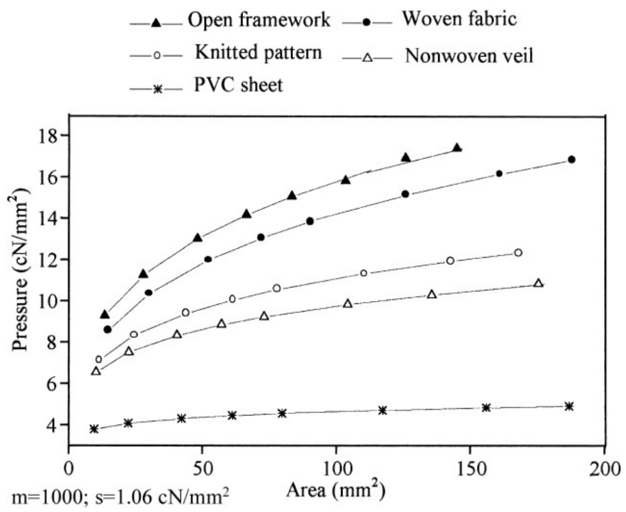

Figure 4: P-A curve predicted from the Steel-Polymers contact.

CONCLUSION

The structural model developed is based on the estimation of the true area of contact from the generalized pressure-area curves of the asperities. This model gives a basis for understanding the underlying causes for changes in friction parameters when tests were performed in fibrous polymers of different structures and when tests were performed in different modes of contact or in different environments.

In summary, we may state that the frictional behavior of the various polymeric fabrics is highly dependent on their physical structures, which should lead to different values of the frictional parameters a , n and the average coefficient of friction μ_a.

The values of a and n depend mainly on the structure of yarns or fibers from which the fabric was woven, and, to a lesser degree, on the weave or arrangement of the polymeric surface, and also on the chemical nature of the component yarns. The application of the structural model to the results obtained in fabric friction shows that the increase in friction was most likely caused by an increase in the true area of contact.

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