Influence of some test parameters on friction in acrylic fibres

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The influence of operational factors on friction in acrylic fibres of 38 mm and 1.65 dtex has been studied. The increase in normal force decreases the coefficient of friction and results in a more pronounced stick-slip effect. The values for friction indices 'a' and 'n' in the equation \( F = aN^n \) are found to be 0.71 and 0.90 respectively. The sliding speed has a great influence on the smoothness of fibre movement. The stick-slip effect is more pronounced at slow sliding speeds and progressively reduces at higher speeds with the result that the difference \( \mu_s - \mu_f \) becomes smaller. The decrease in the area of contact (fringe width) decreases the coefficient of friction.

Keywords: Acrylic fibre, Coefficient of friction, Frictional force, Sliding speed

1 Introduction

Friction, in general, is a force, which opposes the sliding motion between the two surfaces in contact. There has been a great deal of work on friction. It was in 1699 that Amontons discovered the classical laws of friction. These laws state that the frictional force \( F \) is independent of the area of contact between the two surfaces and is proportional to the normal force \( N \) between them and is given by \( F = \mu N \), where \( \mu \) is the coefficient of friction. Later, Bowden and Tabor proposed the adhesion-shearing theory, according to which the junctions are formed at the points of real contact, which must be sheared in order for sliding to occur. Thus, the frictional force \( F \) is given by the product of the true area of contact \( A \) and the bulk specific shear strength of the junctions \( S \), i.e.

\[
F = a N^n
\]

where \( P_y \) is the yield pressure of the material.

These two laws explain the friction in materials which deform plastically, such as ductile metals, but fail to do so in fibres that deform visco-elastically, where \( \mu \) is a function of both normal force and apparent area of contact. However, the value of coefficient of friction can still be used for relative comparison among various samples tested under particular conditions.

The relationship of the form \( F = a N^n \), where \( a \) and \( n \) are constants called friction indices, was found to fit well in case of textile fibres and it was first applied by Lincoln and later used by Lord, Viswanathan and others to study friction in cotton and regenerated cellulosic fibres. Such studies are lacking in case of acrylic fibres.

Further, the fibre friction is largely governed by two factors, namely fibre-related and operational-related factors. The former is determined by geometrical structure and surface characteristics of the fibre. The geometrical structure includes the length, denier, crimp and convolutions, while the surface characteristics constitute the presence of scales, asperities, cavities and amount of finish. The operational-related factors are normal force, sliding speed, and area of contact. Apart from the above factors, the temperature and humidity also influence the fibre friction.

The present work was aimed at studying the influence of operational factors on friction in acrylic fibres.

2 Materials and Methods

Acrylic fibres of 38 mm and 1.65 dtex with bean-shaped cross-section were used.

2.1 Friction Measuring Device

The equipment fabricated by Sengupta et al. for measurement of fibre friction was modified for
greater accuracy of measurement and used. The modified equipment consists of a metallic platform made of mild steel with the top surface covered with a sheet of Teflon to provide a smooth and uniform surface. At one end of the platform, a clamp is provided to hold the fibre fringe, which forms the fixed fringe. At the other end, a frictionless pulley is mounted in the center of a grooved rod, which is supported on both sides by metal bars provided with slots to raise or lower the height of the pulley (Fig. 1).

A special type of fibre holder, which resembles the one developed by Nachane et al.\(^8\) was designed from wood wherein a fibre fringe is held to the leading edge of the holder by a small metallic plate, which can be tightened or loosened with the help of screws and nuts. The metal plate carries a hook, which is positioned at the center of gravity of the fibre holder. The face of the fibre holder coming in contact with the fibres is lined with a thin and smooth wood (sun mica). The specifications of the fibre holder are: length, 30 mm; width, 30 mm; and weight, 20 g.

2.2 Preparation of Fibre Fringes

A fibre fringe consists of a thin fairly uniform layer of parallel fibres, cemented at one end to a piece of card. Fibre fringes are prepared manually by doubling, drawing and combing a small sample in order to render the fibres parallel. In this preparation, the short fibres are removed by combing and any stray long fibre present is pulled out using the thumb and forefinger. The remainder, forming the modal part of the sample, consequently have their ends substantially co-terminus. After cementing one end of the fringe to the piece of card, a comb is drawn three or four times through the fibres to make them parallel and to remove any fibres not properly secured. The fringes thus made are about one inch in width. In the present work, the areal density was kept as constant as possible, averaging about 5 mg/cm\(^2\). The fringes of this density have uniform and adequate thickness and solid appearance when viewed against a black background and does not form a bulky mass\(^4\).

2.3 Measurement of Friction

The equipment described in section 2.1 is placed over the platform of Instron and leveled. One fringe is fixed to the clamp on the platform and forms the fixed fringe. The fibre holder with a fringe held at its leading edge is then placed over the fixed fringe so that the fringes are in contact with each other. The area of contact will depend upon the width of the fringe. Any desired normal force is then applied by placing the weights over the holder. The hook of the holder is connected to the moving crosshead of Instron by a string of cotton cord which passes through the pulley. The string is in-extensible at low normal forces. The initial tension in the string has effect on the frictional force and hence it is important to keep the string straight and fairly taut.

When the crosshead of Instron starts moving up, the tension builds up in the string. Once the tension overcomes the static friction, the holder starts moving so that the relative sliding occurs between the fringes. The sliding motion is stick-slip in nature, which is governed by the fibre type and test conditions. The fibre holder can slide for any distance, depending on the length of fringes. In this study, the sliding distance was kept at 8 mm, since the fringe length was of 38 mm. The sliding speed was changed in the range of 5-100 mm/min.

The maximum force at which sliding starts is termed as static frictional force (F\(_s\)). The dynamic frictional force (F\(_d\)) is calculated by averaging the peak values (crests and troughs) in the stick-slip trace, for a sliding distance of 4 mm, starting from the point of start of sliding. The computer on line with the Instron does the necessary calculations and prints the results and the friction profile.

2.4 Influence of Test Parameters on Friction

Fibre friction has been studied in relation to the normal force, sliding speed and area of contact.

2.4.1 Normal Force

The normal force was varied from 40 cN to 300 cN to study its influence on friction, with the sliding
speed, area of contact and fringe density kept at 10 mm/min, 30mm×25mm and 5 mg/cm² respectively. The logarithm values of $F$ and $N$ were computed and the regression analysis carried out to determine the values of friction indices 'a' and 'n'.

2.4.2 Sliding Speed

The sliding speed was varied from 5 mm/min to 100 mm/min at the constant normal force of 40 cN, keeping the other parameters same as in section 2.4.1.

2.4.3 Area of Contact (Fringe Width)

The effect on friction was studied for two areas of contact by changing the width of the fringe. The two areas of contact were 30mm×25mm and 30mm×12.5mm. The normal force, sliding speed and fringe density were kept constant at 40 cN, 10 mm/min and 5 mg/cm².

3 Results and Discussion

3.1 Normal Force

It is seen from Table 1 that the frictional force (both static and dynamic) increases with the increase in normal force. As expected, the relationship is non-linear (Fig. 2). This is explained as below. As the normal force increases, the nature of contact between the fringes is altered. At higher normal force, the fringe approximately behaves more like a sheet of fibres, presenting a more uniform and constant area of contact. As a consequence, the ratio of frictional force to the normal force decreases. By computing the logarithm values for $F$ and $N$ and carrying out the statistical analysis of the transformed data, the values for 'a' and 'n' were found to be 0.71 and 0.90 respectively with the correlation coefficient of 1.0. The frictional force is given by the relation $F_s=0.71N^{0.90}$. It has also been observed that the increase in normal force results in more pronounced stick-slip effect, which shows that the ease of fibre sliding in an assembly is a function of the normal force acting upon it.

<table>
<thead>
<tr>
<th>Normal force cN</th>
<th>Frictional force, cN</th>
<th>Coefficient of friction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static (Fₛ)</td>
<td>Dynamic (Fₛ)</td>
</tr>
<tr>
<td>40</td>
<td>20.0 (3.1)</td>
<td>17.0 (3.4)</td>
</tr>
<tr>
<td>100</td>
<td>47.6 (2.4)</td>
<td>42.6 (2.8)</td>
</tr>
<tr>
<td>150</td>
<td>66.6 (2.5)</td>
<td>57.9 (3.0)</td>
</tr>
<tr>
<td>200</td>
<td>87.5 (3.0)</td>
<td>77.0 (3.4)</td>
</tr>
<tr>
<td>300</td>
<td>122.5 (2.5)</td>
<td>109.4 (4.1)</td>
</tr>
</tbody>
</table>

Values in parentheses indicate CV %.

Table 2—Influence of sliding speed on fibre friction

<table>
<thead>
<tr>
<th>Sliding speed mm/min</th>
<th>Frictional force, cN</th>
<th>Coefficient of friction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static (Fₛ)</td>
<td>Dynamic (Fₛ)</td>
</tr>
<tr>
<td>5</td>
<td>19.7 (3.9)</td>
<td>16.9 (3.4)</td>
</tr>
<tr>
<td>10</td>
<td>20.0 (3.1)</td>
<td>17.0 (3.4)</td>
</tr>
<tr>
<td>20</td>
<td>19.1 (4.0)</td>
<td>16.9 (3.4)</td>
</tr>
<tr>
<td>50</td>
<td>19.2 (4.3)</td>
<td>17.5 (4.6)</td>
</tr>
<tr>
<td>100</td>
<td>19.0 (5.0)</td>
<td>17.6 (4.5)</td>
</tr>
</tbody>
</table>

Values in parentheses indicate CV %.

Table 3—Influence of area of contact (fringe width) on fibre friction

<table>
<thead>
<tr>
<th>Fringe width mm</th>
<th>Frictional force, cN</th>
<th>Coefficient of friction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static (Fₛ)</td>
<td>Dynamic (Fₛ)</td>
</tr>
<tr>
<td>12.5</td>
<td>16.3 (1.2)</td>
<td>13.4 (3.2)</td>
</tr>
<tr>
<td>25.0</td>
<td>20.0 (3.1)</td>
<td>17.0 (3.4)</td>
</tr>
</tbody>
</table>

Values in parentheses indicate CV %.

![Fig. 2 — Frictional force vs normal force](image-url)
3.2 Sliding Speed

Table 2 shows that the sliding speed has no significant effect on the frictional force. However, it has a great influence on the smoothness of fibre motion. Fig. 3 shows that the stick-slip phenomenon is more pronounced and intensified at lower speeds and it progressively disappears as the sliding speed increases, with the result that the difference \((\mu_c - \mu_a)\) reduces (Table 2). This infers that the fibre movement is smoother at higher speeds.

3.3 Area of Contact (Fringe Width)

Table 3 shows that the frictional force increases as the area of contact increases from \(30 \times 12.5 \text{ cm}^2\) to
30×25 cm². This can be explained as below. The greater area of contact causes more number of contact points to be sheared to start sliding and hence higher frictional force.

4 Conclusions

4.1 The increase in the normal force decreases the coefficient of friction and influences the stick-slip effect.

4.2 The values for friction indices 'a' and 'n' in the equation \( F = aN^n \) are found to be 0.71 and 0.90 respectively.

4.3 The sliding speed does not have a significant effect on the frictional force; however, it greatly influences the stick-slip behaviour (smoothness of fibre movement).

4.4 The decrease in the area of contact decreases the coefficient of friction.

4.5 In general, the friction values obtained can be used for relative comparison among various samples tested under particular conditions and should never be treated as absolute figures because of the fact that the operational and test parameters vary from one process to other with the passage of time.

Acknowledgement

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References