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Stuffer Box Crimping

presented by **Courtaulds Research**

Statement of Problem

A man-made textile fibre production line consists of several different stages. These stages normally include the extrusion of continuous filaments from bulk polymeric solutions, stretching, 'solidifying', washing and drying. Each production line produces a tow consisting of tens of thousands of fibres. At the end of the line, before the fibres are fed into containers, they are often crimped using a piece of textile machinery known as a stuffer box crimper. Its purpose is to introduce a sine wave or saw-tooth variation into the previously straight filaments. This is done in order to provide fibre-to-fibre cohesion. It also enables the fibre to be processed, at a spinning mill, into yarn and gives the final fabric certain desired characteristics depending on the precise nature of the crimp.

The basic features of a crimper are illustrated in Figure 1. It consists of two driven rollers which nip a continuous band of filaments and feeds them into a chamber known as the stuffer box. This box consists of a fixed bottom blade, two fixed side plates and a pivoted top blade which is free to rotate about the axis of the top roller. The rollers and box are constructed from steel, and typical dimensions are illustrated in Figure 2.

The back pressure produced by the friction against the box blades acts to compress the band of filaments as they are pushed forward by the rollers. The fibres buckle under this compressive force and crimp is produced. The strain associated with the buckling is sufficient to cause permanent deformation and the fibres maintain their crimped shape after they are pushed out from the stuffer box. The tow is under tension prior to the crimper and is carried away, under no applied tension, by a simple conveyor belt.

Primary Crimp

The material exits from the roller gap as a thin sheet which is under lengthwise compression. It is postulated that the primary crimp is produced as a result of the buckling of this sheet. The buckling length 2λ is related to the compressive force P by the relation

$$\lambda = \frac{\pi}{2}\sqrt{\frac{EI}{P}} \qquad (*)$$

where E is the Young's modulus of the material and I is the second moment of area, given in terms of the depth h and breadth b of the plate by

$$I = bh^3/12.$$

The effect of the buckling is to produce plastic hinges at the ends and at the mid-point, producing a spring in the form of a corrugated sheet as shown in Figure 3, with different types of primary crimp illustrated in Figure 4.

The corrugated sheet can be regarded as a set of cantilevers with bending stiffnesses EI and of length λ making an angle 2α with each other. This then acts as a 'spring' of stiffness K, so that a force $\hat{P}$ acting on the 'spring' produces a deflection d given by $\hat{P} = Kd$.

By equating the energy of the 'spring' to the energy of deformation of the cantilevers we get

$$K = \frac{12EI}{\lambda^3}.$$

Secondary Crimp

We can alternatively regard this 'spring' as a new strip of elastic material having a depth λ and elastic modulus E'. The geometry is shown in Fig. 6

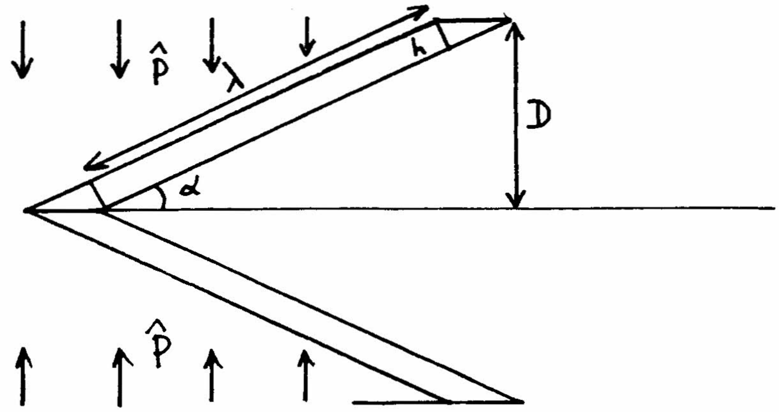

Fig. 6

The undeformed distance D is $\lambda \sin\alpha + h\cos\alpha$. If the deflection is d then the strain ε is d/D. Suppose the resultant force $\hat{P}$ produces this deflection d in each cantilever. We regard this force as being distributed over the entire cantilever to give the stress $T = \hat{P}/b\lambda\cos\alpha \simeq \hat{P}/\lambda b$.

We can then deduce the equivalent Young's modulus E' from T/ε yielding

$$E' = \frac{\hat{P}D}{b\lambda d} = \frac{12EI}{b\lambda^4}(\lambda\sin\alpha + h\cos\alpha)$$

This new strip of elastic material will in turn buckle to form the secondary crimp under a load F, say. This buckled shape then fills the stuffer box and it is possible to estimate the number of primary crimps within the height H of the stuffer box by looking at the two extreme cases. One is when the buckle just fills the stuffer box with no compression of the 'spring' in the vertical direction as shown below.

Then $H = 2n_1 D = 2n_1(\lambda \sin\alpha + h\cos\alpha)$ where n_1 is the number of crimps, and for the estimated dimensions this gives $n_1 \approx 4$. In the second extreme, the 'spring' is fully compressed in the stuffer box which gives $H = 2n_2 h$ leading to $n_2 \approx 7$. The number of primary crimps in the secondary is of the order of 5 which is consistent with these bounds.

In order to determine λ, it is necessary to evaluate the total load on the sheet as it exits the rollers. This is provided by the stuffer box and 3 models are proposed.

<u>Model 1</u>

In the first model it is assumed that there is a constant friction force f per unit length between the top and bottom of the stuffer box and the material.

This gives

$$\frac{dF}{dx} = -2f,$$

subject to

$$F = 0 \ at \ x = L.$$

This then implies

$$F = 2f(L - x)$$

which in turn leads to

$$p = \frac{F}{H}.$$

If it is now assumed that the material is incompressible then this pressure P acts on the top and bottom of the stuffer box and the applied moment M about O is given by

$$M = f\,DL + \int_0^L (x+\delta)\frac{2f}{H}(L-x)dx$$

$$= f\left\{DL + \frac{L^2}{H}(\delta + L/3)\right\}.$$

For $M = 35Nm$, $D = 0.045$, $\delta = 0.021$, $L = 0.2$, $H = 0.01$, this gives $f = 97.3N$ leading to an entry force $F(0) = 38.9N$.

Model 2

Here it is assumed that there is constant load P acting on each column of the material in the stuffer box with a frictional force $f = \mu P$. Then the moment about 0 is given by $M = \mu PDL + \frac{PL}{2}(L + 2\delta)$.

This gives $P = 1306 N/m$ and if $\mu = 0.3$,

the force at entry is given by $F(0) = 2\mu PL \; = 157 N$.

Model 3

This assumes an incompressible material subject to Coulomb friction.

From the equation $\frac{dF}{dx} = -2\mu \, p(x)$, it follows that $F(x) = \int_x^l 2\mu \, p(x) dx + F_e$.

However, $p(x) = \frac{F(x)}{H}$ and so $p(x) = \frac{2\mu}{H}\int_x^l p(x)dx + \frac{F_e}{H}$,

yielding $p(x) = \frac{Fe}{H} e^{2\mu(l-x)/h}$

from which

$$p(x) = p(0)e^{-2\mu x/H}$$

follows.

(Note. This cannot satisfy the condition of zero load at exit $x = L$.)

Also

$$M = \mu D.p(0)\int_0^L e^{-2\mu x/H} dx + p(0)\int_0^L (x+\delta)e^{-2\mu x/H} dx$$

$$= p(0)\left\{H\frac{D}{2}\left(1 - e^{-2\mu L/H}\right) + \frac{H}{2\mu}\left(\delta - (L+\delta)e^{-2\mu L/H}\right) + \frac{H^2}{4\mu^2}\left(1 - e^{-2\mu L/H}\right)\right\}.$$

For $\mu = 0.3$, $e^{-2\mu L/H} = 6 \times 10^{-6}$ and $F(0) = Hp(0) \approx \frac{M}{\left\{\frac{D}{2} + \frac{\delta}{2\mu} + \frac{H}{4\mu^2}\right\}} \approx 410 N$.

The data provided gives an estimated value of $EI \approx 10^{-4}$ which leads to $\lambda = \dfrac{1.571}{10^2\sqrt{P}}$ from (*).

<u>Model 1</u> $\lambda = \lambda_1 \approx 2.52mm$

<u>Model 2</u> $\lambda = \lambda_2 \approx 1.25mm$

<u>Model 3</u> $\lambda = \lambda_3 \approx 0.78mm$

Conclusions

The primary crimp wavelengths of 2λ predicted using the first and second models for the determination of buckling load are comparable with the observed wavelength of 4mm, whereas the third model predicts a wavelength of the order of half that observed in practice. It would appear that the proposed mechanism of formation of primary crimp, namely the generation of plastic hinges associated with sheet buckling, accords well with the observations.

The predicted buckling length of secondary crimp, based on the effective modulus E' and the associated second moment I', is <u>less</u> than the wavelength λ of the primary crimp and is therefore an order of magnitude less than observed experimentally. However, it is not suggested that the secondary crimp is formed in the same way as the primary, since it is unlikely that there will be plastic hinges associated with the buckling of the 'spring'. The secondary creep is presumably associated with the compression of the buckled spring as it is forced into the stuffer box and it has not been possible in the time available to examine this nonlinear deformation problem.

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