Received 25 April 2021; Accepted 08 May 2021.

Research Solution of the Problem of Forming a Flat Structure of Finite Width from a High-Temperature Melt

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ABSTRACT: The paper gives a solution to the problem of forming a flat structure of finite width from a high-temperature melt.

Key words: Matrix, tape, sheath, film, cable, rod, inclusions, plastic zone, edge effects, stresses, deformation, crack.

Introduction

The technology for producing elastically viscous materials (in this case, polymeric and composite) and the production of various structures (hollow cylindrical rods, pipelines, hoses, threads, films, tapes, sheaths, cables, etc.) from such materials is based on the creation of these residual stresses. Residual stresses are created during the period of heating the necessary components and obtaining material, the formation of a given geometric shape and size of structures and during the cooling of the material and structure.

It is of interest to determine the shape and size of the region on a tape of finite width H, in which the one-dimensional field studied above, takes place.

Literature Review

Consider first the tape, which occupies a quarter of the plane (Figure. 1). It is required to find a solution of a nonlinear system [1] satisfying in the region, the following boundary conditions

$$\sigma_x=\sigma_{xy}=0, \qquad \sigma_y=0 \qquad \text{at} \qquad x=0,\ y\geq 0, \tag{1}$$

$$\sigma_x=\sigma_{xy}=0, \qquad \text{at} \qquad y=0, \qquad x\geq 0. \tag{2}$$

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 312 – 317
Received 25 April 2021; Accepted 08 May 2021.

Region $x \geq 0$, $y \geq 0$ is divided into two areas: D^+ - in which the solution constructed above correctly and in which the influence of the edge does not penetrate, D^- - in which the influence of the free edge of the tape is very large (the area of the edge effect).

The D^+ regions — the unperturbed one-dimensional field and the D^- region — of the boundary layer or the edge effect, are separated by a line L, leaving the origin of the coordinates (Fig. 1).

The equation of the contour line L in the xy plane is

$$y=y(x_0).$$

In the field of D^+, the solution was constructed in the previous section.

In the area of D^- the condition of the boundary layer

$$\frac{\partial}{\partial y} >> \frac{\partial}{\partial x}. \tag{3}$$

In view of (3), equations (1) - (2) take the following form

$$\frac{\partial^2 \sigma_{xy}}{\partial x \partial y} = 0, \qquad \frac{\partial^2 \sigma_y}{\partial x \partial y} = 0, \tag{4}$$

$$\frac{\partial^2 \upsilon_y}{\partial x^2} = \frac{1}{E}\frac{\partial \sigma_x}{\partial x} - \frac{v}{E}\frac{\partial \sigma_y}{\partial x} + \alpha\frac{\partial T}{\partial x} + \frac{1}{3}\Phi(I,T)\frac{\partial}{\partial x}(2\sigma_x - \sigma_y), \tag{5}$$

$$\frac{\partial^2 \upsilon_y}{\partial x \partial y} = 2\frac{1+v}{E}\frac{\partial \sigma_{xy}}{\partial x} + 2\Phi(I,T)\frac{\partial \sigma_{xy}}{\partial x}, \tag{6}$$

$$\frac{\partial^2 \upsilon_y}{\partial x \partial y} = \frac{1}{E}\frac{\partial \sigma_y}{\partial x} - \frac{v}{E}\frac{\partial \sigma_x}{\partial x} + \alpha\frac{\partial T}{\partial x} + \frac{1}{3}\Phi(I,T)\frac{\partial}{\partial x}(2\sigma_y - \sigma_x). \tag{7}$$

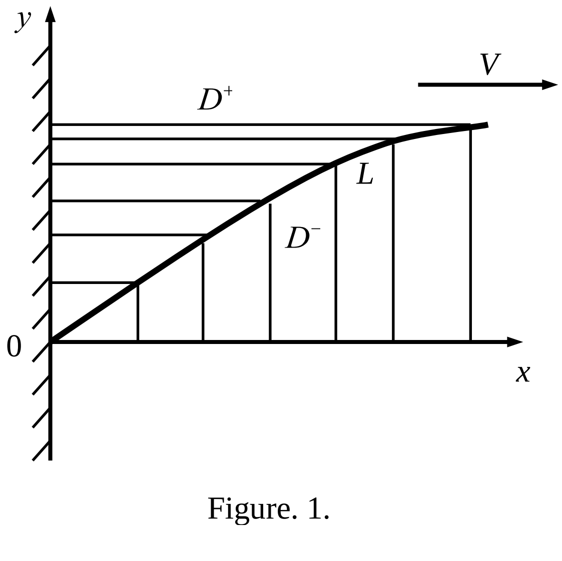

Figure. 1.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 312 – 317
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Topic

The solution of the system of differential equations (2) - (5) is

$$\sigma_{xy} = D_1(x) + D_2(y)\,, \tag{8}$$

$$\sigma_y = A_1(x) + A_2(y)\,. \tag{9}$$

Here A_1, A_2, D_1, D_2 are arbitrary functions.

Differentiating equation (3) with respect to y, and equation (4) with respect to x, and subtracting equation (3) from equation (4), and also taking into account condition (2), we obtain

$$\frac{1}{E}\frac{\partial^2\sigma_x}{\partial x\,\partial y} - \frac{v}{E}\frac{\partial^2\sigma_y}{\partial x\,\partial y} + \alpha\frac{\partial^2 T}{\partial x\,\partial y} + \frac{1}{3}\frac{\partial}{\partial y}\left[\Phi(I,\,T)\frac{\partial}{\partial x}(2\sigma_x - \sigma_y)\right] = 0\,. \tag{10}$$

Equations (6) - (8) are used to determine the three functions σ_x, σ_y, σ_{xy} in the region satisfying the boundary conditions (3) - (4).

According to (2.39) - (1) and (6) - (7), we obtain:

$$A_2(0) + A_1(x) = 0, \qquad D_1(x) + D_2(0) = 0\,. \tag{11}$$

Therefore, we have

$$A_1(x) = -A_2(0)\,, \qquad D_1(x) = -D_2(0)\,. \tag{12}$$

Based on (10) the decision (6) - (7) takes the form

$$\sigma_{xy} = D_2(y) - D_2(0)\,, \qquad \sigma_y = A_2(y) - A_2(0)\,. \tag{13}$$

Substituting (11) into equation (8), we obtain

$$\frac{1}{E}\frac{\partial^2\sigma_x}{\partial x\,\partial y} + \frac{1}{3}\frac{\partial}{\partial y}\left[\Phi(I,\,T)\frac{\partial}{\partial x}(2\sigma_x - A_2(y) + A_2(0))\right] = 0\,. \tag{14}$$

Integrating (12) over the variable y, we find

$$\frac{1}{E}\frac{\partial\sigma_x}{\partial x} + \frac{1}{3}\Phi(I,\,T)\frac{\partial}{\partial x}\left[2\sigma_x - A_2(y) + A_2(0)\right] = A_0(x)\,, \tag{15}$$

where $A_0(x)$ is a certain function.

On the line L separating the D^+ and D^- regions, the gluing conditions must be satisfied, which according to (6) - (7), (9) - (10) and (11) - (12) can be represented as

$$[\sigma_x]=0, \qquad [\sigma_y]=0, \qquad [\sigma_{xy}]=0, \tag{16}$$

where the sign [...] - means a jump of the considered value at the transition line L.

Methods

Therefore, wehave:

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$$\begin{cases} D_2(y) = D_2(0), \\ \frac{1}{3}\Phi(I,T)\frac{\partial}{\partial x}\left[A_2(0) - A_2(y_0(x))\right] = A_0(x), \\ A_2(y_0(x)) - A_2(0) = \sigma_y^+(x). \end{cases} \tag{17}$$

Here:

$$\sigma_y^+(x) = \alpha E\left[T(0) - T(x)\right] + \sqrt{\frac{8}{15}}E\left[\Pi(0,\ T(0)) - \Pi(I,\ T)\right]. \tag{18}$$

According to the first equation (15) and expression (11), the following condition is satisfied in the entire domain D^-

$$\sigma_{xy}=0. \tag{19}$$

The function, the inverse function y = y_0 (x), we denote by x = x_0 (y). Then according to the third equation (15) and (11) in the region we have

$$\sigma_y = \sigma_y^+(x_0(y)). \tag{20}$$

The second equation (15) with the third is reduced to the form

$$-\frac{1}{3}\Phi(I,\ T)\frac{d\sigma_y^+(x)}{dx} = A_0(x). \tag{21}$$

Here, the quantity I according to [1], (17) and (18) is defined in the domain D^- and is equal to:

- in area D^-

$$I = \sqrt{\frac{1}{6}\left[2\sigma_x - \sigma_y^+(x_0(y))\right]^2 + \left[2\sigma_y^+(x_0(y))\sigma_x - \sigma_x\right]^2}\ ; \tag{22}$$

- on contour line L

$$I = \sqrt{\frac{5}{6}}\sigma_y^+(x_0(y)). \tag{23}$$

with the help of (19) and (20) we find $A_0(x)$:

$$A_0(x) = -\frac{1}{3}\Phi\left[\sqrt{\frac{5}{6}}\sigma_y^+(x),\quad T(x)\right]\frac{d\sigma_y^+(x)}{dx}. \tag{24}$$

Results

Substituting (21) and (22) into (3), we obtain

$$\frac{1}{E}\frac{\partial\sigma_x}{\partial x} + \frac{2}{3}\Phi(I,\ T)\frac{\partial\sigma_x}{\partial x} = -\frac{1}{3}\Phi\left[\sqrt{\frac{5}{6}}\sigma_y^+(x),\quad T(x)\right]\frac{d\sigma_y^+(x)}{dx}, \tag{25}$$

Where I as a function $\sigma_x$and$y$defined by the formula (20).

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The last nonlinear partial differential equation of the first order serves to determine the desired function.$\sigma_x(x, y)$.

The characteristic system of equation (23) has the form

$$\frac{dx}{P(\sigma_x, x, y)} = \frac{dy}{0} = \frac{d\sigma_x}{A_0(x)} , \quad (26)$$

where

$$P(\sigma_x, x, y) = \frac{1}{E} + \frac{2}{3}\Phi I(\sigma_x, y)T(x), \quad (27)$$

functionI (σ_x, y) defined by the relations (16) and (20).

Discussions

According to (24), the characteristics of equation (23) are parallel straight lines *y=const*.

Using the notation (25), we rewrite equation (22) in the following form

$$P(\sigma_x, x, y)\frac{\partial\sigma_x}{\partial x} = A_0(x). \quad (28)$$

Required to find the integral surface $\sigma_x=\sigma_x(x, y)$, satisfying equation (26) and the following boundary condition for gluing on the border of the regions D^+ and D^-, that is, the condition on the contour line L

$$\sigma_x=\sigma_x(x, y_0(x))=0 \quad (29)$$

Although the characteristic system for an arbitrary function $P(\sigma_x, x, y)$ cannot be solved analytically, in a closed form, and therefore the general solution of equation (26) cannot be found in an analytical closed form, the numerical solution can easily be found by numerical integration of the characteristic equation

$$\frac{dx}{P(\sigma_x, x, y)} = \frac{d\sigma_x}{A_0(x)} \quad (30)$$

along the characteristic strips *y=const* taking into account the boundary condition (28).

For a strip of finite width, a qualitative picture of the solution is presented in Fig. 2. The open triangle ABC - the unperturbed region of the one-dimensional solution, the rest of the region shaded by the characteristic curves y = const - the boundary layer or the region of the edge effect.

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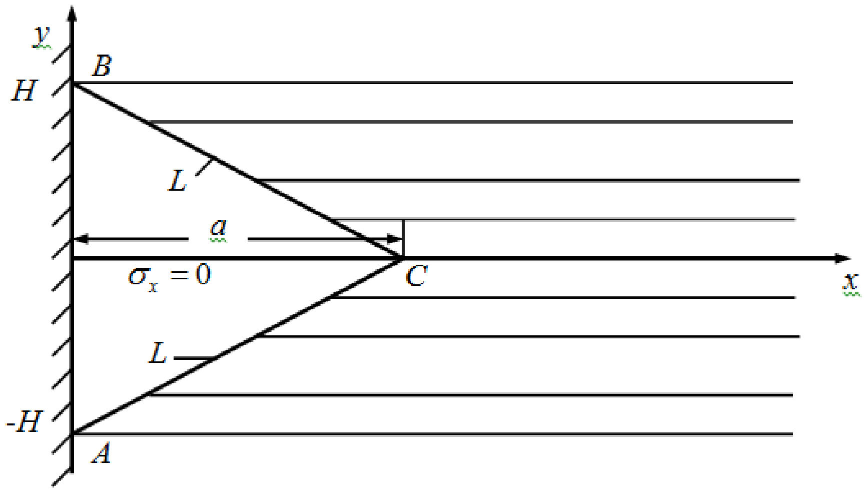

Figure.2

Conclusion

To determine the length parameter that determines the size of the unperturbed zone (see Fig. 2.), it is necessary to use some particular solution obtained by direct calculation of the problem in the exact formulation [1] by the finite element method.

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