TWO–DIMENSIONAL ANALYSIS OF THE CRYSTALLIZATION OF HOLLOW COMPOUND PLASTIC FIBERS

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ICCHMT 2011, Istanbul, Turkey

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INTRODUCTION

Introduction

- Bi–component hollow compound fibers may be manufactured by MELT SPINNING processes.
- Applications
  1. Chemical industry: Filtration and separation processes.
  2. Textile industry.
  3. Optics: Data transmission.
  4. Biomedical industry.
- Necessary: modelling of the drawing process of semi–crystalline hollow compound fibers.
- Previous studies are based on one–dimensional models of amorphous, slender fibers at very low Re and Bi numbers.
- NO INFORMATION ABOUT TEMPERATURE NON–UNIFORMITIES IN THE RADIAL DIRECTION.
- Use of a two–dimensional model for fiber spinning.

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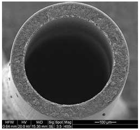

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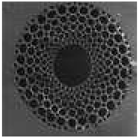

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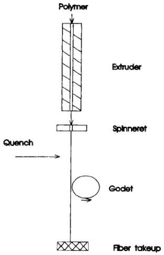
Melt spinning

Involves the extrusion and drawing of a polymer cylinder. Four zones.



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2. Flow Rearrangement Region.
3. **Melt Drawing Zone.**
4. **Solidification region.**

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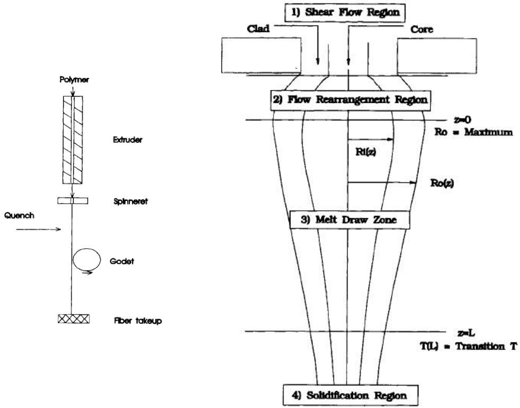

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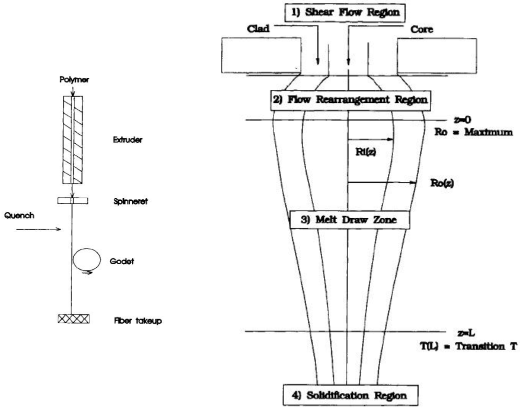

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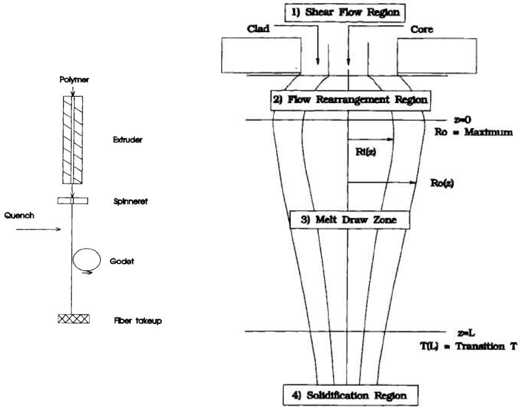

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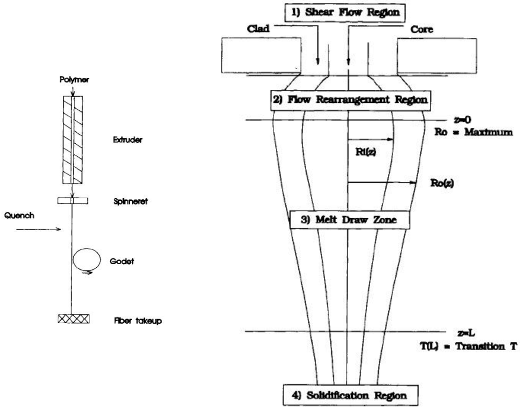

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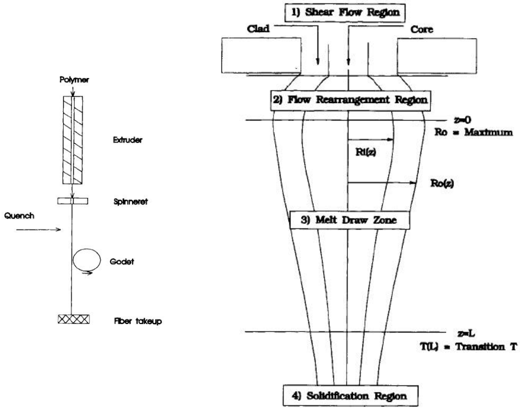

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FORMULATION

Governing equations

- **Mass conservation equation**

$$\nabla \cdot \mathbf{v}_i = 0 \qquad i = 1, 2,$$

where $\mathbf{v} = u(r,x)\,\mathbf{e_x} + v(r,x)\,\mathbf{e_r}$

- **Linear Momentum conservation equation**

$$\rho_i \left(\frac{\partial \mathbf{v}_i}{\partial t} + \mathbf{v}_i \cdot \nabla \mathbf{v}_i \right) = -\nabla p_i + \nabla \cdot \boldsymbol{\tau}_i + \rho_i \cdot \mathbf{f}^m \qquad i = 1, 2,$$

where $\mathbf{f}^m = g\,\mathbf{e_x}$

- **Energy conservation equation**

$$\rho_i\, C_i \left(\frac{\partial T_i}{\partial t} + \mathbf{v}_i \cdot \nabla T_i \right) = -K_i \Delta T_i \qquad i = 1, 2,$$

- **Constitutive equations**
  - Rheology

$$\boldsymbol{\tau} = \mu \left(\nabla \mathbf{v} + \nabla \mathbf{v}^T \right) + \boldsymbol{\tau}_p,$$

where

$$\boldsymbol{\tau}_p = 3c\, k_B\, T \left[-\frac{\lambda}{\phi} F(\mathbf{S}) + 2\lambda \left(\nabla \mathbf{v}^T : \mathbf{S} \right) (\mathbf{S} + \mathbf{I}/3) \right]$$

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Molecular orientation and crystallinity models

- **Crystallization: Avrami–Kolmogorov's theory & Ziabicki's model**

$$\frac{\partial Y_i}{\partial t} + \mathbf{v}_i \cdot \nabla Y_i = k_{Ai}(\mathcal{S}_i)\left(Y_{\infty,i} - Y_i\right) \qquad i = 1, 2,$$

where

$$k_{Ai}(\mathcal{S}_i) = k_{Ai}(0)\exp\left(a_{2i}\mathcal{S}_i^2\right), \qquad i = 1, 2.$$

- Molecular orientation scalar order parameter

$$\mathcal{S} \equiv \sqrt{\frac{3}{2}\left(\mathbf{S} : \mathbf{S}\right)} \qquad \mathbf{S} = \frac{1}{3}\cdot \text{diag}\left(S_{rr}, -\left(S_{rr} + S_{xx}\right), S_{xx}\right),$$

- Molecular orientation tensor equation: Doi–Edwards theory

$$\mathbf{S}_{(1)} = F(\mathbf{S}) + G(\nabla\mathbf{v}, \mathbf{S}),$$

$$F(\mathbf{S}) = -\frac{\phi}{\lambda}\left\{(1 - N/3)\,\mathbf{S} - N\left(\mathbf{S}\cdot\mathbf{S}\right) + N\left(\mathbf{S}:\mathbf{S}\right)\left(\mathbf{S} + \mathbf{I}/3\right)\right\}$$

$$G(\nabla\mathbf{v}, \mathbf{S}) = \frac{1}{3}\left(\nabla\mathbf{v} + \nabla\mathbf{v}^T\right) - 2\left(\nabla\mathbf{v}^T : \mathbf{S}\right)\left(\mathbf{S} + \mathbf{I}/3\right).$$

where subscript (1) denote UCTD operator

$$\Lambda_{(1)} = \frac{\partial\Lambda}{\partial t} + \mathbf{v}\cdot\nabla\Lambda - \left(\nabla\mathbf{v}^T\cdot\Lambda + \Lambda\cdot\nabla\mathbf{v}\right)$$

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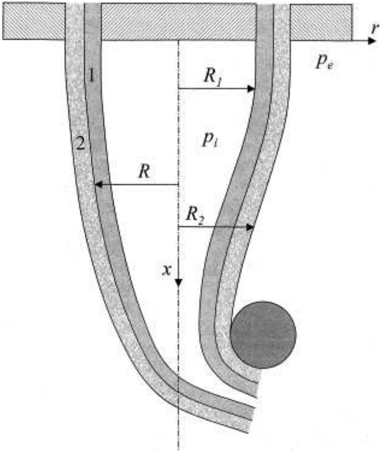

Kinematic, dynamic and thermal boundary conditions are required:

- Initial conditions $(t = 0)$
- Die exit conditions $(x = 0)$
- Take–up point conditions $(x = L)$
- Conditions on free surfaces of hollow compound fiber $(r = R_1(x), r = R(x)$ and $r = R_2(x))$

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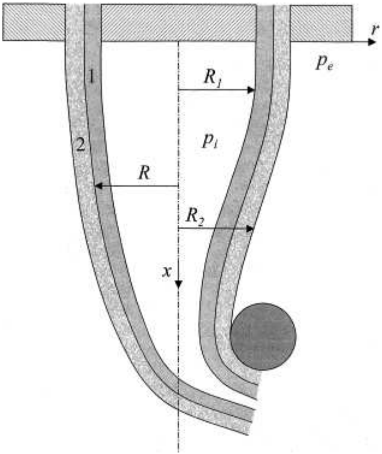

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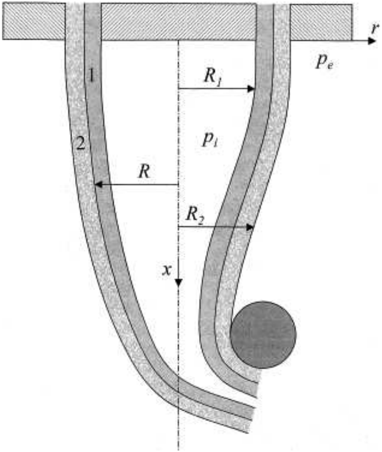

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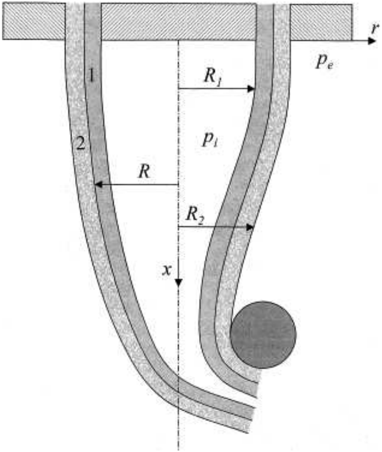

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Non–dimensionalize

- Non–dimensional variables

$$\hat{t} = \frac{t}{(L/u_0)} \qquad \hat{r} = \frac{r}{R_0} \qquad \hat{x} = \frac{x}{L} \quad \Rightarrow \quad \epsilon = \frac{R_0}{L}$$

$$\hat{u} = \frac{u}{u_0} \qquad \hat{v} = \frac{v}{(u_0\,\epsilon)} \qquad \hat{p} = \frac{p}{(\mu_0 u_0/L)} \qquad \hat{T} = \frac{T}{T_0}$$

$$\hat{\rho} = \frac{\rho}{\rho_0} \qquad \hat{C} = \frac{C}{C_0} \qquad \hat{\mu} = \frac{\mu}{\mu_0} \qquad \hat{K} = \frac{K}{K_0}$$

- Non–dimensional numbers

$$Re = \frac{\rho_0 u_0 R_0}{\mu_0}, \quad Fr = \frac{u_0^2}{gR_0}, \quad Ca = \frac{\mu_0 u_0}{\sigma},$$

$$Pr = \frac{\mu_0 C_0}{K_0}, \quad Pe = Re\,Pr, \quad Bi = \frac{hR_0}{K_0}$$

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Asymptotic analysis: 1D model

- **Asymptotic method using the fiber slenderness, $\epsilon << 1$, as perturbation parameter**

$$\Psi_i = \Psi_{i,0} + \epsilon^2 \Psi_{i,2} + O(\epsilon^4) \, ,$$

for the variables $\hat{R}_i$, $\hat{u}_i$, $\hat{v}_i$, $\hat{p}_i$ and $\hat{T}_i$ where $i = 1, 2$.

- **Flow regime steady ($\frac{\partial}{\partial \hat{t}} = 0$) jets and**

$$Re = \epsilon \, \bar{R}, \qquad Fr = \frac{\bar{F}}{\epsilon}, \qquad Ca = \frac{\bar{C}}{\epsilon},$$

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where $\bar{\Upsilon} = O(1)$.

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One–dimensional equations of the 2D model

- **Asymptotic one–dimensional mass conservation equation**

$$\mathcal{A}_1\,\mathcal{B} = V_1,$$

$$\mathcal{A}_2\,\mathcal{B} = V_2,$$

$$\frac{d}{d\hat{x}}\left(\frac{\mathcal{R}_0^2}{2}\,\mathcal{B}\right) = \mathcal{C}\left(\hat{x}\right)$$

where

$$\mathcal{A}_1 = \frac{\mathcal{R}_0^2 - \mathcal{R}_1^2}{2}, \qquad \mathcal{A}_2 = \frac{\mathcal{R}_2^2 - \mathcal{R}_0^2}{2},$$

and

$$\mathcal{C}\left(\hat{x}\right) = \left(\frac{1}{2\,\bar{C}}\right)\frac{\left(\frac{\sigma_1}{\sigma}\right)\frac{1}{\mathcal{R}_1} + \frac{1}{\mathcal{R}_0} + \left(\frac{\sigma_2}{\sigma}\right)\frac{1}{\mathcal{R}_2}}{<\hat{\mu}_{e1,0}>\left(\frac{1}{\mathcal{R}_0^2} - \frac{1}{\mathcal{R}_1^2}\right) + <\hat{\mu}_{e2,0}>\left(\frac{1}{\mathcal{R}_2^2} - \frac{1}{\mathcal{R}_0^2}\right)},$$

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One–dimensional equations of the 2D model

- **Asymptotic one–dimensional axial momentum equation**

$$
\begin{aligned}
(\hat{\rho}_1 V_1 + \hat{\rho}_2 V_2)\bar{R}\,\frac{d\mathcal{B}}{d\hat{x}} &= (\hat{\rho}_1\mathcal{A}_1 + \hat{\rho}_2\mathcal{A}_2)\,\frac{\bar{R}}{\bar{F}} \\
&+ \frac{d}{d\hat{x}}\left(3\left(<\hat{\mu}_{e1,0}>\mathcal{A}_1 + <\hat{\mu}_{e2,0}>\mathcal{A}_2\right)\frac{d\mathcal{B}}{d\hat{x}}\right) \\
+2\,\mathcal{C}\left(\hat{x}\right)\Bigg(-\frac{<\hat{\mu}_{e1,0}>}{\mathcal{R}_1}\frac{d\mathcal{R}_1}{d\hat{x}} &+ \frac{<\hat{\mu}_{e1,0}> - <\hat{\mu}_{e2,0}>}{\mathcal{R}_0}\frac{d\mathcal{R}_0}{d\hat{x}} + \frac{<\hat{\mu}_{e2,0}>}{\mathcal{R}_2}\frac{d\mathcal{R}_2}{d\hat{x}}\Bigg) \\
&- \left(\mathcal{A}_1\frac{d\mathcal{D}_1}{d\hat{x}} + \mathcal{A}_2\frac{d\mathcal{D}_2}{d\hat{x}}\right),
\end{aligned}
$$

where

$$
\mathcal{D}_1 = - <\hat{\mu}_{e1,0}> \frac{2\,\mathcal{C}\left(\hat{x}\right)}{\mathcal{R}_1^2} - \frac{1}{\bar{C}}\left(\frac{\sigma_1}{\sigma}\right)\frac{1}{\mathcal{R}_1},
$$

$$
\mathcal{D}_2 = - <\hat{\mu}_{e2,0}> \frac{2\,\mathcal{C}\left(\hat{x}\right)}{\mathcal{R}_2^2} + \frac{1}{\bar{C}}\left(\frac{\sigma_2}{\sigma}\right)\frac{1}{\mathcal{R}_2}
$$

- Incompressibility condition

$$
\mathcal{V}(\hat{r},\hat{x}) = \frac{\mathcal{C}\left(\hat{x}\right)}{\hat{r}} - \frac{\hat{r}}{2}\frac{d\mathcal{B}}{d\hat{x}},
$$

- **Asymptotic one–dimensional axial momentum equation**

$$(\hat{\rho}_1 V_1 + \hat{\rho}_2 V_2)\bar{R}\,\frac{d\mathcal{B}}{d\hat{x}} = (\hat{\rho}_1 \mathcal{A}_1 + \hat{\rho}_2 \mathcal{A}_2)\frac{\bar{R}}{\bar{F}} + \frac{d}{d\hat{x}}\left(3\,(<\hat{\mu}_{e1,0}>\mathcal{A}_1 + <\hat{\mu}_{e2,0}>\mathcal{A}_2)\,\frac{d\mathcal{B}}{d\hat{x}}\right) + 2\,\mathcal{C}\,(\hat{x})\left(-\frac{<\hat{\mu}_{e1,0}>}{\mathcal{R}_1}\frac{d\mathcal{R}_1}{d\hat{x}} + \frac{<\hat{\mu}_{e1,0}> - <\hat{\mu}_{e2,0}>}{\mathcal{R}_0}\frac{d\mathcal{R}_0}{d\hat{x}} + \frac{<\hat{\mu}_{e2,0}>}{\mathcal{R}_2}\frac{d\mathcal{R}_2}{d\hat{x}}\right) - \left(\mathcal{A}_1\frac{d\mathcal{D}_1}{d\hat{x}} + \mathcal{A}_2\frac{d\mathcal{D}_2}{d\hat{x}}\right),$$

where

$$\mathcal{D}_1 = -<\hat{\mu}_{e1,0}>\frac{2\,\mathcal{C}\,(\hat{x})}{\mathcal{R}_1^2} - \frac{1}{\bar{C}}\left(\frac{\sigma_1}{\sigma}\right)\frac{1}{\mathcal{R}_1},$$

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Two–dimensional equations of the 2D model

- **Two–dimensional energy equation**

$$\mathcal{B}\,\frac{\partial \hat{T}_1}{\partial \hat{x}}+\left(\frac{\mathcal{C}\,(\hat{x})}{\hat{r}}-\frac{\hat{r}}{2}\frac{d\mathcal{B}}{d\hat{x}}\right)\frac{\partial \hat{T}_1}{\partial \hat{r}}=\frac{1}{\bar{P}_1}\frac{1}{\hat{r}}\frac{\partial}{\partial \hat{r}}\left(\hat{r}\,\frac{\partial \hat{T}_1}{\partial \hat{r}}\right)\qquad \mathcal{R}_1\leq \hat{r}\leq \mathcal{R}_0,$$

$$\hat{T}_1(\hat{r},\,0)=\tilde{T}_1(\hat{r}),$$
$$-\hat{K}_1\,\frac{\partial \hat{T}_1}{\partial \hat{r}}(\mathcal{R}_1,\,\hat{x})=0,$$
$$\hat{T}_1\,(\mathcal{R}_0,\,\hat{x})=\hat{T}_2\,(\mathcal{R}_0,\,\hat{x})$$

$$\mathcal{B}\,\frac{\partial \hat{T}_2}{\partial \hat{x}}+\left(\frac{\mathcal{C}\,(\hat{x})}{\hat{r}}-\frac{\hat{r}}{2}\frac{d\mathcal{B}}{d\hat{x}}\right)\frac{\partial \hat{T}_2}{\partial \hat{r}}=\frac{1}{\bar{P}_2}\frac{1}{\hat{r}}\frac{\partial}{\partial \hat{r}}\left(\hat{r}\,\frac{\partial \hat{T}_2}{\partial \hat{r}}\right)\qquad \mathcal{R}_0\leq \hat{r}\leq \mathcal{R}_2,$$

$$\hat{T}_2(\hat{r},\,0)=\tilde{T}_2(\hat{r}),$$
$$-\hat{K}_2\,\frac{\partial \hat{T}_2}{\partial \hat{r}}(\mathcal{R}_2,\,\hat{x})=\bar{B}\,\hat{h}_2\left(\hat{T}_2(\mathcal{R}_2,\,\hat{x})-\hat{T}_{2,\infty}\right),$$
$$-\hat{K}_1\,\frac{\partial \hat{T}_1}{\partial \hat{r}}\,(\mathcal{R}_0,\,\hat{x})=-\hat{K}_2\,\frac{\partial \hat{T}_2}{\partial \hat{r}}\,(\mathcal{R}_0,\,\hat{x})$$

Two–dimensional equations of the 2D model

- **Two–dimensional degree of crystallinity equation**

$$\mathcal{B}\,\frac{\partial Y_i}{\partial \hat{x}}+\left(\frac{\mathcal{C}\left(\hat{x}\right)}{\hat{r}}-\frac{\hat{r}}{2}\frac{d\mathcal{B}}{d\hat{x}}\right)\frac{\partial Y_i}{\partial \hat{r}}=k_{Ai}(0)\exp\left(a_{2i}\mathcal{S}_i^2\right)\,\left(Y_{\infty,i}-Y_i\right), \qquad i=1,2,$$

$$Y_i(\hat{r},\,0)=\tilde{Y}_i(\hat{r}), \qquad i=1,2,$$

- Effective dynamic viscosity

$$\hat{\mu}_{ei,0}\left(\hat{r},\,\hat{x}\right)=\hat{G}_i\,\exp\left(\hat{E}_i\left(1-\hat{T}_i\right)+\beta_i\left(\frac{Y_i}{Y_{\infty,i}}\right)^{n_i}\right)+\frac{2}{3}\,\alpha_i\,\hat{\lambda}_i\mathcal{S}_i^2 \qquad i=1,2.$$

- Cross-sectionally averaged effective dynamic viscosity

$$<\hat{\mu}_{e1,0}>(\hat{x})=\int_{\mathcal{R}_1}^{\mathcal{R}_0}\hat{\mu}_{e1,0}(\hat{r},\hat{x})\,\hat{r}\,d\hat{r}/\mathcal{A}_1,$$

$$<\hat{\mu}_{e2,0}>(\hat{x})=\int_{\mathcal{R}_0}^{\mathcal{R}_2}\hat{\mu}_{e2,0}(\hat{r},\hat{x})\,\hat{r}\,d\hat{r}/\mathcal{A}_2.$$

Two–dimensional equations of the 2D model

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- **Two–dimensional degree of crystallinity equation**

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Two–dimensional equations of the 2D model

- **Two–dimensional equations for the molecular orientation tensor components**

$$\mathcal{B}\,\frac{\partial S_{i\,rr}}{\partial \hat{x}} + \left(\frac{\mathcal{C}\,(\hat{x})}{\hat{r}} - \frac{\hat{r}}{2}\frac{d\mathcal{B}}{d\hat{x}}\right)\frac{\partial S_{i\,rr}}{\partial \hat{r}} = \left(1 - S_{i\,rr}\right)\left(1 + S_{i\,xx}\right)\frac{d\mathcal{B}}{d\hat{x}} - \frac{\phi_i}{\hat{\lambda}_i}\left\{S_{i\,rr} + \frac{N_i}{3}\left[\left(S_{i\,rr} - 1\right)\left(S_{i\,rr} - O_{i\,s}\right)\right]\right\}, \qquad i = 1, 2,$$

$$\mathcal{B}\,\frac{\partial S_{i\,rr}}{\partial \hat{x}} + \left(\frac{\mathcal{C}\,(\hat{x})}{\hat{r}} - \frac{\hat{r}}{2}\frac{d\mathcal{B}}{d\hat{x}}\right)\frac{\partial S_{i\,rr}}{\partial \hat{r}} = \left(1 + S_{i\,xx}\right)\left(2 - S_{i\,xx}\right)\frac{d\mathcal{B}}{d\hat{x}} - \frac{\phi_i}{\hat{\lambda}_i}\left\{S_{i\,xx} - \frac{N_i}{3}\left[\left(S_{i\,xx} + 1\right)\left(S_{i\,xx} - O_{i\,s}\right)\right]\right\}, \qquad i = 1, 2,$$

$$O_{i\,s}(\hat{r}, \hat{x}) = \frac{2}{3}\left(S_{i\,rr}^2 + S_{i\,xx}^2 - S_{i\,rr}\,S_{i\,xx}\right).$$

$$S_{i\,rr}(\hat{r},\,0) = -\tilde{\mathcal{S}}_i(\hat{r}),$$
$$S_{i\,xx}(\hat{r},\,0) = 2\,\tilde{\mathcal{S}}_i(\hat{r}).$$

Mapping: 2D model

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$(\hat{r}, \hat{x}) \mapsto (\xi, \eta)$ maps $\Omega_{\hat{r}\hat{x}} = \{[\mathcal{R}_1(\hat{x}),\, \mathcal{R}_2(\hat{x})] \times [0,\, 1]\}$ into a rectangular domain $\Omega_{\xi\eta} = \{[0,\, 1] \times [0,\, 1]\}$

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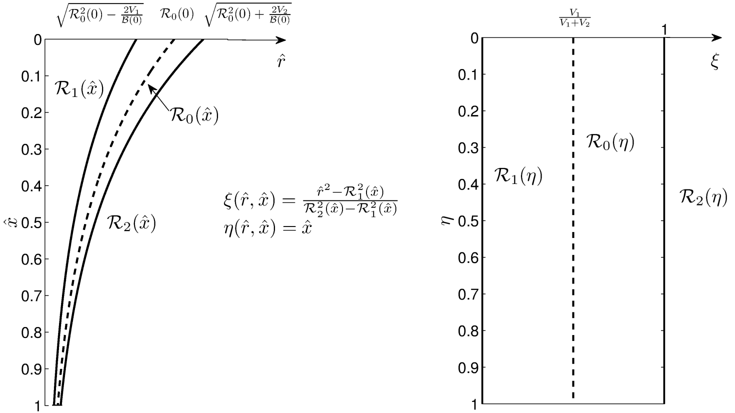

Two–dimensional equations of the 2D model

- **Two–dimensional energy equation**

$$\frac{\partial \hat{T}_1}{\partial \eta} = \frac{1}{2\,(V_1+V_2)}\,\frac{4}{\bar{P}_1}\,\frac{\partial}{\partial \xi}\left(\left(\xi + \frac{\mathcal{R}_1^2}{\mathcal{R}_2^2-\mathcal{R}_1^2}\right)\frac{\partial \hat{T}_1}{\partial \xi}\right) \qquad 0 \le \xi \le \frac{V_1}{V_1+V_2},$$

$$\hat{T}_1(\xi,\,0) = \tilde{T}_1(\xi),$$

$$-\hat{K}_1\,\frac{\partial \hat{T}_1}{\partial \xi}(0,\,\eta) = 0,$$

$$\hat{T}_1\left(\frac{V_1}{V_1+V_2},\,\eta\right) = \hat{T}_2\left(\frac{V_1}{V_1+V_2},\,\eta\right)$$

$$\frac{\partial \hat{T}_2}{\partial \eta} = \frac{1}{2\,(V_1+V_2)}\,\frac{4}{\bar{P}_2}\,\frac{\partial}{\partial \xi}\left(\left(\xi + \frac{\mathcal{R}_1^2}{\mathcal{R}_2^2-\mathcal{R}_1^2}\right)\frac{\partial \hat{T}_2}{\partial \xi}\right) \qquad \frac{V_1}{V_1+V_2} \le \xi \le 1,$$

$$\hat{T}_2(\xi,\,0) = \tilde{T}_2(\xi),$$

$$-\hat{K}_2\,\frac{\partial \hat{T}_2}{\partial \xi}(1,\,\eta) = \frac{\mathcal{R}_2^2-\mathcal{R}_1^2}{2\,\mathcal{R}_2}\,\bar{B}\,\hat{h}_2\left(\hat{T}_2(1,\,\eta) - \hat{T}_{2,\infty}\right),$$

$$-\hat{K}_1\,\frac{\partial \hat{T}_1}{\partial \xi}\left(\frac{V_1}{V_1+V_2},\,\eta\right) = -\hat{K}_2\,\frac{\partial \hat{T}_2}{\partial \xi}\left(\frac{V_1}{V_1+V_2},\,\eta\right)$$

Two–dimensional equations of the 2D model

Francisco J. Blanco–Rodríguez, J. I. Ramos

- **Two–dimensional degree of crystallinity equation**

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- **Effective dynamic viscosity**

$$\hat{\mu}_{ei,0}\left(\xi,\,\eta\right) = \hat{G}_i\,\exp\left(\hat{E}_i\left(1 - \hat{T}_i\right) + \beta_i\left(\frac{Y_i}{Y_{\infty,i}}\right)^{n_i}\right) + \frac{2}{3}\,\alpha_i\,\hat{\lambda}_i\mathcal{S}_i^2 \qquad i = 1, 2.$$

- **Cross-sectionally averaged effective dynamic viscosity**

$$< \hat{\mu}_{e1,0} > (\eta) = \frac{V_1 + V_2}{V_1}\int_0^{\frac{V_1}{V_1+V_2}} \hat{\mu}_{e1,0}(\xi,\eta)\,d\xi,$$

$$< \hat{\mu}_{e2,0} > (\eta) = \frac{V_1 + V_2}{V_2}\int_{\frac{V_1}{V_1+V_2}}^{1} \hat{\mu}_{e2,0}(\xi,\eta)\,d\xi.$$

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$$\mathcal{B}\,\frac{\partial S_{i\,rr}}{\partial \eta} = (1 - S_{i\,rr})\,(1 + S_{i\,xx})\,\frac{d\mathcal{B}}{d\eta}$$
$$-\frac{\phi_i}{\hat{\lambda}_i}\left\{S_{i\,rr} + \frac{N_i}{3}\left[(S_{i\,rr} - 1)\,(S_{i\,rr} - O_{i\,s})\right]\right\}, \qquad i = 1, 2,$$

$$\mathcal{B}\,\frac{\partial S_{i\,xx}}{\partial \eta} = (1 + S_{i\,xx})\,(2 - S_{i\,xx})\,\frac{d\mathcal{B}}{d\eta}$$
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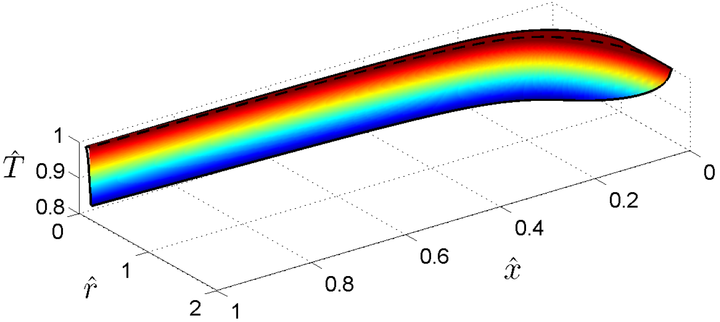
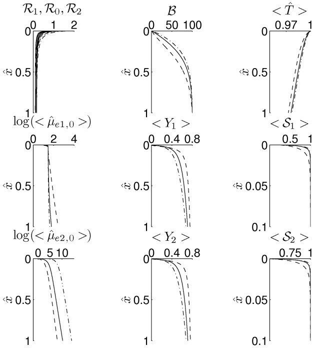
RESULTS AND DISCUSSION

Thermal boundary layer



$E_2 = 10$

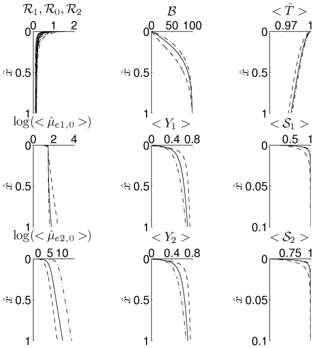
Effect of the cladding's viscosity parameters



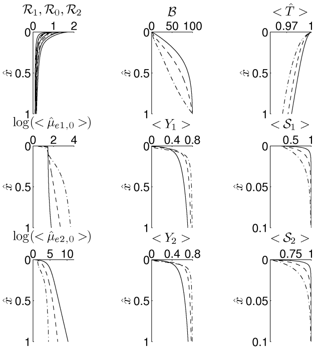
$G_2 = 1$ (–), $G_2 = 0{,}01$ (– –) and $G_2 = 100$ $(- \cdot -)$

$E_2 = 100$ (–), $E_2 = 50$ (– –) and $E_2 = 10$ $(- \cdot -)$

Effect of the cladding's viscosity parameters

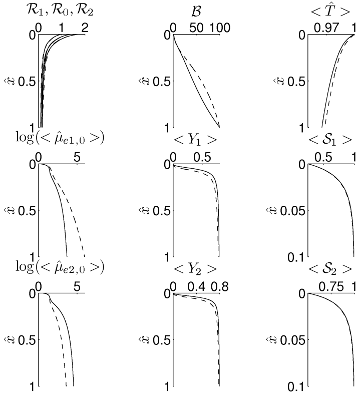


$G_2 = 1$ (–), $G_2 = 0{,}01$ (– –) and $G_2 = 100$ (– · –)



$E_2 = 100$ (–), $E_2 = 50$ (– –) and $E_2 = 10$ (– · –)

1D model vs 2D model



1D (–) and 2D (— · —)

CONCLUSIONS

Conclusions

Contributions of the present work:

1. Development of a quasi–two–dimensional model for semi–crystalline hollow compound fibers with modified Newtonian rheology.
2. 1D model (asymptotic analysis for $\epsilon << 1$) for $\mathcal{R}_i$ and $\mathcal{B}$ and 2D equations for $\hat{T}_i$, $\mathcal{S}_i$ and Y_i.
3. Determination of the two–dimensional fields of temperature, order parameter for molecular orientation and degree of crystallinity for hollow compound fibers.
4. Integro–differential model highly dependent on E_2 and G_2.
5. Find substantial temperature non–uniformities (may affect the degree of crystallization and have great effects on the mechanical, optical,... properties of hollow compound fibers) in the radial direction.

Conclusions

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About the authors...

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