다층 휠름 캐스팅 공정에서의 안정성 분석

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Stability Analysis of Multilayer Film Casting Process

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Introduction

Multilayer coextrusion of film and sheet has developed into an important plastic fabrication process. Different layers may be used to place colors, to bury recycle, to screen ultraviolet radiation, and to control film surface properties. Coextruded films are produced either by the tubular blown film process or the film casting process. The cast film process is more suitable for high volume production on dedicated line because of higher output obtainable by wide dies and more efficient cooling on chill roll. Cast films usually have better optical clarity than blown films because of rapid quenching (Bian, 1998).

In the multilayer film casting process, multiple melt streams from different extruders are combined in a feed block, which produces a multilayer melt. The extruded film from the die is drawn by a chill roll which serves to cool down and solidify the molten film.

When this drawdown ratio is increased beyond a critical value, the multilayer film casting process can become unstable, i.e., instability called draw resonance occurs. This instability is characterized by the periodic oscillation of the film thickness and film width. Since this draw resonance is an industrially important productivity issue as well as an academically interesting stability topic, there have been many experimental and theoretical studies on this subject in last four decades (Pearson and Matovich, 1969; Fisher and Denn, 1976; Lee *et al.*, 2001).

In this paper, the stability of multilayer film casting process using both extension thickening fluids and thinning fluids, has been investigated by nonlinear transient response on the step disturbance.

Modeling

As shown in the schematic diagram of multilayer film casting process (Fig. 1), dimensionless governing equations for isothermal 1D model were represented as shown below (Silagy *et al.*, 1996; Piz-Lopez and Co, 1996a). Especially, to describe the neck-in phenomena, the edge condition was adapted. In the present study, a three layer film (ABA type) composed of an extension thickening fluid (e.g., LDPE) and an extension thinning fluid (e.g., HDPE). To portray these fluid characterization, Phan-Thien-Tanner model with different model parameters was used (Phan-Thien and Tanner, 1977; Phan-Thien, 1978).

Equation of continuity:

$$\frac{\partial(e_1 w)}{\partial t} + \frac{\partial(e_1 wv)}{\partial x} = 0 \tag{1}$$

$$\frac{\partial(e_2 w)}{\partial t} + \frac{\partial(e_2 wv)}{\partial x} = 0 \tag{2}$$

Equation of motion:

$$\sigma_{xx,1} e_1 w + V_r \sigma_{xx,2} e_2 w = F \tag{3}$$

Constitutive equations:

$$K\boldsymbol{\tau}_1 + De_1\left[\frac{\partial \boldsymbol{\tau}_1}{\partial t} + \underline{v}\cdot\underline{\nabla}\boldsymbol{\tau}_1 - \mathbf{L}_1\cdot\boldsymbol{\tau}_1 - \boldsymbol{\tau}_1\cdot\mathbf{L}_1^T\right] = 2\mathbf{D}_1 \tag{4}$$

$$K\boldsymbol{\tau}_2 + De_2\left[\frac{\partial \boldsymbol{\tau}_2}{\partial t} + \underline{v}\cdot\underline{\nabla}\boldsymbol{\tau}_2 - \mathbf{L}_2\cdot\boldsymbol{\tau}_2 - \boldsymbol{\tau}_2\cdot\mathbf{L}_2^T\right] = 2V_r\mathbf{D}_2 \tag{5}$$

where, $K = \exp(\varepsilon De\,\mathrm{tr}\,\boldsymbol{\tau})$, $\mathbf{L} = \nabla\mathbf{v} - \xi\mathbf{D}$, $2\mathbf{D} = [\nabla\mathbf{v} + \nabla\mathbf{v}^T]$

Edge condition:

$$(q\sigma_{xx,1} + (1-q)\sigma_{xx,2})\left(\frac{\partial w}{\partial x}\right)^2 = Ar^2(q\sigma_{yy,1} + (1-q)\sigma_{yy,2}) \tag{6}$$

Boundary conditions:

t=0: $e_{1,0}=q$, $e_{2,0}=(1.0-q)$, $w_0=1.0$, $v_0=1.0$
$v_L=r$ (7)
t>0: $v_L=r(1+\varepsilon^*)$

where, e is the dimensionless film thickness, w is the dimensionless film width, v is the dimensionless velocity in x-direction, $\boldsymbol{\tau}$ is the dimensionless stress tensor, $\boldsymbol{\sigma}$ is the dimensionless total stress tensor, x is the dimensionless distance, t is the dimensionless time, ε and ξ are the PTT model parameters, q is the flow rate ratio of inner layer, Vr is the viscosity ratio, $Ar=(L/W_0)$ is the aspect ratio, De is the Deborah number, r is the drawdown ratio, ε^* is the constant initial disturbance at the take-up and subscript 0, L, S denote T-die, take-up, and steady state condition, respectively.

Results

Extension thickening fluid like LDPE which has long chain branched structure is more stable than extension thinning fluid like HDPE which has linear structure. Moreover, fluid viscoelasticity imbedded in Deborah number (De) stabilizes the process for the extension thickening fluid case, whereas it destabilizes the process for the extension thinning fluid case. As shown in Fig. 2, the stability diagram of monolayer film casting process represents it well. To represent the properties of polymer melts, the PTT model parameter sets are selected as ε=0.015, ξ=0.1 for LDPE and ε=0.015, ξ=0.7 for HDPE, respectively (Phan-Thien, 1978).

The effects of the extrusion ratio of HDPE (q) on the process stability are shown in Fig. 3. As increasing the extrusion ratio of HDPE (q) of the multilayer film casting process, the transient response on the step disturbance

shows less stable behavior and becomes unstable, ultimately. Piz-Lopez and Co (1996b) explained that the stability of multilayer film depended on the extensional and shear viscosities of each fluid in the film. Like the previous results (Piz-Lopez and Co, 1996b), the stability according to the extrusion ratio can be explain using extensional behavior, because extension thinning behavior reduces elongation viscosity. As increasing the extrusion ratio of HDPE, the extensional viscosity of multilayer film also reduces, and the process becomes destabilized.

The effects of fluid viscoelasticity imbedded in Deborah number of outer LDPE resin are examined. For the monolayer case, fluid viscoelasticity of extension thickening fluids stabilize the process. Like the monolayer results, the extension thickening fluids show stabilizing effects and the extension thinning fluids show opposite behavior. As shown in Fig. 4, the fluid viscoelasticity of LDPE stabilizes the multilayer process. On the other hand, for the extension thinning case, the fluid viscoelasticity of HDPE destabilizes the process.

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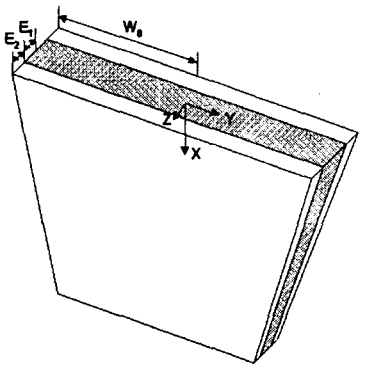


Figure 1. Schematic diagram of multilayer film casting process

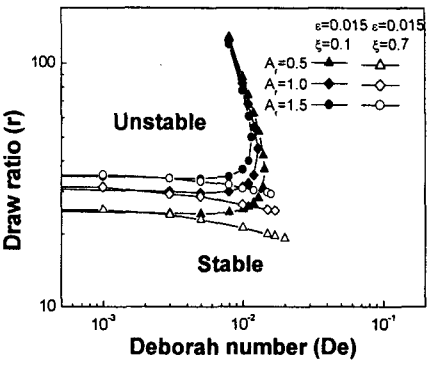
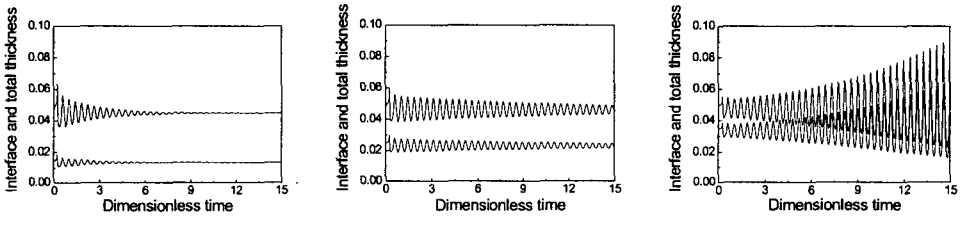
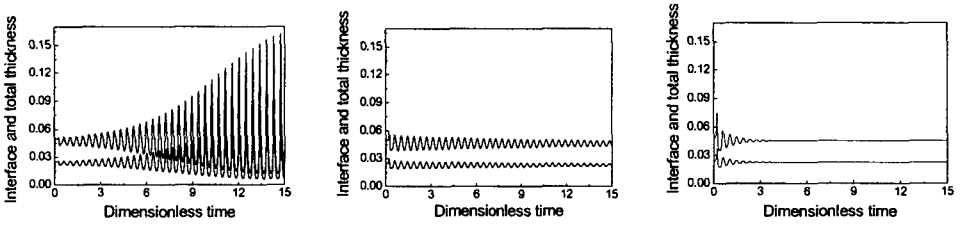


Figure 2. Stability diagram of mono-layer film casting process



(a) (b) (c)

Figure 3. Transient response of total film thickness and interface position for multilayer film casting process at Ar=0.5, r=30, De_1=0.002, and De_2=0.02 (a) q=0.3 (stable), (b) q=0.5 (less stable), and (c) q=0.7 (unstable).



(a) (b) (c)

Figure 4. Transient response of total film thickness and interface position for multilayer film casting process at Ar=0.5, r=30, De_1=0.002, and q=0.5 (a) De_2=0.01 (unstable), (b) De_2=0.02 (less stable), and (c) De_2=0.03 (stable).