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Drying, Stress Development and Deformation in Solvent - Cast Film[2]

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Introduction

The process of making solvent-cast-film is similar to typical coating and drying. The process starts from casting a liquid called dope on a steel band and then dried. But there are some features in process of making solvent-cast-film that usual coating and drying doesn't have. One is that the film is peeled from the substrate after it is dried to some extent. This means that the film is dried from only one side before peeling, and then it is dried from both sides. The second distinctive feature is that a tenter zone is used, and sometimes the film is stretched in the width direction. The third one is that the thickness is usually larger than typical coating, and there is a non-uniform solvent concentration distribution inside the film in the thickness direction.

Considering these features, this research focuses on the deformation of the film, especially curl after peeling and change of thickness profile during drying and stretching.

Drying, stress development, and deformation model

Because the main purpose of this research is to know how the film deforms, two-dimensional model is used here. In the model, the transversal direction is considered as x-axis and the thickness direction as z-axis. Usually, the film is long enough, and the movement of polymer and solvent in machine direction can be neglected. Hence, two-dimensional model is fairly model for considering drying problem of film.

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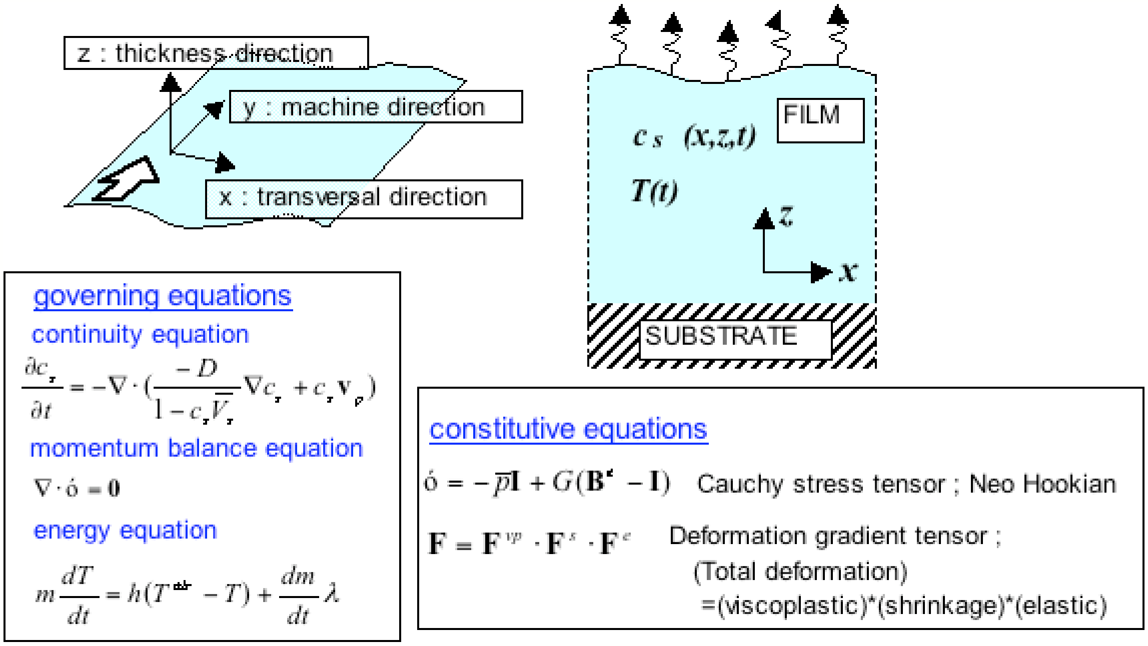


Fig.1 2-D drying – stress – deformation model

The schematic picture of drying, stress development and deformation model is shown in Fig.1. Film consists of two materials; solvent and polymer, and mutual diffusion is considered in the model. The diffusion coefficient is modeled as an exponential function of solvent concentration, based on Vrentas & Duda's free volume theory. The stress development model is based on Lei's 2D elasto-viscoplastic model[2]. Once the drying film reaches the concentration at which it is assumed to change from liquid into solid, the elastic stress is modeled as neo-Hookian up to yielding and viscoplastic beyond yielding. Material properties such as elastic modulus, viscosity and yield stress is considered to be function of concentration and temperature. The 1-dimensional model using mechanical elements is shown in Fig.2. This equation system is solved by Galerkin/finite element method.

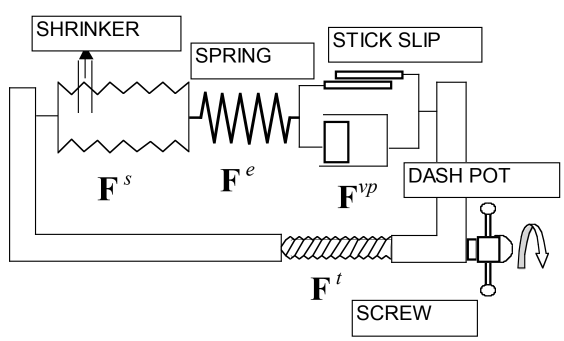


Fig.2 Mechanical 1D model of stress development

Curling

In solvent-cast film making process, the film is dried from one side before peeling, and from both sides after peeling. This means that the film should have a different concentration or different stress between air side and band side. Because of this unbalance, some interesting deformation can be seen through the drying process. Curl is one of deformation that drying condition plays an important part.

When the material is elasto-viscoplastic, curl just after peeling depends on when the film is peeled. The relation between peeling time and the curl just after peeling is plotted in Fig.4. Not only the curl after peeling but also the "permanent" curl depends on the timing of peeling. The relation between peeling time and permanent curl is shown in Fig.5. Using this model the curl when the drying condition is changed can also be predicted.

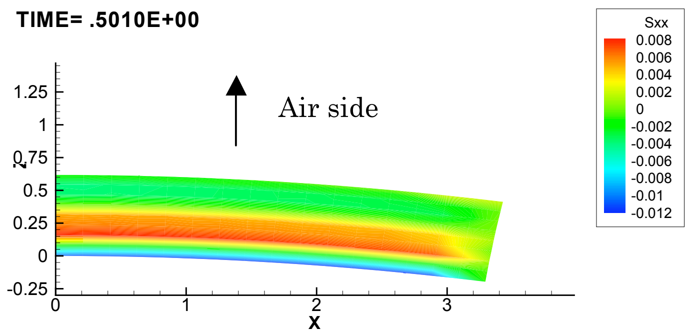


Fig.3 Stress distribution and deformation of the film just after peeling

xo=4.0, zo=1.0, E,μ,k : constant, Elasto-viscoplastic, β=0.5, Sh=5.0, peeling at t=0.5, De=40, k=0.01

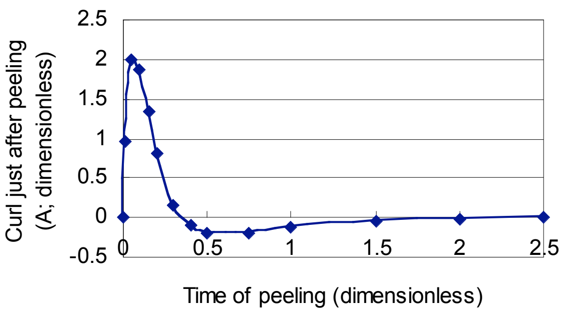


Fig.4 Peeling time and curl just after peeling

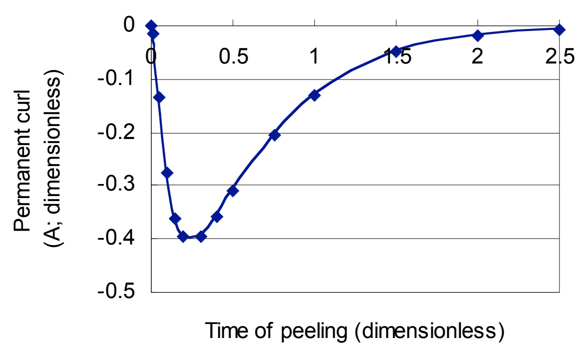
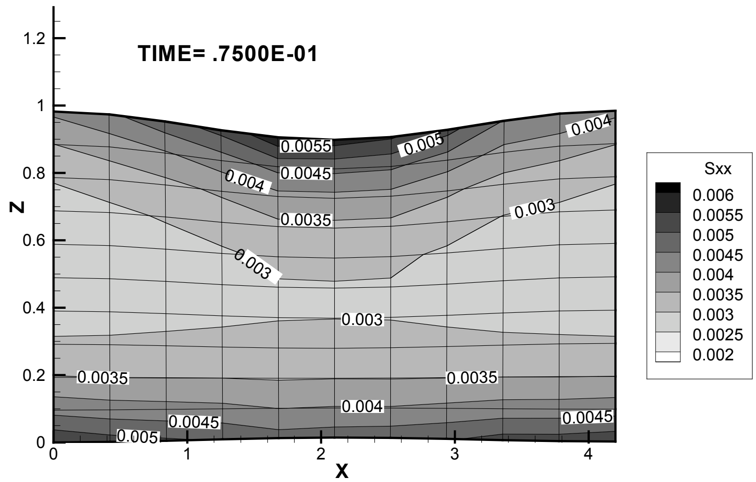


Fig.5 Peeling time and permanent curl

Improvement of unevenness in drying and tentering

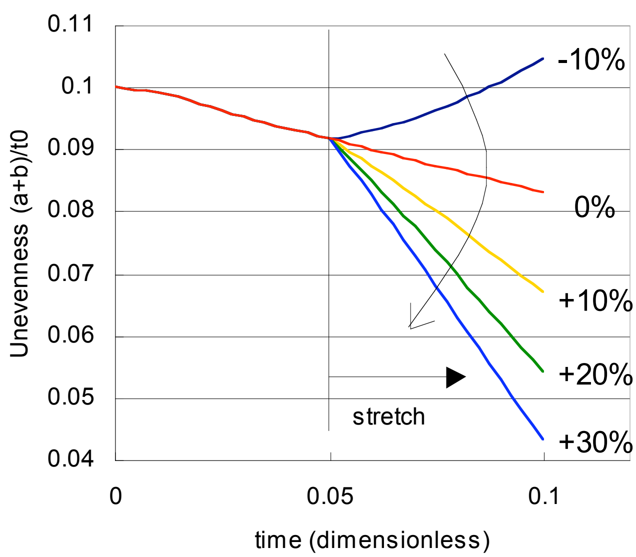
Because dope is very viscous, the unevenness of the film's thickness is inevitable in casting film. Here, the mechanism of deformation of the film during drying and tentering is examined, and how a flat film can be obtained by optimizing the drying and tentering conditions is examined.

One of the deformations that are practically important is the change of unevenness of the film's thickness. We can know how film deforms and how we can optimize the drying and stretching condition by using this model.



Elasto-viscoplastic
Concentration dependent
dynamic parameters
Sh=5, k=0.01
x0=4.0, z0=1.0, δz=±0.1
stretch 30%/dt, dt=0.05
@t=0.075, 15% stretched

Fig.6 In-plane stress distribution during drying and stretching



Elasto-viscoplastic
Concentration dependent
dynamic parameters
Sh=5, k=0.01
x0=4.0, z0=1.0, δz=±0.1
stretch –10~30%/dt, dt=0.05

Fig.7 The relation between unevenness and stretching magnitude

References

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