Experimental and Theoretical Approach of Film Processing

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Abstract

T-die casting film and biaxially oriented films produced by both the tentering process and the double bubble tubular film one are mainly discussed in this presentation.

T-die casting film process is widely used to produce the flat film. Recently the casting film process is required to get high productivity without any instability and unbalanced orientation, and to produce uniform film thickness. In this reason the theoretical approach of film processing is studied to predict the orientation of film and the draw resonance and also to find the optimum process condition which makes high quality film with high production speed.

Biaxially oriented tentering process is widely used to produce plastic films such as packaging film, music & video tapes, condenser film and so on. This process has been required to produce thinner film and more uniform film thickness at high speed without any film break and high quality film. In order to achieve these requirements, the rheological behavior of resin and the experimental and theoretical analyses during the tentering process should be studied. Double bubble tubular process is also presented.

• • Rheology of Polymer

Melt polymer has a visco-elastic property during the polymer processing. Flowability of molten resin in an extruder and a die is mainly dominated by shear viscosity and after exit of the die the elongational viscosity is a main factor for stretchability. These melt behaviors are influenced by molecular structure such as molecular

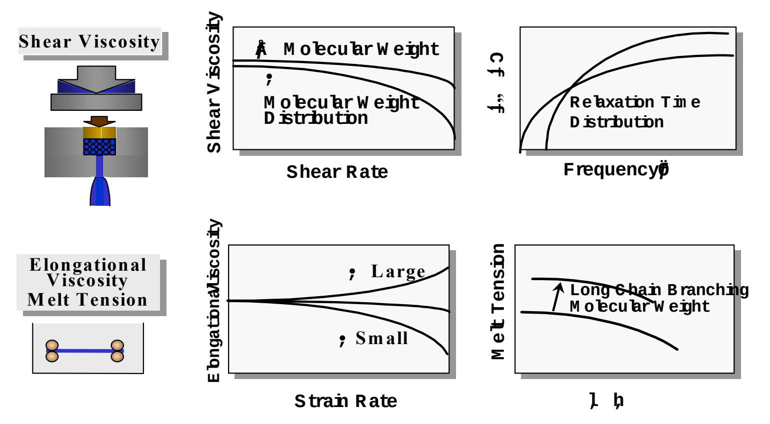

Figure1 Rheological Behavior of Molten Polymer

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weight, molecular weight distribution and long chain branching and further tacticity for polypropylene during the crystallization process.

For example, the melt rheologies are shown in Fig.1 for various methods. High molecular weight portion and long chain branching influence the relaxation time of melt polymer and time-dependent elongational viscosity. Relaxation times are obtained by cone & plate rheometer.

2. T-die Casting Process

T-die cast film process is required to get higher production speed and thinner film without any problems during the production process. Draw resonance of extrusion lamination process is a serious problem if high production speed is reached (Figure 2).

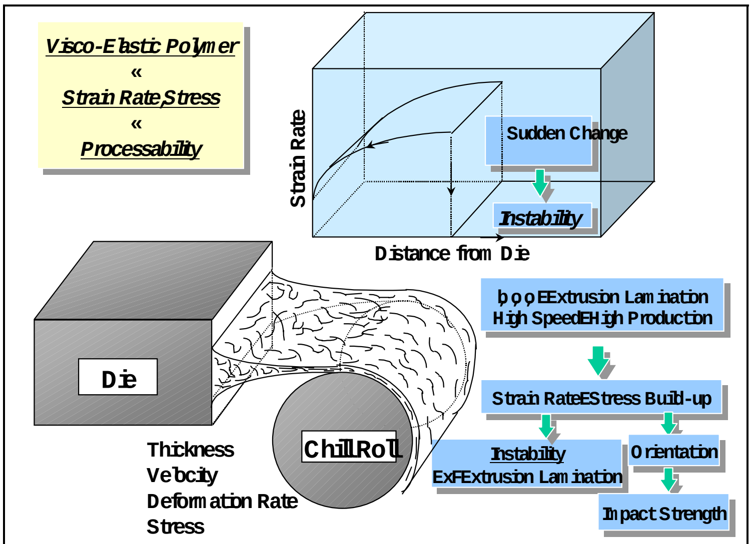


Figure2 Image of Processability and Film Properties of Casting Film

The theoretical approach can predict the deformation rate, stress build-up, temperature distribution of the process and film physical properties. Draw resonance which is an elongational flow instability is also predicted. This approach is useful to find the optimum process condition for good film properties and high production speed. If the theoretical approach is applied for instability of polyolefin polymers, the draw resonance behavior can be predicted. The deformation rate at roll touch position has sudden change and this change makes instability of the film.

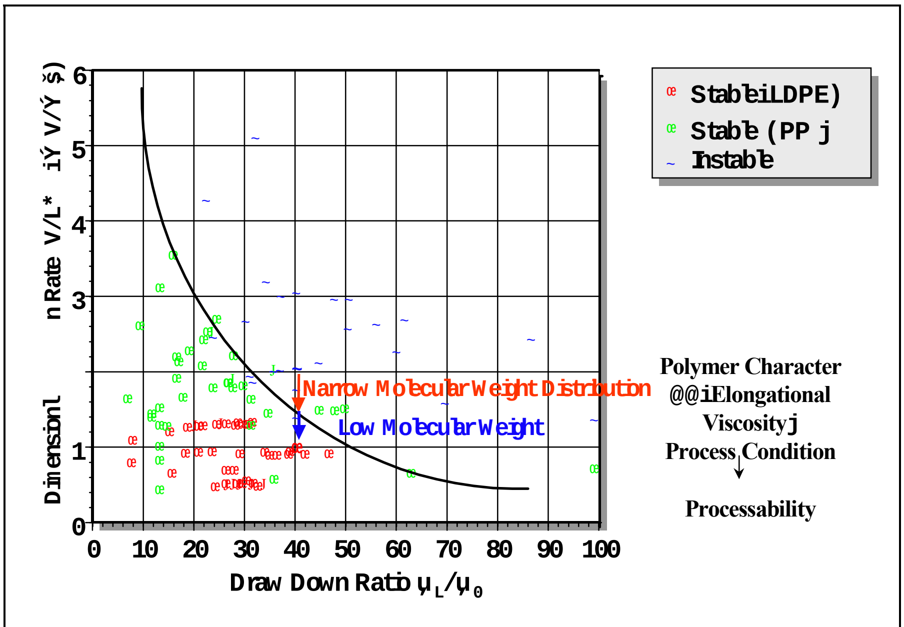


Figure3 Dimensionless Strain Rate-Instability

The instability parameter•is defined as follows.

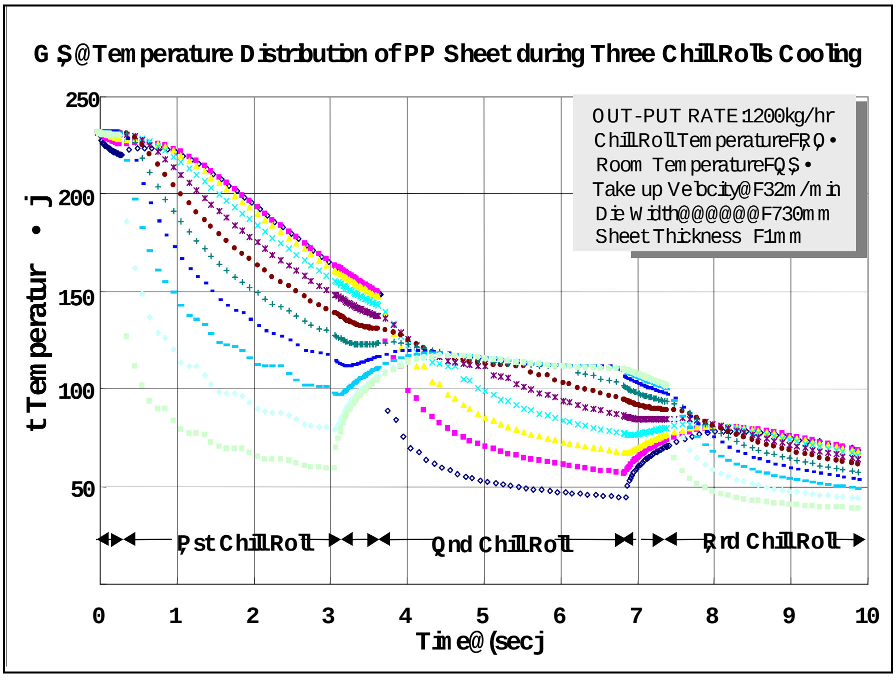
•=L/V *(d•/dz)$_{z=L}$

L: Air Gap, V: Take-up Velocity, (d•/dz)$_{z=L}$: Deformation Rate at the roll touch position

The instability ,namely "draw resonance", is a function of the parameters of dimensionless deformation rate•and draw down ratio V_L/V_0. The reduction of deformation rate gap at the roll touch position improves stability of film. The polymer which is deformed near the exit of the die ,namely, the polymer having strain rate hardening and high activation energy of elongational viscosity has better stability. High air cooling also makes better stability. The theoretical results shown in Figure 3 predict that the narrow molecular weight distribution and the low molecular weight make better stability.

The high orientation film in the machine direction which is apt to be produced by high take-up speed makes low impact strength. To avoid it, it is important to reduce the long relaxation time portion of polymer.

3. Cooling Process



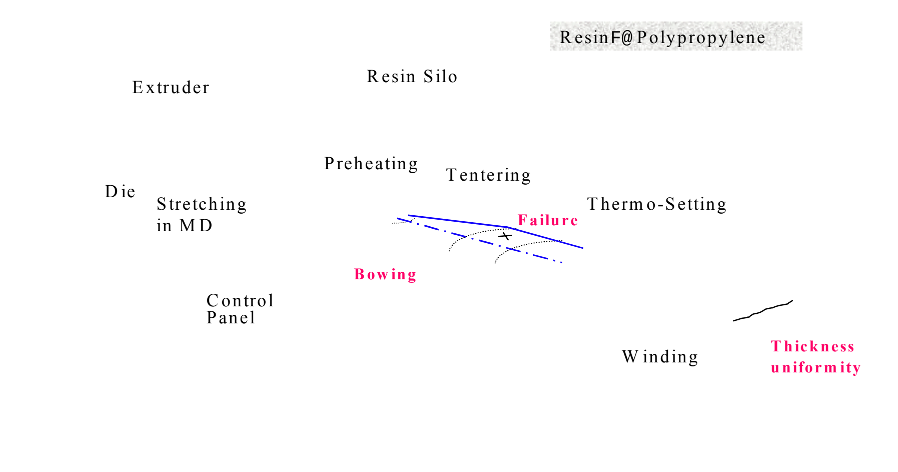
Chill Rolls are very important to control the crystallinity of the sheet which is stretched in the machine direction and the transverse direction in the next stage for the biaxially oriented film. The temperature distribution of sheet during the cooling process influences stretchability during the orientation process because of crystallinity. Figure 4 shows the temperature distribution of the sheets and the temperature difference across the film thickness for three chill rolls' cooling without any water cooling. The temperature differences are large. The water spray cooling system makes higher cooling speed and smaller temperature difference. High cooling rate is preferable to reduce crystallinity. Chill roll size and cooling method are very important.

The high tacticity polymer has high crystallization speed and the high cooling speed is required.

4.Tentering Process

The biaxially oriented polypropylene film shown in Figure 5 is required to be uniform thickness, uniform orientation and high transparency and further no break during high speed production. In these requirement, quick evaluation technique is necessary. The theoretical approach shown in Figure 6 is set up to establish this requirement.

Figure 5. Schematic View of Biaxially Oriented Film Machine



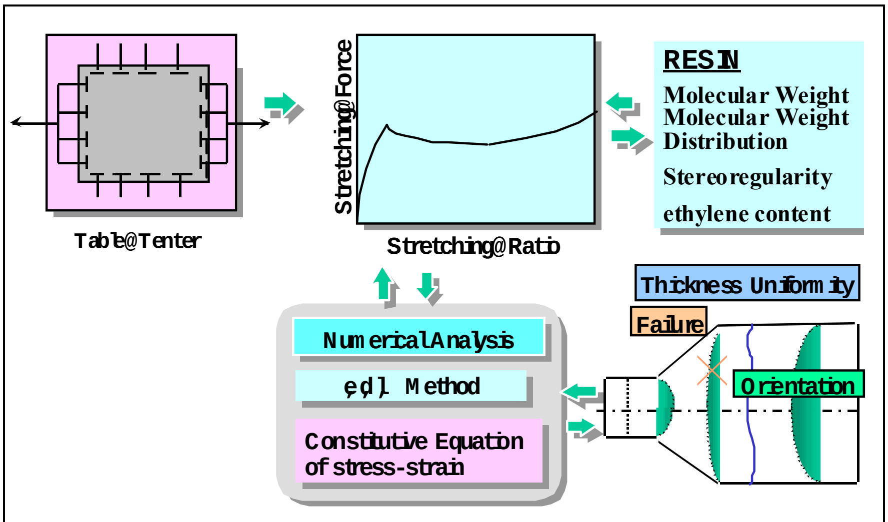


Figure 6. Process Analysis of Biaxially Oriented Film

The evaluation method of film quality and processability such as film uniformity, stretchability and continuous productivity at high speed production are needed by using a small amount of sample and a simple method. This research is the experimental and theoretical approach to clear these kinds of problems.

The temperature range of stretchability is very much dependent on the composition distribution of PP, and stretchability and uniform thickness are dependent on the molecular weight distribution and tacticity of PP which influences stretching force build-up at the higher stretching ratio and initial stretching one. The processability is possible to be predicted by the theoretical analysis and the table tenter data obtained with small amount of resin which are corespondent with resin design.

The visco-elastic model is assumed as a mechanical model and the factors of viscosities parameter •i and elastic moduli •i are obtained by the curve of stretching force and stretching ratio which is obtained by the small size tentering machine. The out-put results of deformation pattern and stress one during the tentering process are shown in Figure 7. These results suggest that bowing phenomena, stress build-up and uniformity are predictable. From this kind of information, processability and optimum polymer design are predicted for biaxially oriented polypropylene.

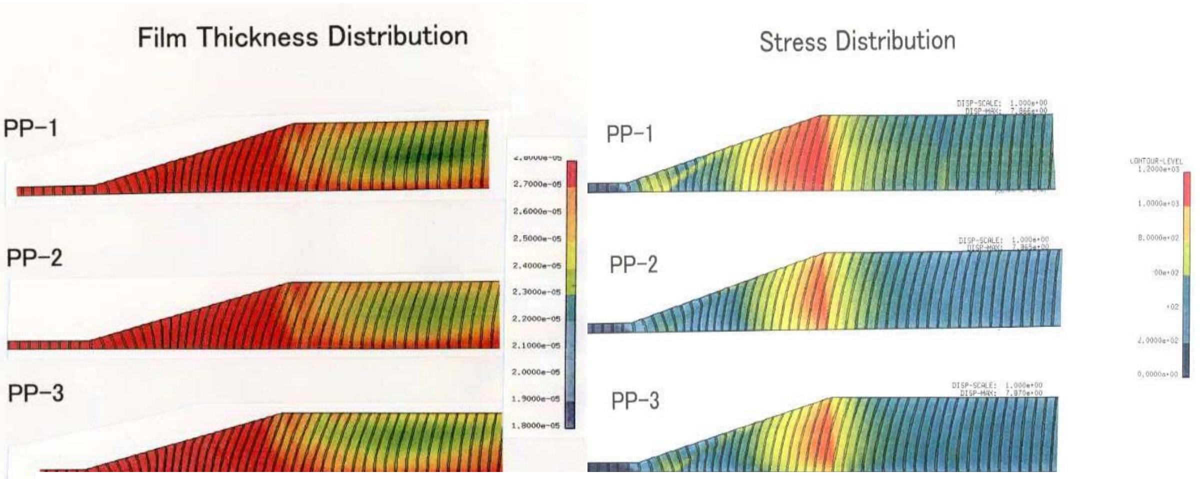


Figure 7. Predicted Results of Film Thickness Distribution and Stress

5.Blown Film Extrusion and Double Bubble Tubular Film Process

Blown film extrusion is one of the most important film processes to produce plastic film. The theoretical analysis is widely studied. The activation energy of polyethylene which is influenced by long chain branching and the amount of branching makes bubble shape change. Power law index of elongational viscosity dependent on molecular weight distribution also influences the bubble shape and velocity profile.

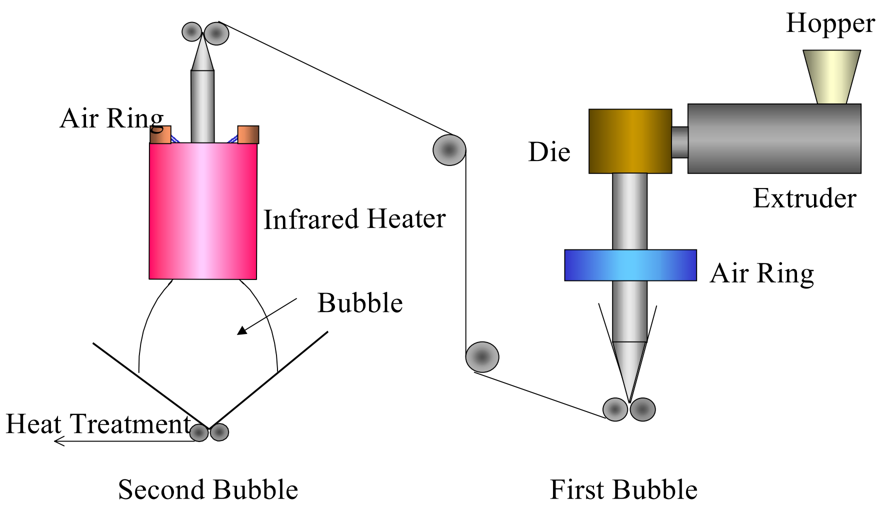


Figure8.Schematic View of Double Bubble Tubular Film Process

Double bubble tubular film process is used to produce the biaxially oriented polystyrene sheet & film (OPS) , shrinkage film of polyolefins, nylon film and so on. One example of double bubble tubular film process for polyolefin PP and PE is shown in Figure 8. The first bubble is formed at high resin temperature and then the second bubble is stretched and inflated at lower temperature and at high stretching force.

The basic theoretical analyses of the first bubble and the second bubble are almost same. The following equations are used to predict the bubble shape ,bubble velocity, temperature and stress distribution. From the membrane theory, the stresses in the machine direction σ_{11} and σ_{22} are balanced by the inside bubble pressure. The force balance equations are as follows.

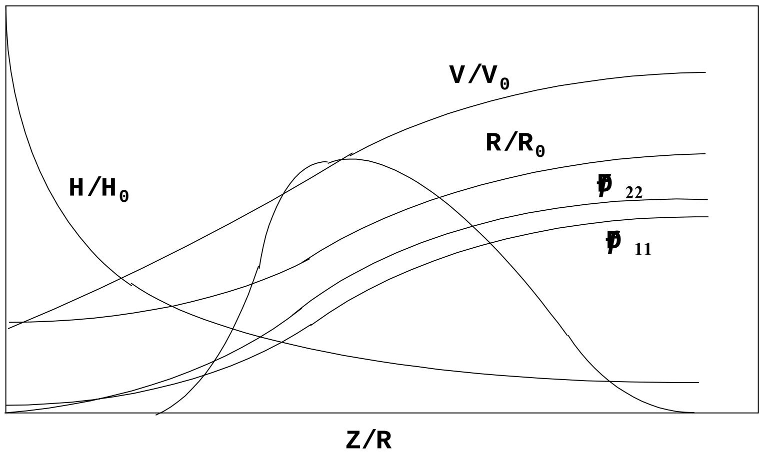


Figure9 @Dynamics of Deformation and Stress Development during Double Bubble Tubular Process of [illegible]

Force balance equation

$$F_z = 2\pi R H \sigma_{11} \cos\theta + \pi (R_L^2 - R^2) P$$

Membrane theory

$$\frac{H\sigma_{11}}{R_L} + \frac{H\sigma_{22}}{R_T} = \Delta P$$

R.,R. • Radii of Bubble Curvature • R • Bubble Radius, F. • Bubble Force • H • Film Thickness,

R. • Final Bubble Radius • •

P • Inside Bubble Pressure

Elongational Viscosity in a molten State is assumed to be followed by Arrhenius type viscosity

•(•d,T,X• •

Aexp • E/RT+GX• • •n-1•/2

A• •0exp(-• • • •0)

E • Activation Energy,

R • Gas Constant •

T. • • • • •,

•. • Viscosity at T_0

X • Crystallinity,

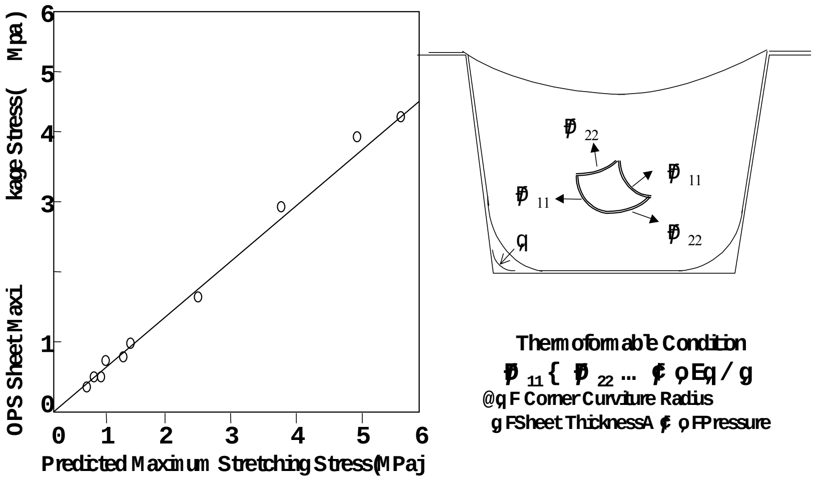


Figure10@Maximum Stretching Stress and Thermformability

Thermoformability is very important for the biaxially oriented polystyrene film and sheet (OPS). The low stretching stress gives low orientation of the sheet and low physical properties.

The stretching stress which is given during the stretching process is preserved inside the sheet and too high stress makes low processability for thermoformability especially at the corner of the tray. Predicted stretching stress has a good relationship with OPS shrinkage Stress. From these results, thermoformability at the corner of the tray and the physical properties of tray are predicted.

References

1. V.Rauschenberger; ANTEC Proceeding 150,56,(1998)
2. T.Kanai; 5th-Polym.Proc.Soc.Meeting (PPS-5) Proceeding
3. T.Kanai,G.A.Campbel; "Film Processing" Hanser Verlag (1999)
4. M.Takashige,T.Kanai; Intern. Polym. Process 38,7 (1990)
5. T.Kanai ,M.Takashige,T.Iwai,J.Shimizu; Senigakkaishi T-272,41 (1985)
6. T.Kanai; 16th-Polym.Proc.Soc.Meeting (PPS-16) Proceeding (2000)