Theoretical analysis for primary film production process and preheating one of double bubble tubular film process

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Abstract

A temperature change and crystallinity one during the primary film production process and the preheating one of the double bubble tubular film were studied theoretically and experimentally. The physical properties and morphological ones of primary film were studied by using the theoretically predicted thermal history. A temperature change and crystallinity one during the preheating process were also predicted theoretically. The validity of analyses for the temperature and crystallinity was studied by comparing an experimental result with a theoretical one.

1. Introduction

The double bubble tubular film of polyolefin such as PP and LLDPE has been widely used in food and various goods packaging because of its excellent mechanical properties and its balanced heat shrinkage. In the primary film production process, this film with low crystallinity is preferable for primary film because of easy stretching. The elevation of the crystallinity in a preheating process is experientially known to influence the stretchability. In this report, a temperature change and crystallinity one during those process were predicted theoretically and also compared with experimental results.

2. Analysis

Primary film production process The model of the cross-section of the primary film in contact with cooling water was considered. The heat-conduction equation of primary film and the boundary condition between film surface and cooling water are shown as follows.

$$\frac{\partial T}{\partial t} = \frac{k}{C_p \cdot \rho} \cdot \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

$$k\frac{\partial T}{\partial x} = h\left(T_W - T_\infty\right) \qquad (2)$$

where T_W is surface temperature, k is thermal conductivity , C_p is heat capacity , ρ is density, T is film temperature, x is film position from cooling water , h is heat-transfer coefficient , T_∞ is temperature of a fluid. Crystallization of resin was considered by using crystallization latent heat. The primary film cooling program was developed and used as a theoretical analysis.

Preheating Process The temperature distribution and crystallization one during the preheating process were predicted theoretically by using eq.(3). The heat balance equation and the crystallization equation are derived by the movement of heat and the change of the crystallization in film minute section dz. The derived heat balance equation is shown below.

$$\rho C_P Q dT = 2\pi R_r \sigma \varepsilon_r T_r{}^4 F \gamma_p \alpha_{pz} dz - 2\pi R dz\, \sigma \varepsilon T^4 + \rho Q \Delta H_c dx - 2\pi R dz h_a (T - T_{room}) \qquad (3)$$

where ρ is film density, C_p is the specific heat capacity, Q is extrusion output, R is film radius, H is film thickness, v is film velocity, R_r is infrared heater radius, σ is the Stefan-Boltzman constant, ε_r is infrared heater emissivity, F is view factor, γ_p is effective efficiency of IR radiation energy,

α_{pz} is heat absorptivity, ε is film emissivity, ΔH_c is enthalpy of crystallization and h_a is heat transfer rate. The crystallization equation is shown below.

$$x(t) = x(\infty)[1 - \exp\{-(\int_0^t K(T)\,dt)^n\}] \quad (4)$$

where $x(\infty)$ is final crystallinity, K is non-isothermal crystallization rate constant, n is Avrami exponent, t is time and K(T) is the following expression that Patel derived.

$$K(T) = \left[\exp(A - \frac{BT}{(T - T_g - 51.6)^2} - \frac{CT_m}{T(T_m - T)})\right]^{\frac{1}{n}} \quad (5)$$

where T_g is glass transition temperature, T_m^0 is equilibrium melting point, A, B, and C are polymer constant. Derived equations (1) and (2) were transformed into the differential equations, and they were solved by using the Runge-Kutta method.

3. Results and Discussion

The result of the analysis of a primary film production process is shown as follows.

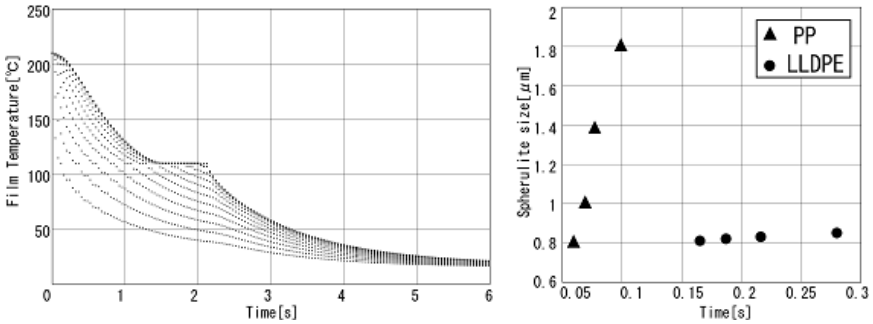

Figure 1: Calculated Results of Temperature of LLDPE in Primary Film Production Process (left) and Comparison with Calculated Results and Spherulite size (right)

Figure 1 shows the temperature distribution of primary film and the plateau area by the crystallization latent heat. The average elapse times of the plateau area were calculated from the analytical results under various cooling water temperature conditions. The results compared them with various experimental values showed that film properties such as haze, density and spherilite size can be predicted in this analysis.
The analytical results of temperature and crystallization in the preheating process are shown below.

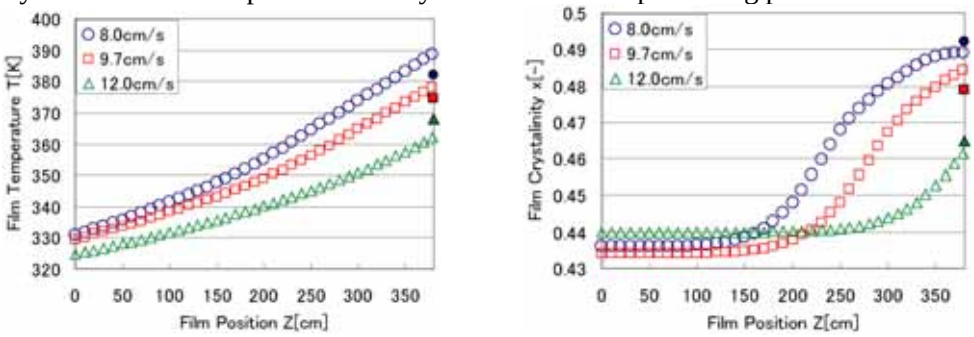

Figure 2: Predicted Film Temperature vs. Film Position and Crystallinity vs. Film Position

It was found that temperature and crystallinity could be predicted in this analysis by comparing an experimental value. A temperature change and crystallinity one during primary film production process and preheating one were predicted theoretically and these results are useful to predict the stretchability and the optimum process condition.