The relationship between process conditions and biaxial stretchability of polyethylene

Toshitaka Kanai[1,2,3]*, Yoshio Nakamura[2], Toshiro Yamada[2]

[1] *KT Polymer, 2411-3 Kuranami, Sodegaura, Chiba, 299-0243, Japan*
[2] *Kanazawa University, Graduate School of Natural Science & Technology, Kakuma-machi, Kanazawa, Ishikawa, 920-1192, Japan,*
[3] *Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto, 606-8585, Japan*
E-Mail of corresponding author: toshitaka.kanai@ktpolymer.com

In recent years, plastic films are essential in our daily lives. Among them, linear low density polyethylene (LLDPE) has good physical properties, such as high impact strength, high tear strength and high tensile strength. However, its stretchable temperature range and film thickness uniformity are not good, compared with polypropylene which is widely used as an oriented film. So LLDPE film is difficult to produce by a biaxially oriented process. Though it is possible to improve the stretchability by optimizing the resin design, the problem still remains that process conditions affect stretchable temperature range and thickness uniformity. Therefore, the purpose of our study is to investigate the effects of process conditions such as cooling temperature and the output rate on the stretchable temperature range and the thickness uniformity.

1. INTRODUCTION

Polyethylene (PE) has good physical properties, is a reasonable price, and is essential for our daily lives. But in the case of production of biaxially oriented film, PE has narrow stretchable temperature windows and poor thickness uniformity.

This research aims to clarify the influence of spherulites and crystallinity on stetchability, which is very much dependent on cooling temperature and output rate, and to find out the optimum process conditions for improving thickness uniformity and controlling stretchable temperature windows.

2. EXPERIMENTAL

2.1 Materials

LLDPE having MFR 1.9g/10min, density 925kg/m^3, Mw/Mn 7.26 was formed into films using an extruder. The process conditions, output rate and cooling conditions, were changed and four samples were produced. These process conditions are listed in Table1. Quench100 means chill roll temperature 30C, output rate 100kg/hr and Slow100, Quench300 and Slow300 are shown in Table 1.

Table 1 Process conditions of each sample

Sample	Out-put Rate (Kg/hr)	Chill Roll Temperature（C）
100-30	100	30
100-60	100	60
300-30	300	30
300-60	300	60

2.2 Influence of Process Conditions on Super-structure

The number and size of spherulites along the thickness direction were measured using phase contrast microscopy. The crystallinity was obtained by DSC measurement.

2.3 Stretching test

The newly developed biaxial stretcher developed by Kanazawa University and Etoh Co., Ltd. was used and the stretchable temperature window and stretchability were evaluated. The stretching test was done under the stretching speed 10mm/sec, the stretching ratios MD 5×TD7 and the preheating time 7min.

3. Results and Discussion

3.1 Spherulite Structure

The spherulites' creation is influenced by both the cooling conditions and shear stress during the extrusion process. Fig.1 shows the distributions of spherulites' number and size along the cross sectional direction. The high output rate condition creates more spherulites than the low output condition, even though the high output condition produces smaller spherulites. More spherulites are created near the surface of the sheet by the shear stress. The spherulites grow at the beginning and then stop the growth because when spherulites come into contact with each other, the growth of spherulites stops.

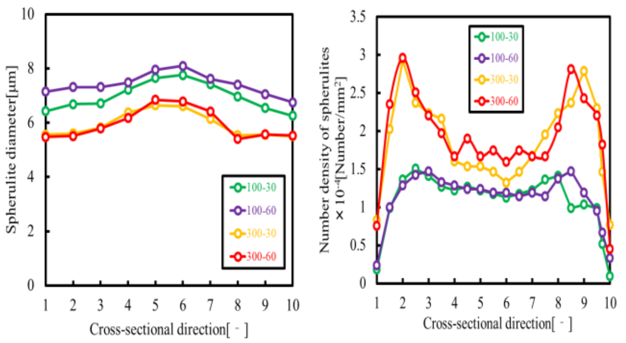

Fig.1 Distribution of spherulites

3.2 DSC Data

DSC data shows that the crystallinity is dependent on the process conditions and high output rate, and slow cooling conditions produce high crystallinity. This result means that a high output rate and slow cooling condition has a slow crystallization speed and long crystallization time, and then crystallization is easier.

3.3 Thickness Uniformity

The data of film thickness was measured using the thickness gauge and standard deviation is shown in Table2.

It shows good thickness uniformity is obtained under the low output and high cooling condition.

Table2 Standard deviation of thickness uniformity

	100-30	100-60	300-60	300-60
Standard deviation of thickness uniformity[μm]	3.55	4.07	7.76	7.90

3.4 Stretching Behavior

The stress-strain curve during stretching is shown in Fig.2. The high output rate conditions have high stress at the yield point and the stress does not increase much after the yield point. It means the strong crystal structure and hard spherulites structure and the thinner part is more easily stretched. As a result, film having lower film thickness uniformity is produced.

The between stress build-up ratio (final stress/yield stress) and deviation of film thickness uniformity is shown in Fig.3. The thickness uniformity is closely related to stress build-up ratio and high stress build-up ratio creates good uniformity.

The yield stress increases with increasing crystallization time which is caused by high shear rate and slow cooling conditions.

This condition produces lower thickness uniformity, film break and narrower stretchable temperature width.

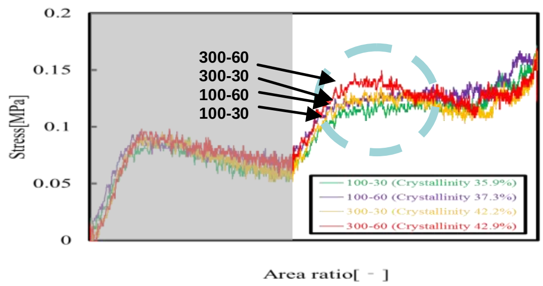

Fig.2 Stress-draw ratio under various process conditions

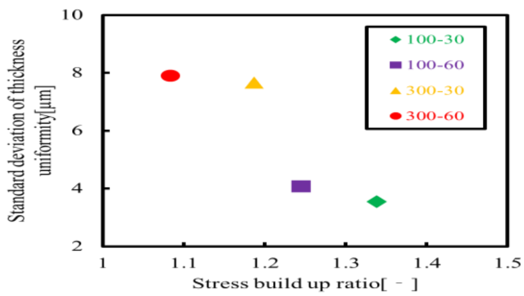

Fig.3 Standard deviation of thickness uniformity-stress build up ratio

4. Conclusion

The film thickness uniformity is dependent on crystallinity and spherulite number. The optimum sheet process conditions require quenching of both sides of the sheet surface and a moderate output rate before stretching, which does not create too many spherulites.