EVALUATION OF STRETCHABILITY AND RESIN DESIGNING OF POLYPROPYLENE FOR BIAXIALLY ORIENTED FILM

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ABSTRACT

Biaxially oriented polypropylene (BOPP) films are widely used for food packaging and industrial films. Recently machine speed has been increasing in order to obtain higher production rate and film thickness has become thinner to reduce the environmental load. The customers' requirements for better production ability and thinner films have been becoming more demanding, but their demands are not always met due to lack of film stretchability in the final product. In order to meet the demands, research on stretchability has been conducted with the goal of finding the optimum material design for developing a new product by analyzing stretching force-strain data using a table tenter. It was found that low crystallinity and wide molecular weight distribution were effective in improving the stretchability and thickness uniformity. By running some tests with a sequential and biaxially oriented stretching machine, it was verified that samples produced by the above designed polymer indicated good thickness uniformity which was considered to be the barometer of stretchability. Furthermore, it was concluded that analyzing the stretching force-strain data obtained from a table tenter is a good method to predict stretchability and film thickness uniformity.

1. INTRODUCTION

BOPP film accounts for a large amount of PP since it is suited for food packaging films or industrial films, because of its high performance in terms of mechanical and optical properties. Recently higher production speeds are required to reduce the production costs and thinner films are requested for the purpose of reducing the environmental load. Yet there are some cases when PP products do not satisfy the demands due to a lack of stretchability. In those cases, film breaking occurs when it is stretched by a tenter machine. And film quality also drops because of wrinkles created by low thickness uniformity.

To overcome the problem, various studies have been performed by many researchers. For example, the relationship between the stress-strain curve of uniaxial stretching and deforming of PP crystal was studied using a spectral birefringence technique. However the results did not show any relationship with stretchability [1]. Kanai gave a report on the prediction of film thickness uniformity using the stress-strain curve obtained by a table tenter in his reports [2]. However, there is no research showing the relationship between the stretching force obtained by table tenter and the actual thickness uniformity data obtained by a sequential and biaxially oriented stretching machine. This report will show the prediction of stretchability using a table tenter and the test results of film thickness uniformity using a sequential and biaxially oriented stretching machine.

2. EXPERIMENTS

2.1 Samples

There are some reports regarding the relationship between the stress-strain curve and resin design. In order to improve film thickness uniformity, Kanai reported that decreasing the stretching force at the yield point (Fy) and increasing the stretching force at a later stage (Fm) were effective [2]. Low crystallinity PP design is considered to be desirable in order to decrease the stretching force at the yield point. Meanwhile, Kanai reported that the stretching force at a later stage increases with increasing the amount of the component with a long relaxation times measured by melt viscoelasticity [3]. Widening the molecular weight distribution (MWD) seems to be a good method of increasing the stretching force at a later stage. Therefore, high crystallinity sample V, three low crystallinity samples B1 through B3, and two wide MWD samples C1 and C2 in addition to the standard sample A were prepared in order to investigate the relationship between stretchability and resin properties (Table 1).

Table 1: Resin properties of samples

Samples		MFR (g/10min)	mmmm (mol%)	$C2^{=}$ amount (wt%)	Mw/Mn (-)
STD	A	3.0	90	0.0	4.6
HC	V	3.0	97	0.0	4.2
LC	B1	3.0	-	0.5	3.6
	B2	3.1	-	0.4	4.1
	B3	2.9	88	0.0	4.6
wide MWD	C1	2.7	90	0.0	5.4
	C2	3.2	90	0.0	5.6

(STD: standard, HC: high crystallinity, LC; low crystallinity, MWD: molecular weight distribution)

2.2 Stretching test using a table tenter

A non-stretching sheet with a thickness of 1mm was made by a sheet forming machine at a chill-roll temperature of 30℃. After the sheet was stretched at 4.6 times in the machine direction at 147℃ by a heated roll type stretching machine, the sheet was stretched at 9.2 times in a transverse direction by the table tenter. At last a BOPP film with a thickness of 24μm was obtained. The stretching force was measured by a load cell which was equipped on a chuck of the table tenter to predict the stretchability of each sample.

2.3 Stretching test using a sequential and biaxially oriented stretching machine

BOPP films were produced by a sequential and biaxially oriented stretching machine (Mitsubishi Heavy Industries Co., Ltd) using samples from B1 to C2 and the standard sample A. PP resins were extruded by an HM tandem type extruder with a discharge amount of 390kg/hr, and a non-stretched sheet with width of 270mm width was made using a roll type casting machine at the roll temperature of 30℃, and take-off speed of 55m/min. After the sheet was stretched in a machine direction for 4.5 times at 138℃ using heated rolls, BOPP film of 15μm thickness and 1m width was obtained through a tenter process with a stretching ratio to the transverse direction 9.5 times. Final machine speed was 270m/min and the strain rate was 423%/s which is close to that of a large size production line of BOPP film. The stretchability of each sample was verified by judging a thickness uniformity of BOPP film which was measured by film thickness distribution.

3. RESULTS AND DISCUSSION

3.1 Examination for predicting a stretchability using a table tenter

At first, the influence of crystallinity on stretchability was examined with samples A and V which have quite different meso pentad values mmmm as parameters of crystallinity (Fig.1). The sheet made by low crystallinity PP sample A was stretched without breaking at the stretching temperature between 158 ℃ and 166℃, which means sample A had a wide process window of 8℃. On the other hand, even though the sheet made by high crystallinity sample V (97%) was successfully stretched from 166℃ to 172℃, it broke during stretching at 164℃. It was found that the stretchability of sample V was inferior to that of sample A, because the process window of sample V was 6℃, which means it is 2℃ narrower than that of sample A.

Furthermore, research for the purpose of grasping the relationship between the stretchability and resin properties was conducted using 6 samples from B1 to C2 and the standard sample A. The stretching force Fy at the yield point of samples from B1 to B3 with reduced crystallinity were lower than that of the standard sample A. The stretching force Fm observed at the maximum stretching ratio of samples C1 and

C2 were larger than that of sample A. The effect of wide molecular weight distribution was confirmed.

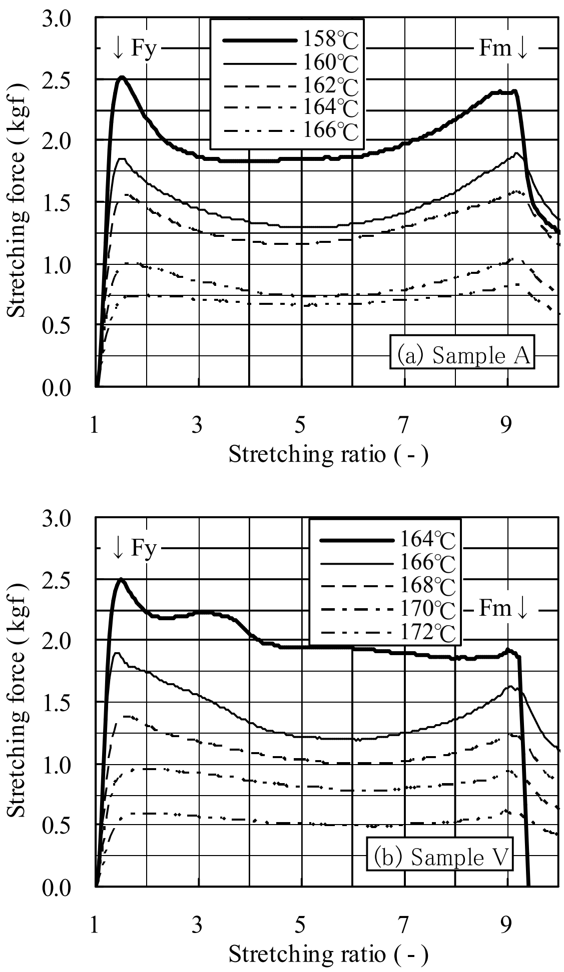

Fig.1; Stress -strain curve of (a) sample A and (b) sample V at several stretching temperatures

3.2 Examination for verifying stretchability using a sequential and biaxially oriented stretching machine

Next, an experiment was conducted to verify stretchability of each sample by measuring film thickness uniformity using a sequential and biaxially oriented stretching machine. The film rolled on a winder was cut, and thickness τ for 2000 points to the transverse direction and 10 points to the machine direction were measured. The film thickness uniformity was evaluated to the transverse direction using the standard deviation σ. Film thickness variation coefficient in the machine direction δ calculated by equation (1) was also used.

$$\delta = \frac{1}{2000}\sum_{j=1}^{2000}\sqrt{\frac{1}{9}\sum_{i=1}^{9}(\tau_{i,j}-\tau_{i+1,j})^{2}} \qquad (1)$$

Both of δ and σ showed a good correlation with the stretching force ratio Fm/Fy obtained by the table tenter (Fig.2). The film thickness uniformity of all samples except for B1 improved in comparison to the standard sample A as was predicted by the table tenter.

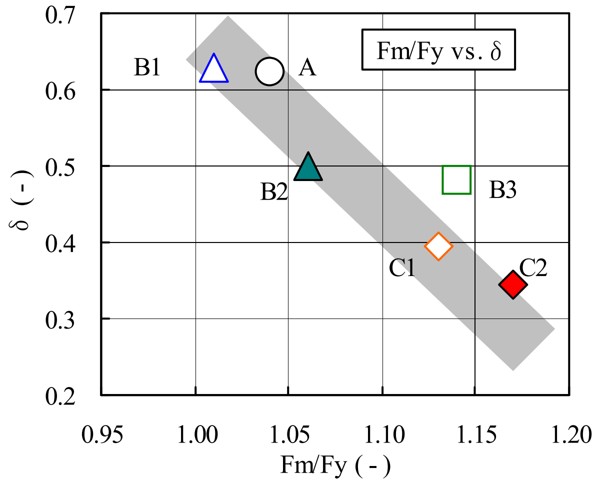

Fig.2; Relationship between Fm/Fy and film thickness uniformity parameter δ

4. CONCLUSION

Reducing the crystallinity of PP resin and widening the molecular weight distribution were effective in improving the production rate and making thinner films. Finally, it was concluded that the analysis of the stretching force obtained by a table tenter was an effective technique in predicting the stretchability of BOPP film.

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