Thickness Uniformity of Double Bubble Tubular Film Process for Producing Biaxially Oriented Nylon6 Film

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ABSTRACT

The analysis of the film thickness uniformity for double bubble tubular film process for nylon6 was investigated. Many process conditions influence film thickness uniformity.

The optimum stretching stress during the double bubble tubular film process exists. The bubble break occurs over stress of 130 MPa and bubble stability occurs below stress of 60 Mpa. In optimum conditions, which means the process condition of set temperature 310°C and stretching ratio 3 keeping bubble stability, no bubble break and good film properties, stretched film uniformity was twice as bad as non－stretched film one. The film uniformity which was stretched in optimum conditions was better than one stretched at higher process temperature and at lower stretching ratio.

In the observations through the polarizing plate of the bubble sample which shows deformation pattern, the equality of deformation pattern was observed. The thickness uniformity of biaxially oriented film was very much influenced by thickness uniformity of non－stretched film.

Actual stretching ratio which means the local stretching ratio along the film width compared with the average stretching ratio, influences tensile modulus and tensile strength at break. In order to obtain the uniform physical properties of film, it is important to produce uniform thickness film. If thickness is large, it delays the rate of increasing temperature during passing through the heating furnace. A local thick portion causes a local drop in stretching stress and a decrease in bubble temperature. As a result, the thicker portions are the more difficult to be stretched, on the contrary thinner portions are easier to be stretched.

Film thickness uniformity is improved when stretching stress is high and bubble stability is good. These factors are influenced by stretching temperature, stretching ratio and air speed from air ring.

1. Introduction

In recent years, environmental problems have come into question in the packaging industry. As these problems, the dechlorination and the refuse reduction have been closed up in this industry. Especially this refuse reduction has been a serious problem, so it is desired that this problem will be solved. In order to achieve this refuse reduction, there is a rapid increasing shift from a bottle to a standing pouch for repackaging use in an effort to utilize resources effectively. For the provision of this standing repackage pouch, thin and strong biaxial oriented nylon film is indispensable.

As shown above, the demand for the biaxially oriented nylon film has become popular. Several kinds of manufacturing processes have been developed to produce this biaxially oriented nylon6 film featured by high strength. Among them the double bubble tubular process producing biaxially stretched nylon film is the best one in terms of impact strength. It is valued highly for the purpose of distribution safety of products.

The biaxially stretched film is required to pass the ensuing process in which there are severe requirements such as multicolor printing. For this reason, it becomes a vital technical problem to improve thickness uniformity. It is known that while the double bubble tubular film process gives better impact strength and more uniform shrinkage balance than the tentering process, yet it is relatively poor in film thickness uniformity[1]. Nylon is also featured by strong hydrogen bonding owing to the molecular structure having polyamide bonding intrinsic to the resin , and therefore it is better simultaneous biaxial stretching than sequential.

The study [2] on film thickness uniformity improvement by means of flow analysis of circular dies as well as the study [3] about film uniformity improvement through cooling control of blown film, automatic bolt control, and the like were reported. There are several reports issued on tubular stretching technology [4 – 15]. The analyses of deformation behavior of nylon 6 were reported previously according to stretching stress analyses [16].

The previous paper discussed three topics:
The relationship between process condition and film stretching stress; deformation rate during double bubble process, birefringence; and scale-up rule for double bubble tubular film process. In this paper, the experiment under the various process conditions was carried out to obtain the guideline for improving film uniformity by clearing the factors governing this film thickness uniformity.

The technical results obtained from this research were used in the production process to produce uniform thickness film. The detail studies under the various process conditions governing the film thickness uniformity in double bubble tubular nylon 6 film process are described below.

2. Experimental

2.1 Experimental Equipment

The apparatus of the double bubble tubular film process shown in Figure 1 was used. Using an extruder (L/D=24) with the diameter of 40mm as well as a circular die with the diameter of 75mm and the lip clearance of 1mm, non – stretched film was produced at the condition of the resin temperature 265℃, blow-up ratio of 1.2, and with a water-cooling ring having the diameter of 90mm.

This raw film is stretched simultaneously in the machine direction and transverse one by using inside bubble air, a drawing machine composed of two pairs of pinch rolls and a heating furnace (a far infrared radiation heater is self-contained).

The stretched film is heat-set using a double bubble tubular film process with heat treatment device.

2.2 Material

The material is Ube Nylon 1024FDX14 (Nylon 6) with mean molecular weight of 24000 and the relative viscosity of η_r=3.5 (sulfuric acid concentration 98%).

2.3 Experimental Method

The effect of process temperature (setting temperature of heater), stretching ratio and air flow on the film thickness uniformity was investigated. Non – stretched film having a variety of local thickness distribution by de-centering the clearance of the die lip intentionally was used in order to obtain the relationship between raw film thickness uniformity and stretched one.

The process conditions of non-stretched film is 265℃ for resin temperature at the die exit, 1.2 for blow up ratio, and 6.0 for draw down ratio respectively. A water cooling method was used to lower crystallinity. The cooling water temperature was adjusted to be 18℃. The stretching process consists of a heating/ stretching furnace and an air ring device. The air ring device was installed at the upper part of the heating furnace so as to fix the stretching start point, and it injected air downward at the angle of 45°.

The standard condition for stretching process was set at 310℃ for process temperature (heater set temperature) and MD (Machine Direction)/ TD (Transverse Direction) =3.0 /3.2 for stretching ratio respectively. The film thickness is 135 μm for non-stretched film, and it became 13.5 μm after stretching. The stretched film was heat treated, using a heat treatment device of the third bubble tubular process to prevent shrinkage, thereby there is no disturbance due to film shrinkage permitting the measurement of film thickness and local physical properties alike.

The thickness uniformity of non-stretched film with heat treatment was measured. The evaluation procedure for thickness uniformity was followed by Figure 2. Shown also was an example of thickness uniformity of both non-stretched film and stretched film. The thickness uniformity at each location was calculated through the mean thickness. The thickness uniformity was obtained by the next equation.

Thickness uniformity(%) =
(thickness at each position - mean thickness) / mean thickness × 100

The result is shown in Figure 3. The regression equation Y = AX + B was obtained by plotting the uniformity (X) of non-stretched film on the axis of abscissa and that (Y) of stretched film on the axis of ordinate respectively, and the regression coefficient (A) was calculated to define as amplification factor. The result is shown in Figure 4.

The inside bubble pressure during the stretching process was measured to calculate stretching stress by using the same method written in previous reports[16].

2.4 Observation and Evaluation of Deformation Behavior

In order to analyze the behavior of deformation pattern, the extruder and take-up device were suddenly stopped and bubble sample was collected.

These deformed samples under the various conditions during stretching process were taken and each of them was inserted between two polarizing plates crossed with each other to observe and assess the deformation state of stretching bubbles by shedding light from below. Each sample under each condition was photographed using a high sensitivity film.

The anisotropy of the orientation of film from the stretching start point to stretching end point was observed.

2.5 Evaluation of Local Properties

The relationship between actual stretching ratio and film tensile properties in the circumferential direction (Transverse Direction) was evaluated. The tensile modulus and the tensile strength at break were measured as tensile properties.

In this evaluation, the stretched film produced by using non-stretched film, which is obtained by de-centering the die lip intentionally, was used.

(non-stretched film thickness uniformity: ±4%, ±10%, ±23%)

3. Results and Discussion

3.1 Effects by Process Temperature

The thickness uniformity of stretched film tends to become worse when the process temperature (heater setting temperature) is raised. (Figure 5) When the process temperature is heightened, the achievement to the strain hardening region is retarded and as a result the thickness uniformity gets worse. (Figure ６)

It may be also understood from the result of observing the polarizing plates that it is important to set the low stretching temperature in order to keep bubble stable while stretching stress is kept low enough to be continuous production without bubble break.

3.2 Stretching Ratio

The film thickness uniformity tends to improve when the stretching ratio in the TD direction is increased. (Figure ７)

When the stretching ratio (TD) increases, the thickness uniformity is improved by reaching the strain hardening. Understandably, it is important to set the high TD stretching ratio in order to keep bubble stable while stretching stress is permissible to be continuous production with bubble break.

3.3 Air Flow

It is understood that air blowing by air ring from the top of the stretching area helps prevent the process temperature too high as well as shortening the deformation range during stretching, thus contributing thickness uniformity very well (Figure 8). It was confirmed that the more air flow is, the better film thickness uniformity becomes.

3.4 Observation of Deformed Bubbles through Polarizing Plates

For the purpose of observing bubbles stretching deformation of film depending on stretching conditions, a suddenly stopped and cut sample during stretching process was taken under the specified process conditions, and a comparative evaluation was studied in terms of anisotropy through the polarizing plates. As a result, while film with good thickness uniformity passes through the range of strong anisotropy in brief time from the stretching start point, the one with poor thickness uniformity is likely to be very unstable since it comes out clearly with uneven deformation in the transverse direction, and the range of strong anisotropy is long from the stretching start point. (Figure9, Figure10)

3.5 Relationship between Non-Stretched Film Thickness Uniformity and Stretched Film Thickness Uniformity

By studying the influence of the thickness uniformity of the stretched film on the thickness uniformity of non-stretched film by changing ±4%, ±10%, and ±23%, it was clear that the poorer the thickness uniformity of non-stretched film is, the worse the thickness uniformity of stretched film becomes markedly. (Figure 11)

In order to obtain the thickness uniformity at each position of film, the thickness uniformity was plotted against that of film after stretching. As a consequence, it was found that the one stands in proportionate relation with the other, and when the regression coefficient was calculated from this inclination, it is approximately 2.0 in the stable stretching range. (Figures 12, 13, 14, 15 and 16)

The amplifying factor of film thickness uniformity is about 2（1.8～2.0）. Therefore it was confirmed that at the condition of stable stretching process, the stretching film thickness uniformity is about twice as bad as non-stretched film thickness uniformity. It has turned out to be vital how much the thickness uniformity of non-stretched film is improved to upgrade that of stretched film. (Figure 17)

It became known that thickness uniformity may be improved even in tubular stretching process by combining these stretching conditions and the improved thickness uniformity of non-stretched film.

3.6 Evaluation of Correlation between Actual Stretching Ratio and Film Physical Properties

The amplifying factor is about 2.0, and it means that thicker portions are more difficult to stretch, and thinner portions are easier to stretch. In other words, the actual stretching ratio is liable to induce difference locally as compared with the setting ratio. It is clear from the experiment that in view of the physical properties of film, the portion with small actual stretching ratio in the TD direction has low tensile modulus in the MD direction. (Figure 18)

In nylon film, its molecular structure leads to a reverse tendency between the direction of stretching ratio and the change in tensile modulus. This is because hydrogen bonding is formed in the direction at right angles to the configuration of molecular chains. In tensile strength at break, the correlation was confirmed with actual stretching ratio. Tensile strength at break is related with a change in the stretching direction. (Figure 19)

It may be understood from the above results that it is important to obtain good film thickness uniformity in order to stabilize the physical properties of film.

3.7 The Consideration of The Generation Mechanism of Thickness Deviation

The double bubble tubular film process is a method for biaxial stretching by the inside bubble pressure, using the device shown in Figure 20.

Stretching stress calculated with the tubular theoretical equation reported by the authors et al. [16]. The maximum stress at the end point of stretching may be obtained by the following equation.

$$\sigma = \triangle P \cdot D / 2t$$

where σ : Stretching stress in the TD direction
$\triangle P$: Inside bubble pressure
D : Bubble diameter at end point of stretching
t : Film thickness at end point of stretching

In the double bubble tubular film process, the stretching stress in the width direction calculated by measuring the inside bubble pressure. And the inside bubble pressure is constant, and therefore if unevenness in thickness is present in the transverse direction, it results in a local change in stretching stress. Figure 21 shows the relationship between stretching stress and stretching ratio, illustrating that the larger stretching ratio is, the higher stretching stress is.

From the above result it turns out that if there occurs difference in stretching stress due to thickness unevenness in the transverse direction, it leads to a local difference in stretching ratio.（Figure 22）

In other words, it may be understood that the larger difference in thickness is, the more stretched thickness uniformity get worsened resulted from an amplification phenomenon.

Also, if thickness is large, it delays the rate in temperature rise during passage through the heating furnace, making temperature difficult to rise compared with small thickness.
The relationship between stretching stress and process temperature is shown in Figure 23.
For this reason, it is assumed that a decrease in film elongation percentage is caused by a local drop in stretching stress and a decrease in bubble temperature. (Figure24, Figure25)
As a result by the combination of these factors, thicker portions are more difficult to stretch, and thinner portions are easier to stretch.
As a consequence stretch film uniformity was twice as bad as non-stretched film one.
So amplifying factor show about 2.0.

3.8 Relationship Between Process Conditions and Stretching Stress, Process Stability, Thickness Uniformity

The result was summarized on relationship between process conditions and stretching stress, process stability, film thickness uniformity at the table.
It was concluded that film thickness uniformity is improved when the stretching stress is higher and the bubble stability is better.
This means that deformation region in the stretching process is short, stretching temperature is low and air blowing is required. The smooth stretching deformation finished in the short time has held the key.

４. Conclusion

As ａ result of the study on the controlling factors of the thickness uniformity in the double bubble tubular process, the conclusion was obtained as follows.

(1) Film thickness uniformity was improved by setting low process temperature and high stretching ratio.
(2) In the optimum conditions, stretched film uniformity was twice as bad as non-stretched film one.
(3) In the observation through the polarizing plate of the bubble sample which shows deformation pattern, the equality of deformation pattern was confirmed.
(4) To get good uniform non-stretched film thickness is important to get good uniform stretched film thickness.
(5) Film thickness uniformity is improved when the stretching stress is higher and bubble stability is better. The key control factors are stretching temperature, air blowing and stretching ratio.

It was found that the thickness uniformity is improved by adjusting the controlling factor of process condition in the double bubble tubular film process.

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Figures

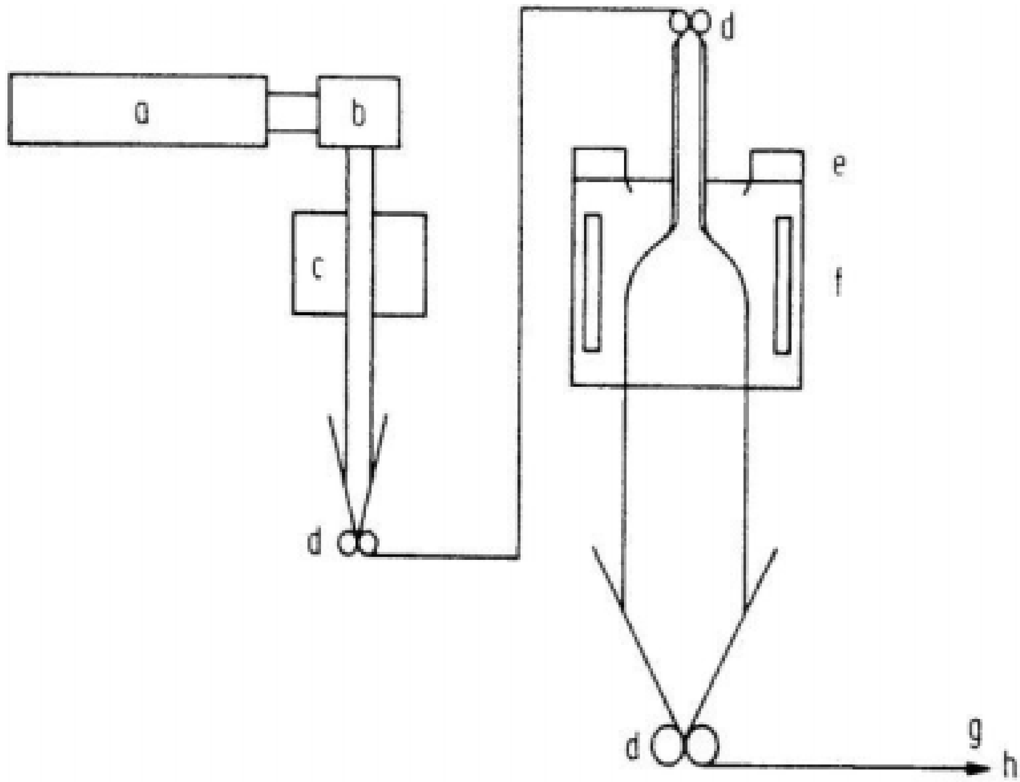


Fig. 1. Schematic view of double bubble tubular film process
a: extruder, b: die, c: cooling bath, d: take up roll, e: air ring, f: heating, g: annealing, h: winding

Fig. 2 Research Method of Thickness Uniformity

Research Method
① Double bubble tubular process
② Evaluation of film thickness uniformity
③ Observation of the polarizing plate of bubble sample
④ Evaluation of amplifying factor
⑤ Correlation between local field stretching ratio and physical property

Fig.3.--B

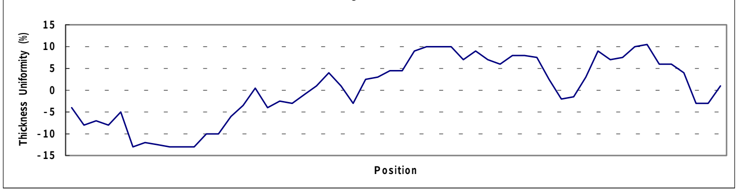


Fig.3.--B

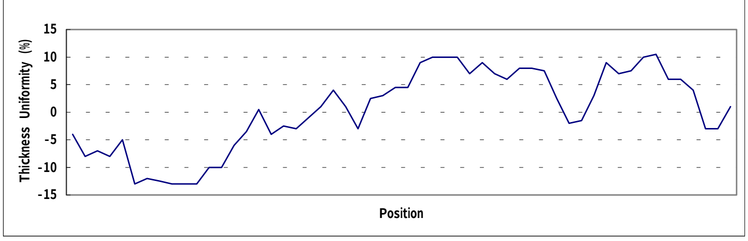


Fig.4.

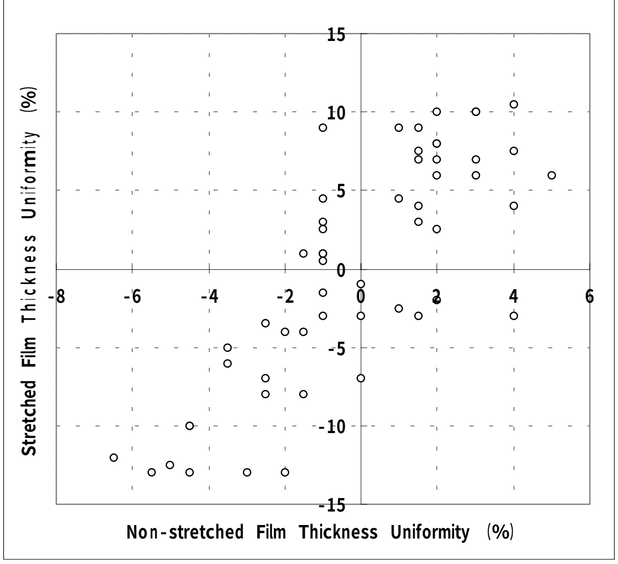


Fig.5.

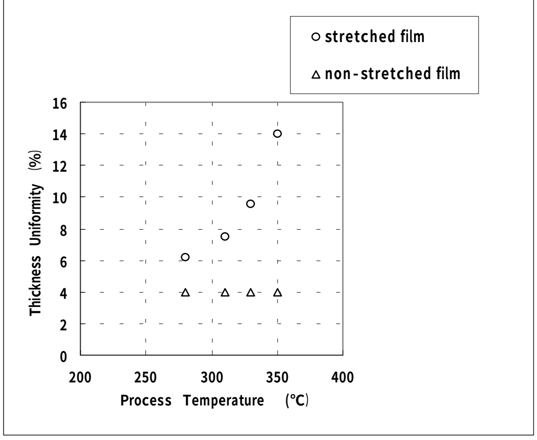
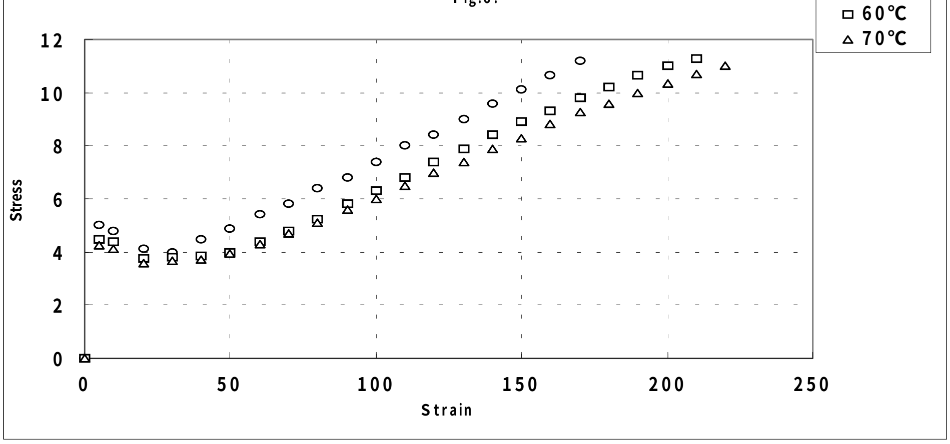


Fig.6.



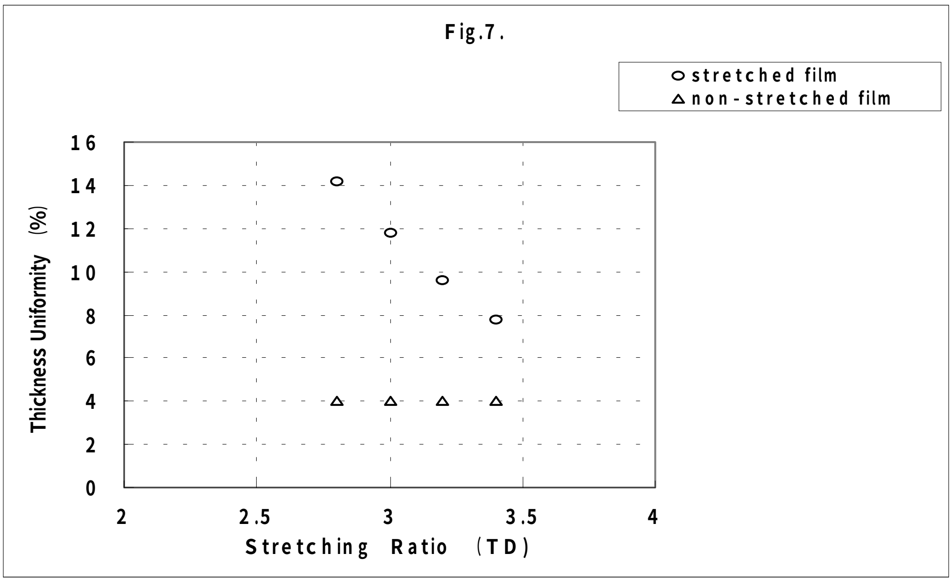


Fig.7.
stretched film
non-stretched film
Thickness Uniformity (%)
0
2
4
6
8
10
12
14
16
2
2.5
3
3.5
4
Stretching Ratio (TD)

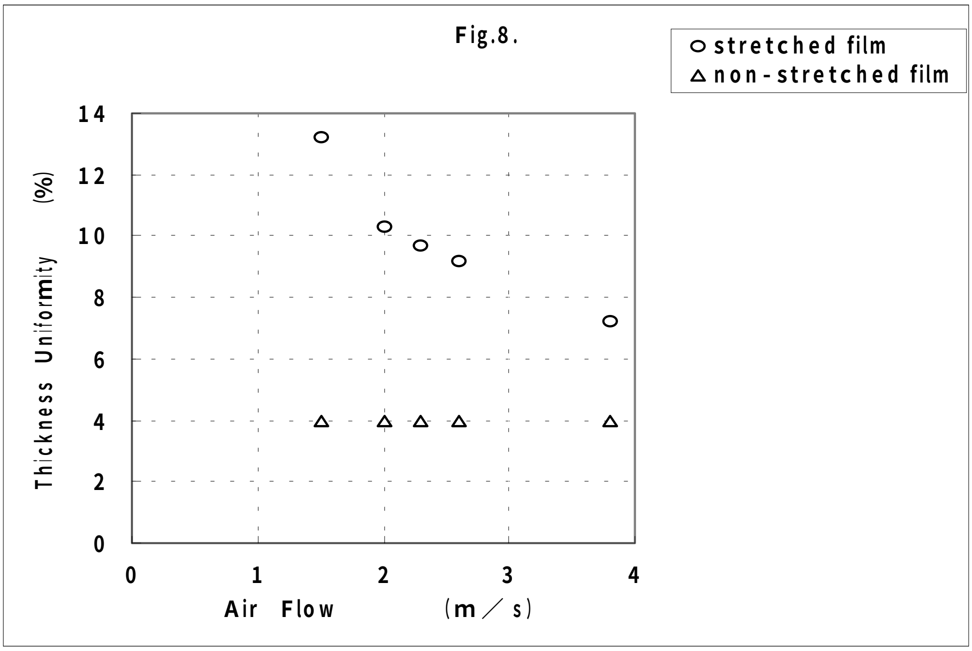


Fig.8.
stretched film
non-stretched film
Thickness Uniformity (%)
0
2
4
6
8
10
12
14
0
1
2
3
4
Air Flow (m／s)

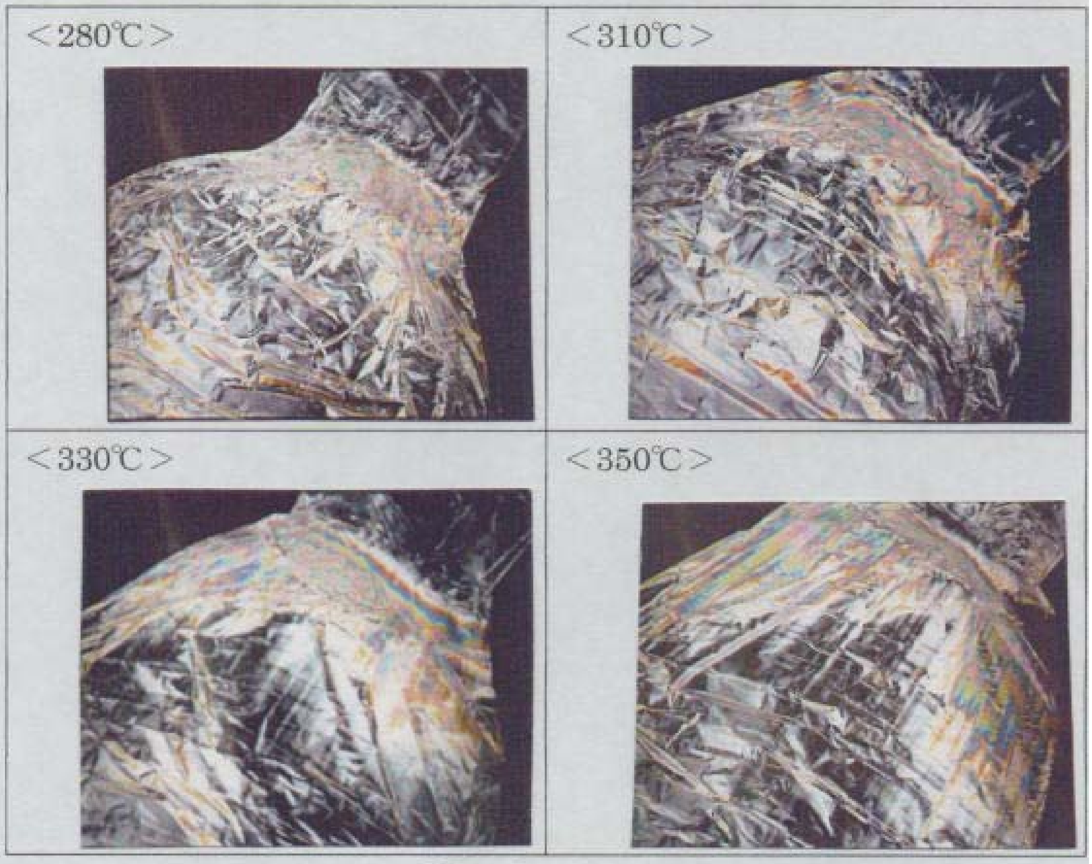


Fig. 9

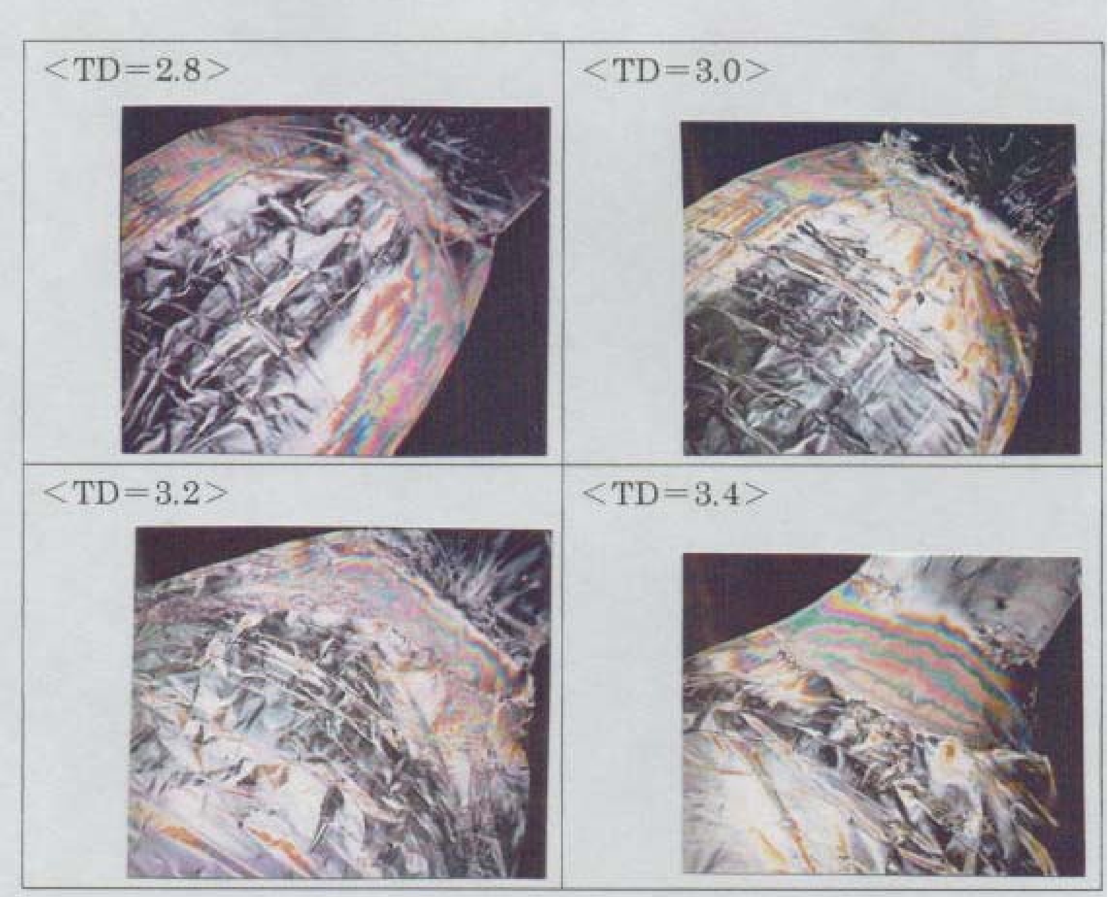
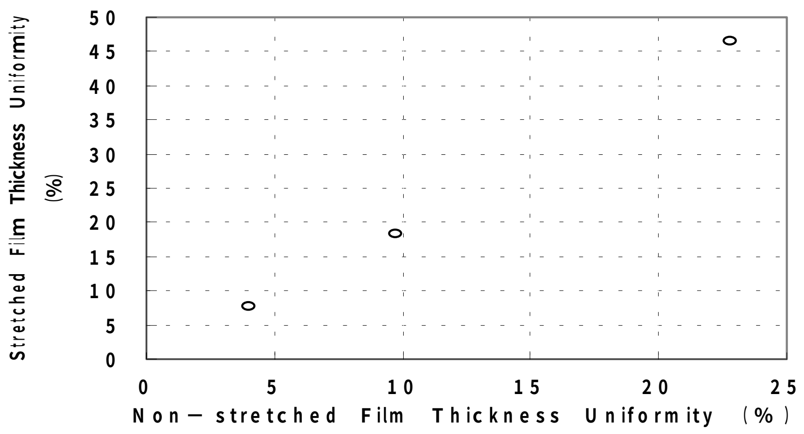

<TD=2.8>
<TD=3.0>
<TD=3.2>
<TD=3.4>

Fig. 10

Fig.11.


Stretched Film Thickness Uniformity (%)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
Non－stretched Film Thickness Uniformity (%)

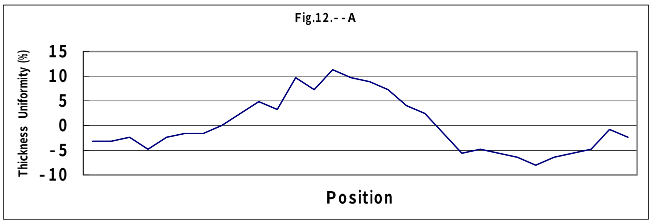


Fig.12.--A
Thickness Uniformity (%)
15
10
5
0
-5
-10
Position

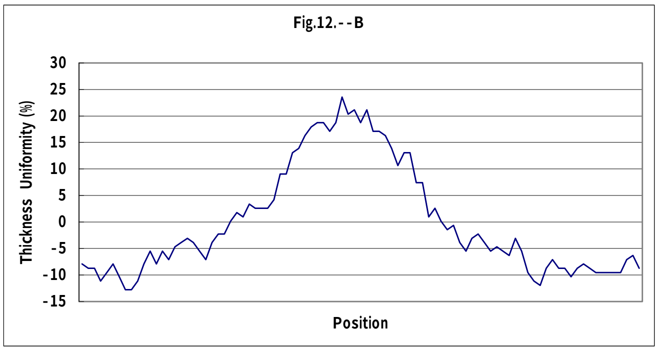


Fig.12.--B
Thickness Uniformity (%)
30
25
20
15
10
5
0
-5
-10
-15
Position

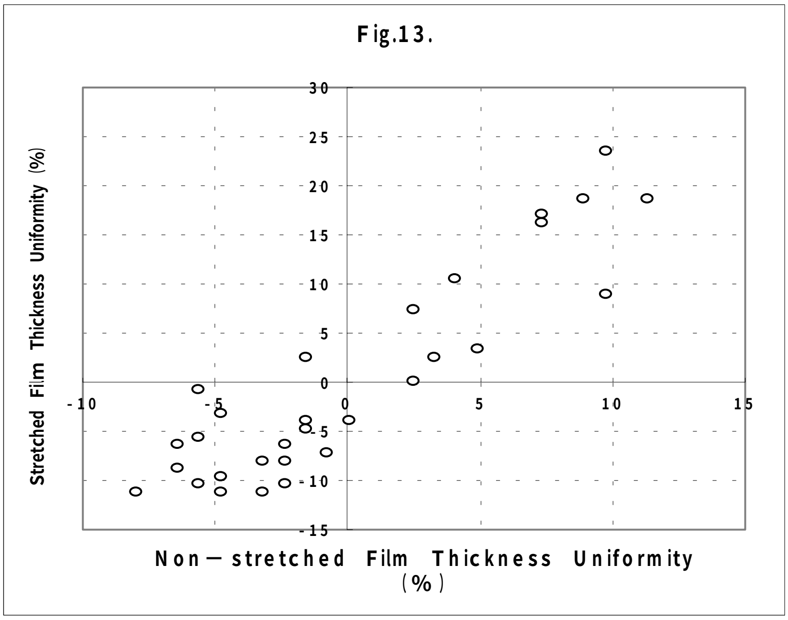


Fig.13.
Stretched Film Thickness Uniformity (%)
30
25
20
15
10
5
0
-5
-10
-15
-10
-5
0
5
10
15
Non－stretched Film Thickness Uniformity
(%)

Fig.14.--A

Fig.14.--B

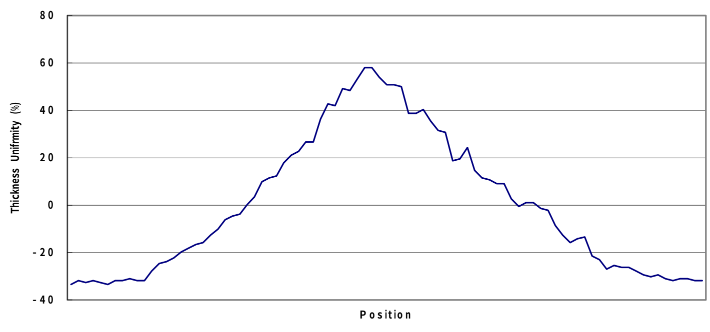
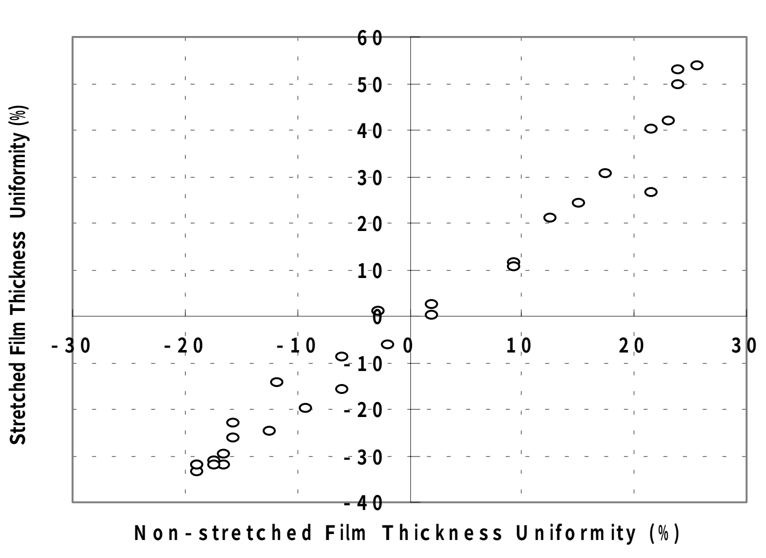


Fig.15.



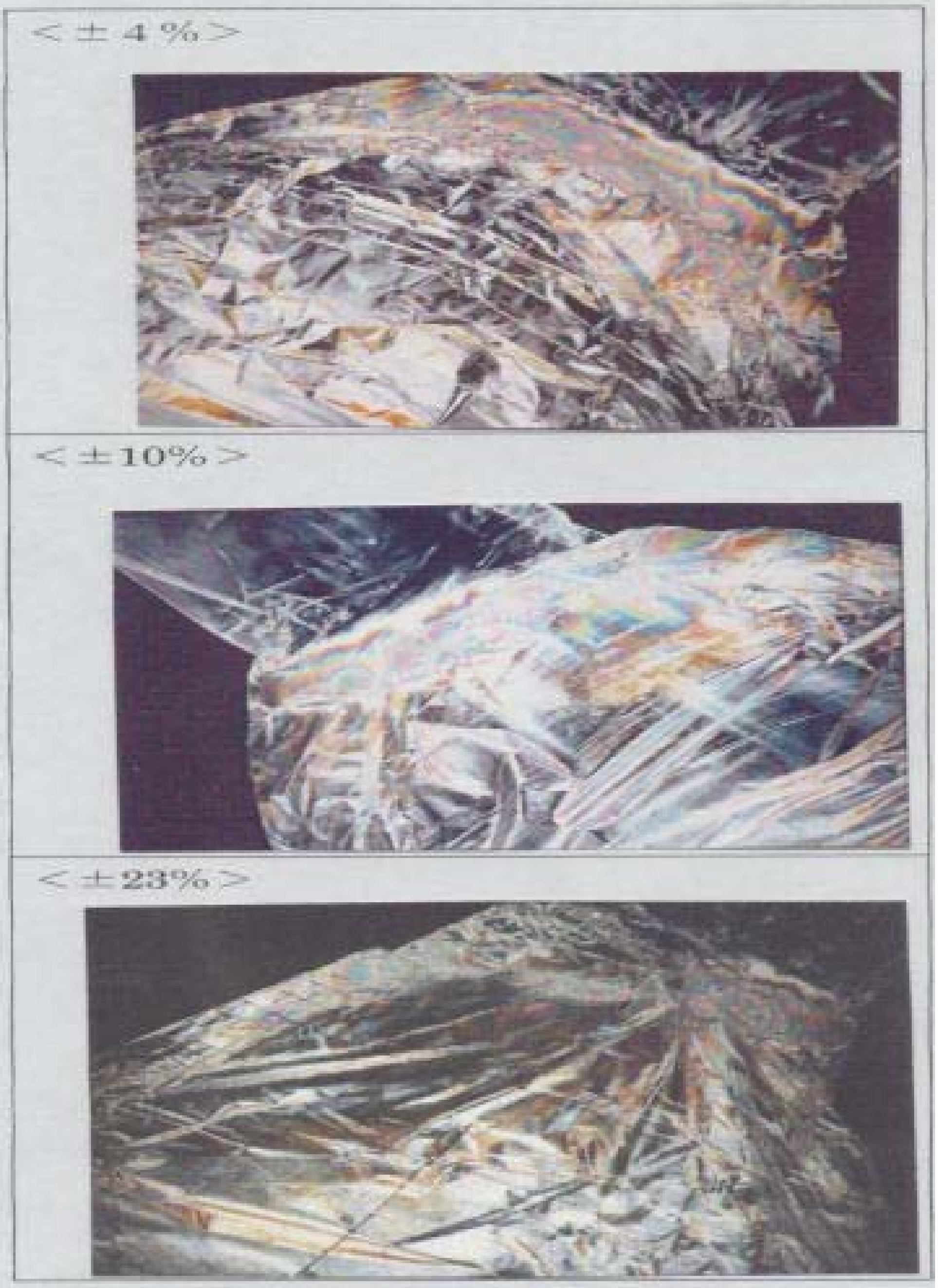
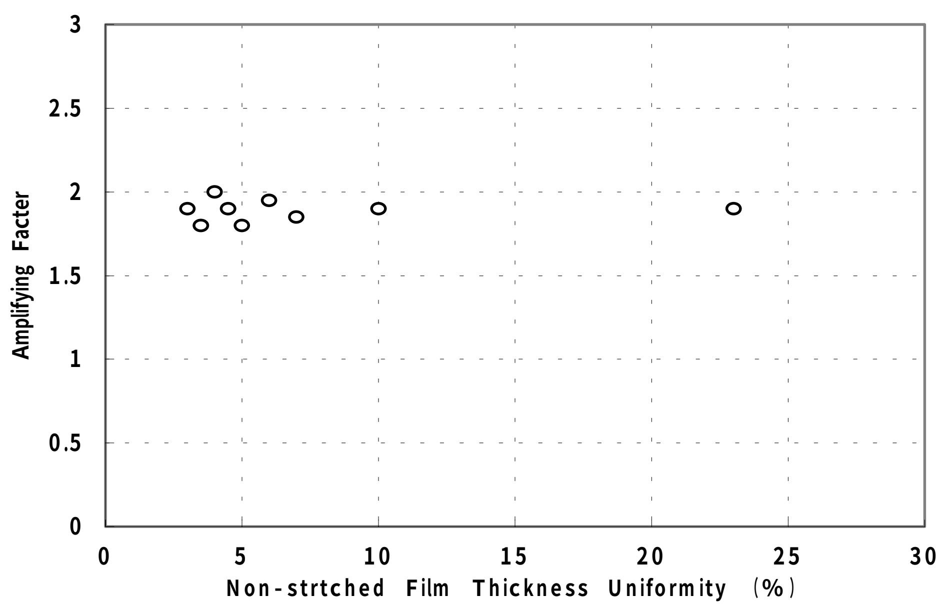


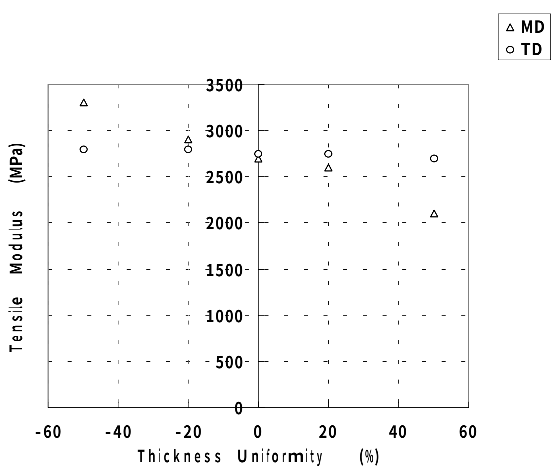
Fig. 16

Fig.17.



Amplifying Facter
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
Non-strtched Film Thickness Uniformity (%)

Fig.18.



MD
TD
Tensile Modulus (MPa)
3500
3000
2500
2000
1500
1000
500
0
-60
-40
-20
0
20
40
60
Thickness Uniformity (%)

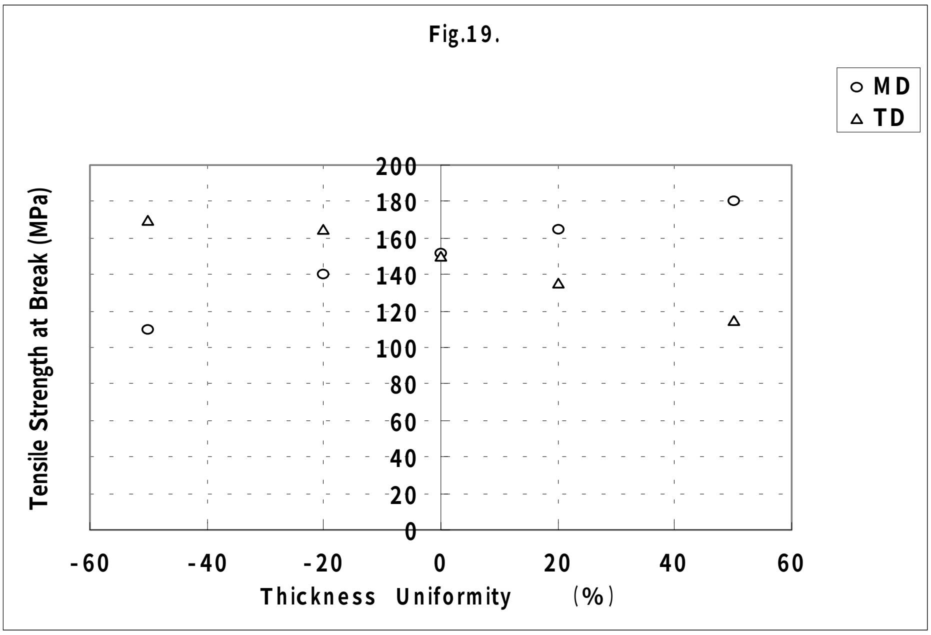


Fig.19.
MD
TD
Tensile Strength at Break (MPa)
200
180
160
140
120
100
80
60
40
20
0
-60
-40
-20
0
20
40
60
Thickness Uniformity (%)

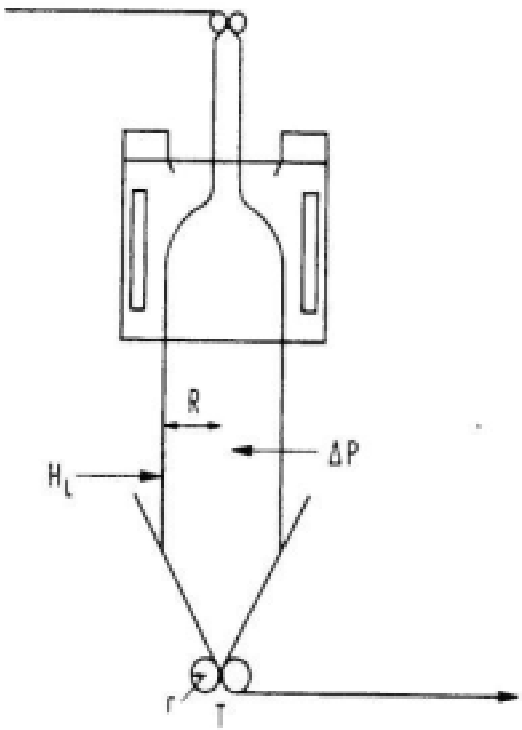


Fig.20 Measurement method of stretching stress

Fig.21.

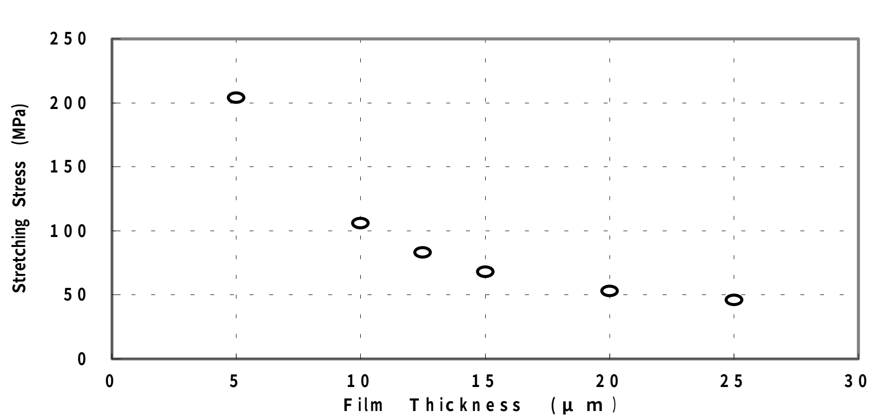


Fig.22.

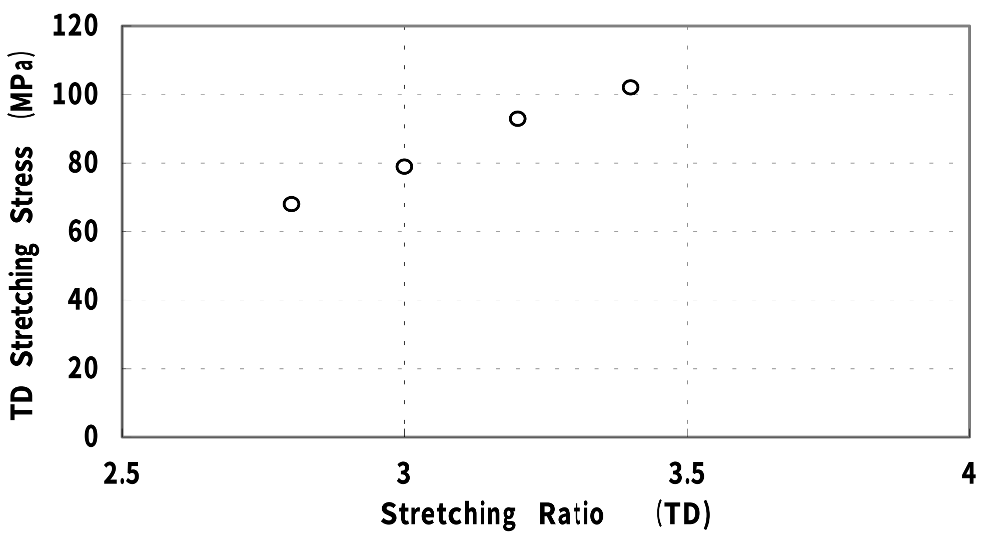

120
100
80
60
40
20
0
TD Stretching Stress (MPa)
2.5
3
3.5
4
Stretching Ratio (TD)

Fig.23.

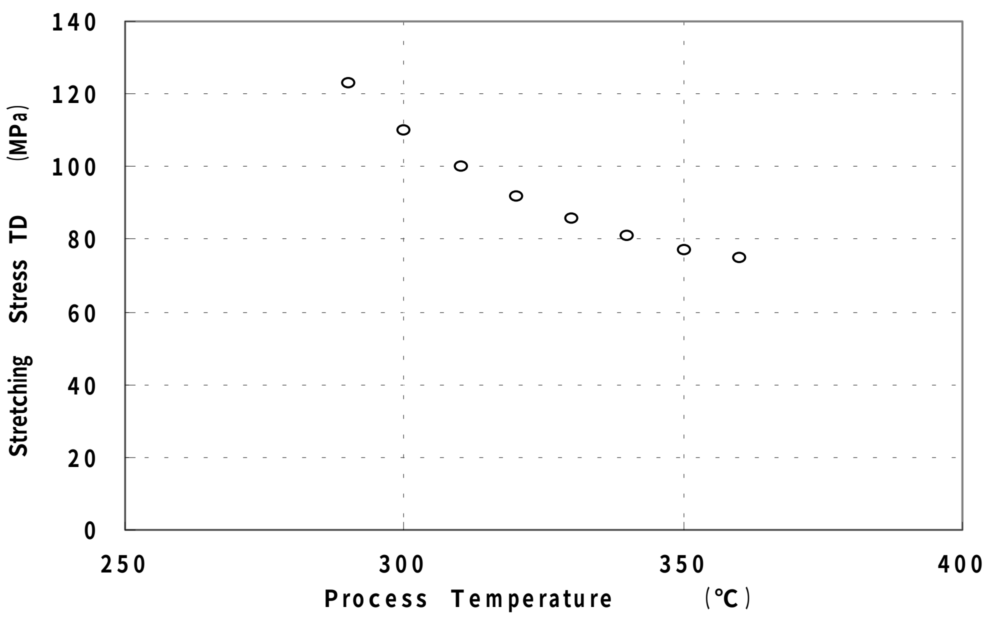

140
120
100
80
60
40
20
0
Stretching Stress TD (MPa)
250
300
350
400
Process Temperature (℃)

Fig. 24.

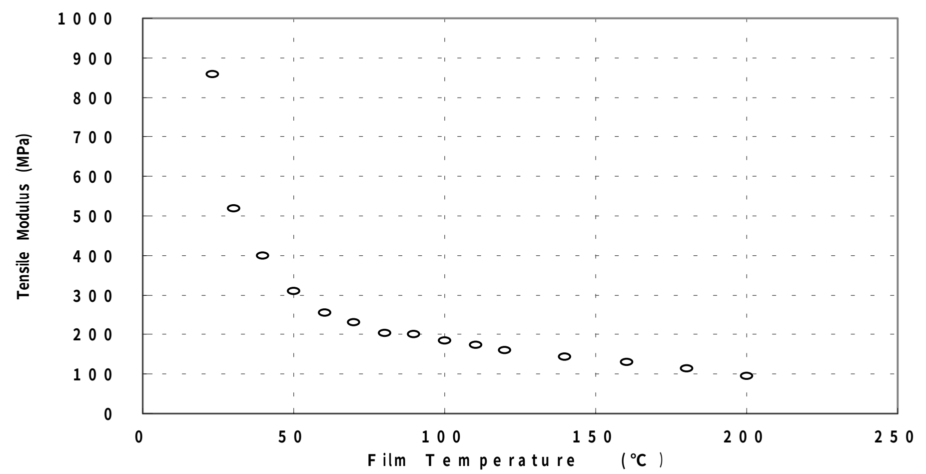


Table 1. Relationship between Process Conditions and Stretching Stress, Bubble Stability, Thickness Uniformity

Process Conditions	Direction	Stretching Stress	Bubble Stability	Thickness Uniformity
Process Temperature	↑	↓	↓	↓
Stretching Ratio	↑	↑	↑	↑
Air Flow	↑	↑	↑	↑
Deformation Rate	↑	↑	↑	↑