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Surface roughness control for stretched polypropylene film

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ABSTRACT

PP film surface roughness is usually controlled by adding additives in order to give slippery properties and prevent blocking. However, when the PP film is used for industrial usages, using a lot of additives is sometimes undesirable, because film characteristics deteriorate when using a lot of additives. In previous studies, it was reported that PP stretched film with a crater-like surface structure had been obtained by selecting appropriate conditions from non-stretched sheet containing β crystals. However, it is not clear how the craters are formed. In this study, it was considered that the structure of non-stretched sheet was closely related to this crater structure seen on the stretched film. As a result, a crater-like structure was clearly observed on the PP film surface after stretching. It was found that the chill roll temperature influenced the crater-like structure after stretching. Furthermore, it was found that the crater-like structure could be controlled by the chill roll temperature.

Keywords; polypropylene, crater-like structure, raw fabric structure

1. Introduction

If the surface of plastic film is smooth, it is difficult to handle it because of blocking when overlapping with other film. Today, in order to give PP films slippery properties and prevent blocking, a lot of additives such as anti-blocking agents (AB agents) and slippery agents are generally used at the film manufacturing site. So the slippery properties and the easily peeled properties between films are improved. As a result, production speed and the winding up release have been improved. However, using a lot of additives is undesirable because a lot of problems may occur. These problems are listed here; firstly, high amounts of additives are disadvantageous for industrial usages which require high purity. Secondly, the film surface may be damaged when it rubs with other sheets because the extraneous substance on the film surface is likely to be poor. Hence, improvement of the slippery properties and the peel properties without adding additives is required.

Properties of β crystals and α crystals are shown in **Table 1**. In the previous study, it was reported that PP stretched film with a crater-like structure had been obtained. This was achieved as β crystals with lower density in PP sheet change into α crystals with a higher density after stretching the sheet which contains both α and β crystals by selecting the appropriate conditions [1]. A crater-like structure refers to the surface roughness structure. However, it is not clear how the crater was formed because a crater-like structure might be observed even if the PP sheet, in which β crystals were hardly observed, was stretched. In this study, the aim was to control the crater-like surface roughness structure. The crater-like structure formation mechanism and the conditions of easy generation crater-like structures were studied using surface observation and structural analysis.

Table 1 Characteristics of Crystalline Structure

Crystalline Structure	Melting point[℃]	Density[kg/m^3]
α crystal	164	936
β crystal	148	921

2. Experiments

2.1 Samples

Properties of PP sheets made by a sheets forming machine (GM Engineering) are shown in **Table 2**. The name of PP sheets was defined by resin name and chill-roll temperature. For example, the sheet named 'A80' means the sheet was made from cast A at a chill-roll temperature of 80℃. In order to clarify the mechanism of the formation of the surface craters, two PP resins with different chill roll temperatures, namely A80 and A30, were prepared. The thickness was 300μm. Chill roll temperature means the temperature of the roll when the melting resin is cooled. The schematic diagram of the casting process including the chill roll is shown in **Fig.1**. A80 and A30 have high tacticity values with a meso pentad ratio mmmm of 96mol% which is a parameter of isotactic index measured in ^{13}C-NMR. Their MFR was 3g/10min.

The surface which comes into contact with the roll is called the chill-roll side, and the surface (the surface which comes into contact with the atmosphere) on the other side of the chill-roll side is called the opposite side of the chill-roll.

Table 2 Molecular characteristic of PP samples

	Samples	A80	A30
Base sheet	Resin[-]	A	
	MFR[g/10min]	3	
	mmmm[mol%]	96	
Raw fabric	Chill roll temperature[℃]	80	30
	Tm[℃]	167	164
	Crystallinity[%]	49	45
	Spherulites size[μm]	20	14

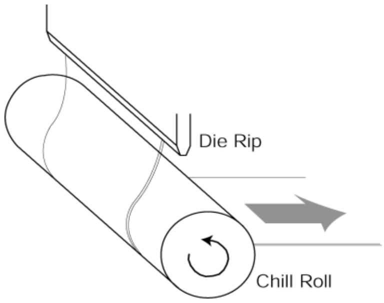


Fig. 1 Schematic diagram of casting process

2.2 Measurement and observation

In order to understand the dynamic structural change in the stretching process, the authors focused on samples A80 of uniaxially-stretched film.

After the PP sheet was cut into a sheet with a length and width of 85mm by 85mm, the PP square sheet was stretched by a table tenter (Bruckner KARO Ⅳ). The stretching temperature was 159℃, and the strain speed was 141%/sec.

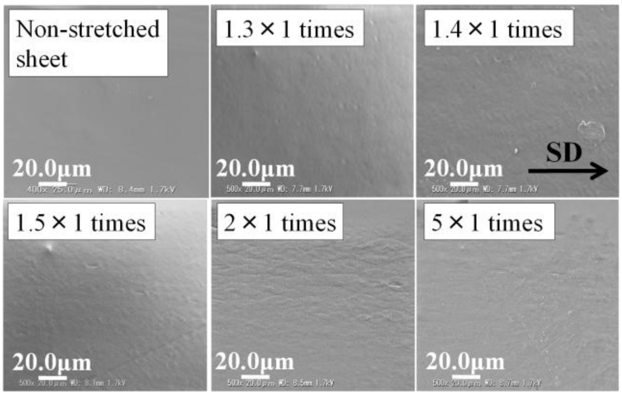
Then the crater formation mechanism was investigated by observing stretching force, surface structure, light scattering and film surface roughness. The stretching force was measured by a load cell which was attached by a chuck in the table tenter at 159 ℃ and 141%/sec. The surface structure of PP sheets and the stretched films were observed by SEM and LSM. Surface roughness was measured by a highly precise shape measuring machine (Surfcorder ET4000AKR). Changes of light scattering by stretching were observed in order to examine the crystalline structure. Moreover, ten points average roughness Rz was used as the surface roughness parameter.

Next, the authors focused on biaxially-stretched film samples A80 and A30 in order to control the crater-like structure. The sectional and surface structure of PP sheets and the BOPP films were observed using an optical microscope and SEM. On observing the PP sheet sectional structure using an optical microscope, crystal sizes were measured by visual inspection from pictures taken with a polarizing lense. Moreover, crater diameter and crater depth formed on samples A80 and A30 were measured in order to examine the influence of the chill roll temperature.

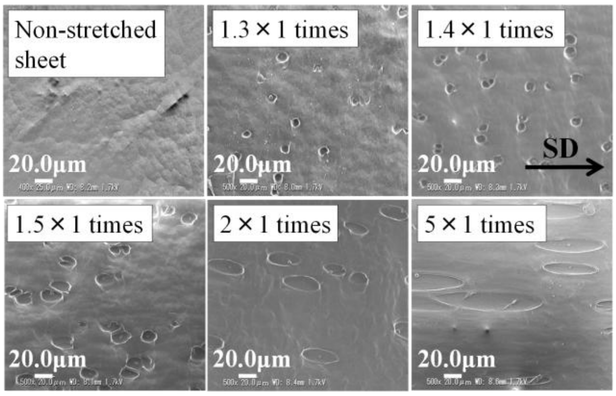
3. Results and Discussion

3.1 Observation of formation behavior of crater

Fig.2 shows the surface observation photograph of the crater formation on sample A80. It was observed with SEM using the chill roll side and the opposite side of the PP films stretched uniaxially at various stretching ratios using a table tenter. On observing the surface structure of the chill-roll side of A80, the craters were not found until the film was stretched at a ratio of 5 times. However, on observing the surface structure of the opposite side of the chill-roll of A80, numerous apertures appeared after being stretched at only 1.3 times in the machine direction. These apertures became dents at 1.5 times in the machine direction. Then these dents extended to the stretching direction after the stretching ratio got higher. As a result, crater-like structures on uniaxially-stretched film were formed. Hence, it was confirmed that the production of craters started from when the apertures were created at the beginning of the stretching process. **Fig.3** shows the cross-sectional view of the opposite side of the chill roll of PP sheets stretched at various stretching ratios. Some apertures appeared in the early period of the stretching process at 1.3 times, and the diameter of the aperture increased with increasing stretching ratio. It was confirmed by observing changes of the cross-sectional structure of the opposite side of the chill roll that these apertures became dents at 1.5 times in the machine direction. Many thick walls appeared on the stretching ratio at 1.5 times, and at the end the walls between craters were torn apart into thin walls.



(a) Chill roll side



(b) Opposite side of chill roll

Fig.2 Change of surface structure

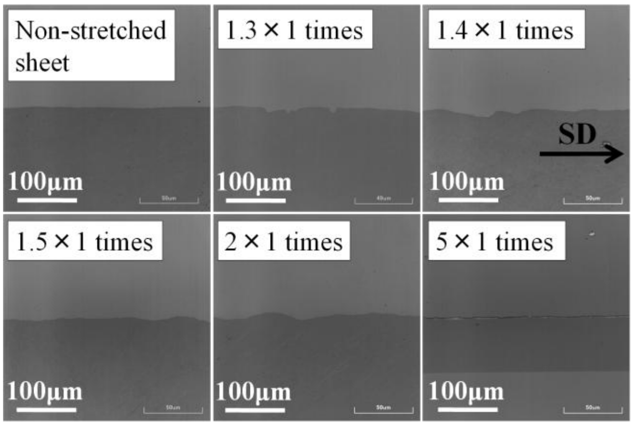


Fig.3 Change of cross-sectional structure of the opposite side of the chill roll

Therefore, the change in the surface roughness on the opposite side of the chill-roll during the stretching process was examined. **Fig.4** shows the change of Rz as a function of the total stretching ratio (=MD×TD). Rz showed a maximum value at a stretching ratio of 1.5 to 2, and then decreased with increasing the stretching ratio.

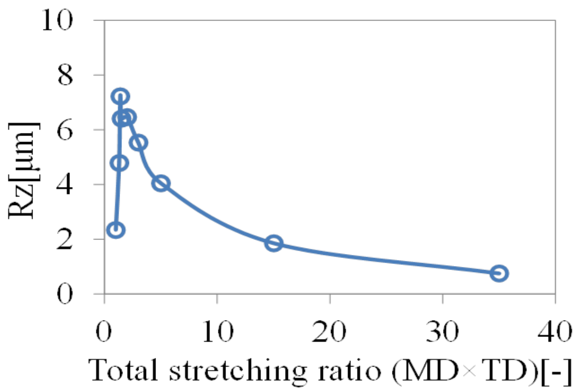


Fig.4 Rz-surface ratio curve

Next, **Fig.5** and **Fig.6** show the stress-stretching ratio curve and change of light scattering obtained at various stretching ratios. The change of light scattering shows the change of a spherulite structure. Moreover, as the optical anisotropy exists in the spherulite structure, an anisotropic clover like scattering pattern was observed. Since the clover pattern is seen in the non-stretched sheet of sample A80, it is considered that spherulite structure exists. Yield points were observed at a stretching ratio of 1.5 times because of the crystallinity and spherulite size, the stretching force gradually decreased at stretching ratios from 1.5 to 5.

Moreover, on observing the changes of light scattering by stretching, the spherulite gradually transformed after the sheet was stretched over 2 times in the machine direction, because the clover pattern observed by light scattering showed spherulites deformed in the stretching direction.

Hence, the spherulites begin to collapse when the stretching ratio past the yield point.

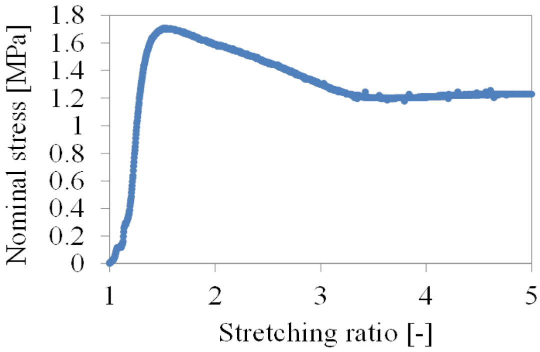


Fig.5 Stress-stretching ratio curve

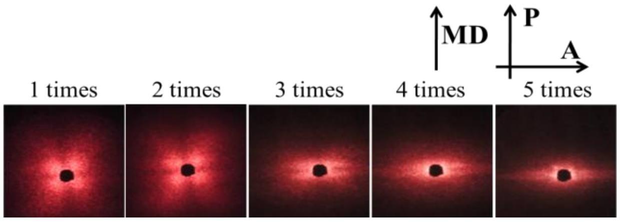


Fig.6 Change of light scattering by stretching

3.2 Control of the crater-like structure

Next, the influence of the chill roll temperature on the crater shape was observed. Surface observation images on the opposite side of the chill-roll after the biaxial orientation of A80 and A30 are shown in **Fig.7**. It was found that a difference between the diameter and the number of craters formed occured. As for surface roughness after stretching, A80 was rougher than A30. It is considered that the crystalline structure of non-stretched sheet shown in **Fig.8** is closely related to this crater shape.

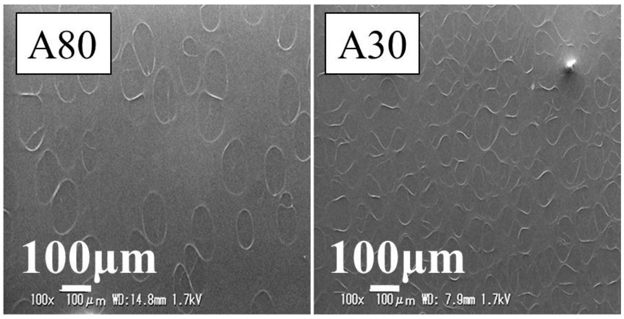


Fig.7 Changes in surface structure of opposite chill roll by biaxial stretching

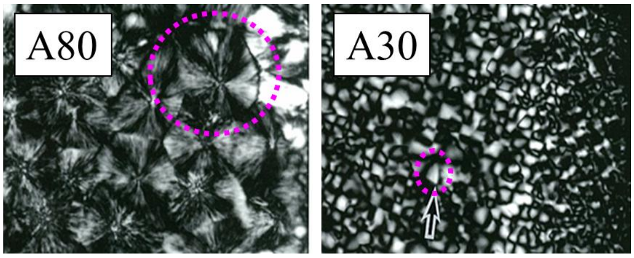


Fig.8 A cross-sectional observation of non-stretched sheet

In addition, in order to examine the influence of the chill-roll temperature more in detail, **Fig.9** shows the crater diameter and crater depth as a function of the chill roll temperature. Both crater diameter and depth increases with increasing the chill roll temperature. Moreover, when the chill roll temperature rises from 80℃ to 90℃, the crater and the depth increases drastically because the crystalline structure of non-stretched sheet became significantly enlarged.

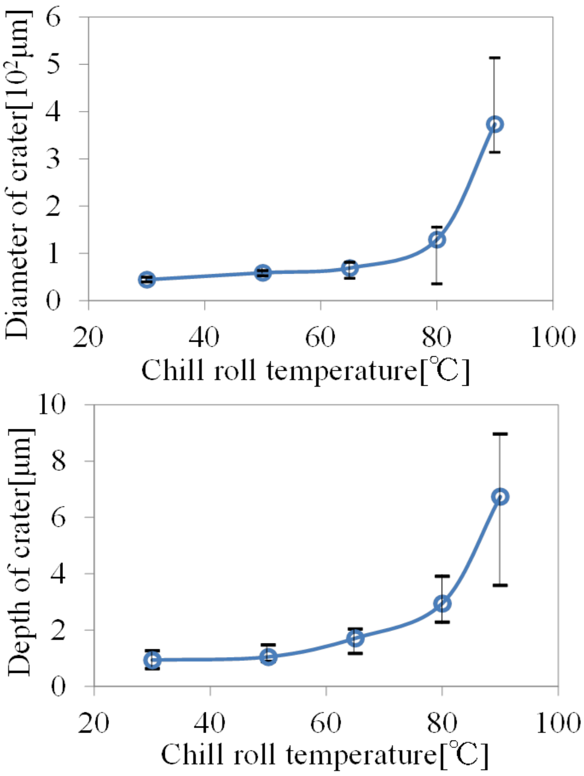


Fig.9 Change of size and depth of crater by chill roll temperature

4. Conclusion

It was clarified that the crater formation was closely related to the partial collapse of the crystalline structure, namely the Spherulites.

It was also found that the crater-like structure was controlled by the chill roll temperature.

Reference

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