

## MECHANICAL PROPERTIES OF INJECTION-MOLDED POLYPROPYLENE WITH PLYWOOD STRUCTURE

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### Abstract

*The structure and mechanical properties of injection-moulded plaques having plywood structure are studied employing PP containing a small amount of N,N'-dicyclohexyl-2,6-naphthalenedicarboxamide as a  $\beta$  form nucleating agent. In the injection-moulded plaque, the direction of molecular orientation in the skin layer is perpendicular to that in the core layer. The orientation direction of PP chains in the core layer is perpendicular to the flow direction owing to the peculiar crystallization from the surface of the needle crystals of the nucleating agent, which aligns to the flow direction by the applied hydrodynamic force. Because of the extraordinary molecular orientation, the thermal expansion between MD and TD samples shows no difference.*

### 1 Introduction

Crystalline structure is of a great technological importance for semi-crystalline polymers because it dominates physical and chemical properties of a final product. In case of isotactic polypropylene (PP), crystalline form has to be examined in detail because PP is a polymorphic material with three modifications, such as monoclinic  $\alpha$ -form, trigonal  $\beta$ -form, and orthorhombic  $\gamma$ -form. In terms of mechanical properties, it is widely accepted that high content of  $\beta$  form crystal is desired to achieve excellent toughness, which is attributed to energy dissipation during yield process accompanied with phase transformation from  $\beta$  to  $\alpha$  form. In general, addition of  $\beta$  nucleating agents and control of mixing and processing conditions are inevitable to obtain PP with a large amount of  $\beta$  form crystals.

It was previously reported that isotactic polypropylene (PP) containing a small amount of N,N'-dicyclohexyl-2,6-naphthalenedicarboxamide as a  $\beta$ -modification nucleating agent shows extraordinary molecular orientation at sheet processing recently [1-3]. PP crystallizes on the surface of the needle crystals of the nucleating agent, in which chain-axis (c-axis) of PP orients perpendicular to the long axis of the needle crystals. Since the needle crystals of the nucleating agent align to the applied flow direction by hydrodynamic force, PP chains orient perpendicular to the flow direction at the sheet processing [1]. The anomalous molecular orientation is, however, affected by mixing condition, resin temperature, and cooling

condition [2]. In other words, the direction of molecular orientation is adjustable by control of processing conditions.

## 2 Materials and testing methods

### 2.1 Materials

Pellets of PP containing 0.05 wt% of *N,N'*-dicyclohexyl-2,6-naphthalene-dicarboxamide (New Japan Chemical, NJ Star<sup>TR</sup> NU-100) were prepared by a co-rotating twin-screw extruder at 280°C. Then, the obtained pellets were fed into the hopper feeder of an injection-molding machine. The thickness of the plaque was 1.0 mm and the mold temperature was controlled at 120°C.

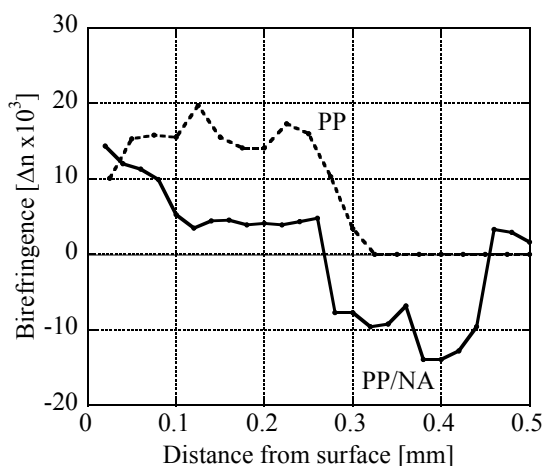
### 2.2 Measurements

Orientation birefringence was measured by a polarized microscope with a tilting compensator using film specimens with 10  $\mu\text{m}$  thickness cut out by an ultra-microtome.

The coefficient of thermal expansion was measured over the temperature range -20°C to 100°C using a thermo-mechanical analyzer (TMA).

## 3 Results and Discussion

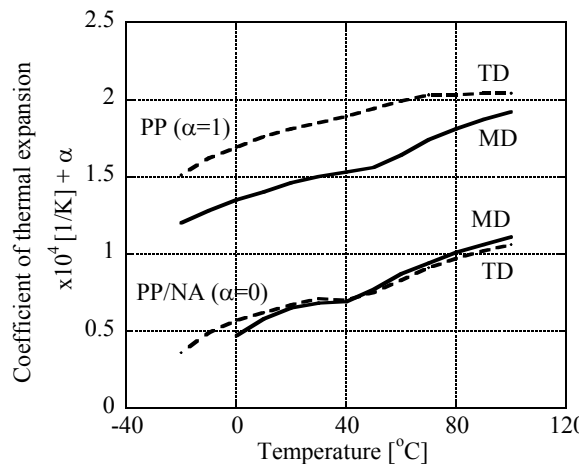
The distribution of birefringence in the thickness direction for an injection-molded plaque of PP without and with the nucleating agent is shown in Figure 1. In case of pure PP without the nucleating agent, undeformed spherulites are detected in the core layer, suggesting that no orientation occurs on average. As a result, molecular orientation to the flow direction is detected only in the skin layer, which is a typical phenomenon for injection-moulded products. On the other hand, the molecular chains in PP with the nucleating agent orient to the flow direction in skin layer, whereas they orient perpendicular to the flow direction in the core layer. This anomalous molecular orientation, as similar to the structure of plywood, affects the mechanical anisotropy significantly.



**Figure 1.** Distribution of birefringence in the thickness direction for the plaques (solid line) with and (dashed line) without the nucleating agent.

The coefficient of thermal expansion is shown in Figure 2. It is clarified that the value of TD is much larger than that of MD for the pure PP, in which high level of molecular orientation to the flow direction is detected in the skin layer by flow-induced crystallization [4-9], as seen in most injection-molded products. The decrease in thermal expansion in MD can be

explained by high mechanical constraint of PP molecules. On the contrary, there is no significant difference between MD and TD for the plaque having plywood structure. This result demonstrates that the mechanical anisotropy of the present sample is completely different from that of a conventional injection-molded product. It seems that the anisotropy of thermal expansion in our sample is adjusted by controlling the structure.



**Figure 2.** Coefficient of thermal expansion of PP with and without the nucleating agent (NA) in (solid line) MD and (dashed line) TD

#### 4 Conclusions

The structure and mechanical properties are studied employing injection-molded products of PP with *N,N'*-dicyclohexyl-2,6-naphthalenedicarboxamide. It is found that the direction of molecular orientation in the skin layer is perpendicular to that in the core layer, as similar to plywood. Further, the coefficient of thermal expansion in MD is found to be almost the same as that in TD, demonstrating that the anisotropy of thermal expansion is reduced using this technique.

#### References

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