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Experimental Analysis for Extrusion Screw Geometry to Produce Highly Transparent Polypropylene Sheets

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The observation was experimentally conducted by using many screws with various geometries to obtain a highly transparent PP melt resin sheet. The pressure distribution in the extruder, melt temperature profiles across melt flow, the extruder throughput and the specific energy consumption were monitored. In a preliminary evaluation, transparent melt web was obtained in a simple straight channel depth screw and a straight channel depth screw with a torpedo type barrier section. The transparency of melted resin sheet was obtained by the screw geometry so that the specific energy consumption was small and the melted temperature was low. Based on these results, the screw of gently tapered compression with a torpedo type barrier section was selected as the basic type of the screw geometry to satisfy both the transparency and the extrusion stability. The screw geometry optimization was conducted using the analysis of melting performance by the cool down experiment and the pressure pattern. As a result, the screw geometry to satisfy the target quality was decided.
Keywords: Extrusion screw geometry, High transparent PP sheet, Torpedo type barrier screw

Introduction

Polypropylene is an excellent resin from the view point of it having a reasonable price, good physical properties and good recycling features etc. However, because it is a crystalline resin, it is rather difficult to obtain a highly transparent sheet, and has been limited development with regards to usage in which a high transparency is requested. In order to obtain a highly transparent polypropylene sheet, a random polypropylene as a base material and various kinds of nuclear agents were used. And also a quick quenching system and a rolling process were adopted for the sheeting process.

In order to improve the internal haze of the sheet, the control of the degree of crystallization is very important. A quick quench process by using water-bath is one of the most effective method[1)]. To obtain a highly transparent appearance with an excellent gloss, it is necessary to decrease the surface roughness of the melted sheet before solidification.

There has been a lot of research in the past for the unstable flow phenomenon of melted polymer that obstructs the transparency[2~6)]. In the latest research, it is reported that "Shark skin" is a phenomenon in which only the surface of melted resin film gets rough. And the cause of it is a rapid change from the shear stress at the wall vicinity in the die land to extension stress in the die exit section[7)]. However, even in the state that the critical range of shear stress is not exceeded, the transparency of melt web depends on the screw geometry of the extruder. Therefore, the transparency should be discussed from another viewpoint.

In this paper, an experimental analysis of the extrusion screw geometry for an external haze of the homo polypropylene melted sheet was conducted.

Experimental Apparatus

Idemitsu polypropylene F-200S (density 910 kg/m^3 and MFR=2.0) was used as a material. Figure 1 shows φ50 mm screw geometry (L/D=26) used for a preliminary evaluation. The extrusion characteristics (extruder throughput capacities, melt resin pressure distribution, pressure fluctuation, and melt temperature of the resin) were measured by using the φ50 mm extruder with the adaptor and die (500 mm in width and 2 mm lip openings) for different geometry of the extrusion screw. Here the same extrusion temperature condition was adopted regardless of the screw geometry and the screw rotational speed. Pictures were taken by fixing a camera at the 1500 mm position from the die to judge the transparency of the melted resin sheet in the die exit.

To examine the melt plasticizing performance, the extruder was stopped by the emergency stop button when a pigment appeared from the die. After it cooled, the extruder was opened and the melt plasticizing phenomena along the screw were investigated.

Results and Discussion

The results of extrusion performance with the different screw geometry are shown in Table 1.

As the result for the transparency of melt web, screw No. 4 (straight screw of 4 mm in the channel depth) and screw No. 6 (Straight channel depth with torpedo type barrier that had the shearing section in the middle part of the screw) were excellent.

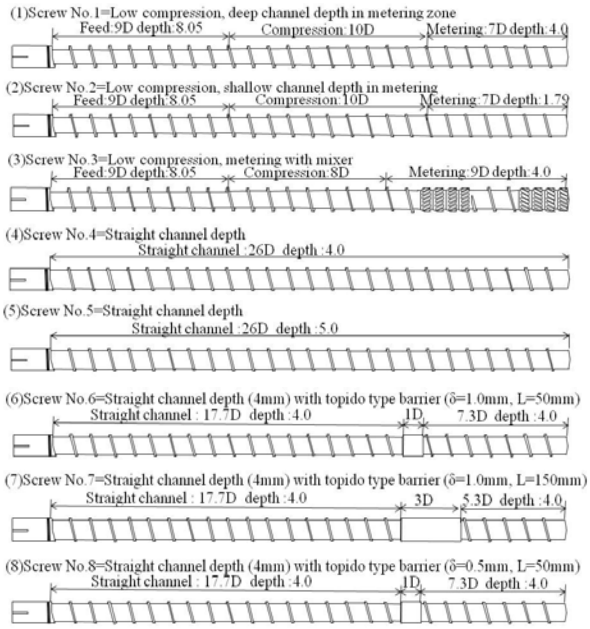

Figure 1. Schematic representation of screw geometries, lengths expressed in extruder screw diameters

At first, screws that are the most general gently tapered compression type (screw No. 1 to 3) were examined. As a result, screw No. 1 which is the deep channel depth in the metering section with the small shear stress showed better transparency. On the other hand, it was confirmed that the gently tapered compression type screw with the strong mixer parts in the metering section (screw No. 3) had low transparency of the melted web.

Next, the straight channel screw No. 4 with the same metering channel depth as screw No. 1 and in comparison with it, screw No. 5 with a deeper channel depth, were examined. As a result, the transparency of the melt web by using screw No. 4 was greatly improved. Regardless of being the same kind of screw, in screw No. 5 of the lower shear stress type, the unmelted resin particles were observed in the melt web and the transparency had deteriorated.

The screw geometry was selected in order to enable the melt plasticization in the early stage of the extruder under even low shear stress conditions. Based on the above-mentioned results, screw No. 6 of a straight channel depth screw with a torpedo type barrier section at the middle part of screw was examined.

It was excellent in respect to the high transparency and the extrusion stability as a

Table 1. Summary of extrusion performance for each screw geometry

Screw No.	Screw Geometry	Extrusion Stability Fluctuation range at screw tip (MPa)	Transparency	Throughput at 150rpm (Kg/H)	Specific Energy Consumption at 150rpm (WH/Kg)	Melt Temperature at 150rpm (℃)
1	Low compression, deep metering channel depth	± 18.5	4	54	0.242	248
2	Low compression, shallow metering channel depth	± 0.3	2	39	0.314	252
3	Low compression, metering with mixer	± 0.3	1	43	0.292	261
4	Straight channel depth (4mm)	± 5.3	5	43	0.169	237
5	Straight channel depth (5mm)	± 9.5	3	57	0.170	228
6	Straight channel depth (4mm) with topido type barrier (δ=1.0mm, L=50mm)	± 0.3	5	43	0.178	245
7	Straight channel depth (4mm) with topido type barrier (δ=1.0mm, L=150mm)	± 0.3	1	43	0.241	256
8	Straight channel depth (4mm) with topido type barrier (δ=0.5mm, L=50mm)	± 0.4	1	45	0.217	254

Definition of transparency : Excellent=5, Very Good=4, Good=3, Fair=2, Poor=1

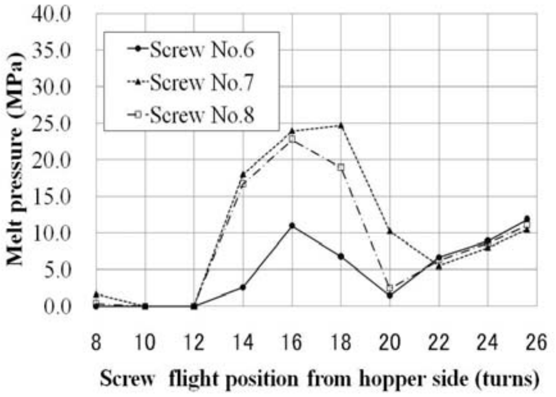

Figure 2. Measured pressure profiles for each screw at screw speed 150rpm

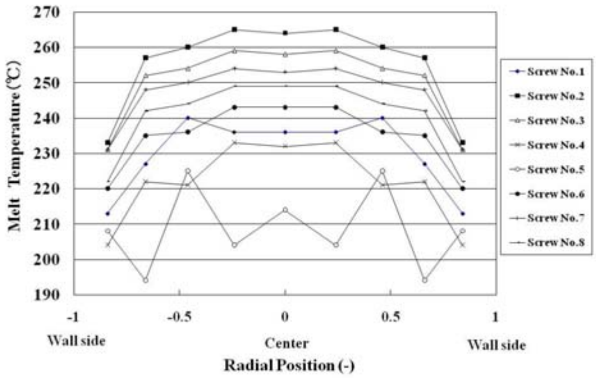

Figure 4. Measured temperature profiles at screw speed 150rpm for each screw

result.

And screw No. 7 (torpedo length=150 mm, clearance of torpedo=1.0 mm) and screw No. 8 (torpedo length=50 mm, clearance of torpedo=0.5 mm) as similar geometry as screw No. 6 were investigated. These two types of screws showed good extrusion stability, but the transparency of the melt web was poor. The melt pressure distributions along these three screws were shown in figure 2. Depending on the torpedo geometry (length and clearance), the melt pressure distributions around the torpedo section (18 turns) were different, and contribution of the shear stress, the shear rate and residence time of torpedo to the transparency of melt web were suggested.

In figure 3, the relationship between average melt temperature at the center of the die exit and specific energy consumption at screw speed 150 rpm were plotted. Additionally, the transparency order of melt web was shown in Figure 3. It was found from the results obtained by experiments of the screw geometry change that high transparency is obtained under the small specific energy consumption and the low melted temperature. In the case of screw No. 5 which was a straight screw of 5 mm in the channel depth, stable melt plasticizing did not occur. As it was estimated from the cross section temperature distribution of melt flow (Figure 4), the unmelted resin particles were mixed in melted resin sheet from the die. And the transparency was not so good even though screw No. 5 was a suitable location as the low specific energy consumption and the low melt temperature of the resin.

Based on the above-mentioned experimental results, in order to obtain highly transparent melt web, it is very important not to generate excessive heat owing to the shear stress or the shear rate on the assumption that the unmelted resin particles are not left. And this transparent mechanism is fundamentally different from the "shark skin" generated at the die exit. That is, the "shark skin" is generated at more than a certain limit of shear stress. It means that the lower the melt temperature, the easier the "shark skin" is generated. On the other hand, the lower

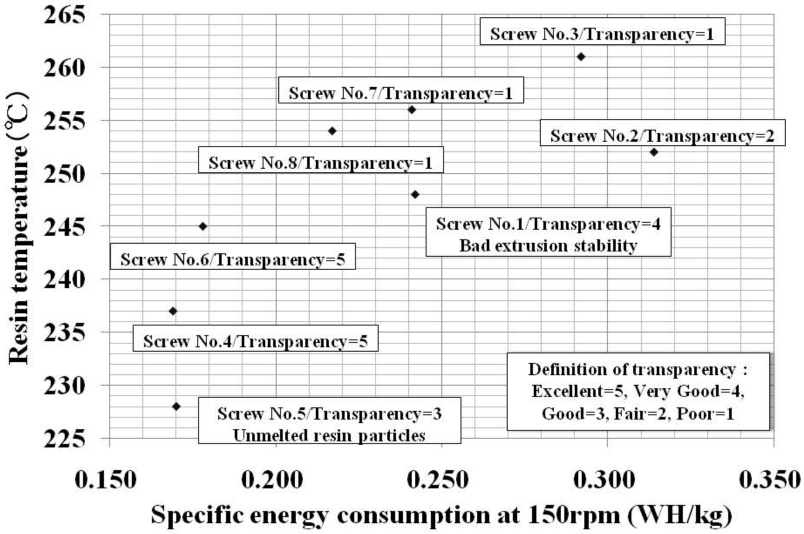

Figure 3. The relationship between average melt temperature and specific energy consumption at 150 rpm for each screw

melt temperature causes higher transparent appearance of melt web depending on the screw geometry.

The straight channel depth screw with a torpedo type barrier achieved the most favorable results for high transparency melt web, and also for the comprehensive evaluation of the extrusion stability, throughput and melt resin temperature. However, in the case of a large size extruder for the production machine, the melt plasticization problem was predicted, and the gently tapered compression screws with a torpedo type barrier were examined in more detail.

When this gently tapered compression screw with a torpedo type barrier was not optimized on the geometry, the ratio of a solid bed in the front section of torpedo was around 60 to 70%. It was confirmed by the screw cool down experiment. This ratio was too high to achieve a stable extrusion. In order to secure extrusion stability under the even high throughput condition, the plasticization capacity was improved by the optimization of the screw geometry. The target ratio of a solid bed in the front section of torpedo was 20% or less, which was generally the proper amount. And also the low melt temperature was pursued as much as possible.

Therefore, the optimization of the lengths of feed, compression and metering zone was attempted, and also the segment which compulsorily destroyed a solid bed in the entrance section of torpedo was newly investigated. As a result, the screw geometry to satisfy the quality demand was obtained by these optimizations for high transparency and extrusion stability.

Conclusions

The transparency of melted resin sheet was obtained by screw geometry so that the specific energy consumption was small and the melted temperature was low. The screw geometry was decided to satisfy the target qualities, which were both high transparency and extrusion stability, by optimizing the geometry of the gently tapered compression screw with a torpedo type barrier.

References

1) A. Fujii : Japanese Patent No. 1407470
2) F. N. Cogswell : J. Non-Newtonian Fluid Mech. **2**, 37 (1977)
3) S. Q. Wang, P. A. Drda and Y. W. Inn : J. Rheol. **40**, 875 (1996)
4) J. R. Barone, N. Plucktaveesak and S. Q. Wang : J. Rheol. **42**, 813 (1998)
5) M. R. Mackley, R. P. G. Rutgers and D. G. Gilbert : J. Non-Newtonian Fluid Mech. **76**, 281 (1998)
6) R. P. G. Rutgers and M. R. Mackley : J. Rheol. **44**, 1319 (2000)
7) H. Kometani et al. : Seikei-Kakou **19**, 118 (2007)