AN IMPROVED FLOW CHANNEL DESIGN FOR FILM AND SHEET EXTRUSION DIES

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Abstract

An improved flow channel design for a die for polymer processing was devised. The design is based on the combination of two conventional die designs to take advantages of both types. The performance of the die with the improved flow channel design was evaluated with a flow simulation. It was expected that the improved die could obtain more uniform flow rate at the die exit than conventional dies without losing other performances such as residence time.

Introduction

The extrusion die is one of the most important equipment to determine the quality of film and sheet products in polymer processing. Requirements for a die have become more and more complicated and diversified because the market of film and sheet products calls for sophisticated functions. Because of this, extrusion die has to fulfill the requirements such as uniformity in thickness and physical properties of products, and productivity.

One of the basic requirements for a die is to distribute the flow uniformly at the exit where its slit has a large width to thickness ratio. It is mainly accomplished by the balance of pressure drop across the entire width of a die. Therefore, the flow channel geometry has to be designed with the consideration of the material properties, operating conditions and rheology. Although conventional dies are also designed with considering those factors, they tend to have limitations to control the thickness uniformity. In some cases, a die may also be required that it can achieve other capabilities such as short residence time in addition to thickness uniformity. It means that a geometry which can achieve two objectives at the same time is needed.

This paper reports an improved flow channel design of die which is devised to enable it to produce uniform thickness products without losing other performances. The concept of the design is to combine the advantages of two conventional dies. Therefore, this die is named as “Hybrid-type Die”. The performance of this die was also discussed by comparison with conventional ones with a flow simulation.

Geometry of Conventional Dies

Two of the conventional die designs are reviewed below.

Coathanger Die

Figure 1 shows a structure of conventional coathanger die. It is comprised of a manifold, whose cross sectional area is tapered from larger at the center to smaller at the edge, and a two step rectangular channel (a preland and a lip land). The length of the preland is not constant from the center to the edge. This design is so popular that a lot of die manufacturers adopt it [1]. The cross sectional area of the manifold and the length and height of the preland assure the balance of the channel resistance. These geometry factors affect the flow rate distribution. In this type of die, it is possible to design a die that can shorten the residence time to prevent melt polymer from deteriorating by setting the taper of manifold appropriately.

Since the coathanger die has a tapered manifold, the channel area at the center of the die is larger than that at the edge. If the inner pressure of the die is high, it will cause larger deformation of the lip clearance at the center of the die than that at the edge. As a result, the deviation of the lip gap in the die across the width results in a nonuniform flow rate distribution at the exit of die. In particular, the tendency becomes significant with the die width increasing.

Taper-Land Die

Figure 2 shows the structure of taper-land die. This type of geometry is adopted in some companies [2,3]. It is comprised of a straight manifold, and a 3-step rectangular channel (a 2-step taper-land and a lip). The 2-step taper-land (rectangular channel) assures the balance of the channel resistance, and the straight positioning of the manifold establishes uniformity of the flow rate across the width. Consequently, the deviation of the lip gap across the width would become uniform even if the die was subjected to inner pressure. It improves the problems that occur in coathanger dies described above.

However, a taper land die gives a relatively long residence time because relatively large cross sectional area of manifold at the end causes a decrease in the velocity of melt polymer. The geometry might cause a problem; for example, in the case that a polymer deteriorates easily by heat.

Improved Flow Channel Design

As mentioned above, each type of conventional die has both merits and demerits. An improved flow channel design was devised to combine the merits and compensate for the demerits of both die types. The geometry of the improved flow channel is shown by Figure 3. The die is named “Hybrid-type Die” as the flow channel design is based on the conventional die designs. It consists of a manifold, which is straight in the width direction, and 3-step rectangular channels like taper land die. However, it differs from the manifold of a taper land die in that the cross-sectional area is gradually decreased from center to end like coathanger type. This design adds one more design factor for balancing the flow resistance: an improved geometry has 4 factors while conventional dies have just 3. The factors for a coathanger die are the length and height of preland, cross sectional area of manifold, while those for a taper land die are the taper and height of 1st and 2nd step land. The increase of design factors is essential to obtain more desired performances with maintaining high uniformity of flow rate at die exit.

We theoretically developed the design formula for this improved flow channel geometry, and it enables us to decide the precise geometry quickly.

Flow Simulation

In order to compare the performance of the improved die and conventional dies, flow simulation based on FAN (Flow Analysis Network) method [4, 5] was conducted. The flow channel geometry of each die used for the simulation is shown by Figure 4. The geometries had been optimized so that the flow channel can provide uniform flow rate at the die across the width under the conditions that the manifold size at the center and the pressure of manifold at the center become comparable. The property of polypropylene, whose melt index (MI) was 5 g/10 min (230^{o}C, 2.16 kg) and melt density was 0.75 g/cm^3, was used for the simulation. The shear viscosity is shown by figure 5 and was modeled using a six constant curve equation as follows:

$$\log\eta = A1 + A2*T + A3*T^2 + A4*T*\log\dot{\gamma} + A5*\log\dot{\gamma} + A6*\log^2\dot{\gamma} \quad (1)$$

where η is the shear viscosity (Ps-s), $\dot{\gamma}$ is the shear rate (1/s), T is the temperature (^{o}C), A’s are curve fit coefficients. The constants are provided in Table 1. The simulation was performed with the throughput of 150kg/hr, the isothermal condition at 230 ^{o}C.

Results and Discussion

The simulation result of flow rate deviation at the exit of die is shown in Figure 6. It shows that all three dies give so highly uniform flow distribution that the deviation is within ± 3%. In particular, the hybrid type gives the most uniform flow distribution that the deviation is less than ± 1%.

Figure 7 shows the simulation result of residence time along each flow pass from inlet of the die to each position at the exit of die across the width. It shows that the residence time at the end of taper land die is 1.5 times longer than that of coathanger die. This is attributed to the straight manifold structure of taper land die that the sectional area of manifold does not decrease form center to end. That structure causes decrease of velocity and longer stay of melt polymer near the end of the manifold. In contrast, the die with improved flow channel exhibits the comparable residence time to the coathanger type. The short residence time indicates that the shear strain rate near the end of manifold is high enough to shorten the process time of resin replacement and color change, and the prevent degradation of melt polymer.

Table 2 shows the comparison of each dies based on the simulation. The results are summarized below.

1. The improved die gives more uniform thickness than conventional one.
2. It is possible to shorten the residence time of polymer from entrance to exit of die. That prevents deterioration of polymer in continuous run.
3. It is possible to prevent wall adhesion of polymer at the manifold because the shear strain ratio at the area can be kept high.
4. It is possible to ensure the highly uniform thickness in actual operation because it has resistance against clam shelling that the deviation across the width of the lip gap change by inner pressure is uniformized.

Conclusion

A “Hybrid-type Die” with an improved flow channel design for polymer processing was devised. From the flow simulation, it was expected that high uniformity of flow rate across the width and the prevention of polymer degradation could be achieved in the die with the improved flow channel design. The main reason of the better performances is that the improved flow design has an additional design factor for balancing the flow resistance compared to conventional designs. This will be more valuable when dies become wider.

References

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3. Peter F. Cloeren, U.S. Patent 5,256,052 (1993).
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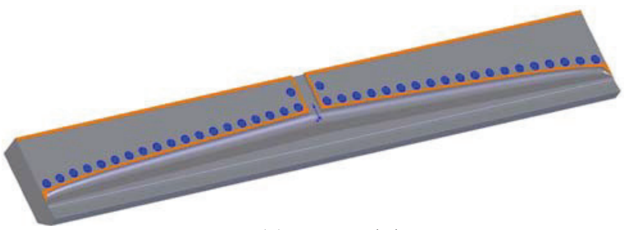
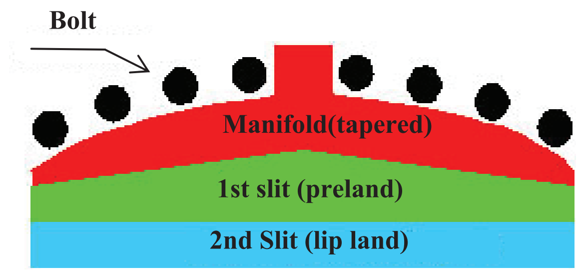
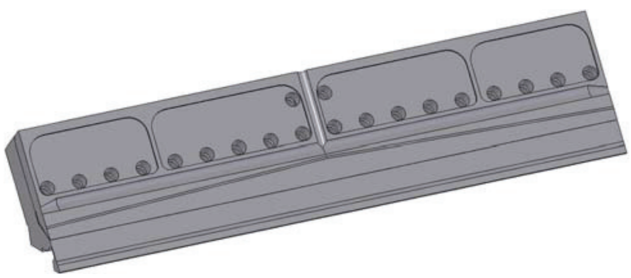


(a) 3D model

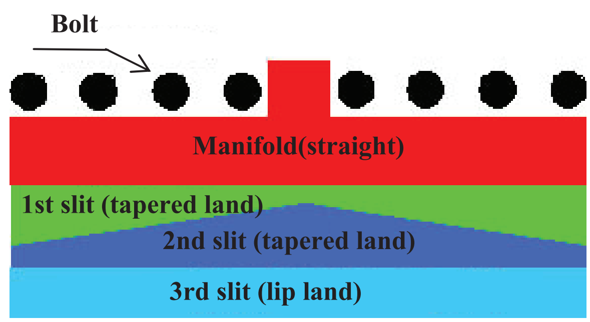


(b) A schematic diagram of flow channel

Figure 1 Structure of coathanger die (conventional die)

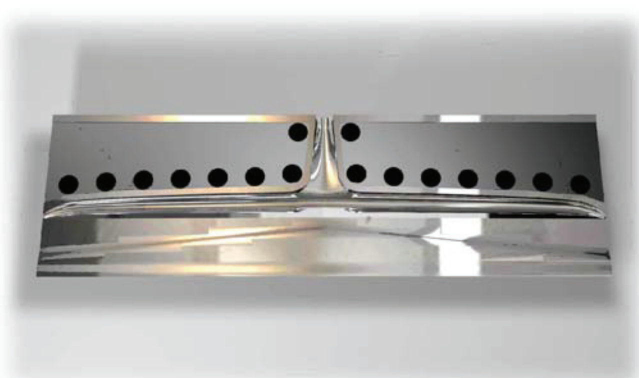


(a) 3D model

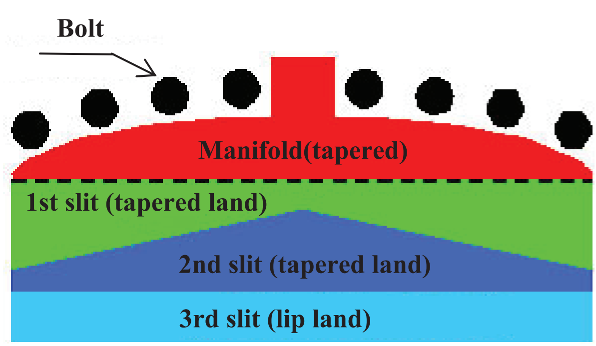


(b) A schematic diagram of flow channel

Figure 2 Structure of taper land die (conventional die)



(a) 3D model



(b) A schematic diagram of flow channel

Figure 3 Structure of Hybrid die (improved flow channel design)

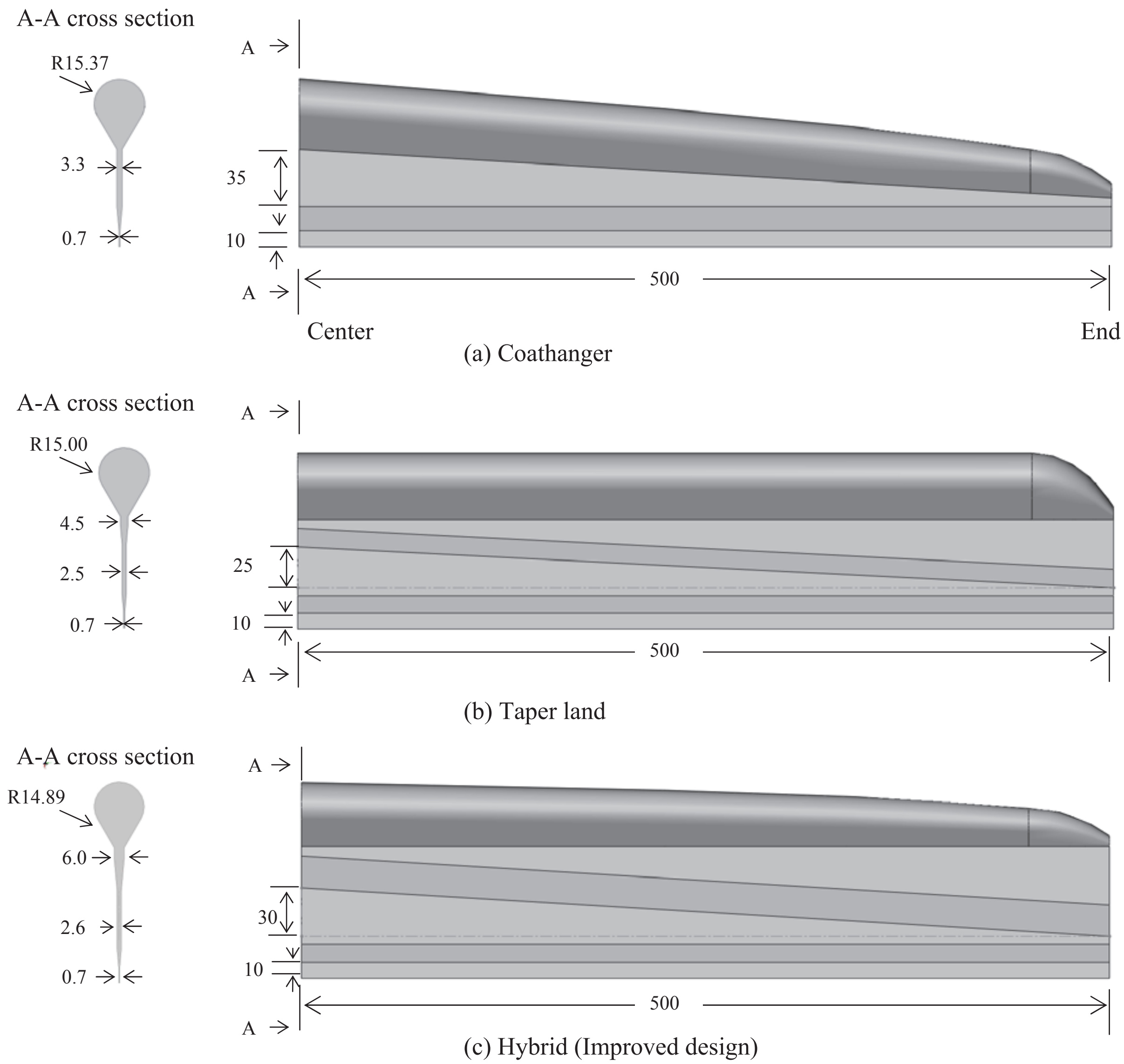


Figure 4 Each flow channel geometry (1/2 symmetrical model) used for the flow simulation (dimensions are in mm)

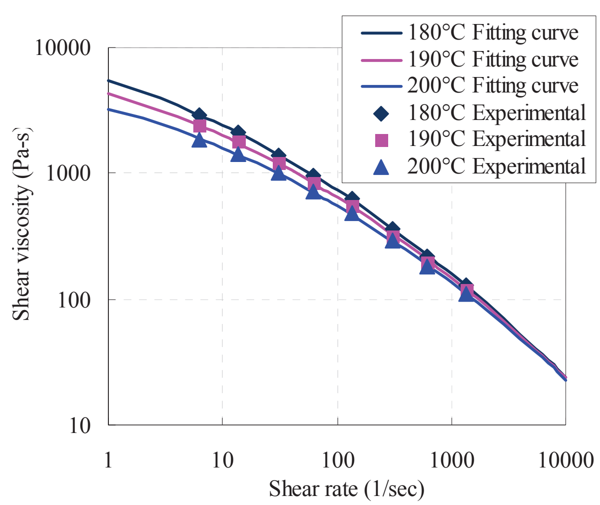


Figure 5 Shear viscosity for the 5 MI PP and the fitting curves.

Table 1 Shear viscosity fitting parameters.

A1	3.971
A2	7.801E-3
A3	-5.053E-5
A4	2.626E-3
A5	-0.7543
A6	-0.07696

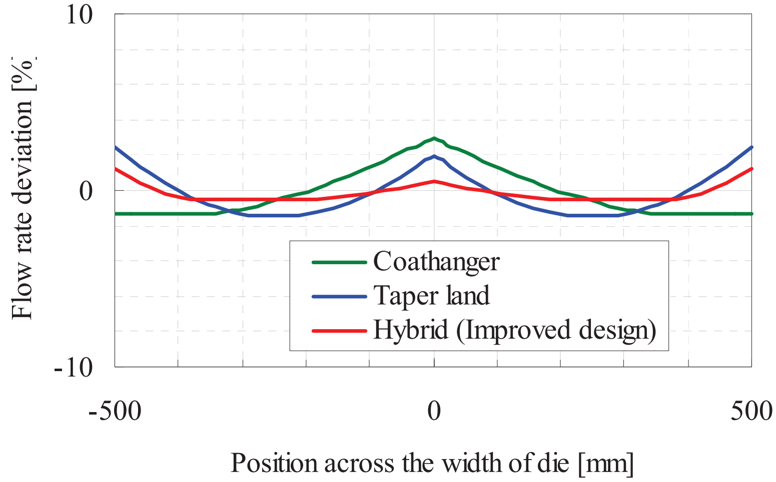


Figure 6 Result of flow simulation for the flow rate distribution

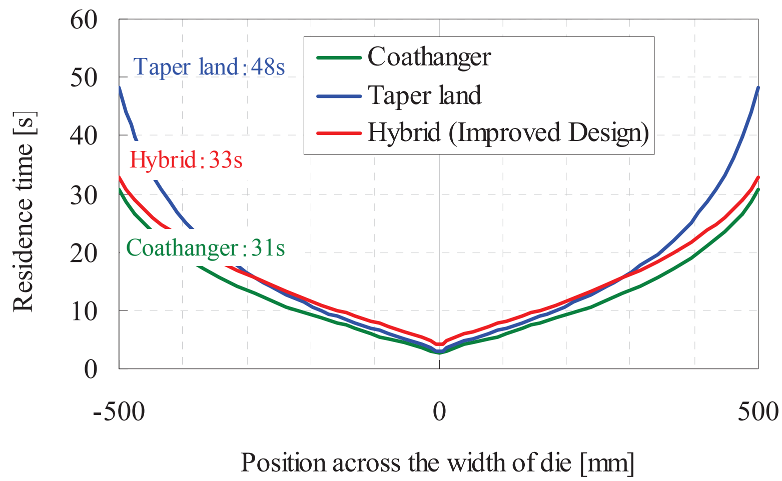
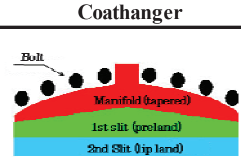
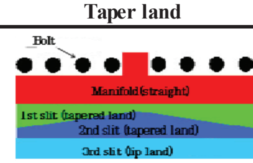
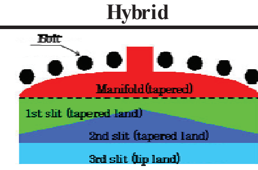


Figure 7 Result of flow simulation for residence time distribution.

Table 2 A comparison of each die.

Type	Coathanger	Taper land	Hybrid
Flow channel geometry			
Uniformity (thickness distribution)	B	B	A
Residence time (degradation, replacement)	A	C	A
Clam shell tolerance	C	A	A−B
Main design factor of flow channel	1. Radius of manifold at center 2. Decrease of manifold Radius 3 Amount of manifold tilt	1. Radius of manifold 2. Height of 1st and 2nd slit 3. Amount of slit tilt	1. Radius of manifold at center 2. Decrease of manifold Radius 3. Height of 1st and 2nd slit 4. Amount of slit tilt

* Five grade evaluation: A (Best) - C (Average) - E (Worst)