The forming simulation of flexible glass with silt down draw method

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Abstract. The slit down draw method is the main manufacturing process of flexible glass. In this study, Flow3DTM software was used to simulate the process of drawing and thinning glass slits during the slit down draw process. The influence of glass viscosity, initial plate thickness and initial plate speed on the glass spreading process was studied. The maximum pull-down force that the root can bear is linearly proportional to the viscosity, the initial thickness of 1.3837 power and the initial plate speed, respectively. The best way to improve the tensile strength of flexible glass is to increase the viscosity. Flexible glass was more easily to obtain with low viscosity, low thickness and low drawing speed.
Keywords: slit down draw method; flexible glass; drawing; simulation.

1. Introduction

Flexible glass is a new type of glass substrate material with a thickness of less than 0.1 mm. It has winding bending, high temperature, anti-aging, good light transmission and other characteristics. Flexible glass is a new type of thin film material for the next generation of flexible display [1-4], touch sensor [5], solar panel [6-9] and other electronic devices, and has attracted much attention from glass process researchers in recent years. Corning, Asahi Glass, Electric Glass and SCHOTT have flexible glass manufacturing technology. Recently, Cheng Jinshu's group at Wuhan University of Technology also succeeded in continuously drawing flexible glass with a thickness of 0.08mm through the slit down-pull method.

In the forming process of flexible glass, the slit down-draw method with simple equipment and thinner thickness of glass is the best flexible glass manufacturing process [10]. During the glass forming process, the glass liquid flows through the elongated slot made of platinum alloy and then made into the sheet by the nip roll [11,12]. In order to grasp the variation law of the sheet tensile, this paper adopts Flow3DTM software [13,14] to simulate the flexible glass slot down forming, and discusses the influence of initial sheet speed, initial viscosity and initial sheet thickness on the glass sheet spreading process.

2. Simulation method

2.1. Modeling

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The geometry of the slit pull-down forming is shown in Figure 1. The width, length and depth are w_x, l and l_x, respectively. The molten glass liquid form a continuous glass plate into the drawing zone after flowing through the slit. In a section close to the slit, the glass sheet is stretched and thinned into a flexible glass by a downward tensile force. This stretched deformed area is called a "root" that is the simulation in this experiment on.

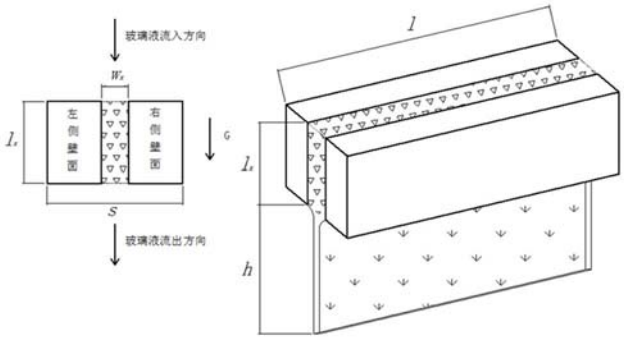

Figure 1. Slit down the tensile model.

2.2. Physical Models, Boundary Conditions and Initial Conditions

Parameters as shown in Table 1:

Table1. Modeling parameters of glass spread model

	Slit width w_0 （mm）	Glass viscosity η （Pa·s）	Entrance speed v_0 （mm/s）
Model I	1, 2, 3, 4	600	5.7
Model II	1	20, 50, 100, 200, 400, 600	5.7
Model III	1	600	2.85, 5.7, 11.4, 22.8

In order to facilitate the calculation of numerical simulation, the following assumptions and simplifications are made for the physical phenomena of the system:

1) Glass liquid is incompressible fluid, that is, constant density;
2) Other physical properties of glass (such as specific heat capacity, thermal conductivity) do not change with temperature, and defects such as bubbles, streaks, crystals and impurities are not considered;
3) The properties of platinum drain plate are constant;
4) Flow and heat transfer of glass liquid are all steady;
5) The effect of surface tension in the simulated area is not considered.
Physical Models: Gravity and Non-Inertial Reference Frame Models, Heat Transfer Models, Viscosity and Laminar Flow Models.

3. Results and Discussion

3.1. The maximum tensile force that the glass plate can withstand

According to the parameters of model I~III, three conditions of w_0 = 1～4 mm; η = 20～400 Pa·s; v_0 = 2.85~22.8 mm/s has been simulated in our present work. The simulation example shows in Figure 2, the glass plate formed immediately after glass emerges from the slit. The weight of the glass plate continues to increase, when the weakest parts of the root can't afford the glass plate gravity fracture simulation ended.

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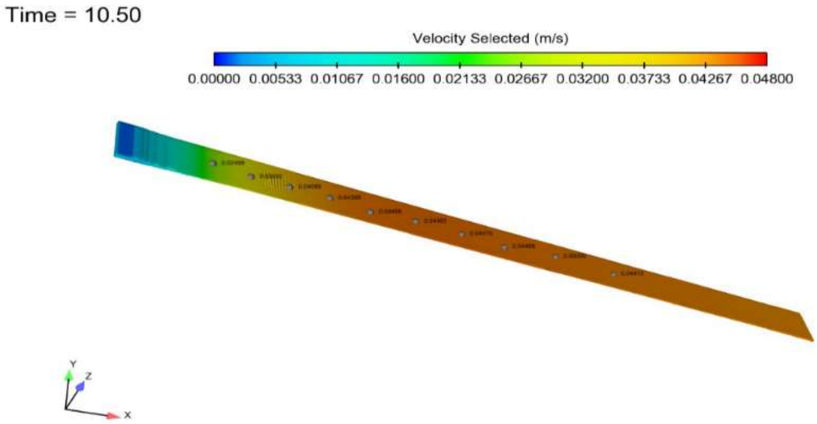

Figure 2. An example of simulation

Figure 3 shows the relationship between the maximum pull-down the glass plate fracture "root" can withstand and other factors. Figure 3(a) is the curve of the initial thickness and the maximum pull-down. The maximum pull-down force and 1.3837 times of the initial thickness have linear relationship: $f_{max} = 1.5018{w_0}^{1.3837} - 0.0672$; Figure 3(b) shows that the relationship between the viscosity of the glass and the maximum pull-down force. The viscosity η and the maximum pull-down force f_{max} approximate the linear relationship: $f_{max} = 0.021\eta + 0.1559$. Figure 3(c) shows the curve of the initial plate speed and the maximum pull-down. The maximum force f_{max} has the relationship of proportional with initial speed: $f_{max} = 0.317v_0 - 0.3191$

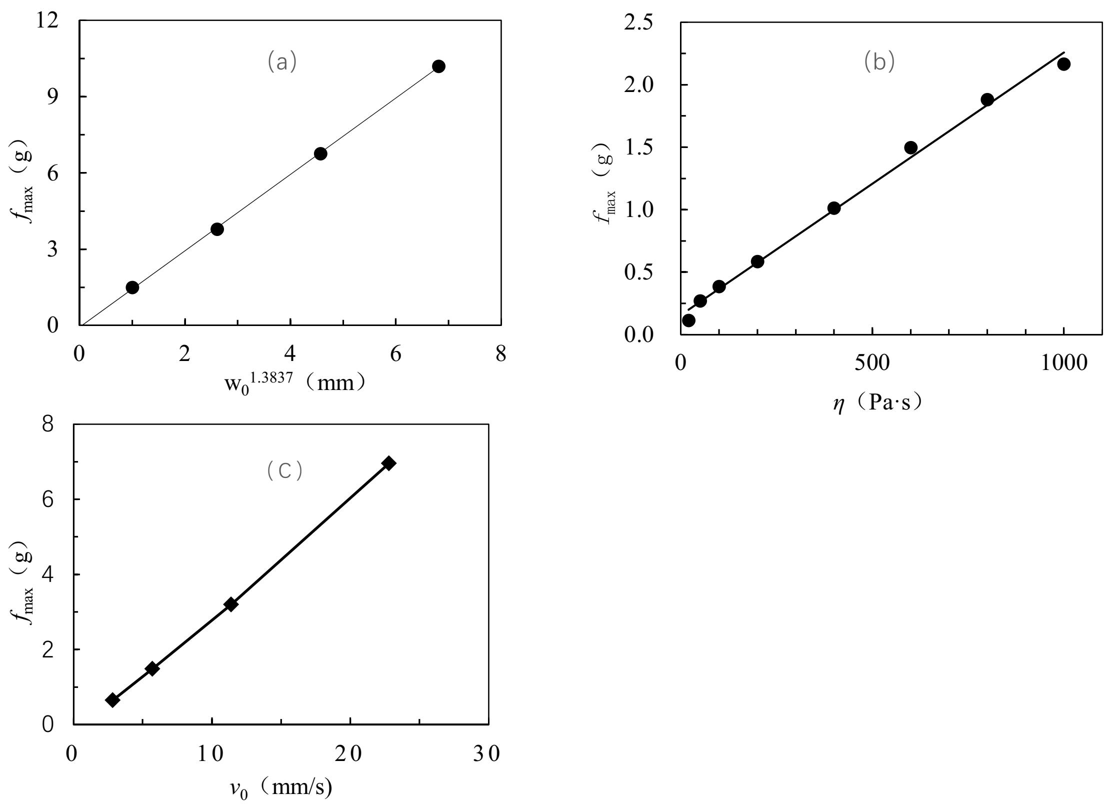

Figure 3. Relationship between f_{max} and w_0、f_{max} and η、f_{max} and v_0.

3.2. The combined effect of viscosity, initial plate thickness and initial plate speed on tensile stress

The maximum pull-down force that the root can bear is proportional to the initial plate thickness of 1.3837 power, the viscosity and the initial plate speed. Therefore, there are three ways to increase the tolerance of the pull force of glass plate: increasing initial thickness, initial viscosity and initial plate speed. The following discussion of the impact of changes of the three process parameters in the slit down-pull method.

The initial plate thickness of the glass is the same as the width of the slit. According to the previous study, the glass flow rate is proportional to the square of the slit width[15]:

$$\mathrm{Q} = \mathrm{K}(h_x {w_x}^2 / l_x\, \eta) \qquad (1\text{-}1)$$

Q is the glass flow, K is the coefficient, h_x is the glass level, w_x is the slit width, l_x is the slit depth, η is the glass viscosity.

The flow rate of the molten glass is also equal to the initial sheet speed v_0, initial thickness w_0 and width l of the product.

$$\mathrm{Q} = v_0 \cdot w_0 \cdot l \qquad (1\text{-}2)$$

Obtain

$$v_0 = w_x K \cdot h_x / l_x \cdot \eta \cdot l \qquad (1\text{-}3)$$

In production, all of the coefficients K、h_x、l_x、η and l are constant, indicating that increasing the slit width causes a rapid increase in the initial plateau speed, as well as increasing the draw ratio of the glass plate, greatly increasing the difficulty of drawing and not suitable for flexibility glass drawing.

Increasing the viscosity of the glass leads to a decrease of the flow rate of the glass, so the viscosity has little effect on the pull-down force. Lower plate speeds also benefit from lower plate speeds. At the same time increase of the viscosity can reduce the glass temperature, and is good for the life of the drain plate. Therefore, it is advantageous to increase the viscosity of the flexible glass.

Initial speed is only proportional to the height of the glass surface, and no other coupling conditions that can be used as a separate process parameters.

3.3. Effect of initial state on plate surface velocity distribution during drawing

In addition to the pull-down force, the plate-speed distribution has a great impact on the flexible glass. Figure 4 is a glass plate velocity profile. The abscissa in the picture is the distance of the glass plate from the slit and the ordinate is the speed of the glass plate. All the curves have the same characteristics: the plate speed increases rapidly with increasing distance from the slit, but does not increase when the plate speed reaches a certain value. This is because when the glass sheet leaves the slit, the pull-down force is greater than the pull-out resistance in the reverse direction. The resultant drag force and pull-down force accelerate the glass sheet. However, as the distance increases, the cumulative drag resistance balances with the pull-down force plate speed is no longer increased.

Figure 4(a) shows the plate speed distribution curve with different initial plate thickness. The larger the initial thickness, the faster the glass sheet is stretched after stretching and the longer the tensile deformation area of the root.

Figure 4(b) is the viscosity of the board surface velocity distribution curve. The lower the viscosity, the faster the sheet speed of the glass sheet after stretching and the shorter the sheet root tensile deformation area.

Figure 4(c) is the plate speed distribution curve of different initial plate speed. The greater the initial board speed after stretch thinning the greater the glass plate speed, and rootstock tensile deformation zone longer.

Summary of the above characteristics: With the decreases of viscosity, increase of initial thickness and the initial plate speed, the glass plate after the balance rate also increased. The deformation distance decreases as the initial plate thickness, viscosity and initial plate speed. Therefore, flexible glass is suitable to be drawn at low viscosity, low thickness, low sheet speed process.

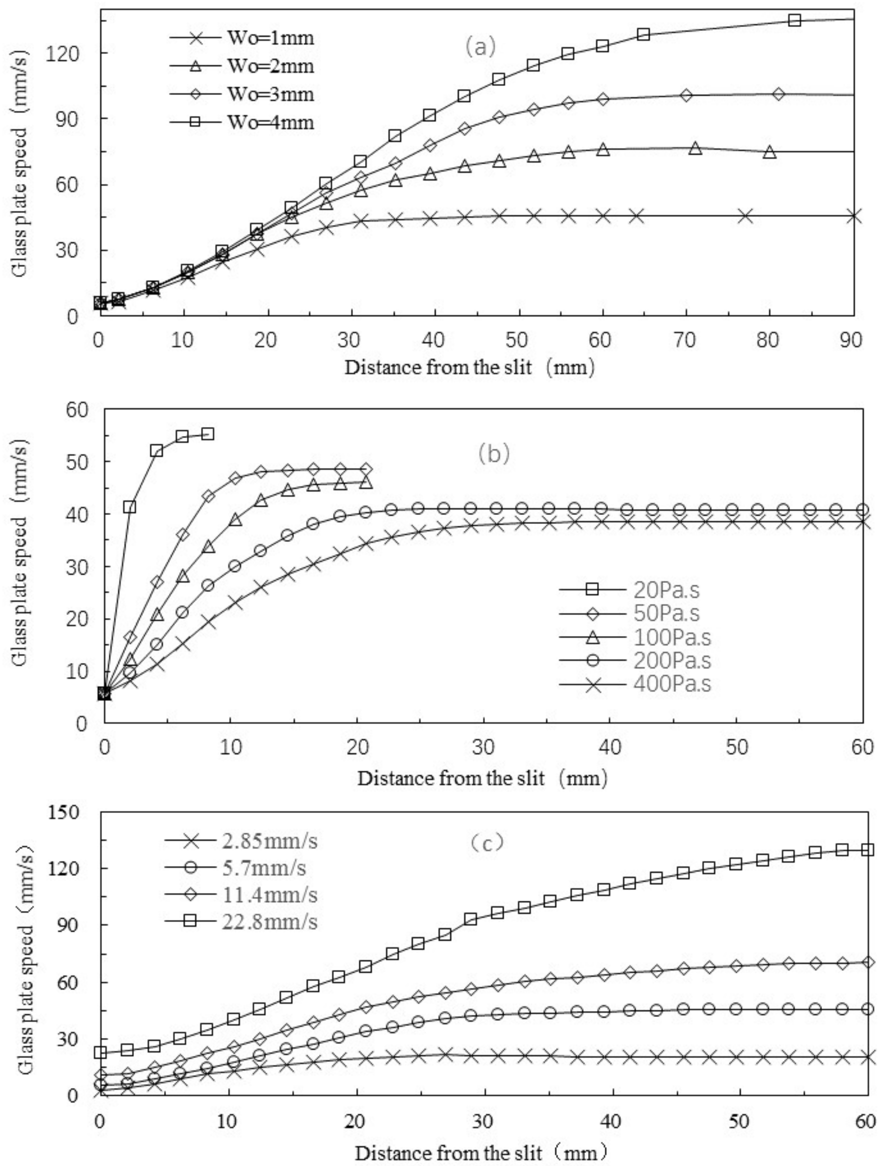

Figure 4. Velocity profile during glass deformation.

4. Conclusion

In this study, 3DTM software was used to simulate the influence of plate surface force and plate surface velocity during the pull-down of flexible glass slits. The study found:

(1)The maximum pull-down force that the plate root can bear is linearly proportional to the initial plate speed and the initial plate thickness of 1.3837, respectively.

(2)Among the three methods to increase the tensile strength of the glass plate, increasing the initial plate thickness of the glass plate is unfavorable for the drawn of glass; increasing the viscosity does not reduce the glass plate from being able to withstand the pull-down force and thinning the flexible glass favorable. The initial speed is not coupled with other conditions and can be used as a separate process parameter.

(3)As the initial thickness increases, the viscosity decreases, the initial plate speed increases, and the speed of the glass plate increases. As the initial plate thickness decreases, the viscosity decreases, the initial plate speed decreases and the deformation distance decreases.

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