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RESEARCH ON MATERIALS FLOW BEHAVIOR DURING V-GROOVE MICRO HOT EMBOSSING PROCESS

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ABSTRACT

The V-groove structure on the surface of optical elements has become a hot issue in current research. In this paper, the hot embossing method is used to form the V-groove on the surface of PMMA. The influence factors and material flow behavior of hot embossing in V-groove are stumouldd through simulation analysis. The results show that the angle, pitch and temperature of V- Has a greater impact; when the material subjected to tensile stress into compressive stress, more conducive to the PMMA material to fill the template microstructure.

1. Introduction

V-groove can change the light propagation direction, LCD light guide plate, antireflection film and other optical devices designed this structure to achieve its optical performance [1, 2]. V-groove forming many ways, there are mechanical processing, laser engraving, micro-imprint method. Because of the advantages of low cost, high efficiency, convenient operation, etc [3]. the V-groove structure replicated by the micro-hot embossing method has become an important technique for V-groove forming. Micro-hot forming mold is non-closed, so the polymer material flow control between the upper and lower mold has been a hot issue of research [4]. The quality of micro hot embossing is not only related to the shape characteristics of the mold, but also to the key process parameters of the hot-embossing process such as pressure, temperature and speed. Only the in-depth study of the V-groove hot embossing process of different shapes of mold material flow characteristics under different conditions in order to determine the optimal design of the V-groove structure and the best combination of process parameters [5,6].

In the past, the research on the micro hot embossing technique was mainly to replicate the rectangular microstructure on the metal template to the thin PMMA polymer layer on the substrate by imprinting [7]. The theoretical and experimental studies have been relatively systematic and sufficient, but there are relatively few studies on the hot embossing technique of directly stamping the V-groove structure on the PMMA board. Due to the difference of the microstructure of the template, the flow behavior of the material and the process conditions during the hot press forming of the rectangular groove and the V-groove are also greatly different, and the thickness of the polymer layer is also an important factor affecting the quality of the imprint, while the thickness of the polymer layer is greater than the embossed depth when hot embossing between PMMA plates [8,9]. In this paper, Deform-3D and Deform-2D, the typical analysis software of material forming process, were used to analyze the influence of geometrical parameters of imprinted template microstructure on the flow behavior of material. Simulations were carried out to simulate the effect of different process conditions on the exterior of the formed V-Topography impact.

2. BASIC THEORETICAL MODEL

Affect the quality of hot forming the main factors are temperature, pressure and duration of action. Since only the template is heated when the template is in contact with the PMMA board, the heat is rapidly transferred from the template to the PMMA board, causing it to rise in temperature and reduce the deformation resistance, but the deformation resistance is still large compared to heating the plastic board, so the pressure is also greater. Due to the depth of the pressure is small, the pressure is a short time, a small heat-affected area, the temperature does not change in the deep layer, but also by the impact of force. The effect of pressure on the hot press forming quality is mainly manifested in that if the pressure is too small, the imprint depth is not enough. If the pressure is too high, only the surface temperature of the polymer is very high, the flow of polymer to the side will increase, and the imprint area The thickness becomes smaller. When the working time increases, there will be a phenomenon of stress relaxation inside the polymer, and the rebound amount will decrease to increase the imprinting depth. In addition, as the action time increases, the heat will be transferred to deeper layers, which is more conducive to the filling of the material in the template forming.

V-groove is hot forming the basic process shown in Figure 1. Firstly, the metal nickel template with the microstructure is mounted on the upper template and heated to above the glass transition temperature of the plastic plate, and then the plastic plate is placed on the lower template and the upper template is pressed at a certain speed to set the plastic profile of the plastic plate After forming the depth of the structure and stay for a period of time, you can replicate in the plastic plate with a concave and convex nickel template complementary V-groove structure.

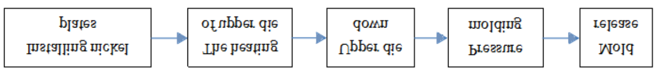


Figure 1: Micro Hot Embossing Process

2.1 Thermal Pressure Mechanical Model

The following assumptions were made to study the effect of temperature, compressive stress, deembossing speed and duration of action on polymer rebound during hot embossing: 1) polymer material isotropic; 2) imprinted at less than 20u Regional temperature equal parts; 3) thermal expansion and contraction does not affect the imprint depth. In order to make the V-groove imprint depth reach the quality requirement, it is necessary to determine the rebound amount according to the hot embossing process conditions and the imprint stress. Polymer material under the effect of compressive stress σ, part of the compressive stress plastic deformation of the material, while the other part becomes the internal stress of the material that is elastic. After stripping, the internal stress to make the material elastic recovery. As the pressure-holding stage, the polymer has obvious time-dependent deformation, and has obvious viscous effect in the elastic deformation. Therefore, the polymer is in the viscoelastic state at this stage. Considering only the elastic recovery of material under a certain action time, a proper time can be obtained experimentally, so that the stress action time is of the same order of magnitude as the internal time scale of the material and the polymer exhibits viscosity and elasticity at the same time. Thus, based on the above conditions and assumptions, a spring and a Maxwell model connected in series can be used to characterize the viscoelastic model of hot embossing of polymers [10,11].

The motion equation of Maxwell model (constitutive equation) is:

$$\frac{d\varepsilon}{dt} = \frac{1}{G}\frac{d\sigma}{dt} + \frac{\sigma}{\eta} \qquad (1)$$

The G is the elastic coefficient of the polymer, η is the viscosity coefficient. For in the process of thermal strain ε is constant, then (1) on the left is 0, then the equation for the humble ordinary differential equation, the solution of this equation are as follows:

$$\sigma(t) = \sigma_T e^{-t/\tau} \qquad (2)$$

In the form of the sigma T polymer at the temperature T and the yield strength of the C points in the tu3; $\tau=\eta/G$, is a characteristic time constant, for the relaxation time, can be obtained through the experiment. It can be seen from (2) that the stress decreases gradually with time and the corresponding elastic response decreases. The viscosity coefficient and the elastic coefficient change with temperature, so the (2) formula also shows the temperature dependence of the polymer thermal pressure forming. Because the v-groove thermoforming is a process of deformation of the polymer under constant pressure, the Maxwell equation is applicable. The viscous coefficient of the eta is the following:

$$\eta = \eta_g \exp\left[\frac{-A_1(T-T_g)}{A_2+(T-T_g)}\right] \qquad (3)$$

Where η_g is the viscosity of the polymer at the glass transition temperature, T_g the glass transition temperature, T is the temperature, A1, A2 is a coefficient?

2.2 Geometric Model and Boundary Conditions

V-groove is thermoforming of the geometric model shown in Figure 2. The jagged microstructures of the imprinted V-grooves have a width of 30μ, a pitch of 30μ and a height of 15μ. Because of embossing directly on the PMMA board, when the imprinting force is greater than the yield limit of the whole material in the imprinting process, the plastic deformation of the whole material can hardly guarantee the V-groove depth. Therefore, the depth of the V-groove is taken as the imprint quality the evaluation index.

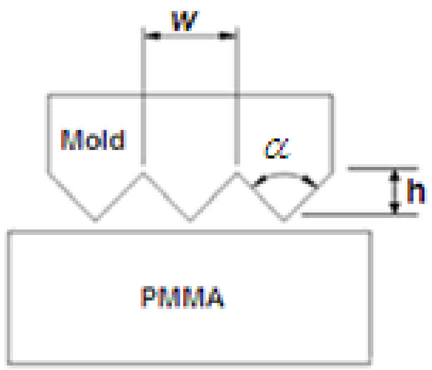


Figure 2: Geometric model of the Figure

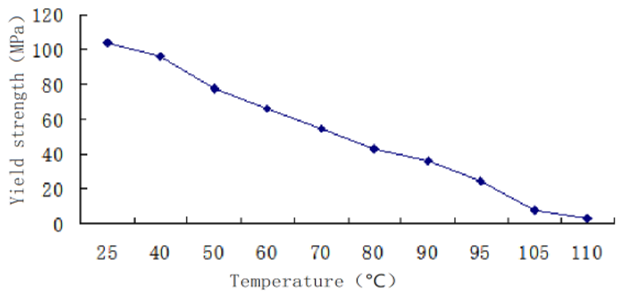


Figure 3: PMMA board strength changes with temperature curve of the Figure

2.3 Material Characteristics

During hot embossing, the mould continuously transfers heat to the PMMA plate to increase its temperature, so the yield strength of the PMMA plate decreases. The curve of the yield strength of the PMMA material as a function of temperature measured experimentally is shown in Figure 3. Because the strength of the template and the backing plate is much greater than that of the plastic, the template and the backing plate are considered as the steel body and the PMMA plate as the plastic body.

3 THE INFLUENCE FACTORS OF MICRO-THERMAL IMPRESSION QUALITY

Deform-3D software was used to simulate the whole process of hot embossing. Set the temperature of the template to 145 ° C and the speed of embossing down to 1 mm / s. After embossing, PMMA material deformation and material flow shown in Figure 5, Figure 6. It can be seen from the figure that during the imprinting process, due to the increase of the imprinting area, the flow of the material to both sides is aggravated, the material is subjected to total yielding and collapses, and the size in the width direction is increased. As the same time, in the region between the template saw tooth structures due to rapid temperature rise, deformation resistance decreases, so the local collapse occurred, resulting in indentation depth is not enough. Therefore, the quality of the imprint of the main factors affecting the microstructure geometry and PMMA imprint during stamping process temperature changes.

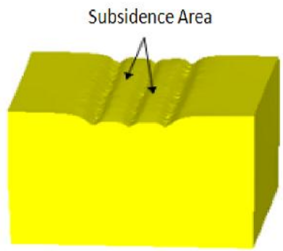


Figure 4: Material deformation of the Figure

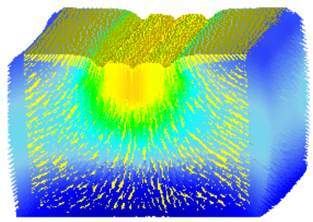


Figure 5: The material flow of the Figure

3.2 The Impact of Angle α

In order to study the effect of the micro-serration angle α on the imprint depth and the material flow behavior of a nickel template, the temperature of the nickel template was set to 140 ° C and the template was pressed at a constant speed of 1 mm/s. The V-groove depth H and V-groove depth H obtained under the conditions of 110 °, 90 °, 70 °, 50 ° and 30 ° are simulated respectively as shown in Figure. 4. It can be seen from the figure that as the angle α decreases, the imprint depth increases. As the angle decreases, the imprinting area decreases, so the imprinting force decreases, so as the depth increases, the material reaches the yield point of the overall time lag, so the overall material to reduce the collapse, the imprint depth will increase.

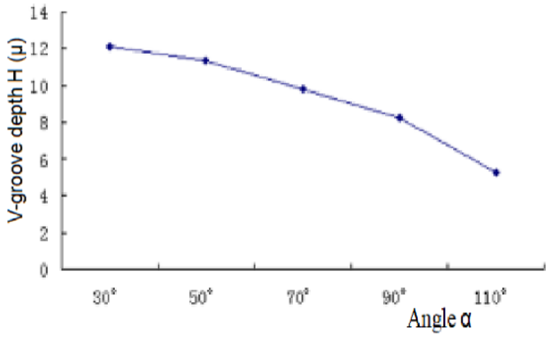


Figure 6: Angle alpha for the depth of the imprint of the Figure

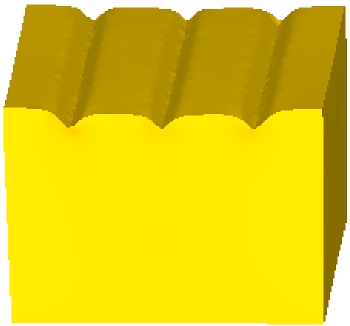


Figure 7: The impact of spacing L of the Figure

3.3 The Impact of Spacing L

In order to study the influence of the V-groove spacing L on the imprint depth, the continuously distributed serrated microstructures in the template were changed to non-continuous distribution with the spacing of the microstructures being 60μ. The imprinting conditions were unchanged. Figure 7 is a picture of V groove pitch of 60μPMMA board embossing results. As can be seen from the figure, when L is increased, the local collapse between the V-grooves decreases, the surface morphology of the V-grooves is good, but the imprint depth is not sufficient. As the microstructure spacing increases, the heat transferred from the template to the PMMA material is more dispersed, so the effect on the morphology of the V-groove decreases. At the same time, the temperature of material between V-grooves slowed down and the yield strength changed little, so the local collapse decreased.

3.4 Template Temperature

The temperature of the template is 145 ° C, and the heat is continuously transmitted to the PMMA during imprinting. The temperature distribution of the PMMA after release is shown in FIG. 8. In the imprint area, the temperature of the material is close to the temperature of the template, with the distance decreases, the temperature showed a significant downward trend. As can be seen from the figure, due to the higher temperature in the embossed region, the material is between the V-grooves collapses higher than other regions, and the V-groove depth decreases. In the heat-affected zone, as the temperature is higher, the material easily flows to both sides, causing the whole to collapse. In the lower part of the material, the material does not flow to both sides due to the constant temperature, so that collapse does not occur. Therefore, in order to reduce the material collapse, to ensure the imprint depth, so that heat cannot be transmitted too fast.

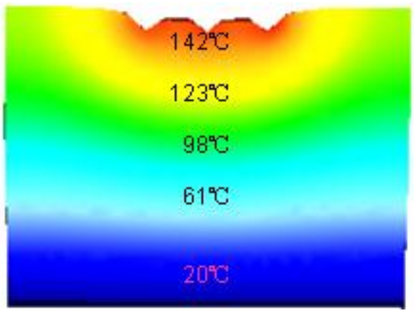


Figure 8: PMMA temperature field distribution of the Figure

4 STUDY ON MATERIAL FLOW BEHAVIOR OF V-GROOVE MICRO HOT EMBOSSING PROCESS

In order to study the flow behavior of materials in the V-groove hot embossing process, the 3D multi-V-groove model is complex in structure and takes up a large amount of memory in the simulation. Therefore, it is very difficult to simulate the detailed behavior of the material flow. Therefore, the three-dimensional model was transformed into a two-dimensional model and the number of V-grooves was reduced. Deform-2D software was used to simulate the whole hot embossing process. The numerical analysis of the model is shown in Figure 9.

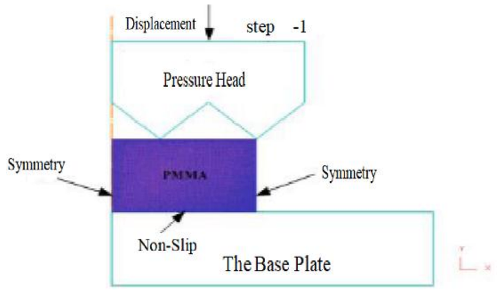


Figure 9: Thermal imprint analysis model of the Figure

Initial simulation conditions: The substrate was set to have an initial plate temperature of 25 ° C, a head temperature of 145 ° C, a reduction speed of 1 μm / s, a reduction of 15 μm and a reduction step of 0.15 μm. The PMMA temperature distribution in the imprinting process is shown in Figure 10, and the measured value of the infrared camera is shown in Figure 11. As can be seen from the comparison of the two figures, the numerical analysis can present the temperature distribution law more accurately.

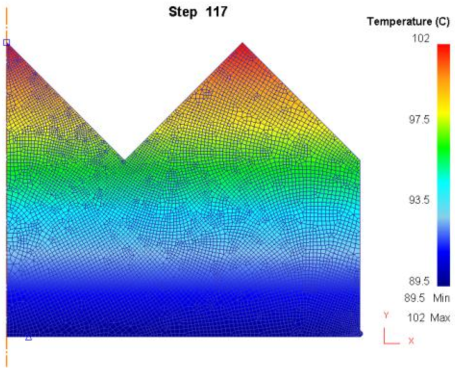
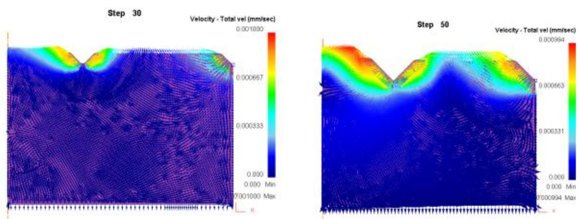


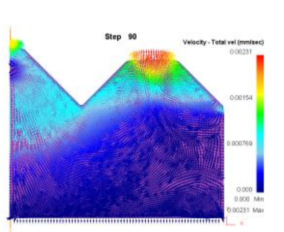
Figure 10: Thermal print temperature map of the Figure

Figure 11: Thermal field infrared thermal imaging of the Figure

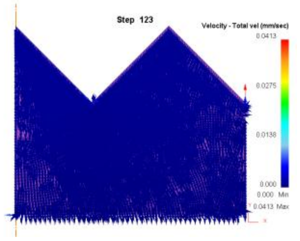
In the imprinting process, according to the law of conservation of mass, it can just form a complete V-groove structure when it is pressed down by 7.5 μm, and when the reduction is more than 7.5 μm, the tensile stress eventually becomes all of the imprinting force, which facilitates further filling of the V-groove structure, with the material flow characteristics during imprinting as shown in Figure. 12.



a. Step30 velocity-Total vel b. Step50 velocity-Total vel



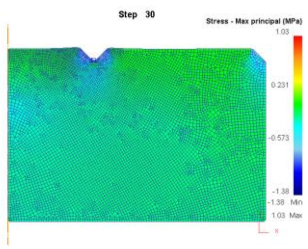
c. Step90 velocity-Total vel



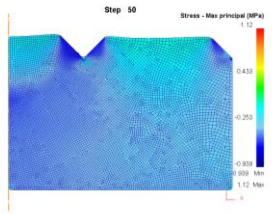
d. Step123 velocity-Total vel

Figure 12: V - groove velocity field distribution of the hot embossing process of the Figure

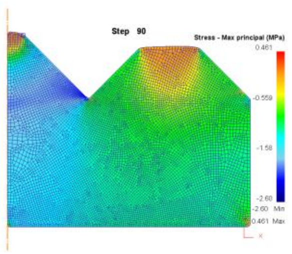
Figure 13 shows the maximum stress distribution in the imprinting process. It can be seen that during the initial imprinting process, the PMMA material of the optical polymer is extruded to the middle due to the pressure of the indenter. In the vicinity of the indenter the material shows compressive stress, while the middle part shows tensile stress. When the V-groove is filled, the overall pressure is reduced. The entire stress field is compressive and helps to shape the V-groove.



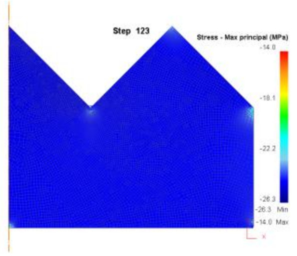
a. Step 30 Stress-Max principal



b. Step 50 Stress-Max principal



c. Step 90 Stress-Max principal



d. Step 123 Stress-Max principal

Figure 13: V - groove maximum stress distribution of the hot embossing process of the Figure

5 CONCLUSIONS

In this paper, the surface of the PMMA polymer was hot-pressed by heating the metal template to study the influence factors of V-groove hot embossing and the material flow behavior during embossing. Deform software was used to simulate hot press forming process. The conclusions are as follows:

1) The V-groove imprinting angle, the V-groove spacing and the temperature of the template have an effect on the quality of the micro-imprint: the smaller the imprinting angle, the greater the imprinting depth; the larger the spacing of the V-grooves, The better the surface morphology of the microstructure; to improve the quality of imprinting, heat transfer rate should be reduced to a deeper level.

2) The simulation analysis of the material flow behavior can improve the analysis efficiency for the model simplification. The analysis results show that when the tensile stress changes to the compressive stress around the microstructure, it will be more conducive to the filling of the microstructure of the template material.

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