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A study on the forming simulation and formability of three dimensional bevel embossing of columnar array microstructures

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A R T I C L E I N F O

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A B S T R A C T

This study conducted three dimensional bevel embossing forming simulation and forming experiment. Using the columnar array microstructure as the cavity insert, along with the self-developed linear control three dimensional bevel embossing system and UV-curing technology, this study carried out the microstructure three dimensional bevel embossing forming process. First, geometric methods were employed to deduce the three dimensional bevel embossing forming mathematical equations for input into Matlab programming software in order to simulate three dimensional bevel embossing results. Next, three dimensional bevel embossing experiment was conducted to discuss the simulated and experimental microstructure formability and process parameters. The experimental results suggested that, the simulated three dimensional bevel embossing results using forming equations are accurately close to the three dimensional bevel embossing experimental results, and the self-developed linear control three dimensional bevel embossing system has perfect embossing formability and high stability.

1. Introduction

With the advancement of science and technology, light materials with easy processability will become the indispensable key raw materials of the future. Forming technology using polymers as the raw materials has been successfully developed and innovated [1–5], gradually becoming the focus of the high-tech industries, including the new generation of optical and MEMS systems. As compared with complex traditional semi-conductor processing technologies, the energy saving and time saving processes of the new technology have been widely developed and applied in recent years [6–12]. However, with increasingly complex requirements of microsystems and the trend of diversification, the linear gradient microstructure has become an important design. Regarding industrial applications, the reflector in an LCD backlight module can adjust the distance from the light source and the angle coupled with the diffusion film to achieve uniform distribution of brightness. If the linear (grayscale) gradients of the reflector surface microstructures can be realized, there will be more opportunities to have more options to optimize the design. If this innovative application can be effectively controlled before mold forming, and the array microstructure's external features after embossing can be forecasted, the embossing replication testing operation can be simplified and cost due to errors can be saved [13–20]. Hence, this study first developed a geometric method to deduce the three dimensional bevel embossing equations as the preparation for embossing forecast. Using Matlab computer software, this study simulated all three dimensional bevel embossing processes and possible three dimensional bevel angles (including angle of rotation and angle of inclination). It also employed the innovative forecast method to discuss the prior simulation of columnar microstructures in the three dimensional bevel embossing process, by settings three dimensional bevel conditions (the angle of rotation, the angle of inclination) and compare with the actual embossing results. The findings can serve as references for future research and industrial applications.

2. Experimental process

2.1. Linear control three dimensional bevel embossing system equipment, cavity, and photoresist

The self-developed linear control three dimensional bevel embossing system equipment is as shown in Fig. 1. The central columnar rotations and embossing transmission shaft of this system are mainly responsible for rotation positioning at the beginning of the process, and the majority of transmission occurring during the embossing process. This study designed the linear positioning axis to control the inclination of the upper mold at both sides. The above driving axial shafts were controlled by the linear control system for rotation and inclined positioning before embossing. In addition, the lower parts included the testing piece bearing platform, quartz glass of high transparency, UV-LED, and

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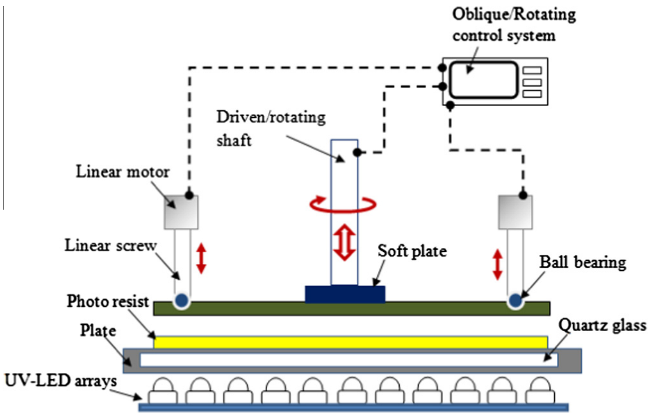

Fig. 1. Equipments of the linear control three dimensional bevel embossing system.

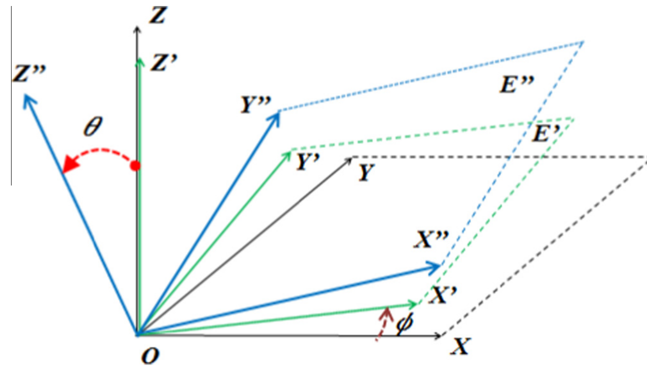

Fig. 3. The coordinates of the geometric method to deduce three dimensional bevel embossing equations.

UV curing equipment to work with the linear system control for three dimensional bevel embossing and three dimensional bevel positioning of the upper mold under different angular parameters.

The original mold uses a columnar array microstructure (diameter: 110 μm height: 140 μm), as shown in Fig. 2. This study used PDMS (poly-dimethylsiloxan, Sylgard™ 184, Dow Corning) to obtain the embossing soft mold by mold rollover, with casting replication and embossing replication materials of SU8 photoresist and PC (Poly-carbonate, Lexan 8010, General Electric Company) plastic, respectively.

2.2. Three dimensional bevel embossing equation deduction and simulation

This study employed the geometric method to deduce three dimensional bevel embossing equations. First, the original coordinate axis *X*–*Y*–*Z* was set, and the embossing rotation angle $\Phi(X'-Y'-Z')$ was determined by the right-hand rule of *Z*-axis. Next, with Y'-axis as the center, the right-hand rule was applied to define the angle of inclination θ for embossing to obtain the new three dimensional bevel embossing coordinates $X''-Y''-Z''$, as shown in Fig. 3, where $\hat{n}$ denotes the original *X*–*Y*–*Z* system coordinates, as shown in (Eq. (1)).

$$\hat{n}(a,b,c) = (-|\hat{n}|\cdot\sin\theta\cdot\cos\phi, -|\hat{n}|\cdot\sin\theta\cdot\sin\phi, |\hat{n}|\cdot\cos\theta) \quad (1)$$

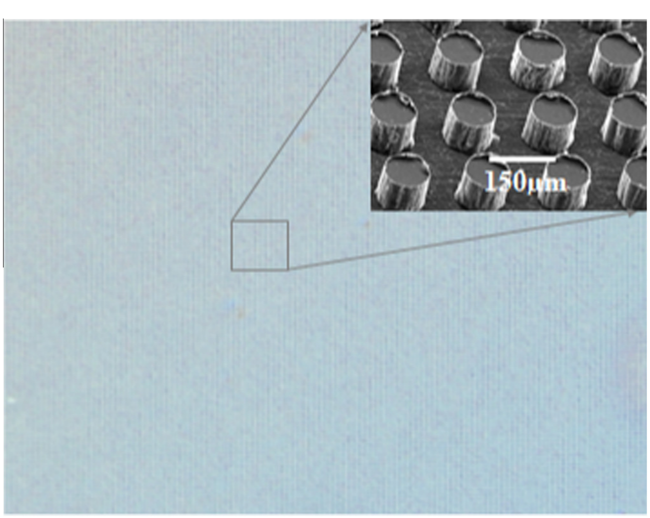

Fig. 2. The original mold uses a columnar array microstructure (diameter: 110 μm height: 140 μm).

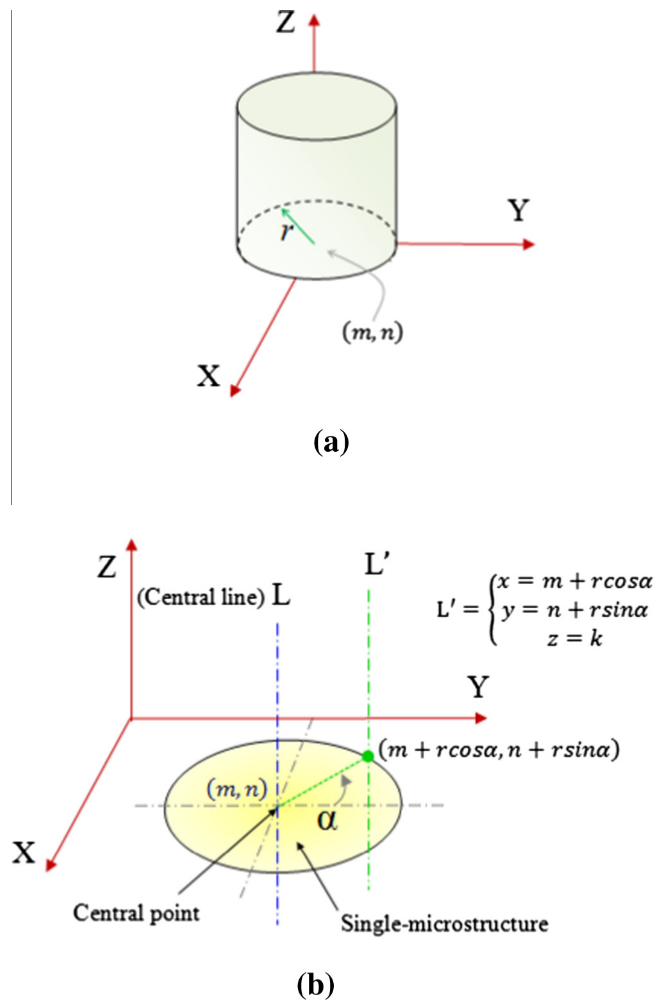

Fig. 4. The coordinates of the (a) micro columnar array (b) three dimensional bevel embossing plane equation (E'') and the central axis line *L*.

The new coordinates after the rotation by angle Φ and angle θ can be deduced through the coordinate transition matrix (R'') to the coordinates of the original coordinate axis *X*–*Y*–*Z*. Hence, the transformations of the new and old coordinates are described, as shown in (Eqs. (2) and (3)).

In terms of *X*–*Y*–*Z* coordinate system, it can be represented as $X-Y-Z=(R'')-1\cdot X''-Y''-Z''$