Replicate Micro-structures of UV Resin by PDMS Mold and Gasbag Roller on PC Film

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The paper addresses the critical challenge: how to increase the contact between roller and substrate and improve the uniformity of pressure. An innovative imprinting mechanism with a circular PDMS mold on a gasbag-roller is developed. The gasbag roller is employed to sustain the circular PDMS mold with microstructure. The contact area has increased significantly from original line contact to area contact. V-cut microstructure has been successfully replicated on PC film using this facility.

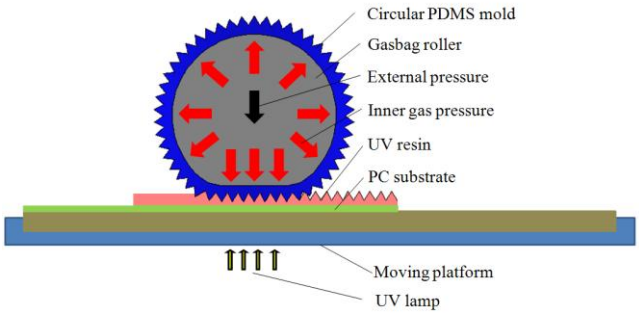
Keywords – Gasbag Roller, UV imprinting, Microstructure

I. INTRODUCTION

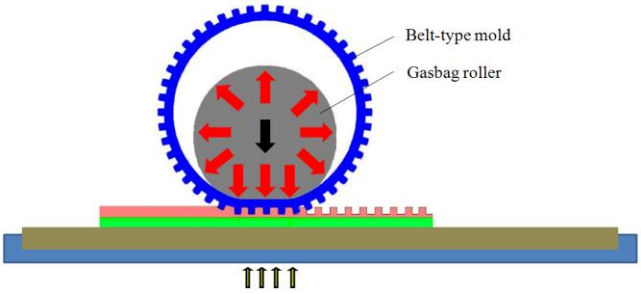
Micro/nano structure is widely used in components such as monitor, cell phone, digital photography, biological detector. For instance, V-cut micro structures on the light guide plate of the monitor can diffuse light uniformly. These micro/nano structures have been fabricated on the surface of polymeric films or plates. Most of them are replicated by hot embossing or injection molding from an electroplated mold. However, there are problems in traditional hot embossing replication, including non-uniform pressure, long heating and cooling cycle time. On the other hand, injection molding is difficult to manufacture surface-structuresd thin and large plates, due to the large flow resistence and thermal-induced residual stress. Furthermore, both processes are batch-wise. Continuous roller imprinting is developed for mass replicating micro structures with fast speed and at low-cost[1].

However, there are two challenges in roller imprinting technology: how to make the roller with micro/nano structures and how to enhance the speed of rollering. In 1997, Gale used the electroplating to reproduce thin Ni sheet with micro/nano structures, and then wrapped it onto the rigid roller. Warp, sliding and mis-alignment have been encountered in systems with such wrapping-based roller molds. To reduce the embossing pressure required, UV resin imprinting technology had been developed [2-6]. However, there was only little contact area and brief time for UV exposure; this prevents increasing the speed of imprinting. Belt type mold was proposed to increase contact area which can effectively enhance the speed of roller, but the uniformity of imprinting pressure is because there is only belt tension between two rollers and normal stress under two rollers. How to make a integrated micro structures and how to maintain uniform pressure and contact area to enhance the speed of roller become the key points. In 2010[9], wu used PDMS to produce a dot mold which length, width and thickness is 150mm, 50mm and 3mm. Finally, it was wrapped into a circular PDMS mold and then he got belt type PDMS mold, as shown in figure 1b. However, the belt type PDMS mold is not integrated so its endurance is suspected.

This research combines gasbag roller and circular PDMS mold to replicate micro structures, as shown in figure 1a. After gasbag roller was inflated with a specific pressure, it will sustain the mold which can avoid warp and deformation effectively. When a external pressure is applied on the shaft of gasbag-roller, the contact area between the roller and the substrate has been increased significantly from original line contact to area contact and to maintain uniformity of pressure by using the gas inside the gasbag. We improve the little contact area with rigid roller and the non-uniform pressure with belt type roller.



(a)



(b)

Fig. 1 combination of circular PDMS mold and gasbag roller to replicate UV resin structures on PC film

II. EXPERIMENTS

In order to produce micro-structures on circular PDMS mold, the first prepared a V-cut micro-structure of the flat light guide plate. It can be obtained a V-cut PDMS mold after casting on the light guide plate by PDMS. We fabricated the V-cut microstructures onto PC film by hot-embossing with PDMS mold and then wrapped PC film on the outer aluminum column. Finally, it can get V-cut structures on circular PDMS mold after PDMS micro casting. shown in Figure 2, The circular PDMS mold size diameter: 63.70 mm, wall thickness: 3 mm, length: 40 mm,The pitch and average height of V-cut structures is 42.947 μm and 7.543 μm measuring by 3D laser microscope shown in Figure 3.

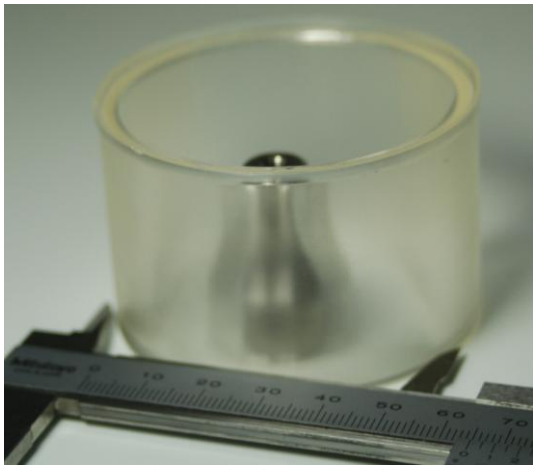
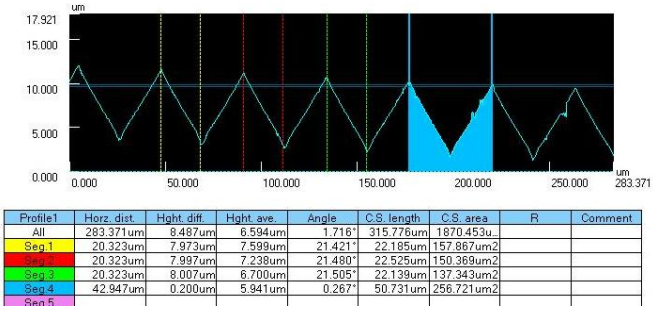


Figure 2 circular PDMS mold



Profile1	Horz. dist.	Hght. diff.	Hght. ave.	Angle	C.S. length	C.S. area	R	Comment
All	283.371um	8.487um	6.594um	1.716°	315.776um	1870.453u..		
Seg.1	20.323um	7.973um	7.599um	21.421°	22.185um	157.867um2		
Seg.2	20.323um	7.997um	7.238um	21.480°	22.525um	150.369um2		
Seg.3	20.323um	8.007um	6.700um	21.505°	22.139um	137.343um2		
Seg.4	42.947um	0.200um	5.941um	0.267°	50.731um	256.721um2		
Seg.5								

Figure 3 3D laser Micrograph of circular PDMS mold structures

A gasbag-roller-assisted UV imprinting facility is designed and constructed for the experiments of replication of the V-cut structures on a polymeric substrate. As show in figure 4, the facility consists of a gasbag roller, an external pressure by pneumatic cylinder, a moving platform and an UV lamp. They are explaned in more detail as follows:

1. The gasbag roller: The gasbag roller is manufactured by wrapping a silicon tube around an aluminum dumbbell-shaped roller. After being inflated with specific gas pressure supplied by an air compressor and regulated by a pressure valve, the gasbag roller will expand and sustain the circular PDMS flexible mold with V-cut microstructure. The sketch with dimensions is shown in figure 4.
2. The pneumatic cylinder: The gasbag roller can exert pressure over certain contact area. However, an external pressure has to be applied on the shaft of gasbag-roller. They are provided by two pneumatic cylinders. The gas pressure is supplied by the air compressor and regulated by a pressure valve. And then contact area between the roller and the substrate has been increased significantly from original line contact to area contact.
3. The moving platform component: The moving platform is driven by two linear slide, ball screw and a servo motor. The sketch of the system is shown in figure 5. Its speed range is 0.1~4 (mm/s).
4. UV lamp component: The UV lamp is implemented 56mm below the platform right under the center of shaft. The wavelength range of the UV light is 365–410 nm. The power of the UV lamp (Philips,UV-A365) is 400 W/cm².

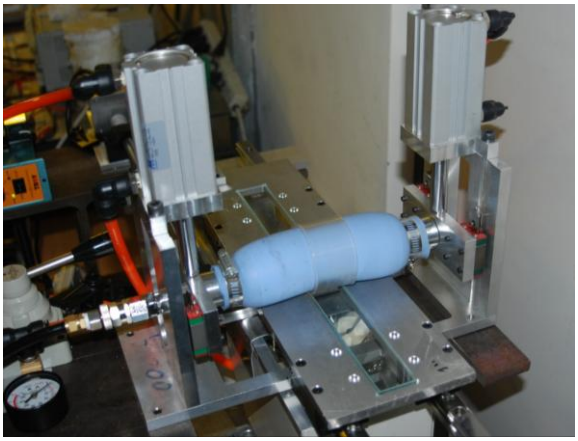


Figure 4 gasbag-roller-assisted UV-based imprinting facility

III. RESULT & DISCUSSION

First, we going to discuss that different external pressure influence the height of micro structures. The figure 5 shows the relation between different external pressure and the height of micro structures when inner gas pressure is fixed at 1.0kgf/cm^2 and the speed of imprinting is fixed 0.239mm/s. When external pressure is 0.2kgf/cm^2, as shown in figure 6(a), the external pressure is too small and the UV resin cannot be filled in the mold which will result in filling insufficiency. When pressure is 0.3kgf/cm2 and 0.4kgf/cm^2, the height of micro structure seen from the3D laser microscope is 7.362μm and 6.396μm separately . We can see from figure 6(b)(c) that micro structures are completely replicated on the PC film. However, when external pressure is increased above 0.5kgf/cm^2, the peak of the v-cut structures on the mold will be deformed because of too large external pressure and then the micro structures will also be deformed, as shown in figure 6(d)(e). The result shows that micro structures cannot be completely replicated with too large or small external pressure, only when external pressure is 0.3kgf/cm^2 and 0.4kgf/cm^2, micro structures can be completely replicated on the PC substrates.

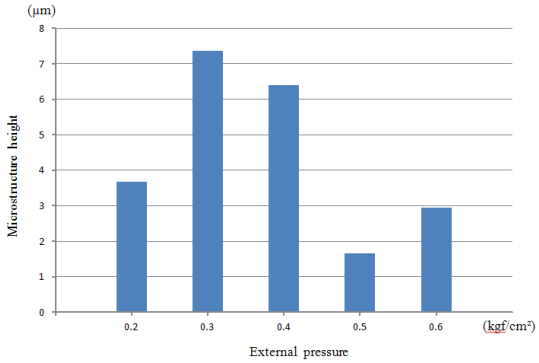


Figure 5 structure replication rate with different external pressure

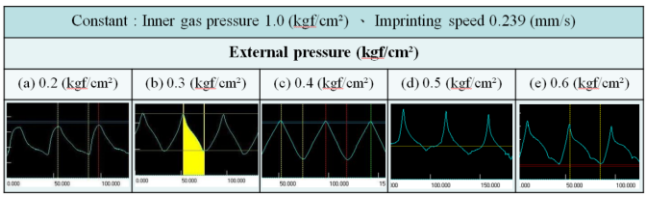


Figure 6 the appearance of structure with different external pressure

When external pressure on the gasbag roller is fixed, we are going to discuss the height of micro structures under different inner gas pressure. As shown in figure 7, when external pressure and speed of moving platform are fixed at 0.3kgf/cm^2 and 0.239mm/s, from macro view, inner gas pressure is not important to the height of micro structures. However, when inner gas pressure is smaller than 0.6kgf/cm^2, the diameter of the expanded gasbag roller is smaller than the inner diameter of the PDMS mold, so PDMS mold cannot surround the gasbag roller completely. The consequence will cause offset easily in roller imprinting, so structures cannot be replicated uniformly on large area. If inner gas pressure in the gasbag is over 0.8kgf/cm^2 , micro structures can be replicated uniformly on large area, but if inner gas pressure in the gasbag reaches to 1.2kgf/cm^2, due to gasbag roller over expanded, the gasbag roller and PDMS mold may be damaged. Therefore, the best inner gas pressure is between 0.8kgf/cm^2 and 1.0kgf/cm^2.

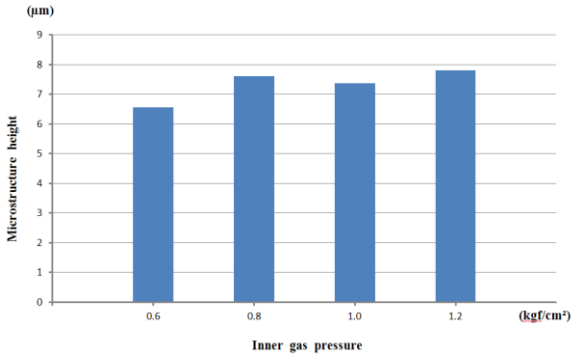


Figure 7 structure replication rate with different inner gas pressure

The structures operational window under different inner gas pressure and external pressure, as shown in figure 8 when we fixed the speed of moving platform at 0.239mm/s, v-cut micro structures can be replicated successfully on the PC substrate. With appropriate inner gas pressure and external pressure, UV resin micro structures can easily be replicated successfully on the PC substrate. We find that too small external pressure will cause UV resin filling insufficiency through experiments. Too large external pressure will cause micro structures to change shape. Too small inner gas pressure will cause mold to offset which cannot form large area micro structures. Too large inner gas pressure will damage the mold.

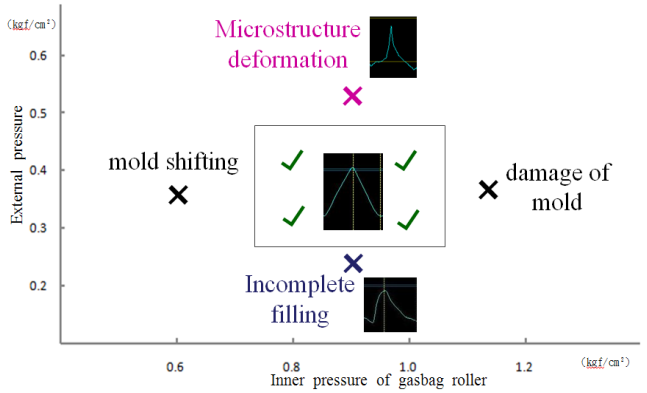


Figure 8 the structures operational window under different inner gas and external pressures

IV. CONCLUSION

In this research, we manufacture an integral PDMS mold and develop the gasbag roller. We combine both to imprint v-cut micro structures successively and successfully. First, we finish developing the UV resin imprinting facility which can be divided into four parts, gasbag roller, pneumatic cylinder component, moving platform component and UV lamp component. The gasbag roller can provide larger forming area in imprinting process. Compared to the imprinting speed, 0.155mm/s, of the rigid roller, the maximum imprinting speed of the gasbag roller is 0.325 mm/s. In addition, the gasbag roller can give uniform pressure by gas and micro structures can be replicated successfully with large area on the PC substrates. The average large area replication rate is 87%. Eventually, the external pressure is the most important parameter to form micro structures. When external pressure is too small, it will cause insufficiency of filling UV resin. When external pressure is too large, micro structures of the mold will be deformed. As a consequence, the most appropriate external pressure is between 0.3kgf/cm2 and 0.4kgf/cm^2.

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