Micro Pattern Machining of Large Drums for Roll-to-Roll Forming Process

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Abstract

In order to cope with the requirements of smaller patterns, larger surfaces and lower costs in the fields of displays, optics and energy, greater attentions are now being paid to the development of micro pattern machining technology. Compared with flat moulds, large drums with micro patterns (roll moulds) have the advantages of short delivery, ease of manufacturing larger surfaces, and continuous moulding. This paper introduced the machining process technology of the roll moulds for display industry. The nickel plating process and machining process for highly uniform micro patterns were presented. The developed technologies were successfully applied to make over 2m-long roll moulds which had prism-shaped patterns with tens of microns for roll-to-roll forming process.

1 Introduction

There is a rising interest on a roll-to-roll forming process using large drums in order to cope with the enlargement of flat panel display products - produced using the components with micro patterns on large surface - and improve the productivity of the components. Compared with the injection moulding process with flat moulds, the roll-to-roll forming process with large drums (roll moulds) has many following advantages[1]. The mould making time could be reduced because the roll moulds were machined by continuous turning process in fast cutting speed around 300m/min while the flat moulds were machined by linear motion-based interrupted grooving process in lower cutting speed up to 10 to 20m/min. The component forming time could be also dramatically reduced because the roll-to-roll forming process produced the components continuously while the injection moulding process produced the components discontinuously. On the contrary, the roll-to-roll forming process has some shortcomings. The form of fabricated components is currently limited to the thin films and the machining process of the roll moulds requires expensive ultra-precision machine tools and well-controlled environment in order to satisfy the specification of optical components. The objective of this paper is to present the machining process technology which is crucial to make roll moulds for roll-to-roll forming process in the field of display industry. The electrolytic plating processes for the roll moulds were discussed, important machining characteristics were introduced for making micro patterns on large drums, and some experimental examples were presented.

2 Electrolytic nickel plating process

The nickel-plated materials are widely used in machining ultra-precision optical components with diamond tools and over 11% of phosphorous (weight %) is generally added to improve machinability as nickel itself was not machined well. The electroless nickel-plating method is generally used for small components, but the method is not suitable for plating over 500um thickness needed for 2m-long drums. The plating technology should be developed along with the machining technology of the plated materials, because the machinability of them is totally different for each plating process. In addition, nickel has higher hardness and tool wear should be considered when machining large surface. Machining experiments were carried out and the plated materials were investigated in order to find the optimal plating conditions. Based on the basic experiments, the temperature (65°C), the acidity (pH 1.3~1.8), and the voltage (6V) of the plating tanks were chosen as fixed variables. The 9 plating conditions - 3 conditions for additive contents and 3 conditions for the proportion of nickel sulphate and nickel chloride - were given as shown in Table 1. For each plating condition, the micro patterns with 90° prism shape having a 50um pitch were machined by splitting the depth of cut into 20um and 7um in a cutting speed of 141.4m/min on the 1200mm region of the drum. The total machining distance was 45.2km. The content of phosphorous and the hardness of the plated drums were measured via an EDS (Energy Dispersive Spectrometer) and a hardness tester. The tool wear in this study was defined as the changed depth of micro patterns caused by tool wear and measured via SEM (Scanning Electron Microscope). The experimental results showed that No. 6 plating condition promised the superior external quality, satisfactory tool wear less than 0.5um which was the limit of shape error, and also confirmed that the content of phosphorous surpassed over 12%, which was the target value.

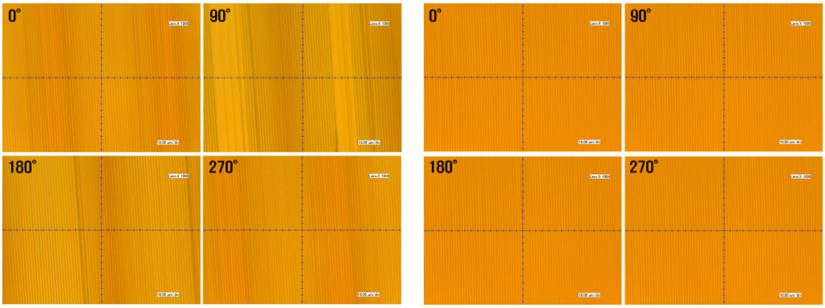
Table1: Comparison of measured data for each plating conditions

No.	Concentration	Additive Contents (ml/l)	Phosphorous contents (wt%)	Hardness (HrC)	Tool wear (um)
1	8:1	50	13.66	58.7	0.35
2	8:1	100	13.09	45.7	0.77
3	8:1	150	11.67	52.3	0.47
4	6:1	50	6.76	49.1	0.72
5	6:1	100	11.04	54.0	0.62
6	6:1	150	12.85	56.1	0.43
7	4:1	50	12.28	54.9	0.87
8	4:1	100	12.65	56.6	0.65
9	4:1	150	13.42	54.5	0.64

3 Uniform machining technology

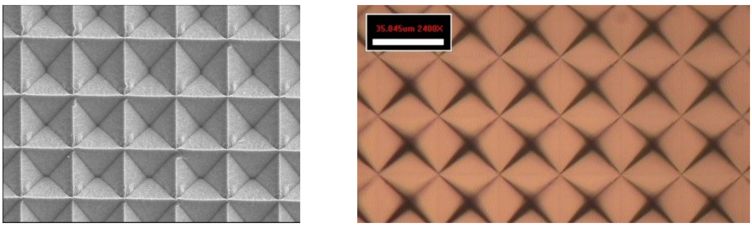
To achieve uniform machining of large surface roll moulds, the distance between a diamond tool and a rotating drum should maintain a constant distance in all machining regions. If the distance is not maintained, the depth of cut will be changed and consequently the pitch size between machined micro patterns will be changed. Static and dynamic balance of the installed drum on the lathe should be compensated in order to remove the oscillation of the rotating drum that may be caused by mass unbalance. A simple experimental result showed that the dynamically balanced drum guaranteed its stable rotation and superior machining quality as shown in Figure 1. If the drum was not compensated, the diamond tool could not cut the whole regions or it could not even touch the surface because of the oscillation of the drum. On the other hand, a diamond tool could cut the whole regions uniformly when both static and dynamic balance of the drum was compensated.

Cross micro patterns were machined as shown in Figure 2. Recently, the need for cross micro patterns is increasing for LED related products. Periodically interrupted cutting occurred naturally when machining in the perpendicular direction to the patterns which had been already machined and the breaking-out phenomena were discovered at the every region where the tool exited. As a result of the machining experiments by changing the cutting speed in interrupted cutting, the breaking-out phenomena at tool exit region could be removed if the cutting speed was set in 5~10m/min as shown in Figure 2 (b).



(a) before compensation (b) after compensation

Figure 1: Machined surfaces (pitch: 4um, depth of cut: 2um)



(a) breaking-out (b) fine machining results

Figure 2: Cross micro patterns

4 Conclusion

The paper introduced the micro pattern machining process technology on large drums which were used as roll moulds for roll-to-roll forming process. As a result of the research performance, highly uniform machining technology of the over 2m-long large surface roll moulds and high-phosphorous contained nickel-plating process were developed and commercialized.

References:

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