Fabrication of Microstructures Using PMMA by Rolling Process

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Abstract

This paper studies patterns for large scale production of microstructures, using the rolling microstamping process with heated substrate. Its working principle is a roll with microgrooves that spins over the heated substrate. The microdeformations will be generated by the heat and pressure undergone by the polymer, in other words, microimpressions, thus obtaining microlenses or microstructures. The materials used for the mold and replica are aluminum and polymethylmethacrylate (PMMA), respectively. Some rectangular channels were machined on the mold (roll), which have been replicated in the PMMA substrate. The pressure of the roller, temperature of the PMMA substrate and speed of lamination are assessed. Lastly, the capability of reproducing the generated profiles by the rolling is evaluated in terms of dimensional and structural quality.

1 Introduction

The processes of replication are able to produce nanometric resolution on large areas and the cost of these replicated structures is virtually independent of its complexity [1]. An efficient alternative to mass production and low cost is the method of rolling microstamping, whose deformation and formation of replicated microstructure occur when a material comes into contact with rolls containing microgrooves on its surface. Common materials to be replicated are thermoplastic polymers such as polycarbonate (PC), polymethylmethacrylate, resists and Novolak type resin cured by UV radiation [2]. The replication quality depends on the plastic material properties, the topography itself, and the process conditions.

The involvement of this work in this technological evolution is based on the study and development of a simpler method of replication using mill roll as a mold because there is evidence of it being a faster and modern method for the manufacture of microlenses and/or microstructures. Its working principle consists of a roll with microstructures which rotates on a thermoplastic polymer.

This work studies the influence of the temperature and distance between cylinders for the replication technique. Emphasis is put on the ability to replicate surface microstructures under normal mill rolling conditions, notably with low-cost materials of the mold and moderate temperatures of the substrate.

2 Experimental Methods

A precision rolling mill manufactured by Laminadores G3™ was used to form the sampels. Its maximum aperture is 4 mm between rolls. The cylinder mold (roll) was machined in aluminum due to its good machinability and high mechanical strength. Several rectangular channels were machined. In this study 16 channels (depth: 50 μm and 100 μm) are analyzed. The profiles generated by the cylinder mold were analyzed using a Veeco™ optical profilometer. The profilometer showed that the machining was successfully performed and the channels showed no burrs or defects in plastic deformation due to high material toughness, as shown in Figure 1.

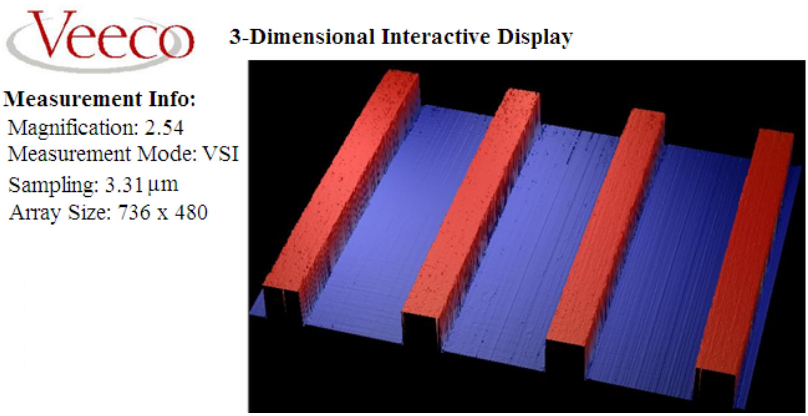


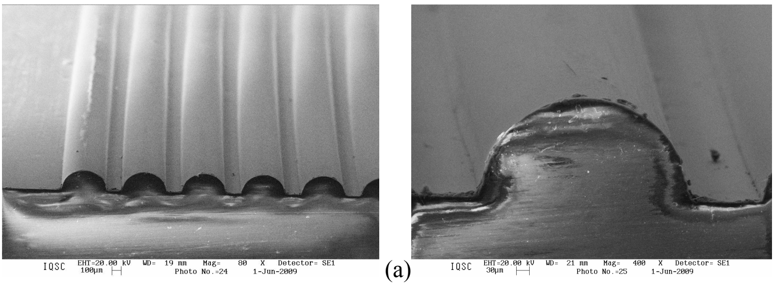
Figure 1. Dimensional analysis of machined part of the cylinder made Veeco™ optical profilometer.

The material used for replication is PMMA, which possesses properties of viscoelasticity. The sample was heated in an oven at 120°C for 24 hours to relieve stress in order to avoid disturbing the experiments results.

In order to verify the parameters that influence the replication rate the temperature, the distance between rolls and the speed of rolling were varied. Temperature variation in this experiment was between 105 °C and 110 °C which is the Tg of PMMA. The distances between rolls were 0.25mm, 0,5mm e 0,75mm. Two rolling speeds 60.3mm/s and 7.5mm/s were used.

3 Results and discussion

Aiming to better analyze the replication, an experiment was carried out with a 2mm thick sample with a 0,5mm distance between rolls and rolling speed of 7.5mm/s as shown in Figure 2. The result of the replication rate was approximately 70% for all channels (replicated areas were measured and compared using a mechanical profilometer).



(a) (b)

Figure 2. (a) Part of the PMMA sample. 2 mm thick replicated at 105°C with 0,5 mm distance between channels. Analyzed by SEM (80x magnification). (b) Channel analyzed by SEM (400x magnification).

In all cases, it was noted that the replicated form was semi-circular (Figure 2) instead of square or rectangle (machined geometric feature of the cylinder mold (Figure 1)). According to [3], the rate of nucleation and linear growth with the temperature are maximum between Tg and Tm (characteristic of the polymer).

Thus, to achieve high replication rates, it will be necessary to lower the rolling speed for the chains to move, coupled with high reduction rate, which influence the mobility of the chains, and a temperature close to Tg, because after replication, the temperature should drop below Tg, paralyzing its movement. The fact that the shape of the replicated feature is semicircular is restricted to the arrangement of chains not being complete, and the crystallization of the structure occurs when the temperature drops. Only with the correct alignment of the rolling speed, temperature and rate of reduction will the high rate of replication be achieved.

4 Conclusions

This paper proposed a novel technique for replication of microstructures onto PMMA substrates. The effects of various processing parameters on the replicability were studied. It was concluded that to attain replication efficiency above 70% it must be taken into account factors such as the speed of rolling and the percentage of material's deformation. For PMMA, the optimal temperature for replication between 105°C and 110°C was identified, because in this range of temperature the material is prone to plastic deformations because of its viscoelastic state. The experimental results in this study suggest that method of rolling microstamping can provide an effective method of fabricating microstructures in polymer substrates. It will provide significant advantages in terms of a shorter cycle time as well as improved product quality.

5 Acknowledgments

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Laminadores G3™

References

[1] Gale, M. T. Replication techiniques for diffractive optical elements. Microelectronic engineering, v. 34, p. 321 – 339, 1997

[2] Ottevaere, H.; Cox, R.; Herzig, H. P.; Miyashita, T.; Naessens, K.; Taghizadeh, M.; Völkel, R.; Woo, H. J. e Thienpont, H. Comparing glass and plastic refractive microlenses fabricated with different technologies. Journal of optics a: pure and applied optics, p. 407 – 429, 2008.

[3] Canevarolo Jr, S. V. Ciência dos polímeros. São Paulo: Artliber Editora, 2002.