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Microstructured multifunctional polymer chips by UV-photopolymerization injection molding

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Abstract
In this paper we present a very promising procedure for fabrication of double-sided structured foils by UV photopolymerization based injection molding process. By using different acrylates (urethane- and epoxy-based, mono- and multifunctionalized) it is possible to control the mechanical parameters of the produced polymer films, e. g. Young's modulus, transition temperature, brittleness. For the polymerization TPO-L is used as an UV initiator. Mechanical properties as well as molding quality of the films prepared by UV-induced injection molding were compared to hot-embossed poly(carbonate) films of the same layout. Problems during demolding were discussed and an improvement by non-adhesive coatings of the tool inserts and the lid-glass is illustrated. Furthermore, we demonstrated the flexibility of the process by successfully tuning the wettability of the poly(acrylate) films from hydrophilic (water contact angle of 30°) to hydrophobic (water contact angle of 106°) by adding suitable additives to the acrylate mixture, e. g. sulfopropyl acrylate or C16/C18 alkyl acrylate derivatives. In this respect, the filling of the microfluidic channels with a test solution in dependence of the water contact angle was also investigated.
The UV-induced injection molding approach promises high flexibility regarding the properties of the resulting films, possible future applications are the fabrication of multilayer films or films with spatially separated areas with different wettability. Based on this idea we present first results of the utilization of a complex tool which allows for the injection of two different acrylate mixtures.

Keywords: UV-induced injection molding, acrylate, hot embossing, micro-fluidic

1. Introduction

The field of microfluidics and disposables for biomedical applications and diagnostic purposes has received large interest during the last years. The key benefit of such miniaturized analytical devices is the portability, which makes them in particular attractive for point-of-care diagnostics. Another aspect regards the easy handling of these integrated devices, which allows for the application even of non-medical staff. Finally, sample and reagent volumes are reduced to a minimum of a few nano- or even picoliters, therefore contributing to the principle of green chemistry. In principle, a number of approaches for the preparation of microstructures for microfluidic assemblies exist and are reported in basic research [1-4], however, the high costs are the main limitation for large scale production. We present a new approach to double-sided microstructured films using UV-induced injection molding for the preparation of disposable sensor chips suitable for diagnostic applications as an environmental friendly alternative to hot embossing [5]. In the following section preparation of the acrylate mixture and the principle of the UV-induced injection molding are described. Furthermore, results of molding quality and the properties of the poly(acrylate) films are presented.

2. Methods

2.1 Preparation of the acrylate mixture

A typical procedure for the preparation of a UV-injection molded poly(acrylate) film was as follows: Samples of mono- and multifunctional acrylates or acrylic oligomers were received from Allnex, Sartomer and Rahn. To a mixture of those acrylates a mass fraction of 1% of the photo-initiator Irgacure® TPO-L was added. The mixture contains up to 10% of hydrophilic or hydrophobic additives in order to tune the wettability.

2.2. UV-induced injection molding

Poly(acrylate) films were prepared using a customized mold made of tool-steel with a glass slide on top. The steel mold consisted of a frame with integrated vacuum channels as well as two acrylate filling channels and a steel insert containing the microstructure to be molded. The steel insert was coated with a non-adhesive coating and the glass slide was silanized with Dynasylan®F 8263 in order to facilitate the demolding of the poly(acrylate) film. The glass slide was fixed on the mold by applying reduced pressure through the integrated vacuum channels. The resulting gap between steel mold and glass was filled with the acrylate mixture followed by photopolymerization using UV LED lamps (12 W/cm^2, 395 nm). Afterwards, the mold was ventilated, the glass slide removed and the poly(acrylate) film pulled off the microstructured steel insert.

3. Results

3.1. Molding quality

Molding quality of the UV-induced injection molded poly(acrylate) compared to the hot-embossed poly(carbonate) was evaluated under the optical microscope as well as by scanning electron microscopy. While using the native microstructured steel mold without any coating, significant defects at the walls of the microstructures were observed due to sticking of the acrylate to the mold. For that reason, the microstructured mold was covered with a non-adhesive

coating, which significantly reduced the defects during the demolding process. An identical fragment of the hot-embossed poly(carbonate) and the UV-induced injection molded poly(acrylate) was examined by scanning electron microscopy. The surface of the microstructure of the poly(acrylate) film appears rougher compared to the smooth surface of the poly(carbonate). This effect can be attributed to the enhanced roughness of the microstructured steel mold due to the non-adhesive coating. The channel walls are well defined for the poly(acrylate) film without any fractions or failures. The quality of the double-sided UV-injection molding was monitored by scanning electron microscopy, as depicted in Fig. 1 (left). The upper side of the poly(acrylate) film was molded from the glass plate, the bottom part from the steel mold. The structure of the glass is well reproduced in the poly(acrylate) film, no cracks and spalling due to problems during demolding are observed.

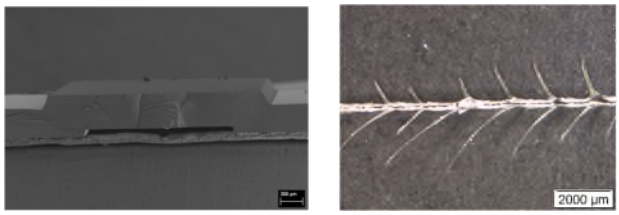

Figure 1. left: SEM image of a detail of a double-sided structured poly(acrylate) film prepared by UV-induced micromolding; right: Optical micrographs of cutting edges obtained at brittle poly(acrylate) films with herringbone pattern.

To sum up, the molding quality of the poly(acrylate) films reached almost the quality of the poly(carbonate) ones. The preparation of double-sided structured poly(acrylate) films was successfully demonstrated.

3.2. Mechanical properties

Hot embossed poly(carbonate) is characterized by high stiffness at moderate flexibility that makes the material well suited for the preparation of mechanical stable sensors on the one hand, but without causing problems during the final cutting process on the other hand. In general, poly(acrylates) are not been used as stand-alone materials so far, but only as coatings and adhesives for a great variety of applications. For that reason, main focus was set on the mechanical properties of the films during the optimization of the acrylates composition. For all poly(acrylate) films prepared by UV-induced injection molding the Young´s modulus as well as glass transition temperature was determined. However, both parameters were not found suitable to represent the desired mechanical properties of the poly(acrylate) films. Since straight cutting edges without any cracks are essential in the final cutting process of the laminated sensor chip, the brittleness during cutting with a paper cutter was determined. A typical optical micrograph of a cutting test using 300 µm thick brittle poly(acrylate) film is illustrated in Fig. 1 (right). Flexible poly(acrylate) films show a straight cutting edge without any cracks.

3.3. Wettability

The wettability of the poly(acrylate) films was tuned between hydrophilic and hydrophobic by mixing suitable additives to the monomer formulation. By adding 3-sulfopropyl acrylate potassium salt to the formulation, the water contact angle decreased to < 20°. Hydrophobic formulations were prepared using a C16/C18 alkyl acrylate mixture, that was mixed to the formulation using a mass fraction up to 10%, resulting in a water contact angle of 106°. Compared to that, an unmodified formulation typically showed water contact angles in the range of 50° to 70°, the poly(carbonate) film was more hydrophobic (water contact angle of 80°).

Double layer film

Peeling tests and cross cut tests (DIN EN ISO 2411) were performed to assess the adhesion between the two layered films. For the tests different double layer films were prepared. As expected, the composite film with two identical formulations showed the best adhesion (peeling force 1.6 N, cross cut test 0). The double layer film with hydrophobic and unmodified poly(acrylates) has a less favorable adhesion (peeling force 1.4 N , cross cut test 0). Finally, the combination of hydrophobic and hydrophilic film showed expectedly the worst adhesion (peeling force 0.3 N , cross cut test 3-4).

5. Summary

In the present contribution, we highlighted a novel and powerful approach employing UV-induced injection molding for the preparation of the polymeric microfluidic part of a disposable diagnostic sensor. The molding quality of the resulting poly(acrylate) films in the micrometer range resembled that of the hot-embossed poly(carbonate) films, as could be revealed by scanning electron microscopy. Furthermore, it was demonstrated, that the UV-injection molding approach can be applied for the preparation of double-sided structured poly(acrylate) films. Key benefit of the UV-induced injection molding approach over the hot-embossing is the ease of tuning the wettability. Current limitations of the new UV-induced injection molding process are observed regarding the mechanical properties of the prepared poly(acrylate) films: A key challenge of the UV-injection molding is still the selection of suitable acrylates in order to obtain poly(acrylate) films that resemble the superior mechanical properties of poly(carbonate), such as a high toughness without brittleness. In the near future, the UV-induced injection molding process promises a high flexibility with respect to modifications in order to produce polymer films with spatially defined wetting properties as well as multilayer films.

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References

[1] H. Becker, C. Gärtner 2000, *Electrophoresis*, **21** 12-26.

[2] H. Becker, C. Gärtner 2008, *Anal. Bioanal. Chem.*, **390** 89-111.

[3] G.S. Fiorini, D.T. Chiu 2005, *BioTechniques,* **38** 429-446.

[4] A. Waldbaur, H. Rapp, K. Laenge, B.E. Rapp 2011, *Anal. Methods*, **3** 2681-2716.

[5] B. Gründig, C. Elsner, B. Abel 2015, patent DE102013203829B4., Leibniz IOM, Germany; Senslab-GmbH.