A Combination of UV curing and thermal Treatment successfully overcomes PDMS Curing Inhibition on 3D-Printed low-cost-resin Molds

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Abstract

We investigate the influence of thermal and UV post-curing treat- ments on 3D printed resin mold and the quality of a pored poly- mer, polydimethylsiloxane, utilized in the world of microfluidics.

1 Introduction

In recent years, the utilization of stereolithography (SLA) 3D printing tech- niques made it possible for the expansion of microfluidics fabrication, without the need of expensive and time-consuming standard clean-room processes [1]. The layer-by-layer polymerization of a photosensitive resin using UV light provides a possibility for the production of various customizable struc- tures, replacing the need for dry-etching and photo mask fabrication. In most cases, printed molds are then replicated into a polymer, polydimethylsiloxane (PDMS) being the most frequently utilized for bioanalytical devices due to its optical, mechanical and chemical properties. Even though this technique gains more and more popularity, there are some reports of PDMS curing being inhibited at its contact zones with these 3D-printed molds, making the quality of the final microfluidic geometry poor and in some cases even not applicable for experimental work. Extensive research of the question why this inhibi- tion occurs, has been performed in [2]. Those authors suggested, based on Mass Spectrometry (MS) measurements, that fragments of photo-initiators, produced during 3D-printing, leach from the mold into the PDMS inhibiting its curing. However, those results were obtained just for two typical photo- initiators and no actual chemical and/or physical mechanism for the observed phenomena was proposed. In this case study we describe our experience with 4 types of low-cost commercial resins that were not studied in the above- mentioned paper [2]. The influence of thermal and UV post-curing treatment of the resin mold on the successive PDMS curing was evaluated qualitatively.

2 Results

A simple microfluidic device with 4 straight channels (600 μm x 600 μm, 30 mm long) was fabricated using a mold produced by a resin-based stereolitho- graphic type 3D printer (Phrozen Sonic Mini 4K), working at 405 nm UV light intensity and having a printing XY-resolution of 30 μm (3840 X 2160 pix- els). The mold was designed with the help of a computer-aided design (CAD) software (SolidWorks 2021, Dassault Systems, France). As mentioned before, four different UV-sensitive resins (Table 1) were investigated and the mold was washed with isopropanol after the printing process. The printed structures were post-cured at 395 nm UV for 2, 4 or 6 min and/or exposed to a thermal treatment at 80°C for 1, 2, 4, or 12 h. In the next step the PDMS pre-polymer (Sylgard 184, Dow Corning, USA) was mixed with the curing agent, degassed, poured into the mold and cured in an oven at 80oC for about 1 h. After peeling it off from the mold, the quality of the hardened PDMS surface was evaluated. In order to find the optimal treatment conditions, we examined the resins listed in 1 at various treatment combinations. Curing quality assessment was based on the microscopically observed quality (i.e. sharpness) of the boundaries between the PDMS mold features and the air. In short, we assumed that larger boundaries were the result of reduced curing quality. Inversed-microscope pic- tures of the PDMS replicas were captured and the images were binarized with the Otsu algorithm (ref) in Matlab (The MathWorks Inc, Natick, USA). Next, the binary images were inversed so that the parts of interest (i.e. the bound- aries) become the true parts of the image. Finally, the total sum of all pixel values was considered to be the evaluation of the boundary surface in the pro- cessed image. Figure 2 represents an example of images of PDMS replica of the AnyCubyc Plant based resin mold for three different cases. In the first one (Fig. 1a)) the mold was treated for 6 min at 395 nm UV light and for 1h at 80°C. This channel replica shows the desired quality of a channel geometry, on the left side and the corresponding edge detection in white on the right side.

Table 1
The resin types, the coresponding colors and the required minimal UV and Thermal Curing Times for optimal replica quality

Resin Brand and Type	Color	UV Time	Thermal Time
AnyCubic Basic	Grey, Green, Clear	4 min	1 h
AnyCubic Plant-based	Green	4 min	1 h
Elegoo ABS-Like	Grey	4 min	2 h
Phrozen Aqua 4K	Grey	4 min	2 h

In general, our results showed no observable differences in the curing quality between 4 and 6 min of UV curing independent of the resin of choice.

Declarations

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Figures

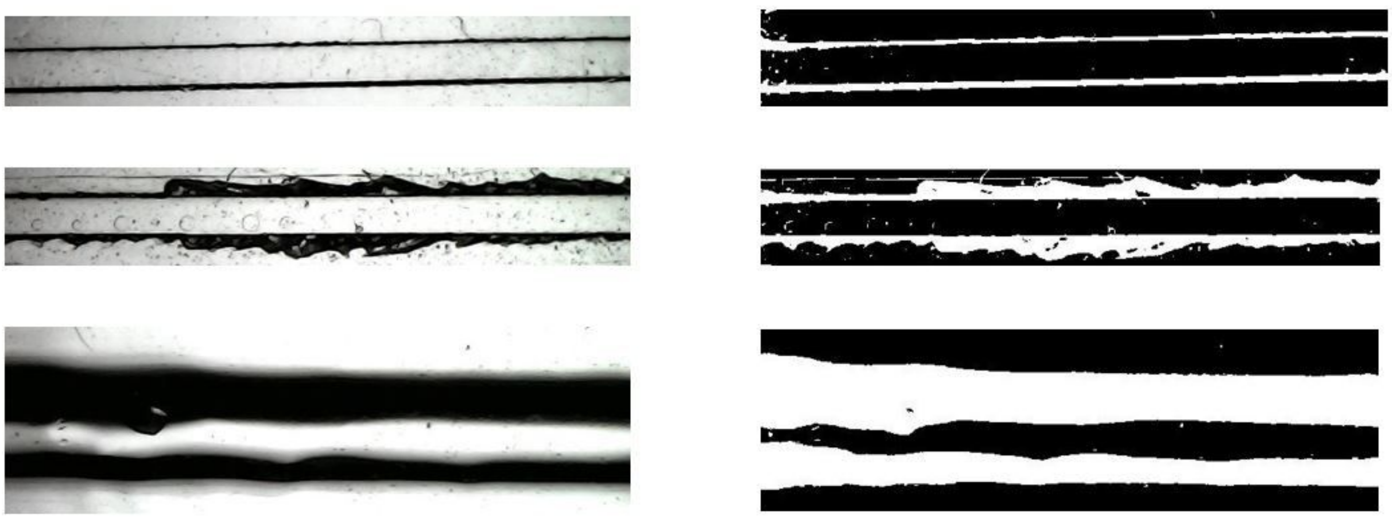

Figure 1

Edge detection with a histogram based approach with a threeshold pixel value of 116. On the left side of the figure are the original microscope images for three different cases and on the right side are the corresponding edges (in white). In a) mold was treated with 395 nm UV light for 6 min and at 80 C for 1 h (edge size is 9297 pixels); in b) with 395 nm UV light for 2 min and at 80 C for 1 h (edge size is 18170 pixels); and in c) no treatment was carried out (edge size is 55324 pixels). The reduction of the edge quality in (b) and (c) with respect to (a) is readily observable.