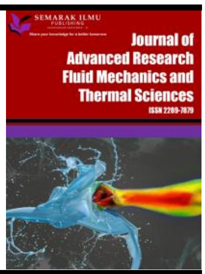
SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



The Effect of Temperature on the 3D Printed Mold using Polyethylene Terephthalate Glycol (PETG), Polylactic Acid (PLA) and Stereolithography (SLA)

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ARTICLE INFO

Article history:
Received 24 May 2023
Received in revised form 9 August 2023
Accepted 17 August 2023
Available online 30 August 2023

Keywords:
3D printed mold; PLA; PETG; SLA; microchannel

ABSTRACT

The usage of 3D printing technology is explored in biomedical applications, specifically for drug delivery systems or cell separation using microfluidic channels. The fabrication of a 3D mold is very crucial, especially for fabricating a Polydimethylsiloxane (PDMS) microfluidic channel. This paper highlights the effect of temperature on the mold using different material elements, which is filament and resin, for fabricating a PDMS microfluidic channel. The mold structure was observed, and the mold was tested by repeating the process ten times. The molds were pre-heated, and the result shows that the structure of PLA mold gives the highest increases in sizing compared to PETG and SLA. The PDMS microchannel fabricated using 3D mold also shows the same result. The sizing of the PDMS microchannel increased linearly as it was tested five times with the same procedure. The mold was successfully fabricated with different materials, and the PDMS microchannel was successfully fabricated using the 3D-printed mold.

1. Introduction

3D-printing technology is widely explored in various applications due to its capability to create a physical object based on geometrical representation as mentioned by a few authors in Shahrubudin *et al.,* [1], Waheed *et al.,* [2], Deshpande *et al.,* [3], and Mpofu *et al.,* [4]. The most trending 3D-printing usage is creating a functional model, an artistic model, or a spare part for education or research purposes shows by author de Almeida Monteiro Melo Ferraz *et al.,* [5], Kamran and Saxena [6], and Li *et al.,* [7]. Recently, the usage of 3D printing technology has been explored in biomedical applications specifically for drug delivery systems or cell separation using microfluidic channels as stated in Kitson *et al.,* [8] and He *et al.,* [9]. Traditionally, microfluidic channel mold is fabricated using complicated fabrication processes like photolithography, coating, and post-baked process. Furthermore, this process required expensive chemicals and equipment to fabricate SU-8 mold only stated in Zhao *et al.,* [10], Tsao [11], and Lee *et al.,* [12]. However, 3D-printing technology has the

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https://doi.org/10.37934/arfmts.108.2.164171

capability to fabricate mold with an excellent structure as good as SU-8 mold as previewed by a few authors in Beauchamp *et al.,* [13], Weisgrab *et al.,* [14], Frascella *et al.,* [15], and Abidin *et al.,* [16]. In addition, there are several researchers who directly used a 3D-printing model to fabricate a microfluidic channel for transferring fluid and integrating it with another component to developing a Lab on Chip system [17-21].

The fabrication of a 3D mold is very crucial, especially for fabricating a Polydimethylsiloxane (PDMS) microfluidic channel. The material selection for the 3D- printer mold is vital to get a very fine PDMS structure of the microfluidic channel. Polyethylene Terephthalate-glycol modified filament (PETG), Polylactic Acid filament (PLA), Acrylonitrile Butadiene Styrene (ABS) filament and etc. materials are commonly used for fabricating 3D-printing models as stated in Chiadò *et al.,* [22] and Johnson [23]. Furthermore, resin material like Stereolithography (SLA) and Digital Light Processing (DLP) is used to fabricate a 3D-printing model. These two types of material are still used layer by layer building until creating wanted models previewed by few authors in Halldorsson *et al.,* [24], Kitson *et al.,* [25], and Amin *et al.,* [26].

This paper highlights the effect of temperature on the mold using different material elements, which is filament and resin, for fabricating a PDMS microfluidic channel. Heat is a critical element in curing and hardening the PDMS solution. So, the mold needs to be heated together with PDMS solution to fabricate the microfluidic channel. PDMS is practically used in microfluidic applications due to its hydrophilic behavior for diffusing fluid in microchannel. At the end of the paper, the capability of different 3D-printer materials is explored by observing the structure of mold and PDMS microfluidic channel. Furthermore, the robustness of the mold is explored by repeating the thermal process several times for PLA, PETG, and SLA materials.

2. Methodology

The fabrication process starts with printing microchannel mold using a 3D printer machine. There are three types of 3D printer material as a mold which is PETG, PLA, and SLA, with dimension stated in Figure. 1. The chemical composition of PETG, a commonly used thermoplastic material, is closely related to that of polyethylene terephthalate (PET), with the exception of modifications made to the glycol component. Specifically, PETG is produced by replacing ethylene glycol in the PET structure with cyclohexanedimethanol (CHDM), resulting in a material that shares a comparable chemical composition with PET. PLA filament is a biopolymer that is produced by fermenting plant-based sources, such as corn-starch, sugar cane, and taro. While the filament is primarily composed of the pure polymer, it may incorporate certain additives in limited quantities to modulate various characteristics, such as intramolecular flexibility, melt viscosity, and colour or visual properties. To a significant degree, the SLA resin bears resemblance to SLA coating, and is comprised of a prepolymer, reactive diluent, photo initiator, and a minor quantity of an auxiliary agent. All the material used are standard use in 3D printed industry.

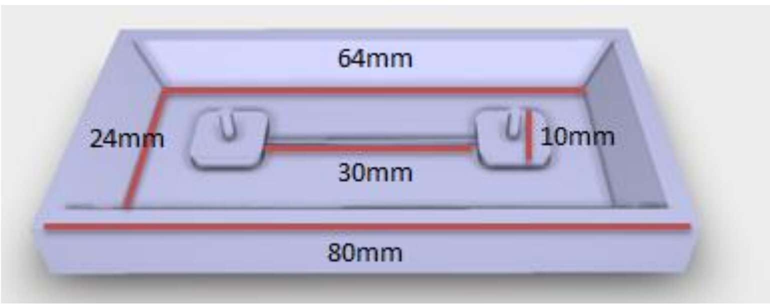

Fig. 1. Schematic of PDMS microchannel fabrication process

Next, the PDMS was prepared by mixing a well-mixed PDMS solution with a curing agent at a ratio of 10:1 in a petri dish, using 20 grams of PDMS solution and 2 grams of curing agent. This solution was then placed in a chamber to remove all bubbles during the mixing process for 60 minutes at -15Hg. Before pouring the PDMS solution, the molds needed to be preheated in the oven for 30 minutes at 55°C. The PDMS solution was then poured into PETG, PLA, and SLA molds and cured in an oven at 60°C for 45 minutes to harden the PDMS. The PDMS was then peeled off from the 3D-printer mold. The structural properties of the PETG mold, PLA mold, and SLA mold before and after heating were inspected using an Olympus BX53M microscope (Olympus Corporation, UIS2 infinity-corrected optical system) with a ten-times magnifying lens. The effect of the PDMS microchannel was also compared between the heated and unheated molds. The schematic of the fabrication process is shown in Figure 2.

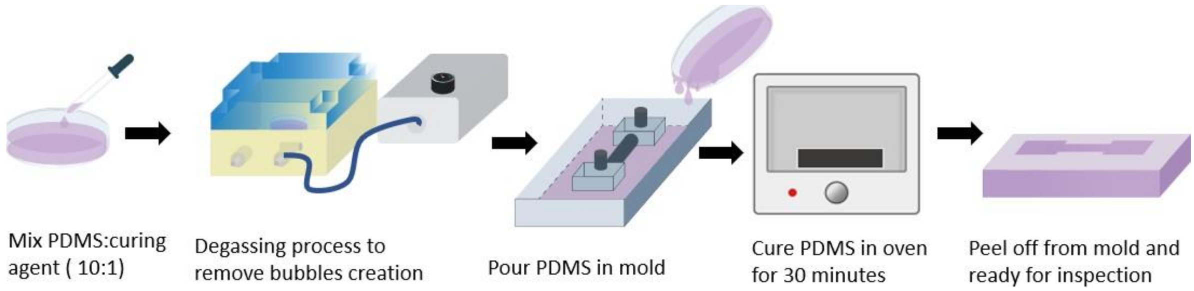

Fig. 2. Schematic of PDMS microchannel fabrication process

3. Results

In this paper observed the effect of heat to the structure of 3D-printer mold. The experiment starts with observing the size of the 3D-mold structure after pre heat the mold at 60 °C. Then the second experiment is observed the effect of PDMS structure when heating the mold. The details of conducted experiment will elaborate details in this part.

3.1 The Size of the 3D-Mold Structure

In the first part of the experiment, the size of the mold was measured before and after preheating. The size of the microchannel for these three molds was compared by repeating the same procedure ten times. Based on the results in Figure 4, the size of the microchannel became wider, with an increment ranging from 0.28% to 5.16%, depending on the material. The highest increment in mold sizing after the heating procedure was observed in the PLA mold, and the lowest increment sizing was observed in the SLA mold, with 5.16% and 0.28%, respectively. After repeating the procedure ten times, the sizing of the microchannel mold became wider. For the PLA mold, it increased from 300 µm to 331.07 µm, as depicted in Figure 3(a). Similarly, the PETG mold increased from 300 µm to 304.33 µm after being heated repeatedly ten times, as shown in Figure 3(b). Figure 3(c) shows the difference between the size of the SLA mold before and after heating, which increased from 300 µm to 301.68 µm. Based on these findings, SLA is a suitable material due to its minimum effect of thermal expansion. The sizing of the PETG and PLA molds were set to 0.3 mm, as the 3D printing machine is capable of producing this size. The molds were made line by line using the machine, as the ink of the PETG and PLA is in a solid string form. Meanwhile, for the SLA, the material is in a liquid form, and at the end, the product was observed using a microscope, and it had the same size as the PETG and PLA molds.

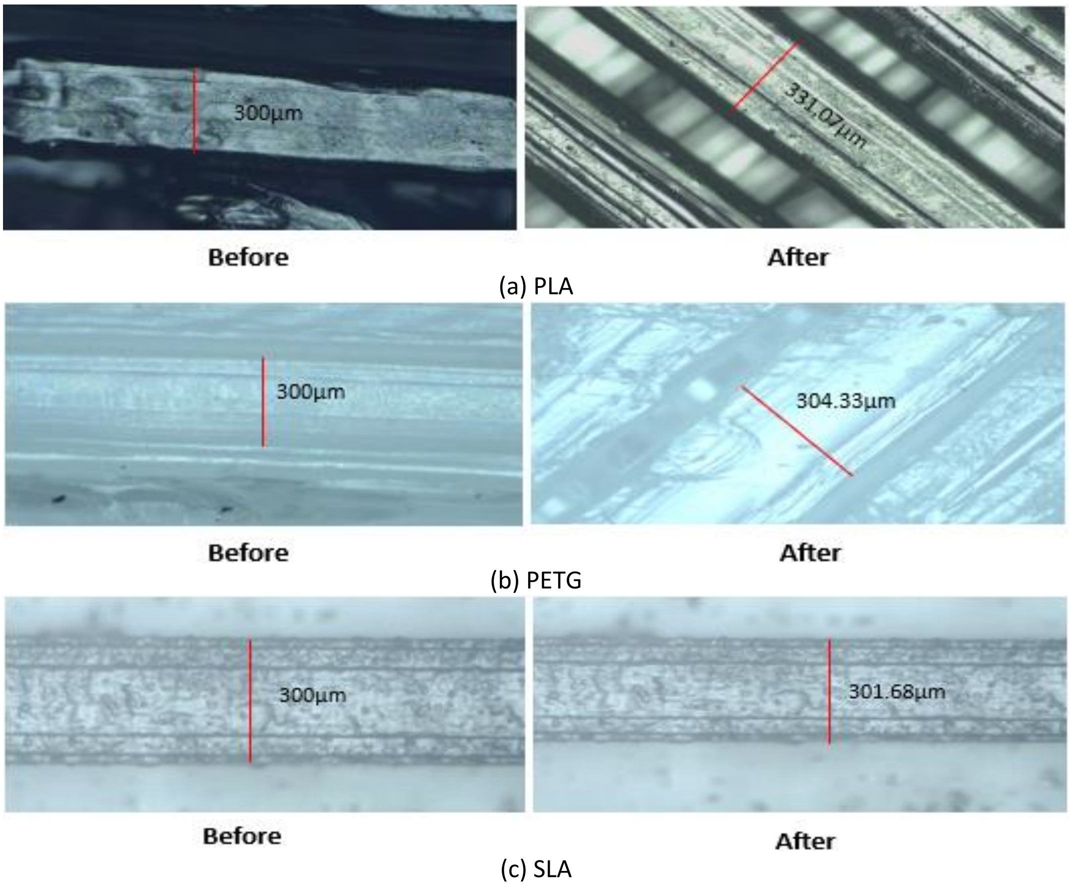

Fig. 3. Size of 3D-printer mold structure before and after the pre-heated procedure

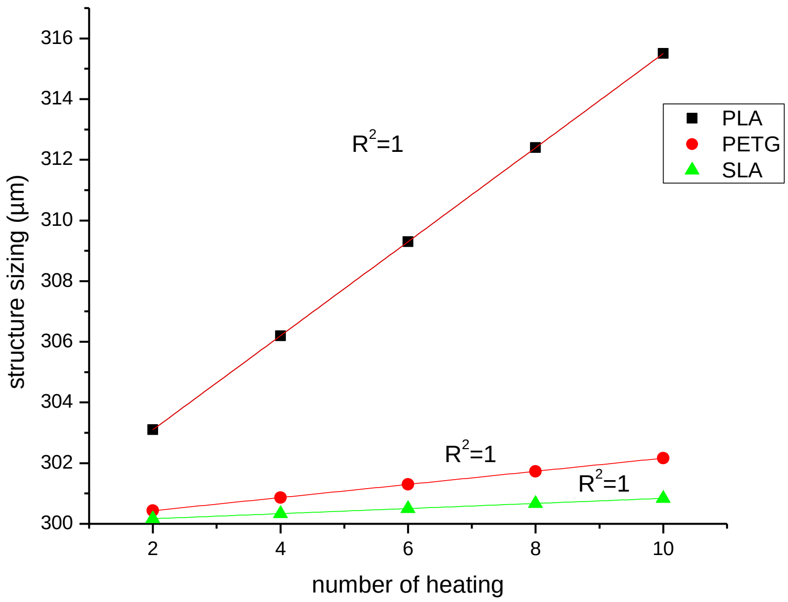

Fig. 4. Structure sizing after heating

3.2 The Effect of Heated Microchannel Mold on the PDMS Microfluidic Channel

This section discusses the impact of heated microchannel molds on PDMS microfluidic channels. Three types of molds (PLA, PETG, and SLA) were used in the experiment, each with a microchannel size of 0.6 mm. The size of each 3D printer mold was measured using an Olympus BX53M microscope. To prevent unintended air during the curing process, all microchannel molds were pre-heated, which affected the size of the microchannels. The study compared the mold materials in terms of the microchannel size before and after the pre-heating process, the size of the microchannel after curing, and the structure of the resulting PDMS microchannel. In this experiment, each mold has been pre-heated 5 times to ensure the consistency of the result by heating for a few times.

The second part of the experiment was observing the size of the microchannel 3D printer mold after the pre-heating process. Based on observations under the microscope, the size of the microchannel mold increased slightly depending on the material. The original size of the microchannel mold was 0.6 µm. After pre-heating, PLA increased to 605.988 µm, with an increment of 0.998%. For PETG, the microchannel increased to 600.5 µm, with an increment of 0.083%. For SLA, the increment was at 0.0083%, the lowest. According to Figure 6, the size of the PDMS microchannel increased linearly as the number of heating increased. Further observation after the first PDMS microchannel was printed showed that the microchannel size increased to 606.984 µm, as shown in Figure 5(a), and for the fifth time, the microchannel increased to 634.92 µm. The increment in size was 5.82% when using a PLA mold. For the next part, the PDMS microchannel printed using a PETG mold was observed. The increment in size from the first to the fifth was 1.47%. At first, the microchannel size was 601.764 µm, as in Figure 5(b), and at the fifth, the size was 600.950 µm. For SLA, the PDMS microchannel size was 600.950 µm at the first printing, as shown in Figure 5(c), and at the fifth, its size was 604.75 µm. The increment in size was 0.791%. At the end of the observation, it showed that the SLA mold gave the most accurate size compared to PLA and PETG. SLA also showed the lowest increment, which is very important in molding applications because any difference between the product and the 3D printed mold would affect the application which also reviewed in the research by Hamid *et al.,* [27].

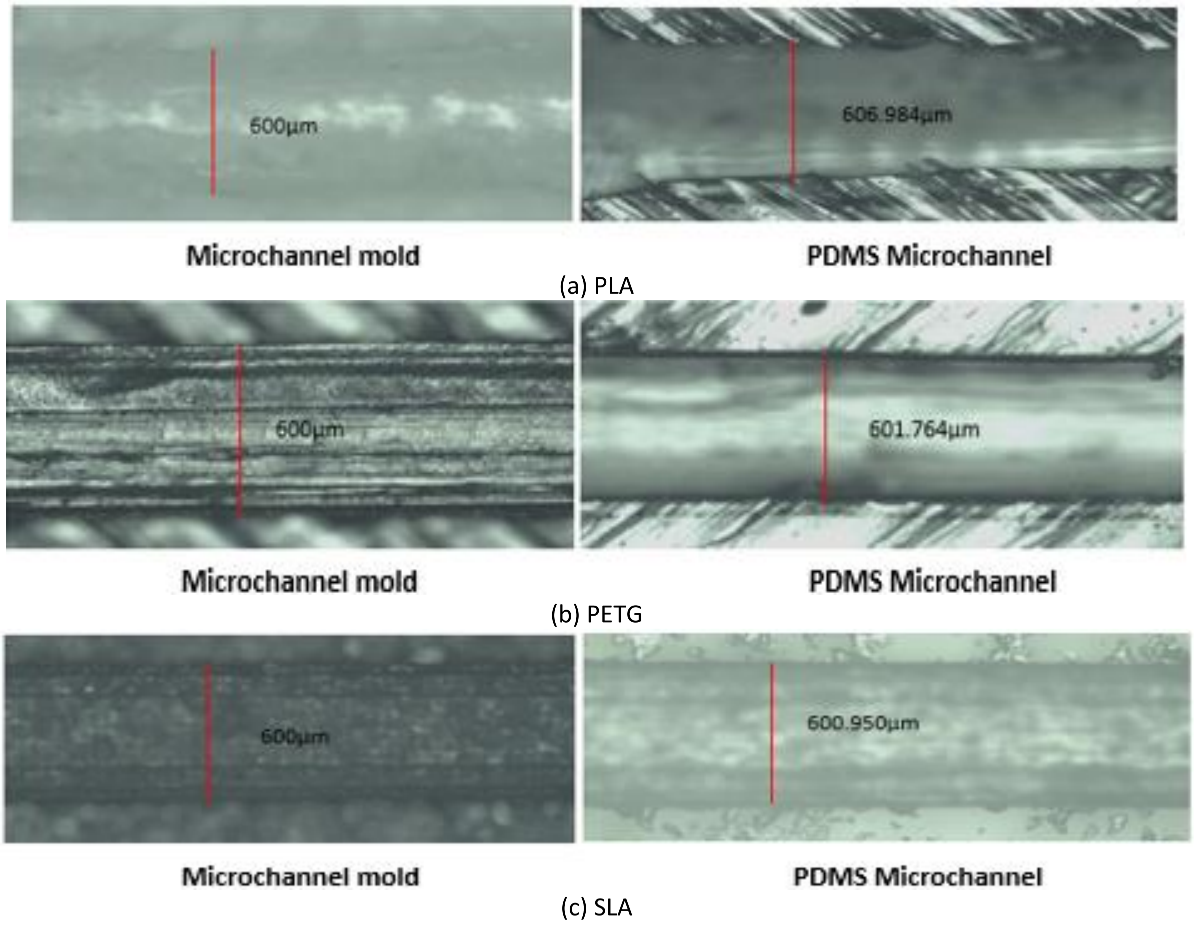

Fig. 5. Size of 3D-printer mold and PDMS microchannel printed using the mold

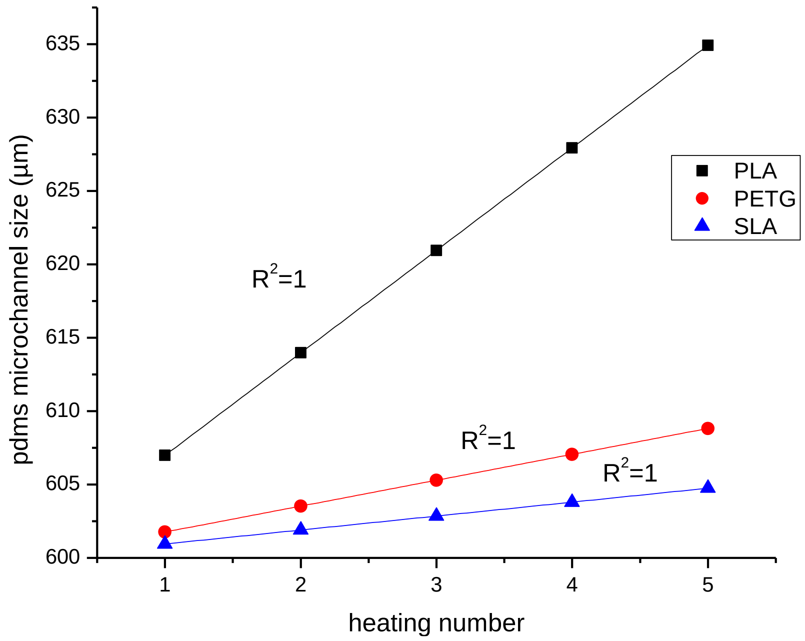

Fig. 6. PDMS microchannel size after printed using the 3D printed mold

4. Conclusions

In this study, we successfully fabricated microchannel molds using 3D printing and PDMS microchannels using these molds. The functionality of the 3D printed mold was found to depend on the material used. After five tests, the PLA mold structure showed a 5.16% increment, while PETG showed only 0.28%. For the PDMS microchannels fabricated using the 3D printed molds, we observed that the PDMS microchannel printed using PLA molds had the highest difference with the original mold, at 5.82%, whereas SLA had only 0.791% difference. Our findings suggest that molds are susceptible to heat, which can increase the size of the structure. Specifically, we found that PLA structures had the highest increment in size compared to PETG and SLA as research by Hamid *et al.,* [27]. Similarly, the PDMS microchannels fabricated using PLA molds showed the highest increment in size compared to those made with SLA and PETG. Based on our results, we do not recommend using PLA material for molds as the heat can change the structure of the mold, compromising the outcome. Our findings highlight the importance of carefully selecting the appropriate material for 3D printing microchannel molds to achieve optimal results.

Acknowledgement

The authors would like to thank the Institute of Research Management and Innovation (IRMI) UiTM for the financial support of Geran Penyelidikan Khas 600- RMC/GPK 5/3/ (254/2020) and the Insitute of Microengineering and Nanoelectronic (IMEN).

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