Research of replication accuracy in some elastomer materials with different Young's modulus

N N Germash¹, N A Esikova¹, P K Afonicheva¹ and A A Evstrapov¹

¹ Institute for Analytical Instrumentation Russian Academy of Sciences, Ivana Chernykh 33A, 198095, St. Petersburg, Russia

E-mail: yilatan_nata@mail.ru

Abstract. In this work we observed three different elastomeric materials with different Young's modulus: Silastic T-4, Plat Set 30, and Lasil-C. Their usage makes it possible to overlap the range of rigidity obtained for Silgard under different curing conditions, without high temperatures and long curing time. The results obtained during the replicas formation using a brass master mold with micro-sized structures for these elastomers were presented. The quality of the replication in materials with low Young's modulus turned out to be better than for Silgard, and for the hard Silastic T-4 – it is comparable to it.

1. Introduction

Due to their properties (optical transparency, thermal and chemical stability, biocompatibility), elastomeric materials are widely used in microfluidics. Polydimethylsiloxane Sylgard-184 (Dow Corning, USA) is most commonly used to create microfluidic devices. The properties of Sylgard-184 are well studied, which is confirmed by many publications with the examples of its use for solving various problems [1]. The Simplicity of Sylgard-184 formation by soft lithography and sealing structures with a glass plate or the same material layer after plasma treatment allows us to quickly create new devices in an ordinary research laboratory. High gas permeability and elasticity of the material make Sylgard-184 suitable for fabrication of "organ-on-chip" devices [2]. A significant drawback of Sylgard-184 is an absorption of small molecules and proteins by the material and a properties instability over time during surface modification. However, in some cases, materials with different rigidity than Sylgard-184 may be required for creating "organ-on-a-chip" systems [3]. Indeed, looking for new suitable materials with necessary properties for prototyping microfluidic devices, focused on solving certain tasks, is highly required and of great interest.

In this paper, we consider three different silicone resin: Silastic T-4, Plat Set 30, and Lasil-C, described in [4]. The elongation at break of these materials is several times higher (4.5 or more) than Sylgard-184 has [5]. Besides, the Silastic T4 and Lasil-C costs of 1 kg is two times, and Plat Set 30 is 4 times lower than Sylgard-184 in the Russian Federation [4]. Higher tensile strength makes it possible to obtain films of smaller thickness and larger area. It is worth mentioning that Silastic T4 and PlatSet 30 have less light transmission than Sylgard-184, and Lasil-C is a non-transparent green material. In addition, we found out that after treatment with oxygen plasma, these materials are firmly connected to themselves and even Silastic T4 can be connected with Lasil-C.

This paper presents the results obtained during the replicas formation using a brass master mold with micro-sized structures for these elastomers. The applicability of master mold materials for Silastic
T4, Lasil-C, and Plat Set 30 was investigated. The material elastic properties were estimated based on the measured Young's modulus.

2. Materials and methods
In this work we compared the elastomeric materials Silastic T-4, Lasil-C (Dow Corning) and PlatSet30 (23stroy, Russia) with Sylgard-184 (Dow Corning).

The formation of microstructures in elastomers was carried out by soft lithography (replica molding) [6] technique using the brass alloy master mold obtained by laser micro-preparation (figure 1). The master mold is an array of convex structures with the size of 1 mm or less, and the height of ~60 microns. The sizes of replicas were estimated: lines (1 mm and 60 microns wide) forming channels in the replica, and cylinders (1 mm and 300 microns in diameter) forming hollows.

Figure 1. Photo of the brass alloy master mold mad obtained by laser micro fabrication, and a ruler

The quality of the structures was studied using a laser scanning confocal microscope TCS SL (Leica). Two surfaces corresponding to the base and top of the structures were scanned and the sizes of the structures (channel width, cylinder diameter) were measured using the standard software for the microscope. For this purpose, we measured 3 identical figures belonged to 3 identical samples (total n=9). For the channels 3 measurements were made from different ends and in the center.

To estimate the side walls quality of linear structures, the replicas were cut by a knife. Thereafter an image of the channel replicas cross-section with a width of 1 mm and 60 microns was recorded by an optical microscope.

The Young's modulus was evaluated by changing of the height of elastomer cylinders (0.5 mm radius, ~3 mm height) when the weight 0.05-0.5 kg was placed on the top [7].

3. Experiment
3.1. Elastomer Young's modulus
The studied elastomers, namely Silastic T4, Plat Set 30, Lasil-C and Sylgard-184, consist of two components, A and B, which polymerize after mixing at room temperature in 24, 4, 8 and 48 hours, respectively. An increase in the elastomer curing temperature can significantly speed up the process of parts obtaining (up to 20-30 minutes), so all the elastomers were cured at 70 °C. For Sylgard-184, the curing time was ~4 hours. The estimated Young's modulus (Table 1) of all the elastomers was lower than that of Sylgard-184 at the same curing temperature. The softest elastomer was Plat Set 30.
Table 1. Young's modulus values for elastomers

| Material       | Compound A:B | Curing temperature, °C | Curing time | Young's modulus, MPa |
|----------------|--------------|------------------------|-------------|----------------------|
| Silastic T4    | 10:1         | 24                     | 24 hour     | 1.90±0.04            |
| PlatSet 30     | 10:1         | 70                     | 20 min      | 1.93±0.03            |
| Lasil-C        | 10:1         | 70                     | 20 min      | 1.09±0.04            |
| Sylgard-184    | 10:1         | 70                     | 4 hour      | 2.71±0.21            |

According to [8] the Young modulus of Sylgard-184 is 1.32-2.97 MPa (this value exceeds the estimates for other elastomers except PlatSet 30), depending on the curing temperature 25-200 °C and, accordingly, the curing time is from 48h to 18 min. However, high temperatures using leads to a greater thermal expansion of the master mold, increases its wear and limits the possibility of using master molds from different less heat-resistant materials. Besides, no significant change in Young's modulus was observed for the studied elastomers when the curing temperature changes from room temperature to 70°C (~0.7 MPa for Sylgard-184 [8]).

The Young's modulus is estimated for various body tissues: elastin – 0.1-0.6 MPa, carotid artery – 0.7-1.1 MPa, femoral artery – 0.9-1.2 MPa, muscles at rest – 0.9 MPa [9]. Thus, the use of Silastic T4, Lasil-C and PlatSet 30 makes it possible to fabricate organ-on-a-chip systems with parameters close to living tissues without high temperature using.

3.2. Study of materials for master mold

For the soft lithography method, master mold from Si/SU-8 obtained by photolithography are widely used [10]. This is an expensive method, since it requires photolithography equipment, which is commonly located and operates in clean rooms. In our laboratory secondary master molds made of glass and UV-curable glue Permabond UV630 and obtained by the method of "capillary casting" (micromolding in capillaries) are also used [11]. For structures with millimeter sizes, it is reasonable to use master molds made by metal milling (for example, in the aluminum alloy D16T [12]). An elastomer layer for microchip sealing is conveniently cast on a sheet of hard plastic, such as a Novattro PC.

The applicability of master mold materials such as Si, glass, SU 8, UV630, brass, stainless steel, polycarbonate and aluminum alloy D16T for casting the studied elastomers was investigated. For this purpose, a drop of elastomer was cured on a plate of the master mold material and the possibility of separating these materials was evaluated. The PlatSet 30 and Lasil-C elastomers were not separated from glass and silicon even when they were pretreated with Molykote S-1011 (marked with the "-" symbol in Table 2). The elastomers were also cast into master molds from these materials. The " + " shows the options when the replica is well separated from the master mold without any processing, and " + / - " - when pre-treating of the master mold is necessary (tested material was covered by Molykote S-1011 for 3 minutes, then rinsed by ethanol and water).

Table 2. Separability of elastomers from various materials after curing

| SU8 | Si | Glass | UV630 | Brass | Stainless steel | PC | D16T |
|-----|----|-------|-------|-------|-----------------|----|------|
| Sylgard-184 | +  | +     | +/-   | +     | +               | +  | +    |
| Silastic T4  | +  | +/-   | +/-   | +     | +               | +  | +    |
| PlatSet 30   | +  | -     | -     | +     | +               | +  | +    |
| Lasil-C      | -  | -     | -     | +     | +               | +  | +    |
The disadvantages of Lasil-C and Plat Set 30 are the inability to work with traditional master molds from Si/SU-8. However, this issue is solved by creating secondary master molds, for example from plastics, or using metal master molds. In addition, it is possible to form a sealed microfluidic chip from these materials by pouring them into a structure made of a soluble material (for example, wax, ABS) between two glasses.

3.3. Structure examination

There is an additional feature of microstructures formation besides the coefficients of thermal expansion of the master mold and the molded material. Namely, the density of the cast material and the wettability of the master mold have a significant impact on the geometric characteristics of the replica.

Table 3 shows the average sizes of the master mold structures and obtained elastomeric replicas. To compare the structures, we used such expression

$$\delta = (a_i - a)/a$$

here $a_i$ is the value for the i-th element of the elastomeric replica, $a$ is the average value for the value of a similar element on the master mold.

**Table 3. Sizes of master mold structures and elastomeric replicas (in microns)**

| Material     | Estimation | 1 mm line | 60 μm line | 1 mm circle | 300 μm circle | 1 mm line | 60 μm line | 1 mm circle | 300 μm circle |
|--------------|------------|-----------|------------|-------------|---------------|-----------|------------|-------------|---------------|
| Master mold  | Average    | 1073.33   | 74.33      | 1086.67     | 314.33        | 1126.67   | 121.00     | 1150.00     | 386.67        |
|              | SD         | 5.77      | 3.51       | 5.77        | 0.58          | 5.77      | 7.94       | 0.00        | 10.79         |
| Sylgard-184  | Average    | 1042.22   | 56.67      | 1061.11     | 308.25        | 1100.00   | 123.67     | 1111.11     | 372.33        |
|              | SD         | 8.33      | 2.06       | 6.01        | 4.46          | 12.25     | 3.61       | 7.82        | 5.94          |
|              | $\delta$   | -0.029    | -0.238     | -0.024      | -0.038        | -0.024    | 0.022      | -0.034      | -0.037        |
| Lasil T-4    | Average    | 1044.44   | 54.33      | 1064.44     | 303.00        | 1117.78   | 130.33     | 1125.56     | 378.89        |
|              | SD         | 10.14     | 3.46       | 5.27        | 3.77          | 10.93     | 3.94       | 10.14       | 6.35          |
|              | $\delta$   | -0.027    | -0.269     | -0.020      | -0.054        | -0.008    | 0.077      | -0.021      | -0.020        |
| Lasil-C      | Average    | 1066.67   | 61.89      | 1078.89     | 311.89        | 1105.56   | 120.44     | 1120.00     | 372.33        |
|              | SD         | 12.25     | 7.52       | 6.01        | 9.23          | 5.27      | 6.62       | 11.18       | 8.54          |
|              | $\delta$   | -0.006    | -0.167     | -0.007      | -0.026        | -0.019    | -0.005     | -0.026      | -0.037        |
| PlastSet 30  | Average    | 1046.67   | 56.44      | 1065.56     | 303.22        | 1104.44   | 122.00     | 1128.89     | 382.67        |
|              | SD         | 8.66      | 4.50       | 8.82        | 4.09          | 14.24     | 10.25      | 12.69       | 6.50          |
|              | $\delta$   | -0.020    | -0.008     | -0.018      | -0.010        | -0.020    | 0.008      | -0.018      | -0.010        |

During the replication the structure sizes reduced. The closest to the original structure sizes were obtained for the material with the minimum Young's modulus – PlatSet 30, the reduction was up to 2%. For Lasil-C, it was up to 3.7%, except for the channel width of 60 microns (deviation up to 16.7%, rounding of the bottom of the channel). The replication quality for Silastic T4 is comparable to Sylgard-184 for 1 mm structures (the change in the structures was up to 3%). For the cylinders with a diameter of 300 microns, when replicating in the Sylgard-184, the size deviation for the upper part and base is up to 4%. For Silastic T4, there is a deviation of 2% for the base, and 5.4% for the top. The channels with a c of 60 microns during the replication in Sylgard-184 and Silastic T4 had a narrowing of the upper part (by 24 and 27%, respectively) and the expansion of the base (by 2.2 and 7.7%).

Since there is a significant standard deviation of sizes between the "similar" shapes on the master mold, the analysis of this value was not carried out.

Table 4 shows optical images of the cross-section of the channels with the width of 1 mm and 60
micronson elastomeric replicas (elastomer on the right). We can observe that the width of the narrow channel of PlastSet 30 is less than that of other elastomers. For materials with a lower Young's modulus (PlatSet 30 and Lasil-C) a deepening around the resulting structures is observed. There is need to investigate in what way it can affect the further sealing.

Table 4. Optical images of cross-sections of linear structures made of elastomers

| Sylgard-184 (transmitance) | Lasil T-4 (transmittance) | PlastSet 30 (transmitance) | Lasil-C (reflectance) |
|---------------------------|---------------------------|---------------------------|-----------------------|
| 1 mm                      |                           |                           |                       |
| 60 μm                     |                           |                           |                       |

4. Results
The applicability of Silastic T-4 and Lasil-C (Dow Corning) and PlatSet 30 (23stroy, Russia) elastomers for microfluidics was investigated. These materials are 2-4 times cheaper than Sylgard-184 and cure faster (4 times at 70°C). In addition, they have a higher tensile strength than Sylgard-184.

The Young's modulus of elastomers was evaluated under the curing conditions of 70°C for 30 min. It ranged from (1.09±0.04) MPa for the PlatSet 30 to (1.93±0.03) MPa for the Silastic T-4. So, it is possible to obtain structures from a material of suitable rigidity without high temperatures using or longpolymerization time.

The elastomers with lower Young's modulus than traditional Sylgard-184 has can allow us to create conditions closer to living matter (organs) for the fabrication organ-on-a-chip systems. Also, the low Young's modulus together with the high tensile strength let us create flow control systems, in particular valves, diaphragms, flexible membranes, etc. Also, additional features make connection possible after plasma treatment of the material with the high Young's modulus (Silastic T-4) and the lower one (Lasil-C). On the other hand, a low Young's modulus can lead to significant structures deformation even under small pressures. Therefore, it is not recommended to use such materials in microfluidic devices, where conditions of sufficiently high rarefaction or pressure are assumed.

The significant disadvantages of Lasil-C and Plat Set 30 are their inapplicability during an operation with traditional master forms from Si/SU-8 and glass/UV630. However, this disadvantage is eliminated by creating secondary master molds, for example, from plastics or using metal master molds. In addition, it is possible to form sealed chips by pouring these elastomers into soluble structures between the two glasses. Made of materials with the lower Young's modulus (Lasil-C and Plat Set 30) structures in replicas more accurately reproduce the sizes of the original than in replicas made of more rigid elastomers. Replicated in Plat Set 30 the structures are reduced (up to 2%). In Silastic T-4 the channels and cylinders with sizes of 1 mm and 300 microns are obtained in approximately the same way as in Sylgard-184. For the channels with the width of 60 microns (the height of the structures is 60 microns), the replication in Sylgard-184 and Silastic T4 shows a narrowing of the upper part (by 24 and 27%, respectively) and the expansion of the base (by 2.2 and
7.7%).

Hence all three materials can be used for the manufacture of microfluidic devices or functional elements of these devices, expanding prototyping capabilities.

References

[1] Kiran R M and Chakraboty S 2020 PDMS microfluidics: A mini review Journal of Applied Polymer Science 137(27):48958

[2] Chia-Wen T 2016 Polimer microfluidics: Simple, low-cost fabrication process bridging academiclab research to commercialized production Micromachines 7(12) 225-236

[3] Afonicheva P K, Bulianitsa A L and Evstrapov A A 2019 Organ-on-Chip - Materials and Manufacturing Methods (Review) Nauchnoe priborostoenie 29(4) 3-18

[4] Dow Corning Sylgard 184 Solar Cell Panel Silicone Elastomer Encapsulation Kit URL: https://www.ebay.com/p/1547012001?iid=203268101447 (accessed: 16.02.2021)

[5] Lassospb URL: https://lassospb.ru/products/category/silikon-jidkyi-rezina-dlya-form (accessed: 20.02.2021)

[6] P. Kim, K.W. Kwon, M.C. Park, S.H. Lee, S.M. Kim, K.Y. Suh Soft Lithography for Microfluidics: a Review // BIOCHIP JOURNAL, 2008, Vol. 2, No. 1, 1-11

[7] Sharfeddin A 2015 Comparison of the macroscale and microscale tests for measuring elastic properties of polydimethylsiloxane Journal of Applied Polymer Science 132(42) 1-6

[8] Johnston I D, McCluskey D K, Tan C K L and Tracey M C 2014 Mechanical characterization of bulk Sylgard 184 for microfluidics and microengineering Journal of Micromechanics and Microengineering 24(7) 035017

[9] Remizov A N, Maksina A G and Potapenko A IA Potapenko 2003 Medical and biological physics (Moscow: Bustard) p 624

[10] Lee J B 2015 Innovative SU-8 lithography techniques and their applications Micromachines. 6 1–18

[11] Xia Y and Whitesides G M 1998 Soft Lithography Angew Chem Int Ed Engl 37(5) 550-575

[12] Germash N N, Esikova N A, Afonicheva P K, Antifeev I E, Petrov D G and Evstrapov A A 2020 Elastomer planar device for nucleic acids extraction Journal of Physics: Conference Series 1697:012043