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Fabrication and evaluation of various types of micro one-way valves through micro rubber molding process †

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Abstract

In recent years, research and development on micro fluid systems has become active in the fields of chemical technology and biotechnology. For the realization of these micro fluid systems, micro fluid devices such as micro-valves and micro pumps are very important. This paper reports the fabrication and experimental evaluation of several micro one-way valves. The valves are fabricated through a micro molding process, which makes the fabrication process simple and suitable for mass production. The experimental results indicate that the developed valve has great performance with a normal flow rate of 130.2 ml/min and a leak flow of 2.2 ml/min. The normal flow rate is 1.4 times higher than that of the previous model.

Keywords: MEMS; Micro fluid device; Micro rubber molding; One-way valve

1. Introduction

In recent years, expectations on the use of micro-fluid systems and micro-fluid devices have been increasing in the fields of chemical technology and biotechnology [1, 2]. A micro valve is one of the key devices and we have been working to develop micro one-way valves [3]. We have studied silicone rubber one-way valve using micro molding process with precise molding die. In the previous report, the flat prototype one-way valves have been fabricated and tested [4]. In this report, we propose several new types of one-way valves with different materials and shapes. Newly proposed valves have three-dimensional structures such as a human aortic valve and V-shaped valves. They are fabricated from two types of silicone rubber with different hardnesses. Valve characteristics such as the pressure drop and leak flow are experimentally clarified. In addition, we observe the motion of the valve disc in fluid by making a transparent acrylic valve body.

2. Design and fabrication

In this section, the designs and fabrication process of several types of one-way valves are presented. The valves are fabricated from RTV silicone rubber through the micro molding process with precise die.

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2.1 Design of several models

2.1.1 Cantilever valve

A cantilever valve consists of a single flat disc, which is often used in conventional pumps. In the previous report [4], we discussed this design with four valve discs with different thickness. In this report, we fabricate the valve discs using softer silicone rubber and evaluate them.

The developed cantilevers are 2.0 mm in outer diameter, and the valve discs are 1.2 mm in diameter. The radial clearance between the valve body and the disc is 0.05 mm.

Three valve discs with different thickness of 0.2, 0.3, and 0.4 mm are designed and fabricated. Silicone rubber with 15 durometer hardness is used. The SEM and CAD images of the developed valve are shown in Fig. 1.

2.1.2 Double gate valve

This valve has two half-moon-shaped cantilever valve discs.

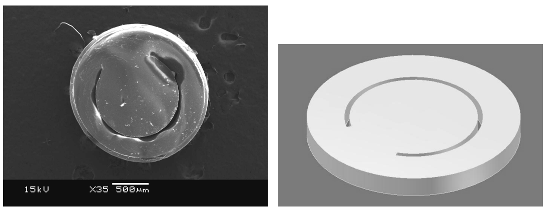

Fig. 1. SEM and CAD images of the cantilever valve (0.2 mm in thickness).

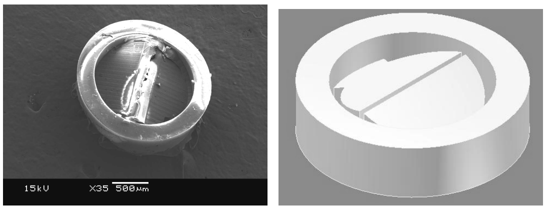

Fig. 2. SEM and CAD images of double gate double gate valve.

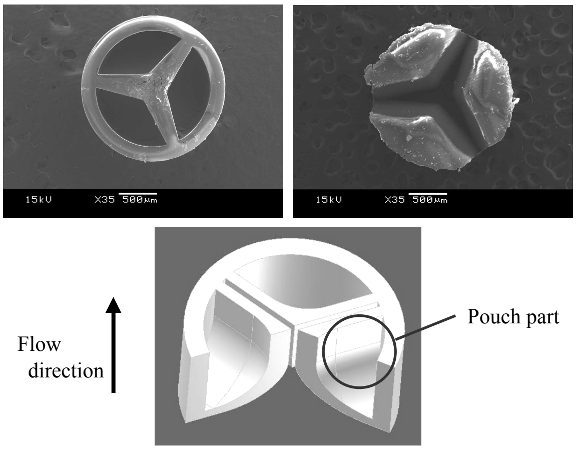

Fig. 3. SEM and CAD images of the aortic valve.

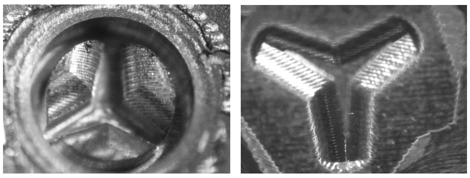

Fig. 4. Precise die for micro molding process (enlarged views of die for aortic valve type).

This design aims to realize a low pressure drop and high response. The prototype is 2.0 mm in outer diameter. The valve disc is 1.2 mm in diameter and 0.5 mm in thickness. The radial clearance between the valve body and the disc is 0.05mm

2.1.3 Aortic valve

This model is designed by imitating a human heart aortic valve. As shown is Fig. 3, the valve consists of three concave pouches. While the flow in the forward direction squashes the pouches and the fluid path is open, the flow in the inverse direction expands the pouches, pressing them against each other and closing the fluid path. The developed aortic valve is 2.0 mm in outer diameter and 0.7 mm in length.

2.2 Micro rubber fabrication

A fine NC milling machine is used to make the dies for the rubber molding process. Fig. 4 shows an example of dies used for the aortic valve. Duralumin is used as the die metal. The cutting accuracy of the milling machine is 10 μm both in the X and Y directions and 5μm in the Z direction. Two liquid mixing type silicone rubbers are used to fabricate the designed valves. We use two types of silicone rubber with different hardnesses at 15 and 28 in durometer hardness.

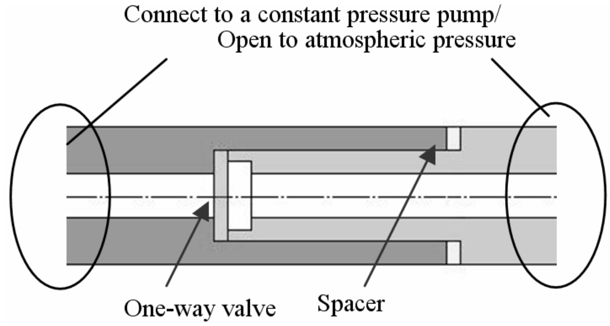

Fig. 5. Experimental setup for testing the static characteristics.

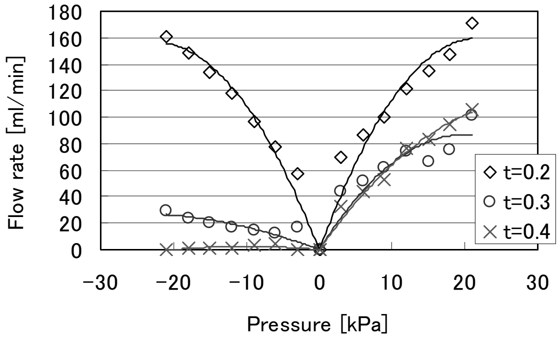

Fig. 6. Pressure-flow rate characteristics of the cantilever valve (rubber hardness=15).

3. Experiments

Experimental evaluations ware made for the developed valves. The characteristics of the pressure-flow in both directions, that is, the pressure drop in the forward direction and the leak flow in the inverse direction, are discuss in section 3.1. Observations on the valve disc motion in flow are presented in section 3.2.

3.1 Pressure - flow characteristics

Fig. 5 shows the testing setup for the pressure-flow characteristics. The upstream port is connected to a constant pressure pump, and the downstream port is open to the atmospheric pressure. The difference in the pressure between the constant pressure pump and the atmospheric pressure causes the one-way valve motion.

The experiments ware conducted with water. The mass flow rate of the water was measured using an electronic valance flow rate transducer during in the change pressure.

The experimental results are shown in Figs. 6-8 and in Table1. Fig. 6 shows the results of the cantilever valves made of rubber with 15 durometer hardness. Fig. 7 shows the result of the double gate valve and the aortic valve made of the rubber with 28 durometer hardness. Fig. 8 shows the results of valves made of the rubber with 15 durometer hardness. The left part of the graph represents the leak flow rate, and the right part represents the forward flow rate. The results are summarized

Table 1. Experimental results of the flow rate in the forward/inverse direction; pressure difference is 21 kPa.

			forward [ml/min]	inverse [ml/min]
Rubber hardness =28	Cantilever valve [4]	t=0.4	52.2	5.3
		t=0.3	72.6	2.8
		t=0.2	88.9	1.8
		t=0.1	133.4	140.1
	Double gate valve		162.7	15.4
	Aortic valve		86.5	18.4
Rubber hardness =15	Cantilever valve	t=0.4	106.2	4.6
		t=0.3	100.9	29.5
		t=0.2	171.1	161.2
	Double gate valve		159.9	92.0
	aortic valve		130.2	2.2

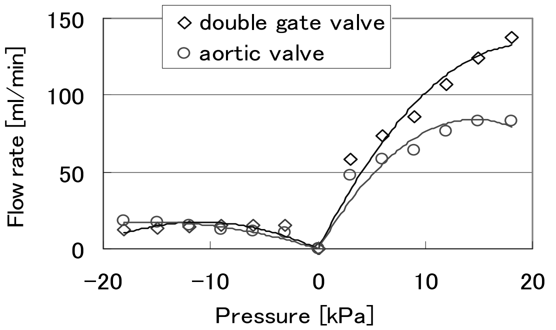

Fig. 7. Pressure-flow rate characteristics of the double gate valve and aortic valve (rubber hardness=28).

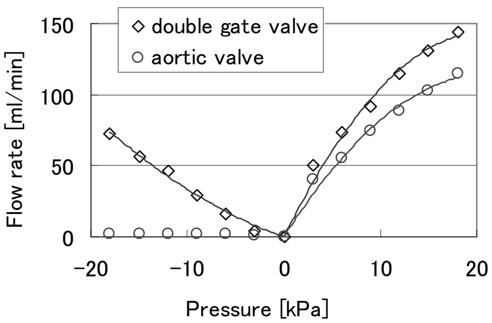

Fig. 8. Pressure-flow rate characteristics of the double gate valve and aortic valve (rubber hardness=15).

in Table 1, where the maximum flow rates in the forward/inverse directions for the pressure of 21 kPa are shown.

As shown in Fig. 6, the cantilever valve with 0.4 mm thickness works very well, while the thinner cantilever valves causes the flow leak in the inverse direction. Table 1 also shows the experimental results of the cantilever valves made of rubber with 28 hardness. The cantilever valve with low stiffness results in high flow capacity in the forward direction and leak flow in the inverse direction.

As shown in Figs. 7 and 8, the double gate valves work as a one-way valve, but the flow leak is not small compared with the other valves.

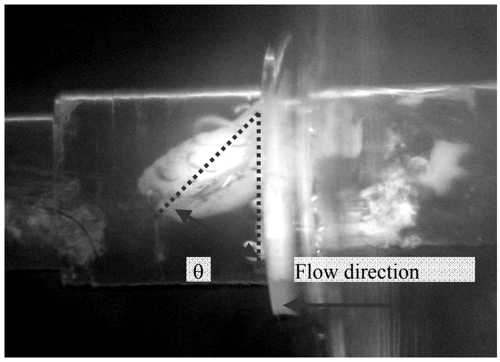

Fig. 9. Observation setup of the valve motion (cantilever, t=0.4, rubber hardness=15, flow pressure=12 kPa).

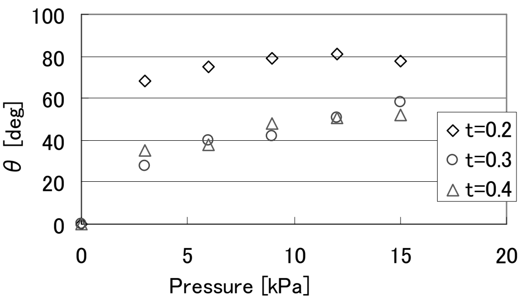

Fig. 10. Inclination angle of the cantilever valve (t=0.2, 0.3, 0.4 mm, hardness=28).

As shown in Figs. 7 and 8, the aortic valves show good performance both in the forward and inverse directions. Specifically, the aortic valve with a rubber hardness of 15 shows the best performance in the prototypes.

3.2 Observation of valve motion

To observe the valve disc motions in flow, we fabricated a valve body from transparent acrylic. As shown in Fig. 9, the inclination angle of the valve disc θ is measured and evaluated. As shown in Fig. 10, the valve disc of 0.3 mm thickness and 0.4 mm thickness shows almost the same inclination angles, but they actually have different flow capacities, as presented in Table 1.

The reason for this is that thick valve discs narrow the flow path and causes the pressure drop.

4. Conclusion

We established a micro rubber molding process using precise die. This process enabled us to design and fabricate several types of micro one-way valves with three-dimensional structures, flat type, double gate type and aortic type with different rubber hardnesses and thicknesses. We made the experimental evaluation on the pressure-flow characteristics and observed the valve disc motions in fluid. The experiments clarified the valve characteristics. The aortic valve showed the best performance, with a forward flow rate of 130.2 ml/min and a leak flow rate of 2.2 ml/min. These values are 1.5 times and 1.2 times higher than those of the previous valve.

Acknowledgment

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