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Developments for a Fluid Valve Using Magnetic Gels

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We have fabricated the fluid valve in a fluid tube of 800 μm in diameter using magnetic gels. The magnetic gel was made from a network of poly(vinyl alcohol) crosslinked by glutaraldehyde and fine particles of iron oxide. When a weak magnetic field was applied to the valve, the valve came into a microtube and, as a result, a flow of water stopped. The valve opened and closed in response to the magnetic field generated by a permanent magnet. The valve worked well under the pressures of water from 0.3 MPa to 1.6 MPa.

Key words: gels, magnetic gel, actuator, microvalve

1. INTRODUCTION

Since the past decade actuators using polymer gels have been widely investigated. Ionic conductive polymer gels such as polyelectrolyte gels undergo bending motion under ac electric fields. Actuators using the bending motion of a polyelectrolyte gel were reported, and they were called gel-looper [1] and gel-eel [2]. Amphiphilic polymer gels swollen by an organic solvent show a motion by spreading the organic solvent [3]. Conductive polymers also have a potential to be an actuator. Polypyrrole films undergo rapid and intensive bending in the solid state induced by the reversible and anisotropic adsorption [4]. Photo reactive polymers show a deformation by UV light. Liquid crystalline gel films containing freestanding azobenzene undergo a significant and anisotropic bending toward the irradiation direction due to the isomerization [5].

We refer to magnetic field-responsive gels as magnetic gels and has a great potential for actuators. The magnetic gel consisted of poly(vinyl alcohol) and magnetic fluids elongates under non-uniform magnetic fields [6,7]. Elastic modulus of magnetic gels such as PVA-magnetic fluids [8], PVA-barium ferrite [9] and κ-carrageenan-barium ferrite [10, 11] gels changes due to magnetization. These studies revealed that the magnetic gels could respond faster and deform larger compared to the other stimuli-responsive gels.

There are some papers describing a fluid valve using on a microchip. The valve made from a piezoelectric element demonstrates a rapid response with applying electric voltage. However, to construct a microvalve less than 1 mm using a piezoelectric element is quite difficult. On the other hand, microvalves using a thermo-sensitive gel have been developed in the past. However, the reaction time acquired for opening and closing of the valve is more than 20 s [12, 13].

We have succeeded in fabricating a microvalve using magnetic gels. Synthesis and fabrication of the valve, and the properties of water flow have been investigated.

2. EXPERIMENTAL PROCEDURES

The magnetic gel valve is made of a finely dispersed powder of barium ferrite and poly(vinyl alcohol) (PVA). A 4 wt.% of PVA aqueous solution and iron oxides Fe_3O_4 (Wako Chemicals) were mixed at 80°C. The mean diameter of magnetic particles was determined as 15 μm. A 25% of glutaraldehyde aqueous solution was used as a crosslinking agent. Crosslinking reaction was taken place by adding hydrochloric acid. The aqueous solution of PVA mixed with iron oxides was poured into a Teflon tube with a diameter of $\phi \sim 1$ mm. The weight fraction of iron oxides was 0.25. The magnetic flux density of the permanent magnet used in the present study was 80 mT.

The flow rate was calculated by the weight of flowed water during 10 sec. The weight of water was measured by an electronic balance.

3. RESULTS AND DISCUSSIONS

Fig. 1 shows the photographs of the microvalve using magnetic gels developed in the present study. The valve can be driven by a permanent magnet as shown in the photograph. The magnetic gel came into the microtube simultaneously with approaching the permanent magnet, and a flow of water stopped. It was found that the magnetic gel was deformed by the magnetic force of the permanent magnet.

Fig. 2 shows the flow rate of the microvalve in response to open-close switching at low pressure of water (0.31MPa).where magnetic gels with 0.2 and 1.0 mol% of crosslinking densities were used. As can be seen in the figure, water flowed synchronized with opening and closing of the microvalve. When the valve was closed, no leak of water was seen for the valve made of magnetic gel with the crosslinking density of 0.2 mol%. Oppositely to this, the flow of water with ~1 ml/min was observed for the valve made of magnetic gel with the crosslinking density of 1.0 mol%.

Fig. 3 shows the flow rate of the microvalve in response to open-close switching at high pressure of water (1.6MPa).where magnetic gels with 0.2 and 1.0 mol% of crosslinking densities were used. Water flowed synchronized with opening and closing of the microvalve in a similar way at low pressure of water. The valve made of magnetic gel with the crosslinking density of 0.2 mol% worked well repeatedly, i.e. closed and opened, even at high pressures. However, the valve with the crosslinking density of 1.0 mol% worked only one cycle; magnetic gel with a high crosslinking density cannot recover its shape once the gel come into a microtube. It might be that the high pressure of water in a microtube affects a shape change of the gel.

Fig. 4 shows the relation between the pressure of water and the flow rates in a period of 10 min. The microvalve of the magnetic gel with 0.2 mol% did not show leakage of water at all the pressures. With increasing the crosslinking density of the gel, the leakage flow rate increased. It is because that the gels with high crosslinking densities are difficult to deform by magnetic fields.

4. CONCLUSION

A microvalve into a fluid tube of 800 μm in diameter has been constructed using magnetic gels. When a weak magnetic field was applied to the valve, the valve came into the microtube as a result a flow of water stopped. The valve opened and closed in response to the magnetic field generated by a permanent magnet. The valve worked well under the pressures of water from 0.3 MPa to 1.6 MPa. Since the driving force is a magnetic field, no electrical leads to the valve are needed. The valve presented here has a great potential to be a microvalve working on a microchip.

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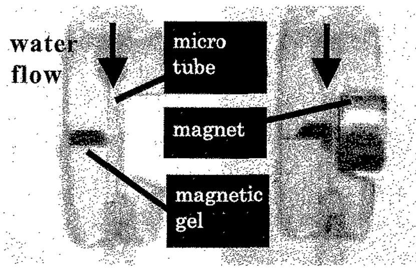

Fig. 1. Photographs of the microvalve developed in the present study. The figures correspond to opened (left) and closed (right) states, respectively.

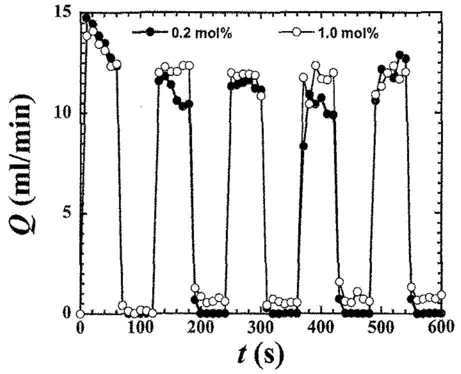

Fig. 2. Open-close switching of the microvalve made of magnetic gels with different crosslinking densities (P=0.3 MPa).

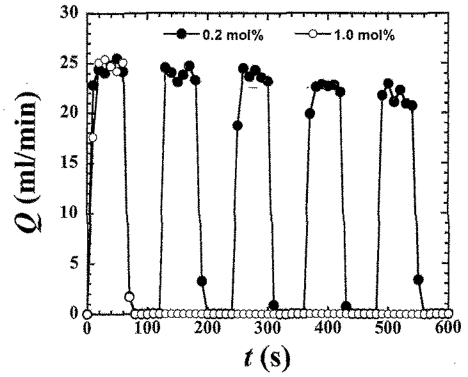

Fig. 3. Open-close switching of the microvalve made of magnetic gels with different crosslinking densities (P=1.6 MPa).

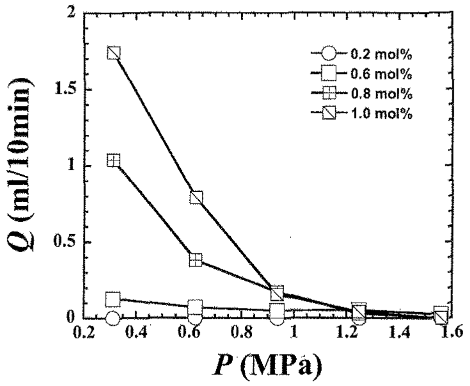

Fig. 4. Pressure dependence of the leakage flow rates of the microvalves made of magnetic gels with various crosslinking densities.

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