Development of 4D Printing System with Magnetic Anisotropy

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Nowadays, 3D printers are widely used for industrial products and personal use. Recently, researchers at MIT and Harvard University proposed a new kind of 3D printer, which not only fabricates the forms of structures but also prints out the deformations of formed ones [1,2]. They are called "4D printer" since the printed object can change a 3-dimensional shape with time, which is the 4th dimension. However, these innovative printers have some disadvantages: the deformation rate is low, and they can work only in water because swelling materials are used. We proposed a new printing system for magnetic elastomer, which is composed of photo curable resin dispersed with magnetic particles. Figure 1 illustrates the system. During the curing process, a magnetic field is applied and particle chain clusters are formed that cause magnetic anisotropy. After printing, the structure is placed under an applied magnetic field, and these chain clusters cause the rotational moment to be along the magnetic flux line. Thus, we can control a whole deformation of a structure by designing oriented angles of particle chains in each portion. With this manufacturing method, variable actuators could be fabricated.

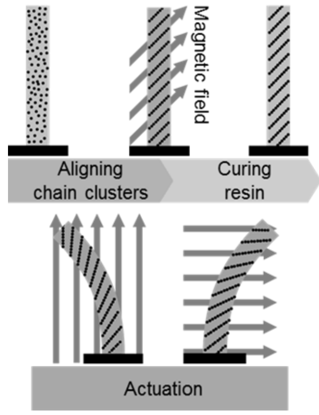

Figure 1. Schematic images of fabrication process and actuation.

We employed UV-curable resin, and carbonyl iron powders were dispersed as magnetic particles. The printing system was based on the conventional stereolithography. The prepared mixed material was poured into a tank. The surface of the printing stage was set in the pool at the depth of one layer. Next, a magnetic field was applied under the pool. A magnetic field was applied at the curing point along to the designed direction. Then, UV laser scanned to cure the designed area of the resin layer. The table went down by a layer-pitch, and the same procedure was repeated.

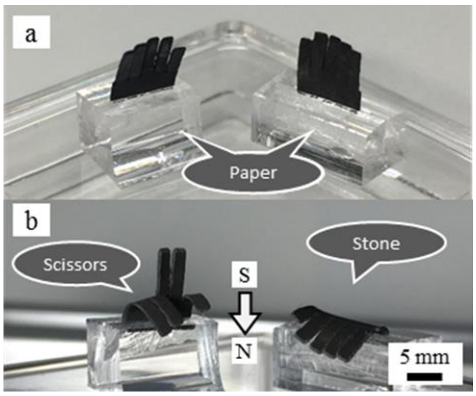

Figure 2. Demonstrarion of scissors paper stone; a) without magnetic field and b) applied magnetic field.

We demonstrated two examples by this system. Figure 2 shows the deformation of hands into scissors, paper, and rock, like in the well-known game "rock-paper-scissors". The fingers had two kinds of directions of magnetic chain clusters. At first, each of the five fingers extended without magnetic field, while, under applied magnetic field, all fingers deformed but 2 fingers bent down. Next, Fig. 3 shows artificial cilia fabricated by this printing system. This structure has 16 x 4 cilia on the side. There are 4 types of periodically magnetic anisotropies in one layer and in the vertical direction. Each artificial cillium can repeat crawling periodically under rotational magnetic field, therefore, the cilia can make a wave with phase differences. In nature, a similar wave can be observed, for example cilia on the surface of a microorganism. This wave is called metachronal wave, which can flow liquid effectively. A traditional method of fabricating magnetic driven actuators can only reproduce a synchronizing movement of cilia. This artificial metachronal wave showed this 3D printing system could be a powerful tool to fabricate micro soft actuators.

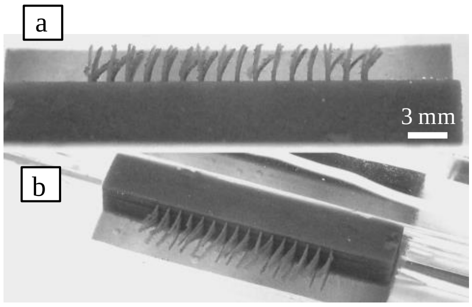

Figure 3. Images of artificial cilia fabricated by 3D printer with magnetic anisotropy; a) Top view and b) Overall view.

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