SMARTERIAL – Smart matter optomagnetic

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***Abstract*—Smart materials, also known as programmable materials, are a combination of different components that have the capability to change shape, move around and adapt to numerous situations by applying an external controllable field. Previous works have used optically guided matter or magnetically actuated materials, but similarly to soft robots, they are limited in spatial resolution or strength. Here we propose combining a low temperature thermoplastic polymer Polycaprolactone (PCL) with ferromagnetic powder particles (Fe). Focused light can heat this compound at specific locations and make it malleable. These heated spots can be actuated by external magnetic fields. Once the material cools down, this process can be repeated, or reversed. The compound can be actuated contact-less in the form of 3D slabs, 2D sheets, and 1D filaments. We show applications for reversible tactile displays and manipulation of objects. The laboratory team has characterised the density, weight, magnetic attraction, magnetic force, phase change, thermal and electrical conductivity and heat diffusion (spread point test) for smart ferromagnetic compounds of different mixture proportions. The main advantages of this smart matter optomagnetic are the high spatial resolution of light and the strong force of magnetic attraction whilst mechanical properties of polymers are practically conserved. Due to the low temperature required and the possibility to use infrared or electromagnetic induction to heat the compound, the smart material can be used in air, water, or inside biological tissue. Eventually, smart materials will enrich collaborative movements, such as grab and hold, and more complex ones, as reshaping and reassembling.**

***Keywords*—Material Science, Programmable materials, Silly Putty, Haptics, Soft Robots, Magnetic and Thermal Control**

I. Introduction

The excellent malleability that thermoplastic exhibits at certain temperatures combined with the ferromagnetic property that includes Fe particles throughout the matrix, make this component an interactive material by applying a magnetic field.

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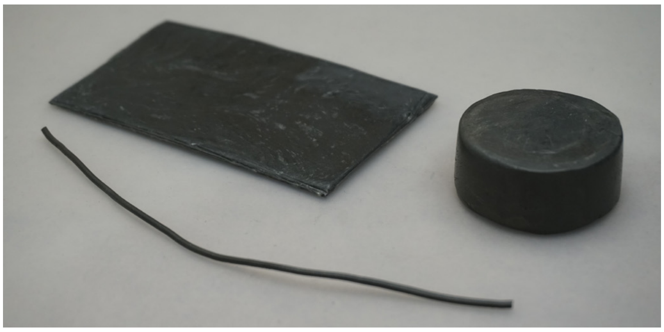

Figure 1. Three different dimensional samples of smarterial. Crafted 3D slab, 2D sheet and 1D filament.

By the application of specific heat sources on the material, these areas of the composite become malleable. Taking into account this property offered by the mixture, a magnetic field is applied to these areas, through a certain gradient of permanent magnets, which will be in charge of attracting the Fe particles that are located within the matrix. The malleable state of the PCL allows the Fe particles to move attracted by the magnetic field, dragging with them the polymeric material and thus modifying the shape of the compound.

This phenomenon allows a large number of applications ranging from the instantaneous formation of Braille code to the printing of different shapes in the same matrix, depending on the thermally altered area and the shape of the subsequent magnetic field applied to the material. Not only is it interesting to build a matrix with this compound, but there are also elements such as filaments and surfaces, with which you can interact in the same way as described for the matrix.

Figure 2. 3D sculpting, 2D patterning (e.g. Braille code) and 1D lettering.

II. Related work

Previous research have shown the high performance that this type of materials are capable of. Millimetre-scale flexible robots[[5]] or small-scale soft continuum robots[2] seems to be the state of the art. These technology came out as a result of the intention to discover a new innovative method to combine human body and robots. Imaging how it is introduced and controlled inside our organism is truly a step forward for medicine. Cargo delivery microswimmer[3], a self-assemble origami robot that can recycle itself[6], multimodal locomotion soft-bodies[1] or insect inspired robots[4] are examples reachable for this material.

III. Methods

The present characterization includes different proportion samples depending on their percentage of iron (Fe) inside the mixture (from 1 to 5). Moreover, the compounds were crafted either by manual transforming (M) or by chemical synthesis (C). Next table expose the compounds of the right picture, following the order from left to right of the both rows:

TABLE I. Iron (FE) proportions inside the compounds

Iron (Fe)	10%	20%	30%	40%	50%
M (%)	M1	M2	M3	M4	M5
C (g)	C1	C2	C3	C4	C5

A. Thermal conductivity

All samples have been placed on a hot-bed at 50ºC. The temperature of each compound have been recorded by a thermal camera RS T-10. It demonstrates that the more iron, the more thermal conductivity the material has. Bear in mind that this also affects the cool-down.

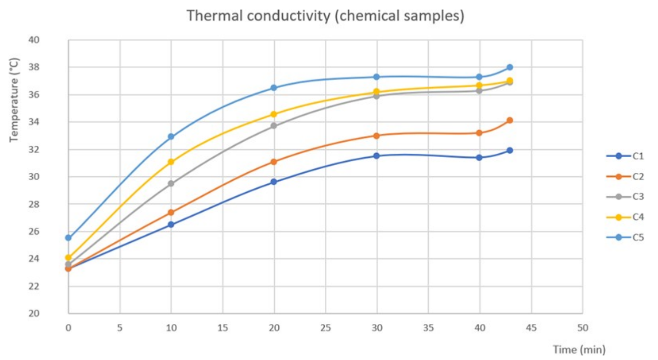

Figure 3. Thermal conductivity results of chemical samples

B. Magnetic force

For this experiment, each sample has been subjected to a vertical force (F), perpendicular to its surface, while on a magnet hanging from a weight scale. Chemical samples C4 and C5 reached more than 5kg.

C. Electrical conductivity

Electrical resistance could be measured by a digital multimeter VC60B+ in two of the samples, C4 and C5. Used as a conductor, C5 can turn on a LED due to its 30kΩ, resistance.

C4 has around 400MΩ, while all other samples have more than 2000MΩ, which is the limit of the ohmmeter.

IV. Discussion and future work

Laboratory team strongly believes that this kind of intelligent materials will have high impact in the society for new innovative incoming technologies. It has the potential to break into novel fields such as assisted physiotherapy, medicine, volumetric displays or even as a new artistic movement.

Acknowledgment

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