Analysis of Physical Properties of a PVA-Borax Magnetic Hydrogel Soft Robot CH5270: Course Project Report

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I. Introduction

We aim to develop a re-configurable magnetic hydrogel robot that can adapt to various environments and tasks by changing its shape and structure. This robot should be able to deform and reconfigure itself in response to different stimuli, such as magnetic fields or external forces. The robot should also be able to perform multiple functions, such as grasping and manipulating objects and navigating through complex spaces. The experiments done in this study are an extension of the work done by Sun et al. in [1]. All experiment recordings have been added to a drive folder. [1] In this study, we make a magnetic hydrogel using a combination of PVA and Borax. We then further add iron fillings to actuate the hydrogel using a magnetic field.

II. Applications

The magnetic hydrogel developed in this study has significant potential for various applications in soft robotics, particularly in biomedical and medical devices. Some of the applications have been listed.

- Minimally Invasive Surgery: The magnetic hydrogel can be used to create soft robotic devices that can navigate through the body and perform precise surgical procedures without causing significant tissue damage.
- Environmental Monitoring: The hydrogel can be used to create soft robotic devices that can assist in cleaning up environmental pollutants, such as oil spills or chemical leaks.

III. Related Work

The development of soft robotic systems has garnered significant attention in recent years due to their potential to mimic the flexibility and adaptability of biological systems. One crucial component in the creation of these systems is the use of hydrogels, which can be designed to exhibit specific properties such as biocompatibility, transparency, conductivity, and adhesive properties. Among various types of hydrogels, polyvinyl alcohol (PVA) hydrogels have been widely used in soft robotics due to their excellent mechanical properties and ability to be cross-linked with borax to enhance their stiffness and durability. [2]

Several studies have focused on developing actuators that can be activated using various stimuli such as heat, moisture, or electrical signals. For instance, researchers have demonstrated the preparation of bilayered hydrogel actuators that can be activated by heat, moisture, or IR light stimuli, exhibiting rapid, reversible, and sustainable bidirectional self-rolling deformation. Our focus was a magnetic actuation, the field strength can be controlled using an electromagnet.

In addition to these studies, researchers have also explored the use of PVA hydrogels in combination with other materials to enhance their properties [3]. For example, a study discussed the development of bioinspired hydrogel robots that can mimic the motion behavior of different natural species, highlighting the potential of hydrogels in various bio-related applications such as drug delivery, sensing, cell delivery, and cargo manipulation.

In the context of magnetic hydrogels, researchers have demonstrated the preparation of PVA hydrogels with iron fillings, which can be used for soft robotic applications. This approach leverages the unique properties of PVA hydrogels, such as their biocompatibility and conductivity, to create soft robotic systems that can be controlled using magnetic stimuli. We delved deeper into the research conducted by [4]. Their research analyzed the performance of the magnetic hydrogel under various conditions.

In a study by Xu et al. [5] they analyzed soft robots with programmable, hardened, adhesive, and reconfigurable properties designed using a mixture of magnetic particles and non-Newtonian fluidic soft materials. These robots can be spread on various surfaces and demonstrate enhanced stiffness through on-demand programmable hardening, enabling them to grasp and actuate objects significantly heavier than their weight.

IV. Methodology

We employed a multi-step approach to develop the reconfigurable magnetic hydrogel robot. The methodology can be

[1] Drive Link: http://surl.li/uhpzw

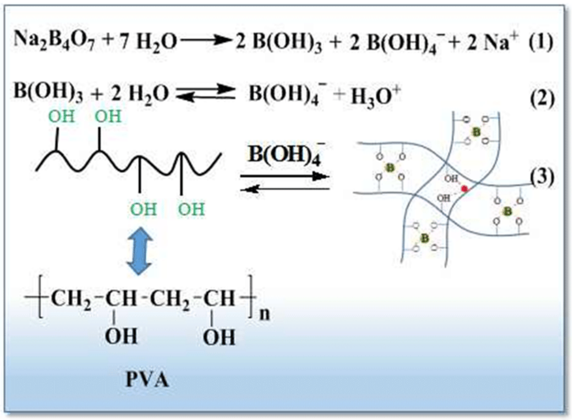


Fig. 1. Reaction Mechanism

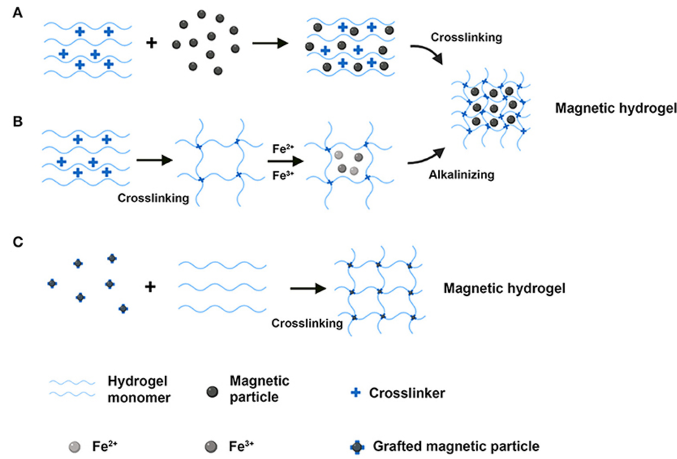


Fig. 2. Structure of the Matrix Created

summarized as follows:

We design the magnetic hydrogel material by combining a ferromagnetic powder with a non-Newtonian polymer. The material chosen has unique properties, which allow it to change shape in response to magnetic fields and external forces. The design also included a reconfigurable structure consisting of interconnected modules that can be rearranged to change the robot's shape and function.

A. Hydrogel

The hydrogel base is made using a combination of Polyvinyl acetate and Borax. This concept has been explored in previous research [6]–[8]

The reaction taking place when combining PVA and borax to create a slime-like hydrogel is a cross-linking reaction between the polyvinyl alcohol (PVA) polymer and borate ions formed from the borax.

When borax is added to water, it dissociates into borate ions. These borate ions can form reversible cross-links with the hydroxyl groups on the PVA polymer chains through a process called complexation.

The borate ions act as cross-linking agents, connecting multiple PVA chains together to form a three-dimensional network structure. This network traps water molecules within its structure, creating a hydrogel with a slime-like consistency.

B. Magnetic Actuation

To create a magnetically actuated hydrogel, we incorporate ferromagnetic material into the hydrogel. Specifically, we add iron fillings to the hydrogel, enabling it to deform in response to the influence of a magnet. This is achieved through the interaction between the magnet's magnetic field and the hydrogel's ferromagnetic material.

The physical properties of the created magnetic hydrogel are then evaluated. This is done by conducting experiments in a controlled environment.

V. Experiments & Results

All experiments were conducted by using a 0.2T magnet. In the experiments, the magnet has been placed has been placed under the spreading surface. The spreading surface used in our case is glass.

All the data collected can be found here

A. Visco-elastic Spreading Without Magnetic Field

This experiment investigates the visco-elastic spreading behavior of the magnetic hydrogel in the absence of an external magnetic field. It likely measures how the hydrogel deforms and spreads under its own weight or other forces.

Snapshots of the experiment at 3-second intervals can be found in Figure 3.

B. Visco-elastic Spreading With Magnetic Field

This experiment examines the visco-elastic spreading of the magnetic hydrogel when an external magnetic field is applied. The magnetic field can influence the hydrogel's deformation and spreading behavior compared to the case without a field. Snapshots of the experiment at 3-second intervals can be found in Figure 4. We can infer that the spread without the magnetic field is more as compared to the spread with the magnetic field.

C. Self Healing Under Magnetic Field

This experiment tests the self-healing properties of the magnetic hydrogel when subjected to a magnetic field. This is done by observing its ability to recover its original structure and properties under the influence of the magnetic field.

Samples of the results can be found in Figure 5. We notice that in the presence of a magnetic field, the hydrogel reconnects itself and is once again one unit.

D. Necking with Magnetic Field

The necking experiment investigates the formation of a "neck" or localized thinning region in the magnetic hydrogel when a magnetic field is applied. This can provide insights into the material's response to non-uniform deformation under magnetic forces.

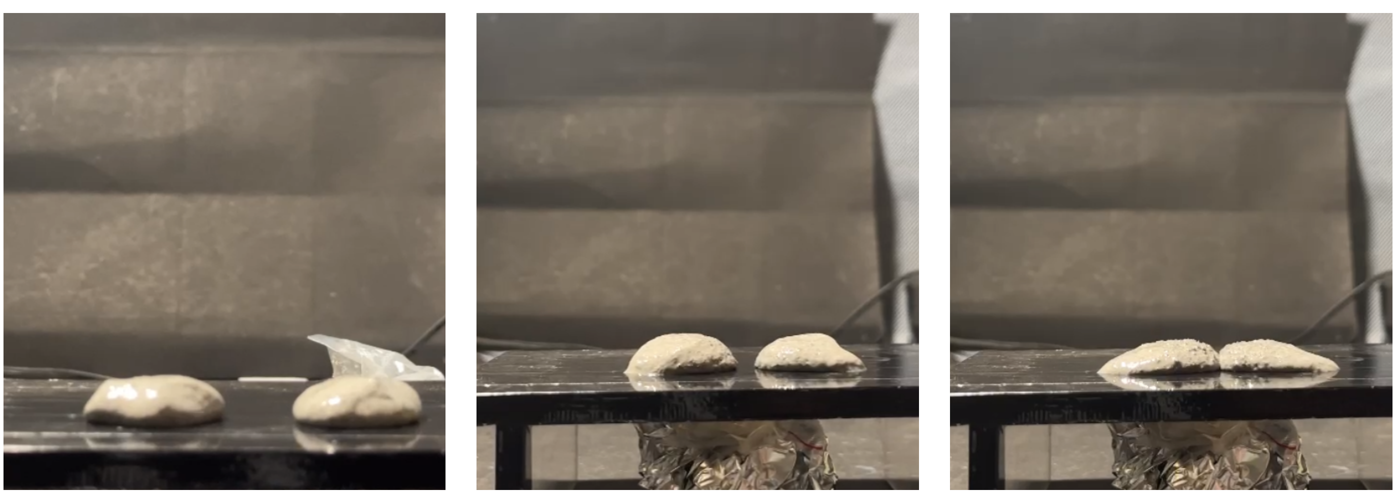
Samples of the results can be found in Figure 6. The hydrogel initially exhibits a gradual increase in strain under

(a) (b) (c)

Fig. 3. Visco-elastic Spreading Without Magnetic Field

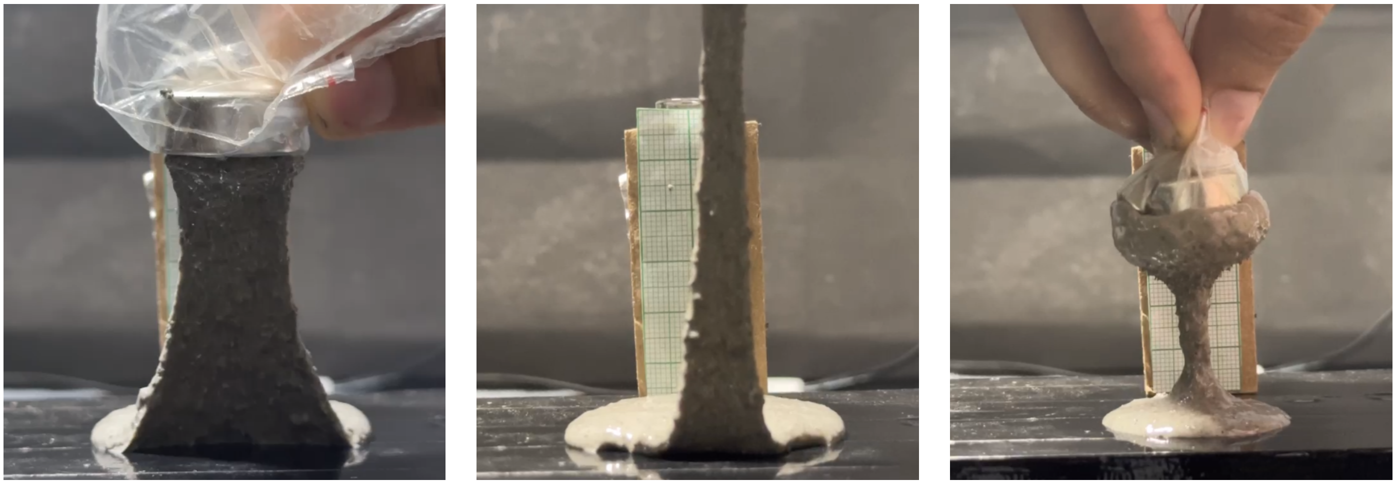
(a) (b) (c)

Fig. 4. **Visco-elastic Spreading With Magnetic Field**



(a) (b) (c)

Fig. 5. Self Healing (a) is without any magnetic field and (b) & (c) are in the presence of a field



(a) (b) (c)

Fig. 6. Necking with Magnetic Field

tensile stress, indicating its ability to absorb and distribute the stress. However, as the stress continues to increase, a localized region of the hydrogel begins to deform more rapidly, leading to the formation of a neck. This necking phenomenon will result in a reduction of the hydrogel's cross-sectional area, making it more susceptible to further deformation or failure.

E. Horizontal Creeping

This experiment studies the horizontal movement or "creeping" of the magnetic hydrogel on a surface under the influence of a magnetic field applied in the horizontal direction. It demonstrates the ability to induce directional motion in the hydrogel using magnetic fields.

Based on our experiments we concluded that the maximum horizontal length attained is about 10 cm. A few snapshots of the vertical creeping experiment can be found in Figure 7.

F. Vertical Creeping

Similar to the horizontal creeping experiment, this test examines the vertical movement of the magnetic hydrogel when a magnetic field is applied in the vertical direction. It shows the hydrogel's ability to climb or move vertically under magnetic actuation.

Based on our experiments we concluded that the maximum height attained is about 16 cm. A few snapshots of the vertical creeping experiment can be found in Figure 8.

VI. CONCLUSIONS

Based on the performance we can conclude that the material developed can be used for the development of a soft robot.

In this study, we have successfully developed a novel magnetic hydrogel by incorporating iron fillings into a PVA + Borax hydrogel matrix. The resulting hydrogel exhibits excellent magnetic properties, allowing it to be controlled and manipulated using external magnetic fields. We have demonstrated the potential of this hydrogel in various soft robotic applications.

The development of this magnetic hydrogel opens up new avenues for the creation of soft robotic systems that can be used in a wide range of applications, from biomedical and medical devices to environmental monitoring and cleanup. The unique properties of the hydrogel, such as its ability to change shape and adapt to different environments, make it an attractive material for a variety of uses.

Future work will focus on further optimizing the properties of the hydrogel and exploring its potential in real-world applications. We believe that this technology has the potential to revolutionize the field of soft robotics and enable the creation of new, innovative devices that can improve people's lives.

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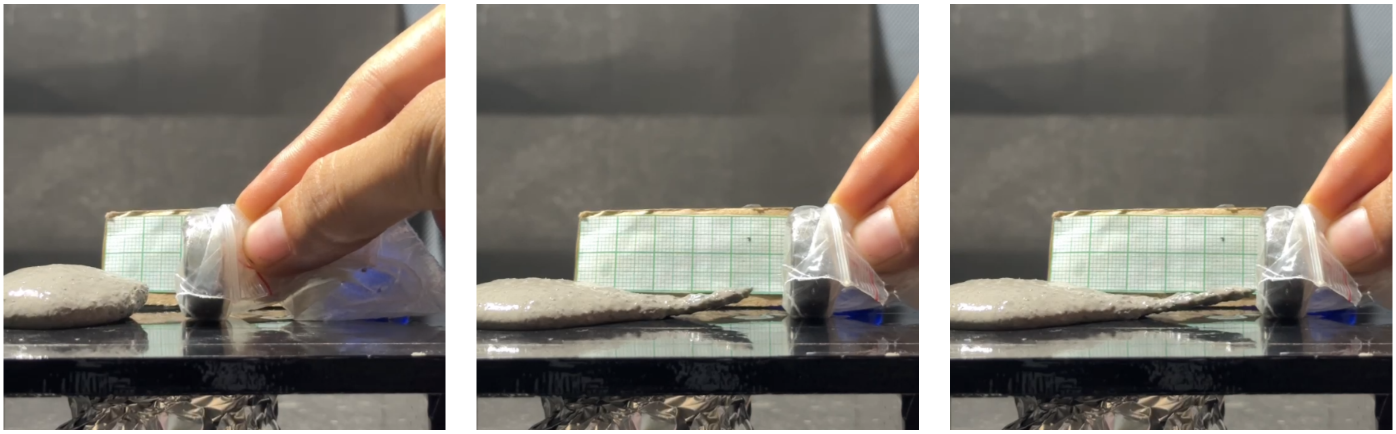

(a) (b) (c)

Fig. 7. Horizontal Creeping at Different timestamps

(a) (b) (c)

Fig. 8. Vertical Creeping at Different timestamps