The new dawn of magnetic polymers

The Magneto project is attempting to develop new smart composite materials with unusual magnetomechanical properties. Project lead, Kostas Danas, carries out experiments to give magnetic properties to polymers, which could pave the way for exciting new applications in many sectors

Working at the Ecole Polytechnique Campus, Principal Investigator, Prof. and CNRS Researcher Kostas Danas, is half way through his research term on the Magneto project, with just over two years to go. He is a pioneer in materials science and mechanics, a branch of research that has the potential to redefine the possibilities of how materials behave. It's an important task since creation of a new composite material could essentially open up possibilities for engineering new applications that would be otherwise challenging to develop.

"It's about creating new materials that have interesting properties," explains Kostas Danas. "Magnets are usually a hard material – they are made of hard metal, which means they are not easily deformable. The Magneto project's idea is to develop polymers that have magnetic properties and operate them in their unstable regime. As polymers are soft materials, they can be easier for use in a number of applications because they are deformable. The question that drives the Magento project is, 'how do you make a polymer magnetic but still keeping it deformable?'"

Kostas argues, that at a basic level, the methods he is using to give magnetism to a soft material consist of mixing the right substances and architecting them in the right way.

Cooking up a composite

"The way we do it feels much like following a recipe when you are cooking. You need the right ingredients and the right quantities, so on one level – this is a straightforward chemistry experiment," concludes Kostas.

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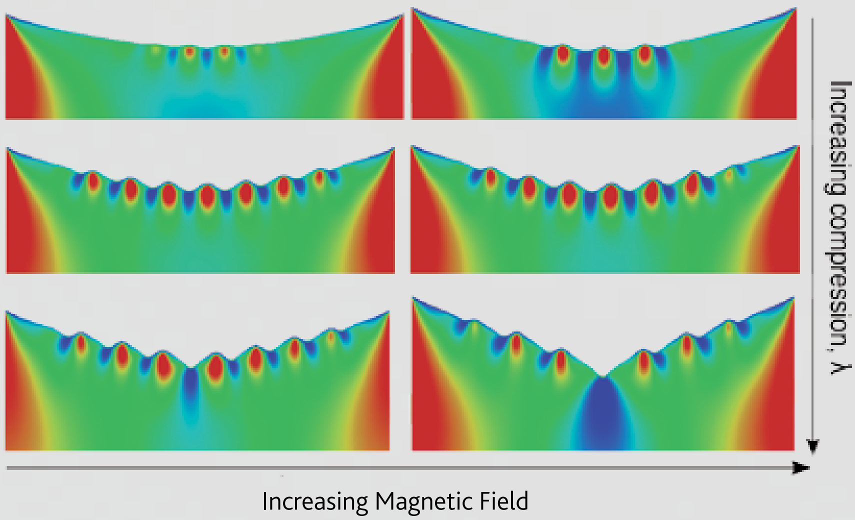
"For the sake of explaining, let's take the example of a polymer we can all comprehend, a plastic glove, like the kind you do the washing up with in the kitchen. This glove is not magnetic, so how do I make a glove that is? I first make the polymer by mixing two liquids together. Suppose I then mix the liquid polymer with nano or microparticles of iron or permanent NdFeB micromagnets, which is a powder. You see how this is like cooking? I then create a new glove, which is almost as soft as the original glove but now, because of the particles, this material deforms or sticks, as it's attracted by the magnet. Also, if bended or deformed towards a critically stable state, wrinkles and controlled roughness can be obtained on the surface of the material. All this is called magneto-mechanical coupling because when you apply a magnetic field to it, it deforms and vice versa. Such materials can be magnetically activated and act as soft sensors or actuators."

Because of the methods and ingredients involved – creating such smart composite materials is relatively cheap to do, which is a plus for the research but also for real life applications.

For increased control of the final geometry and material architecture, the project makes use of 3D printing to accelerate and control better the process of creating moulds.

"If we didn't have 3D printing we would need to go to a technician who would have to produce the mould for us, which is much more difficult and sometimes impossible. With 3D printing we can design efficiently and fast complex geometries while we can fabricate moulds that can't be done with start out techniques," says Kostas.

With 3D printing, the composite material can be architected, validated and probed for response.



Full field numerical magneto-mechanical simulations of magnetoelastic films upon magnetoelastic substrates. The strain field is shown in color. Roof-type patterns called crinkles are obtained. Such patterns can potentially help unravel and read DNA sequences.

Programmable curvature

A technique known as programmable curvature brings hope for the development of a number of possible applications, relevant to the Magneto project's research.

"We begin with a flat material that doesn't occupy much space and by compressing it or pushing it in different directions or even better magnetising it, it becomes 3D. One way to imagine this is to think of creating the Eiffel Tower from a film that is flat but by compressing it, it becomes 3D. The process can create properties, such as better stiffness, optimised geometry and even electro-magneto-mechanical properties. This is a very scalable process that can contribute to civil engineering to create, for example, buildings that you can transport easily. They don't occupy space but when you reach the site, you can unfold them into 3D structures. This is obviously on a very big scale – but you can do the same thing on small scales, which is what we are interested in and have important applications in small electronic devices, biology and bio-implants."

Some of the application concepts born from the project rely on programming curvature at small scales.

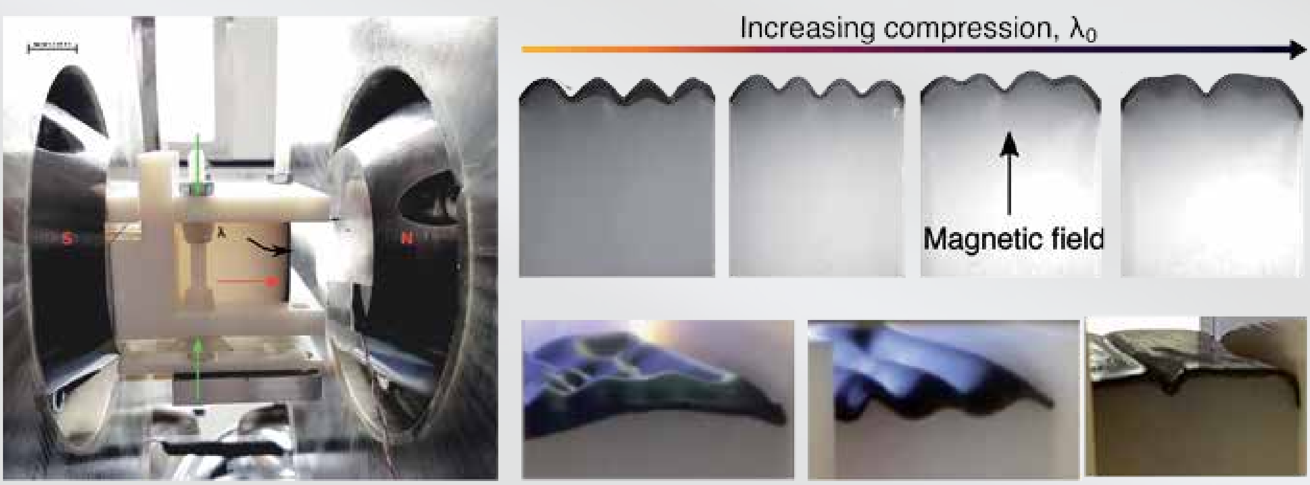
"Imagine stents that are used to keep arteries open in the human body. You could make it easier to put these objects inside people. You could introduce a small flat or compact object inside a body, drive it towards its desired position and unfold it into a 3D stent and all this by simply applying external magnetic fields."

Limited only by imagination

Whilst Kostas is working at the laboratory level, there are clearly identified ideas for future applications with such materials, which industry could exploit.

A number of people from academia and industry interact with Kostas and have brainstorming discussions, where new ideas come to the fore and take shape. These ideas are academic, some of which can be taken to the laboratory.

For example, a braille reading device. This could rely on a thin film that deforms when a magnetic field is applied. By using small magnetic fields, micro bumps could be made which would become braille on the film. You could achieve this with a high degree of control over manipulating the



Experimental setup for magneto-mechanical experiments. Several surface patterns of sinusoidal and roof type (crinkles) are obtained by depositing a magneto-elastic film on a passive substrate.

MAGNETO

Active Magnetorheological Elastomers: From Hierarchical Composite Materials to Tailored Instabilities

Project Objectives

The aim of the MAGNETO project is to develop new composite materials with extreme properties, specifically magnetorheological elastomers (MREs) which combine magnetic particles embedded in a soft polymeric non-magnetic matrix, giving rise to a coupled magneto-mechanical response at the macroscopic scale when subjected to magento-mechanical external stimuli.

Project Funding

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Kostas Danas

Kostas Danas is a Senior Research Scientist in the Solid Mechanics Laboratory at CNRS and Associate Professor at Ecole Polytechnique. His main research interests are in the field of solid mechanics and physics with an emphasis on smart composite materials and structures.

instabilities, to form the bumps. Other ideas include new haptic and touchscreen technologies and even a way to enable movement in the joints of a prosthetic leg – where soft solids could bend in the right places when activated.

Another research direction that Kostas and his team look into includes possibilities to activate the control of material stiffness, for cell growth.

Jet Propulsion Laboratory visited the Laboratory of Solid Mechanics (LMS) at Ecole Polytechnique in France and commented that one of Kostas' experiments could have purpose for a NASA mass spectrometer in future missions to Mars, because magnetic fields can be applied in non-gravitational systems.

"This is an application that I wouldn't have in mind because I am not even close

> It's impossible for me to think of **all the applications possible from this research** but new ones keep being revealed as time goes on. **The potential is far reaching.**

"I am ultimately a scientist, so I am not necessarily the best person to develop devices for industry but the concepts are there for a company equipped and able to do the engineering for this and to take it to market," says Kostas.

Revelations about how these materials could become applied are regularly forthcoming. The former Director of NASA's

to that field. It's impossible for me to think of all the applications possible from this research but new ones keep being revealed as time goes on. The potential is far reaching. Close and brainstorming-type interaction between scientists and industrial people is perhaps the best way to go from an academic laboratory to a real life application."

Refreshable braille display