Active Magnetorheological Elastomers: from Hierarchical Composite Materials to tailored Instabilities

Reporting

Project Information

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**Summary of the context and overall objectives of the project**

In this project, and inspired by natural and biological systems which operate at marginally stable regimes, we propose the “novel use of hierarchical, soft magneto-active composites” to obtain extreme material properties via appropriate tailoring of their “unstable” response. For this to be achieved, an appropriate combination of physics, material and mechanics knowledge needs to be put together and extended. The importance of this subject to society is related to the potential knowledge that is created as well as the potential applications that can derive from the present project. Specifically, in the last century, the engineering community as well as common sense has regarded material and structural instabilities as a negative feature that should – by all means – be avoided during design and daily use. This is not the case in the present proposed subject. On the contrary, by controlling such instabilities hierarchical composite materials one can obtain novel and extreme responses, which beyond the point that the instability occurs the response remains stable and reversible, thus making the material useful in a loading range that before has been considered as forbidden. In particular, these instabilities can lead to enhanced roughness (for use in the context of haptic devices, hydrophobic or self-cleaning surfaces, morphing structures), as well as to significant increase in local stiffness (for use in substrates for cell-growth) or negative Poisson ratios (for use in acoustics applications). And the novelty in this case “is the creation of such instabilities in an active manner”, i.e. by controlling a magnetic field.

In this regard, the overall objectives of the project are:

1. To fabricate and experimentally study hierarchical magnetorheological elastomers (MREs) with novel nano- and micro-architectures.
2. To develop numerical Finite Element (FE) and theoretical models that are able to deal with the full magneto-mechanical coupling at large strains and at several length scales.
3. To tailor magneto-mechanical instabilities present in such MRE systems in order to obtain...
enhanced and unusual material and structural responses.

The above mentioned objectives have been achieved to a complete extent during the ERC project and novel directions have emanated towards 3D printing of MREs and modelling of additional coupled phenomena such as electro-magneto-mechanical materials.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

Concerning the first and third objective, we have immediately addressed one of the main goals of the project. The goal of this task has been to show that with proper combination of magnetic and mechanical loads we can control surface patterns and curvatures by use of structural and material instabilities. In addition, we are in the process of showing experimentally that the proper design of the structure and proper fabrication of the materials allows reducing substantially the critical magnetic field needed to obtain such surface patterns. This, in tum, implies that one can build a low-energy device to perform such surface pattern control. The second objective, work is carried out in the modelling of the microstructure of magnetorheological elastomers (MREs) and the understanding of the iron-particle interactions upon the overall response of the composite. For now, we have significant findings and scientific challenges that we need to overcome to understand the how such interactions affect the overall response of these materials. In parallel, we also work on the magneto-mechanical characterization of MREs. This work is necessary to feed all the other studies with appropriate material constitutive laws that are obtained by direct analysis of the experiments. Finally, in the context of tailored instabilities, we have addressed the possibility of programming and controlling hierarchical instabilities by use of 3D printed structures. This work is achieved by proper combination of numerical, theoretical and experimental validation. A study in the context of liquid crystals activated by electric fields has also been carried out. This subject is in the same lines as the magneto-mechanical problems since we are exploring the possibility of using again the instabilities present in such materials to create controllable surface patterns at low electric fields. Finally, at the level of the group we are exploring a number of other possible geometries, materials and structures that could lead to innovative and energy efficient active devices. These new directions are in complete agreement with the main objectives of the project and we expect that novel results be underway.

The results obtained during the ERC project have been published in several international journals and presented in a number of conferences. In parallel, we have published in ZENODO a first version of general purpose subroutines for the modelling of magnetorheological materials and devices.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)
In order to achieve the construction of MRE prototypes the knowledge and understanding of the role of the microarchitectures upon the overall behavior of MREs is critical. The big challenge in the project is first the identification and then the design of materials systems that reach a critical state and thus can become unstable at relatively low magnetic fields (less than 0.1 Tesla) in order to avoid the use of bulky magnets to trigger the desired instabilities. Based on the above-presented proof-of-concept prototypes, the PI of this project believes that such materials and devices are now feasible by the use of optimized micro-architectures and proper combination of pre-applied mechanical loads.

At this point, it should be pointed out that even though the focus of the project is on magneto-active materials, the general idea of marginally stable materials and use of instabilities of hierarchical composites to obtain desired material response and extreme properties is more general. In this regard, we are also exploring the potential of using the same notions in the neighboring field of liquid crystals which allow for a low energy-efficient devices in a large number of devices including LCD screens and windows as well as driven electric fields and light along preferential directions.

The choice is large and the number of potential technological applications even larger. Thus, even though the current project involved initially some high-risk steps (such as the low magnetic field instability triggering) we are now more optimistic that we can indeed repeatably manufacture, test and control the response of such marginally stable materials. From the purely scholar point of view, the present project gives by ow some answers in bridging the gap between neighboring, albeit distant in several occasions, scientific fields such as physics and mechanics or physics and materials.

Finally, the knowledge obtained by the present ERC research programme is already being transferred to undergraduate students by teaching and national and international internship posts. The younger students have access to high-end equipment, such as a 3D printer and relatively high-field electromagnets, which makes them eager to follow a career in this technological field. In this regard then, the new materials and structures that are developed can also serve society indirectly by knowledge transfer to the undergraduate students who are the next generation engineers and innovators.
Magneto-mechanical Instabilities and chiral structures

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