Editorial: Synthesis, Characterization and Applications of Magneto-Responsive Functional Materials

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Background

Magneto-responsive functional materials, in particular, magnetorheological (MR) materials (in forms of liquid, elastomer, grease or others), have gained significant attention from around the world. The materials, with drastic rheological property changes, have been heavily investigated to develop smart devices and applications, ranging from micro-sized sensors to large-scale energy dissipation devices for civil engineering applications. Cross-disciplinary research activities are still booming with aims to 1) render larger MR effect with better stability and durability; 2) understand and characterise the complex material behaviour with existing or new rheology theories; 3) apply innovations to design MR devices or actuators in many forms for respective targeted applications; and 4) address underlying concerns from end-customers for application-related obstacles. This Research Topic is set to provide platform for scientists and researchers to exchange latest developments in the field. The topic includes wide coverage of the focusing theme on technologies and innovations in the afore-mentioned four areas. We are proud to present 10 peer-reviewed contributions offering insights on synthesis, characterization and applications of MR materials from leading researchers in the world.

Major highlights of the contributions

MR fluids as important MR material have been used to design various intelligent vibration control devices, such as brakes, clutches, dampers and mounts, as well as medical apparatus. Over the past two decades, numerous designs have been proposed and tested based on the four operational modes of the MR fluid. To summarise the latest development, Hua et al. (2021) presented a dedicated review on the structural configurations of MR fluid based device in 2018-2020. In particular, the section on MR fluid devices for medical application includes several innovative devices, such as robotic bone biopsy, haptic actuator and tactile device, which are highlights worthy of attention. Conclusive remarks and future perspectives are also offered by the authors. Another topic review on the role of MR fluid in precision machining is given by He et al. (2021). Especially, the state-f-the-art review on the surface polishing equipment is the first piece in the community to comprehend the outstanding research work in the area.

There has been continuous effort in upgrading the performance of MR fluid, in terms of larger MR effect, low sedimentation and high stability. When subjected to magnetic field, the particles in the carrier form chain or column structures along the field direction which can only be broken until external force/stress reaches certain threshold, namely yield stress. The improvement on MR effect can be achieved through the modifications on the magneto particles and carrier fluids. The interface between particles and carrier fluids plays substantial role on the performance of MR fluid. Tong et al. (2021) proposed the use of ionic liquid and silicon oil with same viscosity as carrier fluid to prepare MR fluid. It is shown that the new MR fluid possesses a higher yield stress up to 90 kPa, around 20kPa more than a silicon oil based MR fluid. The experimental results was explained by the enhanced interactions between the particles encouraged by the fact that ion fragments in the ionic liquid would form an ion layer on the

surface of the particles. Jang et al. (2021) adopted another approach to enhance MR effect, i.e., coating Carbon Iron (CI) particles with hard-magnetic barium ferrite (BF) nanoparticles. The hard-magnetic BF nanoparticles have hexagonal plate-like structure and they have high magnetocrystalline anisotropy, high Curie point, relatively high magnetic saturation value and coercive force, and superior chemical stability and corrosion resistance. SEM images reveal that the $BaFe_{12}O_{19}$ particles are attached in the space between the CI particles, which proved to enhance the MR efficiency, reduce particle aggregation thus improve suspension stability.

The gravitational force of the heavy ferrite particle induces settling of the particles due to the mismatch with the low-density carrier fluid. Sedimentation in MR fluid has indeed become a burning issue to resolve facing the application of MR devices, or at least with technology to monitor the sedimentation inside the device. Zhang et al., (2021) proposed an in-situ capacitance sensing approach to capture the settlement of MR fluid within a MR damper cylinder. An open plate capacitor configuration is designed in the above research. The system was calibrated using theoretical simulation and experiment, and the proposed system can be used for long-term monitoring of the particle settling of MR fluid in any fabricated MR device.

To overcome the influence of disturbances, either internal or external, to the performance of the MR impact buffer system, Wang B et al. (2021) proposed a hybrid control strategy with sliding mode active disturbance rejection control based on extended state observer. The proposed control method is validated through numerical simulation and exhibits superiority with fast response, minimal overshooting and great immunity to nonlinear hysteresis.

Besides MR fluids, other forms of MR materials such as MR elastomer, gel and grease, have been brought into centre stage of the field lately. Similar as the trajectory of MR fluids, research activities on other MR materials were mainly from material scientists and are expected to rapidly shift to engineers. Wang BC et al. (2021) explored the feasibility of MR elastomer (also called Magneto-Sensitive rubber, or MS rubber) to be used in semi-active vehicle suspension. A constitutive model was proposed to accurately replicate the behaviour of MS rubber. They then used H-infinity control strategy for a quarter car model featuring MS rubber semi-active suspension to examine the performances under a bump and a random ground excitation. Future perspectives on this proposal are discussed and amply insights are presented in this article. Gong et al. (2021) developed a novel MR polymer gel utilising carbon nanotubes and CI particles to mix into polymer gel matrix. An unusual nonlinear magneto-electro-mechanical response, i.e. rate-dependence, is observed together with high performance sensing behaviour. Thus, the new material has promising futures in both active control and electromechanical sensing, either separately or combined. Mao et al. (2021) investigated the magneto-induced normal stress in MR gel under quasi-statically monotonic and periodically cyclic loading. Detailed experimental testing and observation can all be found in this article with ample insights.

Understanding the rheological properties is the key to unlock the potentials of MR materials for future applications. Usually, storage/loss modules and Lissajous curves from the oscillatory shear tests are used to extrapolate the rheological properties. However, they each possess drawbacks to explicit the detailed nonlinear behaviour. Wang H et al. (2021) utilised Fourier transform-Chebyshev analysis to quantitatively interpret the influence of the frequency on the non-linear rheology of MR grease. The strain-stiffening/softening and shear thickening/thinning features of the materials can be easily expressed using this method, which offers a new way in the field to examine the complex behaviour of MR materials, especially under sophisticated influences of magnetic field, complex strain and temperature.

Summary

The collection of the special topic contributions provides latest development in the magneto-responsive materials in various aspects, such as state-of-the-art review, material development and characterisation, constitutive modelling, numerical method and simulation. We, editors, hope that you find these articles useful and enjoyable to read, and are perhaps inspired from them.

Author Contributions

YL prepared the draft. XG, YDL and JW edited the draft.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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