Chapter

Magnetorheological Elastomers: Materials and Applications

Taixiang Liu and Yangguang Xu

Abstract

Magnetorheological elastomers (MREs) are a type of soft magneto-active rubber-like material, whose physical or mechanical properties can be altered upon the application of a magnetic field. In general, MREs can be prepared by mixing micron-sized magnetic particles into nonmagnetic rubber-like matrices. In this chapter, the materials, the preparing methods, the analytical models, and the applications of MREs are reviewed. First, different kinds of magnetic particles and rubber-like matrices used to prepare MREs, as well as the preparing methods, will be introduced. Second, some examples of the microstructures, as well as the microstructure-based analytical models, of MREs will be shown. Moreover, the magnetic field-induced changes of the macroscopic physical or mechanical properties of MREs will be experimentally given. Third, the applications of MREs in engineering fields will be introduced and the promising applications of MREs will be forecasted. This chapter aims to bring the reader a first-meeting introduction for quickly knowing about MREs, instead of a very deep understanding of MREs.

Keywords: magnetorheological elastomer, composite material, microstructure, vibration reduction, energy absorption

1. Introduction

Magnetorheological elastomers (MREs) are a type of soft particle-reinforced magneto-active rubber-like composite material, whose physical or mechanical properties can be altered upon the application of a magnetic field [1–5]. MREs can be usually prepared by mixing micron-sized magnetic particles into nonmagnetic rubber-like matrices. In the presence of a magnetic field, MREs exhibit a magnetorheological effect providing a field-dependent physical or mechanical property, for example, a controllable modulus, due to the sensitive response of the magnetic particles to the field. While the field is removed, MREs will reclaim their original, natural property. It is believed that the embryo of MREs is firstly reported by Rigbi and Jilken [1, 6] in 1983, although the discovery of the basic magnetorheological effect can be historically retrospected to the 1940s for magnetic fluid [7]. MREs can be regarded as a solid-state analog to magnetorheological fluids (MRFs) [8–12]. In general, MREs exhibit a unique field-dependent material property when exposed to a magnetic field, and can overcome major issues faced in MRFs, for example, the deposition of iron particles, sealing problems, and environmental contamination. Such advantages offer MREs great potential for designing intelligent devices to be used in various engineering fields, especially in fields that involve vibration
Smart and Functional Soft Materials

reduction, isolation, and absorption [1, 13–16]. Recently, the study of the sensing behavior of MREs explosively emerged, for example, for sensing mechanical and magnetic signals [17–22].

From the first report of MREs with soft ferrite particles filling into natural rubber [6], the research of the materials and related preparing methods of MREs develops very quickly. Briefly speaking, MREs consist of three basic components: magnetic particles, nonmagnetic elastic matrices, and additives. For the magnetic particles, higher permeability, higher saturation magnetization, and lower remanent magnetization are highly desirable for obtaining stronger magnetic field-sensitive effect. At present, the micron-sized carbonyl iron powder invented by BASF in 1925 is widely used [23, 24]. For the elastic matrix, there are lots of polymeric rubbers, for example, natural rubber [25, 26], silicone rubber [27–31], poly dimethylsiloxane (PDMS) [32–34], etc., for consideration. According to need, high modulus or low modulus can be chosen, but that the magnetic particles can be locked in the matrix in the absence or presence of a magnetic field is a basic requirement. For the additives, they are determined according to the choice of the particles and the matrix, and silicone oil is usually used as an additive in the fabrication of MREs [1]. Depending on the choice of the matrix, the preparing methods of MREs are many and various, and a high-temperature or room-temperature vulcanization curing method is usually used. Attributed to applying a magnetic field in the curing process, MREs can be prepared with anisotropic particle-formed microstructure. This kind of MREs is called anisotropic MREs. When no field is applied during the curing process, prepared MREs have isotropic particle-formed microstructure and this kind of MREs is called isotropic MREs. It is worth mentioning that the properties of isotropic MREs can differ much from those of anisotropic MREs.

Due to magnetic field-sensitive response of the magnetic particles, the material properties of MREs can be altered by using a magnetic field. For MREs, the magnetorheological effect is defined as the ratio of the value increment of a property at a measured magnetic field to the initial value of that property at zero magnetic field. In most studies, the distinctive change of the storage or loss modulus of MREs is a common concern. The magnetorheological effect is characterized by the ratio of modulus increment $\Delta G$ at a measured magnetic field to the initial modulus $G_0$, i.e., $\Delta G/G_0$. For example, Figure 1 gives the magnetic field-dependent shear storage modulus of MRE. The initial modulus $G_0$ of the MRE is about 0.6 MPa resulting from the initial state of MRE materials. When applying a magnetic field,

![Figure 1](image)

*Figure 1.* The magnetic field-dependent shear storage modulus of MREs (modified from Refs. [13, 35]).
the interaction between the magnetic particles of MRE will occur and result in the alteration of the storage modulus. The modulus of this MRE can reach 1.5 MPa in the presence of field and thus the relative change of modulus can be larger than 100%. It should be noticed that, besides the magnetic field, the temperature [36–39], the relative humidity [40], and even the $\gamma$ radiation [41] can influence the physical or mechanical properties of MREs. Based on the magnetic field-induced change of the physical or mechanical properties of MREs, lots of magnetorheological devices have been designed. In the late 1990s, Ginder et al. [2, 42] and Carlson et al. [3] had done the pioneering works and suggested controllable-stiffness components and electrically-controllable mounts based on MREs. Recently, Li et al. [1] and Ubaidillah et al. [43] have presented state-of-the-art reviews on magnetorheological elastomer devices. From these reviews, one can conclude that MREs can be used in many devices including but not limited to vibration absorbers, vibration isolators, sensors, controllable valves, and adaptive beam structures.

In this chapter, the materials, the preparing methods, the analytical models, and the applications of MREs will be reviewed. In the following section (Section 2), the materials, i.e., the magnetic particles, the nonmagnetic matrix and the additives, as well as the preparing methods of MREs will be introduced. In Section 3, the microstructures of prepared MREs, the analytical models of MREs, and some typical macroscopic properties of MREs will be presented. The relationship between the microstructures and the macroscopic properties will be qualitatively discussed. Then the applications of MREs will be briefly introduced in Section 4. Finally, Section 5 will give a summary of this chapter.

### 2. Materials

#### 2.1 Magnetic particles

To the magnetic particles, higher permeability, higher saturation magnetization, and lower remanent magnetization are highly desirable for obtaining stronger magnetic field-sensitive effect. Among a variety of magnetic particle materials, micrometer-sized carbonyl iron (CI) powder is currently widely used as a magnetic particle for preparing MREs. For a quick recognition, Figure 2(a) shows an example of the macroscopic image of CI powder. It shows that the CI powder is a very fine powder material. Figure 2(b) and (c) shows the scanning electron microscopy (SEM) images of CI powder (Type CN, produced by BASF SE Inc.) with different magnifications. The diameter of this kind of CI powder is several micrometers.

In general, the size of the magnetic particles can range from several micrometers to hundreds of micrometers [47, 48]. Figure 3 gives the size distribution of CI powder from experimental test. The size distribution can be analytically modeled by a lognormal distribution model as the following equation (Eq. (1)) shows.

$$
P(d) = \frac{1}{d\sigma\sqrt{2\pi}} \exp \left[ -\frac{(\ln(d) - \mu)^2}{2\sigma^2} \right],
$$

in which $P(d)$ is the probability density distribution function of the diameter of CI powder material. $d$ is the diameter of the CI particle. $\mu$ and $\sigma$ are the expectation and variance of $\ln(d)$. The tap density of CI powder is usually about 3.0 g/cm$^3$ and the real density of CI powder is about 7.0 g/cm$^3$.

Beside the size distribution of CI powder, the magnetic property of CI powder draws more attention of researchers. Higher permeability, higher saturation magnetization, and less remanent magnetization of magnetic particles are always highly desirable for
obtaining stronger magnetic field-sensitive effect. As is shown in Figure 4, CI powder shows very high permeability, saturation magnetization, and very little remanent magnetization. The value of saturation magnetization can reach more than 600 kA/m and there is little remanent magnetization when magnetic field is removed. This mainly results from the fact that the content of Fe element in CI powder is usually more than 97.5% in weight fraction. Attributing to the excellent magnetic property, CI powder is widely used for fabricating materials including but not limited to MREs.
2.2 Elastic matrices and additives

A basic requirement of elastic matrices for fabricating MREs is that the matrices have soft elastic property, meaning that the matrices can stably hold the magnetic particles under no magnetic field and have a finite deformation under a magnetic field. For the elastic matrices, there are lots of polymeric rubbers that can be considered as candidates, for example, silicone rubber [50], natural rubber [51], butadiene rubber [52], butyl rubber [53], polyurethane [54], polydimethylsiloxane [55], epoxy [56], etc. For instantly having a basic recognition of the matrices, the following Figure 5 gives some examples of image and applications of widely used silicone rubber.

The modulus of these matrices differs much from each other. For example, under normal conditions, the modulus of silicone rubber can be lower than 1.0 MPa [27]. That of natural rubber often reaches several MPa [25]. The shear modulus of PDMS varies with preparation conditions, but is typically in the range of 0.1–3.0 MPa [55]. The modulus of polyurethane can range from 0.01 MPa to several hundred MPa, attributed to its raw materials from fluid-like to solid-like [54]. Among a large amount of rubbers, silicone rubber compounds have characteristics of both inorganic and organic materials, and offer a number of advantages not found in other organic rubbers. From Figure 5, one can know that silicone rubbers have mechanically low modulus and good chemical stability and are nontoxic, nonpolluting, and human-body-friendly in daily use. As is shown in Figure 6, compared to the modulus of other rubbers, the modulus of silicone rubber is much lower within a large range of temperature. Besides, the thermal conductivity of silicone rubber can vary in a wide range. Based on the above-mentioned properties, silicone rubber can be chosen as an ideal soft elastic matrix for preparing MREs and is widely used in fabricating MREs. The other rubber matrices, with some unique mechanical or physical properties for special usage, can also been used in fabricating MREs according to need.

Besides the magnetic particles and the elastic matrices, additives are also key components for preparing MREs. Silicone oil is usually used as an additive in material fabrication of MREs. When the molecules of the silicone oil enter the matrix, the gaps between the matrix molecules are increased, and the conglutination of the molecules is decreased. Apart from increasing the plasticity and fluidity of the matrix, the additives can average the distribution of the internal stress in the materials, which makes a stable material property for MR elastomer materials [1, 58]. The other additives include but are not limited to carbon black [59–61], carbon nanotubes [62–65], silver nanowire [20], Rochelle salt [30], gamma-ferrite additives [66], etc.
2.3 Preparing methods

A simplified illustration of the processing for preparing MREs is shown in Figure 7. Usually, the magnetic particles and the matrix are mechanically mixed with some additives into a mixture. The mixture has a very low yield stress, meaning that the mixture can easily deform and usually creep with itself. Then the mixture vulcanizes at room temperature (called room-temperature vulcanizing, RTV [4]) or high temperature (called high-temperature vulcanizing, HTV [45]) higher than 120°C. During the vulcanizing, in case of applying a magnetic field, the magnetic particles can move in the matrix and gradually aggregate forming chain-like structures along the direction of the field. After the magnetic field-assisted curing,
Figure 7.
Illustration of the processing for preparing MREs. The magnetic particles and the matrix are mixed with additives into a mixture. When the mixture is cured with no external magnetic field, the mixture will be cured into isotropic MREs. However, in the case of the mixture curing under a uniform magnetic field, the mixture will be cured into anisotropic MREs.

Figure 8.
Prepared cylindrical (a) and block (b) MREs with different thicknesses from 6.35 to 2.54 cm [67].

anisotropic MREs, meaning that the magnetic particles form chain-like microstructures in MREs, can be prepared. When curing with no magnetic field, the magnetic particles will disperse uniformly in the matrix after vulcanization and thus isotropic MREs are prepared. Figure 8 shows some images of prepared MRE samples.

3. Microstructures and macroscopic properties of MREs

3.1 Microstructures of MREs

As a basic concern in the research of MREs, there are lots of studies focusing on the microstructures of MREs. Almost every report about a newly prepared MRE will show its microstructure. Figure 9 gives some typical SEM images with different times of magnification of the microstructures of carbonyl iron powder-embedded, natural rubber-based MREs samples. The volume fractions of iron particles for all samples are 11%. Figure 9(a) shows the images of a MRE sample cured with no magnetic field. It shows that the carbonyl iron particles randomly and uniformly disperse in the matrix. These two images are typical images showing the microstructures of isotropic MREs. The other images, i.e. Figure 9(b–f), show the microstructures of anisotropic MREs cured with magnetic field. As is shown, the magnetic particles will aggregate forming chain-like microstructures. The stronger the magnetic field intensity is when curing, the longer and thicker the magnetic particle-formed chains, as
the magnetic interaction of neighbor particles is stronger. When the magnetic field is not strong enough, for example, 200 mT, the magnetic particles in the matrix can only move within a small width of range, resulting in that the magnetic particles can only form some short chain-like microstructures. The spaces between these chains are small. With the enhancement of the magnetic field during curing, the spaces will get wider and the anisotropy of MREs will get higher, implying that the properties of MREs will get more anisotropic.

In recent years, the tendency to use quantitative methods instead of a qualitative analysis for structural investigation of the structure of nano- and microstructures has been increasing. Tomographic data open the possibility to achieve detailed quantitative data using techniques of digital image processing [69, 70]. To experimentally study the three-dimensional (3D) microstructures of MREs, Borin’s group [71, 72] firstly used the X-ray micro-computed tomography (XμCT) method to investigate the microstructures of MREs.

Balasoiu et al. [70] allowed a detailed structural analysis of both isotropic MREs and anisotropic MREs. Figure 10 shows the exemplary XμCT images of silicone rubber-based isotropic and anisotropic MRE samples. The iron particles in these MREs have an average particle size of approximately 35 μm. With XμCT images, single microparticles and aggregates as well as their spatial position can be identified. As can be seen, the particles are distributed homogeneously in the isotropic MRE sample and form chain-like structures in the anisotropic one. Figure 11 shows two extracted particle-formed columns from the reconstructed XμCT image. In this figure, the direction of the magnetic field was parallel to the longitudinal axis of the cylindrical shape holders and to the gravitational force. From this XμCT image, one can see how the particle chain forms and can go further to model MREs based on the image. Recently, the motion of particles in MREs was investigated by using XμCT [73]. It has been shown that XμCT is a powerful technique to investigate the inner structure of macroscopic samples without destroying the specimen. The XμCT technique also achieves high spatial resolution and allows the derivation of valuable local and statistical information, such as particle size and position, from the reconstructed 3D images. Furthermore, the nondestructive XμCT investigations.
of the 3D microstructures of MREs introduce the possibility of investigating the influence of the number and size of columns on the macroscopic mechanical and rheological properties of MREs.

3.2 Analytical models

The study of the microstructure-based analytical model of MREs is always a key work for deeply knowing about MREs. Some pioneering works had been done studying the model of MREs in the late 1990s [74, 75] and a single-chain model was proposed assuming that the MREs are fully filled with single chains (Figure 12(a)). From these studies, it was reported that the optimum particle volume fraction for the largest fractional change in modulus at saturation is predicted to be 27%. Calculations of the zero-field shear modulus perpendicular to the chain axis indicate that it does not exceed the modulus of a filled elastomer with randomly dispersed particles of the same concentration. In 2010, Li and Zhang proposed bimodal particle-based chain-model of MREs (Figure 12(b)) [76]. In their work, theoretical and experimental
studies of the mechanical performance and magnetorheological effects of MREs fabricated with mixtures of large and small particles were performed and an effective permeability model was developed to theoretically analyze the MR effect of bimodal particle-based MR elastomers. Six years later, a composite chain model (Figure 12(c)) was proposed [77, 78]. In this work, a particle chain composed of multiple kinds of particles with different sizes of diameter was introduced and a modeling strategy which accounts for elastic constituents and a nonlinear magnetization behavior of the particles is pursued. Most recently, a 3D multimodal chain model [79] has been proposed. In this model, magnetic particles with log-normal size distribution of diameter were introduced as fillers in soft elastic matrix. At the same time, a finite element model was built according to this model (Figure 12(d)). With the finite element model, one can computationally study the macroscopic physical or mechanical properties of MREs. In addition, as a basic issue, the study of the interaction between two magnetic particles still keeps developing [80–82]. Moreover, besides the microstructure-based analytical model of MREs, the phenomenological continuous medium-based models were also studied [83–93]. These works focus on theoretically and/or experimentally studying the magneto-viscoelastic models for MREs.

3.3 Macroscopic properties

The most important characterization of MREs is that their macroscopic physical or mechanical properties can be altered upon the application of a magnetic field. For a long time, most studies have focused on the magnetic field-induced changes of the modulus or damping of MREs [1]. The shear storage/loss modulus or damping property of MREs can be measured by dynamic mechanical analyzer (DMA) or rheometer. As examples, Figure 13 shows the magnetic field-dependent shear storage modulus and damping of MRE samples. For some natural rubber-based MRE samples with different weight fraction of carbonyl iron particles, one can find that the magnetic field-induced change of their shear storage modulus can reach near or above two times of their initial magnitude. Moreover, as a characterizing of the damping property of MREs, the relationship between shear stress and shear strain, under various magnetic field strengths of silicone rubber-based MRE, is shown in Figure 13 (right). The results show that such MREs have controllable damping properties. The increase of the stress-strain loop area with magnetic field demonstrates that the damping capacity of MREs is a function of applied magnetic field. These field-dependent mechanical properties make MREs much promising in many engineering fields, especially in vibration reduction.

Figure 12. The evolution of the model of MREs from (a) single chain model [73], to (b) bimodal chain model [74], to (c) composite chain model [75], and to the latest (d) multimodal chain model [77].
Magnetostriction of MREs is also a key concern when studying MREs [75, 95–97]. Figure 14 shows the simulated magnetostriction in MRE with different volume fractions of structured particle distributions. It shows that the magnetostriction of MREs is magnetic field-dependent. The intenser the field is and the higher the volume fraction of magnetic particle is, the larger the magnetostriction is. Further, full-field magnetostriction/deformation of a silicone rubber-based MRE under uniform magnetic field has been studied [98]. It shows that both isolated particles and grouped particles result in the concave-convex deformation of the MRE sample. Recently, the magnetic field-dependent electrical conductivity of MREs was emergently studied [99–105]. These field-dependent properties make MREs much promising in actuating and sensing.

4. Applications

In 1993, Kordonsky pointed out that magnetorheological effect can be a base of new devices and technologies [106]. Years later, Carlson and Jolly gave an introduction of magnetorheological devices [3]. By possessing variable physical
or mechanical properties when subjected to a magnetic field, MREs are natural candidates to be developed in many applications. In 2014, Li et al. [1] presented a state-of-the-art review on MRE-based devices. From this review, one can find that MREs can be used in many devices including but not limited to vibration absorbers, vibration isolators, sensors, controllable valves, and adaptive beam structures.

### 4.1 Vibration absorbers

Ginder et al. [107] firstly constructed a simple one-degree-of-freedom mass-spring system—an adaptive tuned vibration absorber—that utilizes MREs as variable-spring-rate elements. After that, the research on vibration MRE-based absorbers developed quickly (e.g., Refs. [13, 108–112]). **Figure 15** shows the sketch of a designed MRE-based vibration absorber composed of a semi-active vibration absorption unit and a passive vibration isolation unit. The vibration absorption unit is composed of a magnetic conductor, a shearing sleeve, a bobbin core, an electromagnetic coil winding, and a circular cylindrical MRE vulcanized between the shearing sleeve and the bobbin core. The magnetic conductor, the bobbin core, and the electromagnetic coil are supported on the shearing sleeve through the MRE. The magnetic conductor and the bobbin core are connected by a bolt, and the shearing sleeve is fixed to the lower housing. The outer surface of the shearing sleeve is in clearance fit with the inner surface of the magnetic conductor, and the magnetic conductor can move vertically along the shearing sleeve. The MRE works in pure shear mode, and the magnetic conductor, the bobbin core, and the electromagnetic coil form the dynamic mass of the MRE-based vibration absorber together. The proposed MRE-based vibration absorber can absorb the vibration energy and thus reduce vibration.

### 4.2 Vibration isolators

Vibration isolators are devices which can isolate an object, such as a piece of equipment, from the source of vibration. Vibration isolators can be categorized into two groups: base isolation and force isolation, and the isolating modes have active and passive vibration isolation [113]. In Ref. [1], Li et al. had given a review on the application of vibration isolators for mechanical engineering and civil engineering. There are many works that focused on the study of MRE-based vibration isolators, for example, Refs. [16, 91, 92, 114–118]. **Figure 16** shows an example

---

*Figure 15.* The 3D drawing (left) and the schematic representation (right) of a MRE-based dynamic vibration absorber [109].
of the designed layout and prototype of MRE-based isolator working in squeeze/elongation-shear mode. It shows that the initial vertical stiffness and damping coefficient of the magnetorheological elastomer isolator are $1.14 \times 10^6$ N/m and 495.8 N·s/m, respectively. The relative increase in stiffness and damping is 66.57% and 45.55%, respectively. Due to the properties of controllable stiffness and damping of MREs, the isolation transmissibility and root mean square of acceleration response can be reduced by 41.2% and 65.3%, respectively. The proposed MRE isolator can be used as a controllable stiffness device and has great potential in the field of vibration suppression for heavy equipment. [116].

4.3 Other applications

In addition to the field-sensitive elastic property, MREs possess several functions such as magnetoelasticity, magnetoresistance, magnetostriction, piezoresistance, and thermoresistance [1, 119]. The reasons for these functions are the changes in the spacing between the magnetic particles due to external loadings, which produce variations of the physical or mechanical properties of the MRE materials. Based on their field-sensitive properties, MREs have been developed for use as sensors and actuators, for example, force sensor [120], magnetoresistive sensor [18], magneto-sensitive strain sensor [20], flexible tri-axis tactile sensor [21], self-powered tribo-sensor [22], combined magnetic and mechanical sensor [17, 121], soft actuator [122], actuators for valves [123], MEMS magnetometer [124], etc. Moreover, the microwave response [125, 126] and 3D printing properties of MREs [127–129] have also been recently reported. It is worth being pointed out that the application of MREs is explosively developing.

5. Summary

In this chapter, the materials and applications of MREs are briefly reviewed. Firstly, raw materials, including the magnetic particles, the rubber-like matrices, and the additives, are introduced. As the kind of the raw materials is getting more and more inconstant, there are a variety of raw materials that can be used to prepare MREs. Attributing to the variety of the raw materials, the kinds of prepared MREs are much various and the study on the MRE materials is a long-lasting discovery.
or inventive subject. Meanwhile, the XμCT technique can be used to study the microstructures and microstructure-based mechanisms of MREs. With the development of MRE materials, the property of MREs gets more and more various. The application of MREs has quickly developed in the engineering field of vibration reduction and the application range of MREs is getting wider and wider. In addition to the conventional applications in vibration reduction, the sensing and actuating applications of MREs are recently explosively developed. Moreover, the microwave-response and the 3D printing of MREs are newly emerged subjects, which can be much promising in engineering applications in the near future.

Acknowledgements

The support of the National Natural Science Foundation of China (Grant Nos. 11602242 and 11502256) is acknowledged. The authors are grateful for the helpful suggestions of Prof. Xinglong Gong at the University of Science and Technology of China and the support of the colleagues who provided the original figures for the article.

Conflict of interest

There is no conflict of interest.

Author details

Taixiang Liu¹ and Yangguang Xu²*

1 Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang, China

2 College of Aerospace Engineering, Chongqing University, Chongqing, China

*Address all correspondence to: xyg@mail.ustc.edu.cn

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
References

[1] Li YC, Li JC, Li WH, Du HP. A state-of-the-art review on magnetorheological elastomer devices. Smart Materials and Structures. 2014;23:123001. DOI: 10.1088/0964-1726/23/12/123001

[2] Ginder JM, Nichols ME, Dlie LD, Tardiff JL. Magnetorheological elastomers: Properties and applications. Proceedings of SPIE. 1999;3675:131-138. DOI: 10.1117/12.352787

[3] Carlson JD, Jolly MR. MR fluid, foam and elastomer devices. Mechatronics. 2000;10:555-569. DOI: 10.1016/s0957-4158(99)00064-1

[4] Gong XL, Zhang XZ, Zhang PQ. Fabrication and characterization of isotropic magnetorheological elastomers. Polymer Testing. 2005;24:669-676. DOI: 10.1016/j.polymertesting.2005.03.015

[5] Li WH, Zhang XZ. Research and applications of MR elastomers. Recent Patents on Engineering. 2008;2:161-166. DOI: 10.2174/1874477X10801030161

[6] Rigbi Z, Jilkén L. The response of an elastomer filled with soft ferrite to mechanical and magnetic influences. Journal of Magnetism and Magnetic Materials. 1983;37:267-276. DOI: 10.1016/0304-8853(83)90055-0

[7] Rabinow J. The magnetic fluid clutch. AIEE Transactions. 1948;67:1308-1315. DOI: 10.1109/t-aiee.1948.5059821

[8] Ashour O, Rogers CA, Kordonsky W. Magnetorheological fluids: Materials, characterization, and devices. Journal of Intelligent Material Systems and Structures. 1996;7:123-130. DOI: 10.1177/1045389X9600700201

[9] Bossis G, Volkova O, Lacs S, Meunier A. Magnetorheology: fluids, structures and rheology. In: Odenbach S, editor. Ferrofluids, Lecture Notes in Physics. Heidelberg: Springer; 2002. pp. 202-230. DOI: 10.1007/3-540-45646-5_11

[10] de Vicente J, Klingenberg DJ, Hidalgo-Alvarez R. Magnetorheological fluids: A review. Soft Matter. 2011;7:3701-3710. DOI: 10.1039/c0sm01221a

[11] Choi HJ, Kim CA, Kwon TM, Jhon MS. Viscosity of magnetic particle suspensions. Journal of Magnetism and Magnetic Materials. 2000;209:228-230. DOI: 10.1016/s0304-8853(99)00695-2

[12] López-López MT, Zugaldía A, González-Caballero F, Durán JDG. Sedimentation and redispersion phenomena in iron-based magnetorheological fluids. Journal of Rheology. 2006;50:543-560. DOI: 10.1122/1.2206716

[13] Deng HX, Gong XL. Application of magnetorheological elastomers to vibration absorber. Communications in Nonlinear Science and Numerical Simulation. 2008;13:1938-1947. DOI: 10.1016/j.cnsns.2007.03.024

[14] Popp KM, Kroger M, Li WH, Zhang XZ, Kosasih P. MRE properties under shear and squeeze modes and applications. Journal of Intelligent Material Systems and Structures. 2010;21:1471-1477. DOI: 10.1177/1045389X09355666

[15] Li WH, Zhang XZ, Du H. Magnetorheological elastomers and their applications. In: Visakh PM, Thomas S, Chandra AK, Mathew AP, editors. Advances in Elastomers I: Blends and Interpenetrating Networks. Berlin: Springer; 2013. pp. 357-374. DOI: 10.1007/978-3-642-20925-3_12

[16] Wang Q, Dong XF, Li LY, Ou JP. Study on an improved variable stiffness tuned mass damper based on conical magnetorheological
elastomer isolators. Smart Materials and Structures. 2017;26:105028. DOI: 10.1088/1361-665X/aa81e8

[17] Wang XJ, Gordaninejad F, Calgar M, Liu YM. Sensing behavior of magnetorheological elastomers. Journal of Mechanical Design. 2009;131:091004. DOI: 10.1115/1.3160316

[18] Bica I. Magnetoresistor sensor with magnetorheological elastomers. Journal of Industrial and Engineering Chemistry. 2011;17:83-89. DOI: 10.1016/j.jiec.2010.12.001

[19] Ausanio G, Iannotti V, Ricciardi E, Lanotte L, Lanotte L. Magnetoo-piezoresistance in magnetorheological elastomers for magnetic induction gradient or position sensors. Sensors and Actuators A: Physical. 2014;205:235-239. DOI: 10.1016/j.sna.2013.10.009

[20] Hu T, Xuan SH, Ding L, Gong XL. Stretchable and magneto-sensitive strain sensor based on silver nanowire-polyurethane sponge enhanced magnetorheological elastomer. Materials and Design. 2018;156:528-537. DOI: 10.1016/j.matdes.2018.07.024

[21] Kawasetsu T, Horii T, Ishihara H, Asada M. Flexible tri-axis tactile sensor using spiral inductor and magnetorheological elastomer. IEEE Sensors Journal. 2018;18:5834-5841. DOI: 10.1109/JSEN.2018.2844194

[22] Qi S, Guo HY, Chen J, Hu CG, Yu M, Wang ZL. Magnetorheological elastomers enabled high-sensitive self-powered tribo-sensor for magnetic field detection. NanoScale. 2018;10:4745-4752. DOI: 10.1039/c7nr09129j

[23] Japka JE. Microstructure and properties of carbonyl iron powder. Journal of Metals. 1988;40:18-21. DOI: 10.1007/BF03258115

[24] Carbonyl iron [Internet]. Available from: https://en.wikipedia.org/wiki/Carbonyl_iron [Accessed: Dec 30, 2018]

[25] Chen L, Gong XL, Jiang WQ, Yao JJ, Deng HX, Li WH. Investigation on magnetorheological elastomers based on natural rubber. Journal of Materials Science. 2007;42:5483-5489. DOI: 10.1007/s10853-006-0975-x

[26] Khimi SR, Pickering KL, Mace BR. Dynamic properties of magnetorheological elastomers based on iron sand and natural rubber. Journal of Applied Polymer Science. 2015;132:41506. DOI: 10.1002/app.41506

[27] Bose H. Viscoelastic properties of silicone-based magnetorheological elastomers. International Journal of Modern Physics B. 2007;21:4790-4797. DOI: 10.1142/S0217979207045670

[28] Zhang W, Gong XL, Li JF, Zhu H, Jiang WQ. Radiation vulcanization of magnetorheological elastomers based on silicone rubber. Chinese Journal of Chemical Physics. 2009;22:535-540. DOI: 10.1088/1674-0068/22/05/535-540

[29] Li R, Sun LZ. Viscoelastic responses of silicone-rubber-based magnetorheological elastomers under compressive and shear loadings. Journal of Engineering Materials and Technology. 2013;135:021008. DOI: 10.1115/1.4023839

[30] Bunoiu M, Bica I. Magnetorheological elastomer based on silicone rubber, carbonyl iron and Rochelle salt: Effects of alternating electric and static magnetic fields intensities. Journal of Industrial and Engineering Chemistry. 2016;37:312-318. DOI: 10.1016/j.jiec.2016.03.047

[31] Japka JE. Silicone rubber based magnetorheological elastomer: magnetic structure tested by means of neutron depolarization and magnetic force microscopy methods. Journal of Physics:
Magnetorheological Elastomers: Materials and Applications
DOI: http://dx.doi.org/10.5772/intechopen.85083

Conference Series. 2017;848:012016. DOI: 10.1088/1742-6596/848/1/012016

[32] Tian TF, Zhang XZ, Li WH, Alici G, Ding J. Study of PDMS based magnetorheological elastomers. Journal of Physics: Conference Series. 2013;412:012038. DOI: 10.1088/1742-6596/412/1/012038

[33] Li WH, Nakano M. Fabrication and characterization of PDMS based magnetorheological elastomers. Smart Materials and Structures. 2013;22:055035. DOI: 10.1088/0964-1726/22/5/055035

[34] Perales-Martínez IA, Palacios-Pineda LM, Lozano-Sanchez LM, Martínez-Romero O, Puente-Cordova JG, Elias-Zúñiga A. Enhancement of a magnetorheological PDMS elastomer with carbonyl iron particles. Polymer Testing. 2017;57:78-86. DOI: 10.1016/j.polymer testing.2016.10.029

[35] Danas K, Kankanala SV, Triantafyllidis N. Experiments and modeling of iron-particle-filled of magnetorheological elastomers. Journal of the Mechanics and Physics of Solids. 2012;60:120-138. DOI: 10.1016/j jmmps.2011.09.006

[36] Zhang W, Gong XL, Xuan SH, Jiang WQ. Temperature-dependent mechanical properties and model of magnetorheological elastomers. Industrial & Engineering Chemistry Research. 2011;50:6704-6712. DOI: 10.1021/ie200386x

[37] Gong XL, Fan YC, Xuan SH, Xu YG, Peng C. Control of the damping properties of magnetorheological elastomers by using polycaprolactone as a temperature-controlling component. Industrial & Engineering Chemistry Research. 2012;51:6395-6403. DOI: 10.1021/ie300317b

[38] Ju BX, Tang R, Zhang DY, Yang BL, Yu M, Liao CR. Temperature-dependent dynamic mechanical properties of magnetorheological elastomers under magnetic field. Journal of Magnetism and Magnetic Materials. 2015;374:283-288. DOI: 10.1016/j.jmmm.2014.08.012

[39] Xiang CL, Gao P, Liu H, Zhou H. Experimental and theoretical study of temperature-dependent variable stiffness of magnetorheological elastomers. International Journal of Materials Research. 2018;109:1-16. DOI: 10.3139/146.111590

[40] Lian CL, Lee KH, Lee CH. Effect of temperature and relative humidity on friction and wear properties of silicone-based magnetorheological elastomer. Tribology Transactions. 2018;61:238-246. DOI: 10.1080/10402004.2017.1306636

[41] Liao GJ, Xu YG, Wang FJ, Wei FY, Wan Q. Influence of γ radiation on the shear modulus of magnetorheological elastomer. Materials Letters. 2016;174:79-81. DOI: 10.1016/j.matlet.2016.03.085

[42] Ginder JM, Nichols ME, Elie LD, Clark SM. Controllable-stiffness components based on magnetorheological elastomers. Proceedings of SPIE. 2000;3985:418-425. DOI: 10.1117/12.388844

[43] Ubaidillah SJ, Purwanto A, Mazlan SA. Recent Progress on Magnetorheological solids: materials, fabrication, testing, and applications. Advanced Engineering Materials. 2015;17:563-597. DOI: 10.1002/adem.201400258

[44] BASF SE [Internet]. Available from: http://www.monomers.basf.com [Accessed: Dec 30, 2018]

[45] Zhu H. Fabrication of practical magnetorheological fluids and their properties [thesis]. Hefei: University of Science and Technology of China; 2010
[46] Liu TX, Gong XL, Xu YG, Xuan SH, Jiang WQ. Simulation of magneto-induced rearrangeable microstructures of magnetorheological plastomers. Soft Matter. 2013;9:10069-10080. DOI: 10.1039/c3sm52130c

[47] Lokander M, Stenberg B. Performance of isotropic magnetorheological rubber materials. Polymer Testing. 2003;22:245-251. DOI: 10.1016/S0142-9418(02)00043-0

[48] Stepanov GV, Abramchuk SS, Grishin DA, Nikitin LV, Kramarenko EY, Khokhlov AR. Effect of a homogeneous magnetic field on the viscoelastic behavior of magnetic elastomers. Polymer. 2007;48:488-495. DOI: 10.1016/j.polymer.2006.11.044

[49] Liu TX. Study on the magneto-mechanical behavior of magnetorheological plastomers and its microstructure-based mechanism [thesis]. Hefei: University of Science and Technology of China; 2015

[50] Silicone rubber [Internet]. Available from: https://en.wikipedia.org/wiki/Silicone_rubber [Accessed: Dec 30, 2018]

[51] Natural rubber [Internet]. Available from: https://en.wikipedia.org/wiki/Natural_rubber [Accessed: Dec 30, 2018]

[52] Polybutadiene [Internet]. Available from: https://en.wikipedia.org/wiki/Polybutadiene [Accessed: Dec 30, 2018]

[53] Butyl rubber [Internet]. Available from: https://en.wikipedia.org/wiki/Butyl_rubber [Accessed: Dec 30, 2018]

[54] Polyurethane [Internet]. Available from: https://en.wikipedia.org/wiki/Polyurethane [Accessed: Dec 30, 2018]

[55] Polydimethylsiloxane [Internet]. Available from: https://en.wikipedia.org/wiki/Polydimethylsiloxane [Accessed: Dec 30, 2018]

[56] Epoxy [Internet]. Available from: https://en.wikipedia.org/wiki/Epoxy [Accessed: Dec 30, 2018]

[57] Characteristic properties of silicone rubber compounds [Internet]. Available from: http://www.shinetsusilicone-global.com/ [Accessed: Dec 30, 2018]

[58] Leblanc J. Rubber-filler interactions and rheological properties in filled compounds. Progress in Polymer Science. 2002;27:627-687. DOI: 10.1016/s0079-6700(01)00040-5

[59] Chen L, Gong XL, Li WH. Effect of carbon black on the mechanical performances of magnetorheological elastomers. Polymer Testing. 2008;27:340-345. DOI: 10.1016/j.polymertesting.2007.12.003

[60] Nayak B, Dwivedy S, Murthy K. Fabrication and characterization of magnetorheological elastomer with carbon black. Journal of Intelligent Material Systems and Structures. 2015;26:830-839. DOI: 10.1177/1045389X14535011

[61] Lu HL, Wang WJ, Yang FF, Wang GP, Rui XT. Effect of carbon black with large particle size on dynamic mechanical analysis of magnetorheological elastomers (MREs). Materials Research Express. 2018;5:095703. DOI: 10.1088/2053-1591/aad88b

[62] Aziz S, Mazlan S, Ismail N, Ubaiddillah U, Choi S, Khairi M, et al. Effects of multiwall carbon nanotubes on viscoelastic properties of magnetorheological elastomers. Smart Materials and Structures. 2016;25:077001. DOI: 10.1088/0964-1726/25/7/077001

[63] Aziz S, Mazlan S, Ismail N, Ubaiddillah U, Khairi M, Yunus N. Rheological properties of carbon nanotubes-reinforced magnetorheological elastomer.
Journal of Physics: Conference Series. 2017;795:012074. DOI: 10.1088/1742-6596/795/1/012074

[64] Poojary U, Hegde S, Gangadharan K. Experimental investigation on the effect of carbon nanotube additive on the field-induced viscoelastic properties of magnetorheological elastomer. Journal of Materials Science. 2018;53:4229-4241. DOI: 10.1007/s10853-017-1883-y

[65] Aziz S, Ubaidillah U, Mazlan S, Ismail N, Choi SB. Implementation of functionalized multiwall carbon nanotubes on magnetorheological elastomer. Journal of Materials Science. 2018;53:10122-10134. DOI: 10.1007/s10853-018-2315-3

[66] Lee CJ, Kwon SH, Choi HJ, Chung KH, Jung JH. Enhanced magnetorheological performance of carbonyl iron/natural rubber composite elastomer with gamma-ferrite additive. Colloid and Polymer Science. 2018;296:1609-1613. DOI: 10.1007/s00396-018-4373-0

[67] Gordaninejad F, Wang XJ, Mysore P. Behavior of thick magnetorheological elastomers. Journal of Intelligent Material Systems and Structures. 2012;23:1033-1039. DOI: 10.1177/1045389X12448286

[68] Chen L, Gong XL, Li WH. Microstructures and viscoelastic properties of anisotropic magnetorheological elastomers. Smart Materials and Structures. 2007;16:2645-2650. DOI: 10.1088/0964-1726/16/6/069

[69] Bakshi SR, Batista RG, Agarwal A. Quantification of carbon nanotube distribution and property correlation in nanocomposites. Composites: Part A. 2009;40:1311-1318. DOI: 10.1016/j.compositesa.2009.06.004

[70] Balasoiu M, Craus ML, Anitas EM, Bica I, Plescitl J, Kuklin AI.

Microstructure of stomaflex based magnetic elastomers. Physics of the Solid State. 2010;52:917-921. DOI: 10.1134/s1063783410050070

[71] Gunther D, Borin D, Gunther S, Odenbach S. X-ray microtomographic characterization of field-structured magnetorheological elastomers. Smart Materials and Structures. 2012;21:015005. DOI: 10.1088/0964-1726/21/1/015005

[72] Borbath T, Gunther S, Borin D, Gundermann T, Odenbach S. XμCT analysis of magnetic field-induced phase transitions in magnetorheological elastomers. Smart Materials and Structures. 2012;21:105018. DOI: 10.1088/0964-1726/21/10/105018

[73] Gundermann T, Odenbach S. Investigation of the motion of particles in magnetorheological elastomers by X-μCT. Smart Materials and Structures. 2014;23:105013. DOI: 10.1088/0964-1726/23/10/105013

[74] Jolly MR, Carlson JD, Munoz B. A model of the behaviour of magnetorheological materials. Smart Materials and Structures. 1996;5:607-614. DOI: 10.1088/0964-1726/5/5/009

[75] Davis LC. Model of magnetorheological elastomers. Journal of Applied Physics. 1999;85:3348-3351. DOI: 10.1063/1.369682

[76] Li WH, Zhang XZ. A study of the magnetorheological effect of bimodal particle based magnetorheological elastomers. Smart Materials and Structures. 2010;19:035002. DOI: 10.1088/0964-1726/19/3/035002

[77] Metsch P, Kalina KA, Spieler C, Kastner M. A numerical study on magnetostrictive phenomena in magnetorheological elastomers. Computational Materials Science. 2016;124:364-374. DOI: 10.1016/j.commatsci.2016.08.012
[78] Kalina KA, Metsch P, Kastner M. Microscale modeling and simulation of magnetorheological elastomers at finite strains: A study on the influence of mechanical preloads. International Journal of Solids and Structures. 2016;102-103:286-296. DOI: 10.1016/j.ijsolstr.2016.10.019

[79] Liu TX, Xu YG. Soft magneto-sensitive particle-reinforced composite material and its tunable three-dimensional microstructure. In: The 18th U.S. National Congress for Theoretical and Applied Mechanics; 5-9 June 2018; Chicago, USA

[80] Shen Y, Golnaraghi MF, Heppler GR. Experimental research and modeling of magnetorheological elastomers. Journal of Intelligent Material Systems and Structures. 2004;15:27-35. DOI: 10.1177/1045389X04039264

[81] Biller AM, Stolbov OV, Raikher YL. Modeling of particle interactions in magnetorheological elastomers. Journal of Applied Physics. 2014;116:114904. DOI: 10.1063/1.4895980

[82] Biller AM, Stolbov OV, Raikher YL. Two-particle element of a magnetorheological elastomer under a cyclic magnetic field. Journal of Physics: Conference Series. 2018;994:012001. DOI: 10.1088/1742-6596/994/1/012001

[83] Dorfmann A, Ogden RW. Magnetoelastic modelling of elastomers. European Journal of Mechanics A/Solids. 2003;22:497-507. DOI: 10.1016/S0997-7538(03)00067-6

[84] Chatzigeorgiou G, Javili A, Steinmann P. Unified magnetomechanical homogenization framework with application to magnetorheological elastomers. Mathematics and Mechanics of Solids. 2014;19:193-211. DOI: 10.1177/1081286512458109

[85] Ethiraj G, Sridhar A, Miehe C. A Magneto-visco-elastic model for magnetorheological elastomers. Proceedings of Applied Mathematics and Mechanics. 2014;14:515-516. DOI: 10.1002/pamm.201410245

[86] Agirre-Olabide I, Lion A, Elejabarrieta MJ. A new three-dimensional magneto-viscoelastic model for isotropic magnetorheological elastomers. Smart Materials and Structures. 2017;26:035021. DOI: 10.1088/1361-665X/26/3/035021

[87] Kou Y, Jin K, Xu LQ, Zheng XJ. A novel phenomenological model for dynamic behavior of magnetorheological elastomers in tension-compression mode. Smart Materials and Structures. 2017;26:065011. DOI: 10.1088/1361-665X/aa6126

[88] Kou Y, Jin K, Xu LQ, Zheng XJ. A viscoelastic constitutive model for magneto-mechanical coupling of magnetorheological elastomers. Smart Materials and Structures. 2017;26:115017. DOI: 10.1088/1361-665X/aa8d3d

[89] Cantera MA, Behrooz M, Gibson RF, Gordaninejad F. Modeling of magneto-mechanical response of magnetorheological elastomers (MRE) and MRE-based systems: a review. Smart Materials and Structures. 2017;26:023001. DOI: 10.1088/1361-665X/aa549c

[90] Kalina KA, Brummund J, Metsch P, Kastner M. Microscale modeling and simulation of magnetorheological elastomers. Proceedings of Applied Mathematics and Mechanics. 2017;17:27-30. DOI: 10.1002/pamm.201710008

[91] Wang Q, Dong XF, Li LY, Ou JP. A nonlinear model of magnetorheological elastomer with wide amplitude range and variable...
frequencies. Smart Materials and Structures. 2017;26:065010. DOI: 10.1088/1361-665X/aa66e3

[92] Agirre-Olabide KP, Elejabarrieta MJ. Linear magneto-viscoelastic model based on magnetic permeability components for anisotropic magnetorheological elastomers. Journal of Magnetism and Magnetic Materials. 2018;446:155-161. DOI: 10.1016/j.jmmm.2017.09.017

[93] Wang Q, Dong XF, Li LY, Ou JP. Mechanical modeling for magnetorheological elastomer isolators based on constitutive equations and electromagnetic analysis. Smart Materials and Structures. 2018;27:065017. DOI: 10.1088/1361-665X/aaabdb5

[94] Li WH, Zhang XZ, Du HP. Development and simulation evaluation of a magnetorheological elastomer isolator for seat vibration control. Journal of Intelligent Material Systems and Structures. 2012;23:1041-1048. DOI: 10.1177/1045389X11435431

[95] Ginder JM, Clark SM, Schlotter WF, Nichols ME. Magnetostrictive phenomena in magnetorheological elastomer. International Journal of Modern Physics B. 2002;16:2412-2418. DOI: 10.1142/S021797920201244X

[96] Guan XC, Dong XF, Ou JP. Magnetostrictive effect of magnetorheological elastomer. Journal of Magnetism and Magnetic Materials. 2008;320:158-163. DOI: 10.1016/j.jmmm.2007.05.043

[97] Sun SL, Peng XQ, Guo ZY. Nonlinear magnetostrictive effect of magnetorheological elastomers. Advanced Materials Research. 2014;833:291-294. DOI: 10.4028/www.scientific.net/AMR.833.291

[98] Gong XL, Liao GJ, Xuan SH. Full-field deformation of magnetorheological elastomer under uniform magnetic field. Applied Physics Letters. 2012;100:211909. DOI: 10.1063/1.4722789

[99] Kchit N, Bossis G. Electrical resistivity mechanism in magnetorheological elastomer. Journal of Physics D: Applied Physics. 2009;42:105505. DOI: 10.1088/0022-3727/42/10/105505

[100] Zhu XL, Meng YG, Tian Y. Nonlinear pressure-dependent conductivity of magnetorheological elastomers. Smart Materials and Structures. 2010;19:117001. DOI: 10.1088/0964-1726/19/11/117001

[101] Bica I. The influence of hydrostatic pressure and transverse magnetic field on the electric conductivity of the magnetorheological elastomers. Journal of Industrial and Engineering Chemistry. 2012;18:483-486. DOI: 10.1016/j.jiec.2011.11.067

[102] Bica I, Anitas EM, Bunoiu M, Vatuzlik B, Juganaru I. Hybrid magnetorheological elastomer: Influence of magnetic field and compression pressure on its electrical conductivity. Journal of Industrial and Engineering Chemistry. 2014;20:3994-3999. DOI: 10.1016/j.jiec.2013.12.102

[103] Ge L, Gong XL, Wang Y, Xuan SH. The conductive three dimensional topological structure enhanced magnetorheological elastomer towards a strain sensor. Composites Science and Technology. 2016;135:92-99. DOI: 10.1016/j.compsctech.2016.09.015

[104] Wang Y, Xuan SH, Dong B, Xu F, Gong XL. Stimuli dependent impedance of conductive magnetorheological elastomers. Smart Materials and Structures. 2016;25:025003. DOI: 10.1088/0964-1726/25/2/025003

[105] Wang Y, Xuan SH, Ge L, Wen QQ, Gong XL. Conductive
magnetorheological elastomer: Fatigue dependent impedance-mechanic coupling properties. Smart Materials and Structures. 2017;26:015004. DOI: 10.1088/0964-1726/26/1/015004

[106] Kordonsky WI. Magnetorheological effect as a base of new devices and technologies. Journal of Magnetism and Magnetic Materials. 1993;122:395-398. DOI: 10.1016/0304-8853(93)91117-P

[107] Ginder JM, Schlotter WF, Nichols ME. Magnetorheological elastomers in tunable vibration absorbers. Proceedings of SPIE. 2001;4331:103-110. DOI: 10.1117/12.432694

[108] Deng HX, Gong XL, Wang LH. Development of an adaptive tuned vibration absorber with magnetorheological elastomer. Smart Materials and Structures. 2006;15:N111-N116. DOI: 10.1088/0964-1726/15/5/N02

[109] Hoang N, Zhang N, Du H. An adaptive tunable vibration absorber using a new magnetorheological elastomer for vehicular powertrain transient vibration reduction. Smart Materials and Structures. 2011;20:015019. DOI: 10.1088/0964-1726/20/1/015019

[110] Liao GJ, Gong XL, Xuan SH. Phase based stiffness tuning algorithm for a magnetorheological elastomer dynamic vibration absorber. Smart Materials and Structures. 2014;23:015016. DOI: 10.1088/0964-1726/23/1/015016

[111] Xin FL, Bai XX, Qian LJ. Principle, modeling, and control of a magnetorheological elastomer dynamic vibration absorber for powertrain mount systems of automobiles. Journal of Intelligent Material Systems and Structures. 2017;28:2239-2254. DOI: 10.1177/1045389X16672731

[112] Sun SS, Yang J, Yildirim T, Du HP, Alici G, Zhang SW, et al. Development of a nonlinear adaptive absorber based on magnetorheological elastomer. Journal of Intelligent Material Systems and Structures. 2018;29:194-204. DOI: 10.1177/1045389X17733053

[113] Ibrahim RA. Recent advances in nonlinear passive vibration isolators. Journal of Sound and Vibration. 2008;314:371-452. DOI: 10.1016/j.jsv.2008.01.014

[114] Yang J, Du HP, Li WH, Li YC, Li JC, Sun SS, et al. Experimental study and modeling of a novel magnetorheological elastomer isolator. Smart Materials and Structures. 2013;22:117001. DOI: 10.1088/0964-1726/22/11/117001

[115] Behrooz M, Wang XJ, Gordaninejad F. Modeling of a new semi-active/passive magnetorheological elastomer isolator. Smart Materials and Structures. 2014;23:045003. DOI: 10.1088/0964-1726/23/4/045013

[116] Yu M, Zhao LJ, Fu J, Zhu M. Thermal effects on the laminated magnetorheological elastomer isolator. Smart Materials and Structures. 2016;25:115039. DOI: 10.1088/0964-1726/25/11/115039

[117] Li YC, Li JC. On rate-dependent mechanical model for adaptive magnetorheological elastomer base isolator. Smart Materials and Structures. 2017;26:045001. DOI: 10.1088/1361-665X/aa5f95

[118] Tao Y, Rui XT, Yang FF, Chen GL, Bian LK, Zhu W, et al. Design and experimental research of a magnetorheological elastomer isolator working in squeeze/elongation-shear mode. Journal of Intelligent Material Systems and Structures. 2018;29:1418-1429. DOI: 10.1177/1045389X17740436

[119] Martin JE, Anderson RA, Odinek J, Adolf D, Williamson J. Controlling percolation in field-structured particle composites: Observations of giant
thermoreistance, piezoresistance, and chemiresistance. Physical Review B. 2003;67:094207. DOI: 10.1103/PhysRevB.67.094207

[120] Li WH, Kostidis K, Zhang XZ, Zhou Y. Development of a force sensor working with MR elastomers. 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics; 14-17 July 2009; Singapore

[121] Ghafoorianfar N, Wang XJ, Gordaninejad F. Combined magnetic and mechanical sensing of magnetorheological elastomers. Smart Materials and Structures. 2014;23:055010. DOI: 10.1088/0964-1726/23/5/055010

[122] Kashima S, Miyasaka F, Hirata K. Novel soft actuator using magnetorheological elastomer. IEEE Transactions on magnetics. 2012;48:1649-1652. DOI: 10.1109/TMAG.2011.2173669

[123] Bose H, Rabindranath R, Ehrlich J. Soft magnetorheological elastomers as new actuators for valves. Journal of Intelligent Material Systems and Structures. 2011;23:989. DOI: 10.1177/1045389X11433498

[124] Du GT, Chen XD. MEMS magnetometer based on magnetorheological elastomer. Measurement. 2012;45:54-58. DOI: 10.1016/j.measurement.2011.10.002

[125] Butera A, Alvarez N, Jorge G, Ruiz MM, Mietta JL, Negri RM. Microwave response of anisotropic magnetorheological elastomers: Model and experiments. Physical Review B. 2012;86:144424. DOI: 10.1103/PhysRevB.86.144424

[126] Yu M, Yang PA, Fu J, Liu SZ, Qi S. Study on the characteristics of magnetosensitive electromagnetic wave-absorbing properties of magnetorheological