Magnetorheological Elastomers: A Review

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Abstract. This present paper reviews on the material compositions of magnetorheological elastomer (MRE) as presented by researchers. As the article review, this paper much focuses on the selection of the material in the MRE ingredients. MRE has been known as a new kind of smart material over past decades. MREs offer innovative solutions for various applications in the engineering field since the rheological properties of MREs can be controlled by an external magnetic field. The characteristic responses of MRE are influenced by many factors such its elastomer matrix, the size, distribution, composition, percentage volume of filler particles and so on.

Introduction

Magnetorheological elastomers (MREs) belong to a group of smart materials, whose mechanical and magnetic properties can be controlled continuously, rapidly and reversibly under the application of an external magnetic field [1-5]. Traditionally, magnetorheological (MR) material is composed of MR fluids and MR foams. The first discovery of MR material was first prepared by Thomas Rabinow in 1951, which is MR fluids [6]. In MR fluids, iron particles are suspended in a liquid carrier fluid. MR foams, in which the controllable fluid is contained in an absorptive matrix or magnetic particles are dispersed in a foam-like matrix [7].

MRE is a new member of the magnetorheological family, where it is the solid analogue of MR fluids and may be a good solution to overcome the disadvantages of MRF [8,9]. The obvious advantages of MRE are that the particles are not able to prone to setting with time and so there is no need for containers to keep the MR material in a fixed place [2,6,7,10]. MRE is the solid-state analogue of MR fluids, in which the fluid component is replaced with rubber-like solid materials such as natural or synthetic rubber as well as their blends. Typically, MRE consists of micron-sized magnetic particles suspended in a non-magnetic matrix [7,11]. The particles inside the elastomer can be distributed homogeneously or in aligned form. Magnetic fields are applied to the polymer composite during crosslinking so that particles form chainlike or columnar structures, which are fixed in the matrix after curing. Figure 1 (refer Fig. 1) illustrates aligning MREs’ iron particles along the direction of the magnetic field.

Because of their unique characteristics, MREs have attracted increasing attention and have obtained broad application prospects recently. Based on literature, recent interest in application of MRE on various fields such as automotive industry, earthquake-resistance and vibration control [7]. Deng et al. [12,13] developed adaptive tuned vibration absorbers. Chen [14] investigated the damping of MRE, where his result was very helpful to be applied in MRE based adaptive tuned vibration absorbers. The vibration reduction effect can be enhanced by the low damping ratio. Eem et al. [15,16] also studied MRE for seismic protection of based isolated-structures. Besides that, Li et al. [17,18] performed a series of studies to develop and characterize MRE as based adaptive seismic isolator.
Materials

Studies of several available literatures on the preparation of MRE composites describes that the composites of MRE are matrix, filler and some additives such as cross-linking agents, antioxidants and mixing aids may be used.

**Matrices.** Rubber is commonly used for the matrix instead of gels. The rubber types can be natural rubber, silicone rubber, thermoplastic rubber, synthetic rubber, butyl rubber and so on [5,19–21]. The choice of the matrix based of MRE is very flexible referring to the purposes and applications of the MRE. Soft matrix such as silicone rubbers is the best selection for fabricating MRE in order to get the high MR effects [21]. Silicone rubber also has been widely used in preparing MRE because it is easy to be processed. Nevertheless, this soft matrix is with worse mechanical performances and hence is not applicable to be used in engineering vibration control. Consequently, natural rubber has a very good mechanical properties, flexibility and processing performances which are suitable for wide applications [3,6]. Even though natural rubber is the best choice for the elastomer matrix of MRE in controlling structural vibration, it has low performance to overcome damping compared to butyl rubber [21]. Apart from that, butyl rubber has excellent chemical stability and insulation, which has a high damping property compared to other types of rubbers [3,4].

**Magnetic fillers.** Filling an elastomeric material with magnetizable particles influences the mechanical properties of the composite when an external magnetic field is applied. The properties of MRE depend on the selection of matrix and magnetizable particles. Filler particles should be homogenous and well distributed into the elastomer to produce a good network interaction [6,7]. The magnetic fillers normally used in MRE should be magnetizable ferromagnetic. They can be iron, nickel and cobalt [6] which are spherical or nearly spherical in shape and having a diameter of some micrometre [22] in the range of about 1 to 100 microns [7]. Most of previous researchers have used pure iron for the micron sized particles in order to create the magnetization of MRE. Some alloys of iron and cobalt can also be used to good effect, nevertheless the use of these particles in MRE is not common and widespread as iron [7,10]. The iron particles can be clarified as a good choice of filler because of their high permeability, low permanent magnetization and high saturation magnetization [6,21,22]. High permeability and high saturation magnetization provide huge interaction between particles, hence the high effect of MR.

According to Davis [23] the increasing of the filler volume fraction over 27% in the MRE does not further the increase of MR effect. However the increment of the filler volume over than 30% will deteriorate the mechanical performances of MRE by using tensile test [24].This is because material with high volume fractions of filler material have high zero-field modulus. Hence, the MR effect can be quite low. An experiment that conducted by [1] also verified that an increase of 0.03 in tan δ values at higher peak strain (10%) in shear testing of aligned MRE containing 30 volume % of iron. The increment of particle size of filler materials will decrease the mechanical performances of MRE, although the MR effect can increase [21]. Thus, the iron...
concentration should be 30% by volume in order to achieve a good MR effect [25]. Due to experiments that have proved by previous researchers, the “optimal” iron volume concentration is about 30%, which can generate the maximum modulus or stiffness of MRE [16,26].

**Additives.** Most of previous researches reported includes some additives as parts of MRE ingredient. Some of additives that have been used are as follows: reinforcing agent, vulcanizing agent, plasticizer, accelerator, age-resistor and crosslinking agent, which are added to increase the mechanical performances of MRE. The reinforcing agent such Carbon Black (HAF N330) [3,27] can improve rubber workability in term of tear strength. The amount of reinforcing agent can be varied due to the purpose and application of MRE. Stearic acid act as a lubricant which can modify the rubber mechanism and increase the filler particle properties [19]. Zinc oxide (ZnO) and sulphur [25,28,29] are the most common additives use in MRE composition. ZnO is a vulcanizing agent for polychlorophene rubber, however, for other rubbers ZnO acts as an activator. The range amount of ZnO is from 3-5 pphr while sulfur can be 0.1-5 pphr [30]. Age-resistor or antioxidant is the optional ingredients in the MRE, which used to reduce the ageing process in the vulcanizates and slow down the deterioration of MRE. The amount of antioxidant that usually preferred in the range of 1-3 pphr [30].

**Conclusion.**

Selection of size and dimension of magnetic filler can be varied due to the purpose and application of MRE product. The full process of MRE preparation not also had been discussed in details in most journals. It is recommended to apply such models that have been done by the previous researchers experimentally. The previous experiments can be a worthy guideline to be implemented for further exploration. Hence, any changes of the results testing can be compared and discussed later.

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