An EPDM/MVQ polymer blend based magnetorheological elastomer with good thermostability and mechanical performance†

Song Qi, a Miao Yu, *a Jie Fu, a Mi Zhu, a Yuanpeng Xie a and Wang Li a

Magnetorheological elastomers (MREs) with outstanding magnetic-control properties are highly desirable for applications such as vibration attenuation, smart sensing, and soft robots. However, the low strength and thermolability of these materials still restrict their application in attenuating the vibration of large-scale devices. In this paper, we prepared an MRE based on ethylene-propylene-diene monomer (EPDM)/methylvinyl silicone rubber (MVQ) polymer blends. The resulting MRE showed good thermostability and mechanical properties. Good interfacial interaction and particle dispersion were achieved by modifying the surface of carbonyl iron powder (CIP) with silica coating by the sol–gel method. The compatibility between the EPDM and MVQ was promoted using silane coupling agents. Moreover, the resulting MRE had high mechanical strength and elongation at break. The dynamic viscoelastic properties of the MRE were tested using a rheometer. The influences of frequency, strain, matrices, temperature, and magnetic fields were discussed comprehensively, and relevant physical mechanisms were proposed. Finally, thermal aging tests were performed to evaluate the heat resistance of the MRE. Analytical results showed that the resulting MRE could be significantly applied to reduce the vibration of large devices because of its excellent mechanical properties and thermostability.

1. Introduction

Magnetorheological elastomers (MREs), which are also known as magneto-sensitive elastomers, belong to a class of smart materials that consist of a polymeric matrix with embedded magnetic microparticles or nanoparticles, such as carbonyl iron particles (CIPs).1–7 The mechanical properties of MREs can be controlled rapidly, continuously, and reversibly by adjusting the applied magnetic field. As versatile smart engineering materials, MREs are highly desirable for various engineering applications, such as sound absorption, vibration isolation, intelligent sensors, electromagnetic absorption, and soft robots.8–18 Similar to other magnetorheological (MR) materials, the magnetic-field drive device of an MRE is an electromagnet. According to Joule’s law, the coils in an electromagnet generate considerable heat when the electromagnet induces a strong magnetic field.19 Given the long-term self-heating effects, the performance of MR devices remarkably varies compared with their initial state, especially for large-scale devices. The instability caused by high temperature is a great challenge in the development of control strategies and it significantly reduces the performance of an MR device.

Many studies have examined the effect of temperature on MRE materials and devices.20,21 Yu et al. investigated the effect of temperature on the characteristics of an MRE isolator and proposed the use of heat-conducting silicon grease and air cooling to improve its stability.22 The instability of an MR device caused by self-heating is essentially attributed to the thermolability of the MR material. Zhang et al. studied the temperature-dependent mechanical properties of MREs based on cis-polybutadiene and natural mixed rubber. The results suggest that the storage modulus is strongly dependent on temperature.23 We previously studied the influence of temperature on the creep recovery and stress relaxation of MREs. The results showed that creep and relaxation aggravated when the temperature increased.24,25 Thermal aging tests have also been performed to study the long-term stability of MREs.26–28 In addition to the MR effect and mechanical strength, thermostability is another important parameter of an MRE. Hence, this parameter should be considered when the MRE is applied on large-scale devices.

The polymeric matrix, as an important part of a particle-reinforced polymer composite, is the important factor affecting...
the characteristics of an MRE. In general, the applied load is transmitted through the matrix to the reinforcing particles by shear stress, and it is wrapped with the particles to protect it from corrosion, oxidation, etc. A variety of rubber elastomers such as polyurethane (PU), natural rubber (NR), silicone rubber (SR), or other elastomers are used as the matrices for the MRE. Among these matrices, SR has flexible macromolecular chains, good Si–O bond thermal stability, low hardness, high elasticity, and excellent filling capacity. Thus, SR is one of the most suitable candidates for the MRE matrix. However, the low strength of SR limits its application in large-scale devices.

Novel preparation methods should be developed to improve the mechanical strength and maintain the good thermostability and MR properties of SR-based MREs.

Polymer blends are an effective tool to improve the comprehensive performance of composite materials. Given their synergistic effect, polymer blends can overcome the disadvantages and integrate the advantages of different matrices. Different kinds of MRE based on diverse polymer blends, such as SR/polystyrene, cis-polyybutadiene rubber/NR, and PU/epoxy resins have been prepared. Ethylene-propylene-diene monomer (EPDM) is one of the most commonly used engineering materials. This monomer is prepared from ethylene, propylene, and ethylenedienorbornene or 1,4-hexadiene or dicyclopentadiene terpolymer. The EPDM has a low ablation rate, high thermal resistance, low brittle temperature, good aging resistance, and good atmospheric resistance. Few studies have reported on EPDM-based MREs, and their MR effect is low. The low MR effect is mainly because of the high hardness of the EPDM. The high Mooney viscosity limited the pre-structure of the CIPs during vulcanization under a magnetic field, which reduced the anisotropy of the MRE. Moreover, the nonpolarity of the molecular chain of the EPDM hampered the strong interfacial interaction between the EPDM and CIPs, which led to the agglomeration of the particles. Fortunately, the MVQ with low Mooney viscosity could overcome these disadvantages of the EPDM. Many reports have confirmed the feasibility of preparing EPDM/SR polymer blends. The results show that the incorporation of the EPDM into SR can improve the aging resistance and mechanical properties. Thus, we speculate that the EPDM/SR polymer blend is an excellent candidate for preparing high-performance MREs.

Therefore, EPDM/methylvinyl SR (MVQ) was prepared to improve the mechanical properties and thermostability of the MRE. The surface of carbonyl iron powder (CIP) was modified with silica coating by the sol–gel method to improve the interfacial interaction and dispersion. Moreover, the compatibility between the EPDM and MVQ was promoted using silane coupling agents. In the matrix, the silane coupling agent and MVQ with low Mooney viscosity could improve the particle dispersion and anisotropy of the MRE. The mechanical properties and dynamic viscoelasticity were evaluated by the extension and oscillatory shear tests, respectively. The influences of matrix and temperature on the MR properties were discussed systematically. In addition, thermogravimetric analysis (TGA) and thermal aging tests were performed to study the thermostability of the MREs.

2. Experimental

2.1. Materials

The raw materials used to modify the surface of CIP were as follows. The pure CIPs (type: CN; 1–8 μm) were purchased from BASF, Germany. Tetraethoxysilane (TEOS; chemically pure) was used as the silica precursor for surface modification, which was provided by Baichuan Chemical Co. Ltd. Absolute ethyl alcohol, which was provided by Chongqing Dongfeng Chemical Co. Ltd., was used as a reaction medium. Hydrochloric acid (36.5–38%, analytical reagent), which was purchased from Chongqing Chuanlong Chemical Co. Ltd., was employed as a catalyst.

The raw materials used to prepare the MRE were as follows. The necessary matrix materials included EPDM (type: 3062EM, Mitsu Chemicals, TPX) and MVQ (type: 110-1, Wantai Silicon Rubber Co. Ltd). 2,5-Dimethyl-2,5-di(t-butyl peroxyl)hexane (AD) provided by Guangzhou Zhongjie Chemical Co., Ltd, was employed as a vulcanizing agent; KH570 provided by Guangzhou Zhongjie Chemical Co., Ltd, was employed as a silane coupling agent. Paraffin oil purchased from Chongqing Dongfeng Chemical Co. Ltd was used as a plasticizer. Precipitated silica provided by Fujian Yuaxiang Chemical Co., Ltd, was employed as a reinforcing filler.

2.2. Surface modification of CIPs

The surfaces of CIPs were modified with silica coating by a simple and convenient sol–gel method. The synthesis is briefly described as follows. First, TEOS was dissolved in ethanol in an appropriate molar ratio, and a small amount of hydrochloric acid was added to provide an acidic pH for the reaction and serve as a catalyst. The solution was mechanically stirred under ultrasonication for 2 h, during which a silica overlayer network was created through hydrolysis and condensation reaction. Then, a certain amount of CIPs was mixed into the solution and mechanically stirred for 2 h. After further reaction, a silica coating was uniformly formed on the surfaces of the particles. In order to remove the residual organic matter from the surface, the particles were washed several times with alcohol and deionized water. After being collected using a permanent magnet, the particles were dried at 60 °C under vacuum for 24 h. Finally, dispersed modified CIPs were obtained by fully grinding. The schematic and characterization of the surface-functionalization of CIPs are shown in Scheme S1 (ESI†). Additional details on the synthesis and characterization of the silica-coated CIPs can be found in our previous work.

2.3. MRE preparation

The synthetic process of the MRE based on the EPDM/MVQ polymer blend is shown in Fig. 1a. First, the MVQ gum was mixed with a certain amount of CIPs and KH570 using an internal mixer for 30 min at 40 °C. The silane coupling agent can build covalent bonds between the particles and MVQ. At the same time, the EPDM rubber was melt-blended with the addition of paraffin oil and precipitated silica in a two-roll mill at 80 °C for 20 min. The paraffin oil was used to reduce the hardness and improve the processability of the EPDM. After heat softening, the EPDM rubber was added to an internal
mixer and mixed with the MVQ mixture for 30 min. Then, the vulcanizing agent AD was added to the mixture using a two-roll mill at 50 °C for 10 min. Finally, the mixture was poured into an aluminum mold and cured under a constant magnetic field (0.6 T) and at 100 °C for approximately 30 min. In order to obtain excellent anisotropy, the MVQ with low Mooney viscosity should be dominant in the polymer blend. The samples were then post-cured in a flat-panel vulcanizing machine at 120 °C for 2 h. The samples were allowed to stand before the tests (matured for 24 h at room temperature). The formulae of the MRE samples in this paper are listed in Table 1. Taking into account both their mechanical strength and MR effects, the MRE samples with dominant MVQ contents were prepared. The MRE samples were named after the matrix components, namely, MVQ-MRE, M8E2-MRE, M7E3-MRE, M6E4-MRE, and M5E5-MRE.

2.4. Characterization

Fourier transform infrared spectroscopy (FT-IR) (Nicolet iS50, Thermo Fisher Scientific, USA) was employed to determine the chemical groups of MVQ, EPDM, and MRE. The magnetic properties (\(M-H\) curve) were determined using a vibrating sample magnetometer (Lake Shore 7407) at laboratory temperature. The morphologies of the particles and MRE samples were examined using a scanning electron microscope (SEM; MIRA3 TESCAN) employing an accelerating voltage of 5–10 kV. The thermolytic properties of the MRE samples were tested using a thermogravimetric analyzer (TGA, METTLER TOLEDO, Switzerland). The MRE samples were tested from 40 °C to 600 °C at a heating rate of 10 °C min \(^{-1}\) under a nitrogen atmosphere. The thermal aging experiments for the MRE samples were conducted at 90 °C for nearly 72 h.

The tensile properties were evaluated using a material test machine (CTM2100, CTM, China) with a crosshead speed of 5 mm min \(^{-1}\), wherein the stretching direction is perpendicular to the particle chain of the anisotropic MRE. Each sample was cut into a dumbbell shape with a thickness of 2 mm and a middle width of 4 mm (Fig. S2b, ESI†). The reported values of the tensile properties were the average calculated values of the five samples. The thermal aging experiments for the MRE samples were performed at 90 °C for 72 h.

An advanced commercial rheometer (Model: MCR301, Anton Paar) was employed to test the dynamic viscoelastic properties and MR behaviour of the MRE based on the shear oscillation mode. The photograph of the rheometer and schematic of the structure are shown in Fig. S2a (ESI†). A parallel-plate rotor and an MR device were installed in the rheometer. The testing magnetic field of the MR device was generated using an electromagnet.
The magnetic flux density $B$ was changed from 0 T to approximately 1.2 T by adjusting the direct current (DC) power supply. In addition, the testing temperature was controlled using a fluid circulator, and the testing temperature reached as high as 85 °C. In this paper, all dynamic viscoelastic properties were tested at room temperature (25 °C) except for temperature tests. The details of this rheometer can also be obtained from our previous work. In this article, the samples were cut into disc forms with a diameter of 20 mm and a thickness of 2 mm. During the test, the samples were secured between a stationary lower plate and an upper plate connected to a rotor subject to force torsional oscillations, wherein the direction of the magnetic field is parallel to the particle chain of the anisotropic MREs.

3. Results and discussion

3.1. Microstructure observation

Scanning electron micrographs of pure and silica-modified CIPs are shown in Fig. S1b (ESI†). The SEM images show that the pure and silica-modified CIPs have a spherical shape with a micron size. In addition, compared to the bare surfaces of the pure particles, there is a hazy silica layer coated on the surfaces of the silica-modified particles. Fig. 1b shows the SEM graph of the M7E3-MRE sample. The particle chain structures parallel to the magnetic field could be observed in the matrix, which can be attributed to the good processability of the MVQ. In addition, no distinct particle agglomeration occurred, which improved the mechanical and MR properties of the MRE. Thermal aging deteriorated the interfacial defects of the MRE, as marked by red circles in Fig. 1c. Interfacial defects were mainly attributed to the loss of free plasticizers at high temperatures. This result suggests that a moderate amount of plasticizer is essential for MRE performance.

3.2. FT-IR analysis

The chemical groups of MVQ, EPDM, and MRE were verified by FT-IR analysis. The FT-IR spectra of the MVQ, EPDM and MRE in the 4000–500 cm$^{-1}$ region are illustrated in Fig. 2a. For the FT-IR spectrum of the MVQ, the peak at 2960 cm$^{-1}$ corresponded to the $-\text{CH}_2-$ bond of the MVQ, and the observance of the absorption bands at approximately 1160 cm$^{-1}$ indicated the carbon skeleton. Absorption peaks at approximately 1622 cm$^{-1}$ and 800 cm$^{-1}$ corresponded to the $-\text{Si}-\text{O}-$ bond of the MVQ in the EPDM curve, the peaks at 2924 cm$^{-1}$ and 2854 cm$^{-1}$ corresponded to the $-\text{CH}_2-$ stretching vibration. The peak at 1377 cm$^{-1}$ corresponded to the absorption of $-\text{CH}_3$, and the vibrations at 1460 cm$^{-1}$ indicated the C–CH$_3$ bond. In addition, the absorption peak of C=C appeared at 1640 cm$^{-1}$, and the peak at 733 cm$^{-1}$ corresponded to the characteristic peak of ethylene. Analysis of these peaks shows that the positions and characteristics of the absorption peaks were all in agreement with the MVQ and EPDM. Compared with the FT-IR spectra of the MVQ and EPDM, the spectrum of the MRE exhibited the characteristic peaks of both materials. These characteristic peaks indicated that the EPDM/MVQ polymer blend was successfully synthesized and used as the matrix of the MRE.

3.3. Thermogravimetric analysis (TGA)

Fig. 2b shows the TGA curves of the five different MRE samples. Three mass loss episodes are shown in the curves. The first episode occurred very gradually from 250 °C to 340 °C, which indicated the degradation of the paraffin oil. The second and third stages at 450–600 °C included the thermal decomposition of the MVQ and EPDM. The thermal decomposition at 450–550 °C was aggravated by the incorporation of the EPDM, and this phenomenon could be attributed to the lower pyrolysis temperature of the EPDM rubber than that of MVQ. Conversely, the residual weight increased with the EPDM content. The phase structure of the polymer blend has an important influence on the thermal properties. In the blended rubber, the high-content MVQ was formed as the “sea phase”, and the low-content EPDM was the “island-phase”. The two-phase structure played a major role in determining the pyrolysis temperature of the material, and the interface of the two-phase structure could improve the residual quality by slowing the heat transfer. Hence, the MREs based on the EPDM/MVQ polymer blend had good thermostability, and the mass loss was less than 7% at temperatures below 450 °C.

3.4. Mechanical properties

The mechanical properties of the MRE samples were characterized in terms of their tensile strength, moduli, elongation at break, and shore A hardness. Thermal aging tests were conducted to study the heat resistance of the MRE. The mechanical and MR properties of the aged samples were also tested to discuss the influence of thermal aging. Fig. 3a shows the typical tensile stress–strain curves of the MRE samples. The curves with different slopes and lengths indicated the great influence of the EPDM content on their mechanical parameters. Fig. 3b shows the tensile moduli of the MRE samples, and these parameters were calculated based on the stress–strain curves in the 0–50% strain range. The tensile modulus increased with the EPDM content, and this phenomenon could be attributed to the high modulus of the EPDM. The modulus of the aged sample slightly increased compared with the unaged one because of the vulcanization and loss of the plasticizer during the heat aging process. Analysis of the hardness of MREs showed the same results (Fig. S2d, ESI†). Fig. 3c illustrates that the tensile strength was also improved by the incorporation of...
the EPDM, and the thermal aging treatments slightly reduced the tensile strength. Fig. 3d shows that the elongation at break first increased and then decreased with EPDM content. The molecular chain of the EPDM had better extensibility than MVQ, and the silane coupling agent improved the compatibility of the EPDM and MVQ. The entanglement of the molecular chains at the interface of the two-phase structure facilitated the transfer of stress. Therefore, the elongation at break initially increased with EPDM content. Phase separation and the growing interfacial defects lead to a decrease of the elongation at break with further increase in the EPDM content. Hence, the MRE samples exhibited excellent mechanical properties with a tensile strength and an elongation at break of up to 5.9 MPa and 793%, respectively, and good heat resistance. Compared with the unaged samples, changes in the tensile strength and elongation at break of the aged samples were less than 9.6% and 8.1%, respectively. Therefore, the EPDM/MVQ polymer blend could effectively improve the mechanical properties and thermostability of the MREs.

3.5. Dynamic viscoelastic properties

The storage ($G'$) and loss ($G''$) moduli were tested in shear oscillation mode to evaluate the dynamic viscoelastic properties of the MRE. Fig. 4a and b illustrate the dependence of the storage and loss moduli on the oscillation shear frequency. In these sweep-frequency tests, the shear strain is set to 0.01%, the normal force is kept at 10 N and the frequency sweep range is 0.5–100 Hz. It can be seen that the storage and loss moduli of the MRE samples are functions of frequency, and both parameters increased with frequency. The test results were consistent with those of previous reports, which could be attributed to the speed mismatch between the slower movement of the polymer molecular chains and the rapid shear force applied to the sheet matrix. The dynamic response time of the MRE within the unit period decreased with increasing frequency, resulting in the failure of the molecular chain of the matrix to complete stretching and shrinking in time. The increased frequency froze more tiny structures consisting of the polymer matrix and particles, which resulted in an increased stiffness for the whole material system. Therefore, a low frequency should be selected when studying the influence of other factors in diminishing the influence of frequency. In addition, similar to the tensile modulus, the storage and loss moduli were improved by the incorporation of the EPDM. The shear modulus of the MREs in the zero field can be calculated by the Einstein–Guth–Gold equation as follows:

$$G' = G_0(1 + 2.5\phi + 14.1\phi^2)$$

where $G'$, $G_0$ and $\phi$ are the shear storage modulus of the polymer composite, the shear modulus of the unfilled matrix and the volume fraction of reinforced particles, respectively. The shear modulus of the MRE increases with the content of EPDM mainly because the modulus of the EPDM was considerably larger than that of the MVQ. In addition to the enhancement of the EPDM, the synergistic effect based on the entanglement of molecular chains is another reason that cannot be ignored. Since the silane coupling agent promotes the compatibility of the MVQ and EPDM, the entanglement improved the stability of the molecular chain structure, and this characteristic resulted in a higher modulus.

Fig. 4c and d illustrate the storage modulus and loss modulus of the MRE samples with different EPDM contents as functions of oscillation shear strain, respectively. In these sweep-strain tests, the shear frequency is set to 5 Hz, the normal force is kept at 10 N and the strain sweep range is 0.001% to 20%. As can be seen from Fig. 4c, the storage modulus was constant over a low strain range, which is also referred to as the linear viscoelastic (LVE) region. In this paper, the LVE limit is defined as the point where the experimental
data deviate 5% from the approached straight line, as indicated by the mark. The small strains in the LVE region were selected in the subsequent tests to better study the influence of the magnetic field on the dynamic viscoelastic properties. Another phenomenon is that the storage modulus decreases sharply with strain over the large strain range, which is also referred to as the nonlinear viscoelastic (NLVE) region. This strain softening behavior, also termed the Payne effect, has been studied extensively in the field of polymer composite materials. It's generally recognized that there are two types of interactions that occur in a particle-reinforced elastomer, which are named particle–matrix and particle–particle interactions. The storage modulus of the elastomer strongly depends on these two interactions, thereby highly affecting the Payne effect. As the EPDM content is increased, the presence of the two-phase structure and the reduction of the particle–matrix interaction lead to a more pronounced Payne effect. As the EPDM content is increased, the presence of the two-phase structure and the reduction of the particle–matrix interaction lead to a more pronounced Payne effect, as shown in Fig. 4c. Fig. 4d shows a peak in each curve of the loss modulus, and the peak was located at the stage where the storage modulus decreased sharply. This phenomenon was mainly due to the higher energy generated in the continuous rupture of the structure. In addition, the increasing loss modulus with the EPDM content indicates that the two-phase structure enhanced the dissipation of the frictional energy of the molecular chains and particles.

3.6. Magneto-induced properties

Magneto-induced properties are one of the most important characteristics for evaluating MREs. In the magnetic-field scanning tests, the shear frequency is set to 5 Hz, the normal force is kept at 10 N and the strain amplitude is set to 0.01%. Generally, the MR effect can be calculated by the following formula:

\[
\text{MR effect} = \frac{\Delta G'}{G_0'}
\]

where \(\Delta G'\) is the magnetically induced storage modulus and \(G_0'\) is the initial storage modulus. Fig. 5a shows the storage modulus as a function of magnetic flux density, and this phenomenon illustrates outstanding MR effects. It can also be observed that the initial storage modulus increased with EPDM content, and this result is consistent with the results reported in Section 3.5. Given the increasing initial storage modulus, the MR effect predictably decreased as the EPDM content increased, as shown in Fig. 5b. Overall, the MRE samples still have a good MR effect, which was mainly attributed to the good processability of the MVQ and the interfacial enhancement of silane coupling agents. Among the samples, M7E3-MRE had an MR effect of 153%, and this sample was chosen to study the effect of temperature on the magnetic properties. Fig. S3a (ESI†) illustrates similar MR properties of the aged sample. The low changes (less than 6.2%) in the storage modulus indicated the good heat-proof aging of the MRE. Fig. S3b (ESI†) shows that the initial storage modulus slightly improved upon thermal aging, and the underlying reason is the same as that for the tensile modulus and hardness in Section 3.4.

Damping is an important property of viscoelastic materials, and damping capacity can be evaluated by the loss factor:

\[
\text{Loss factor} = \frac{G'}{G_0'}
\]
where $G'$ is the storage modulus and $G''$ is the loss modulus. Fig. 5c shows that the loss factor decreases with increasing magnetic flux density. This phenomenon is consistent with the results reported in many previous articles.\textsuperscript{58-60} Generally, the overall damping capacity of an MRE is mainly based on the intrinsic damping of the matrix and the interface damping between the particles and the matrix.\textsuperscript{37,59} The interface damping was dependent on the interfacial friction between the particles and the matrix. This phenomenon is determined by the magnetic flux density and elastic interactions of the matrix. The relative movement between the matrix and particles tended to be stable as the magnetic field became stronger. The decreasing interface damping resulted in a reduced loss factor. It can also be observed that the loss factor increased with EPDM content. This phenomenon occurred mainly because the polymer blend could improve the intrinsic damping of the matrix. Fig. S3c (ESI†) illustrates the loss factor of the aged sample, while Fig. S3d (ESI†) shows that the initial loss factor slightly improved upon thermal aging. This phenomenon is primarily due to the fact that the interfacial defects caused by thermal aging result in higher interfacial damping.

The same magnetic-field scanning tests were performed at different temperatures in the range of 25–85 °C to study the influence of temperature on the magneto-induced properties. Fig. 5d illustrates the dependence of the storage modulus of M7E3-MRE on the magnetic flux density at different temperatures. The storage modulus slightly decreased as the temperature increased, and the change in the initial storage modulus was less than 5.8%, as illustrated in Fig. 5f. It is mainly because the activity of the paraffin oil enhanced with increasing temperature. The plasticizer molecules are in a free state and act as a lubricant between the rubber molecular chains, which makes the rubber molecule chain to slip easily. Therefore, the modulus of the MRE decreases slightly with increasing temperature.

The contour lines in Fig. 5d indicate that the MRE exhibited good thermal stability under low magnetic fields, and the change in the saturated modulus was less than 8.9%. The excellent temperature stability of the MRE was mainly due to the synergistic effect of the EPDM and MVQ in the polymer blends. The improved interfacial interaction and compatibility of the EPDM with MVQ caused by the silane coupling agent was also beneficial in enhancing the temperature stability. Fig. 5e shows the dependence of the loss factor of M7E3-MRE on the magnetic flux density at different temperatures. The initial loss factor slightly increased with increasing temperature, as shown in Fig. 5f. The activity of the molecular chain became stronger with increasing temperature. This phenomenon resulted in higher energy dissipation. With a stable molecular chain structure in the matrix, the loss factor of MRE change was also less than 9.4%. Therefore, the EPDM/MVQ polymer blend enabled excellent thermal stability of the MRE.

4. Conclusions

In this study, we synthesized a high-performance MRE based on an EPDM/MVQ polymer blend. The MRE showed excellent mechanical properties with a tensile strength and an elongation at break of up to 5.9 MPa and 793%, respectively, after the interfacial interaction and matrix compatibility were improved. The results of TGA and thermal aging tests revealed the outstanding heat resistance of the MRE. TGA results indicated that the mass loss of the MRE was less than 7% at temperatures below 450 °C. The changes in the tensile strength and elongation at break of the aged samples were less than 9.6% and 8.1%, respectively, of the corresponding values for the unaged samples. The influences of frequency, strain, matrices, temperature, and magnetic fields on the dynamic viscoelastic properties were discussed comprehensively. The results indicated that the incorporation of the EPDM improved the dynamic modulus and loss factor, and the MREs exhibited excellent temperature stability while maintaining a high MR effect. Hence, the proposed MRE with excellent mechanical properties and thermostability can be significantly applied to attenuate the vibration of large devices.

Conflicts of interest

There are no conflicts to declare.

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Notes and references
