

Effect of Carbon Black on the Dynamic Mechanical Properties of Magnetorheological Elastomers

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ABSTRACT: In this work, dynamic properties of magnetorheological elastomers (MREs) based on iron sand and natural rubber, with different contents of carbon black filler (30 and 50 phr) were investigated. $\tan \delta$ was measured using dynamic mechanical analysis (DMA) over a range of frequency (0.01–130Hz) and strain amplitude (0.1–4.5%). $\tan \delta$ was found to be higher for anisotropic MREs with additions of carbon black, with 20-40% improvement over the whole frequency range explored and 6-15% improvement over the strain amplitude range explored. The results exhibited the advantages of carbon black in improving the damping performance of the MREs. The morphological characteristics of the MREs were also examined with scanning electron microscopy.

KEYWORDS: Magnetorheological elastomers, carbon black and damping.

I. INTRODUCTION

Magnetorheological elastomers (MREs) are a new group of damping materials which consist of a non-magnetic matrix (normally an elastomer) containing a suspension of magnetically permeable particles. Damping occurs by the viscous flow of the rubber matrix and inclusion of magnetic particles in rubber enables additional damping through magnetic particle interaction and interfacial damping. Furthermore, damping and stiffness can be controlled by the application of an applied magnetic field during fabrication or in service

MREs can be fabricated to contain a uniform suspension of magnetic particles (isotropic MREs) [1]. However, it has been found that when a magnetic field is applied during curing, chain-like structures of magnetic particles are formed within the rubber (anisotropic MREs) which provides much larger damping and stiffness [1]. The magnetic particles of choice are carbonyl iron, magnetite, iron oxides, barium ferrite or Terfenol-D [2] and suitable matrix materials include natural rubber, silicone rubber, polybutadiene, polyisobutylene, polyisoprene and polyurethane rubber [2]. In this study, natural rubber was used as a matrix because of its associated ease of processing and good damping performance and iron sand was chosen as magnetic particles because it has high permeability and saturation magnetisation and low cost [3].

The damping of MREs depends not only on the types of rubber matrix and magnetic particles, but also on the level of adhesion between the particles and the rubber matrix. Surface modification of iron sand using silane coupling agent was found to provide coupling between iron sand and natural rubber [4]. It has also been reported that addition of nanosized reinforcement such as carbon black into MRE formulations can improve the damping [5].

The objective of this work is to assess the influence of carbon black on the dynamic properties of MREs based on iron sand and natural rubber. The loss tangent, commonly called $\tan \delta$, is considered as the fundamental parameter to assess damping. $\tan \delta$ is obtained by dividing the loss modulus (G'' or E'') by the storage modulus (G' or E') [1].

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II. EXPERIMENTAL

The compound formulation used in this study contains 100phr natural rubber, 5phr zinc oxide, 5phr stearic acid, 2phr n-cyclohexyl-2-benzothiazole sulfenamide (CBS), 1phr tetramethylthiuram disulphide (TMTD), 5phr wax, carbon black and iron sand. Fabrication of MREs consisted of 4 major steps: compounding of MREs using a conventional two roll mill, curing under an applied magnetic field using specially-developed electromagnetic-heat coupled device (capable of generating magnetic fields of 0 mT to 1000 mT) at 80oC for 30 minutes, vulcanization in a compression moulder at 150oC and post cure treatment by cooling the MREs under an applied magnetic field at room temperature. Tan δ was measured by means of dynamic mechanical analyser (DMA 8000) under shear mode testing. The tan δ value was obtained over a frequency range of 0.01–130Hz and a strain amplitude range of 0.1-4.5%. The microstructures of MREs were observed using HITACHI S-4700 SEM.

III. RESULTS AND DISCUSSION

Figure 1 shows SEM images of MREs prepared in the absence of a magnetic field and in the presence magnetic field. In image (a), iron sand particles were homogeneously distributed in the rubber matrix without forming obvious aggregation. In image (b), clearly, curing under magnetic field encouraged the iron sand particles to organise into chain-like columnar structures. In image (c), it can be seen that the presence of carbon black has constrained the movement of iron sand particles and the chain-like columnar structures are shorter and less aligned than anisotropic sample.

In the frequency range of 0.01-130Hz, the results showed that additions of carbon black gave good improvement of tan δ , the tan δ values for anisotropic MREs containing 30phr and 50phr carbon black were 21% and 43% higher than anisotropic MREs. The effect of carbon black on tan δ was further analysed using storage modulus (G') and loss modulus (G'') plots. The results revealed that G' and G'' for samples containing carbon black are much higher than anisotropic MREs. The G' increases with increasing carbon black content up to the highest values at 50 phr carbon black. The increase in G' can be explained by increased carbon black particle-rubber interactions and carbon black particle-particle interactions as reported by number of researchers [6, 7], such that lead to the formation of a carbon black filler networks in the rubber matrix. The increase of G'' with increasing carbon black content during deformation can be explained by the increased energy loss that occurs due to the breakdown and reformation of the carbon black filler networks.

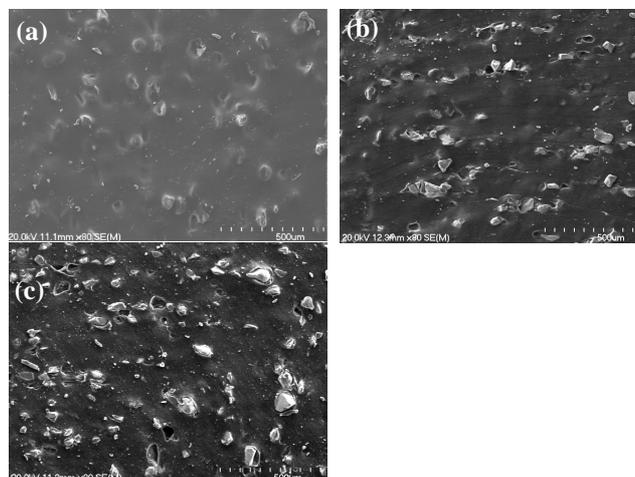


Figure 1: SEM images of MREs (a) isotropic, (b) anisotropic and (c) anisotropic with carbon black reinforcement

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Over the strain amplitude range of 0.1-4.5%, $\tan \delta$ of anisotropic MREs containing 30phr and 50phr carbon black were higher than anisotropic MREs (6% and 15%, respectively) over the whole strain amplitude range explored. The G' and G'' for samples containing carbon black were also found higher than anisotropic MREs, which is not surprising given similar trends with influence of frequency on G' and G''

IV. CONCLUSION

It was found that alignment of magnetic particles occurred for anisotropic MREs as a consequence of curing the materials under an applied magnetic field at elevated temperature. SEM also revealed that addition of carbon black into anisotropic MREs constrained the movement of iron sand particles; chain-like columnar structures became shorter and less aligned. Energy absorption for anisotropic MREs with additions of carbon black was generally found higher than anisotropic MREs, with 20-40% improvement over the whole frequency range explored and 6-15% improvement over the strain amplitude range explored. The results demonstrate the use of carbon black in improving the damping performance of MREs.

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