



# Comparison of dynamic properties of magnetorheological elastomers with existing antivibration rubbers



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## ABSTRACT

Tan  $\delta$  and energy dissipated during hysteresis testing of isotropic and anisotropic MREs containing silane modified iron sand particles in a natural rubber matrix were compared with existing antivibration rubbers. Tan  $\delta$  was measured using dynamic mechanical analysis (DMA) over a range of frequency (0.01–130 Hz), strain amplitude (0.1–4.5%), and temperature (–100–50 °C). Energy dissipated was measured using a universal tester under cyclic tensile loading. The chosen antivibration rubbers for comparison contained different contents of carbon black filler (30, 50 and 70 phr) in a natural rubber matrix. It was found that energy absorption for comparative samples was generally higher than isotropic and anisotropic MREs over the range of frequency and strain amplitude explored, as well as in hysteresis testing and this was believed to be largely due the presence of carbon black in the formulation. Further assessment was carried out on materials that were the same as anisotropic MREs except they had additions of carbon black. The energy absorption was found higher than comparative samples with the same carbon black contents, supporting the use of iron sand to improve damping. However, trends for energy absorption at around  $T_g$  were found to reverse which is considered to be due to the segmental motion of rubber chains being by far the most significant influence on energy absorption in the glass transition zone.

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## 1. 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. The magnetic particles of choice are carbonyl iron, magnetite, iron oxides, barium ferrite or Terfenol-D [1–3] and suitable matrix materials include natural rubber, silicone rubber, polybutadiene, polyisobutylene, polyisoprene and polyurethane rubber [4–11]. The main advantage of MREs is that the damping and stiffness can be varied by application of an applied magnetic field during fabrication or in service. MREs can be classified into two kinds: isotropic MREs and anisotropic MREs [12]. Fig. 1 shows structure of isotropic and anisotropic MREs. Isotropic MREs can be

characterized by having a uniform magnetic particle distribution in the matrix. Anisotropic MREs have a special chain-like structure of magnetic particles in a matrix resulting from curing the matrix under an applied magnetic field. Over the past few years, MREs have attracted increasing attention and have been considered for applications such as adaptive tuned vibration absorbers [13], automotive engine mounts [8] and semi active seismic dampers [14].

In this study, isotropic and anisotropic MREs based on natural rubber and silane modified iron sand particles were prepared. The natural rubber was used as a matrix because of its associated ease of processing and good damping performance [14–16] and iron sand was chosen as magnetic particles because it has high permeability and saturation magnetisation, low cost and is readily available in New Zealand. Surface modification of iron sand using silane coupling agent was found to provide coupling between iron sand and natural rubber [15]. It has also been reported that the silane modified particles decrease the interfacial tension around the particles and results in improved dispersion of magnetic particles in isotropic MREs and an improved degree of magnetic particle alignment in anisotropic MREs [16,17].

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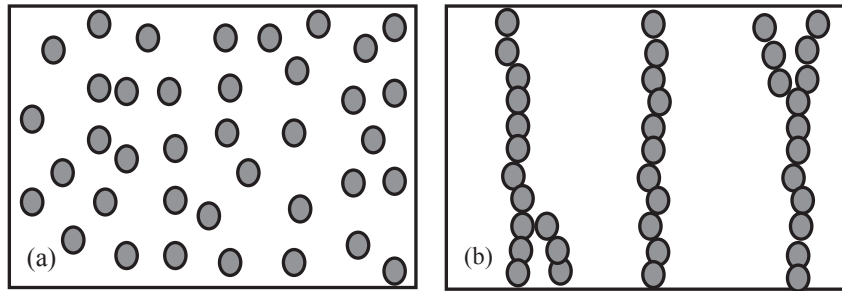


Fig. 1. MRE structure: (a) isotropic MRE; and (b) anisotropic MRE.

This work aims to assess the potential of developed MREs for potential use in vibration damping. The dynamic properties of isotropic and anisotropic MREs were compared with existing antivibration rubbers. The dynamic properties were investigated using two different methods. The loss tangent, commonly called  $\tan \delta$ , is considered as the fundamental parameter to assess damping.  $\tan \delta$  gives a comparison of the energy lost to that stored; it is obtained by dividing the loss modulus ( $G''$  or  $E''$ ) by the storage modulus ( $G'$  or  $E'$ ) [12,18]. The other estimate of damping used was the amount of energy dissipated during cyclic deformation, which can be calculated from the area of the hysteresis loop. The antivibration rubbers for comparison were prepared according to existing formulations from published patents (see details in Table 1). Those chosen, contained different contents of carbon black filler (30, 50 and 70 phr) in a natural rubber matrix. In addition, anisotropic MREs containing silane modified iron sand and a predetermined amount of carbon black were also prepared in order to investigate the influence of carbon black on the damping performance of the MREs.

## 2. Experimental

### 2.1. Materials

Natural rubber (SMR L grade) and other chemicals including zinc oxide, stearic acid, *n*-cyclohexyl-2-benzothiazole sulfenamide (CBS), tetramethylthiuram disulphide (TMTD), paraffin oil, and naphthenic oil were all purchased from Field Rubber Limited, Auckland. Bis-(3-triethoxysilylpropyl) tetrasulphane (TESPT) was purchased from Leap Lab Chem Co. Ltd. Carbon black was purchased from Shijiazhuang Changhang Co. Ltd. Iron sand was collected from Ngarunui Beach, Raglan. The iron sand was then milled using a planetary mono mill (Pulverisette 6) produced by Fristech GmbH and subsequently sieved to obtain a 45–56  $\mu\text{m}$  particle size range.

### 2.2. Surface modification of iron sand

The surface modification of iron sand was carried out using an aqueous alcohol solution method. Iron sand particles were subjected to surface treatment with TESPT at 6 wt% relative to the weight of the particles. An aqueous alcohol solution of 95 vol% ethanol was used and the pH of the solution was adjusted with acetic acid to 4.0–4.5. TESPT of predetermined quantity was dispersed in the ethanol solution at a ratio of 1:100 and the mixed solution was stirred for 5 min to ensure hydrolyzation of the silane coupling agent. The iron sand particles were then added and stirred for an additional 30 min at room temperature to ensure a uniform distribution of the coupling agent on the surface of iron sand particles. The mixture was filtered and washed three times with ethanol to remove unreacted coupling agent. The treated iron sand particles were then dried at 80 °C in an oven until a constant weight was achieved.

### 2.3. Preparation of MREs and comparative samples

The compound formulation used in this study is given in Table 2. The formulations of comparative samples based on published patents comprised of natural rubber and carbon black as the major components with processing aids and crosslinking agent. Additives such as anti antioxidant, anti-thermal aging agent and petroleum resin were excluded from the formulations. Formulations were compounded using a conventional laboratory two roll mill (model XK150) according to ASTM designation D3184-80. The front roller speed was 24 rpm and the rear roller speed was 33 rpm, the roller diameters were 150 mm, friction ratio of two rollers was 1:1.4 and the roller temperature was set to 80 °C. The nip gap (distance between front and back roller) was maintained at 2 mm during compounding. The compounding began with softening the rubber on its own in the two roll mill (mastication). Mastication reduces the viscosity and increases the plasticity of natural rubber by mean of heat generated in the two roll mill through conduction from the

Table 1  
Comparative samples' patent specifications.

Comparative sample	Patent number	Applicant	Title	Description
1	US 2011/0166276 A1 [18]	Tokai Rubber Industries Ltd	Antivibration rubber composition	The invention relates to a vibration damping rubber composition to be used for an engine mount or the like adapted to support an engine in an automobile or the like and suppress transmission of vibrations.
2	EP 0 481 810 B1 [19]	Sumitomo Rubber Industries Ltd	Rubber composition for laminated vibration proofing structure	The present invention relates to a rubber composition for use in the seismic isolation of a bridge, a building or a house.
3	US6180711 B1 [20]	Yokohama Rubber Co. Ltd	Rubber composition for seismic isolation laminates	This invention relates to a rubber composition for seismic isolation laminate for buildings.

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