Damping Properties and Microstructure of Magnetorheological Composites Based on Iron Sand and Natural Rubber

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INTRODUCTION

Material with high damping capability is desired from the viewpoint of vibration suppression in structures. Rubber is by far the most commonly used material for damping; here damping relies on the energy absorbed due to viscous flow that occurs during deformation in this viscoelastic materials. However, enhancement of damping through rubber modification or rubber selection to increase viscous flow, not surprisingly, generally results in a reduction in stiffness and strength [1]. More recently, a new class of damping materials, magnetorheological elastomers (MREs) have been developed such that inclusion of magnetic particles in rubber enables additional damping through magnetic particle interaction and interfacial friction. Furthermore, damping and stiffness can be varied by application of an applied magnetic field during fabrication or in service. MREs can be utilised for damping, either alone or within a composite structure such as those including steel plates.

The magnetic particles of choice for MREs are iron particles and suitable matrix materials include natural rubber, silicone rubber, polybutadiene, polyisobutylene, polyisoprene, and polyurethene rubber [2-5]. However, one of the biggest challenges in developing MREs is cost. Carbonyl iron particles, the most commonly used particles, are expensive at $13-15/kg in bulk. More cheaply produced iron particles, iron oxide (Fe_3O_4) and barium ferrite ($BaFe_{12}O_{19}$) tend to be irregular in shape, have wider size distributions, and simply do not perform as well [6, 7].

This work aims to fabricate novel iron sand and natural rubber MREs. Iron sand was chosen because it has high permeability and saturation magnetisation, low cost, and is readily available in New Zealand. It is derived from erosion of andesitic and rhyolitic volcanic rocks which are the main types of iron ore deposits in New Zealand. Iron sand is a dark, high-density sand that occurs along the west coast of the North Island from Wanganui to Kaipara Harbour near Auckland, over a distance of 480 km. It contains titanomagnetite, a mineral itself containing iron and titanium, which is highly magnetic.

In this study, the Taguchi method was employed to investigate the effect of a number of factors, namely, iron sand content, iron sand particle size and applied magnetic field during curing on tan δ over a range of frequency (0.01–130Hz) and strain amplitude (0.1-4.5%). Furthermore, morphological characteristics of the MREs were also examined using scanning electron microscopy (SEM).

METHODS

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. The data were then analysed using S/N ratio and ANOVA to predict the optimal combination of factors and experiments were conducted for verification.

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), there are obvious gaps between iron sand particle and natural rubber, which suggests that weak interaction of iron sand and natural rubber.

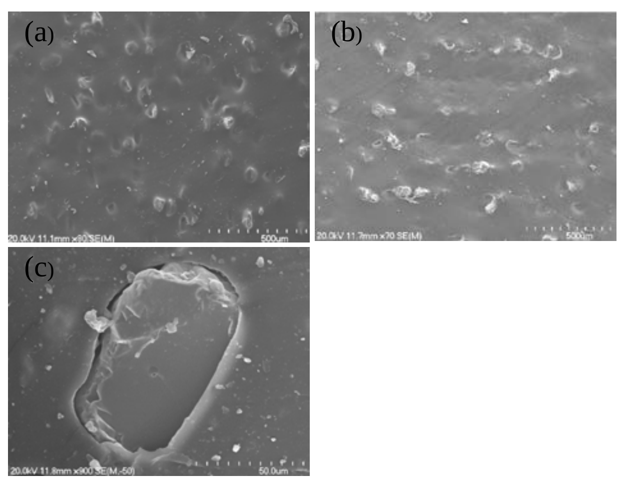

Figure 1 *SEM images of MREs (a) curing in the absence of a magnetic field, (b) curing in in the presence magnetic field and (c) interphase of iron sand-natural rubber matrix*

In the frequency range of 0.01-130Hz, S/N ratios showed that the best composition to obtain the highest tan δ was

70 phr iron sand, 45–56 µm particle size and 300 mT magnetic field during curing. An experiment was conducted and the results agreed with the suggested optimum conditions. The ANOVA results showed that the iron sand content had the greatest influence on tan δ. This is likely to be because, as the iron sand content increases, more interactional force between the magnetic particles and rubber matrix occurs at the interface and more energy is dissipated. It was also noted that the tan δ was frequency dependent over the whole frequency range.

Over the strain amplitude range of 0.1-4.5%, S/N ratios showed that the best composition to obtain the highest tan δ was 30 phr iron sand, 56-75 µm particle size and 500 mT magnetic field during curing. An experimental result agreed with the suggested optimum conditions. However, the ANOVA showed none of the factors have significant influence on tan δ when measured over a range of strain amplitude. This could be attributed to the poor bonding between iron sand and rubber as supported by morphology. The weak interaction between the iron sand and natural rubber was fully disrupted at low strain amplitude and therefore, at high strain amplitude, the damping was mainly dominated by the rubber matrix. The damping now relies on the internal friction of the disentangling long chain rubber molecules during viscous flow.

CONCLUSION

In this work, novel iron sand and natural rubber MREs were manufactured and the Taguchi method was used to obtain the effects of iron sand content, iron sand particle size, and applied magnetic field during curing on tan δ over a range of frequency and strain amplitudes. The results of S/N ratio and ANOVA showed that MREs were frequency-dependent and iron sand was the main influence. However, no factor showed significant influence over a range of strain amplitude. The morphology showed curing MREs under magnetic field formed chain-like columnar structures and the interphase of iron sand and natural rubber was poor.

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REFERENCES

[1] Lakes, RS *Journal of Composite Materials 36, [3], 287-297 (2001)*

[2] Chen, L, *et al Polymer Testing 27, [3], 340-345 (2008)*

[3] Chokkalingam, R, *et al Journal of Composite Materials 45, [15], 1545-1552 (2010)*

[4] Sun, TL, *et al Polymer Testing 27, [4], 520-526 (2008)*

[5] Wang, Y, *et al Polymer Engineering & Science 46, [3], 264-268 (2006)*

[6] Sun, Y, *et al Materials Research Bulletin 45, [7], 878-881(2009)*

[7] Makled, MH, *et al Journal of Materials Processing Technology 160, [2], 229-233 (2005)*