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EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF MAGNETORHEOLOGICAL ELASTOMER

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Graphical abstract

Abstract

Magnetorheological elastomers (MREs) have much interest in engineering applications. However, the mechanical properties of MREs are still under ongoing researches. This paper presents the results from tensile test, hardness and rebound test that were carried out in order to understand the mechanical properties of MRE with the influence of carbon black content. The addition of carbon black was varied with the amount of 20 pphr, 40 pphr and 60 pphr of carbon black. The development of the MRE composites was manufactured by following the conventional rubber compounding process. The optimum cure of each MRE composite was determined by using a Rheometer 100. The mechanical properties through tensile test were obtained by using an Instron Tensile Machine, meanwhile hardness and resilience were carried out by using Wallace Dead Load Hardness and Dunlop Tripsometer, respectively. The results of tensile strength were not consistent with the addition of carbon black. In meantime, hardness value increases as the carbon black increases. The decreasing pattern of MRE resilience could be observed when the carbon black content increases.

Keywords: Magnetorheological elastomers, MRE, mechanical properties

1.0 INTRODUCTION

Magnetorheological elastomers (MREs) are classified under smart materials, whose properties changes upon the application of an external magnetic field [1-6]. Through literature sense, MRE has focused on several areas in engineering applications such as adaptive tunable vibration absorbers [7, 8, 9], sensors [10, 11], noise barrier systems [12], dampers [13], seismic isolators [14-17]and etc.

The discovery of MR material was first prepared by Rabinow in 1948, which is magnetorheological fluids (MRF) [7, 18, 19, 20]. Most of past researchers has claimed that MRE is a new member of the magnetorheological family where it is the solid analogue of MRF [6]. In MRF, 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. Nevertheless, MRF has some weakness; i.e. leakage in application devices [21]. In consequence, MRE was introduced, where the liquid is replaced by a solid-state material. MRE was expected to be a good solution to overcome the disadvantages of MR fluids.

MRE is made up of magnetic fillers in non-magnetic elastomer matrix, which make MRE differs from other typical elastomers. Kallio [3] explained that the magnetic fillers inside the elastomer can be distributed homogenously (isotropic) or they can be grouped to form aligned structures. In order to produce an aligned or anisotropic structure, the polymer composite has to be exposed to a magnetic field before curing, so that the columnar particle structures are formed and become locked in their places during crosslinking. If there is no external magnetic field is applied during the curing, the structure of MRE can be categorized as isotropic. However, the development of anisotropic MRE are very complicated and difficult to be manufactured widely. In addition, it would be convenient if the use of magnetic fields before the curing could be avoided. Thus, the study of isotropic MRE still contributes a significant value until to date.

The studies from [22, 23] have been the major guidelines to most researches. Lokander and Stenberg, [23] studied MRE blend of natural rubber with two different types of nitrile rubbers; Perbunan 1845 and Perbunan 3445. Thus, they suggested that the MR effect can be increased by the addition of plasticizers or by using a softer matrix material, such as silicone rubber. Nevertheless, the use of soft matrix as elastomer based lead to worse mechanical properties of MRE which is not applicable to be used in most engineering applications. Chen *et al*. [4, 24] claimed that natural rubber contributes excellent mechanical properties of MRE.

In other works, the effects of different shapes, sizes and volume contents of the magnetic fillers on MRE properties have been investigated [22]. Kallio [3], claimed that larger particles offer stability and less agglomerate. Nano size of particles tend to be agglomerate easily but cannot be separated again once they have agglomerated. Limited researches have been conducted by studying the effects of carbon black on mechanical properties of MRE. Until to date, only [25] studied the effect of carbon in order to increase the MRE performances by using natural rubber as matrix based. Nayak *et al*., [26] conducted the study of the mechanical and thermal properties of MREs with and without addition of carbon black.

Thus, in this paper, a series of MRE composites were developed without applying an external magnetic field. The contents of carbon black were varied in MRE with addition of 20pphr, 40pphr and 60pphr. The mechanical test through tensile, hardness and rebound test were carried out.

Table 1 Formulation of MRE Compounds

Ingredients	Recipe (pphr)[a]			
	CB00 (Control sample)	CB20	CB40	CB60
Natural rubber SMR L	100	100	100	100
Carbon black N220	0	20	40	60
Carbonyl iron powder	30	30	30	30
Zinc oxide	5	5	5	5
Stearic acid	2	2	2	2
Antioxidant	2	2	2	2
Sulphur	1.5	1.5	1.5	1.5
CBS	0.5	0.5	0.5	0.5
TMTD	0.5	0.5	0.5	0.5

[a]All ingredient were carried out at part per hundred rubber

2.0 EXPERIMENTAL

2.1 Material

Elastic matrix and magnetic particles are the main ingredients of MRE. In this experiment study, SMR L grade natural rubber was selected as MRE matrix based. In order to develop the MRE compounds, carbonyl iron particles, type C3518 were purchased from Sigma-Aldrich Sdn. Bhd. (M). Carbon black N220 was varied with addition of 20pphr, 40pphr and 60 pphr in MRE compounds. N-cyclohexyl-2-benzothiazyl sulphenamide (CBS) and tetramethylthiuram disulphide (TMTD) were chosen as the accelerator to improve the properties of elastomers. Other standard rubber compounding materials such as zinc oxide, stearic acid and sulphur were of commercial grades. Sulphur is the main vulcanizing agent in most rubber cases. Zinc oxide acts activator meanwhile stearic acid acts as a co-activator.

2.2 Preparation of Rubber Compound

MRE Compounds were developed by following a typical formulation of a vulcanized rubber compound as shown in Table 1. Generally, the formulation of elastomer is given in a specific amount based on a total 100 parts of the rubber (pphr). The fabrication of the MRE consists of three major steps: i.e. mixing, cure assessment and vulcanization. The compounding of MRE was conducted using a two-roll mill. Figure 1 illustrates the MRE compounds were obtained in sheets and conditioned at 23±°C for 24 hours before cure assessment.

Figure 1 MRE compound is obtained in a sheet

2.3 Cure Assessment

The optimum cure time was determined using a moving die rheometer, Rheometer 100. A recorder with a graph paper is attached to the rheometer to record the signals. The rheometer was run at 150°C up to 60 minutes. The measurements were performed accordingly to BS ISO 3417:2008 [27].

2.4 Vulcanization

The MRE compounds were compression-moulded using a hot press machine at 150°C to the respective cure times of MRE compounds. The final samples of MRE after compression moulded are shown as in Figure 2.

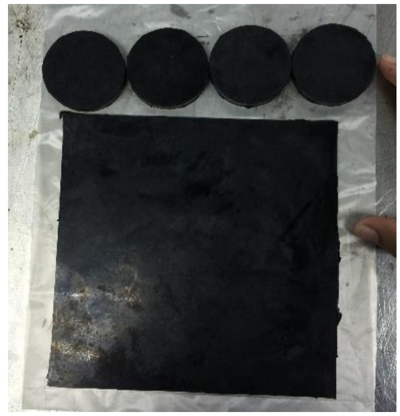

Figure 2 Final samples after compression-moulded

2.5 Testing

In order to determine the tensile strength, the dumbbell test pieces were tested by using an Instron Universal Tensile Machine equipped with 500N load cell at a static crosshead speed of 500 mm/min according to BS ISO 37:2011 [28]. The results reported here are average of five dumbbell test pieces as shown in Figure 3.

Figure 3 Dumbbell test pieces

The indention of hardness of these four MRE were measured by a Wallace Dead Load Tester according to the method described by BS ISO 48:2010 [29]. A Wallace Dunlop Tripsometer was used to determine the rebound of MRE by referring to BS 903-A8:1990 [30]. This experimental study was conducted as in the flowchart as shown in Figure 4.

Figure 4 Block diagram of the processes of the system

3.0 RESULTS AND DISCUSSION

3.1 Tensile Strength

Figure 5 shows the results of mechanical properties in terms of tensile strength. The addition of carbon black N220 was varied in MRE compounds with value of 20 pphr, 40 pphr and 60 pphr. Based on the results, it is obvious that the addition of carbon has an effect to the MRE strength. After added in carbon black with the amount of 20 pphr the tensile strength of MRE has a large decrement by 36.8%. By incorporating the carbon black with the amount of 40 pphr, the tensile strength could achieve the tensile strength 59.1% more than CB20. Then, the tensile strength dropped back when added in 60 pphr of carbon black.

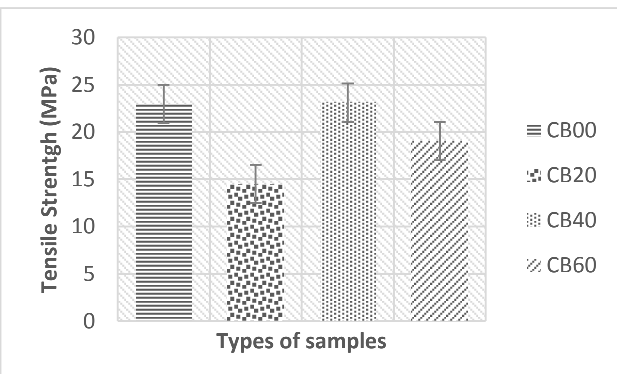

Figure 5 Effect of carbon black in MRE on tensile strength

3.2 Hardness

Referring to the graph, the increasing pattern of hardness results can be seen in Figure 6. The lowest value of hardness starts from CB00 with a value of 42.3 IRHD, followed by CB20, CB40 and CB60 with values of 49.5 IRHD, 55.5 IRHD and 68.0 IRHD respectively. Thus, the addition of carbon black gives a gradual increment on hardness of MRE. As more filler added leads to more rigid elastomer composites. Also, results in higher modulus elastomers.

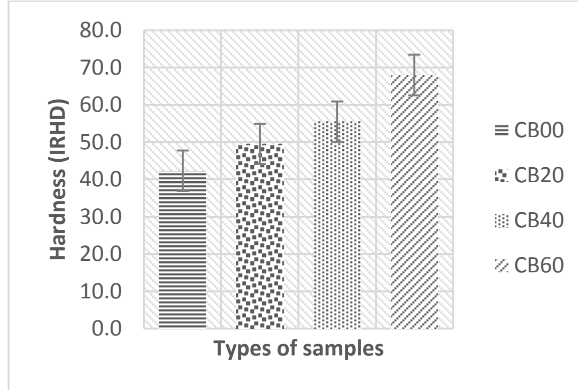

Figure 6 Effect of carbon black on hardness

3.3 Rebound Test

The rebound values of four MRE compounds with varies addition of carbon black were compared as in Figure 7. The addition of carbon black with the amount of 20 pphr increases when compared to CB20. The addition of carbon black from 40 pphr to 60 pphr lead to decreasing values of MRE compounds. This results explained the viscoelastic behaviour of elastomer, where energy loss is due to internal friction in the rubber itself. Less rebound value shows low dissipation of energy during recovery. This phenomenon is significant to be implement in MRE, which requires low damping properties.

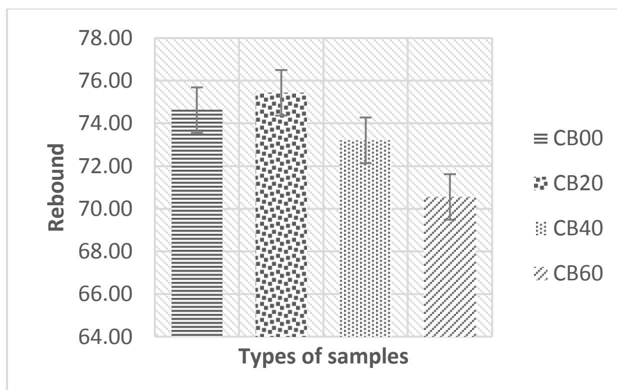

Figure 7 Effect of carbon black on rebound

4.0 CONCLUSION

In this study, four MRE compounds were prepared by incorporating with different amount of carbon black 0 pphr, 20 pphr, 40 pphr and 60 pphr. The mechanical properties of these four MRE were determined through tensile test, hardness test and rebound test. From the observation, it was found that, the addition of carbon black in MRE give effect on their mechanical properties. As more carbon black added in the MRE compounds, MREs become stiff and hardness increases, whereas resilience decreases. As conclusion, the addition of 40 pphr could be understood as the optimum content of carbon black in MRE since it gives the highest strength, permitted range of hardness and moderate rebound value.

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