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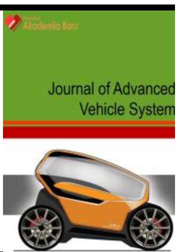

Simulation of a Pre-structure Device for Fountain-like Magneto Elastomer via Finite Element Magnetic Method (FEMM)

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ABSTRACT

The ability of a pre-structure device for curing the fountain-like alignment of CIPs in a magnetorheological elastomer (MRE) is simulated in this study. In order to generate the fountain-like magnetic flux in the device, the device was equipped with an electromagnet coil and a cylindrical permanent magnet to pick-up the pass magnetic flux trough the MRE mould. While the electromagnetic coil is utilised to control the generated magnetic flux density in the device via manipulating induced currents for different magnetic fields. The analysis then was conducted by using Finite Element Magnetic Method (FEMM) software to determine the magnetic flux density in the device as well as the fountain-like shape of magnetic flux lines that flew in the MRE mould. In the simulation, the primary factor in determining the strength of the magnetic field across the mould is the change in current. The simulation has found that the current required to generate around 0.24T is about 1A comprise of electromagnetic coil and permanent magnet.

Keywords:
Finite Element Magnetic Method (FEMM); Fountain-like; electromagnetic coil; magnetorheological elastomer; mould; permanent magnet

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1. Introduction

Magnetorheological elastomer (MRE) is a kind of smart material as the application of magnetic field stimuli can quickly modify its mechanical characteristics, controllably and reversibly [1], [2]. MRE normally comprised of soft magnetic particles in micronized and are integrated into a polymeric matrix as a filler [3]. MRE has piqued the interest of researchers on MRE's fabrications, characterizations and potential applications for the past two decades [4], [5]. In fact, MRE has

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currently been tested as a controllable vibration absorbers, sensors and actuator system [6]. MRE can be formed into two types, namely isotropic and anisotropic MREs by ways of the magnetic particles distributed in the elastomeric matrix [7]–[9]. For instance, in isotropic MRE, the melt MRE will be cured without the presence of magnetic field causing the magnetic particles to distribute evenly entire the matrix area. Meanwhile in anisotropic MRE, the induced magnetic field during curing process will lead the magnetic particle to align within the matrix phase, following the lines of magnetic flux within the melt MRE. As a result, anisotropic MRE would normally possesses higher MR effect due to closer gap between the aligned particles in the MRE that exhibited stronger magnetic forces especially with presence magnetic field [10]. This type of MRE however, require extra processing in order to have the aligned particles in the MRE, compared to the isotropic-typed MRE [5].

Among factors that influence the performance of MRE including the types of elastomeric matrix, types of magnetic particles, particle’s sizes and shapes, and presence of additives, direction or orientation of the particle in the MRE is one of the significant concerns to vary the resultant properties of the MRE [11], [12]. It has been demonstrated that MRE exhibits a high correlation between magnetic and mechanical characteristics by incorporating aligned particles into the elastomeric matrix [13]–[15]. Boczkowska et al [10] studied the MRE that made up of CIPs in a polyurethane matrix and reported that the sample with 30° of particle’s chain orientation exhibit the greatest increased in storage modulus in the present of magnetic field compared to 0°, 45° and 90°. In recent research, the correlation between particle-chain alignment and resultant properties has been demonstrated by Zhang et al. [16] in circular oscillation shear mode test. The results revealed that the magneto-induced shear modulus and the MR effect increased respective to the particle chain's orientation angle. The MRE with 15° to the y-axis has a greater storage modulus than the other alignments in their work, which comprised of 0°, 5°, 10°, and 15° of particle’s alignments.

On the contrary, it is difficult to address which angle of aligned particles in MRE would result the highest stiffness or storage modulus since different angles have been highlighted to achieve the improvement target. Most of earlier research have concentrated on a certain angle of aligned particles in order to obtain enhanced viscoelastic properties of MREs [10], [16]–[18]. Therefore, various angles of particles chain alignment are introduced in this current research of anisotropic MRE as it is expected to cause higher stiffness compared to previous reported studies. In the research of anisotropic MRE, particles alignment is a key factor to address in which the design and development of a curing device is necessary to control the aligned particles during curing the anisotropic MRE. The flux lines generated in the uncured MRE will be the fountain-like which is expected that the CIPs are aligned following the fountain-like flux lines in the elastomeric matrix. The design of a pre-structure curing apparatus will be developed, and the finite element magnetic simulations (FEMM) will be performed in order to predict the magnetic flux lines generated inside the chamber and also in the MRE.

2. Design and Simulation

In order to get desired anisotropic MRE with fountain-like alignment of CIPs, design of electromagnetic circuit become an important factor to drive the CIPs to be aligned accordingly. The fountain-like flux lines in the uncured MRE are based on the magnetic flux lines produced by cylindrical permanent magnet. **Error! Reference source not found.** illustrates the magnetic flux density that generated by the permanent magnet and passed through the MRE, respectively. The magnetic fluxes generated will lead the CIPs to align according to the lines and resultant fountain-like of CIPs will be acquired after completing the curing process of the anisotropic MRE. The flux curvature nevertheless can be adjusted depending on the distance of the MRE's position from the magnetic source that also will determine the flow of magnetic flux lines in the MRE.

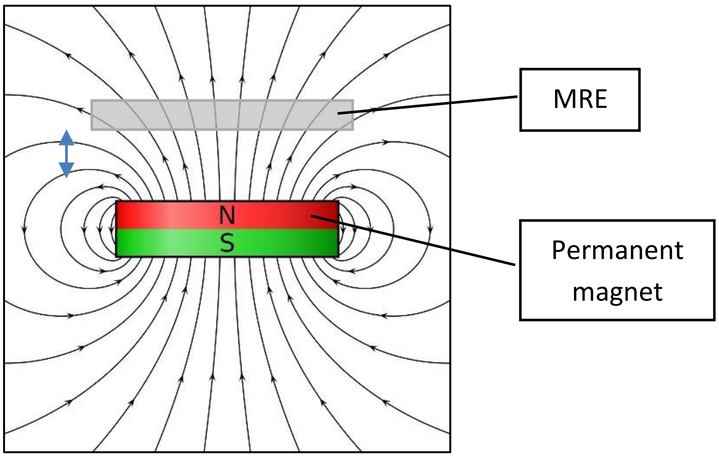


Fig. 1. Magnetic flux lines generated by the cylindrical permanent magnet.

Table 1
Device's part list and its dimension.

No.	Part List	Dimension
1	*Bobbin*	*ID: 85 mm, OD: 111 mm, ht.: 105 mm.*
2	*Coil*	*OD: 150 mm.*
3	*Permanent magnet*	*Disc-shaped, OD: 20 mm, ht.: 5 mm.*
4	*MRE mould*	*OD: 30 mm.*

Figure 2 shows the pre-structure design used in the Finite Element Magnetic Method (FEMM) simulation with the set parts and dimensions shown in Table 1. The cylindrical permanent magnet with a dimension of 30 mm in diameter and 8 mm in thickness, in a combination with an electromagnetic coil were used in this work in order to create a controlled fountain-like magnetic flux density in the MRE. In the FEMM simulation and analysis, the electromagnetic coil was set with 2000 turns of 18 AWG insulated copper wire, that winding to a plastic bobbin. The AWG insulated copper wire was used due to high electrical conductivity and around 2000 turns were wound to the bobbin in order to acquire around 0.2T of applied magnetic flux density.

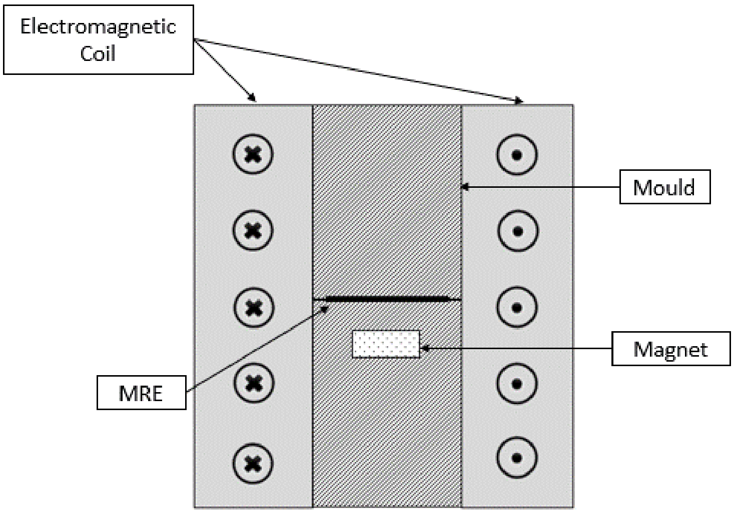


Fig. 2. The schematic diagram of the pre-structure device.

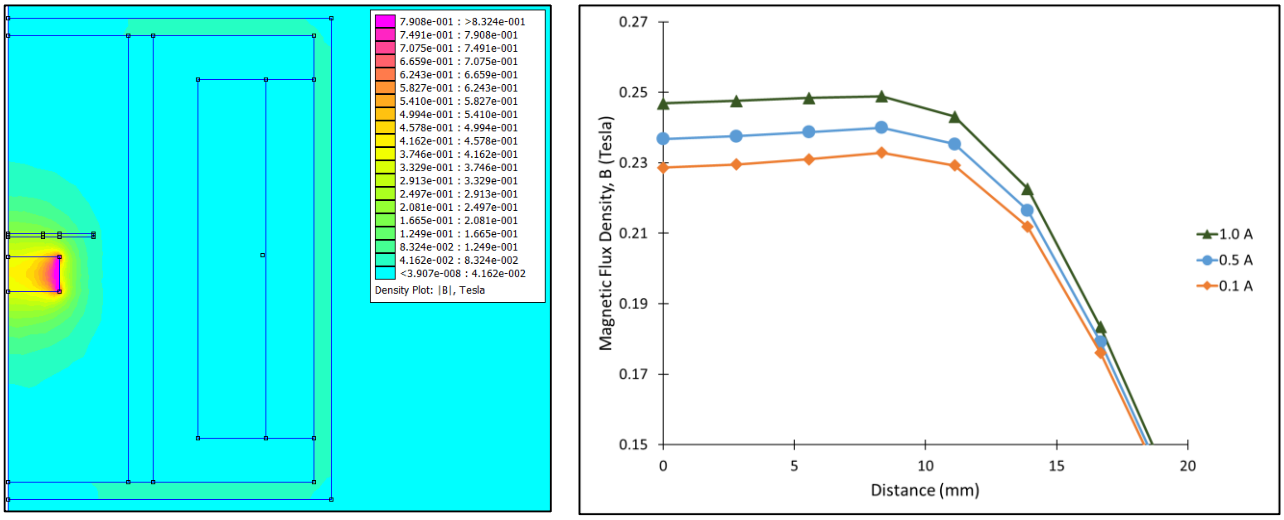
The mould for the device was made of non-magnetic material, particularly aluminium that does not affect the flow of magnetic flux that generated in the device. This would also allow the magnetic flux generated from both electromagnetic coil and permanent magnet to flow in a curve-lines passed through the mould. The FEMM was used to simulate and analyze the magnetic flux density generated inside the mould's chamber by the electromagnetic circuit. Prior to the fountain-like curve of magnetic flux generated in the uncured MRE, various currents were manipulated in order to achieve the optimum magnetic flux density that passed through in the MRE, thus the fountain-like alignment of CIPs will be acquired upon completing curing process of the MRE. Table 2 depicted the detailed input parameters to generate the fountain-like MREs magnetic flux lines in the pre-structure device.

Table 2
Input parameters of FEMM to simulate the magnetic flux flow in pre-structure device.

Component Name	Material	Relative Permeability (μ_r)
Coil wire	*Copper (18 AWG)*	*1*
Casing	*1010 Steel*	*902.6*
Bobbin	*Polyethylene*	*1*
Mould	*Aluminium*	*1*
Permanent magnet	*N45*	*1.05*
MRE melt	*Silicon rubber and CIPs*	*0.7958*

3. Results and Discussion

The entire setup of fountain-like MRE in the pre-structure device has been simulated to predict the formation of fountain-like magnetic flux lines and respective control of magnetic field strength within the chamber. Fig. **3** (a) shows the distribution of magnetic flux density analyzed via FEMM software. Different colours have been observed within the chamber indicating that different distribution of magnetic flux density has been passed through each part. The variation in magnetic flux density that befallen through the MRE mould however is depicted in Figure 3 (b). It shows that, by manipulating the induced currents from 0.1 to 1A, the resultant magnetic flux density, B that passed through the MRE mould would be vary, respectively. The increased of applied currents will increase the strength of the magnetic field and the stronger magnetic field would drive the distinct aligned CIPs following the lines of the magnetic flux (fountain-like) that passed through the MRE. Throughout the simulation however, the position of magnetic flux lines is not affected by changes in magnetic field strength when input current was varied as only the density of magnetic flux lines will be increased as increased in magnetic field strength. In order to have distinct fountain-like of CIPs in the MRE, the highest applied current of 1.0A which equivalent to around 0.24T will be chosen as the input magnetic field during curing of the MRE.



(a) (b)

Fig. 3. Magnetic flux density for fountain-like alignment: (a) Distribution throughout the mould and (b) Value across the MRE mould

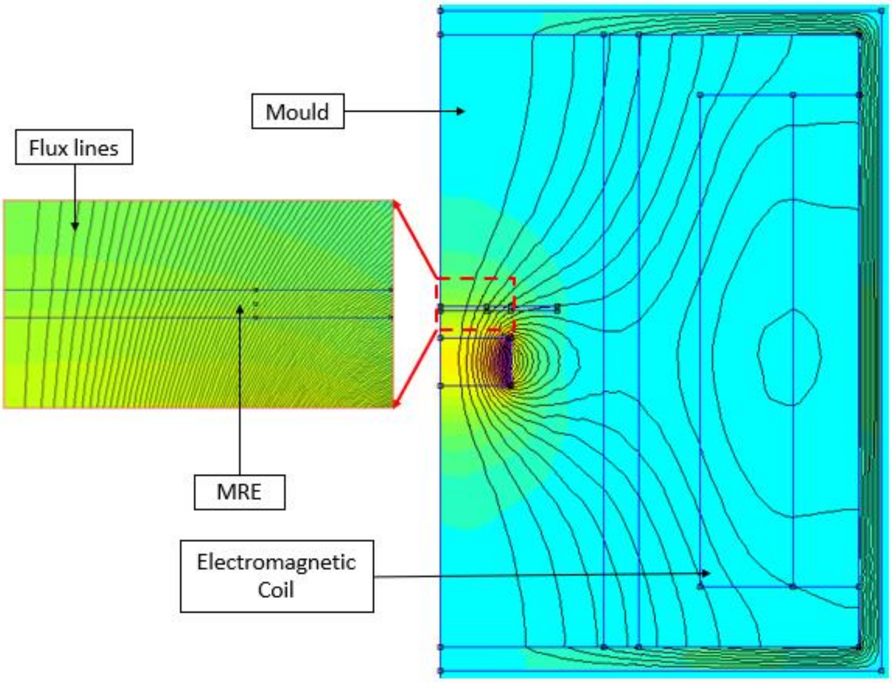


Fig. 4. Generated fountain-like magnetic flux lines across the pre-structure device.

Fig. **4** shows the magnetic flux lines generated in the FEMM software that also generated entire the chamber including the flux lines that passed through the MRE mould. Via magnified area of the mould in red dots square shape, the fountain-like flux lines can be seen forming inside the MRE mould and it is expected that the CIPs in the uncured MRE will be aligned according to the lines of magnetic flux thus the particles will be cured and embedded in the MRE in such aligned manner. It is noted that the generated flux lines that passed through the MRE mould would not be influenced by the mould since the mould was made of non-magnetic material. However, the generated magnetic flux that passed through the mould will be equipped with the permanent magnet that helps to pick-up the magnetic flux thus the flow of magnetic flux lines in the MRE will be in fountain-like, respectively.

5. Conclusions

The design of pre-structure device for fountain-like MRE was developed to acquire fountain-like alignment of CIPs in an MRE. FEMM software was used to determine the generated magnetic flux density in the pre-structure device with set parts and positioned of both magnetic sources; electromagnetic coil and permanent magnet. It can be concluded that the electromagnetic coil exerts a significant influence on the overall generated magnetic flux density in the device with the permanent magnet functioned to pick-up the magnetic flux lines that passed through the MRE mould. Thus, the fountain-like of magnetic flux could be generated within the MRE mould that also permit the CIPs to align along the fountain-flux lines. Therefore, the CIPs will be cured in the MRE in such fountain-like manner in order to achieve the improvement target of having enhanced rheological properties of the MRE.

Acknowledgements

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