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Test method

The evaluation and implementation of magnetic fields for large strain uniaxial and biaxial cyclic testing of Magnetorheological Elastomers

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A R T I C L E I N F O

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A B S T R A C T

Magnetorheological Elastomers (MREs) are “smart” materials whose physical properties are altered by the application of magnetic fields. In previous studies the properties of MREs have been evaluated under a variety of conditions, however little attention has been paid to the recording and reporting of the magnetic fields used in these tests [1]. Currently there is no standard accepted method for specifying the magnetic field applied during MRE testing. This study presents a detailed map of a magnetic field applied during MRE tests as well as providing the first comparative results for uniaxial and biaxial testing under high strain fatigue test conditions. Both uniaxial tension tests and equi-biaxial bubble inflation tests were performed on isotropic natural rubber MREs using the same magnetic fields having magnetic flux densities up to 206 mT. The samples were cycled between pre-set strain limits. The magnetic field was switched on for a number of consecutive cycles and off for the same number of following cycles. The resultant change in stress due to the application and removal of the magnetic field was recorded and results are presented.

1. Introduction

Magnetorheological Elastomers (MREs) are classified as smart materials that undergo a change in their physical properties which is observed as an increase in modulus when a magnetic field is applied to an MRE [2]. The increase in the modulus is caused by the ferromagnetic particles which are added to the elastomer during the curing process, tending to align with the applied magnetic field. The alignment occurs because the applied field results in dipole–dipole interactions between the particles which move to screen each other from the field and adopt a minimum energy configuration [3].

All MREs consist of two key components, the elastomeric matrix and ferromagnetic particles. MREs can also be classified into two broad groups; isotropic and anisotropic. Isotropic MREs contain an almost homogeneous distribution of magnetic particles whereas anisotropic MREs contain aligned particle chains. These chains are formed by the application of a magnetic field during the curing process [4]. Once the matrix has been cured, the particle mobility is reduced and the aligned chains remain in position. MREs with aligned particles normally exhibit a greater Magnetorheological effect than isotropic MREs when the magnetic field is applied parallel to the direction of the particle chains [4].

To date, MRE testing has predominantly been carried out on uniaxially loaded samples [5]. However the data provided on the magnetic fields prevents an accurate replication of many tests as the magnetic field is stated as uniform in both flux density and direction over the entire sample volume. The greater the distance between the magnetic poles, the less accurate this statement becomes [1,5,6].

The focus of this research is twofold. Firstly to provide an accurate representation of a magnetic field applied to MRE samples during both uniaxial tensile and biaxial bubble inflation fatigue tests and secondly, to provide the first comparative results between uniaxial and biaxial cyclic loading testing for an MRE exposed to the same magnetic field under both test modes.

2. Apparatus and materials

2.1. Magnetorheological Elastomers

The MRE samples used in all tests reported in this paper consist of isotropic carbon black filled 1.65% (volume per volume) vulcanised natural rubber with 18.3% (volume per volume) iron

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particles Previous studies [2–4,7–9] have focused on soft elastomer matrix (silicone or urethane) based MREs as these elastomers have a greater particle mobility and hence undergo a greater increase in modulus when a magnetic field is applied. Other studies [10–12] have focused on natural rubber based MREs as their superior physical (modulus) and fatigue properties offer potential applications such as Adaptive Tuned Vibration Absorbers (ATVAs) [11].

As the primary goal of this study is to specify a magnetic field and evaluate its effect on two separate test methods, variations in test results due to sample manufacture or orientation (particle chains in anisotropic samples) were minimised by use of isotropic samples produced by a replicable commercial production method.

The samples used in the uniaxial tensile strength tests were 70 mm × 20 mm × 1 mm strips with the direction of extension being in the direction of the 70 mm length. For the biaxial bubble inflation tests, discs of 50 mm diameter and 1 mm thickness were used.

2.2. Electromagnetic array

All magnetic fields applied in this study to both the uniaxial and biaxial tests were generated by the same electromagnetic array. A prototype of this array was described in a previous study by the authors [1] but has since undergone further modifications to increase the flux density. An FEA model of this modified array is shown in Fig. 1. Electromagnets have a number of advantages and disadvantages when compared with permanent magnets. The main advantage offered by permanent magnets is that they do not require a constant input of power to maintain the magnetic field [13]. This is offset by the fact the an electromagnetic array allows for the field to be turned on and off during a test so that data can be collected with and without the magnetic field applied for the same sample during a single test. The same tests can be repeated using fields of different flux density by altering the current supplied to the coils.

The magnetic array discussed here uses low carbon steel rods of 50 mm for the magnetic core and magnetic circuit. This arrangement is shown in the FEA model (FEMM4.2 modelling software [14]) in Figs. 1 and 3D schematic in Fig. 2.

The array consists of four 1500 turn electromagnets with current flowing in one direction for the two central coils and in the opposite direction for the two side coils to give the same north and south pole arraignment as the open access Halbach array used in NMR imaging by Hills [15]. The magnetic circuit is a constant 50 mm diameter for the entire circuit length to maximise the flux density of the field which can be applied to the samples. The updated array incorporates the same cooling system power supply and side coils of the prototype [1].

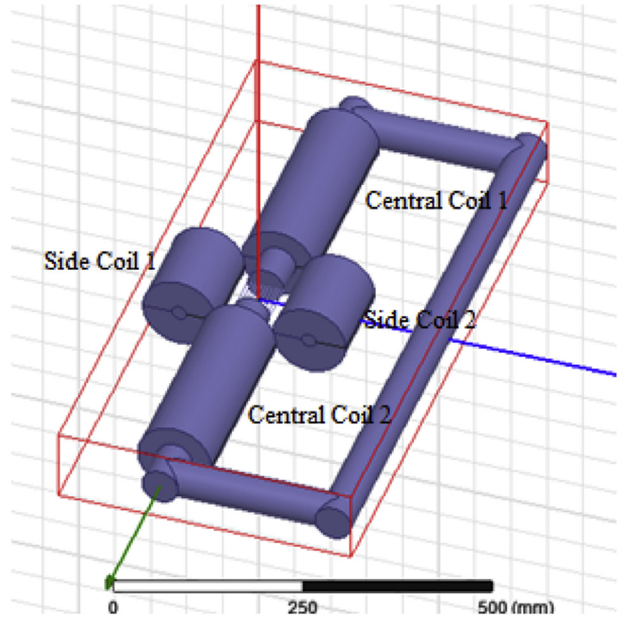

Fig. 2. 3D schematic showing position of electromagnets.

3. Testing methods

3.1. Uniaxial tensile fatigue tests

Uniaxial tensile fatigue tests were performed on 70 mm × 20 mm × 1 mm isotropic natural rubber MREs with the strain applied along the 70 mm length of the sample (ie zero strain $l_0 = 70$ mm) and the cross sectional area of the sample being 20 mm^2. These tests were conducted on a Zwick uniaxial tensile test machine.

All tests carried out were constant strain amplitude tests. The stress was calculated as true stress from the load cell output. $\sigma_{true} = \frac{F\lambda}{A}$ where σ_{true} is the true (Cauchy) stress, F is the force on the load cell, A is the initial cross sectional area of the sample, and λ is the stretch ratio (strain+1). All modulus values reported in this study are for $E_{true} = \frac{\sigma_{true}}{\varepsilon}$ where ε is the strain.

The magnetic fields were field was applied perpendicular to the strain direction for all uniaxial tests. Each test consisted of 500 cycles at 1 Hz with the field switched off for the first 50 cycles and being switched on at the 50th cycle for the next 50 cycles before being switched off at the 100th cycle. This off/on switching of the magnetic field continued until the test ended with the field in the on position for cycles 450 to 500.

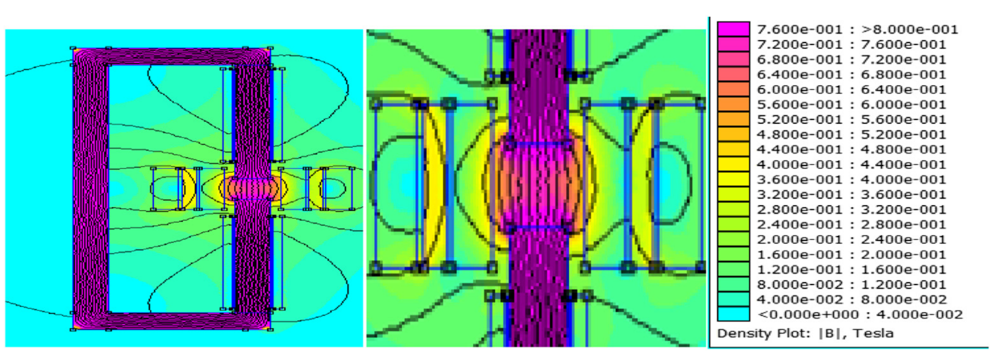

Fig. 1. 2D FEA model of the array used during testing.