CHAPTER 1
INTRODUCTION

Magneto Rheological Elastomers (MRE) have been the subject of intense research during the past few decades. They exhibit novel properties and are potential materials for new generation devices [1, 2]. These elastomers are new engineering materials included in the category of active materials whose mechanical properties can be controlled by an external magnetic field [3]. They can be utilized in transduction and vice versa. These two important properties of magneto rheological (MR) elastomers give rise to many potential applications in the form of actuators, transducers, automobile suspension systems, clutches, breaks, vibration isolators and dampers [4,5]. This is analogous to the behavior of an MR fluid system or an electro rheological (ER) system [6]. The cross-linked chains of magnetically coupled particles are thought to be responsible for enhancement of its elastic shear modulus under the influence of an external magnetic field [7]. The rheological properties of MR elastomers can be changed continuously, rapidly and reversibly by applying a varying electric or magnetic field [8]. By the use of suitable control mechanism and feedback system they can be thoroughly utilized to sense external perturbations [9].

MREs are the solid state analogues of MR fluids. MRE can provide dynamic stiffness elements capable of operation over a wide range of conditions [10,11]. This controllability in response to an applied magnetic field is achieved by embedding magnetic particles into a cross linked polymeric rubber matrix. During cross linking or curing each particle in MRE is held in position until magnetic or mechanical perturbations induce changes in the configuration of the embedded particles [12,13].

The filler element used in MRE is magnetic in nature. An added advantage of incorporating nanosized fillers in an elastomer matrix is that they reinforce the matrix and improve the mechanical properties. Magnetic field assisted curing of MR
elastomers can produce an alignment of magnetic particles in the field direction creating a chain like structure in the host matrix. This can modify the stiffness of the rod and a change in natural frequency of the material is expected. Other than this, addition of filler to a polymer matrix can change the viscosity of the material by the relation

\[ \eta_F = \eta_U (1 + 2.5C) \]  \hspace{1cm} (1.1)

where \( \eta_F \) is the viscosity of the filled sample, \( \eta_U \) is the viscosity of the unfilled sample and \( C \) is the volume concentration of the filler [14].

MREs require an elastomer matrix which can be polar or non-polar. Ferromagnetic fillers are incorporated in the matrix according to an operatic recipe. The alignment of particles in the matrix and the formation of chain like structure inside the matrix aids in modifying the stiffness of MRE. This can be achieved by polling the magnetic particles by applying an external magnetic field during curing.

This chapter describes the basic properties of elastomers such as storage modulus, loss modulus and loss factor (\( \tan \delta \)). The motivation of the present work is also brought out together with the objectives of the present investigation.

1.1. POLYMER

Elastomers are polymers with special elastic property known as viscoelasticity and having low Young’s Modulus and high failure strain when compared to other materials. The term elastomer arises from elastic polymer and sometimes used instead of rubber like substances. The monomers of these polymers are made of carbon, hydrogen, oxygen, and silicon. They are amorphous in nature and their existence is always above the glass transition temperature which facilitates segmental motion in elastomers[15].
Elastomers are also known as thermo sets, which require vulcanization or curing, and at the same time, they are thermoplastic. The linking of polymer chains during vulcanization/curing is known as cross-linking. The cross-linked polymer chains distribute the applied stress and attain the property of elasticity to regain its size and shape on the withdrawal of the deforming force. These cross linkages between monomers actually convert a polymer into an elastomer. In the absence of this linkage, application of stress on a polymer will produce permanent set of deformation having zero elasticity or maximum plasticity [16].

1.2. RHEOLOGY

Rheology is the study of flow or deformation of matter not particularly in the liquid state, but also in the case of soft solids/solid in the plastic flow region and other similar materials known as soft matter. Rheological properties are exhibited by substances having a complex micro structure such as polymers, mud, suspension like substances, food and additives, bodily fluids other bio materials coming under the category of soft matter [17].

Fluids with a constant value of viscosity for a specific temperature come under the category of Newtonian fluids. Here the viscosity changes with temperature but does not vary with strain rate. Only few fluids have this constant viscosity and they are known as Newtonian fluids. However, for the other large group of fluids, the viscosity changes with strain rate and are called non Newtonian fluids. Usually viscoelastic properties of elastomers (polymer) are defined on the basis of different parameters including temperature, pressure and time. Other important variables affecting viscoelasticity of a polymer are molecular weight and weight distribution, chemical composition, degree of hardening and crystallinity, types of component concentration, dilution with solvents or plasticizers and mixture with other materials to form composites [18]. The above dependence of viscoelasticity of polymers with such variables can be explained on the basis of molecular theory. This is made possible by
introducing new concepts like free volume, the monomeric friction coefficient and spacing between entanglement loci. These factors can be manipulated to tailor the physical and chemical properties by altering the microstructure. Viscoelasticity indicates the combined response via, viscous and elastic properties of the materials, which is under strain.

Viscoelasticity of a material is due to motions of flexible polymer molecules and their entanglements and network junctions. Thus, the rearrangement of these polymer molecules for a short range is very rapid while for a long range namely it is very slow. More than that, under stress a new assortment of configuration can be obtained. The nature and rates of change of the configurational rearrangements and the nature of the molecular interactions over a wide range of time scales can be obtained by studying viscoelastic properties [19].

The word ‘Rheo’ is a Greek word which means flow and ‘Ology’ means study of. Scientists who study the properties of non-Newtonian fluids are called Rheologists.

1.3. ELECTRO AND MAGNETO RHEOLOGY

Electrorheological and Magnetorheological fluids are also known as controllable fluids[20]. They are used in rotary brake of aerobic equipment and in a linear damper for lorry seat suspensions to enhance the comfort of drivers. Another important application of MR fluid is in magneto rheological finishing of optical components.

They are very much useful in stress transfer and damping devices. Electro and magneto Rheological fluids show a novel property, in that their rheological properties are dramatically altered by applying external electric and magnetic fields respectively. A typical scheme is shown below (Figure 1.1).
Electrically Active Polymers (EAP) is the solid-state analogue of an Electrorheological liquid. EAP can be used as sensors, actuators, and artificial muscles. A change in applied voltage changes the molecular composition or structure of the polymer which results in its expansion, contraction or bending (Figure 1.2). This motion of EAP is smoother than that and produced by mechanical devices. But energy consumption of EAP is very high and its lifespan is also very short. Artificial muscles fabricated using EAP’s can produce natural movements to biomedical and robotic devices[21].
1.4. FERROFLUIDS

Ferrofluids are rheological fluids and find innumerable engineering applications. They usually contain ferrite particles that are less than 10 nanometer in diameter and exhibit only weak field dependent rheology. It is also known as a liquid magnet and is a colloidal mixture of magnetic nano particles. A Surfactant locked in the magnetic particles prevents the magnetic particles from being stuck together. Ferrofluids can be synthesized with hydrocarbon as carriers or they can be aqueous based. Hydrocarbon based ferrofluids find engineering applications while aqueous based fluids are known for their biomedical applications [22].
They are used in high-end speakers and in the laser heads of CD and DVD players. Their important uses are in low friction seals for rotating shaft motors, computer disk drives, seals, study of magnetic domain structure in magnetic tapes, rigid and floating disk, geological rocks, magneto optical discs, crystalline and amorphous alloys, garnets, steels, drug delivery etc. In the absence of a magnetic field, all the magnetic particles in ferrofluids are oriented in random directions. By applying a magnetic field, all the suspended magnetic particles align in the direction of the magnetic field producing spikes in the field direction (Figure 1.3). Withdrawal of the field will restore the random orientation of magnetic particles in the carrier fluid [23].

1.5. MAGNETORHEOLOGICAL FLUIDS

As the particle size of the suspended particle in a Ferro fluid is 10nm, its magnetic properties are inferior to its bulk counterparts. So it cannot be used in damper, clutches and brakes. For that, we have to prepare MR liquids using micron size particles as filler.

Figure 1.4. MR Fluid (a)magnetic field off (b)magnetic field on

Application of MR fluids are of relevance to engineers and can be used in many damping devices. Here ferrofluids are not preferred [24]. The reason for this is simple. There is a huge difference in the yield shear stress of the MR and ferrofluids,
which affects the maximum force the fluid can provide. MR fluids are more efficient than ER fluids because they possess high field induced inter particle forces and having high yield stress than ER fluids (figure 1.4).

1.6. MAGNETO RHEOLOGICAL ELASTOMERS

MR materials exhibit variable stiffness/multiple stiffness and find applications in adaptive structures of aerospace, automotive civil and electrical engineering applications. MR elastomers (MRE) show excellent mechanical properties. Their rheological properties vary in accordance with the change in applied magnetic field. They are equivalent to MR fluids but are solid state analogues of MR fluids. In MRE, magnetostrictive/ magneto active particles are fixed in the polymer matrix during the curing process. This matrix withstands high strains so as to get the shape of element. The magneto rheological effect of these elastomers depends on dipole interactions between ferromagnetic particles. Under the influence of a magnetic field, particles try to align themselves parallel to the magnetic field. This will produce a strain on aligned chain like microstructures inside the polymer matrix [25] and hence produce a change in dimension of the elastomer as shown in Figure 1.5.

![Figure 1.5. MR elastomer a) without field and b) with field](image)

Vulcanization keeps the alignment of particles intact inside the matrix as such and after the completion of curing process elastomers is ready for test or use. It can be
shown that MR rods with aligned microstructure exhibit enhanced MR effect than that with isotropic microstructure.

1.7. FUNDAMENTALS OF MAGNETISM

The earliest experiments with magnetism involved the lodestone, which was magnetite, known for its ability to attract bits of iron. Therefore, magnetism began with ferrites. Now we must explain how a spontaneously magnetized substance exhibits the magnetic properties familiar to us. If all the moments in a macroscopic sample were aligned, a very strong external magnetic field would be produced. This magnetic field represents a great deal of energy. If the moments were rearranged to reduce this external field, then the overall free energy would be reduced and render a more stable state. Magnets play an important role in our daily life. As we are familiar, a variety of devices are employed in the electromagnetic industry [26].

1.7.1. Classes of Magnetic materials

The origin of magnetism is based on orbital and spin motions of electrons and how they interact with one another. Different types of magnetism can be defined on the basis of response of these materials to magnetic fields. It can be seen that matter is magnetic in nature but with some difference in their magnetic properties. In some materials, there is no collective interaction of atomic magnetic moments, whereas other materials exhibit strong magnetic interaction. They are classified into

1) Diamagnetism
2) Paramagnetism
3) Ferromagnetism
4) Antiferromagnetism
5) Ferrimagnetism
The first two in the group have no collective magnetic interaction and are not magnetically ordered. However, in the last three groups, materials exhibit long-range magnetic order below a certain critical temperature. Ferromagnetic and ferrimagnetic materials are usually considered as “magnetic.” The rest are weakly magnetic and considered as “nonmagnetic”.

(1) **Diamagnetism:** It is a fundamental property of all materials, although it is usually very weak. It is due to non-ordering behavior of orbital electrons when placed in a magnetic field [27]. Diamagnetic materials are made up of atoms, which have net magnetic moments. This is because all the orbital shells are filled and no free electrons exist. However, when exposed to a magnetic field, a negative magnetism is produced and therefore susceptibility of these kinds of materials is negative. In zero field, magnetization is also zero. Susceptibility of a diamagnetic substance is temperature dependent. Examples of diamagnetic materials are quartz, calcite and water. A typical diamagnetic material under the influence of a magnetic field is shown below. (Figure 1.6)

![Figure 1.6. Diamagnetism](image)

(2) **Paramagnetism:** In this type of materials, some of the atom or ions have a net magnetic moment due to unpaired electrons in their partially filled orbits. Like diamagnetism, in this case also individual magnetic moments do not interact magnetically. Thus when the field is removed magnetization is reduced to zero. However, in the presence of a magnetic field, there is a partial alignment
of the atomic magnetic moments in the direction of the field resulting in a net positive magnetization and positive susceptibility of a paramagnetic substance is temperature dependent and based on Curie’s Law[28]. Under normal temperature and moderate field, the paramagnetic susceptibility is small. But for very low temperatures and high field it is independent of applied field but depends on total Iron content in it.

Figure 1.7. Paramagnetism

Many minerals containing iron are paramagnetic in nature at room temperature. Some examples are Monotmorillonite(clay), Pyrite (sulphide), Nontronite(Fe rich clay), Biotite (silicate), Siderite (Carbonate). The arrangement of individual magnetic moment under zero and applied field are shown in Figure 1.7.

(3) Ferromagnetism: Unlike paramagnetic materials, the atomic moments in these materials exhibit very strong interactions. They are produced by the electronic exchange forces and result in parallel and antiparallel alignment of atomic moments. The magnitude of these exchange forces are very high and is of the order of 1000 Tesla. The exchange force is a quantum mechanical phenomenon arising out of the relative orientation of the spins of free electrons. Ferromagnetic materials usually show parallel alignment of moments resulting in large net magnetization even in the absence of a magnetic field. A typical ferromagnet in the magnetized and unmagnetized
state is shown in figure 1.8. Fe, Co, Ni and many of their alloys exhibit ferromagnetism at room temperature.

Two important characteristics of ferromagnetic materials are (1) spontaneous magnetization and (2) existence of magnetic ordering temperature [29]. The spontaneous magnetization is the net magnetization that exists in a uniformly magnetized microscopic volume in the absence of a field. Its magnitude depends on the spin magnetic moments of electrons. The saturation magnetization of a ferromagnetic material is the maximum induced magnetic moment that can be acquired by it in a magnetizing field. Beyond this field, magnetization remains a constant and hence it is called as saturation magnetization. Saturation magnetization is an intrinsic property, independent of particle size but dependent on temperature. When compared to paramagnetic susceptibility, ferromagnetic susceptibility is very high value. Even if the electronic exchange forces in ferromagnetic material are very large, thermal energy supersedes the exchange and produces a randomizing effect. This happens at a particular temperature called Curie temperature. Below Curie temperature, the ferromagnetic material is ordered and above it they are in disordered state.

![Ferromagnetism](Figure.1.8)

**Figure.1.8 Ferromagnetism**

Saturation magnetization is the maximum possible magnetization of a material. Remanence is the remaining magnetization when magnetizing field
is removed. Coercivity is the strength of the magnetizing field that is to be applied to the ferromagnetic material in the opposite direction so that remanence becomes zero.

(4) Ferrimagnetism: More complex forms of ordering of magnetic moments can be seen in ionic compounds like oxides. One such magnetic ordering is called ferrimagnetism. In this material, the magnetic structure is composed of two magnetic sublattices separated by Oxygen. The exchange interactions are mediated by an oxygen anion. These interactions are called indirect or superexchange interactions[29]. The strongest superexchange interactions results in an antiparallel alignment of spins between two sublattices. In ferrimagnetic materials, these magnetic moments of sublattices are not equal and result in a net magnetic moment (Figure.1.9). So it is quite similar to ferromagnetism and characterized by spontaneous magnetization, Curie temperature, hysteresis and remanence. However they possess very different magnetic ordering. Figure 1.9 is the arrangement of moments. Magnetite is a well-known ferrimagnet.

![Ferrimagnetism](image)

(5) Antiferromagnetism: When magnetic moments of the two sublattices in a magnetic structure are equal and opposite, the net magnetic moment is zero (figure 1.10). This type of magnetic ordering is called antiferromagnetism. Antiferro magnetic materials also have zero remanence, no hysteresis but a small positive value for susceptibility that varies with temperature. In the case of antiferromagnetism, there is a critical temperature called Neel temperature,
above which the susceptibility obeys the Curie–Weiss Law for paramagnetic materials but with a negative intercept showing negative exchange interactions [30]. If the spins in the two sub lattices are slightly tilted or canted, a very small net magnetization can be produced. This is called canted antiferromagnetism. Hematite is a well-known example.

Figure 1.10. Antiferromagnetism

1.7.2. Magnetic Anisotropy

Ferromagnetic materials can be divided into a large number of sub volumes called domains. Each domain is spontaneously magnetized to saturation but the direction of magnetization varies from domain to domain. The net vector sum of all moments therefore produces a total magnetization of near zero. The dependence of magnetic properties on a specific direction is called magnetic anisotropy. There are different types of anisotropy. They are magneto crystalline anisotropy which depends on the crystal structure, shape anisotropy is dependent on grain size and stress anisotropy is related to the applied or residual stresses.

Magnetic anisotropy affects the shape of hysteresis loops and controls the value of coercivity and remanence. Anisotropy is of utmost importance in technology because Material Engineers use this for commercial applications.

**Magneto crystalline anisotropy**: It is the energy required to deflect the magnetic moment in a single crystal from the easy to the hard direction. The easy and hard
directions arise from the interaction of the spin magnetic moment with crystal lattice known as spin orbit coupling [31].

**Stress Anisotropy:** Another effect of spin orbit coupling is magnetostriction. Magnetostriction originates from the strain dependence of anisotropy constants. Upon magnetization, a previously demagnetized crystal experience a strain that can be measured as a function of applied field along the principal crystallographic axis. A magnetic material therefore changes its dimension when magnetized. In the reverse process, the application of a suitable stress can produce a change in magnetization. A uniaxial stress can produce a unique easy axis of magnetization, if the stress is sufficient to overcome all other anisotropy. Magnitude of stress anisotropy is described by two more empirical constants known as magnetostriction constant and level of stress.

**Shape anisotropy:** It is due to the shape of grain. A magnetized body will produce magnetic poles at the surface. This surface charge distribution, acting in isolation, is itself another source of magnetic field called the demagnetizing field. It is called so because it acts in opposite direction to the magnetization producing the same.

### 1.7.3 Domain Theory

A magnetic material is actually composed of small regions called magnetic domains within each of which the local magnetization is saturated but not necessarily parallel. Domains are small but much larger than atomic distances. The existence of domains is quite important because some magnetic properties especially coercivity and remanence vary with grain size.

The maximum coercivity for a given material occurs within its single domain range. For larger grain sizes, coercivity decreases as the grains subdivides into domains. For smaller grain sizes, coercivity again decreases, but this time due to randomizing of thermal energy.
Multi-domain grains are magnetically soft and having low values of coercivity and remanence.

As the particle size continuously decreases within single domain range, another critical point is reached, at which remanence and coercivity go to zero. At this stage particle becomes super paramagnetic.

1.8. MAGNETOSTRICTION

The deformation produced in a magnetorheological elastomer under an applied magnetic field is called Magnetostriction. Magnetostrictive materials are typically mechanically biased in normal operation. A compressive load is applied to a material, which is due to magneto elastic coupling, forces the domain structure to orient perpendicular to the applied force. When a magnetic field is applied, the domain structure rotates producing the maximum possible strain in the material. A tensile preload should orient the domain structure parallel to the applied force. This has not yet been observed due to the brittleness of the material.

Magnetostriction can be measured by noting the small changes in the length of the elastomer rod when an external magnetic field is applied. This change in length of the rod is called longitudinal magnetostriction $\lambda = \Delta L / L$. In the absence of saturation magnetization the combined effect of longitudinal and transverse magnetostriction causes no net change in the volume of the material. When a sufficient magnetic field is applied to saturate the magnetization, both longitudinal and transverse magnetostrictions have the same sign, the resulting change in the volume of the rod is called volume magnetostriction (Barrett effect). As volume magnetostriction is always much smaller than longitudinal magnetostriction, the term magnetostriction generally refers to longitudinal or linear magnetostriction[32].

For an MRE, dimension changes are due to interactive coupling between the applied magnetic field and the magnetic moments of the material’s individual domain. All these magnetic domains get aligned in the direction of the magnetic field. Schematic of the above phenomena is shown below (Figure 1.11)
The anisotropy of a magnetic material varies with strain and correspondingly the magnetic material lattice will distort /strain spontaneously if the resultant strain lowers the anisotropy energy.

The magnetostriction between the demagnetized state and saturation is structure sensitive so general constitutive relations for the magnetostriction are not possible. However, an explicit solution exists for cases when the strains are due primarily to 90° domain rotations. In practice, these rotations occur in a single crystal with uniaxial anisotropy in which the field is applied in a direction perpendicular to the easy axis or a polycrystalline material in which the magnetic moments have been brought to complete alignment in a direction perpendicular to the applied. The latter case implies that the perpendicular stress energy is sufficient to dominate the crystal anisotropy.

\[
\lambda = \frac{3}{2} \lambda_s \cos^2 \varphi
\]  

Where \( \lambda \) is magnetostriction, \( \lambda_s \) is saturation magnetostriction and \( \varphi \) is the angle between the Ms vectors and the field direction. Recognizing that the bulk magnetization along the field direction is given by
\[ M = M_s \cos \phi, \] where \( M \) is magnetisation and \( M_s \) is saturation magnetisation.

Above equation becomes

\[ \lambda = \frac{3}{2} \lambda_s \left( \frac{M}{M_s} \right)^2 \quad (1.3) \]

This provides a quadratic relation between the magnetization and magnetostriction[33].

The major advantage of MRE’s is that particles are not able to settle with time and there is no need of a vessel to contain them. The possibility of hazardous waste leakage is no more with a solid MRE. Secondly, the particles in a solid MR will not affect the performance and durability of a piece of equipment as much as the interaction of particles in MR fluid. Usually MR solids work only in the pre yield region while MR fluid, typically work in the post yield state.

MR elastomers normally work in the pre yield regime of linear viscoelastic region. In viscoelastic materials a part of the deforming force or corresponding input energy is stored and released during each cycle and some is dissipated as heat. The storage modulus \( G' \) represents the capacity of the material to store energy of deformation, which contribute to material stiffness. The loss modulus \( G'' \) represents the ability of the material to dissipate the energy of deformation.

Usually magnetically soft particles are used as fillers in an appropriate matrix to produce magneto mechanical coupling. Magnetic field induced stiffening is due to magnetic dipolar interaction. The attraction between two magnetic dipoles could increase the shear modulus of the material. Stiffness change also depends on the volume fraction of the particle, magnitude, and frequency of the strain[34].

By measuring magnetic interaction energy between two dipoles, the strength of magnetic interaction can be calculated. If the field applied is along the aligned chains and in the vertical direction, the magnetic interaction energy is given by

\[ U = \frac{\mu_0 m^2}{4\pi r^3 (1 - 3 \cos^2 \theta)} \quad (1.4) \]
Where, $\mu_0$ is the magnetic constant, $\theta$ is the angle between the line connecting the two dipoles and the direction of magnetization. The magnetic interaction energy depends on the dipole moment as well as the chain geometry.

1.9. LINEAR VISCOELASTIC THEORY

Figure 1.12 shows relation connecting stresses and strains of three group of materials, perfectly elastic, purely viscous and viscoelastic. For an elastic material, stress response is in phase with strain.

Figure 1.12. Relation connecting stresses and strains of three group of materials, (a) perfectly elastic, (b) purely viscous and (c) viscoelastic

The general equation related to sinusoidal deformation $\gamma$ of small amplitude $\gamma_0$ at fixed pulse $\omega$ is given by

$$\gamma = \gamma_0 \sin \omega t.$$  \hspace{1cm} (1.5)

For a purely viscous material stress is $90^0$ out of phase with strain and a viscoelastic material would yield a stress having components both in phase and out of phase. Thus viscoelasticity of the material can be described by a complex modulus $G^*$. 

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\[ G^* = G' + iG'' \quad (1.6) \]

where \( G' \) is the storage modulus and \( G'' \) is the loss (out of phase) modulus.

Loss factor \( \tan \delta \) of the material is given by the relation

\[ \tan \delta = \frac{G''}{G'} \quad (1.7) \]

The loss factor of a material is the ratio of energy dissipated from the material per radian to the stored energy during a study state sinusoidal excitation. Magneto rheological materials in the form of fluids, foams, and elastic come under the category of smart materials and functional materials. Application of an external magnetic field can tune their rheological properties. MR fluids are liquids whose shear flow properties can be controlled for applications in torque transfer and vibration control devices. MR foams are high-end application of MR fluids with maximum efficiency. MR elastomers are solid-state analogues of MR fluids whose stiffness can be controlled to provide suspension devices and tunable mounts. At the US ‘National Bureau of standards, JacobRabinow carried out an initial study on MR fluids. At the same period, William Winslow was concentrating on the work associated with electro rheological fluids. Bingham plastic model gave a satisfactory explanation to the field depend behavior of MR fluids[35]. Micron sized MR particles will support several hundreds of magnetic domains. Domain dipole rotation in the presence of a field causes interparticle attraction and thus maximum magneto rheological effect.

1.10. POLYMER MATRIX

In the present study polymer matrix selected is natural rubber. Sulphur is added for the vulcanisation of natural rubber. It brings cross linking and converts rubber to create bound structure. Usually 0.5 to 5phr (part per hundred rubber by weight) Sulphur is added. Certain chemicals, termed accelerators, after we used with
Sulphur shorten the time of vulcanisation and improve the physical properties of rubber. Despite the fact that inorganic accelerators, like white lead, lead monoxide, lime and magnesia are used as accelerators, the organic accelerators are found to be additional active. Some examples are MercaptoBenzoThiazoleDisulphide(MBTS), TetramethyThiuramDisulphide(TMTD), CyclohexylBenzthiazylSulphenamide (CBS), ZincDibutyl Carbonates (ZDC) etc. The proportion needed is comparatively tiny, usually 0.5 to 1.0 part per 100 gm of rubber being spare. Most accelerators need the presence of zinc oxide to exert their full effectiveness, and a few need an organic acid, like stearic acid [36].

1.11. FILLERS

The filler materials appropriate for MR solids are pure Iron and Carbonyl Iron. Thanks to their high porosity and low remnant magnetism and high saturation magnetization. High porosity and high saturation magnetization provides high inter particle interaction and there by high MR effect[37].

1.12. MOTIVATION

As has been described earlier, the importance of MREs lies in its ability to react to external stimuli to modify parameters like stiffness constant, resonant absorption, viscosity etc. The incorporation of ferromagnetic fillers in the matrix for various loadings of the filler necessitates that they are impregnated into the matrix according to a specific recipe. They are to be moulded into rods as well as sheets. The recipe has to be worked out on a trial and error means. The moulded sheets/rods must be homogeneous, where the particles are uniformly distributed. In this investigation, it is intended to incorporate two types of fillers namely Iron and Carbonyl Iron.

In the case of iron containing MREs, the effect of particle size on its different properties is also to be investigated. For this, commercially available iron is milled to
make nanosized powders. In the first phase of the investigation, both micro and nanosized fillers will be incorporated and rods and sheets will be moulded with and without the application of external magnetic field. For this a complete setup for moulding sheets and rods are to be designed. This has to be designed and fabricated. This forms a part of the objectives of the present work. Evaluation of magnetostriction of these MREs is of importance for micro actuator applications. A non-contact method of LDV will be employed for this. Necessary accessories for the estimation of micro actuation under different magnetic fields will also be fabricated. They include magnetic assemblies, power amplifiers. A complete automated system with laser, power amplifier, Dynamic Signal Analyzer (DSA), Vibration controller will be assembled for this purpose. This is yet another objective of the present work.

A second type of MREs consisting of Carbonyl Iron of different particle size also will be made and tested for its micro actuation. The evaluation of magnetic properties especially its loop parameters are also necessary, for this, Vibrating Sample Magnetometry (VSM) will be used. The various mechanical properties namely, Young’s Modulus, Storage Modulus, Loss Modulus and Stiffness are also to be evaluated by employing DMA and Instron Mechanical Analyzer. The magnetodielectric properties of MREs are seldom studied thoroughly. The magnetodielectric properties of MREs will be evaluated at various frequencies. Finally the results are to be correlated.

So, the objectives of the present work can be listed as follows.

- Design and fabrication of a set up for curing MRE rods in an applied magnetic field.

- Design and fabrication of a set up for curing MRE sheets in an applied magnetic field (1)Normal (2) horizontal to the plane of the sample.
• Preparing iron powders of different crystallite sizes by high energy ball milling.
• Mixing and homogenizing of Fe and Carbonyl Iron powders in natural rubber matrix for the realization of MRE rods and sheets
• Structural characterization of the prepared samples using XRD.
• Structural characterization of the prepared samples using TEM.
• Morphological characterization of the prepared samples using SEM.
• Studying the mechanical properties of the prepared samples using Instron mechanical Analyser.
• Magnetic characterization using Vibrating Sample Magnetometer.
• Actuation measurements using Laser Doppler Vibrometer.
• Shear studies of MRE sheets using modified DMA.
• Studying the dielectric properties of these samples using an impedance analyzer.

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