INVESTIGATION OF THE INFLUENCE OF AGING OF DAMPING PROPERTIES ON SILICONE- BASED MR ELASTOMERS

A Graduate Project Report submitted to Manipal Academy of Higher Education in partial fulfilment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY

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CERTIFICATE

This is to certify that the project titled **Investigation of the influence of aging of damping properties on silicon-based MR Elastomers** is a record of the bonafide work done by **Hrishik Kunduru** (190933009) , **Abhinandan Kausthub** (190933011), **Krutika Tandel** (190933016), submitted in partial fulfilment of the requirements for the award of the Degree of Bachelor of Technology (B Tech) in **AERONAUTICAL ENGINEERING** of Manipal Institute of Technology, Manipal, Karnataka, during the academic year 2022 -2023.

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ABSTRACT

Magnetorheological (MR) elastomers are a subclass of smart materials which exhibit tuneable mechanical properties in the presence of a magnetic field. They could be utilized in a variety of industries, including robotics, energy management, and vibration control. In this study, the effects of aging on silicone-based MR elastomers are examined, which are recognized for their excellent damping capabilities. The mechanical properties of materials can be altered by aging, a natural process that is influenced by environmental factors like temperature, humidity, and oxidation over time.

The investigation consisted of exposing MRE samples to predetermined humidity levels and using free vibration test to examine how the damping ratio and natural frequency changed as a result. The frequency response data from the free vibration test were used to calculate the damping ratio and determine the natural frequency of the MRE samples.

The results showed that the damping ratio and natural frequency of MREs can be highly affected by humidity exposure. After being exposed to humidity, the damping ratio varied, with some samples showing an increase and others a decrease. The distribution and interactions of the magnetic particles within the material, as well as variations in the rubber matrix's viscoelastic characteristics, can be implicated in this behaviour. The MREs' inherent frequency also changed, with some samples showing a change as a result of moisture absorption and softening effects.

In order to build and optimise MRE-based systems and devices in contexts where humidity variation is a concern, the study's findings offer useful insights into the dynamic behaviour of MREs under humidity exposure.

Key words: Magneto-Rheological Elastomers (MRE), Aging, Vibration, Natural frequency, Damping ratio, Silicone, Carbonyl Iron Particles.

LIST OF TABLES

LIST OF FIGURES

Contents

CHAPTER 1

INTRODUCTION

Magnetorheological (MR) materials possess rheological properties which can be controlled rapidly and reversibly by external magnetic field application. These materials consist of a soft, elastomeric matrix induced with particles having magnetic properties. The magnetic particles, which are typically iron or iron oxide particles with a diameter of a few micrometres, react to an external magnetic field by aligning along its lines, forming a web of magnetic chains that can change a material's mechanical properties. Rheology is the branch of physics which deals with the materials deformation or flow in response to applied stresses [1, 9]. Due to their distinctive and adaptable mechanical properties, making them quite suitable for an assortment of engineering applications, MREs have garnered significant research interest in recent years. MREs are particularly well suited for applications such as vibration control, energy harvesting, and sensing because they provide the ability to adjust their stiffness, damping, and other mechanical properties quickly and reversibly.

1.1 Properties:

The type, size, and vol. fraction of the magnetic particles, along with the cross-linking density of the polymeric matrix, can all be changed to customise the characteristics of MREs [2, 5]. Mechanical characteristics that can be influenced by an external magnetic field include rigidity and damping [4, 6]. Their properties are determined by several factors, including the properties of the elastomeric matrix, the magnetic particle content and distribution, as well as the orientation and strength of the external magnetic field. The capability of MREs to quickly and irreversibly alter their dampening characteristics when in the presence of an external magnetic field is another crucial characteristic. Due to their ability to dissipate energy and lessen the effects of sudden impacts or vibrations, they are perfect for uses like shock absorbers.

1.2 Applications:

MREs have thus been widely used in a variety of industries, including vibration control, robotics, biomedicine, and aircraft [2,3,5,7,8]. Though their use cases obviously exceed just aircraft components. They are now utilized in the present day in complex parts and machines such as shock isolators, stiffness devices, vibration absorbers, etc. MRE’s have only begun their journey of being explored and developed in the past few decades and this is a stride to further the study of MRE’s, their properties and applications in the future. The rheology of suspensions of magnetic particles at low magnetic fields was originally described by Jolly et al. in the mid-1990s, which is when MREs first came into existence [9]. Since then, there has been a substantial advancement in the creation, evaluation, and use of MREs [1, 3, 7]. Due to their biocompatibility and adjustable features, there has been an increase in interest in creating MREs for biomedical applications in recent years. This field is still constantly developing and expanding, and new developments are frequently reported. Consequently, it is crucial to keep researching and studying MREs in order to learn more about its distinctive qualities and potential uses.

1.3 Challenges

Despite significant progress in the development of magnetorheological elastomers (MREs) and their potential applications, there are still some shortcomings that need to be addressed. One of the major challenges in the development of MREs is the limited understanding of the complex interactions between polymer matrix and the magnetic particles, which can result in unpredictable mechanical behaviour and reduced performance. Another challenge is the difficulty in controlling the magnetic particles distribution within the matrix, which can affect the response of the material to an external magnetic field. Additionally, the fabrication of MRE's with reproducible properties can be challenging due to the sensitivity of the material properties to processing conditions. Furthermore, MREs are susceptible to environmental factors such as temperature, humidity, and aging, which can affect their mechanical properties over time. These limitations highlight the need for further research to improve the understanding of the behaviour of MREs, optimize their fabrication processes, and develop more durable and reliable materials for practical applications.[10]

1.4 Preparation of samples:

The underlining focus is to further study and understand the limits of these properties. The preparations of the samples include the process where the samples were made with a liquidized silicon product with a resultant hardness of 715. It is fed with a curing agent with a ratio of 13 grams of silicon to 0.3 grams of curing agent. A mould was used to complete the structural hardening. Another set of samples was made with an iron-based additive. CIP, carbonyl-Iron particles of size 6μm were added to the sample prior to curing to embed magnetic properties hence magnetorheological elastomers. These samples will then be assembled along with 2 parts made from aluminium blocks, arranged to depict the vibrational transference that the elastomers can provide from one plate to another. This effect will be further tested by keeping the samples in an environmental chamber to further study the damping and vibrational properties after being influenced by humidity.

Studying the impact of ageing on these materials' damping qualities is the objective of the investigation into the effects of ageing on silicon-based MR elastomers. The investigation's specific goals are to ascertain how silicon-based MR elastomers' dynamic mechanical characteristics vary over time and evaluate how ageing affects these materials' performance in vibration control applications. To discover any alterations in the mechanical behaviour, the inquiry will comprise experimental testing of the damping characteristics of the MR elastomers at various ageing durations. Finding the results of its damping and vibrational properties may alter the way the scientific world approach shock and vibrations, a way to understand frequencies and possibly even control and harness the power to relocate, reimburse and recycle the energy for necessary purposes.

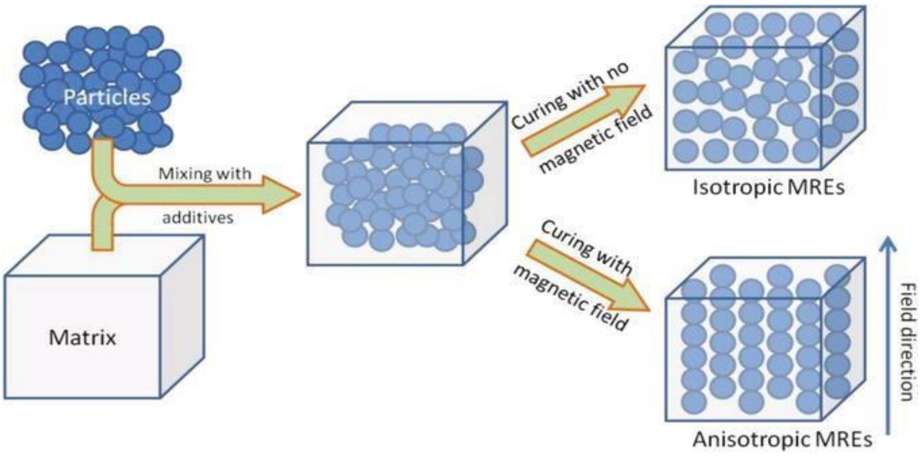

Figure 1. Production of MRE [26]

CHAPTER 2
BACKGROUND THEORY

MR elastomers have only had a few applications thus far in contrast to MR fluids. This is primarily due to the field-dependent modulus changes not being wide enough. This just means the current crop of MR elastomers lacks sufficient MR effects for further utilization as of now. Thus, material research is the top focus to significantly improve the applications of MR elastomers. Thankfully, several organisations have made an attempt to create high-efficiency MR elastomers.

By the studies conducted, silicone-rubber based MRE's have an MR effect as high as 878%. Also, they created and tested MR elastomers based on natural rubber, with a comparatively low MR effect of 133%. The findings imply that the elastomeric matrix is crucial in maximising the MR impact. The mechanism underlying the significantly improved MR impact, however, has not yet been disclosed. Researchers looked at the performance of MR elastomer-based vibration absorbers in shear, longitudinal, and squeeze, longitudinal, and shear modes.

According to findings, MR elastomer absorbers operating in the squeeze mode had the highest frequency shift, measuring to 507%. This study showed the value of using the right design configurations when creating high-performing MRE devices. In conclusion, MR elastomers are significant intelligent or functional materials with a wide range of application possibilities, which encourages further study in this field. These elastomers' unique anisotropic properties and controlled stiffness will be utilised in a variety of applications, and the past ten years of research into MREs will soon bear fruit.

2.1 Literature reviews:

In order to fully utilise MREs for damping applications, intensive research has been put into examining and understanding their aging with respect to damping qualities after they are exposed to change in humidity. This literature review seeks to offer a thorough summary of the research that has already been done on the exploration of the damping characteristics of MREs. This review intends to identify major trends, difficulties, and future directions in the field by synthesising the knowledge and insights obtained from numerous research initiatives. This will ultimately help to enhance MRE-based damping technologies.

Table 1: Literature review

Author	Keywords	Sample	Objective	Conclusion
J. M. Ginder,	Stress/strain Natural frequencies Damping factor	CIP embedded in cis-polyisoprene	The dynamic shear storage and loss moduli of disc-shaped MR elastomer specimens were measured as a function of the strain amplitude and frequency using a servo hydraulic testing system.	Induced magnetic fields have higher mechanical storage and loss moduli. Takeaway: Magnetic fields and their effect on Silicone properties
C. Ruddy, E. Ahearne	Smart material, MRE	Ferromagnetic particle in Silicone oil	Vibration tests for change in damping factor and the properties of its modulus when under a magnetic fields of varying compositional factors	Damping properties of MRE's increases by optimizing particle density and alignment Takeaway: Particle density and alignment change with aging.
J. David, **Mark R. Jolly**	MR fluids, MR foams, MR Elastomers	Raw sample of an elastomer with a high hardness index	Stress tests with and without a magnetic field and current involved	Stress tests and exposure to magnetic field showed an increase in property exhibition

Weihua Li **Xianzhou Zhang**	MRE, field-dependent modulus, rheological properties	Finely divided particles of iron, nickel, cobalt, iron-nickel alloys, iron-cobalt alloys, iron-silicon alloys	Investigation into the idea that the MREs fabricated with different particle sizes can provide larger field-dependent modulus	MR fluids, MR foams, and MR elastomers are all members of the MR material family. A distinctive property of MR elastomers is that an external magnetic field can be used to regulate their modulus.
T.L. Suna, **X.L. Gonga,**	cis-Polybutadiene rubber, magnetorheologica l elastomers, damping characteristics, and stress softening	Two types of spherical magnetic filler were used to fabricate MREs	Damping properties of magnetorheologica l elastomers based on cis-polybutadiene rubber	Damping qualities vary. The remaining strain energy drops as the amount of iron particles in the matrix increases, and for isotropic MREs at the same particle content, it is smaller than for structured MREs. The distinction is the result of how energy is lost.
Siti Aisha Abdul Aziz,	Thermal aging, matrix Hardness test Micrograph analysis Rheological properties	SR-MRE samples	Magnetorheological Elastomers Based on Silicone Rubber: Thermal Aging Rheological Behaviour	Change in rubber structure – voids The hardness decreased by up to 7% during thermal ageing. The storage modulus of SR-MRE grew with thermal ageing, showing better rheological properties. Under varied pressures, the Payne effect was seen in both SR-MRE samples. The breakdown of the matrix chain and the interaction between the matrix and the particles

				caused the storage modulus to drop with increasing magnetic field.
Bo Zhang, **Yongan Cao,**	Magnetorheological elastomers, viscoelasticity, loss factor, MR effect, coating material	Fe@C Fe CO ð Þ5 = Fe + 5CO	Dynamic mechanical properties of MRE	With superior mechanical performance, a high MR effect, and a low loss factor, Fe@C creates the necessary MRE. The use of a tank shock absorber requires a kind of clever material with a high MR effect and great damping performance.
Marke Kallio	Elastic characteristics, mechanical properties, viscoelastic qualities, iron-carbonyl compounds, stiffness damping properties, magnetic field strength, external load, and particle network structure are all terms used to describe magnetorheologica l elastomers.	Basic MRE	The magnetorheological elastomers' elasticity and damping capabilities	Both isotropic and aligned magnetorheologica l elastomers (MREs) can have their damping characteristics and dynamic stiffness altered by the application of an external magnetic field. Isotropic MREs exhibit linearly increasing dynamic stiffness with filler volume fraction when evaluated passively (without the magnetic field). If the filler volume fraction is greater than 15%, the stiffness and damping in isotropic MREs both rise when the magnetic field is applied. When the filler volume

				fraction is between 27 and 30 vol.%, in isotropic MREs, the stiffness and damping are tuneable with the magnetic field strength.
Siti Aishah Abdul Aziz,	phase shift angle, thermal ageing, loss factor, damping qualities, rheological properties, and magnetorheological elastomer	SR-MRE samples	Loss factor behaviour	With thermal age, the surface is rougher and has more voids and CIP clumps. The aged sample's magnetic saturation has nearly reached 100% due to the thermal influence of the ageing process.

2.2 Literature summary:

The research papers cited above present a comprehensive analysis of magnetorheological elastomers (MREs) and their applications. The papers cover a wide range of topics, including the synthesis and characterization of MREs, the design and optimization of MRE-based devices for vibration control and energy harvesting, and the challenges and limitations in the development of MREs. The papers utilize various experimental techniques and mathematical models to investigate the mechanical and magnetic properties of MREs, and to evaluate their performance in different applications.

The literature presented above all have certain characteristics in common in which they represent the efficiency of a magnetorheological elastomer in different forms of its measurable properties. With the aid of the conclusions drawn by this literature, the following properties were kept in mind to reflect the literary results:

1. Weight
2. CIP ratio
3. Shape
4. Silicone properties
5. Experimental setup
6. Design implementation

These parameters are set to their ideal state to achieve a response curve accustomed to the transmissibility ratio over the setup. The damping and vibrational values will be measured to study the efficiency and properties of the samples used.

CHAPTER 3
METHODOLOGY

3.1 Objectives:

The project's principal goals are as follows:

- Sample preparation with the use of silicone paste, curing agent and with or without CIP; measured to be identical for experimental accuracy.
- Investigate and derive experimental results toward understanding the damping ratio and natural frequencies when samples are subjected free vibration test.
- Investigate and deduce the effects of humidity on the results obtained previously.

3.2 Methodology:

The methodology adopted in this experiment consists of preparation of the samples and testing them. The preparation of sample includes the process of mixing curing agent along with the silicone for just the raw silicone samples; whereas for CIP samples, iron particles are added to the mixture. The free vibration test is conducted by setting the system into vibrations by just tapping on it and the readings are recorded with the help of accelerometer.

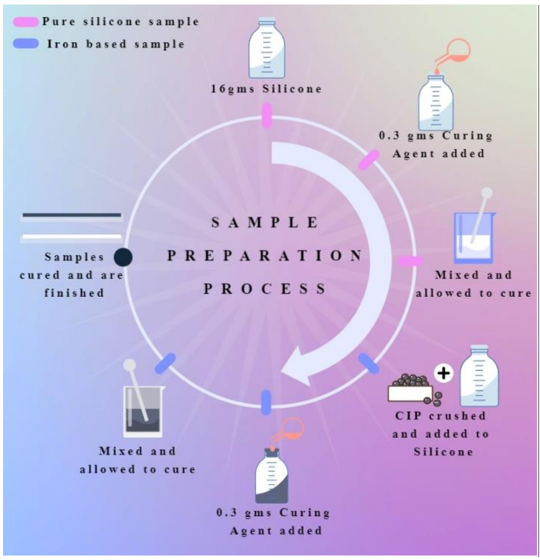

Figure 2. Sample preparation process

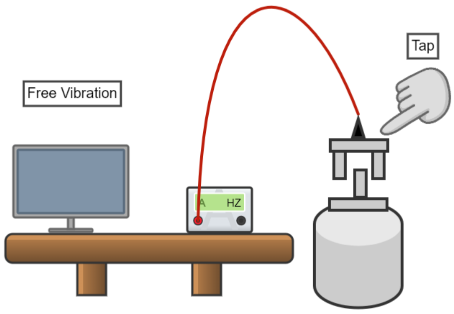

Figure 3. Pictorial representation of the experiment

3.2.1. Measuring the amount of Silicon and CIP needed:

i. Using digital Vernier Calliper, the measurements of the mould is estimated to be 5.1 x 10 x 180 mm.

ii. The requires weight needs to be taken for Silicone base is around 11 grams but considering 0.2 correction approximate weight taken is 13 grams

iii. The size of CIP is 6 μm and the weight is estimated to be 27 % by volume which makes it approximately 25 grams including the corrections.

3.2.2. Preparation of the sample:

i. For the base silicone sample, the moulds are first cleaned by using thinner

ii. 13 grams of silicone base is poured into the container which is then mixed with 0.3 grams of curing agent

iii. The mixture is stirred enough to have uniform composition

iv. Before it hardens, the mixture is transferred from the container to the mould

v. Desiccator is then used to eliminate all the air bubbles by creating vacuum

vi. The sample is then left to harden for 1-2 days

vii. For the base + CIP, along with silicon and curing agent, 25 grams of minute iron particles is mixed with the solution.

viii. Same procedure from (iv) till (vi).

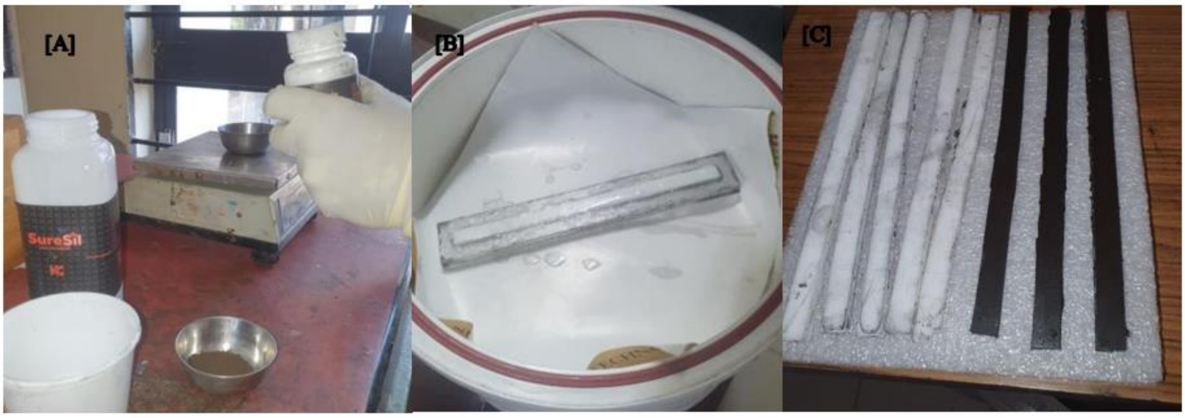

Figure 4. [A] Measuring setup, [B] Desiccator, [C] Raw silicone and CIP samples

3.2.3. Experiment setup:

i. An aluminium component is needed to anchor the silicone samples to the electrodynamic shaker in order to test how frequencies vary over time. This aluminium component has been designed by using AutoCAD.

ii. An aluminium sheet of 80x80x10 inches has been cut using abrasive water jet CNC machine which uses a high-pressure jet of water mixed with abrasive material to cut through hard materials with precision and versatility.

iii. After the parts (base plate, top plate, and three elevations) have been cut, a 1/8 drill bit is used to make drill holes so that the elevations can be attached to the plates.
iv. The elevation screw holes are then threaded using a tapping tool, with the first tap being for the lines and the next two being for the screws.
v. After that, the parts are put together to provide the clamping alternative for the MRE strips onto the electrodynamic shaker.

Figure 5. Aluminium components

3.2.4. Dynamic test:

i. After the samples are prepared, a free vibration test is conducted by mounting the component along with the sample on a sturdy base with a motion detecting sensor known as accelerometer
ii. By tapping the sample right next to the accelerometer, the readings for week 0 for both raw silicone and CIP samples are recorded with the help of LabVIEW application.

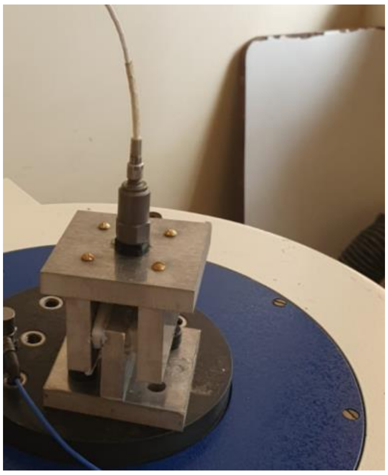

Figure 6. Experimental setup

3.2.5. Comparing properties after aging:

i. After placing the MRE strips in an environmental chamber for a specific period of time, the comparisons will be made for week 2 with respect to the strips not exposed to the humidity

ii. The change in properties will be noted which will help us understand the deviation in the characteristics.

3.3 Parameters of silicone base:

The supplier of the silicone and the curing agent used is a significant corporation of producers by the name of SureSil, who focuses on practical and industrial products and the supplier of CIP is Chengdu nuclear, China. The table below mentions the specifications of Silicone.

Table 2: Silicone specifications based on company data

Parameters	Values
Mixing ratio(by weight)	100:3
Appearance/ colour	White
Hardness (Shore A)	20±2
Mixed viscosity (mPa.s)	15000±500
Working time (mins)	30~40
Curing time (hours)	3~5
Tensile strength (MPa)	≥4.0
Tear strength (KN/m)	≥24.8
Shrinkage (%)	<0.2
Elongation at break (%)	≥500

3.4 Modelling:

With the help of designing software such as Catia and AutoCAD, the making of the sturdy aluminium component was possible. Abrasive water jet CNC machine was then used to cut the parts according to the modelling done in the software. The design of this aluminium component is such as to produce a double lap shear on the clamped silicone strips. This test is widely used to assess the adhesive bond strength between the two sample (silicone and CIP) strips.

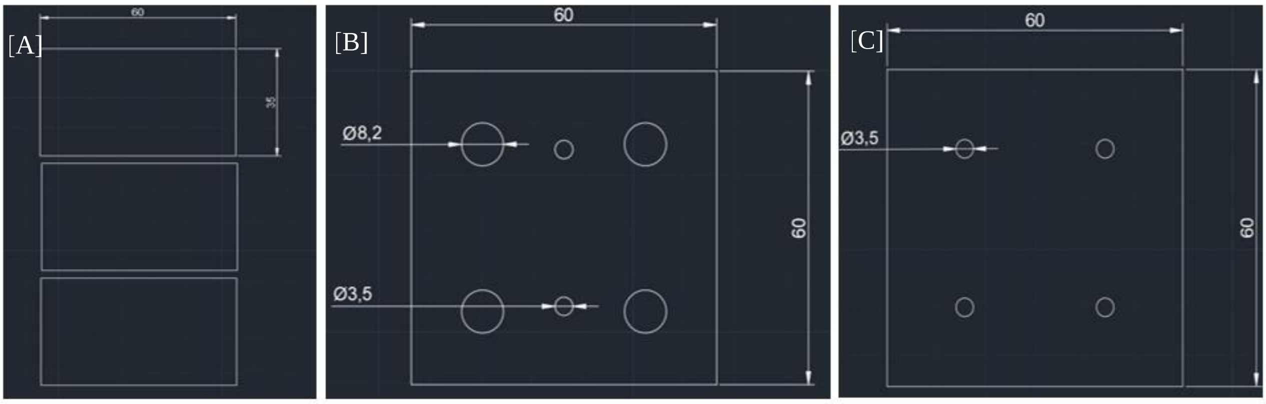

Figure 7. AutoCAD modelling of [A] elevations, [B] base, [C] top part of aluminium component

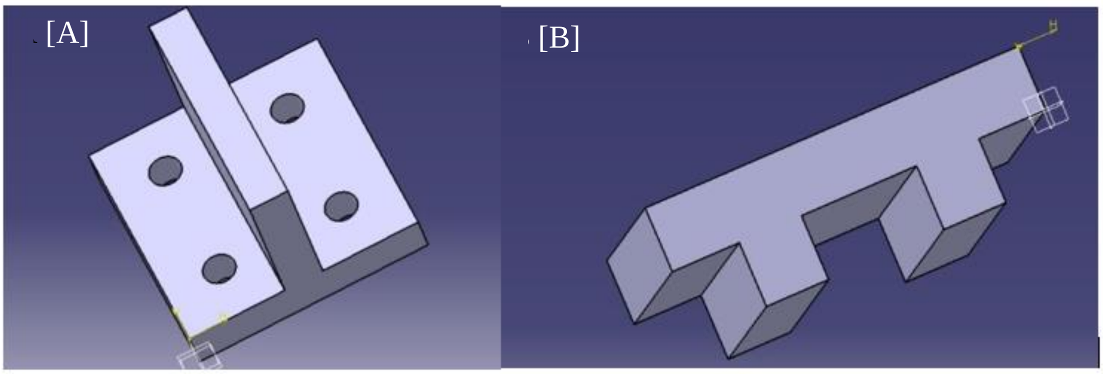

Figure 8. Catia modelling of [A] top, [B] base part of aluminium component

3.5 Properties of the prepared samples:

The samples have been prepared based on the calculations taking into consideration the mould dimensions, density of the base, weight of the silicone base and CIP

Table 3: Specifications of prepared samples

Sample No.	Composition	Silicone + 3grams	Curing-Agent (grams)	CIP (grams)
1	Silicone	13	0.3	0
2	Silicone	13.3	0.3	0
3	Silicone	13.5	0.3	0
4	Silicone	13.5	0.3	0
5	Silicone	13.5	0.3	0
6	Silicone + CIP	13.5	0.3	25.8
7	Silicone + CIP	13.5	0.3	25.9
8	Silicone + CIP	13.5	0.3	25.9

CHAPTER 4
RESULT ANALYSIS

Magnetorheological elastomers (MREs) are smart materials that respond to an external magnetic field by changing their mechanical properties. MREs can be influenced by changes in the environment, including humidity, even though magnetic fields are the main factor in their sensitivity. The MREs may experience specific alterations when exposed to humidity fluctuations in an environmental chamber, which can be described as follows:

1) Swelling/Shrinking: MREs' dimensions might alter as a result of swelling or shrinking because they can take in or release moisture from the air. MREs normally expand when the relative humidity rises, while MREs may contract when the relative humidity falls. The precise content and formulation of the MRE determine the degree of swelling or shrinking.
2) Mechanical properties: MREs' mechanical behaviour can be affected by humidity. The absorption of moisture can change the material's stiffness, modulus, and damping characteristics. Higher relative humidity tends to soften MREs, making them more flexible, but lower relative humidity might stiffen the substance. These alterations to mechanical characteristics may have an impact on how MREs react to magnetic fields.
3) Stability and durability: MREs may experience long-term consequences if exposed to high humidity levels for an extended length of time. Over time, the material may become less mechanically and magnetically effective due to moisture absorption. When exposed to various humidity levels, it is critical to take into account the long-term stability and durability of MREs.

Experimentation and characterisation are required to completely comprehend the precise changes that take place in a certain MRE formulation during humidity variations. MREs' behaviour can change depending on the material they contain, processing methods, and environmental factors. Therefore, it is crucial to carry out controlled studies in environmental chambers to assess how MREs react to humidity and how that affects their mechanical and magnetic properties.

4.1 Free vibration test:

Free vibration tests are conducted to analyse the damping characteristics and natural frequency of a system when it is allowed to vibrate at its own free will with any external excitation. These tests help researchers comprehend the dynamic behaviour and structural integrity of the system. The test was conducted to understand the change in damping ratio and natural frequency of the samples by putting the system into vibration mode by tapping it. The vibrations are then recorded with the help accelerometer of sensitivity 9.91 mV/g and the necessary data has been derived.

4.2 LabVIEW software:

LabVIEW 2016 is a graphical programming environment created by National Instruments, which is now part of Keysight Technologies. It enables users to design applications for data acquisition, instrument control, and industrial automation. The manufacturing, engineering, and research sectors all use it extensively. Connecting to and processing data from sensors, such as accelerometers, is one of LabVIEW's many applications. For processing and interpreting accelerometer data in real-time or for future analysis, LabVIEW provides a number of tools for signal analysis, filtering, visualisation, and data logging.

4.3 Results:

The damping ratio and natural frequency are two essential factors that define the behaviour of the system in the context of vibrations and systems containing mass and springs.

1) Damping ratio: The damping ratio, frequently represented by the symbol ζ (zeta), indicates how much an oscillatory motion is suppressed or resisted by a system as shown in eq1.

$$\zeta = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} \quad \text{... (1)}$$

where, ζ: Damping ratio
δ: Logarithmic decrement

2) Natural frequency: A system's natural frequency, which is sometimes represented by ω (omega), is a metric of how quickly it vibrates or oscillates when no outside forces are present as shown in eq2.

$$\omega = \sqrt{\frac{k}{m}} \quad \text{... (2)}$$

where, ω: Natural frequency (in radians per second)
k: Stiffness of the system
m: Mass of the system

4.4 Sample readings:

Following are the sample readings noted from the LabVIEW 2016 software.

WEEK 0

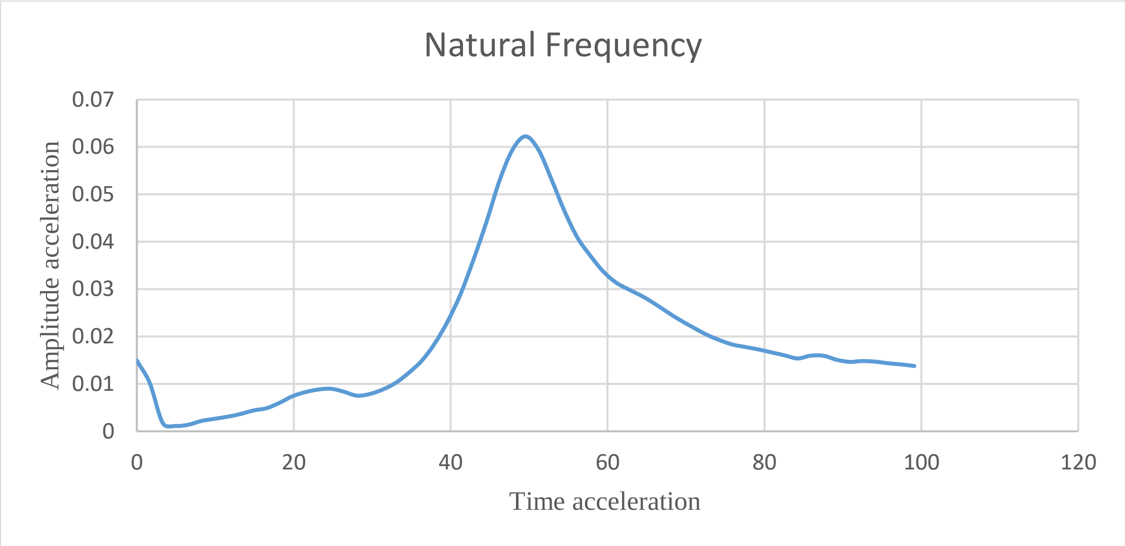

Figure 9. Natural frequency of raw silicone

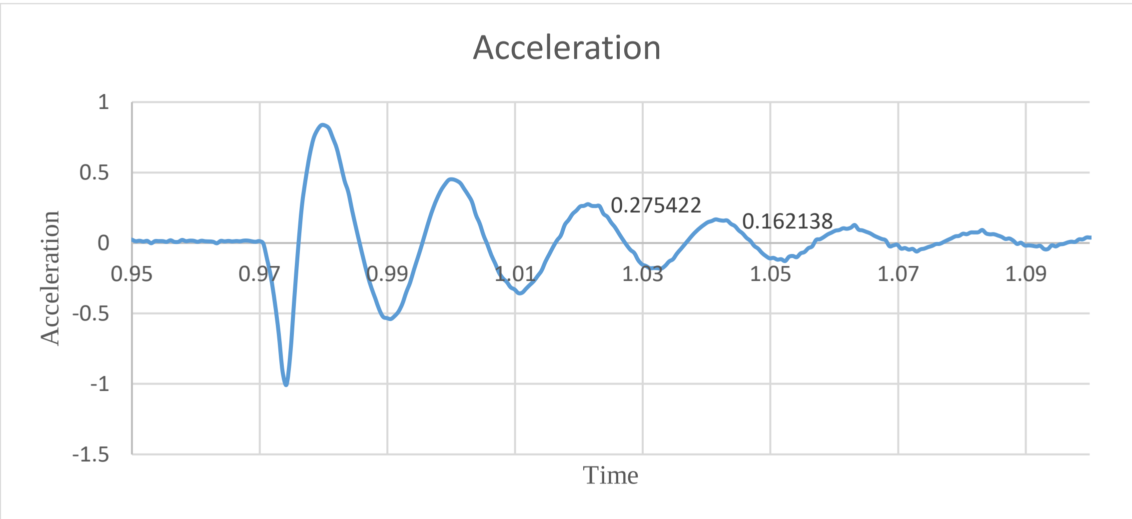

Figure 10. Damping ratio of raw silicone

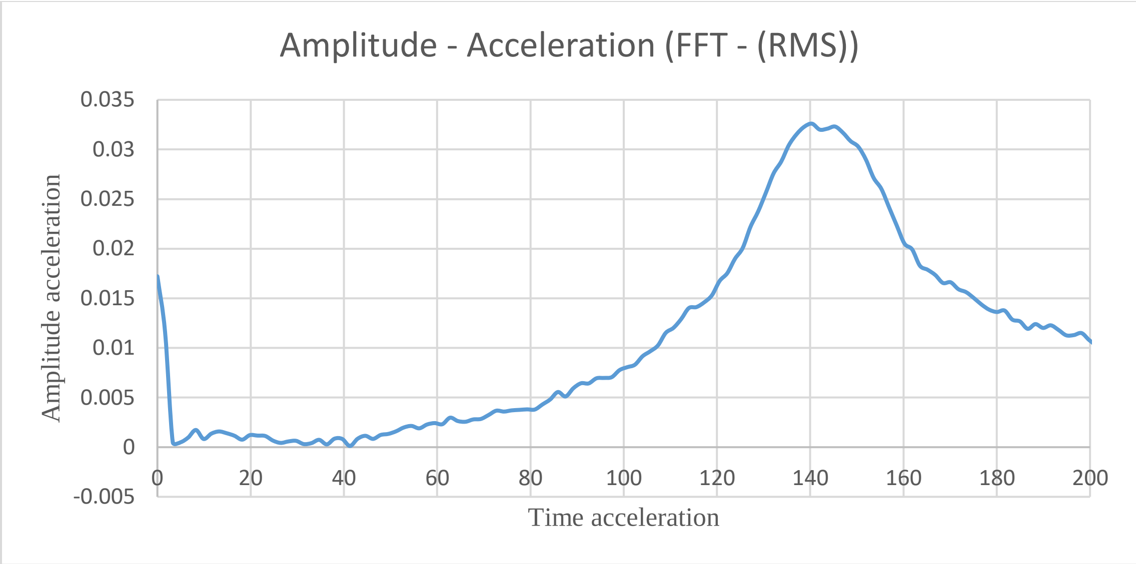

Figure 11. Natural frequency of CIP

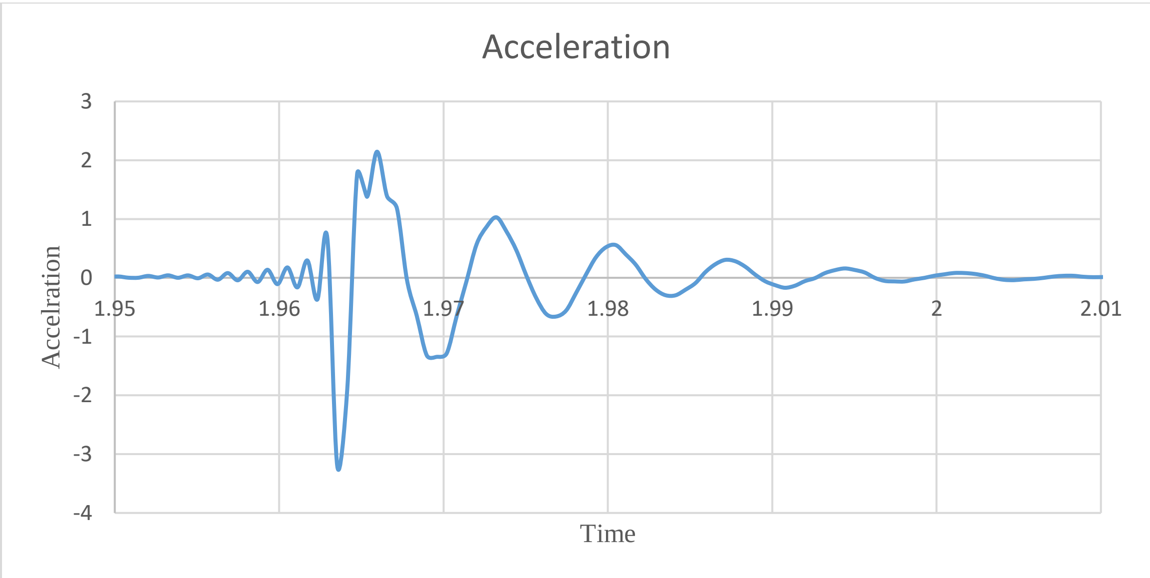

Figure 12. Damping ratio of CIP

WEEK 2

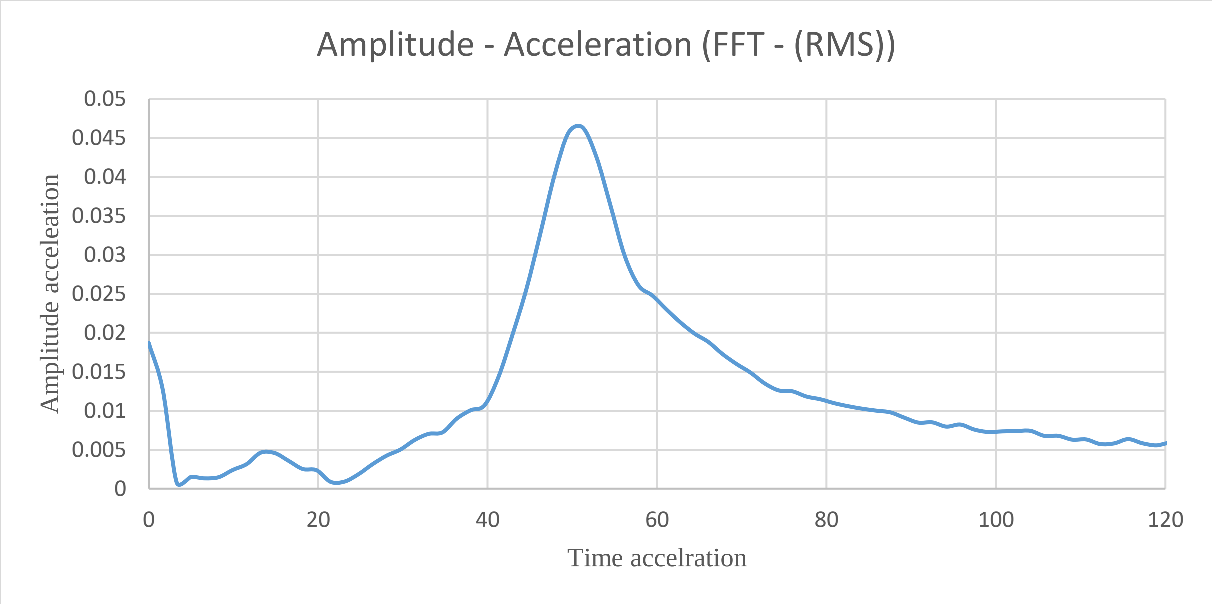

Figure 13. Natural frequency of <u>raw silicone</u>

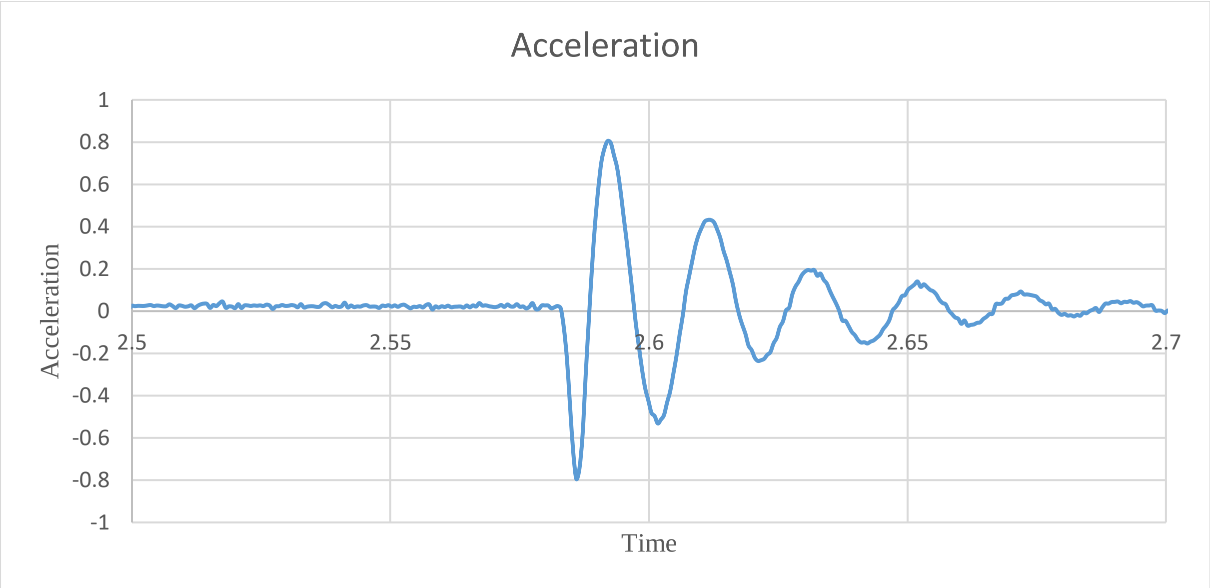

Figure 14. Damping ratio of <u>raw silicone</u>

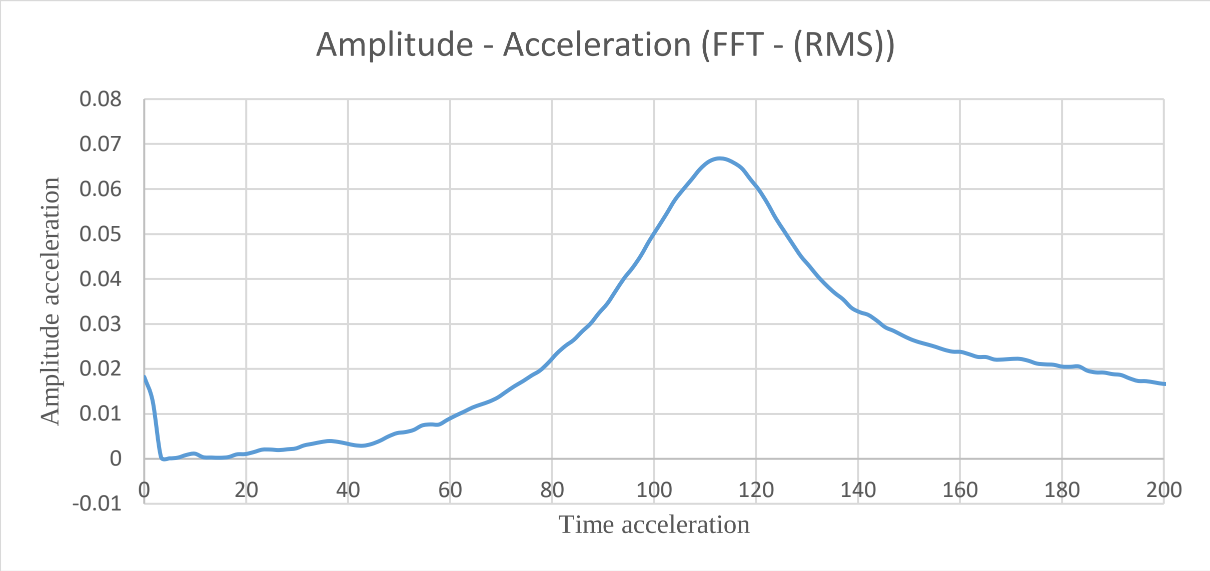

Figure 15. Natural frequency of CIP

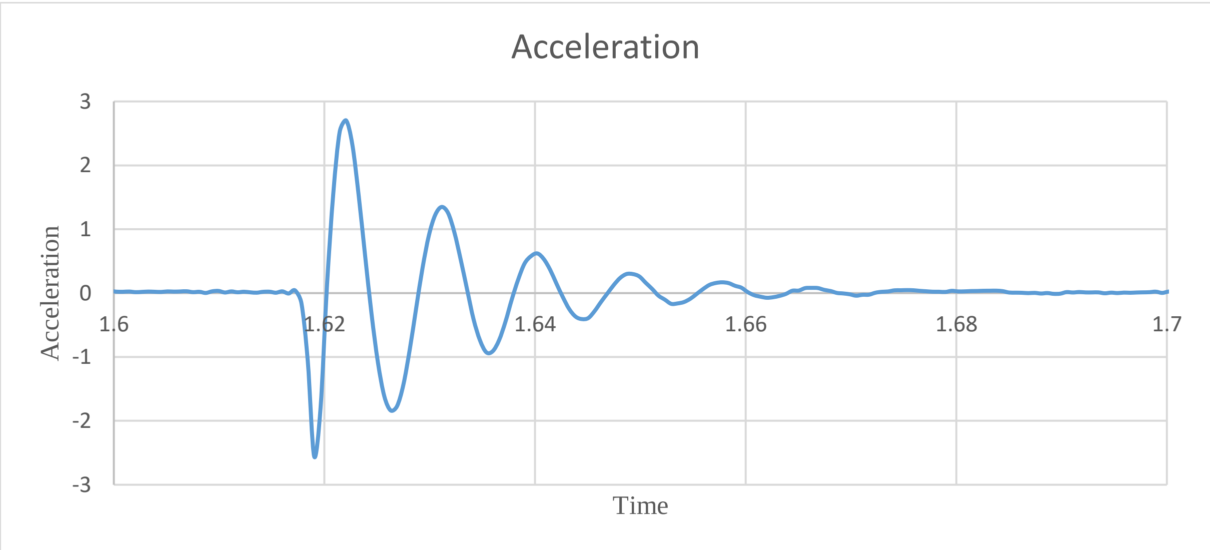

Figure 16. Damping ratio of CIP

With the help of trial and error method, these two factors are deduced by considering the ‘n’ peaks from the graph and calculating the logarithmic decrement of the vibration pattern for both week 0 and week 2. The results obtained are as follows:

Table 4. Results obtained

	Specimen	$\delta = \ln(x_1/x_2)$	δ_{avg}	ζ	ω (rad/s)
week 0	Silicone	0.609			
		0.507	0.545	0.086	50
		0.519			
	Silicone+ CIP	0.737			
		0.587	0.643	0.102	140
		0.604			

	Specimen	$\delta = \ln(x_1/x_2)$	δ_{avg}	ζ	ω (rad/s)
week 2	Silicone	0.632			
		0.693	0.655	0.104	51.2
		0.642			
	Silicone+ CIP	0.693			
		0.778	0.742	0.117	112.3
		0.756			

4.5 Comparison:

The average peak value has sustained itself to being consistent, allowing for more accurate sets of readings. The raw silicone and CIP induced silicone have been aged from week 0 to week 2 where it is seen the initial stages of the samples exhibit a lower overall ratio for damping as natural frequency shows a decrease in value overall.

The damping ratio has increased based on 2 weeks of aging signifying that the exposure to an environmental chamber affecting the humidity, is allowing the sample absorb the moisture and water content to decrease stiffness, hence there is a reduction in natural frequency.

The overall δ_{avg} value has seen an increase as well, this can be the result of the mass gained by aging and so the logarithmic decrement method for each peak shows a substantial increase in values within 2 weeks of aging.

A very discreet comparison can be seen as the cycles of vibration diminish much faster as damping increases, this can be a direct result of the increased bodily resistance gained by the sample through amassed water content.

The disturbances seen in a few graphs represent the minor human errors which can in turn authenticate the peaks as it highlights the point of contact for each reading, this would mean consistency is maintained at ideal conditions.

CIP samples would play a larger role in affecting the properties of flexibility, resistance and elasticity as when exposed to magnetic fields, the sample would have external force playing a part in repelling and diminishing shocks and vibrations, making it a great method for future scope in mechanical and automotive sectors.

The results overall show an increase in vibrational reduction, resonance suppression, shock absorption and could potentially be a choice for noise reduction as well.

It's crucial to keep in mind that the ideal damping ratio value relies on the particular application and specifications. To attain the intended performance, different materials and systems may have varying optimum damping qualities.

CHAPTER 5
CONCLUSION

5.1 Conclusion:

Magneto-Rheological elastomers make great materials for shock absorbing and resistance as they seem to exhibit a great deal of elasticity and flexibility. The results have shown that exposure to a humid environment allows for the sample to increase its damping ratio and decrease its natural frequency, causing a reduction in stiffness as CIP makes a considerable effect on the aging characteristics. Aging may have an upper hand in elevating materialistic properties when prolonged for longer periods of time.

The higher the damping ratio, the more effectively the shocks will dissipate energy and reduce vibrations. Reducing vibrations may be one the biggest methods of improving mechanical efficiency. Machinery tends to break due to these excess shocks and vibrations which cause a large amount of capital to be poured, increasing costs and profit margins. The efficiency of the machine reduces as its longevity and functionality would not be measurable.

A lower damping ratio general indicates a lower decay rate and so underdamped systems may oscillate for undesirable lengths of time. The higher the damping ratio, faster the decay rate and so the material essentially resets faster inflicting less of a damage on itself.

A higher damping coefficient will diminish the response by unwanted vibrations or shock. This would depend on the overall operating frequency of the machine as well.

5.2 Future scope:

This brings about future scope of being able to implement growth in prosthetics, vibration absorbers, isolators, magneto-resistors and electromagnetic wave absorption. Many of the fabrication processes have resulted in more of a sustainable method of handling vibrations which have been successful in many leading industries like automotive industry, space industries, bio-medical sectors and mostly scientific research in relation to vibrational transmissibility.

CIP would play a big role in the future as magnetic fields would be a force harnessed to be used against any irregularities including unwanted vibrations or shock. The mechanical and automotive sectors already use such technology to improve their machinery in terms of efficiency and output, harnessing lost energy would be a sense of direction a lot of industries aim towards for, as resource management and efficiency are never ending quests in the eyes of research.

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<tr><td>Project duration</td><td>4 Months</td><td>Date of final presentation</td><td>30/05/23</td></tr>
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Annexures

The table below represents the trial and error method used for each reading of raw silicone and CIP for both week 0 and week 2

		Specimen	Peak value	x_1/x_2	$\delta=\ln(x_1/x_2)$	δ_{avg}	ζ	ω (rad/s)
Week 0	Trial 1	Raw silicone	0.819	1.85	0.615	0.487	0.077	142
			0.441	2.03	0.708			
			0.217	1.15	0.139			
			0.188					
		CIP	5.14	2.59	0.951	0.718	0.113	139
			1.98	1.72	0.542			
			1.15	1.94	0.662			
			0.59					
	Trial 2	Raw silicone	0.82	1.84	0.609	0.545	0.086	50
			0.45	1.66	0.507			
			0.27	1.68	0.519			
			0.16					
		CIP	2.14	2.09	0.737	0.643	0.102	140
			1.02	1.8	0.587			
			0.55	1.83	0.604			
			0.3					

		Specimen	Peak value	x_1/x_2	$\delta=\ln(x_1/x_2)$	δ_{avg}	ζ	ω (rad/s)
Week 2	Trial 1	Raw silicone	0.79	1.88	0.632	0.655	0.104	51.2
			0.42	2	0.693			
			0.21	1.9	0.642			
			0.11					
		CIP	3.48	2.03	0.708	0.763	0.121	112
			1.71	2.375	0.865			
			0.72	2.05	0.717			
			0.35					
	Trial 2	Raw silicone	0.95	1.82	0.599	0.552	0.0875	51.2
			0.52	1.86	0.62			
			0.28	1.55	0.438			
			0.18					
		CIP	2.7	2	0.693	0.742	0.117	112.3
			1.35	2.177	0.778			
			0.62	2.13	0.756			
			0.29					

For the result analysis, the following trials are considered. The reason behind this consideration is that the x1/x2 showed similar trend

Week 0	Raw	Trial 2
	CIP	Trial 2
Week 2	Raw	Trial 1
	CIP	Trial 2

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