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Perspective

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Magnetorheological brushes are a relatively unknown type of Magnetic Material

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Abstract

In the presence of a magnetic field, the viscosity and storage modulus of magnetic materials like magnetorheological (MR) fluids and magnetorheological elastomers change significantly. There are numerous studies on these MR fluid and elastomer materials. In contrast, the MR brush is less frequently investigated and comprehended. The brush-like structures made from chains of magnetic particles embedded in a carrier matrix, typically fluids or elastomers, are what make up an MR brush. The magneto-mechanical properties of the magnetorheological fluid (MRF) brush and the magnetorheological elastomer (MRE) brush are the focus of this investigation. The investigation measured the stiffness and the MR response, which is the change in MRF and MRE brushes' properties when subjected to a magnetic field. The concentration of magnetic particles and the curing flux density (for MRE brush) were examined to learn more about how the magnetic effect is influenced by the material and preparation parameters. In this study, a proposed metric for comparing the brushes' responsiveness is the Magnetorheological response index. The MRE brush has a higher absolute stiffness but a lower MR response than the MRF brush, according to the findings. When there are more magnetic fillers in MRF and MRE brushes, the MR response gets stronger. MRE brushes have a better MR response than MRF brushes, which could be related to an increase in the magnetic flux density during the curing process. This study opens up a new avenue in the field of magnetic materials thanks to its fundamental investigation of both solid and fluid MR brushes. When soft and tuneable bristle-like structures are desired, this new category of magnetically controllable materials might be used.

Keywords: Magnetorheological brush; Magnetorheological fluid; Magnetorheological elastomer; Magnetic field; Magnetoactive materials

Introduction

Magnetic micro- and nano-sized particles distributed in a carrier medium make up the structural components of magnetic materials. Based on the physical state of the carrier medium in the absence of a magnetic field, they are broadly divided into fluids and solids (such as elastomers).

Magnetoactive materials have received a lot of attention from a variety of fields in recent years, resulting in significant advancements in the development of materials, particularly composites. To improve the performance of magnetoactive composites, various matrices, magnetic fillers, and fabrication methods, such as traditional molding, digital processes, and 3D printing, are being investigated. Because of their advantages, such as remote contactless actuation, high actuation strain and strain rate, self-sensing, and instantaneous response, these multifunctional materials have the potential to be used in a wide range of fields, including but not limited to biomedical engineering, civil engineering, robotics, and biomedical engineering. However, in order to fully utilize the various functionalities provided by these materials, a comprehensive comprehension of the magneto-mechanical response remains necessary despite increased adoption.

Materials with a fluid carrier medium, such as mineral oil or hydrocarbon oil, are referred to as MR fluids (MRF). Particle-reinforced composites called MR elastomers (MRE) are composed of a carrier medium and a solid elastomer like natural rubber, silicone, or another polymer. Due to their ability to revert from a liquid to a semi-solid state in response to an external magnetic field, MRF are adaptable. Due to the magneto-induced interaction and alignment of the magnetic particles, this change is achieved through a change in viscosity of several orders of magnitude [1]. MRF are used in shock absorbers, clutches, seismic protection devices, and braking systems for high-performance automobiles due to the significant and reversible transitions they undergo.

However, the gradual sedimentation of the magnetic particles that are suspended in the carrier medium is a major issue with MRF. In MRF, the attractive particles are allowed to move around in the transporter liquid without any an attractive field. The greater gravitational pull in this state causes the particles to separate. The oxidation-caused corrosion of the magnetic particles and the MRF's gradual thickening are two additional issues. The MRF's responsiveness deteriorates as a result of these issues, which result in material instability. As a result, MRFs are not very long-lasting and need to be replaced frequently.

MR elastomers (MRE) can reversibly change their properties, for example, versatile moduli and shape at miniature/milli-scales and are the strong simple to MRF. MRE are made out of elastomers with attractive particles inserted inside the elastomer network. As a result, MRE function as magnetic field-responsive elastomers. The distribution and orientation of the magnetic particles within the matrix, which can be ordered or random, further affects the MRE's properties. MRE is used in actuators, force sensors, and vibration absorbers. On the off chance that an attractive field is applied during the restoring system, particles specially adjust to the attractive transition bearing and the subsequent material becomes anisotropic. Isotropic properties of the

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material typically result from curing in the absence of a magnetic field. Because the magnetic particles are restricted by the cross-links of the polymer matrix, MRE do not exhibit the issues that are associated with MRF, such as sedimentation and corrosion.

The magnetic particles align and form chain-like structures in the direction of the applied magnetic field when a magnetic field is applied to an MRF. The particle chains resemble the bristles of a brush in this structure. A magnetorheological (MR) brush is the name given to this kind of brush. The MR brush's free-standing bristles, in contrast to MRF's enclosed volume and MRE's fully solid structure, are its primary distinguishing feature. In soft robotics, as well as in magneto-abrasive finishing, which is able to achieve nanometer surface finishes with minimal surface damage, the fine structures of magnetorheological brushes have been utilized. MRFs on their own are susceptible to instability, despite their advantages, and incorporating corrosion remains challenging. Due to MRE's superior stability and durability, it is worthwhile to investigate the development of MRE brushes as a promising alternative to MRF brushes. MR brushes, on the other hand, have only been the subject of a small number of studies, so this subject remains largely unexplored. A comparison between solid and fluid MR brushes has never been attempted, despite the fact that MRE brushes may provide better stability than MRF brushes. In addition, the thickness, shape, and height of the bristles in relation to the filler loading and applied magnetic flux density have not yet been reported, which may have an impact on the operation of MR brushes as well as their performance [2]. To fully utilize the MR brush's potential, such fundamental research is required. The MR response, which is a measure of the change in effective stiffness caused by the applied magnetic field, and effective stiffness are the most common characteristics of MR brushes.

Soft robotics is a rapidly growing field with numerous potential applications, including interactions between humans and robots and biomedical devices. Due to their two-way actuation, quick responsiveness, and flexibility of the matrix material, magnetic field responsive materials are a particularly promising class for the development of flexible humanoid robots. New features like tuneable stiffness or shape-morphing capabilities are made possible by these magnetic field responsive materials, which can be programmed to respond to external magnetic fields. In addition, Additive Manufacturing (AM), also known as 3D printing, is a layer-by-layer manufacturing process that enables designers to embed multifunctionality into their parts that is impossible with conventional manufacturing methods. Unlike conventional forming methods, AM does not require the use of a magnetic field to fabricate the intricate structures of MR brushes. By carefully and slowly converting MR fluid to MR elastomer during the process, a recently reported computationally guided direct ink writing AM technique has the potential to produce highly controlled MR structures [3].

The goal of this study is to add to the growing body of knowledge about magnetoactive materials known as MR brushes. It focuses on comprehending their magnetomechanical properties and the parameters of the material and preparation that affect them. Samples of MRF and MRE brushes were made for the experimental study, and their MR performance was looked into and compared. Using compression testing with samples exposed to an external magnetic field, the magnetorheological response of MR brushes has been investigated. The concentration of magnetic particle loading, compression rate, and magnetic flux density were examined in relation to the MR response [4].

Materials and Methodology

As received, carbonyl iron particles (44890, Sigma-Aldrich, Singapore), silicone oil (AP1000, Sigma-Aldrich, Singapore), and elastomer (SS-6B, Silicone Solutions, USA) were utilized. According to the supplier, the elastomer has a durometer of 30 Shore A, a tensile strength of 1.37 MPa, and an elongation at break of 250% after curing, while the silicone oil has a viscosity of 800-1200 mPas at 25°C.

Carbonyl iron powders (CIP) (5-9 m spherical particles, depending on the supplier) were used to prepare the MRF brush samples in concentrations ranging from 50 wt. percent to 80 wt. percent. In order to produce a homogeneous suspension, silicone oil and CIP were mechanically mixed thoroughly before being agitated by sonication in a water bath for thirty minutes [5]. An additional curing step was added to the preparation of the MRE brush samples, which were prepared at the same concentrations as the MRF brush. The composite resin was poured into a mold, where a magnetic field can be used to create columnar chains of magnetic particles that give the structure its bristle-like shape [6]. The example stayed undisturbed at 25°C for 24 hours for the elastomer to fix totally, according to the provider's detail. In addition, this casting procedure was repeated using four distinct concentrations of CIP at three distinct magnetic flux densities.

As depicted a straightforward experimental apparatus was designed and constructed. During the compression tests on both the MRF and MRE samples as well as the curing phase casting of MRE samples, the apparatus provides a controlled and programmable range of magnetic flux densities. The magnetic field was created with a 25 mm x 25 mm x 25 mm solid cubic NdFeB permanent magnet. The gap between the permanent magnet and the spacer was changed to maintain the desired magnetic flux density for the apparatus. Three equally spaced points on the top surface of the magnetic field generator, exactly above the permanent magnet, were used to measure the reported magnetic flux values [7].

Results and Discussion

Magnetorheological fluid brushes

The response of MRF brushes to various configurations with varying compression rates and magnetic fields is shown. The force-displacement response is observed to be primarily influenced by the concentration of CIP and the magnitude of the magnetic field. The effect of strain rate on samples across 50 weight percent and 80 wt. %, indicates that the applied strain rate seems to have no effect on the MRF brushes.

The results of compression testing shed light on how bristle structures are formed at various magnetic flux densities. The maximum displacement that occurs during compression, as depicted in, occurs when the upper compression plate reaches the lower point (1.1 mm above the bottom platform), indicating the bristle height. For the higher concentration of CIP, the MR bristle height variation was more pronounced. At low magnetic flux, the longer, weaker bristles formed, whereas the shorter, more rigid bristles formed at a higher magnetic flux density.

The change in properties of magnetorheological (MR) materials in the presence of a magnetic field is referred to as the magnetorheological (MR) response. The stiffness of MRF brushes can be used to determine a method for assessing their MR response. Materials with a non-linear stress/strain response, such as MR materials, are typically characterized by the tangent modulus. The material's instantaneous stiffness is represented by the tangent modulus, which is calculated by taking the slope of the stress-strain curve at the given strain. Because the brush structures' geometry is difficult to define, the analysis concentrates on stiffness rather than modulus. The maximum stiffness value is chosen for analysis and a method that is comparable to obtaining tangent modulus across the entire force-displacement response is used to determine stiffness.

The compression force and displacement of MR brushes are plotted in the graphs that have been provided. At high field, the effects of compression rate on samples with 50 percent and 80 percent CIP concentration, respectively, the impact of filler focus on examples within the sight of Low and High field. Peak force and maximum displacement, also known as bristle height, can be observed. It is evident that the response is unaffected by strain rate at a constant CIP concentration. However, as can be seen in bi, the CIP concentrations used have a significant impact on the curve's trend, which is distinct and distinct. Peak load is increased at higher concentrations of CIPs, resulting in longer bristles. The magnetic fields and MRF brushes' reported absolute stiffness are depicted. For all of the samples, the compression rates had little effect on the stiffness. As a result, the 60 mm/min compression rate was selected for the remainder of this investigation's comparisons and discussions. Instead, the magnetic field and CIP concentration have a more significant impact.

As a result, the MR response of MRF brushes is highly influenced by the concentration of magnetic particles. The dependence of the slope with respect to the concentration of CIP demonstrates that the CIP concentration has a significant impact on the stiffness of the brushes [8].

Magnetorheological elastomer

Brushes In order to contrast the results with those of MRF, four concentrations of MRE brushes were made. Nonetheless, the higher centralizations of MRE brushes with 70 wt.% and 80 wt.% were viewed as inadmissible because of the fragility of the columnar chains. As can be seen, this led to the specimens' fracture. As a result, MRE brushes with a high CIP concentration would not work well, but MRE brushes with a higher loading of magnetic fillers can be made to use a more flexible elastomeric matrix with a greater elongation to failure [9]. On the other hand, this pattern was not observed at lower concentrations of 50% and 60% CIP, and the brush structure remained unaltered throughout the test. In addition, the results and discussion will only take into account the MRE brushes containing 50% and 60% weight.

Using an optical microscope, the effect of the flux density on the curing of the MRE brushes is shown. Within each of the three magnetic flux densities used for curing, the bristle structures clearly differ. Fine columnar bristles are present in samples that have been cured at a higher flux density. The regular column shapes and uniform distribution of the individual bristles make them stand out more. Fine bristles form similarly at the sample's edges, as seen in the microscopy images [10].

The competition between gravitational, viscous, and magnetic forces, in addition to surface tension, influences the magnetic flux density, which in turn influences the formation of the bristles. It is anticipated that the magnetic force will prevail over all interacting forces at high flux densities, causing the magnetic particles to preferentially align, resulting in bristles of uniform and regular shape. In any case, such a fascinating peculiarity must be perceived by means of in-situ examination and mathematical displaying which isn't inside the extent of this work [11].

Discussion

In order to investigate the formation of their structures and the magnetorheological response under compressive loading when exposed to an external magnetic field, magnetorheological fluid and solid elastomer brushes were constructed. The elastomeric equivalents of magnetorheological fluid and elastomer brushes were cured under three different magnetic flux densities with CIP concentrations ranging from 50 to 80 weight percent [12]. The bristles of MRE brushes made with 70 and 80 weight percent CIP were found to be structurally weak and susceptible to damage during compression testing, with the bristles breaking. As a result, experiments focused on 50 and 60 weight percent brush configurations. A metric known as the MR response index was proposed to compare the magnetorheological response of MRF and MRE brushes in relation to their stiffness. Key findings from the investigation can be summarized as follows:

The MR response index of MRE brush could be higher than that of MRF brush when cured at high magnetic flux density, but this was only observed for the 50 wt. percent of the brush. The MR response index decreased with an increased curing flux density for 60 wt. percent of the MRE brush associated with the off-state (absence of a magnetic field) stiffness of the MRE brush Based on this investigation, MRE brushes with a low concentration of CIP provide an attractive alternative to MRF [13]. When making MRE, you can control and fine-tune the curing field strengths to get the best MR response and, more importantly, control how the brush structure is made, including the length, thickness, and density of the bristle clusters. Additionally, structural applications benefit more from MRE's higher initial modulus preference.

It is difficult to make a direct comparison between fluid and solid brushes. As a result, low stiffness-compliant materials for MRE brushes should be considered in future research to expand our understanding. Still, this study's method of getting the MR response index provides a useful metric for comparing the properties of fluid and solid brushes [14].

Conclusions

According to the findings of this study, the best MR material response may not always require the highest concentration of filler materials. Instead, controlled and improved functionality may be achieved by paying close attention to the parameters of the process and the form of the materials themselves. Additionally, soft robotics-specific functionally graded material systems could be created by combining fluid and elastomeric materials. Using additive manufacturing (AM) processes, functionally graded structures of this kind can be made with greater design flexibility. In addition, computational modeling can be helpful in the design and optimization of magnetic brushes during fabrication and in further comprehending the behavior of MR bristles.

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Conflict of Interest

None

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