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Experimental dynamic analysis of composite sandwich beams with magnetorheological honeycomb core

Felipe de Souza Eloy[a,*], Guilherme Ferreira Gomes[a], Antonio Carlos Ancelotti Jr.[a], Sebastião Simões da Cunha Jr.[a], Antonio José Faria Bombard[b], Diego Morais Junqueira[a]

[a] *Mechanical Engineering Institute, Composite Technology Center – NTC, Federal University of Itajuba (UNIFEI), Av. BPS, 1303, 37500-903 Itajuba, Brazil*
[b] *Physics and Chemistry Institute, Federal University of Itajuba (UNIFEI), Av. BPS, 1303, 37500-903 Itajuba, Brazil*

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ABSTRACT

This study deals with the manufacturing and testing of sandwich beams with carbon/epoxy composite skins and a honeycomb core filled with magnetorheological elastomer (MRE) in different proportions of magneto/elastomer (w/w%). Free and forced vibration tests conducted under several magnetic field intensities were performed to evaluate dynamic properties of the sandwich beams. The experimental results favorable reduction of mechanical vibrations, especially on the fundamental mode of the structure in question. We can see that MRE sandwich beam shifted the natural frequencies and amplitude of vibration due to the increase of an induced magnetic field.

1. Introduction

Mechanical vibrations are present in the most diverse types of processes and applications. While it is beneficial in many cases, it is of the utmost importance to have control to prevent or predict structural failure.

It is known that the dynamic behaviors of flexible structures are critical to the effective operation of many applications such as automobiles, aircrafts and space platforms. With appropriate control, undesirable resonance can be reduced or eliminated avoiding structural failures. Passive damping treatments have been successfully applied to various structures to attenuate their vibration response and eliminate vibration-induced noise [29].

With the technological development of materials and processes in recent years, a new class of materials was introduced, the so-called "smart materials". These materials have the ability to adapt in the best possible way to engineering design requests, most of times through intelligent sensors, coupled or integrated. Those materials have the ability to change one or more of their material properties under the influence of an external stimulus.

Magnetorheological Elastomers (MREs) belong to a class of materials known as Smart Materials [28]. These materials show variations in their rheological properties when subjected to varying magnetic fields. They have a quick time response, in the order of milliseconds, and thus are potentially applicable to structures and devices when a tunable system response is required. When incorporated into an adaptive structural system, they have the advantage of yielding higher variations in the dynamic response of the structure [29].

Equally important, Li et al. [18] in their work indicated that researchers continue to develop new MREs with new materials to meet new requirements. There were many application prospects, which provided an impetus for continued research in this area. Numerous applications, such as brakes, dampers, clutches and shock absorbers systems [13,23]. Which make use of controllable stiffness and the unique anisotropic characteristics of these elastomers, will be developed and the research efforts of the past decade in MREs will pay off in the near future.

In addition, MREs are considered a new group of damping materials, which consist of a non-magnetic matrix containing a suspension of magnetically permeable particles. Damping occurs by the viscous flow of the rubber matrix and the inclusion of magnetic particles in the rubber enables additional damping through magnetic particle interaction and interfacial damping [14].

In recent years, attention has been directed towards the use of various active and semi-active damping treatments and vibration control. Distinct among these treatments are those in which controllable fluids are used that are embedded in a laminated composite structure to control their vibrations. MRE materials, due to their semi-active control capabilities, are candidate materials, which can cause changes in both damping and stiffness of the structure, simultaneously. Their use in the

* Corresponding author.
E-mail address: felipeeloy@unifei.edu.br (F. de Souza Eloy).

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Nomenclature

ABS	Acrylonitrile butadiene styrene
B	beam width
E	Elasticity modulus
G	Elasticity modulus
G^*	complex shear modulus
G'	storage modulus
G''	loss modulus
I	complex number
L	beam length
MR	Magnetorheological
MRE	magnetorheological elastomer
PLA	polylactic acid
S	honeycomb square dimension
s_1	composite skin thickness
s_2	honeycomb thickness
s_3	composite skin thickness
t	Time
t_1	honeycomb total thickness
t_2	honeycomb base thickness
t_3	honeycomb square thickness
w	honeycomb width
$y(t)$	displacement time response
$\dot{y}(t)$	velocity time response
ζ_0	damping factor free of magnetic field
ζ_{MF}	damping factor influenced by a magnetic field
ρ_{30}	composite mass with 30% of particles
ρ_{60}	composite mass with 60% of particles
ρ_c	composite mass
τ	shear stress
υ	Poisson ratio
γ	shear stain
ω_0	natural frequency free of magnetic field
ω_d	damped natural frequency
ω_{MF}	natural frequency influenced by a magnetic field
ω_n	natural frequency

proposed applications is based on the concept of optimized control with minimum energy addition via semi-active control [29]. In addition, elastomers are a major asset in various industrial applications. Their specific mechanical properties, in terms of adapted hyperelasticity, give them positive vibration and acoustic damping properties [3].

Modeling the vibrational response of structures is one of the major issues related to sizing and the design. The prediction of natural frequencies is an important industrial problem, particularly in the advanced fields such as space and aerospace industries. Indeed, the technology used to improve the construction of these structures is characterized by increased stiffness and damping of mechanical structures [1]. In the same way, the effect of the MRE layer in the presence or absence of a magnetic field has substantial quantitative and qualitative alterations on the nonlinear dynamical behavior of the system in the vicinity of fundamental and principal resonances [35].

Sandwich composite structures are widely used in applications where devices with high stiffness/weight ratio, strength/weight ratio and energy absorption capacity are important. Typical uses are demanded in aerospace, automotive and naval industries. Sandwich structures are formed from two thin skins bonded to outer faces of a lightweight core. The mechanical behavior of a sandwich composite structure depends on the material used for construction, especially of core material and topology. In general, conventional honeycomb cellular cores provide better mechanical stability, stiffness and energy absorption when crushed out-of plane if compared with typical random porous foams [6,21,9]. The possibility of designing the rigidity of the sandwich panel through the geometric configuration of the cell makes this type of construction very attractive for studies involving the use of MRE.

The recent advancement of additive manufacturing, such as 3D printing, enables fabrication of cellular structures with numerous and complex cell formats, and is therefore a promising technique for the control of honeycomb mechanical behavior [30]. Most studies involving sandwich composite structures and MRE are based on non-supported cores using only MRE materials, like silicone-based elastomers bonded to metallic skins. In general, the design of structures using sandwich panels requires high compressive and shear strength, so the bonding of the faces to the core is extremely important.

The novelty on this approach refers to the use of 3D printed honeycomb core material filled by MRE with carbon fiber/epoxy skins. The advantage of this type of construction is to provide better bonding of core to the skins, increasing the general mechanical behavior of the sandwich composite structure.

In the present study, MRE sandwich beams composed of carbon fiber/epoxy skins and a 3D printed honeycomb core, filled with magneto/elastomer with a ratio of mass concentration of 30 and 60% (magnetic particles), are experimentally investigated under free and forced vibration tests at different magnetic field intensities. A dynamic response analysis was performed in order to characterize the effect of the magnetic field over natural frequencies and amplitude properties.

This manuscript is organized as follows: In Section 2, a general bibliographic review is presented, addressing the scientific innovation of the subject. In Section 3, the manufacturing process of the (magnetorheological) MR sandwich beams are shown. In Section 4, the methodological procedure is presented. In Section 5, the main results are presented. Finally, Section 6 draws the conclusions.

2. Background

Because of the wide range of applications of MREs, efforts have been made to develop new MREs. Recent studies have been reported on the topic. Lokander and Stenberg [20] studied MRE solids made from nitrile rubber with various acrylonitrile contents, where the polarizable particles were large and irregularly shaped. Zhou and Wang [38] presented a sandwich beam with a soft core composed of an MRE part and non-MRE parts. In their study, an attempt was made to provide a fundamental analysis on how magnetic fields change the dynamic flexural rigidity of the proposed sandwich beam by changing the shear modulus of the MRE part.

At the same time, Zhou and Wang [39] dealt with numerical simulation and indicated that the magnetoelastic loads affect the dynamic properties of the vibrating beam significantly only when the thickness of the beam is extremely small. Similarly, Lockette et al. [19] fabricated and tested samples of magnetorheological elastomers comprised of a silicone elastomer in dynamic shearing experiments. Results from field-dependent dynamic shearing experiments were consistent, the relative MR effect being proportional to the square of the magnetization.

In the same way, Li et al. [43] presented theoretical and experimental studies of the mechanical performance and magnetorheological effects of magnetorheological elastomers (MREs) fabricated with mixtures of large and small particles. Experimental results agreed fairly well with theoretical analysis. The theoretical prediction of the optimum mixture ratio between large and small size particles was experimentally verified. In addition, Hu et al. [10] manufactured and tested an MRE between two thin aluminum layers. The experimental results show that the first natural frequency of the MRE sandwich beam decreased as the magnetic field applied to the beam was moved from