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Theoretical and experimental analysis on impact resistance of metal rubber vibration isolator

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Abstract: Metal rubber is recognised as an innovative high-efficiency damping material with excellent damping characteristics and energy dissipation capabilities, enabling effective vibration control. In this study, the focus is on the static characteristics and vibration damping performance of metal rubber vibration isolators under impact loads. Quasi-static test results demonstrate significant hysteresis and nonlinear stiffness properties in metal rubber, with its performance significantly influenced by relative density and wire diameter. The vibration isolating performance of metal rubber vibration isolators can be effectively evaluated using the impact isolation coefficient and logarithmic decrement rate. Impact tests reveal that metal rubber vibration isolators with varying relative densities and wire diameters exhibit distinct energy dissipation behaviours. Metal rubber samples with minimum wire diameter and maximum relative density demonstrate excellent vibration isolation performance at a pre-compression of 2 mm. This provides a new damping solution for applications in heavy machinery impact scenarios.

Keywords: metal rubber; MR; quasi-static test; impact isolation coefficients; logarithmic decrement rate.

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1 Introduction

Over the past decade, there has been a notable increase in the demand for efficient vibration isolation solutions across various industries including construction, aerospace, automotive, and manufacturing (Babitsky and Vepruk, 1998; Ibrahim, 2008; Amburay et al., 2014). These sectors are often confronted with significant vibrations stemming from the operation of heavy machinery, dynamic loads, and external disturbances. The consequential vibration and impact loads wield significant influence over the integrity of structures, precipitating phenomena like fatigue failure and structural degradation (Soltangharai et al., 2016; Mehta and Purohit, 2022; Boukhalkhal et al., 2024; Harle, 2024). Conventional vibration isolators, commonly utilising metal springs and rubber materials for damping, have demonstrated subpar performance in handling intricate environments (Rahman and Ahmed, 2011; Tang and Brennan, 2013; Salim et al., 2014; Roncen et al., 2019; Banić et al., 2020; Rahnavard et al., 2020; Wu et al., 2020). Hence, the integration of advanced damping materials becomes imperative to enhance performance and prolong the operational lifespan of mechanical and structural components (Purohit et al., 2008; Treviso et al., 2015; Wang et al., 2019, 2022; Chen et al., 2022).

Metal rubber (MR), composed of metallic wire mesh woven through specialised processes, forms a porous and complex microstructure exhibiting significant nonlinear and hysteresis characteristics (Purohit et al., 2008; Hong et al., 2012, 2013; Fu et al., 2019). Research indicates that MR possesses high compressive strength and excellent energy absorption capacity under static compression, with its static stiffness properties accurately described by macro-micro static stiffness prediction models (Xu et al., 2018; Zhang et al., 2021). In terms of dynamic mechanics, MR demonstrates notable nonlinear and hysteresis characteristics under high-speed impact loads and exhibits outstanding dynamic mechanical performance across various frequencies and amplitudes. This is especially true in simulated marine environments characterised by high humidity and salt fog (Lin et al., 2013; Liu et al., 2019; Wang et al., 2021). In high-temperature environments, nickel-based superalloys and shape memory alloy (SMA) MR exhibit exceptional high-temperature strength and deformation recovery capabilities (Zhang et al., 2013; Ma et al., 2015). Furthermore, enhancements in damping performance and energy absorption capacity have been achieved through optimisation of the metal mesh structure, adoption of corrugated structures, and incorporation of soft magnetic wound wire materials into composite structures (Wang et al., 2020, 2021). Advanced forming processes, such as graded extrusion technology, further improve the uniformity and performance stability of MR, providing technical assurance for its large-scale industrial applications (Yang et al., 2010; Yan et al., 2017). These studies offer a robust theoretical foundation and practical guidance for the application of MR in vibration control, high-temperature environments, and impact energy absorption.

As a novel functional material, MR exhibits significant engineering application potential due to its unique three-dimensional network structure and excellent mechanical properties. Currently, this material is widely used in advanced weaponry, including artillery vibration isolation, missile damping mechanisms, bearing damping systems, and buffer systems for aircraft landing gear (Ertas, 2009; Ning et al., 2012; Wang et al., 2015, 2021; Soleimanian et al., 2023).

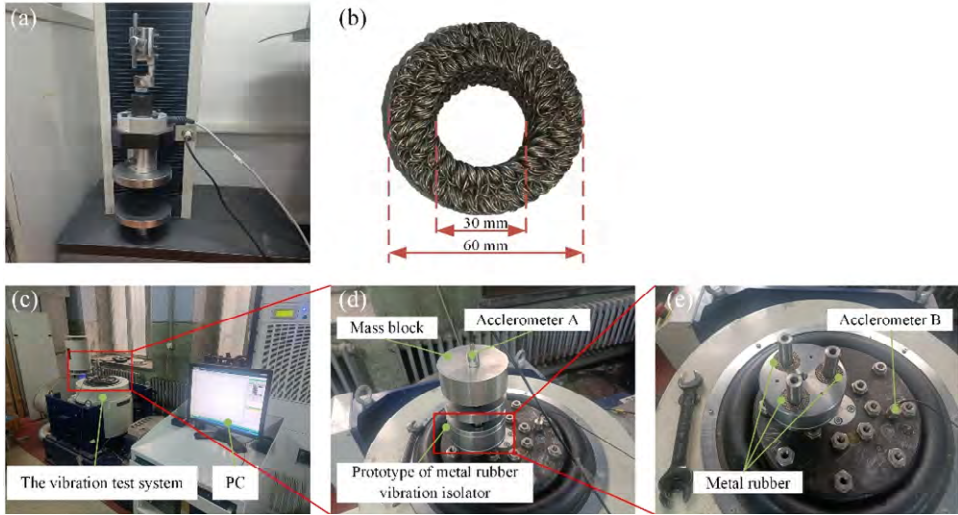
Comparing the stiffness characteristics of MR and conventional rubber isolators under acoustic vibration conditions, MR exhibits superior performance (Wang et al., 2014). In terms of static characteristics, research utilising Abaqus software has revealed the mechanical properties and deformation behaviour of MR dampers (You et al., 2022). Additionally, studies on its nonlinear static and dynamic characteristics, through experimental testing and numerical simulations, systematically analyse the response characteristics of MR vibration isolators under various loading conditions (Wang et al., 2010). The dynamic stiffness of hollow cylindrical rubber isolators was further enhanced in design precision and performance prediction capability through waveguide analysis (Östberg et al., 2013). Researchers have delved into improving damper performance via optimisation models (Ning et al., 2012), nonlinear design (Ma et al., 2023b), and structural optimisation (Ma et al., 2023a). These studies not only enhance the understanding of MR vibration isolators' performance but also promote their practical engineering applications. For example, in mechanical transmission systems, semi-active vibration control strategies of MR vibration isolators have demonstrated significant vibration reduction effects (Soleimani et al., 2023). In the design of tuneable frequency dampers, MR block tuned mass dampers have achieved efficient vibration attenuation over a broad frequency range (Rieß et al., 2021). In addition, simulation methods for MR vibration isolators represent an important area of research. Previous studies have modelled and analysed their nonlinear stiffness characteristics, revealing that MR isolators exhibit significant nonlinear stiffness (Liu et al., 2023b). This strong nonlinearity can cause a frequency shift in the vibration response of the isolation system. In summary, these research outcomes indicate that MR vibration isolators possess broad application prospects and significant performance advantages in practical engineering applications, providing inspiration for the design of dampers in heavy machinery.

This research stems from the increasing demand for effective vibration isolation solutions in heavy machinery applications, particularly in environments subject to high-impact loads. While previous studies have examined the mechanical properties of MR, there remains a need for a comprehensive analysis. This study aims to investigate the effects of wire diameter and relative density on the mechanical properties of MR through a combination of theoretical modelling and experimental validation. The methodology includes quasi-static and impact tests to evaluate the performance of MR samples with different configurations. The results provide insights into the optimisation of MR isolators for practical engineering applications.

2 Materials and method

2.1 Quasi-static experiments on MR

Quasi-static tests are primarily conducted to measure the hysteresis and stiffness characteristics of MR. These tests were performed using a WDW-5Y electronic universal testing equipment, as illustrated in Figure 1(a). MR is created by winding stainless steel wire into a hollow cylindrical shape. The detailed experimental setups for the tests are detailed in Table 1. Figure 1(b) illustrates the MR described as case 1 in Table 1, with an outer diameter of 60 mm, an inner diameter of 30 mm, a height of 25 mm, and a relative density of 0.22.

Figure 1 Experimental details (see online version for colours)**Table 1** Parameters of test specimens

No.	Wire diameter (mm)	Relative density	Mass (g)	Outer diameter (mm)	Inner diameter (mm)	Height (mm)
Case 1	0.5	0.22	91.41	60	30	25
Case 2	0.15	0.2	14.21	32	16	15
Case 3	0.15	0.25	17.76	32	16	15
Case 4	0.15	0.3	21.31	32	16	15
Case 5	0.1	0.25	17.76	32	16	15
Case 6	0.2	0.25	17.76	32	16	15

2.2 Evaluation method and experimental arrangement

2.2.1 Isolation mechanism and evaluation method

MR can be seen as a parallel connection of two parts: nonlinear spring and viscous damper, consequently, the mechanical model of the MR is shown in Figure 2.

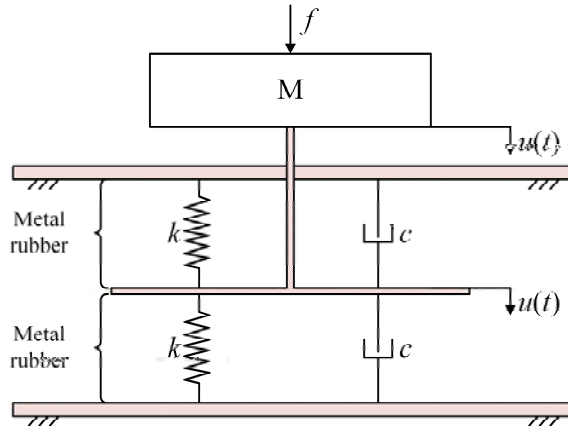
The dynamic equation of MR vibration isolator can be expressed as:

$$M\ddot{u}(t) + c\dot{u}(t) + ku(t) = 0 \quad (1)$$

where M represents the mass block, k represents the nonlinear stiffness, c represents the viscous damping of MR, $u(t)$ represents the absolute displacement of the mass block.

In impact scenarios, due to the short duration of the impact, the damping characteristic of the isolation system has minimal influence on the maximum response of the system, playing a significant role only in subsequent sustained vibration processes. Hence, equation (1) can be simplified to:

$$M\ddot{u}(t) + ku(t) = 0 \quad (2)$$

Figure 2 Mechanical model of the double-layer MR vibration isolator

For the convenience of analysis, the impact load was equivalently modelled as a rectangular pulse. When the impact occurs, the impact force acted briefly on the vibration isolation system. Therefore, the theoretical analysis model of the MR vibration isolation system after the impact can be transformed into a second-order differential equation with initial conditions: $u_0 = 0$, $\dot{u}_0 = v_0$, as shown below:

$$\begin{cases} \tau' = \int_0^\tau f(t)dt / f_{\max} \\ M\ddot{u}(t) + ku(t) = 0 \\ v_0 = \frac{\tau' f_{\max}}{M} \end{cases} \quad (3)$$

where $f_{\max}$ is the amplitude of impact load, τ is the impact duration, τ' is the impact time of equivalent rectangular pulse.

For the equations system (3), the vibration response of the vibration damping system was obtained as shown in equation (4).

$$u(t) = \frac{v_0}{\omega_n} \sin(\omega_n t) \quad (4)$$

where ω_n is the natural frequency of the vibration damping system, and it is calculated as:

$$\omega_n = \sqrt{k/M} \quad (5)$$

According to the equation (4), the maximum deformation $u_{\max}$ of the MR and the maximum restoring force $F_{\max}$ of the vibration isolation system, as shown in equation system (6):

$$\begin{cases} u_{\max} = v_0 / \omega_n \\ F_{\max} = kv_0 / \omega_n \end{cases} \quad (6)$$

Based on the equation system (6), it can be inferred that the maximum deformation of the MR vibration isolation system is dependent on both the natural frequency of the isolation

system and the impact energy. A higher natural frequency results in greater deformation of the MR, while a higher impact energy leads to increased deformation.

The evaluation criteria used in related research today are varied when it comes to vibration isolators' ability to reduce vibration (Zhao et al., 2014; Guo et al., 2023; Liu et al., 2023a; Kim et al., 2023; Mamazizi et al., 2023; Zheng and Kishiki, 2023). The impact isolation coefficient was chosen in this study as the assessment metric for the MR vibration isolator's impact resistance (Zhao et al., 2014). The impact isolation coefficient η calculation procedure was illustrated in equation (7).

$$\eta = \frac{F_{\max}}{f_{\max}} = \frac{kv_0}{\omega_n f_{\max}} = \omega_n \tau' \quad (7)$$

where $F_{\max}$ is the maximum response amplitude of the vibration isolation system, and $f_{\max}$ is the maximum excitation amplitude. The smaller the value of η , the better the vibration isolation performance of the vibration isolator.

Theoretical analysis results demonstrate a close correlation between the impact isolation coefficient of the MR vibration isolation system, the natural frequency of the system, and the impact time of the equivalent rectangular pulse. With the impact duration held constant, the impact isolation coefficient increases with the increase in the natural frequency of the vibration isolation system. In other words, as the stiffness of the vibration isolation system increases, the effectiveness of impact isolation decreases. When the stiffness of the vibration isolation system remains constant, the impact isolation coefficient is positively correlated with the impact duration, with an increase in the impact duration gradually diminishing the impact isolation effectiveness of the vibration isolation system.

When a metallic rubber damper undergoes free vibration after a short-term impact, its amplitude gradually decays over time. Consequently, the vibration damping performance of the vibration isolator can be assessed using the logarithmic decrement rate δ , calculated as shown in equation (8),

$$\delta = \frac{1}{n} \ln \frac{A_1}{A_{n+1}} \quad (8)$$

where A_1 represents the amplitude of first cycle, A_{n+1} denotes the amplitude of the $n + 1^{\text{th}}$ cycle, and n indicates the number of cycles.

2.2.2 Experimental devices

Owing to the huge structure of the MR vibration isolator and the execution difficulty of the experimental test, the MR vibration isolator was scaled down in proportion. The isolator prototype was composed of ZG25Mn2.

The MPA403/M124A electric vibration test system from Aerospace Hill Testing Technology Co., Ltd. was the apparatus used for impact tests. The Donghua DH8304 dynamic signal testing and analysis system was used to perform the model test. Before the experiment, acceleration sensors were installed on both the vibration test platform and the mass block to collect excitation and response signals. The experimental devices are shown in Figures 1(d)–1(e).

In the vibration test platform's control system, parameters such as waveforms, amplitude, and impact signal width were specified. The vibration platform was adjusted

using the controller to execute the impact test. Considering the practical application where MR undergoes pre-compression, pre-compression levels were set at 1 mm, 1.5 mm, and 2 mm, respectively. Impact tests of varying durations were conducted on five groups of MR samples (case 2 to case 6). The impact amplitude is set to 2.0 g. The test durations ranged from 0.002 seconds to 0.01 seconds, with intervals of 0.002 seconds, resulting in a total of 75 tests.

3 Results and discussion

3.1 Static properties of MR

3.1.1 Effect of imposed displacement

Figure 3(a) illustrates the typical force-displacement curve for the MR sample from case 1 in Table 1. The force-displacement curve of MR exhibits significant nonlinearity, with the stiffness increasing as displacement rises. This nonlinear behaviour is further influenced by the interaction between the imposed displacement and the material's microstructure. As the MR is compressed, the metallic wires slide and reposition themselves within the porous network, altering the internal friction forces at different displacement levels. In the initial phase, where displacement is small, the wires are relatively loose, and friction plays a dominant role in resisting deformation, leading to higher energy dissipation. However, as displacement increases and the wires become more aligned, frictional forces reduce, and the energy dissipation capability decreases accordingly. The loss factor is a crucial parameter for evaluating the energy dissipation capability of MR and depends on the compression level, as shown in Figure 3(d). The observed inflection point in the loss factor curve marks a transition where the MR shifts from a high-friction regime to a lower-friction state, as the internal structure becomes more ordered. This trend indicates that MR's damping performance is highly dependent on the degree of wire alignment and interaction under varying displacement conditions.

3.1.2 Effect of relative density

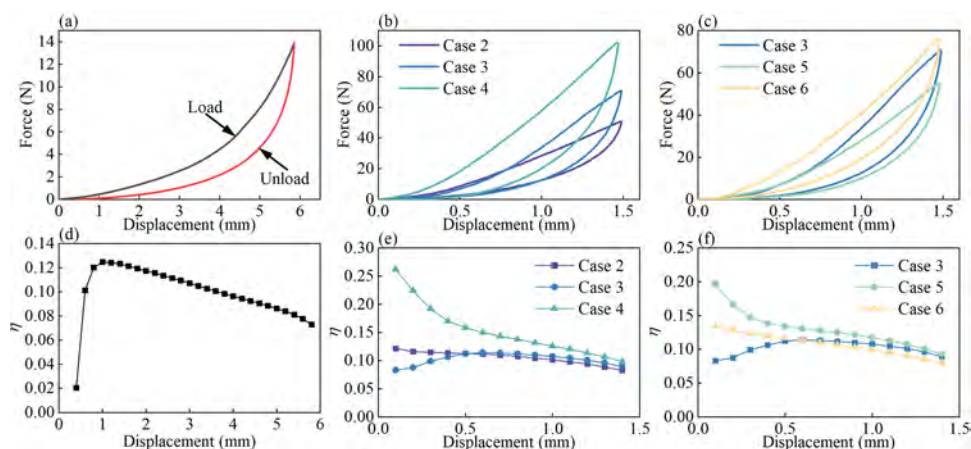
Figures 3(b) and 3(e) illustrate the effect of relative density on the force-displacement curve and loss factor of MR, respectively. For cases 1 and case 3 in Figure 3, the initial increase in the loss factor is due to significant friction between metal wires at lower displacements, where energy dissipation is maximised. As displacement increases, the wires align more uniformly, reducing friction and, consequently, the loss factor. However, in case 4, with a higher relative density, the MR exhibits greater stiffness at smaller displacements. The more uniform initial alignment of the wires leads to less friction from the start, causing a continuous decrease in the loss factor without a peak.

3.1.3 Effect of wire diameter

Figures 3(c) and 3(f) illustrate the impact of wire diameter on the force-displacement curves and loss factors of MR, respectively. A larger wire diameter corresponds to higher stiffness, primarily due to the enhanced structural integrity provided by thicker wires, which effectively resist deformation. However, under the same volume and relative density conditions, MR with a smaller wire diameter exhibits a more uniform

arrangement of internal metal wires and a greater number of friction points, leading to increased energy dissipation at lower displacements. As displacement increases, the friction between the wires diminishes, resulting in a decrease in the loss factor. Moreover, the internal stress distribution of MR varies with different wire diameters. Smaller wire diameters concentrate stress at local contact points, enhancing friction and energy dissipation, while larger wire diameters distribute stress more evenly, reducing local friction and thus lowering the loss factor. This phenomenon highlights the balance between structural stiffness and energy dissipation. The variation in loss factor indicates that MR with a smaller wire diameter is more suitable for applications requiring high energy dissipation and damping, whereas MR with a larger diameter provides better structural support and lower energy loss.

Figure 3 Hysteresis loop and loss factor of MR (see online version for colours)

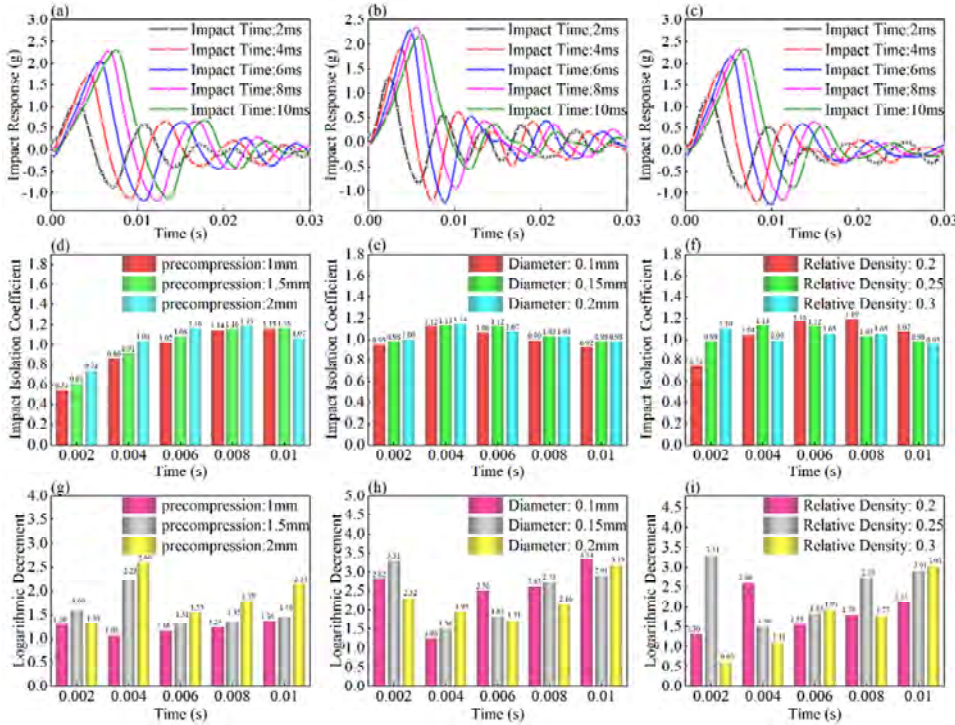


3.2 Results and analysis of impact tests

Figures 4(a)–4(c) show the response curves for three different impact tests. Additional impact response results can be found in Figure S1 in Supplementary files. As shown in the figures, the impact response rapidly declines to a lower level within a short time. To facilitate a direct comparison of the performance of MR vibration isolators with varying parameters, the impact isolation coefficient and logarithmic decrement rate are calculated for each configuration. The results are summarised in Table 2 and Table 3, respectively.

Figures 4(d)–4(f) illustrate that the impact isolation coefficients of MR vibration isolators vary significantly with different pre-compression levels and relative densities. In contrast, the differences among dampers with different wire diameters are relatively small. This trend is consistent with Figure S2 in supplementary files. According to equation (7), a smaller impact isolation coefficient indicates less transmission of the impact signal to the damper, resulting in better isolation performance. All MR samples demonstrated lower impact isolation coefficients at a pre-compression of 2 mm, highlighting the effectiveness of the MR vibration isolators in mitigating peak impact values. Specifically, at a pre-compression of 2 mm, the MR vibration isolator with a wire diameter of 0.1 mm or a relative density of 0.3 achieve the minimum impact isolation coefficient.

Figure 4 Impact response, the impact isolation coefficient, and logarithmic decrement rate of experimental tests, (a) impact response results of case 2 when pre-compression is 1 mm (b) impact response results of case 3 when pre-compression is 1 mm (c) impact simulation results of case 2 when pre-compression is 2 mm (d) impact isolation coefficients of case 2 under different pre-compression levels (e) impact isolation coefficients of MR with different wire diameters under a pre-compression of 2 mm (f) impact isolation coefficients of MR with different relative densities under a pre-compression of 2 mm (g) logarithmic decrement rate of case 2 under different pre-compression levels (h) logarithmic decrement rate of MR with different wire diameters under a pre-compression of 2 mm (i) logarithmic decrement rate of MR with different relative densities under a pre-compression of 2 mm (see online version for colours)



Figures 4(g)–4(i) reveal that the logarithmic decrement rate of metallic rubber dampers varies considerably with different pre-compression levels, wire diameters, and relative densities. The comparison of the logarithmic decrement rate under different conditions is shown in Figure S3 in supplementary files. According to equation (8), a larger logarithmic decrement rate indicates a more rapid decay of the oscillation of the impact signal. As shown in Figure 4(g) and Figures S3(a)–S3(d), the logarithmic decrement rate is relatively high and exhibits relatively minimal fluctuation when the pre-compression is 2 mm. This indicates that the MR experiences the more faster amplitude decay under a compression of 2 mm. Therefore, the subsequent analysis is conducted with a pre-compression of 2 mm. As shown in Figures 4(h) and 4(i), the logarithmic decrement rate of the MR vibration isolator is maximised when the wire diameter is 0.1 mm and the relative density is 0.3. This indicates that under these conditions, the amplitude decay performance of the metal damper is optimal, allowing the amplitude to decay to a lower level in a shorter time frame.

Table 2 The impact isolation coefficients of experimental tests

Impact time (ms)	Case 2			Case 3			Case 4		
	L1a	L2b	L3c	L1	L2	L3	L1	L2	L3
2	0.54	0.61	0.74	0.66	0.75	0.98	0.85	1.01	1.1
4	0.86	0.91	1.04	0.96	1.01	1.13	1.11	1.16	0.99
6	1.02	1.08	1.16	1.14	1.19	1.12	1.18	1.13	1.05
8	1.14	1.16	1.19	1.17	1.2	1.03	1.10	1.01	1.05
10	1.15	1.16	1.07	1.1	1.06	0.98	1.03	0.96	0.95
Impact time (ms)	Case 5			Case 6					
	L1	L2	L3	L1	L2	L3			
2	0.72	0.8	0.95	0.69	0.78	1.0			
4	1.01	1.1	1.12	0.98	1.05	1.14			
6	1.11	1.17	1.06	1.1	1.18	1.07			
8	1.13	1.12	0.99	1.14	1.1	1.03			
10	1.06	1.01	0.92	1.09	1.0	0.98			

Table 3 The logarithmic decrement rate of experimental tests

Impact time	Case 2			Case 3			Case 4		
	L1a	L2b	L3c	L1	L2	L3	L1	L2	L3
2 ms	1.3	1.6	1.3	1.87	1.09	3.31	1.32	2.80	0.62
4 ms	1.06	2.23	2.6	1.15	1.07	1.5	1.0	1.11	1.11
6 ms	1.16	1.31	1.55	2.42	1.50	1.83	1.58	1.8	1.93
8 ms	1.24	1.35	1.79	1.72	2.14	2.73	2.73	4.01	1.77
10 ms	1.36	1.46	2.14	1.82	2.13	2.91	2.26	3.02	3.03
Impact time	Case 5			Case 6					
	L1	L2	L3	L1	L2	L3			
2 ms	1.13	1.72	2.82	0.98	0.7	2.32			
4 ms	1.17	1.39	1.26	0.98	0.82	1.95			
6 ms	1.64	1.96	2.5	1.96	1.63	1.71			
8 ms	1.91	1.87	2.62	1.94	1.95	2.16			
10 ms	2.07	2.15	3.34	2.35	2.44	3.19			

The analysis shows that the optimal parameters for the MR vibration isolator, achieving the best vibration reduction performance, are a pre-compression of 2 mm, a wire diameter of 0.1 mm, and a relative density of 0.3, consistent with the trends observed in Figure 3. In general, the MR vibration isolator effectively reduced the impact amplitude, thereby verifying its suitability and efficiency in heavy machinery applications. This offered robust substantiation and proof for the implementation of MR vibration isolators in heavy machine operation.

4 Conclusions

This study systematically investigates the static and dynamic mechanical properties of MR across varying relative densities and wire diameters, with a focus on its nonlinear stiffness and energy absorption capabilities under impact loads. Based on the experimental results, the main conclusions of this study are as follows:

- 1 MR samples exhibit notable nonlinear stiffness and hysteresis characteristics in quasi-static experiments, with this nonlinearity becoming more pronounced as displacement increases. This behaviour is primarily attributed to frictional changes caused by the sliding and rearrangement of metal wires within the internal microstructure of the MR.
- 2 The static mechanical properties of MR are significantly influenced by relative density. A quantitative analysis shows that as the relative density increases from 0.2 to 0.3, the loss factor increases by approximately 15% to 115%, depending on the displacement. Specifically, at a displacement of 0.1 mm, the loss factor for a relative density of 0.2 is 0.12, while for a relative density of 0.3, it reaches 0.26, representing a 115% increase in energy dissipation capability. This variation demonstrates that higher relative density enhances friction between metal wires, improving the damping performance of the material.
- 3 Impact experiment results indicate that MR samples with minimum wire diameter and maximum relative density demonstrate excellent vibration isolation performance at a pre-compression of 2 mm. This suggests that MR vibration isolators can effectively reduce the transmission of impact loads, making them suitable for vibration isolation and impact protection in heavy machinery applications.

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Supplementary files

Figure S1 Impact response of impact test, (a) the impact response results of case 2 when pre-compression is 1.5 mm (b) the impact response results of case 3 when pre-compression is 1.5 mm (c) the impact response results of case 2 when pre-compression is 2 mm (d) the impact response results of case 4 when pre-compression is 1 mm (e) the impact response results of case 4 when pre-compression is 1.5 mm (f) the impact response results of case 4 when pre-compression is 2 mm (g) the impact response results of case 5 when pre-compression is 1 mm (h) the impact response results of case 5 when pre-compression is 1.5 mm (i) the impact response results of case 5 when pre-compression is 2 mm (j) the impact response results of case 6 when pre-compression is 1 mm (k) the impact response results of case 6 when pre-compression is 1.5 mm (l) the impact response results of case 6 when pre-compression is 2 mm (see online version for colours)

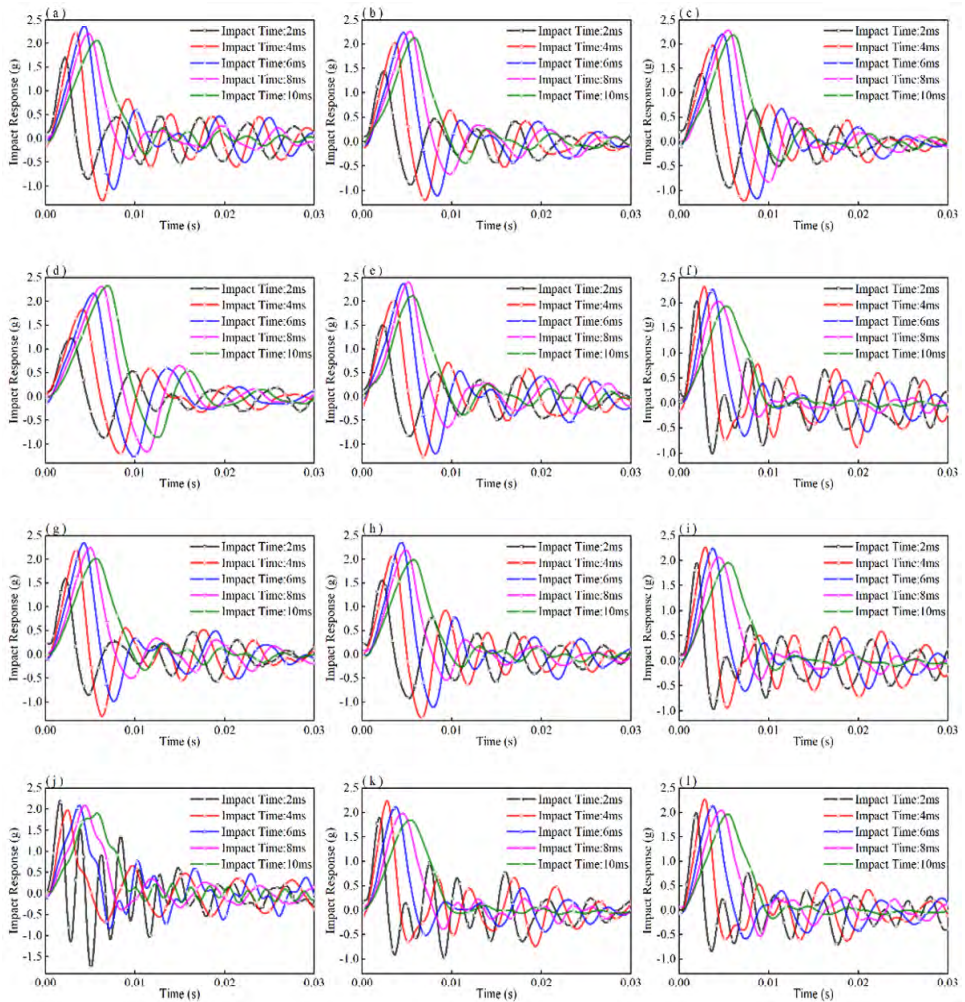


Figure S2 Impact isolation coefficients of impact tests, (a) impact isolation coefficients of case 3 under different pre-compression levels (b) impact isolation coefficients of case 4 under different pre-compression levels (c) impact isolation coefficients of case 5 under different pre-compression levels (d) impact isolation coefficients of case 6 under different pre-compression levels (e) impact isolation coefficients of metal rubber with different wire diameters under a pre-compression of 1 mm (f) impact isolation coefficients of metal rubber with different wire diameters under a pre-compression of 1.5 mm (g) impact isolation coefficients of metal rubber with different relative densities under a pre-compression of 1 mm (h) impact isolation coefficients of metal rubber with different relative densities under a pre-compression of 1.5 mm (see online version for colours)

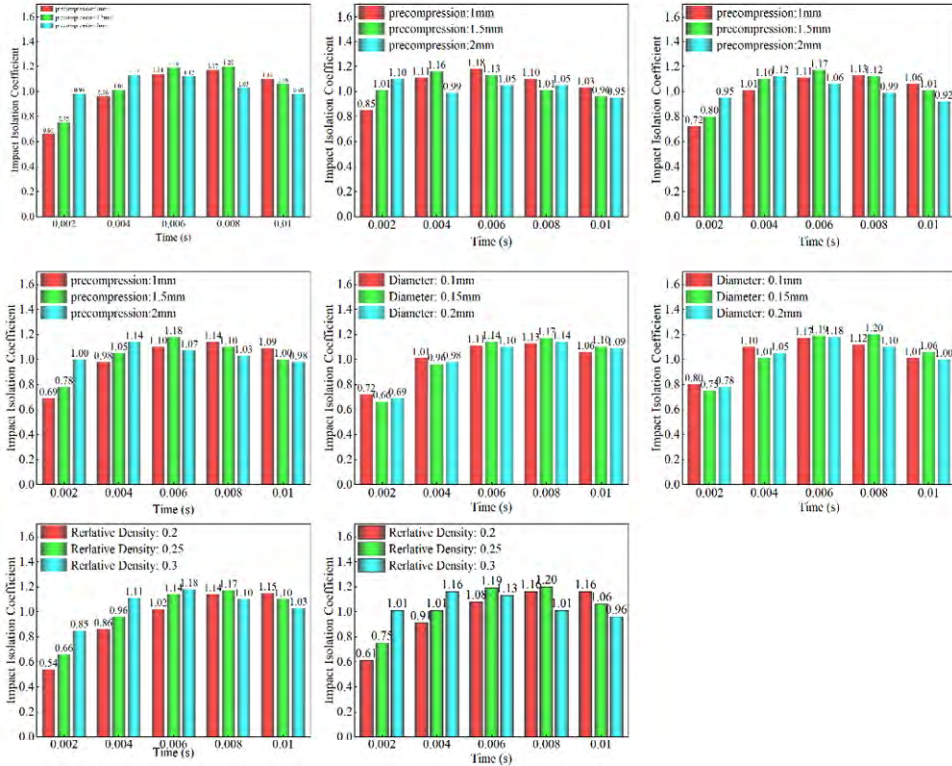


Figure S3 Logarithmic decrement rate of impact tests, (a) logarithmic decrement rate case 3 under different pre-compression levels (b) logarithmic decrement rate of case 4 under different pre-compression levels (c) logarithmic decrement rate of case 5 under different pre-compression levels (d) logarithmic decrement rate of case 6 under different pre-compression levels (e) logarithmic decrement rate of metal rubber with different wire diameters under a pre-compression of 1.5 mm (f) logarithmic decrement rate of metal rubber with different wire diameters under a pre-compression of 2 mm (g) logarithmic decrement rate of metal rubber with different relative densities under a pre-compression of 1.5 mm (h) logarithmic decrement rate of metal rubber with different relative densities under a pre-compression of 2 mm (see online version for colours)

