Comparing Study on Metal Rubber and High Polymer Rubber

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Abstract. In this paper, the metal rubber and rubber were systematically compared, on the basis of comprehensive comparison of the manufacturing technique property of the metal rubber and high polymer rubber, the physical and mechanical properties of the two materials, especially the elastic and damping properties, were emphasize compared. Finally, the scope of application of the two materials was discussed. The results of this study has certain guiding significance for application of metal rubber properly by the researchers engaged in the vibration isolation and damping of engineering.

1. Introduction

Rubber is a kind of viscoelastic damping material, which has been widely used in engineering. However, in the process of long-term use, rubber materials also expose some defects[1], such as aging, softening (at high temperature) or hardening (at low temperatures), bad corrosion resistance, and the elastic damping performance is greatly affected by temperature and frequency. Metal rubber is a new type of high elasticity and large damping materials[2], which developed to overcome the inherent shortcomings of rubber materials. Because the inside of metal rubber is a spatial network of macromolecules like a rubber structure which formed by metal wires interlacing and hooking with each other, and metal rubber has elasticity and damping performance as rubber, so it got its name.

Based on a large number of experimental studies, the detailed experimental data have mastered, and the comparative research on the pros and cons of the two materials were carried out. The main purpose is to maximize strengths and avoid weaknesses, so that metal rubber materials can be applied in engineering scientifically and reasonably.

2. Comparison of Manufacturing Process Performance

Although rubber and metal rubber have similarities in spatial network structure and elasticity and damping properties, there are big differences in manufacturing processes between the two materials.

2.1. Raw Materials

The main raw materials of rubber are consisted of raw rubber (natural rubber and synthetic rubber), reclaimed rubber and various compounding agents. Natural rubber comes from rubber-containing plants in nature and is the most versatile general-purpose rubber. Synthetic rubber, such as SBR, BR, neoprene, butyl rubber, silicone rubber, fluorine rubber, nitrile rubber, etc, is made by the artificially synthesized method, different varieties have different properties and uses[3].

The raw material of metal rubber is metal wires, its specific chemical composition is determined by working conditions (such as temperature, humidity, aggressive media, load, etc.). A reasonable selection of the grade of metal wire plays an important role in the process of manufacturing metal
rubber. As the smallest basic unit of metal rubber, the metal wire with the high elastic modulus and strength are required.

2.2. Manufacturing Process
The rubber molding process includes complex processes such as plasticizing, compounding, mixing, calendering, extrusion, molding, and vulcanization. The vulcanization molding methods of rubber products mainly include model vulcanization, autoclave vulcanization and continuous vulcanization. The methods of model vulcanization include molding vulcanization, molding movement vulcanization, injection vulcanization and liquid injection vulcanization. Among them, molding vulcanization is the method that the sealed model is pressurized and heated while molding and vulcanizing the rubber in a prescribed shape. It is widely used because the model is cheap and the equipment is simple.

Metal rubber products are mainly manufactured by cold forming. Firstly, coiling metal wires of different diameters and materials into spiral coils, secondly, through a special process, the spiral coil is stretched with a fixed pitch and then woven and laid in a certain shape to make a blank, at last, the blank is placed in a mold of the desired shape for cold forming and post-treatment. Metal rubber blank and product are shown in Figure 1 and Figure 2.

![Figure 1. Metal rubber blank.](image1)

![Figure 2. Metal rubber product.](image2)

By comparison and analysis, the following results can be found, rubber materials are prepared by combining chemical synthesis and mechanical processing, while metal rubber materials are more prepared by mechanical processing. Because the rubber has good fluidity, rubber products are more easy to form various complex shapes, while the fluidity of metal rubber blanks is relatively poor, and it is difficult to form metal rubber products with complex shapes, and the stamping die design is also more complicated.

2.3. Product Performance Adjustment
The main performance indexes of rubber materials include Shore A hardness, tensile strength MPa, elongation at break %, compression set rate %, loss factor η, etc. The performance improvement methods of rubber materials usually include the selection of rubber base materials and fillers, the optimization of vulcanization system and anti-aging system[3]. By these improvement measures, not only the physical and mechanical properties of rubber materials (including tensile strength, tensile stress, modulus, etc.) can be adjusted, but also its damping performance, aging and fatigue resistance performance can be improved.

The main performance indexes of metal rubber materials include compression strength MPa, compression stiffness KN/mm, compression set rate %, loss factor η, etc. The performance improvement methods of metal rubber materials include the selection of wire grades, the diameter of metal wire spiral coils, the tension pitch, blank laying method and the optimization of winding angle, stamping process design, etc.[4]. By these improvement measures, the physical and mechanical properties of metal rubber materials (including compression strength, compression stiffness, and compression set rate) can be adjusted, its damping and anti-fatigue aging performance can also be improved.
By comparison and analysis, the following results can be found, the performance improvement methods of rubber materials focus on chemical synthesis methods, while the performance improvement methods of metal rubber materials focus on mechanical processing methods.

3. Comparison of Physical and Mechanical Properties
Experimental studies have shown that because of the different raw materials and preparation processes of metal rubber and rubber, there is a big difference in the physical and mechanical properties of the two materials.

3.1. Elastic Deformation and Damping Energy Dissipation Mechanism
Rubber is a kind of viscoelastic materials, belongs to high-molecular polymer. It is usually composed of small and simple chemical units to form long-chain molecules. The molecules and molecules are connected to each other by chemical bonds or physical entanglements, and are linked to form three-dimensional molecular network in a three-dimensional direction, thousands of molecules are copolymerized or polycondensed to form a high molecular polymer. One molecule of a high molecular polymer is composed of more than 1,000 atoms, and the molecular weight exceeds 10,000. The entire molecule presents an irregular tortuous shape, which makes the distance between the two ends of the molecules is much smaller than the straightened length. An unstretched polymer is like a group of long and irregular long-chain molecular entanglements. The molecules of the polymer are prone to relative motion, and the internal chemical unit of the molecules can also rotate freely. Therefore, when subjected to external force, the zigzag molecular chain will be stretched, twisted and other deformations. On the other hand, the chain segments between the molecules will produce relative slippage and twist. When the external force is removed, the post-deformed molecular chain must be restored to its original position, and the relative motion between the molecules will be partially restored, releasing the work done by the external force, which is the elasticity of the viscoelastic materials, but the slip and the torsion between the molecular chain segments cannot be completely restored, permanent deformation is produced, which is the viscosity of the viscoelastic materials. The work done in this part is converted into heat energy and dissipated in the surrounding environment, which is the reason for the damping of the viscoelastic materials.

Metal rubber uses a variety of highly elastic metal wires as raw materials. Through a series of technological processes, such as spiral forming, stretching, winding, molding, and post-treatment, a new type of high elasticity and large damping material is finally formed. The internal structure of metal rubber is that metal wires interact and hook with each other to form a spatial network of macromolecular links as the rubber polymer structure. When metal rubber is deformed under load, on the micro level, it displays slip friction, extrusion and deformation between the metal wires hook structure, on the macro level, it displays a nonlinear hysteresis functional constitutive similar to elastic-plasticity, which can dissipate a large amount of vibration energy[5], and the essence of damping energy dissipation is the dry friction between metal wires.

It can be seen that although rubber materials and metal rubber materials have a similar spatial network structure, they are very different in elastic deformation and damping energy dissipation mechanism.

3.2. Change Law of Elasticity and Damping Characteristics
Through a large number of experimental studies, the elasticity and damping characteristics of rubber materials are mainly affected by environmental temperature and vibration frequency. According to the typical curve of its elasticity and damping performance with environmental temperature at a specific frequency, it can be seen that there are three temperature zones. In different areas, there are obvious differences in the elasticity and damping properties of rubber materials, as shown in Figure 3.
From left to right: the frequency does not change, the temperature is from low to high
From right to left: the temperature does not change, the frequency is from low to high

Figure 3. Curves of the elastic and damping properties of rubber with temperature or frequency.

The first zone is the glassy zone, in this zone, the elastic modulus is high and the damping loss factor is small. The third zone is the rubbery zone, in this zone, the elastic modulus is low and the damping loss factor is not high. The zone between the first and the third zone is the transition zone. In this zone, the elastic modulus drops sharply, and the damping loss factor reaches the maximum value, that is so-called damping peak. Generally, although the characteristics of rubber are affected by the vibration frequency importantly, it is only a minor position compared with the influence of temperature. The influence of frequency also has a certain law, which depends on the temperature zone of rubber. Under the condition of a certain temperature, the elasticity modulus of rubber mostly increases with the increase of frequency, and the damping loss factor varies greatly with frequency, and there is a maximum value at a certain frequency.

It has shown that, for most viscoelastic damping materials, there is an equivalent relationship between temperature and frequency. The effect on its performance is that high temperature is equivalent to low frequency, low temperature is equivalent to high frequency.

Metal rubber materials are very different from rubber materials due to the preparation of raw materials and manufacturing processes, and their elasticity and damping characteristics are significantly different from those of rubber materials. The hardness and geometric characteristics of metal rubber materials have the small correlation of temperature so the elasticity and damping characteristics of metal rubber materials are very little affected by temperature. If the load and vibration frequency remain unchanged, its elasticity and damping characteristics almost remain constant in a wide temperature range[6]. The curves of loss factor η and dissipated energy Δw of metal rubber materials with temperature is shown in Figure 4.

Experimental research shows that the elasticity and damping characteristics of metal rubber materials are mainly affected by the deformation amplitude and load frequency[6]. The curves of loss factor η and dissipated energy Δw of metal rubber materials with vibration amplitude and frequency are shown in Figure 5 and Figure 6.
With the increase of the amplitude, the dry friction slip distance of the wires increases, the friction pairs involved in slippage also increase, so the energy consumption will inevitably increase. At the same time, due to the significant nonlinear hardening characteristics of metal rubber materials, the maximum restoring force of the component rises rapidly with the increase in amplitude, so the maximum elastic storage energy will increase significantly, and the rate of increase is faster than the rate of increase of dissipated energy, which causes the loss factor $\eta$ to decrease with the increase of amplitude.
The loss factor $\eta$ and dissipated energy $\Delta w$ of metal rubber gradually decrease with the increase of frequency. When the frequency increases, the dry friction slip between the wires cannot keep up with the vibration frequency, so the slip is insufficient, which leads to the reduction of dry friction energy consumption. The friction coefficient between the wires also decreases with the increase of frequency, which has an adverse effect on the dry friction energy consumption.

Through comparative analysis, it can be seen that, on the one hand, the elasticity and damping characteristics of rubber materials are affected by temperature, and at the same time, the heat dissipation coefficient of rubber materials is small, it is easy to generate heat under alternating loads and generate thermal stress fatigue and aging phenomenon, which also causes the degradation of elasticity and damping characteristics. On the other hand, the large correlation of the elasticity and damping characteristics of rubber materials with the temperature and vibration frequency, which also makes the problem of elasticity and damping characteristics with frequency matching when it works in a larger range of environmental temperature and load frequency.

The elasticity and damping characteristics of metal rubber materials are mainly affected by the size of the load within a certain frequency range, and this effect is very beneficial to the high efficiency of the metal rubber vibration isolator. If the load amplitude is small, the metal wire contact points only undergo compression elastic deformation, and the metal rubber vibration isolator have sufficient rigidity to maintain the stability of the structure. If the load is large or the metal rubber are greatly deformed near the resonance zone, most of the internal metal wire contact points of the metal rubber materials will have sliding friction, the combined effect of increased energy dissipation coefficient and stiffness softening can make the metal rubber vibration isolator consume a large amount of vibration energy to reduce the resonance peak and generate resonance frequency drift to avoid structural resonance. The curves of the acceleration transmissibility of the MR vibration isolator are shown in Figure 7.

![Figure 7](image-url)

**Figure 7.** The curves of the acceleration transmissibility.

However, a large number of experiments have shown that the elasticity and damping characteristics of metal rubber materials will also slowly change with the wear and local plastic deformation of the contact parts of the metal wires. Now, for improving the stability of the elasticity and damping characteristics of metal rubber materials, the research work on advanced manufacturing process is ongoing. Preliminary research results show that, by adopting a series of new manufacturing processes, the stability of elastic damping performance of metal rubber materials has been improved.

### 3.3. Damping Energy Consumption

The mechanism of the damping of rubber materials and metal rubber materials shows that the hysteresis loop is an important feature of energy consumption. The area surrounded by the hysteresis
loop has a direct relationship with the damping energy consumption of damping. To describe and analyze it mathematically, it can make a quantitative analysis of the energy consumption of damping. Therefore, the damping loss factor of the two materials is expressed by the ratio of the energy consumed to its elastic deformation energy. The hysteresis curves of rubber materials and metal rubber materials are shown in Figure 8 and Figure 9. The loss factor $\eta$ is calculated by using the following formula:

$$
\eta = \frac{\Delta W}{2\pi W}
$$

$\Delta W$ ——The energy dissipated in one cycle of harmonic vibration.

$W$ ——Maximum elastic energy storage.

$\sigma$ ——Force

$\epsilon$ ——Displacement

$W$ ——Maximum elastic energy storage.

Figure 8. Hysteresis loop of rubber materials.  Figure 9. Hysteresis loop of metal rubber materials.

At present, the damping loss factor of rubber materials produced at home and abroad is generally about 1 to 2 under the shear condition at room temperature (25°C). However, as shown in Figure 5, the damping loss factor or damping energy dissipation capacity of rubber materials is greatly affected by temperature. The damping loss factor of cylindrical and sleeve-shaped metal rubber materials under compression or shear have been measured, the results show that the damping loss factor is not constant, which changes with the frequency and amplitude of the relative deformation [7]. The damping loss factor generally varies between 0.1 and 0.4.

Through comparative analysis, it can be seen that from the absolute measurement value of the loss factor, the damping energy dissipation capacity of rubber materials is significantly higher than that of metal rubber materials. However, as shown in Figure 6, the damping loss factor or damping energy dissipation capacity of metal rubber materials isn’t affected by temperature. Therefore, in the environment with large temperature changes, the damping and energy dissipation stability of metal rubber is better than that of rubber materials.

3.4. Elastic Deformation Ability

In the process of deformation, the rubber material will be permanently deformed due to the slippage and torsion between the polymer molecular chain segments can’t be recovered. In general, the permanent deformation rate of the rubber materials varies significantly with the model. The research results show that the permanent deformation rate of rubber materials also changes with the high and low environmental temperature.

The elastic properties of metal rubber materials under the station of compression are also determined by the value of the elastic recovery. However, the deformation that occurs during the loading process cannot always be fully recovered, and depending on the applied load value, there may be a large unrecoverable deformation component. Therefore, to determine the elastic characteristics of metal rubber materials, it is necessary to know the recoverable and unrecoverable deformation.
components in the total deformation and the relationship between these components and the original parameters of the material. The deformation of the metal rubber materials under load is accompanied by the elastic-plastic deformation and relative sliding between turns. When the load is removed, the turns will try to return to the original position under the action of elastic force, but due to residual deformation, the element cannot return to the original position. With the increase in the number of loading-unloading cycles will increase the residual deformation and reduce the recoverable deformation. After a certain number of cycles (the number depends on the material organization and load force), the proportional relationship between the residual deformation and the deformation trended to be stable. Experimental research shows[4]that the permanent deformation rate of metal rubber materials varies between 1% and 5%. The study of the relationship between the relative deformation of metal rubber materials with different material densities (the ratio of residual deformation to the original height value) and the relative load force (the ratio of the load force to the stamping pressure) had been done, it shows that when the relative load changes between 0 and 0.05, the residual deformation mainly depends on the friction force, when the relative load changes between 0.15 and 0.25, it is in the gradual change area of the characteristic curve, it may be that the elastic force overcomes the frictional force without hysteresis, and the external force can only be used to make the individual turns which is in a compressive stress state after stamping occurs plastic deformation. This area is most conducive to stabilizing the elastic properties of the material, because the load is large enough at this time, and the development of unrecoverable deformation is slow. If the load continues to increase, the residual deformation will increase sharply. At this time, the material almost loses its own characteristics. This can lead to an important conclusion: in order to make the metal rubber products that have been "trained" in advance can work reliably, the stamping pressure of the metal rubber products should generally be 6.7 times greater than the use load.

Through comparative analysis, it can be seen that the elastic deformation ability of metal rubber materials is mainly affected by the size of the load, and the elastic performance is stable within the range of the use load. At the same time, the compression set rate is less than that of rubber, and it has little relationship with the change of temperature. In order to increase the service life of the elastic damping elements manufactured by the metal rubber materials that are deformed by compression, that is, to increase the load cycle during elastic deformation, it is recommended to use the technology of armored compression springs to strengthen the internal structure of the metal rubber materials.

At the same time, it should be emphasized that because the internal structure of the metal rubber materials is mechanically interlaced hooks between the turns, its tensile strength is significantly less than the compressive strength. Although the use of high-energy electric pulse discharge strengthening technology can improve the tensile strength, but it is recommended to use the compression direction first.

3.5. Resistance to Harsh Environments

Compared with rubber materials, because metal rubber materials are made of high-strength metal wires that are suitable for harsh working environments, they have obvious working ability in harsh environments such as space radiation, oil pollution, acid corrosion, salt spray, mold, high and low temperature, etc. At the same time, it is better than rubber materials in terms of fatigue aging life and long-term storage. Therefore, the application range of metal rubber materials is significantly wider than that of rubber materials, and it is more suitable for working in a variety of very harsh environments.

4. Conclusions

Based on the comparative analysis of rubber materials and metal rubber materials, the following results can be found, rubber materials have certain advantages in terms of product molding ability, maximum loss factor and tensile strength; but in terms of compression strength, fatigue aging life, and stability of elasticity and damping characteristics, especially in terms of resistance to harsh working environments, metal rubber materials have obvious advantages.
5. References

[1] Jianzhong Wu 2009 Design and research of type III track shock absorber fasteners (Beijing: Beijing Jiaotong University)

[2] Hongyuan Jiang 2001 Research on manufacturing technology and application of metal rubber J. Mechanical Engineer 35 pp35-36

[3] Kongyong Lin 1989 Rubber Industry Handbook vol 6 (Beijing: Chemical Industry Press)

[4] Zhongying Li 2000 Design of Metal Rubber Components (Beijing: National Defense Industry Press)

[5] Hongrui Ao 2003 Research on dry friction damping mechanism and application of metal rubber (Harbin: Harbin Institute of Technology)

[6] Junfang Hou 2018 Research on energy consumption and fatigue characteristics of metal rubber materials in high and low temperature environments (Shijiazhuang: Ordnance Engineering College)

[7] Huirong Hao 2019 Research on elasticity, energy dissipation and fatigue characteristics of non-circular cross-section wire metal rubber (Shijiazhuang: Ordnance Engineering College)