Study on Performance Optimization and Physical Properties Testing of a New Type of High Thermal Conductive Damping Coating

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Abstract. Surface coating of damping paint is a common method to suppress structural vibration and reduce noise, but damping paint has poor thermal conductivity which limits its application to transformers, reactors and other equipment that have high requirements for heat dissipation. In this paper, a new type of high thermal conductivity damping coating is prepared by emulsion polymerization, among which, a polyurethane emulsion with internal cross-linking structure and an acrylic emulsion with polymerization function are used as main agents, mica powder is used as the main damping function filler. By adjusting the proportion of non-metallic thermal conductive filler Al₂O₃ and thermal conductive fiber to explore the influence of different thermal conductive fillers on the thermal conductivity and damping performance of the damping coating. The paint is applied to aluminum and iron plates, and the sound insulation capacity is tested to study the influence of paint thickness, fiber addition, fiber type, viscoelasticity, and temperature aging on the sound insulation performance of damping sound insulation panels. The test results show that by adding thermally conductive filler Al₂O₃ and thermally conductive fibers, a thermally conductive network chain is formed inside the damping coating, which greatly improves the thermal conductivity of the coating while ensuring the damping performance and the effect of vibration and noise reduction.

Keywords: Damping coating; The conductivity; Damping performance; Sound insulation performance

1. Introduction

With the development of society and the improvement of industrialization, noise pollution has become more and more serious, which has seriously affected people's normal life and work. The noise control methods of electrical equipment can be roughly divided into two types: sound source control and transmission path control. The sound source control is to reduce the body noise of the equipment by adopting new technologies and new materials, and transmission path control is to block the propagation of noise by setting up acoustic enclosure, sound barriers or firewalls.
Coating a layer of damping paint on metal structures, such as pipes, equipment shells, metal sound barrier surfaces, etc., is a commonly used effective measure to suppress structural vibration and reduce noise. However, the commonly used damping paint has poor thermal conductivity, which limits its application on transformers, Reactors and other equipment that have high requirements for heat dissipation. Some scholars have proposed some methods to improve the heat dissipation of the damping coating, such as adding aluminum powder and zinc powder to the coating, scholars have proposed some methods to improve the heat dissipation of the damping coating, such as adding aluminum powder and zinc powder to the coating, scholars have proposed some methods to improve the heat dissipation of the damping coating, such as adding aluminum powder and zinc powder to the coating, nevertheless, on one hand, metal powder is not easy to stir uniformly to form local deposits, on the other hand, effective contact with each other can't be formed, which result in poor heat dissipation.

In this study, a new type of high thermal conductivity damping coating was prepared by using a polyurethane emulsion with internal crosslinking structure and an acrylic emulsion with polymerization as the main agent, and mica powder as the main damping functional filler. The effect of thermally conductive fillers on the thermal conductivity and damping performance of damping coatings is explored by changing the type and proportion of thermally conductive fillers. The sound insulation of aluminum and iron plates coated with different ratio damping coatings which prepared by emulsion polymerization was tested. In addition, the effect of coating thickness, fiber addition, fiber type, viscoelasticity, and temperature aging on the sound insulation performance of damping sound insulation panels were studied.

Results indicated that, firstly, the thermal conductivity of the damping coating with graphene fiber is the best, and the aluminum fiber is the second. Secondly, the higher the thermal conductivity of the material, the damping peak appears at the higher temperature. Besides, it was observed that the sound insulation of the damping aluminum plate increases significantly with the increase of the damping thickness, and the low-frequency sound insulation is greatly improved. Furthermore, with the increase of aluminum fiber content, the low frequency sound insulation of damping aluminum plate and damping iron plate decreased, while the medium frequency sound insulation increased, and the same effect was observed with the increase of plasticizing dose.

2. Preparation of damping coating

2.1. Main experimental reagents and equipment

| Serial number | Name                          | Type         |
|---------------|-------------------------------|--------------|
| 1             | Polyurethane emulsion         | WE2150       |
| 2             | Acrylic emulsion              | R-20         |
| 3             | Mica powder                   | 2000 mesh    |
| 4             | micro particles of Al\text{2}O\text{3} | 10\text{μm} |
| 5             | Aluminum fiber                | 90\text{μm}  |
| 6             | Graphene                      | 5/50\text{μm} |
Table 2. Damping coating group distribution ratio

|     | Hypokeimenon(g) | Al_2O_3(g) | Carbon black(g) | Alumin-um fiber(g) | Graphene(g) | Plasticizer(g) |
|-----|-----------------|------------|-----------------|--------------------|-------------|----------------|
| 1   | 600             | 30         | /               | /                  | 15          | 30             |
| 2   | 600             | 30         | /               | /                  | 30          | 30             |
| 3   | 600             | 30         | /               | /                  | 60          | 30             |
| 4   | 600             | 30         | /               | /                  | 30          | 60             |
| 5   | 600             | 30         | /               | 15                 | /           | 30             |
| 6   | 600             | 30         | /               | 30                 | /           | 30             |
| 7   | 600             | 30         | /               | 60                 | /           | 50             |
| 8   | 600             | /          | 30              | /                  | 15          | 50             |
| 9   | 600             | /          | 30              | /                  | 30          | 50             |
| 10  | 600             | /          | /               | 15                 | /           | 50             |
| 11  | 600             | /          | /               | 30                 | /           | 50             |
| 12  | 600             | /          | /               | 60                 | /           | 50             |

The aluminum content of aluminum fiber is more than 99.5%, the equivalent diameter is 90 microns on average, and the length is about 3 mm.

![Figure 1. Electronic scan of aluminum fiber](image)

2.2. The preparation process of damping coating

1) Preparation of dispersant

A certain amount of polyurethane emulsion and acrylic emulsion, which was weighed according to Table 3, was mixed and stirred at the speed of 1000 r/min to 1300 r/min for 25 to 35 minutes. Then, the mixed emulsion was stirred at the speed of 300 r/min to 400 r/min for 25 to 35 minutes after a certain amount of defoamer was added.

2) Addition of fillers and additives

Corresponding weight of mica powder, Al_2O_3 microparticles (carbon black), aluminum fibers (graphene) were added to the obtained dispersant slowly while stirring. And then, the speed was reduced to 100 r/min to 300 r/min for 30 minutes to 40 minutes.
3. The performance of damping coating

3.1. Thermal conductivity test
According to Standard GB/T 10297, the thermal conductivity of the samples at temperature of 40℃, 60℃, and 80℃ were tested using transient hot wire method by TC3200 thermal conductivity meter produced by Xi’an Xiaxi Electronic Technology Co., Ltd.

The test steps are as follows, place the sample as required, set the target temperature, wait for the temperature to rise, and perform thermal balance monitoring when the target temperature is reached. When the temperature fluctuation is less than 0.1k/10min, end thermal balance monitoring, set the measurement parameters and start the measurement. The measurement parameters are: repeat Test 5 times, with an interval of 3min, each acquisition time is 10s, and the test voltage is 1.2V.

3.2. Dynamic mechanical performance test
A The dynamic mechanical properties were tested with the DMA1 dynamic thermomechanical performance analyzer produced by Mettler Toledo, Switzerland. The range of temperature is -190 to 600 ℃, the heating rate is 0.1℃/min to 20℃/min, the range of force is 0.001N to 10N, the amplitude is ±1.0mm, the range of frequency is 0.001Hz to 300Hz.

3.3. Sound insulation performance test
According to the traditional function method, the impedance tube produced by Beijing Reputation Acoustics Technology Co., Ltd. is used to test the sound absorption and insulation capacity of the samples. When testing the sound insulation capacity, the test results of each sample are taken as the average of 5 tests.

3.4. Aging performance test
The aging performance of the samples was tested by the GZX-9240MBE digital display blast drying oven produced by Shanghai Boxun Industrial Co., Ltd. Medical Equipment Factory at the temperature of 80℃ for 72 hours, and then the sound insulation of the aging samples was tested.

4. Results and analysis

4.1. Analysis of thermal conductivity
Three thermally conductive fillers, including aluminum fiber, graphene, and carbon black were selected for comparison in order to explore the influence of different thermally conductive fillers on the thermal conductivity of damping coatings.

![Figure 2. Thermal conductivity of damping paint at different temperatures](image-url)
It can be seen from Fig 2 that the thermal conductivity of the damping coating with graphene fibers is the best, the thermal conductivity of which reach to 1.722 at 40°C, and it decreases as the temperature increases, and it drops to 1.584 at 80°C. The thermal conductivity of the damping coating with aluminum fiber is second, the thermal conductivity of which is 1.336 at 40°C, and the thermal conductivity is basically unchanged as the temperature increases. The thermal conductivity of the damping coating with graphene and carbon black is the worst, and it decreases slightly as the temperature increases. The result is closely related to the thermal conductivity of the three fillers. The thermal conductivity of graphene fibers is more than 600W/m•K. The thermal conductivity of aluminum fibers, alumina and carbon black is about 250W/m•K, 30W/m•K and 1.7W/m•K, respectively.

4.2. Damping performance analysis
1) The influence of temperature on damping performance
The damping performance of the material is significantly different under different ambient temperatures and frequencies. Three thermally conductive fillers including aluminum fiber, graphene, and carbon black were selected to test its Young's modulus and damping coefficient at different temperatures under the action of 100Hz excitation force, the results are shown in Fig 3.

![Figure 3. Damping coefficient of damping paint at different temperatures](image)

It can be seen from the Fig 3 that the higher the thermal conductivity of the material, the damping peak appears at the higher temperature.

The damping coefficient of the graphene fiber-added damping coating reaches to 0.66 at 70.30°C, and the Young's modulus decreases from about 200 MPa to about 30 MPa as the temperature rises. The
The damping coefficient of the damping coating with aluminum fiber reaches up to 0.72 at 59.73°C, the Young's modulus decreases from more than 100 MPa to more than 20 MPa as the temperature increases. The damping coefficient of the damping coating with graphene fiber and carbon black reaches to 0.49 at 48.47°C, and the Young's modulus decreases from more than 100 MPa to more than 20 MPa as the temperature increases. The low-frequency damping coefficient of the damping coating with aluminum fiber is the highest, followed by the damping coating with carbon black, and the worst with the graphene damping coating.

2) Influence of frequency on damping performance

The young's modulus and damping coefficient of three kinds of thermal conductive fillers including aluminum fiber, graphene and carbon black at 40°C were tested, the results are shown in Fig 4. It can be seen from the figure that the low-frequency damping coefficient of the damping coating added with aluminum fiber is the highest, followed by the damping coating added with carbon black, and the damping coating added with graphene is the worst.
4.3. Analysis of sound insulation performance

1) The influence of damping coating thickness on sound insulation

Damping plate samples with different damping coating thickness were prepared using NO.6 damping coating to paint on aluminum plate and iron plate with 1mm. The sound insulation of each sample is shown in the Fig 5.

It can be observed from Fig 5 that the sound insulation of the damping aluminum plate increases significantly with the increase of the damping thickness, and the low-frequency sound insulation is greatly improved. However, the increase rate decreases as the thickness increases. Besides, the sound insulation of the damping iron plate increases with the increase of the damping thickness, however, the increase rate of the sound insulation is smaller than that of the aluminum plate because of its relatively excellent performance in sound insulation. Compared with pure aluminum plate, the sound insulation of damping aluminum plate of 4mm damping coating is increased from 18.11dB to 41.45dB at 100Hz. In addition, the sound insulation of damping aluminum plate with 4mm damping coating is increased from 37.64dB to 42.59dB at 100Hz.

2) The effect of fiber addition on sound insulation

Figure 6. The influence of the amount of thermally conductive fiber on the sound insulation performance

It can be observed from Fig 5 that the sound insulation of the damping aluminum plate increases significantly with the increase of the damping thickness, and the low-frequency sound insulation is greatly improved. However, the increase rate decreases as the thickness increases. Besides, the sound insulation of the damping iron plate increases with the increase of the damping thickness, however, the increase rate of the sound insulation is smaller than that of the aluminum plate because of its relatively excellent performance in sound insulation. Compared with pure aluminum plate, the sound insulation of damping aluminum plate of 4mm damping coating is increased from 18.11dB to 41.45dB at 100Hz. In addition, the sound insulation of damping aluminum plate with 4mm damping coating is increased from 37.64dB to 42.59dB at 100Hz.
Damping plate samples with a total thickness of 4mm were prepared using NO.5, NO.6 and NO.7 damping coating to paint on aluminum plate and iron plate with thickness of 1mm. The sound insulation of each sample is shown in the Fig 6.

It can be seen from the figure that with the increase in the amount of aluminum fiber added, the low-frequency sound insulation of the damping aluminum plate and the damping iron plate are reduced, and the intermediate-frequency sound insulation has increased. For the damping aluminum plate, the sound insulation of it didn’t change much when the aluminum fiber addition amount is increased from 15g to 30g, however, it reduced from 41.57dB to 24.5dB at 100Hz as the amount was further increased to 60g. For the damping iron plate, the sound insulation of it reduced from 43.95dB to 32.78dB at 100Hz with the amount of fiber added is increased from 15g to 60g. It is inferred that the excessive addition of aluminum fiber improves the thermal conductivity and affects the overall compactness of the damping material, resulting in a decrease in low-frequency sound insulation.

3) The effect of fiber types on sound insulation

Damping plate samples with a total thickness of 4mm were prepared using NO.2 and NO.6 damping coating to paint on aluminum plate and iron plate with thickness of 1mm so as to study the effect of different thermally conductive fibers on the sound insulation. The sound insulation of each sample is shown in the Fig 7.

![Figure 7. The effect of fiber type on sound insulation performance](image)

![Figure 8. The effect of viscoelasticity on sound insulation performance](image)
It can be seen from the figure that the sound insulation of aluminum fiber is larger than that of the graphene fiber damping plate. The sound insulation of the damping aluminum plate with aluminum fiber and graphene fiber is 41.7dB and 31.45dB at 100Hz, respectively. Besides, the sound insulation of the damping iron plate with aluminum fiber and graphene fiber is 40.08dB and 36.68dB at 100Hz, respectively. The density of aluminum fiber is greater, on one hand, which makes the damping coating more dense, on the other hand, the large density difference with the matrix makes it easier to form interface reflection and loss.

4) The effect of viscoelasticity on sound insulation
Damping plate samples with a total thickness of 4mm were prepared using NO.6 and NO.11 damping coating to paint on aluminum plate and iron plate with thickness of 1mm so as to study the effect of viscoelasticity on the sound insulation. The sound insulation of each sample is shown in the Fig 8.

It can be observed from the figure that the low-frequency sound insulation of the damping aluminum plate and the damping iron plate are reduced, and the intermediate frequency sound insulation is increased as the amount of plasticizer increases.

The sound insulation of the damping aluminum plate with 30g plasticizer is 41.7dB at 100Hz, and it reduced to 34.05dB when the addition of plasticizer was increased to 50g. Besides, the sound insulation of the damping iron plate with 30g plasticizer is 40.08dB at 100Hz, and it reduced to 39.41dB when the addition of plasticizer was increased to 50g.

An increase in the amount of plasticizer will increase the elasticity of the damping coating, but it will reduce the plasticity of the coating, which make the performance of suppressing vibration and deformation deteriorate.

5) The influence of temperature aging on sound insulation
Damping plate samples with a total thickness of 4mm were prepared using NO.6 damping coating to paint on aluminum plate and iron plate with thickness of 1mm, which were placed in an oven at a temperature of 80°C and run continuously for 72 hours to investigate the changes in sound insulation. The sound insulation of each sample is shown in the Fig.9. It can be seen from the figure that temperature aging has little effect on the sound insulation of the damping aluminum plate and the damping iron plate.

![Figure 9. Influence of temperature aging on sound insulation performance](image)

5. Summary
In this study, a new type of high thermal conductivity damping coating was prepared by using a polyurethane emulsion with internal crosslinking structure and an acrylic emulsion with polymerization as the main agent, and mica powder as the main damping functional filler. The effect of thermally conductive fillers on the thermal conductivity and damping performance of damping coatings is explored by changing the type and proportion of thermally conductive fillers. The sound insulation of aluminum and iron plates coated with different ration damping coatings which prepared by emulsion
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