Research progress on application of spray-type damping coating

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Abstract. This paper analyzes the current control requirements of mechanical vibration and noise in the fields of ships. The author briefly introduces the working principle and main classification of damping coatings, and describes the current domestic and international aspects from the types of spray-type damping coatings and spraying processes. The research progress and application of spray-type damping coatings such as asphalt damping coating, PVC based damping coating, polyurethane based damping coating, waterborne acrylic based damping coating and IPN damping coating and metal alloy coating are reviewed. The development trend and application considerations are summarized in this paper at last.

1. Introduction

With the gradual development of modern society and the continuous upgrading of equipment, people have put forward higher requirements for noise control in facilities [1]. The vibration and noise of the ship during operation will not only cause structural damage and affect the normal operation of the equipment, but also easily cause damage to the life and health of the crew [2-4]. Spray-type damping paint, as a new type of lightweight, environmentally friendly, and good construction, has the advantage of better construction performance than traditional damping materials such as sheet profiles, damping steel plates, and non-spraying damping paints [5-7]. With the worldwide emphasis on environmental protection, the development of equipment and facilities should be overcome from the aspects of performance, light weight, and environmental protection. This article describes the introduction of damping materials, the research progress and construction methods of spray-type damping coatings, and comprehensively explores the development and application of spray-type damping coatings.

2. Introduction to Damping Technology

Damping technology is one of the important means to effectively control the vibration and noise generated by locomotives, ships and other equipment during operation [8-10]. At present, the commonly used damping materials are mainly sheet-like profiles such as asphalt and damping rubber sheets and damping coatings. The damping sheet profile often needs to develop different shapes of materials according to the structural requirements. The damping effect is good, but the raw materials have toxic sources, and usually need to use an adhesive to connect to the substrate. The temperature dependence is strong. There are certain restrictions on the use of closed environments. In addition, for complex structures, internal cabins or irregularly shaped areas, it is difficult to achieve effective full coverage of damping sheet profiles, and damping coatings can effectively solve the above problems [11-12]. Commonly used damping coatings currently use solvent-free resins and functional fillers, which have
large viscosity, and are mainly applied on-site by brushing, scraping, or roller coating.

Figure 1 (a) Solid asphalt mat (b) Damping rubber (c) Damping paint

3. Spray-type damping paint

Compared with traditional solid asphalt mats and rubber damping sheets, spray-type damping coatings further improve the coating's process performance on the basis of easy construction of the damping coatings, which can meet a variety of construction methods. As we all know, water-based coatings can reduce the risk caused by the volatilization of organic solvents during construction, and meet the requirements of national environmental protection regulations. High-damping, fast-drying water-based coatings are the current research hotspots of spray-type damping coatings.

3.1 Viscoelastic damping paint

Different from the structure-reinforced vibration and noise reduction method, spray-type viscoelastic damping paint uses the viscoelasticity of polymer materials. When subjected to external vibration, the mutual friction between polymer chains and chain will transform orderly mechanical energy into sequential thermal energy which will be dissipated, and the macroscopic performance is that the material cannot be recovered in time after being removed by external forces, which can effectively reduce structural vibration and noise [13-15]. Damping technology reduces vibration and noise without changing the original structural design and equipment position, and is especially suitable for shipbuilding and other industries with frame structures as the main body.

3.1.1 Asphalt damping paint

As the earliest representative of solvent-based damping coatings, bitumen-type damping coatings are composed of bitumen as the main material and a small amount of high-molecular polymers and fillers such as asbestos and silica. They are divided into heat-curing and room-temperature self-drying. Traditional asphalt-based damping coatings are inexpensive and have low construction requirements. They are often used to reduce mechanical vibration of diesel engines and generator bases. However, its further application is limited due to its high toxicity, low strength and poor damping effect. Zhang Bingzhu et al. [16] prepared an acrylic modified asphalt damping coating for vehicle bottoms, which was prepared by adding polymer emulsion, water-dispersed asphalt, fillers, and additives to the mixture and stirring well. The introduction of acrylic structure improves the elasticity of the coating and improves the damping performance of the coating. The loss factor is ≥0.5 at -15 °C ~ 60 °C. The surface state of the coating is intact after 50cm drop ball impact test.

3.1.2 PVC-based damping paint

PVC-based damping coatings are a class of solvent-free damping coatings made of polyvinyl chloride (PVC) polymer as a film-forming substrate and dispersed with plasticizers, functional fillers, additives, and curing agents. Solvent-free PVC plastisol appeared in Europe in the late 1960s, and is widely used in automotive anti-stone impact coatings and interior damping coatings due to its wide range of sources and good construction properties. The research of PVC-based damping paints in China only started in the late 1980s. Usually, after the primer is dried, the required parts are sprayed and heated to dry. There is still a hidden danger of releasing toxic substances in the long run.

Based on this, HaoTonghui et al. [17] prepared a water-based PVC-based damping coating. First,
Copolymerize sodium polyvinylbenzenesulfonate, polyacrylate, and polyvinyl chloride to obtain a hydrophilic dispersion PVC resin, and then mix it with vinyl chloride emulsion. The loose spherical PVC resin obtained by the method is compounded, and finally, plasticizers, fillers, lubricants, stabilizers and other additives are added, and sprayed on the surface of the substrate and baked at 120 ° C for 40 minutes to form. The acrylate in the resin base material has better plasticity to polyvinyl chloride, and the hydrophilic group contained in the sodium polyethylene benzene sulfonate can also change the coating into a hydrophilic dispersion type, thereby achieving low VOC green environmental protection. The elongation at break is 336%, the loss factor can reach 0.64, and the damping effect is good. This is mainly due to the large steric hindrance of sodium polyvinylbenzenesulfonate, and the molecular chains are easily entangled with each other, which increases internal friction between polymers. At the same time, the coating has high viscosity at low shear rate and low viscosity at high shear rate, and has good anti-sagging performance and sprayability.

![Figure 2 Schematic diagram of hydrophilic dispersion type PVC resin](image)

### 3.1.3 Polyurethane-based damping paint

Polyurethane molecules are composed of flexible soft segments and rigid hard segments, and contain a large number of hydrogen bonds and polar groups, and have high elasticity at room temperature. At the same time, the thermodynamic incompatibility between the hard segment and the soft segment results in a certain degree of micro-phase separation structure inside the polymer, so the damping loss factor is high, which is suitable for use as a resin base material for damping coatings. Polyurethane-based damping paint are a class of polymer damping materials that were studied earlier at home and abroad. This type of damping coating is mostly solvent-free, which makes spraying difficult.

Liang Longqiang et al. [18] prepared a Qtech-413 two-component solvent-free constrained damping coating based on polyurea technology, and controlled the micro-phase separation of the soft and hard segments through molecular structure design to achieve the purpose of wide temperature range and high damping. Component A is an isocyanate prepolymer, and component B is a combination of amino-terminated polyether, amine chain extender, and auxiliary agent. It can be sprayed with high temperature, high pressure, and impact mixing equipment, which has the characteristics of high efficiency, energy saving and no pollution. This product has been applied in the Qingdao subway tunnel, which can play an excellent vibration and noise reduction effect during the subway operation.

### 3.1.4 Water-based acrylic damping paint

Based on the above description, during the transition from the solvent-based to the solvent-free type of spray-type damping paint, although the adverse effects of volatile organic compounds on the environment and human health were gradually overcome, the higher paint viscosity brought about a certain problem for coating construction. At present, domestic research mostly focuses on water-based vibration-damping coatings, with a solid content of 60% to 80%. It is based on acrylate copolymer emulsion and added functional fillers and additives. It can be self-drying or drying. Water-based
acrylic-based damping coatings have obvious advantages over other water-based damping coatings, and there are also many examples of use at home and abroad.

Su Kun et al.\textsuperscript{[19]} prepared a sprayable liquid damping material with a high solid content based on an aqueous acrylic emulsion. The glass transition temperature (T\textsubscript{g}) of the resin was adjusted to meet the damping requirements of vehicles in cold and high-temperature weather. Compared with traditional asphalt damping coatings, this coating has a series of advantages such as low density, high damping, green environmental protection, construction safety, etc., one-time coating of 5 mm wet film without sagging, and it can form a stable film with excellent heat resistance, water resistance and mechanical properties under the condition of 140°C × 30 min. The damping loss factor of the coating in a wide temperature range is greater than 0.3, which has high practical value. Liao Meidong\textsuperscript{[20]} prepared a spray-type water-based acrylic damping coating. The composite loss factor of the coating at room temperature (10 ~ 30°C) is 0.05 ~ 0.14, larger than the solid damping pad. At the same time, the dry film density is smaller than the solid damping pad, and the weight can be reduced by 40% under the same thickness. This product is in the promotion stage and has not been applied on a large scale. The cost is higher than that of solid-state damping pads.

American PPG Commercial Company launched a water-borne spray-type acrylic damping coating Audioguard with vibration and noise reduction functions. The fiber and resin are combined and cured to prepare a hard coating, which can be covered by spraying or by means of spraying facilities to difficult-to-reach complex parts. As a water-based, zero-VOC product, it can achieve the purpose of reducing vibration and noise in a completely harmless way to the ecology and nature. The coating is suitable for fire fighting and emergency vehicles, and it can significantly reduce the noise of sirens and roads, thus giving the rescuers and patients a quiet driving environment.

3.1.5 IPN damping paint

Polymer viscoelastic materials have obvious damping properties, can convert vibration energy into heat energy within the glass transition temperature and release it, resulting in mechanical loss. The interpenetrating network polymer (IPN) damping material that has appeared in the past three decades refers to two or more polymers entangled with each other in the reaction stage to produce "forced mutual dissolution", which improves the compatibility between the components and can be significantly broadened. The damping temperature range of the coating is significantly improved and the performance of the coating in terms of damping, corrosion resistance and heat resistance are also improved.

Qingdao Aierjiajia\textsuperscript{[21]} launched an Air ++ 3101 one-component multifunctional water-based damping coating, which is composed of a core-shell IPN acrylic emulsion, damping pigments, fillers, flame retardants and additives. With water as the solvent, it is non-toxic and has no odor. It can play a role in vibration and noise reduction in a wide temperature or wide frequency range. Adopting spraying or scraping construction method, it has been used to reduce vibration and noise of ships, railway locomotives, passenger cars and other equipment. It has excellent damping and silencing effects. At the same time, the dry film has good flame retardancy and can withstand gas cutting and welding operations. Zhuang Jianhuang et al.\textsuperscript{[22]} prepared a polyurethane-epoxy interpenetrating network polymer corrosion-resistant damping coating, by combining epoxy resin with high modulus, high connection strength, good corrosion resistance and polyurethane with excellent damping properties to obtain transparent IPN polymers. Studies have shown that when the mass ratio of polyurethane to epoxy resin is 7:3, the material has the best damping performance and corrosion resistance, and the loss factor tan\(\delta\) can reach 0.96. At the same time, the coating remains intact after 600 hours of artificial seawater resistance, which can effectively improve the vibration and noise of marine machinery and equipment, and maintain good corrosion resistance.

3.2 Metal alloy coating

Hard coatings such as metals and ceramics have good damping properties and can absorb part of the vibration energy to reduce vibration stress. In contrast, non-metallic damping materials are lightweight, and their damping performance is often tens or even hundreds of times that of metal
coatings. Some special metal materials (such as Mg, Mn-Cu, Ti-Ni, Cu-Al-Ni, Al-Zn, Mg-Zr) and other alloys have higher damping factors and are called high-damping metals or high-damping alloys [23]. The metal damping coating can overcome the shortcomings of low strength and poor heat resistance of non-metallic damping materials, and is widely used in the aerospace field, which greatly reduces the possibility of vibration damage failure of engine parts.

4. Spray method

Because spray-type damping paints are all high-viscosity, uniform fluids, it is difficult for the paint to flow at low shear rates. When the applied shear stress exceeds the minimum stress in the paint, the paint can flow. At present, high-pressure airless spraying is used for viscoelastic damping coatings, and plasma spraying is used for metal coatings.

4.1 Air spraying

Air spraying is a common construction method in the coatings industry. The spraying operation is carried out by atomizing the coating with compressed air. This method is relatively easy to operate and can choose paint spraying conditions arbitrarily, which is especially suitable for the shipbuilding industry, but air spraying is only for damping paints with relatively low viscosity, and the construction range is limited.

Beijing RongliHengye has developed a sprayable RLHY-52 damping coating, which can also be directly painted on the surface of the substrate to meet the sound insulation and noise reduction of large equipment such as ships and trains. However, the decrease in paint viscosity often results in poor thick paintability and prolonged construction period. Therefore, it is necessary to carry out research on the spraying process of conventional damping paint with large viscosity.

4.2 High-pressure airless spraying

High pressure airless spraying is a construction method that does not use compressed air as power and relies on the coating to form atomization under high pressure. It is suitable for damping coatings with high viscosity. When the high-pressure pump applies high pressure to the thick coating (11 ~ 31MPa), the high-pressure fluid will swell sharply due to the sudden drop in pressure after spraying out of the nozzle. The fluid will break up to form fine droplets to atomize, while retaining enough kinetic energy to make the coating particles splash onto the surface of the substrate.

Robot spraying construction is currently the main construction method of spray-type damping coatings [24-25]. The equipment is mainly divided into glue supply and conveying system, temperature control system, flow control system and robot spraying system. Before construction, the construction area of the robot should be simulated. During the process, pay attention to put the gun head into the water to keep the gun head wet and clean it in time. Finally, in order to avoid cracking, blistering, and incoherence of the damping coating, the robot spray thickness should be reasonably set.

Figure 3 Schematic diagram of robot spraying simulation
4.3 Plasma spraying

Plasma spraying heats metal powders with damping properties through the center of the plasma arc flame flow to a molten or semi-melted state, which is sprayed at high speed with the flame flow and deposited on the surface of the pretreated workpiece. After plasma spraying, the metal coating has high density, high adhesion strength, and smoothness, which can effectively ensure the effective exertion of the coating's damping performance.

![Image of metal coating cross-section](image)

Figure 4 Cross-section view of metal coating after plasma spraying [26]

5. Conclusion

The development of spray-type damping coatings has gone through the development of solvent-based, solvent-free, water-based development to meet the requirements of environmental protection. As the main representative of spray-type damping coatings, water-based acrylic-based damping coatings have obvious weight reduction effects and a wide range of applications, which can meet the vibration damping requirements of metal substrates, and have a low VOC content, and meet the requirements of environmental protection.

However, water-based acrylic-based damping coatings often need to be cured at high temperatures quickly, which has certain limitations for the application of large steel structures such as ships. The two-component solvent-free polyurethane-based and water-based polyurethane-based damping coatings can quickly form films at room temperature, and have wider application prospects in the marine field. However, although solvent-free polyurethane-based damping coatings are easy to be thickly applied at room temperature, they often have high viscosity, which brings certain difficulties to spraying operations; while water-based polyurethane-based damping coatings are easy to crack when a single film is formed, resulting in internal defects in coating. Based on this, how to improve the film-forming process of spray-type damping paint and increase the spraying efficiency of damping paint should be the main research direction of scientific researchers in the next stage.

References

[1] Yu Jie, Zhan Fengchang. Influencing factors of damping performance of damping coatings [J]. Coating Industry, 1994, 4: 1-4.
[2] Zhang Ping, Yu Quanhu. Brief analysis of ship vibration and noise reduction measures [J]. Jiangsu Shipbuilding, 2010, 27 (3): 1-4.
[3] Wang Ying, Zhou Chunyan, Liu Huarong. Preparation and performance testing of environmentally-friendly noise-reducing coatings for ships [J]. Experiment Research and Application, 2013, 16 (6): 9-15.
[4] Kim W, Argento A, Mohanty P S. Damping characteristics of a spray-deposited shape memory alloy beam [J]. Journal of Sound and Vibration, 2014, 333: 3356-3366.
[5] Yu L M, Ma Y, Zhou C G et al. Damping efficiency of the coating structure [J]. International Journal of Solids and Structure, 2005, 42 (11-12): 3045-3058.
[6] Chen Y G, Wu H C, Zhai J Y et al. Vibration reduction of the blisk by damping hard coating and its
intentional mistuning design [J]. Aerospace Science and Technology, 84: 1049-1058.

[7] Xi Hongpeng, Zhou Gaoliang, Chen Sijun, etc. Talking about the application of LASD material in automobile manufacturing [J]. Modern Painting, 2016, 19 (8): 70-72.

[8] Wang F, Guo L H, Qiu T et al. A direct polymerization approach toward hindered phenol / polymer composite latex and its application for waterborne damping coating [J]. Progress in Organic Coating, 2019, 130: 1-7.

[9] Deng Y J, Zhou C, Zhang M Y et al. Effects of the reagent ratio on the properties of waterborne polyurethanes-acylate for application in damping coating [J]. Progress in Organic Coating, 2018, 122: 239-247.

[10] Limarga A M, Duong T L, Gregori G et al. High-temperature vibration damping of thermal barrier coating materials [J]. Surface and Coatings Technology, 2007, 202 (4-7): 693-697.

[11] Zhou Xin, Xiao Xinxiao, Wang Ruigan, et al. Effect of spray damping thickness on wheel vibration and sound radiation [J]. Noise and Vibration Control, 2014, 34 (4): 48-55.

[12] Yang Baojun. Feasibility analysis of spray-type damping material [J]. Automotive Materials and Coatings, 2017, 23: 31-33.

[13] Man Zhongbiao, Zhan Nana, Guo Cheng et al. Research progress of silicone rubber damping materials [J]. World Rubber Industry, 40 (1): 15-19.

[14] Huang Zhili, Zhang Congli, Zheng Shuoring, et al. Research progress on polyurethane damping materials [J]. Thermosetting Resin, 25 (4): 49-52.

[15] Yang Kai, Yin Wenqing, Li Qinlong, et al. Development of waterborne deck damping coatings [J]. Chemical Technology, 2014, 22 (3): 19-22.

[16] Zhang Bingzhu, Tang Erjun, Fu Chaoxia, etc. Acrylic modified asphalt vehicle bottom coatings [J]. China Coatings, 2001, 5: 26-28.

[17] Hao Tonghui, Huang Yi, Zhang Qunchao. A damping composition containing a hydrophilic dispersion type PVC resin and its preparation method [P]. Application No.: 201811166850.3.

[18] Liang Longqiang, Huang Jian, Huang Microwave, etc. Construction Technology and Quality Control of Spraying Viscoelastic Damping Materials in Qingdao Metro [J]. Advanced Chemical Materials, 2017, 45 (1): 228-230.

[19] Su Kun, Li Yonggang, Wu Xiangdong, et al. Preparation and properties of new sprayable and damping materials [J]. Experimental Research and Application, 21 (6): 12-14.

[20] Liao Meidong, Lin Xiaowei, He Kaixin, et al. Research and application of spraying water-based acrylic liquid damping material [J]. Modern Painting, 2017, 20 (11): 70-72.

[21] Li Deliang, Guo Yan, Wang Baozhu. Application of New Damping Coatings in Ship Vibration and Noise Reduction [J]. Environmental Engineering, 2014, 32: 163-167.

[22] Zhuang Jianhuang. Preparation and Characterization of Polyurethane-Epoxy Interpenetrating Network Polymer Corrosion Damping Coatings [J]. Materials Protection, 2019, 52 (1): 65-69.

[23] Pakkirappa H, Mahesha K, Sachidananda K B. Vibration damping behavior and surface characterization of magento-mechanical powder coated AISI304 stainless steel [J]. Surface and Coatings Technology, 2017, 324: 382-389.

[24] He Bin, Xiao Qihong, Li Xuan, et al. Application of new water-based damping materials in automotive coatings [J]. Coating Industry, 2014, 44 (6): 61-64.

[25] Zhao Changhu, Liu Huilin, Wang Nan, etc. Application of environmentally-friendly water-based sprayable vibration-damping materials on car bodies [J]. J Technology Applications, 2016, 1: 50-57.

[26] Yu L M, Ma Y, Zhou C G et al. Damping capacity and dynamic mechanical characteristics of the plasma-sprayed coatings [J]. Materials Science and Engineering A, 2005, 407: 174-179.