Experimental study on resistance stability and durability of road active deicing conductive Ethylene Propylene Diene Monomer rubber composites

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Abstract. Active deicing is the main way to deal with snow and ice disaster now. In order to realize the purpose of active heating deicing, a kind of Ethylene Propylene Diene Monomer (EPDM) multilayer composite with conductivity is proposed in this paper. The resistance stability of conductive EPDM rubber composite is measured after pressure sensitivity, freezing-thawing cycle and high-temperature tests. The results show that the conductive EPDM rubber composite developed in this paper has good compression stability and good resistance durability after low temperature freezing-thawing cycle and high-temperature test.

1. Introduction

Road ice and snow disasters have been affecting many regions in the world, seriously affecting the normal operation of traffic. In order to realize the rapid snow melting and deicing on roads, countries have adopted artificial snow removal, chemical snow removal, heat pipe method and more and more widely used electric heating snow melting and deicing methods. Artificial and mechanical snow removal is slow in work efficiency and consumes a lot of manpower and material resources. At the same time, there are serious safety risks in the process of snow removal. Therefore, chemical deicing method[1, 2] has been widely used. Chemical deicing method can effectively solve the problem of road icing, but the presence of chemical ions has caused serious impacts on roads, bridges[3, 4] and the surrounding environment[5]. Based on the above problems, more and more scholars began to study the use of active deicing.

Active deicing material is an important part of road active deicing. The resistance of carbon fiber sheet is low. Therefore, Lim et al.[6] added carbon fiber sheet directly to the concrete. It was able to melt snow and remove ice from roads, but it did not protect the carbon fiber cloth. Carbon fiber thermal conductor is a material with low resistance and insulation protection. Yang et al.[7] added carbon fiber wire to asphalt concrete to prepare a conductive flexible material. It is concluded that the prepared conductive flexible material has good durability and it is an effective active deicing material for road. There are many researches on the addition of conductive materials such as steel fiber[8, 9], graphite[10] into asphalt concrete. However, due to the poor conductivity of concrete, a large amount of conductive materials are needed to effectively achieve the purpose of low resistance. Therefore, more studies have been made on the preparation of low resistance composites by adding conductive materials to polymer materials such as rubber.

At present, more conductive materials such as conductive carbon black[11], nickel-plated graphite[12] and metal[13] are added to rubber materials to prepare conductive composites. Hsiao et
al.[14] added single-wall nanotubes to fluoro rubber to prepare porous conductive composites. The pressure test verified that the composites had good resistance stability and shape recovery. Athawale[15] prepared steel fiber silicone rubber composite material. The results showed that the resistance value of the composite material decreased sharply after adding steel fiber, and it had good conductivity under various loads. Huang[16] studied the pressure-sensitive properties of composites filled with conductive fillers of different contents, and also studied the influence of temperature on the conductivity of pressure-sensitive composites.

The conductive composite material has good mechanical properties and durability, which has good development potential in the study of road snow melting and deicing. In this study, a conductive EPDM rubber composite material with stable resistance was proposed. Carbon fiber cloth with low resistivity was added to EPDM rubber to produce a multilayer conductive composite material through high temperature and high pressure. The uniaxial compression test was used to test the resistance stability of the conductive composite material after different compression deformation, and then the resistance changes were measured through freezing-thawing cycle and high-temperature test. The results show that the conductive EPDM rubber composite has good resistance stability and durability, and can be used for a long time in road.

2. Materials

The conductive Ethylene Propylene Diene Monomer (EPDM) rubber composite studied in this paper is used as active snow removal and ice melting material for road. Among them, carbon fiber cloth with high conductivity and good mechanical strength (Yuezhi Industrial Company, Shanghai, China) is woven from 12k carbon fiber, and carbon fiber cloth is used as the heat-producing layer of composite materials. Because the EPDM rubber (Sanhe Great Wall Rubber Company, Hebei, China) has a low cost and is easy to use, it is used as a protective and bonding material for carbon fiber cloth. The mechanical strength of the composite was improved by adding carbon black and vulcanizing agent dicumyl peroxide (Kaiyin Chemical Company, Shanghai, China) to EPDM. Finally, the conductive EPDM rubber composite was obtained under high temperature and high pressure.

3. Experiments

Conductive EPDM rubber composites are used as active snow and ice removal materials in roads, so it is of great significance to study the resistance stability of the composites after compression. The compression samples were prepared according to the compression test size of the electronic universal testing machine (Mettes Test Machine factory, Tianjin, China), which were Φ70×6.5 mm. And the electrodes were installed on both sides of the samples. The conductive EPDM rubber composite material was placed in the universal testing machine, and the variation of resistance value of the sample was recorded by a multimeter (Figure 1).

![Figure 1. Pressure sensitive test of conductive composite.
Because northeast China is an obvious region of seasonal frozen soil, the stability of resistance of composites after freezing-thawing cycle was studied. The samples were placed in a refrigerator at -20°C.
(Figure 2). After being frozen for 24 hours, the samples were taken out and placed at room temperature at 25°C for 24 hours, and repeated for 20 times. A multimeter was used to measure the resistance value of the samples every 5 cycles, and three parallel samples were used for each batch to record the change of resistance value of the samples after 20 freezing-thawing cycles.

4. Results and discussions

4.1. Resistance and pressure sensitivity test of conductive composites

Figure 4 shows the relationship between the strain and resistance of conductive EPDM rubber composites after compression deformation. As can be seen from the figure, the strain of the composite material increases with the increasing pressure. In the initial stage, the resistance of conductive composites have no obvious changes, has maintained a 2.2 Ω. When the strain reaches 0.2, the resistance value of the composite material decreases. Until the strain is 0.3, the resistance to 2.1 Ω. After surging pressure, resistance of the composite material has not changed. After unloading the conductive resistance of EPDM composites back to 2.2 Ω. After three times pressure experiments, the change form of resistance value kept the same change trend, and the change rate of resistance value was 4.5%, and no change occurred after the strain reached 0.3.
4.2. Resistance durability test study after freezing-thawing cycle

As you can see from Figure 5, after 5 freeze-thaw cycles, the resistance of the composite has not changed, still 6.4 Ω. But after 10 cycles, resistance to 6.5 Ω. After 15 and 20 times cycles, resistance has not changed. After 20 freezing-thawing cycles, the resistance value of the conductive composite changed to 1.6%, which had little influence on the stability of the circuit and could be basically ignored. During the freezing-thawing cycle, the external moisture cannot enter into the composite material, so there will be no change in the composite material structure, which has little influence on the resistance value of the conductive composite material. Therefore, the conductive EPDM rubber composite material in the actual use of the process, because the low temperature environment will not cause a large change in the resistance. It ensures that the purpose of melting snow and melting ice can be realized stably in the process of melting snow and deicing, and proves the feasibility of using composite materials in extreme environments.

4.3. Resistance durability test study after high-temperature

As can be seen from Figure 6, the resistance value of the conductive composite fluctuates with the increase of heating time. After 120 h after high temperature, resistance 6.4 Ω remain the same. Because the conductive EPDM rubber composite is vulcanized at 160℃, it is less sensitive to temperature. So, it can ensure that the properties of the material change slightly in the environment below the preparation temperature. In practice, the temperature in northeast China rarely exceeds 60℃. Therefore, after the treatment at 60℃ for 120 h, the resistance value of the composite material changed little, indicating that the resistance durability of the composite material is relatively good, which can meet the requirements of long-term use in the road.

5. Conclusion

A conductive Ethylene Propylene Diene Monomer(EPDM) rubber composite with low pressure sensitivity and good resistance durability was prepared. The resistance stability of the composite was studied by compression test. With the deformation of the composite increasing, the resistance value changed by 4.5%, the resistance value returned to the initial resistance value after unloading. Through
freezing-thawing cycle and high temperature tests, the resistance durability of conductive EPDM rubber composite was studied. After repeated cycles at low temperature and high temperature, the resistance value of the composite unchanged. The results show that EPDM rubber is a kind of composite material with non-significant pressure sensitive characteristics, which will not cause circuit fluctuation due to the action of vehicle load during using, ensuring that the composite material can provide heat continuously and realize the purpose of melting snow and ice. The conductive EPDM rubber composite has good resistance stability and durability, which can effectively realize ice melting, and has a broad prospect in the future road deicing.

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References
[1] L.F. Yan X, Liu T, Zhang Y, Ma X and Wang X, Effects of deicing chemicals on ecological environment., Chin J Ecol, 27 (2008) 2209-2214.
[2] J. Espinha Marques, J.M. Marques, A. Carvalho, P.M. Carreira, R. Moura, C. Mansilha, Groundwater resources in a Mediterranean mountainous region: environmental impact of road de-icing, Sustainable Water Resources Management, 5 (2017) 305-317.
[3] A. Poursaee, A. Laurent, C.M. Hansson, Corrosion of steel bars in OPC mortar exposed to NaCl, MgCl2 and CaCl2: Macro- and micro-cell corrosion perspective, Cement and Concrete Research, 40 (2010) 426-430.
[4] F. Pruckner, O.E. Gjørv, Effect of CaCl2 and NaCl additions on concrete corrosivity, Cement and Concrete Research, 34 (2004) 1209-1217.
[5] G.R. Hopkins, S.S. French, E.D. Brodie, Jr., Increased frequency and severity of developmental deformities in rough-skinned newt (Taricha granulosa) embryos exposed to road deicing salts (NaCl & MgCl2), Environmental pollution, 173 (2013) 264-269.
[6] T.Y. Yang, ZJ; Singla, M; Song, GB; Li, Q, Experimental Study on Carbon Fiber Tape-Based Deicing Technology, JOURNAL OF COLD REGIONS ENGINEERING, 26 (2012) 55-70.
[7] J. Yang, X. Zhu, L. Li, H. Ling, P. Zhou, Z. Cheng, A. Su, Y. Du, Prefabricated Flexible Conductive Composite Overlay for Active Deicing and Snow Melting, Journal of Materials in Civil Engineering, 30 (2018) 04018283.
[8] J. Gao, H. Guo, X. Wang, P. Wang, Y. Wei, Z. Wang, Y. Huang, B. Yang, Microwave deicing for asphalt mixture containing steel wool fibers, Journal of Cleaner Production, 206 (2019) 1110-1122.
[9] T.M. Phan, D.-W. Park, T.H.M. Le, Crack healing performance of hot mix asphalt containing steel slag by microwaves heating, Construction and Building Materials, 180 (2018) 503-511.
[10] B.C. Bai, D.-W. Park, H.V. Vo, S. Dessouky, J.S. Im, Thermal Properties of Asphalt Mixtures Modified with Conductive Fillers, Journal of Nanomaterials, 2015 (2015) 1-6.
[11] J. Zhang, S. Feng, X. Wang, DC current voltage characteristics of silicone rubber filled with conductive carbon black, Journal of Applied Polymer Science, 94 (2004) 587-592.
[12] L. Valenta, A. Bojtos, Mechanical and Electrical Testing of Electrically Conductive Silicone Rubber, Materials Science Forum, 589 (2008) 179-184.
[13] W. Xiao, Y. Lei, Z. Xia, X. Chen, Y. Han, J. Nie, Effect of silver plating time on the properties of conductive silicone rubber filled with silver-coated carbonyl nickel powder, Journal of Alloys and Compounds, 724 (2017) 24-28.
[14] F.-R. Hsiao, I.F. Wu, Y.-C. Liao, Porous CNT/rubber composite for resistive pressure sensor, Journal of the Taiwan Institute of Chemical Engineers, 102 (2019) 387-393.
[15] A.A. Athawale, A.M. Joshi, Electrically conductive silicone rubber–steel fibre composites, Journal of Elastomers & Plastics, 44 (2012) 325-334.
[16] Y.X. Huang, B; Ming, XH; Fu, XL; Ge, YJ, Conductive Mechanism Research Based on Pressure-Sensitive Conductive Composite Material for Flexible Tactile Sensing, 2008 International Conference On Information And Automation, 1-4 (2008) 1614-+. 