Effect of Carbon Fiber on Microwave Deicing Efficiency of Pavement Concrete

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Abstract. Snow and icing on roads in winter will bring serious consequences to traffic safety. Microwave deicing, as a new type of environmentally friendly road surface deicing method, has the characteristics of environmental protection, pollution-free, and high ice removal rate, but its low deicing efficiency limits its use. Carbon fiber has good electrical and thermal conductivity, wear resistance, etc., and can provide a new composite material for road surface deicing. Taking carbon fiber concrete as the research object, the effect of different carbon fiber length on the microwave heat absorption efficiency of concrete is studied. The results found that: as the length of carbon fiber increases, the temperature rise at the same time increases exponentially, the higher the efficiency of carbon fiber concrete for absorbing and heating.

Keywords. Carbon fiber, concrete, microwave deicing, heat absorption efficiency

1. Introduction

In winter, the phenomenon of road area freezing in the colder areas of our country is widespread. In recent years, the south has also encountered heavy snowfalls many times, causing huge losses [1]. At present, the common deicing methods mainly include artificial deicing, mechanical deicing and chemical deicing [2]. Manual deicing refers to the use of shovels, blades and other tools to remove snow and ice on the road surface, and is usually suitable for small-scale removal. Mechanical deicing refers to the use of large mechanical devices instead of manpower to remove snow and ice on road surfaces. The chemical deicing method refers to spreading chemical reagents on the road surface to reduce the freezing point, so as to achieve the purpose of deicing, but the long-term use of chemical reagents will cause different degrees of corrosion on the road surface [3, 4]. Therefore, finding an efficient and environmentally friendly deicing method has become an issue of increasing concern [5].

Microwave deicing technology mainly relies on the principle of microwave selective heating [6]. When microwaves melt snow and ice, road icing hardly absorbs microwave energy, so microwaves can penetrate ice. Because road materials can absorb microwave energy, microwaves can heat the road surface layer. After the road layer absorbs microwave energy, it converts it into heat energy, thereby heating the ice layer to melt [7]. After the idea of using microwaves to heat and de-ic the road surface was proposed, many scholars have paid attention. In 2012, Dedong Guo et al. [8] conducted an experimental study on snow melting and deicing technology based on the coupling effect of microwave and magnet, and found that the microwave heating efficiency of magnetite aggregate is 20 times higher than that of ordinary aggregate. The efficiency of microwave heat absorption is 10-30 times higher than that of ordinary asphalt concrete. In 2018, Junliang Liu et al. [9] studied the effect of different iron black content on concrete microwave deicing, and concluded that the more iron black content, the better the microwave deicing efficiency. In 2020, Haowen Chen et al. [10] studied the
influence of different microwave absorbing admixtures on the microwave heating efficiency of concrete pavement. After comparative experiments, it was found that after adding Fe3O4, the concrete strength changed little, and the microwave heating effect and deicing effect were better. It is good. These scholars have studied the effects of different types of wave absorbing agents on the efficiency of microwave deicing, but there are few studies on the microwave heat absorption efficiency of concrete with different carbon fiber lengths. They only focus on the comparison of simple carbon fiber concrete and ordinary concrete microwave deicing efficiency, but not study the length of carbon fiber and the temperature distribution of the concrete surface after wave absorption. Therefore, this article has carried out research on the microwave heat absorption efficiency of concrete mixed with different length carbon fiber.

As a new generation of composite material reinforced fiber material, carbon fiber has the characteristics of high strength ratio, low density, corrosion resistance, ablation resistance, good electrical and thermal conductivity, and small heat transfer coefficient, which can effectively improve the efficiency of concrete microwave deicing [11-13]. This experiment takes the concrete mixed with carbon fiber as the research object, mixed with carbon fibers of different lengths, and tests the changing law of the microwave deicing efficiency of carbon fiber concrete with different lengths, and observes the deicing effect of different length carbon fiber concrete.

2. Experiment

2.1. Selection of Raw Materials

The raw materials used in the preparation of concrete specimens are: cement, sand, gravel, water, water reducing agent, and carbon fiber. Ordinary Portland cement (PO) is used for cement; Bahe natural sand is used for fine aggregate; limestone crushed stone produced by a hammer crusher is used for coarse aggregate. In this paper, coarse aggregate is divided into large stone (20~40 mm) and medium stone (10~20 mm), small stones (5~10 mm); the mixing water is tap water supplied from Baqiao District, Xi'an; the water reducing agent is PCA type polycarboxylic acid water reducing agent produced by Shaanxi Zhongyi Chemical Co., Ltd. The content of carbon fiber is selected to account for 0.3% of the concrete volume, and the length of carbon fiber is 0.1 cm, 0.3 cm, and 0.6 cm. The concrete mix ratio used in the experiment was designed according to JGJ 55-2011 "General Concrete Mix Ratio Design Regulations" [14]. In the end, the weight of each component is as shown in table 1:

| Component     | Cement | Water | Sand | Stone | Water reducing agent | Carbon fiber | Total |
|---------------|--------|-------|------|-------|----------------------|--------------|-------|
| Quality /kg   | 320    | 140   | 592  | 1377  | 3.52                 | 4.86         | 2432  |

2.2. Specimen Preparation and Test Equipment

2.2.1. Specimen Preparation Process. In this paper, the size of the concrete specimen is designed to be 50cm×50cm×5cm, and the corresponding size plastic mold is made, as shown in figure 1. The preparation process of concrete refers to the preparation process of cement concrete in the actual project, which mainly includes seven steps of raw material preparation, metering, mixing, charging, vibrating, curing and demoulding.
2.2.2. Specimen Equipment and Test Methods. The test was carried out using an open microwave deicing test system designed independently. The system consists of a magnetron, self-designed open microwave deicing equipment, optical fiber temperature sensor, etc. The optical fiber sensor is a YL-PL passive optical fiber temperature sensor, which is used to measure the temperature at a certain point on the upper surface of the concrete specimen. A paperless recorder is used to store temperature data.

Carry out absorbing and heating tests with different carbon fiber lengths. The length of the carbon fiber is 0.3 cm, and the height of the horn of the microwave emission source from the surface of the concrete specimen is 20 mm, as shown in figure 2. Use optical fiber sensor and paperless recorder to measure temperature rise curve.

3. Test Results and Analysis

3.1. Analysis of Temperature Rise Curves of Concrete Specimens with Different Lengths of Carbon Fiber

Place the optical fiber temperature sensor on the center point of the concrete specimen surface, irradiate it for 90 s, and record it every 1 s. Each group of specimens is subjected to five repeated tests, and then the average value of the five tests is taken to obtain concrete specimens containing carbon fibers of different lengths. Temperature-time curve (figure 3), and record the maximum temperature rise rate, stable value and temperature rise amplitude of different test pieces (table 2). From the temperature rise curve and the temperature rise amplitude table, it can be seen:

- With the increase of heating time, the temperature of the center point on the surface of the concrete specimen gradually increased, which indicates that the carbon fiber concrete can absorb microwaves and generate heat.
- The longer the length of the added carbon fiber, the faster the temperature rise rate on the surface of the concrete specimen. It can be seen from the figure that the temperature rise rate of the specimens with carbon fiber lengths of 0.3 cm and 0.6 cm is always higher than that of the PC specimens, and the carbon fiber length is 0.1 cm. The temperature rise rate of the specimen is lower than that of the PC specimen, indicating that the wave-absorbing and heat-releasing ability of concrete can be improved when the length of carbon fiber reaches a certain
value. When the length of carbon fiber is 0.6 cm, the temperature rise at the center of the surface of the concrete specimen is the largest.

![Temperature-time curves of carbon fiber concrete specimens with different lengths.](image)

**Figure 3.** Temperature-time curves of carbon fiber concrete specimens with different lengths.

**Table 2.** Maximum temperature rise rate, stable value and temperature rise range of different specimens.

| Specimen   | PC | 0.1CF | 0.3CF | 0.6CF |
|------------|----|-------|-------|-------|
| Max        | 0.48 | 0.29  | 0.6   | 0.72  |
| Stable value | 0.45 | 0.28  | 0.56  | /     |
| Temperature rise | 32.3  | 22.4  | 42.9  | 51.4  |

3.2. Temperature Distribution of Carbon Fiber Concrete after Wave Absorption

The temperature rise curve can only reflect the change law of the temperature at the center point of the specimen surface over time, and cannot fully reflect the effect of carbon fiber length on the efficiency of concrete wave absorption and heating. Therefore, it is also necessary to understand the spatial temperature of the specimen surface under microwave irradiation. Figure 4 is an infrared image of the surface of a concrete specimen with different lengths of carbon fiber. It can be seen from the figure analysis:

- When the length of the carbon fiber is greater than 0.1 cm, as the length of the carbon fiber increases, the area of the red area in the center of the concrete specimen becomes larger and larger, and the area of the green edge on the surface of the concrete specimen gradually increases, that is, as the carbon fiber length increases, the temperature in the center of the specimen becomes higher and the diffusion area gradually increases. It shows that as the length of carbon fiber increases, the absorbing ability of concrete specimens gradually increases.

- When the length of the carbon fiber is 0.1 cm, the red area in the center is approximately circular. When the length is 0.3 cm, the red area in the middle gradually expands to the left and right sides, and the expanded color is lighter. When the length is 0.6 cm, the middle red area further expands to both sides, and the color is darker than when the length is 0.3 cm, but the color on the left and right sides is still lighter than the center area. This shows that as the length of the carbon fiber increases, the temperature of the specimen increases unevenly.


As the length of carbon fiber increases, the white area in the center of the concrete specimen gradually increases. When the length of carbon fiber is 0.1 cm, the white area hardly exists. When the length of carbon fiber is 0.3 cm and 0.6 cm, the white area increases and the color becomes darker. It shows that the temperature of the center point of the test piece is gradually increasing, and the temperature difference with the edge area is getting larger and larger.

![Infrared imaging of concrete specimen surface](image)

**Figure 4.** Infrared imaging of concrete specimen surface.

### 3.3. Comparative Analysis of Deicing Effect

The carbon fiber concrete specimens were subjected to the microwave irradiation test on the upper ice layer, and the test results are shown in figure 5. From the analysis in figure 5, we can get:

- The deicing area of the 0.1CF specimen was 22.1 cm², and that of the PC specimen was 125.59 cm². The deicing area of the 0.1CF specimen was much smaller than that of the PC specimen. It shows that when the length of carbon fiber is 0.1 cm, the addition of 0.3% carbon fiber can not enhance the microwave deicing efficiency of concrete, but will reduce the microwave deicing ability of concrete.

- 0.3 CF specimen deicing area of 149.12 cm², 0.6 CF specimen deicing area of 163.73 cm², far higher than 0.1 CF specimen deicing area, carbon fiber length is 0.1 cm, with the increase of length of carbon fiber, carbon fiber concrete de-icing ability showed a trend of increase gradually, shows that carbon fiber length is 0.1 cm can promote the microwave deicing efficiency of carbon fiber concrete.
3.4. Mechanism Analysis
Carbon fiber has the advantages of high strength, low density, corrosion resistance and low thermal expansion coefficient, which is widely used in the strengthening of composite materials. In addition, the conductive and thermal properties of carbon fiber and the high dielectric loss provide the possibility of microwave absorption. However, due to the low resistivity and weak magnetic loss of carbon fiber, the direct application of carbon fiber to composite material will cause strong reflection of electromagnetic waves. Therefore, it is necessary to design the structure of carbon fiber or modify the surface of carbon fiber to improve its absorbing performance. Carbon fiber on the influence of concrete has the following two aspects: on the one hand, the conductivity of the concrete increases, the specimen internal generate electricity loss, loss of heat production will increase to a certain extent, on the other hand, the concrete from the insulator into a semiconductor, resistivity by infinity fell sharply, added to concrete surface reflectivity, abate the electric field intensity of transmitted wave, is not conducive to the absorbing heat of concrete [15]. In this study, carbon fiber was added into concrete, and the length of carbon fiber was studied and designed, so as to explore the wave absorption performance of carbon fiber concrete by increasing its length. Finally, it is concluded that when the length of carbon fiber is larger than 0.1cm, the microwave heat absorption efficiency of carbon fiber concrete can be effectively improved, so that the advantages of carbon fiber can be fully played in concrete.

4. Conclusion
This experiment uses the self-designed open microwave deicing test system to mainly study the influence of the length of carbon fiber on the microwave deicing efficiency of concrete. The main content is to study the heat absorption efficiency of carbon fiber concrete and the distribution law of the surface temperature of specimens under microwave irradiation. The main conclusions are as follows:

Figure 5. Deicing effect of concrete specimen.
By adding carbon fiber, the conductivity of heat-conducting concrete is enhanced, the polarization strength of concrete is improved, and the wave-absorbing performance of concrete is improved.

As the length of carbon fiber increases, the temperature at the center of the concrete specimen surface will gradually increase. According to the test results, when the length of carbon fiber is 0.6 cm, the temperature rise of concrete specimen is the largest, which is 59% higher than that of PC specimen.

When carbon fiber length is 0.1 cm, microwave reflectivity increases the concrete road face, is not conducive to absorb microwave heating de-icing, concrete when carbon fiber length more than 0.1 cm, concrete specimen surface temperature rise rate with the increase of carbon fiber length showed a trend of increase gradually, to choose appropriate length in actual application of carbon fiber to achieve the effect of wave absorption performance of reinforced concrete.

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