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Effect of magnetite on concrete mechanics and microwave deicing performance

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Effect of magnetite on concrete mechanics and microwave deicing performance

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Abstract. Magnetite aggregate is used as a absorbing material. In order to study the mechanical properties, absorbing heat and deicing efficiency and frost resistance of magnetite concrete, I prepared the magnetite aggregate concrete with 0, 20%, 40%, 60%, 80% and 100% magnetite content, which be used to measure the compressive strength, flexural strength and surface temperature rise curve of magnetite aggregate concrete under microwave irradiation. The results show that the addition of magnetite aggregate can effectively improve the mechanical properties and deicing efficiency of concrete. With the increase of magnetite aggregate, the compressive strength and flexural strength increase gradually, and is approximately linear with the content of magnetite aggregate. With the increase of magnetite aggregate, the absorption and heating efficiency of magnetite aggregate concrete increases gradually. When the content of magnetite aggregate reached 100%, the efficiency of absorbing heat and deicing increased by 71.3% and 69.7% respectively.

1. Introduction

In the northern part of China, the road surface friction coefficient is drastically reduced due to road surface freezing, which seriously threatens traffic safety. Studies have shown that snowfall icing can reduce the road surface friction coefficient by 70~80%. If the deicing is not timely, the consequences of rollover and road surface may occur during the icing road [1-3]. Therefore, it is necessary to find an effective deicing method to remove ice in time. In the existing deicing method, chemical deicing uses a chemical reagent such as NaCl on the road surface to reduce the melting point of ice and snow to improve the deicing efficiency. This method is simple and convenient to operate, but the chemical reagent is easy to corrode the road surface and the deicing effect at low temperature is not ideal [4-6]. Mechanical de-icing method is to use various mechanical devices to remove road surface icing. This method has high deicing efficiency, but mechanical removal still has defects that damage the road surface [7,8]. Heating de-icing method is to melt the ice layer by high temperature heating. When the temperature is too high, the road surface is easily "baked". If the temperature is too low, the deicing efficiency is low, and the method is very energy-consuming [9, 10]. Therefore, it is necessary to find a de-icing method that is economical, efficient, environmentally friendly, and does not damage the road surface.

The microwave deicing method uses microwave heating to increase the surface temperature of the pavement. Since the ice layer does not absorb microwaves, the microwave directly penetrates the ice layer to heat the pavement material, thereby melting the ice layer in contact with the road surface, thereby achieving the purpose of deicing. The method has little damage to the road surface and does not pollute the environment, and saves energy. It is an ideal deicing method at present [11-14]. Many scholars have studied the microwave deicing of pavement. For example, Sun Ling, Yu Wenyong et al.

[15] studied the microwave deicing efficiency of copper-doped slag concrete. The results show that the microwave deicing efficiency of copper slag concrete is significantly improved. Hopstock[16] studied the absorbing properties of iron shale asphalt concrete. The results show that the absorbing properties of shale concrete are much better than those of ordinary asphalt concrete. Gao Jie[17] studied carbon fiber cement emulsified asphalt. The microwave deicing efficiency of the mortar heating belt shows that the microwave heating rate is the best when the fiber volume is 0.4%~1% and the microwave is applied for 30s. Most of these studies focus on the microwave heating performance of asphalt concrete, while there are few studies on cement concrete pavement. At the same time, the above research mostly focuses on the microwave heating efficiency of concrete, and there is little research on the strength of pavement materials. The research on the mechanism of electromagnetic loss of pavement materials has not been reported. Therefore, it is of certain significance to study the microwave deicing performance and electromagnetic loss mechanism of magnetite aggregate concrete.

In this paper, magnetite aggregate is used to replace the ordinary aggregate in concrete to prepare magnetite aggregate concrete, and the microwave-heating deicing experiment is carried out on the concrete specimen by using the self-designed open microwave launching device, and the surface of the concrete specimen is passed. The effect of temperature-increasing curve on the absorption heat and microwave deicing efficiency of magnetite aggregate concrete with different contents was studied. At the same time, the mechanical properties and electromagnetic loss performance of magnetite aggregate concrete were studied and carried out. Mechanism analysis. The research results have certain significance for the promotion and application of microwave deicing.

2. Experiment

2.1Test raw materials and mix design

The cement is selected from Qinling Brand 42.5R grade Portland cement in Yaoxian County, Shaanxi Province. The physical and mechanical properties of the cement are shown in Table 1: The fine aggregate is selected from the Weihe River sand with a fineness of 3.21, the density is 2.56 g/cm^3, and the bulk density is 1.45 kg/L, containing 0.9% mud. There are two kinds of coarse aggregates: limestone gravel and magnetite crushed stone. Limestone crushed stone with a density of 2.71 g/cm^3 and a bulk density of 1.45 kg/L. The magnetite crushed stone adopts the magnetite of Henan Wujiang Water Treatment Material Co., Ltd. The main physical indexes are shown in Table 2. The water reducing agent was selected from PCA type polycarboxylate water reducing agent produced by Shanxi Zhongyi Chemical Co Ltd, and the water reduction rate was 35%. The amount of water reducing agent is 10% of the mass of the cement. The concrete and magnetite aggregate concrete mix ratio is shown in Table 3.

Tab.1 Test results of physical and mechanical properties of cement

Initial setting time	Final setting time	Stability	Standard consistency water requirement (%)	Fineness (80 μm sieve residue, %)	Flexural strength (MPa)		Compressive strength (MPa)	
					3 d	28 d	3 d	28 d
2h10min	5h10min	Boiling qualified	27.5	1.6	6.5	8.9	31.0	48.6

Tab.2 Major physical indicators of magnetite

Density	Bulk density	Mud content	Iron content	Mode hardness value	Particle size	
					5mm~10mm	10mm~20mm
3.38 g/cm^3	2.07 kg/L	0.2%	35%~40%	6	60%	40%

Tab.3 Mixture ratio of magnetite aggregate concrete /(kg/m^3)

Magnetite replacement rate/%	Cement	Water	Small stone	Medium stone	Big stone	Small stone (magnetic)	Big stone (magnetic)	Sand	Water reducing agent
0	330	139	132	395	789	0	0	670.3	3.3
20	330	139	108	324	647	202	134	638.7	3.3
40	330	139	83	248	496	412	275	610.4	3.3
60	330	139	56	169	337	630	420	584.8	3.3
80	330	139	29	86	172	855	570	561.7	3.3
100	330	139	0	0	0	1085	723	540.6	3.3

According to the test content of this paper, three kinds of concrete specimens are prepared: cube test piece（150mm×150mm×150mm）for microwave heating test, deicing efficiency test and compression test, and rectangular test piece for flexural test（100mm×100mm×400mm）, rectangular test piece （110mm×55mm×40mm）for electromagnetic parameter measurement.

2.2Experimental instruments and procedures

The compression test was carried out with the HYY type electro-hydraulic servo material test system, and the flexural test was carried out using a concrete bending test machine (Fig. 1). The compressive strength test uses standard cubic test pieces, and the flexural strength test uses a rectangular test piece of 100 mm × 100 mm × 400 mm. The test procedure is referred to the "Standard for Testing Methods of Mechanical Properties of Ordinary Concrete" (GB/T 50081-2002), and the loading rate is controlled at 0.5 MPa/s.

Fig. 1 Compression and folding device

The microwave heating test and the deicing efficiency test were carried out using an open microwave launcher manufactured by Shenzhen Megmet Electric Co Ltd, consisting of a magnetron, a heat dissipation fan window and a microwave control box (Fig. 2). The microwave heating test uses a non-ice layer cube test piece with a temperature sensor, and the magnetite aggregate concrete test pieces with the content of 0%, 20%, 40%, 60%, 80%, and 100% are sequentially placed. Microwave heating is performed directly under the waveguide of the microwave transmitting device, and the real-time temperature of the center point of the upper surface of the test piece is recorded by a temperature controller. The deicing efficiency test uses the upper ice layer cube test piece of the preset temperature sensor, and the magnetite aggregate concrete standard cube test piece with the dosage of 0%, 20%, 40%, 60%, 80%, 100% The ice was treated, the thickness of the ice layer was set to 20 mm, and the initial value of the ambient temperature was set to -30 °C.

a) magnetron b) cooling fan window box c) microwave control

Fig.2 Microwave emission device

The electromagnetic parameter test test uses the transmission reflection electromagnetic parameter test fixture (Fig. 3) and the vector network analyzer (Fig. 4) produced by Chengdu Tianheng Electric Science and Technology Co Ltd. In the electromagnetic parameter test, I put the test piece into the test fixture, the smooth surface of the test piece should be on the same side as the incident end and keep the same section on the side of the clamp, then tighten the screw, start testing and data through the vector network analyzer. Acquisition processing.

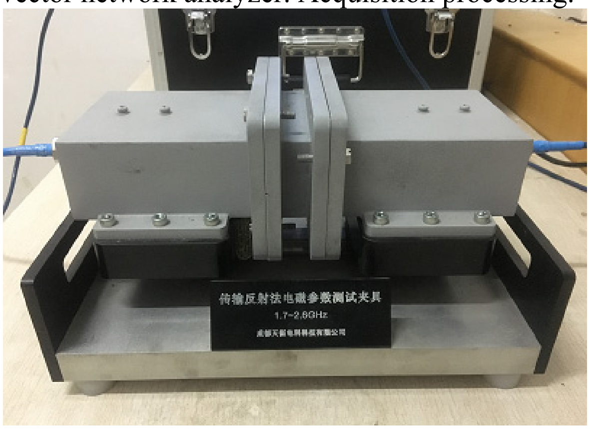

Fig.3 Electromagnetic parameter test fixture

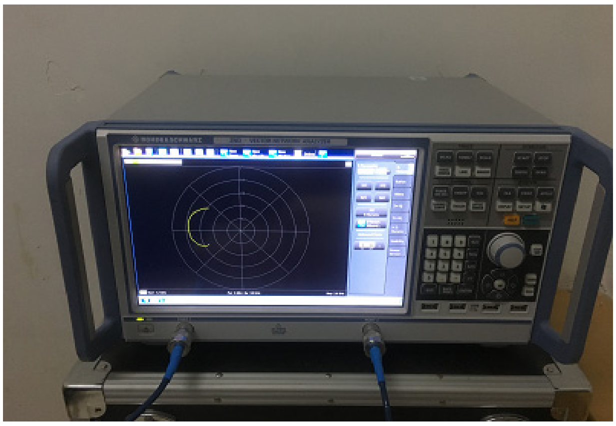

Fig.4 Vector network analyzer

3. Results and discussion

3.1Mechanical properties of magnetite aggregate concrete

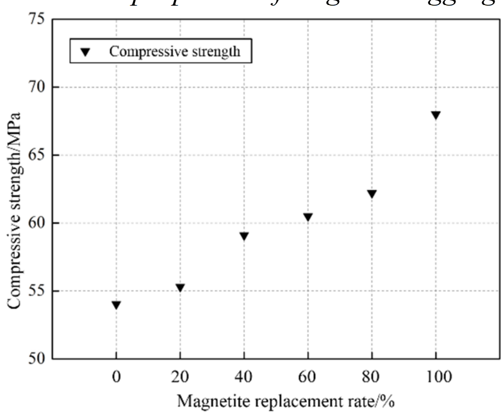

Fig. 5 Change chart of compressive strength

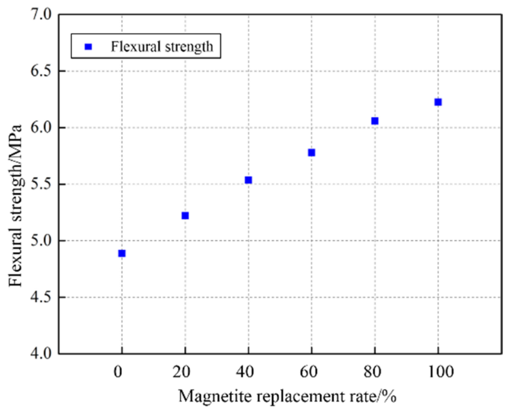

Fig. 6 Change chart of bending strength

Figures 5 and 6 show the compressive strength and flexural strength of concrete with magnetite aggregate, respectively. It can be seen that the compressive and flexural strength of magnetite aggregate concrete increases as the replacement rate of magnetite increases. The compressive strength of 20%, 40%, 60%, 80% and 100% magnetite aggregate concrete increased by 2.4%, 9.4%, 12.0%, 15.2% and 25.9%, respectively, and the flexural strength increased respectively. 6.1%, 12.2%, 18.4%, 24.5%, and 26.5%. It can be seen that when the dosage is 100%, the compressive and flexural strength is greatly improved. Moreover, the static compressive strength and flexural strength of concrete are approximately linear with the amount of magnetite. Because the magnetite aggregate itself has high strength, it can enhance the skeleton support of the aggregate after being incorporated into the concrete. At the same time, the magnetite aggregate has a good surface roughness and a tight bond with the cement matrix. Therefore, the higher the replacement rate of the magnetite aggregate, the better the mechanical properties of the concrete.

3.2Magnetite aggregates microwave heating temperature rise curve

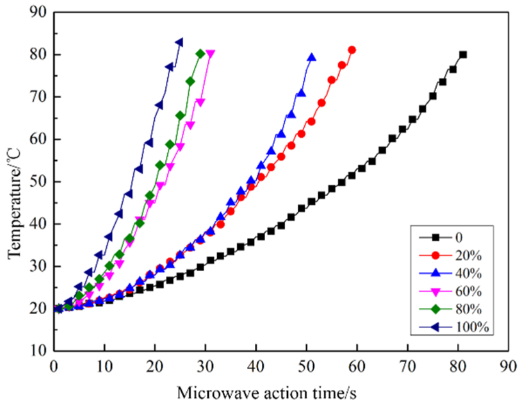

Fig. 7 Temperature rise curve of center point on upper surface of specimen

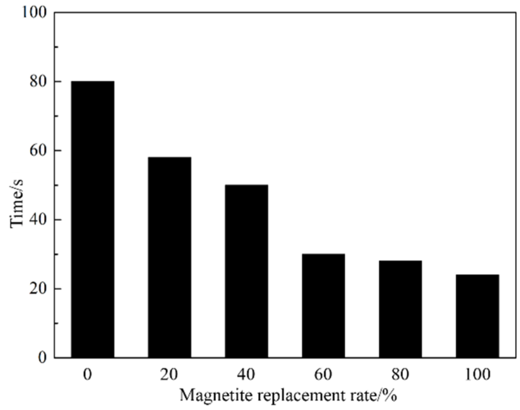

Fig.8 Specimen heating time

Figure 7 is the temperature rise curve of the center point of the concrete specimen under different microwave magnetite replacement rates under microwave irradiation. It can be seen that: with the increase of the amount of magnetite ore aggregate, the average temperature rise rate of the center point of the test piece gradually increases. When the amount of magnetite aggregate reaches 100%, the center point of the concrete specimen reaches 2.745 ° C / s. At this time, the average temperature rise rate of ordinary concrete is 0.763 ° C / s. The rate of temperature rise of magnetite concrete with a replacement rate of 100% is 3.6 times higher than that of ordinary concrete, and the increase is large. This is because the magnetite aggregate itself has strong magnetism and contains more polar molecules. When it is incorporated into concrete, it can increase the polar molecular content per unit volume of concrete, thereby increasing the electromagnetic loss capacity of concrete, so magnetite The microwave heating efficiency of aggregate concrete is significantly improved. At the same time, the replacement rate of magnetite aggregate directly affects the content of polar molecules in concrete. Therefore, the greater the replacement rate of magnetite, the greater the rate of temperature rise on the surface of the test piece. Fig. 8 shows the time required for the surface center point of each of the above-mentioned test pieces to rise from 20 ° C to 80 ° C. It can be seen that with the increase of the replacement ratio of magnetite ore, the time required for the temperature of the upper surface of the test piece to increase from 20 °C to 80 °C is gradually shortened, which is also the same as the temperature rise rate of magnetite aggregate concrete.

3.3Microwave deicing performance of magnetite aggregate concrete

a)0% b)20% c)60% d)100%

Fig. 9 Deicing effect of magnetite aggregate concrete specimen

In order to study the effect of the amount of magnetite on the microwave deicing efficiency of the concrete, I placed a 20 mm thick ice layer on the 150mm×150mm×150mm test piece and microwaved. Figure 9 is a comparison of the ice layer morphology of the magnetite aggregate concrete surface after microwave heating for 80 s. It can be seen that: (1) the microwave can directly heat the surface of the concrete specimen through the ice layer, so that the ice layer on the contact surface of the specimen melts, and the ice layer is separated from the surface of the concrete specimen. (2) microwave heating The melting zone of the ice layer first appeared at the center of the upper surface and then gradually spread to the entire surface. (3) After microwave heating for 80s, the 0% dosing test piece did not change significantly, and the liquid water but ice appeared on the upper surface of the 20% dope test piece. The layer has not been damaged, 60% of the sample has liquid water and the ice layer is damaged, but the ice layer is still attached to the surface of the concrete specimen. The liquid water of the 100% dosage specimen has been completely evaporated, and the ice layer has completely separated from the concrete. surface. Therefore, microwave heating can effectively de-ice the surface of magnetite aggregate concrete, and under the same conditions, with the increase of magnetite aggregate replacement rate, the deicing effect is more obvious.

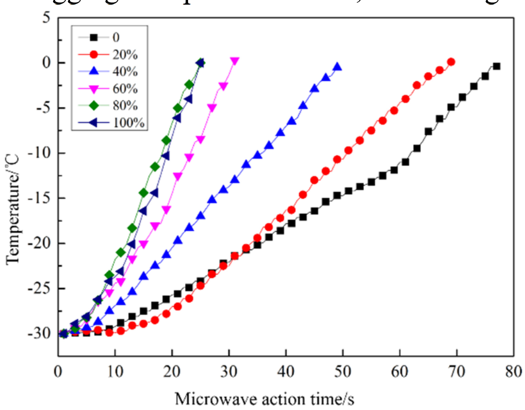

Fig. 10 Temperature rise curve at the center of specimen surface

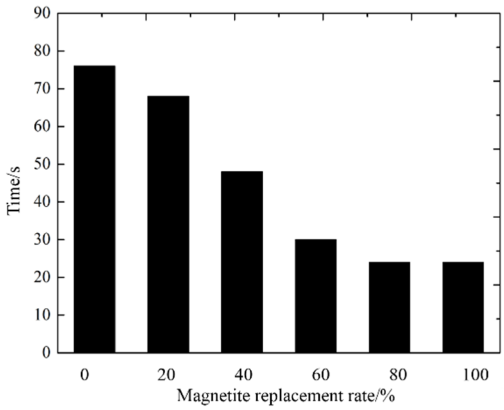

Fig. 11 Specimen heating time

Fig. 10 is a temperature rise curve of the center point of the upper surface of the concrete specimens of different magnetite aggregates under microwave irradiation, and Fig. 11 shows the time required for the temperature of the upper surface of the test piece to rise from -30 °C to 0 °C. It can be seen that: (1) With the increase of the amount of magnetite ore aggregate, the time required for the temperature of the upper surface of the test piece to rise to 0 °C is gradually shortened. (2) under the same conditions, the dosage is 20%, 40%, 60%, 80%, 100% of the magnetite aggregate concrete surface center point temperature reached 0 °C required time is 68s, 48s, 30s, 24s, 23s, respectively, compared with the concrete concrete microwave deicing efficiency increased by about 1.1 times 1.6 times, 2.5 times, 3.2 times, 3.3 times. therefore, the addition of magnetite aggregate can significantly improve the microwave deicing efficiency of concrete, and with the increase of the amount of magnetite aggregate, the concrete microwave deicing efficiency gradually Upgrade.

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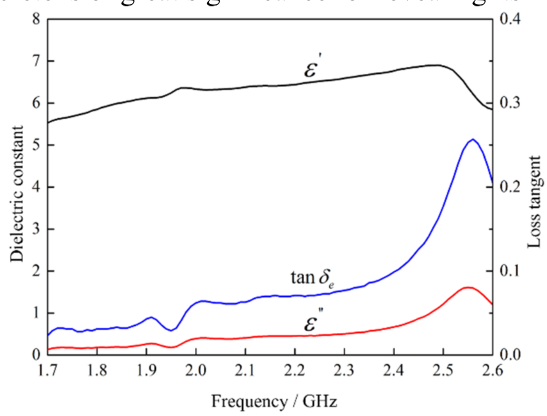
3.4Electromagnetic loss performance of magnetite aggregate concrete

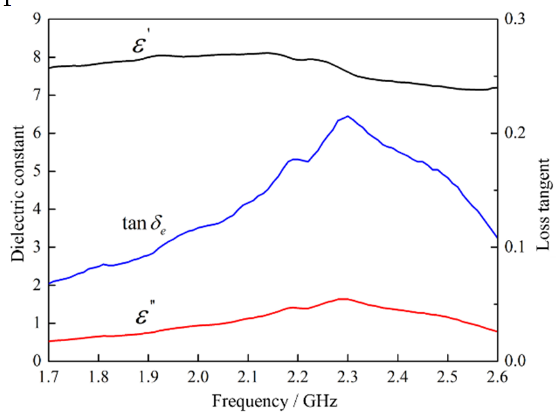
Electromagnetic loss performance directly affects the absorption and loss efficiency of the medium to microwaves. Equation 1 is the power loss per unit volume of medium for microwave energy [11]

$$P = 0.556 fE^2 \varepsilon_r^{\cdot} \tan\delta \times 10^{-12} \qquad (1)$$

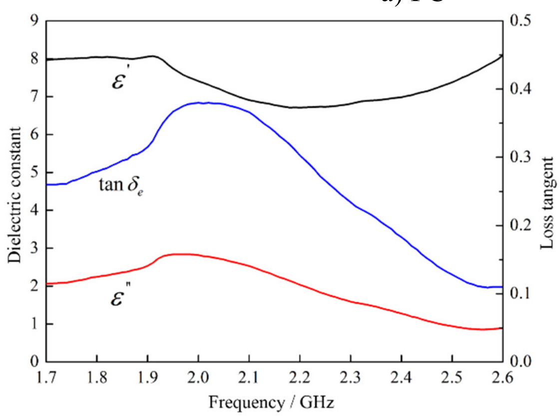
P is the power loss of the microwave in the unit medium, f is the microwave frequency, E is the field strength, $\varepsilon_r^{\cdot}$ is the complex dielectric constant, and $\tan\delta$ is the loss tangent. It can be seen that the dielectric constant of the material and the loss tangent have a significant effect on the microwave loss power of the concrete. Therefore, studying the electromagnetic parameters of magnetite aggregate concrete is of great significance for revealing its improvement mechanism.



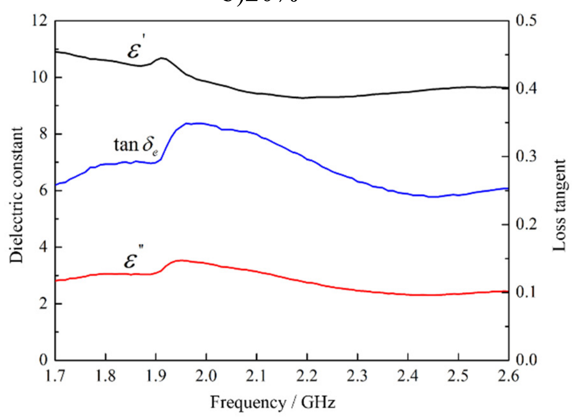
a) PC



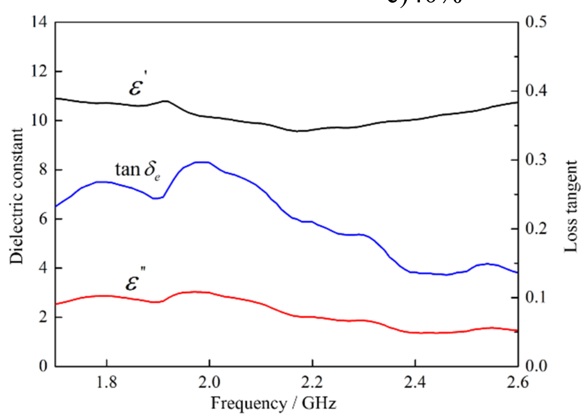
b)20%



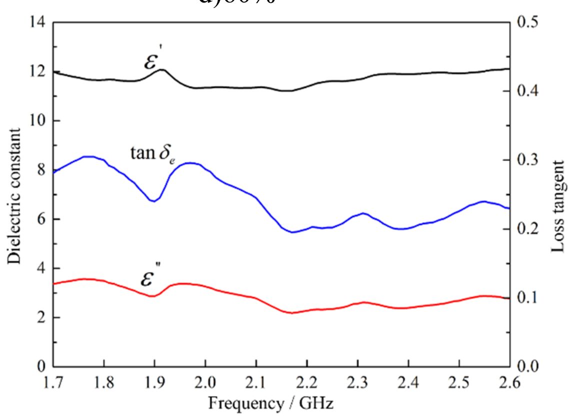
c)40%



d)60%



e)80%



f)100%

Figure 12 Effect of microwave frequency on dielectric properties of concrete

It can be seen that: (1) the amount of magnetite has a significant influence on the electromagnetic parameters of concrete, and with the increase of the amount of magnetite, the real part of the complex permittivity and the imaginary part of the complex permittivity increase to different degrees. (2) The real part of the complex dielectric constant of ordinary concrete specimens is between 5.5 and 6.9, the imaginary part of the complex dielectric constant is between 0.1 and 1.6, and the electrical loss tangent is between 0.03 and 0.26. When the amount of magnetite is 60%, the real part of the complex permittivity of the magnetite aggregate concrete specimen is between 9.3 and 10.9, and the imaginary part of the complex permittivity is between 2.3 and 3.5. The electrical loss tangent is Between 0.24 and 0.35. The replacement of magnetite aggregates has a significant effect on the improvement of the complex permittivity and loss tangent of concrete. This is because as the replacement rate of magnetite aggregates increases, the amount of iron oxides in concrete increases gradually. The ability of these materials to polarize and absorb electromagnetic waves in electromagnetic fields is enhanced, and the complex dielectric constant of concrete materials is enhanced. The real part, complex permittivity and loss angle increase gradually, which indicates that magnetite aggregate concrete has better electrical loss, dielectric loss characteristics and certain magnetic loss performance. Magnetite aggregate concrete has better electromagnetic loss performance.

3.5Mechanism analysis

Magnetite aggregate can better improve the microwave heating performance and electromagnetic loss performance of concrete, and its influence mechanism can be explained from the following aspects. The loss mechanism of magnetite aggregate concrete is divided into three categories: electrical loss, magnetic loss and dielectric loss.

Magnetite aggregate is a resistive absorbing material. When the electromagnetic wave incident on the surface of the composite has an electric field component perpendicular to the material arrangement, the magnetic material is blocked by the matrix material or other wave-transparent material between the absorbing agents. The skin effect is produced on the iron ore cross section. The resulting eddy current loss converts microwave energy into electrical energy and converts it into thermal energy, thereby heating the concrete specimen. At the same time, magnetite belongs to a kind of magnetic material. As a component of aggregate is incorporated into concrete in a certain proportion, magnetization and demagnetization will occur inside the concrete under the irradiation of electromagnetic waves. In this process, microwave energy will be converted into thermal energy. At the same time, the polar molecules in the concrete and in the magnetite are rotated and rubbed in the microwave field, thereby converting the microwave energy into heat energy. There are many polar molecules such as ferroferric oxide in magnetite, so it has a better effect on the microwave heating performance and electromagnetic loss performance of concrete.

4. Conclusion

In this paper, magnetite aggregate concrete with different replacement rates was prepared, and its absorbing heat and deicing performance and electromagnetic loss performance were tested. The variation rules and influence mechanism were analyzed. The main conclusions were as follows:

(1) The static compressive strength and flexural strength of the magnetite aggregate concrete are improved to different extents. The higher the magnetite aggregate replacement rate, the better the mechanical properties of the concrete. When the amount of magnetite aggregate reaches 100%, the static compressive strength and flexural strength of concrete are increased by 25.9% and 26.5%, respectively.

(2) Magnetite aggregates enhance the absorbing heat efficiency of concrete. With the increase of the amount of magnetite aggregate, the temperature rise rate of the upper surface of the concrete specimen gradually increases. When the magnetite aggregate content reaches 100%, the absorbing heat efficiency is about 3.6 times higher than that of plain concrete. .

(3) Magnetite aggregates enhance the microwave deicing efficiency of concrete. With the increase of magnetite aggregate replacement rate, the microwave deicing efficiency of concrete is gradually improved. and the deicing time is gradually shortened.

(4) As the replacement ratio of magnetite aggregate increases, the electromagnetic loss capacity of concrete increases. The complex dielectric constant and loss tangent are greatly improved. When the magnetite replacement rate is 100%, the real part of the complex permittivity of the concrete is 11.2~12.1, the imaginary part of the complex dielectric constant is 2.3~3.5, and the electrical loss tangent is 0.20~0.31. Compared with ordinary concrete, the increase is larger.

References

[1] Wang W, Li C, Tang G, et al. Effect of Road Adhesion Coefficient on Tractor-Semitrailer Cornering Braking Stability[C]. Mechanical Engineering and Control Systems: Proceedings of 2015 International Conference on Mechanical Engineering and Control Systems (MECS2015). 2016: 166-170.
[2] Liu B, Zhang K, Tao C, et al. Strategies for anti-icing: low surface energy or liquid-infused?[J]. RSC Advances, 2016, 6(74): 70251-60.
[3] Lv Yongheng, Feng Xiaoxin. Research on Impact Evaluation of Ice and Snow Weather on Pavement[J]. Road and Traffic Engineering, 2014, 32(4): 39-42.
[4] Cutler H E, Wang K, Schaefer V R, et al. Resistance of Portland cement pervious concrete to deicing chemicals[J]. Transportation Research Record, 2010, 2164(1): 98-104.
[5] Yang Quanbing. Study on the Influence of Salt and Snow Melting Agent Types on Concrete Corrosion Damage[J]. Journal of Building Materials, 2006, 9(4): 464-7.
[6] NAN Xueli, WANG Chaojie, LIU Jinxin, et al. Effect of Coupling Conditions of Freeze-Thaw Cycle and Chloride Salt Erosion on Frost Resistance of Polymer Fast Hard Cement Concrete[J]. Material guide, 2018, 31(23): 177- 181.
[7] Wang Jiefu. Vibration removal mechanism of ice and snow and optimization of vibration compaction [D]. Changchun: Jilin University, 2011.
[8] Heshmati M, Haghani R, Al-Emrani M. Durability of bonded FRP-to-steel joints: Effects of moisture, de-icing salt solution, temperature and FRP type [J]. Composites Part B: Engineering, 2017, 119: 153-167.
[9] Zhao Hongming. Experimental study on concrete pavement and bridge deck melting snow with carbon fiber heating line [D]. Dalian: Dalian University of Technology, 2010.
[10] Gao Jie, Zhang Zhengwei, Han Zhenqiang, et al. Research progress of electromagnetic wave absorbing materials for microwave melting ice and snow pavement[J].Materials Review, 2016, 30(23): 87-95.
[11] Liu J, Xu J, Lu S. Investigations on microwave deicing effects on graphite-modified concrete[J]. RSC Advances, 2017, 7(62): 39237-43.
[12] Guan Minghui, Xu Yugong, Lu Taijin, et al. Application of Microwave Heating Technology in Clearing Road Ice Accumulation[J]. Journal of Beijing Jiaotong University, 2003, 27(4): 79-83.
[13] Li Xiao, Xu Yugong, Liu Weili. Research on Microwave Deicing Method[J]. Journal of Harbin Institute of Technology, 2003, 35(11): 1342-3.
[14] Wuori A F. Ice-pavement Bond Disbonding: Surface Modification and Disbonding [R].Strategic Highway Research Program, National Research Council, 1993.
[15] Sun Ling, Yu Wenyong, He Dongyu, Yang Weijie.Experimental study on concrete performance and microwave deicing efficiency of copper slag pavement[J].Journal of Heilongjiang Institute of Technology.2017,(1):1-4.
[16] Hopstock D M. Microwave-absorbing road construction and repair material [R]. Final Report to NRRI on Idea Evaluation Subcontract, 2003.
[17] Gao Jie. Design of carbon fiber-cement emulsified asphalt mortar heating belt and microwave deicing function [D]. Xi'an: Chang'an University, 2014.