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Experimental Study on Dielectric Properties of Pavement Structure Layer Based on Radar Image

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This paper aims to study the dielectric properties of pavement structural layer by using radar images. Asphalt cement mixture was taken as a case study to analyze the dielectric properties of the pavement structure layer material. The results show that it has been found through research that there is a close relationship between the dielectric properties of the pavement structure layer material and the gross volume, and the value of the dielectric constant may be affected by changes in the relative density of the hair volume. Therefore, the radar image has a certain applied research value in the dielectric properties of the pavement structure layer materials, and it is worthy of reference of relevant parties.

1. Introduction

The road surface radar detection is a kind of better detection method, and the geological survey of highway construction project is of great significance. Relevant geological survey personnel can be determined by geological radar detection technology and the geological structure, etc. In the construction process of highway engineering, the construction personnel often need to measure the thickness of the pavement structure layer through radar detection technology to avoid quality problems in the construction process. In asphalt concrete pavement quality detection, through the radar image, it shows the road foundation structure layer. In combination with relevant data results analyzed asphalt mixture spalling and porosity, the pavement compaction and water content management have the important influence. Radar images are part of the ground-penetrating radar (GPR) method, which can clearly reflect the underground structure. Highway engineering is one of the municipal infrastructure projects, which is of great importance to the safety of urban residents.

In this paper, the dielectric properties of asphalt materials and cement materials in pavement structure layer are explored by combining with radar image technology. First of all, the basic theory of dielectric property of medium, pavement structure layer material dielectric properties and dielectric properties of asphalt mixture test were discussed, and then from the asphalt mixture specimen dielectric constant and the relationship between MAO volume relative density, net plasma dielectric characteristic test and cement mixture permittivity dielectric property changes in testing summary analysis.

2. Literature review

In the late 80s of last century, some developed countries began to develop road surface penetrating radar technology and applied them to highway survey and detection. Zhao stated that the United States invented the first highway mine in 1994. Finland and the United States made a lot of research work. The United States combined ground penetrating radar and FWD technology to detect the technical performance of material characteristics of road pavement structure. In Finland, the ground penetrating radar was used to detect the thickness of road pavement structure and detect the corresponding experimental data (Zhao et al., 2013).

Starting in the early 1990s, China applied ground penetrating radar to the detection of asphalt pavement. Jilin Traffic Research Institute took the lead in road detection by road ground penetrating radar. Researchers Barrios and so on tested the diseases of the highway pavement from Changchun to Siping section. The equipment used was imported SIR-10B ground penetrating radar, and its effect in detecting the road diseases was good (Barrios et al., 2017). Then, the Hebei Province Wing Min Company also did the related

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experimental research. The researchers tested the road thickness from Shijiazhuang to Anyang, and the equipment used was also the SIR1-10B type ground penetrating radar. In addition, the Guangdong geophysical team actively joined the mor geophysical center and the researcher Bilodeau made related detection to the airport runway diseases of Liuzhou, Guangxi. With the continuous development of technology, GPR is gradually used in all walks of life and applied to practical engineering (Bilodeau et al., 2014). In China, some technology companies use GPR in tunnel engineering, which can quickly and accurately detect the thickness of tunnel sinking, the condition of engineering disease and the amount of steel used in the tunnel. Yang and other scholars believed that the ground penetrating radar could effectively improve the detection efficiency and testing results (Yang et al., 2013). In recent years, many technology companies in China have begun to do a lot of research on GPR technology, and have achieved good results. For example, Han found that Beijing AADL International Technology Exploration Technology Company invested a lot of manpower and material resources (Han et al., 2015). Through the joint efforts of researchers, the CBS-9000 ground penetrating radar was successfully developed, which was mainly used in road engineering. At the same time, many scientific research units and colleges and universities have done a lot of research work on the theory and working principles of GPR. For example, the researchers of Henan Road Detection Engineering Technology Research Center have done a lot of research work in the practical engineering application of ground penetrating radar. Romeo and others introduced that, because of the late start of the technology of GPR in China on the whole, the research work was in the initial stage. Many prior technologies that integrated modern technology, electromagnetic wave technology and information technology were not advanced (Romeo et al., 2014). It needs to do a lot of perfection and it is urgent to study systematically.

With the continuous development of the economy, in order to achieve rapid and efficient transportation, the Ministry of Transportation has increased its investment in highway construction and maintenance, which has promoted the rapid development of highway construction, and the mileage of the expressway is increasing year by year. This increases the difficulty of expressway maintenance to a certain extent, and makes the workload of highway maintenance rapidly increase. Road detection can reduce the difficulty of road maintenance. At the same time, through the result of road detection data, it can also judge the use of road and the extent of road damage, and can realize that the result of road test data can play an important role in the maintenance and road reconstruction in the road engineering. Therefore, the use and destruction of the road can be reflected from the accurate and objective evaluation of the road, and the road use condition is evaluated accordingly. At the same time, the key of road maintenance - road detection radar is a new type of detection equipment, which is not destructive to the road detection. Compared with the traditional road detection equipment and related technologies, ground penetrating radar is rich in road detection items, fast detection speed (80km/h), high sampling density, real-time imaging processing of data, and no damage to road surface. Therefore, regular inspection of road conditions under heavy traffic volume has become a particularly difficult and arduous task. In the early days, road surface quality tests were often performed through core drills, and the corresponding performance tests were made for these specimens. This method has a huge amount of work, and the accuracy of the test results is not accurate. There is certain damage to the original pavement structure and the overall beauty of the pavement, and there are some hidden dangers in the core sampling in the road. In order to solve the malpractice of core sampling method, Moriyoshi had no delay to develop a highway detection technology with rapid detection, simple operation and strong test results (Moriyoshi et al., 2013).

Ground penetrating radar (GPR) is a new type of detection equipment, and it is not destructive to highway detection. At present, by contrasting with the traditional detection methods and techniques, GPR has good detection advantages, and the GPR is gradually used in practical engineering practice. Lavrova found that in road engineering, ground penetrating radar detection technology was not only used in highway construction stage, but also in highway maintenance stage. The main detection items of ground penetrating radar in the application of road detection included the following three aspects: the investigation of the subgrade disease, the detection of the thickness of the pavement, the quality of the maintenance of the highway and the detection of the cracks in the road. In addition, the road base damage detection, road surface subsidence detection, road surface clearance testing, road pavement density testing, road pavement network testing and other projects can also be carried out (Lavrova et al., 2016).

In conclusion, ground penetrating radar (GPR) has the advantages of non-destructive, fast and high accuracy in the application in road engineering. However, at present, many engineering units cannot correctly grasp the principle, method, accuracy and reproducibility of the ground penetrating radar, and cannot correctly identify and analyze the type of rutting through ground penetrating radar. Therefore, on the basis of detailed understanding of the working principle of GPR, the related data collected in the asphalt test section and the research status of the ground penetrating radar in the application of asphalt pavement detection, the advanced non-destructive testing equipment is compared with the traditional method and method of testing equipment, and then the application in the identification of road structure thickness and rutting type is studied. Finally, the ground penetrating radar is applied to detect a highway project in Chongqing.

3. Research method

3.1 Basic theory of dielectric property

During the propagation of electromagnetic waves, various types of media are encountered. Many of them appear as lossy insulators in the microwave band. We call them dielectrics and are generally non-magnetic. The non-magnetic isotropic material is considered from the electromagnetic properties, and its dielectric properties can be described by the three related physical constants. These three physical constants are the dielectric constant ε conductivity σ, permeability μ. In the static electromagnetic field, the polarization characteristics of the dielectric constant reaction medium and the magnetization characteristics of the permeability medium react, and the conductivity of the conductivity medium depends on Joule's law, which determines the loss of electromagnetic energy. When the electrical conductivity is very large, the material can be regarded as a metal in nature, and when σ is small, it can be regarded as a medium.

Dielectrics can be roughly divided into two types. One is that the internal has a natural dipole moment, which is called a polar dielectric, and the other has no inherent dipole moment, called a non-polar dielectric. There are almost no charged particles in the dielectric that can freely travel through the interior. Therefore, under the influence of the electric field, the internal movement of the medium can only be a slight displacement of positive and negative charges in the opposite direction. This kind of tiny displacement phenomenon is called polarization of the dielectric. The polarization mode of the dielectric has specific forms for both non-polar dielectrics and polar dielectrics. For non-polar dielectrics, if the displacement occurs under the action of an electric field, the core and electrons are called electron displacement polarization; if displacement occurs, positive and negative ions are called ion shift polarizations. For polar molecules, due to the inherent dipole moment inside, the dipole must be deflected by a certain angle along the direction of the electric field under the action of an electric field. This kind of polarization due to dipole steering is called polar orientation of polar molecules. Or relax polarization. (The dielectric polarization diagram is shown in Figure 1 below.)

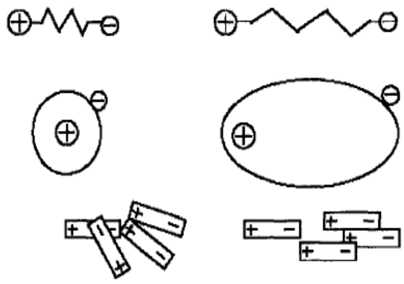

Figure 1: Dielectric polarization diagram

3.2 The dielectric properties of the pavement structure layer material

In general, pavement layer materials include cement mixes, asphalt mixes, and subgrade soils, but they are all composite media that contain several single media such as rock, air, and water. The dielectric properties of composite media are affected by many factors: the dielectric properties of each component and the volume ratio, frequency, temperature, and chloride content. Since the dielectric constant of water is large, the water content (or humidity) has a great influence on the dielectric constant of the composite medium. In general, as the water content increases, the dielectric constant of the composite medium increases significantly. The dielectric constant of the composite medium can be obtained through actual measurement. Under the condition of knowing some parameters such as the dielectric constant and the volume ratio of each component, it can also be calculated through the dielectric constant of the composite medium. The real and imaginary parts of the common surface material dielectric constant is shown in Table 1.

3.3 Experimental analysis of dielectric properties of asphalt mixture

At present, most of the high-grade highways use asphalt pavement. The reason is that it has many inherent good properties as follows: it has sufficient mechanical strength, so the asphalt pavement can well withstand the various forces generated by vehicles passing through the road; there are certain elastic and plastic deformation ability, thus able to withstand the strain occurred without damage; adhesion with the car tires better, which can ensure traffic safety. There is a high degree of vibration absorption, which can ensure that the car runs fast and smooth without noise. Dust, easy to clean and flush, do not pollute the air; asphalt pavement repair work is relatively simple, and the old asphalt pavement can be recycled; construction and maintenance of asphalt pavement, can be widely mechanized. With the above superior road performance, asphalt pavement has been widely used at home and abroad, and it occupies a large share in the construction of modern high-grade highways.

Table 1: The real and imaginary parts of the common surface material dielectric constant

Pavement materials	Dielectric constant Real component	Imaginary part
air	1	-0.01
water	81	-0.50
ice	3	-0.05
asphalt	4.5-6	-0.035
Strip asphalt concrete	<4	-0.035
Wet asphalt concrete	>8	-0.27
Dry flexible base	<8	-0.20
Wet flexible base	>12	-0.80
Saturated flexible base	>16	-1.2
Wet clay	>20	-1.50
Gravel subgrade	8-15	-0.50
The old concrete	8	-0.47
New concrete	10-20	-2.2

This experiment used two grades of asphalt mixture: AC-1311 and AC-161, and three kinds of whetstone ratio %4, %5, %6 design. The grading of bituminous mixtures is shown in Table 2, and the median grading was used in the tests.

Table 2: Grading of bituminous mixtures (square hole sieve)

Screen (mm)	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
AC-16I	100	95~100	75~90	58~78	42~63	32~50	22~37	16~28	11~21	7~15	4~8
AC-13II		100	90~100	60~80	34~52	22~38	14~28	8~20	5~14	3~10	2~6

According to the test procedure, the asphalt mixture was mixed in the laboratory with an asphalt mixture mixer. The standard specimen compaction method was used for the specimen production method. The specimen size was a cylindrical specimen of φ101.6mm×63.5mm. After the preparation of the test piece is completed, the permittivity tester is first used to determine the dielectric constant of the test piece. The dielectric constant tester used was imported from Finland and measured at a frequency of 40 to 50MHz. The measurement principle is that different materials will cause the capacitance of the probe to change, and the dielectric constant will be measured. The measured dielectric constant here refers to the real part of the complex relative permittivity. Finally, the volumetric relative densities of the test pieces were measured by the wax seal method and the volume method. In addition, the dielectric constant of the asphalt was measured using a dielectric constant tester of 2.753, and the dielectric constant of the aggregate (stone) was 8.197. The dielectric constant of air was considered to be 1.

4. Results and discussion

4.1 The relationship between dielectric constant and relative volume density of asphalt mixture

The dielectric constant of the bituminous mixture test piece is about 5.1, and the average value is based on the oil stone ratio. The results are shown in Table 3. From Table 3, it can be seen that the dielectric constant of AC-16I specimen increases with the increase of the ratio of oil and stone, but the dielectric constant of AC-13II specimen does not always increase with the increase of the ratio of oil to stone, and the ratio of oil to stone increases. The increase of %5 to 6% shows a decrease in the dielectric constant. It can be seen that the impact of the oilstone ratio on the dielectric constant of the asphalt mixture specimens is small and insignificant. In addition, comparing the dielectric constant values of the AC-13II and AC-16I specimens, it can be seen that the influence of the gradation type of the mineral and the maximum particle size on the dielectric constant are not obvious.

Table 3: The dielectric constant value of asphalt mixture

Oil oil-stone ratio		4%	5%	6%
Type of asphalt mixture specimen	AC-13II	5.120	5.174	5.061
	AC-16I	4.849	5.125	5.272

There is a linear correlation between the dielectric constants of the asphalt mixture specimens and the relative densities of two kinds of specimens measured by the wax seal method and the volume method respectively. R2 is 0.7 or more, 0.7383 and 0.7788, respectively. The correlation is good, and the relative density of wool volume measured by volume method is better. The degree of compaction of asphalt pavement is equal to the ratio of actual density to maximum density, which is directly related to density. Due to the good linear correlation between the dielectric constant and the density of the asphalt mixture specimen, the density can be obtained from the dielectric constant of the pavement material, and then the compaction degree index of the road surface can be obtained, thereby inverting the asphalt for the use of road surface radar non-destructive testing technology. The degree of road compaction provides a theoretical basis.

4.2 Dielectric property test of paste

Dielectric constants and densities of pulp samples were averaged according to the water-cement ratio, as shown in Table 4. It can be seen that the dielectric constant value of the cement paste has a certain relationship with the water-cement ratio. It shows that with the increase of the water-cement ratio, the density decreases and the dielectric constant also increases. If the water-cement ratio is 0.3 minimum, the dielectric constant is also relatively small; the water-cement ratio is 0.5 and the dielectric constant is relatively large. This is because the ratio of water to cement directly determines the level of water content inside the test piece. When the water-cement ratio is high, the water content is relatively high, and water contributes greatly to the dielectric constant of the sample, so the dielectric constant value becomes relatively bigger.

Table 4: The dielectric constant of the net pulp specimen

Water cement ratio than	0.3	0.35	0.4	0.45	0.5
Apparent relative density	2.054	1.970	1.910	1.839	1.765
Day 7 permittivity	19.302	21.767	23.761	22.929	25.200
The 28th dielectric constant	16.094	17.463	17.35	17.175	17.988

4.3 Experimental analysis of the dielectric constant of cement mixture during the age

The test cement mix was designed according to the cement stabilized macadam base layer, and the water content was 6%. The water-cement ratio and the paste corresponded to 0.3, 0.35, 0.4, 0.45, and 0.5, respectively. Four test pieces were prepared for each group, and the mineral grade was shown in Table 5, the median value was taken during the test. The cement mix specimen was compacted by a standard compaction device (heavy 11 method) and the specimen size was φ152mm x120mm cylindrical specimen. After the test piece was made, it was placed under indoor conditions. The dielectric constant was measured using a dielectric constant tester (24-hour interval). After the measurement was completed, the test piece was placed in water and cured for 30 minutes. Leave for the next day at room temperature and continue measuring for 28 days.

Table 5: Grading of cement mixtures (square hole sieve)

Mesh size (mm)	31.5	26.5	19	9.5	4.75	2.36	0.6	0.075
By mass percentage (%)	100	90~100	72~89	47~67	29~49	17~35	8~22	0~7

5. Conclusion

In this paper, asphalt and cement mixtures are used as research cases to analyze the media characteristics of pavement structure materials. In the dielectric properties of asphalt mixture, when the relative density of the hair volume is gradually increased, the dielectric constant value will also affect the growth. The linear relation between pavement structure material and wool volume density can be reflected by radar image technology, which can provide data reference for road structure construction. In the 28-day age period, the dielectric constant of the cement mixture is in a decreasing trend, and the early-stage decline is faster than that in the middle-late period and gradually becomes stable. As the strength and density of the pavement structure material increase gradually, the dielectric constant value will also increase, and the correlation between the volume of the hair and the dielectric constant of the cement material will be lower.

This study mainly explores the nodal characteristics of pavement structure materials, and studies the relatively single material content, which is difficult to fully reflect the dielectric properties of pavement materials. The related dielectric constant model also needs further correction and experimental verification, especially for the pavement surface in accordance with the material dielectric constant model.

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