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# Laboratory investigation on deicing characteristics of asphalt mixtures using magnetite aggregate as microwave-absorbing materials

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## HIGHLIGHTS

- Asphalt mixtures containing magnetite aggregate as microwave absorber were prepared.
- Deicing characteristics of asphalt mixtures with magnetite aggregate were studied in laboratory.
- *MHE* test, microwave reflection and *MDT* test of asphalt mixtures were conducted.
- SEM, EDS and XRD were adopted to conduct microscopic analyses.

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## ABSTRACT

Natural magnetic components in magnetite are outstanding microwave absorbers, which can be used in asphalt pavement for deicing practice. Therefore, asphalt mixtures containing magnetite aggregate as microwave absorber for different replacements of conventional basalt aggregate were prepared in this work and their deicing characteristics were studied in laboratory. Properties of asphalt mixtures incorporated with magnetite and basalt aggregates were tested, respectively. Microwave heating efficiency (*MHE*), microwave reflection and microwave deicing time (*MDT*) tests of asphalt mixtures were conducted. In addition, scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) and X-ray diffraction (XRD) were adopted to conduct microscopic analyses. The results show that asphalt mixtures with magnetite aggregate present better performances at high temperature compared to those containing basalt aggregate with the same content, even though slightly lower water and temperature resistance are observed. The *MHE* of magnetite aggregate is 6.15 times that of basalt aggregate. The minimum reflectivity value of asphalt mixtures containing 80% magnetite content reaches −11.3 dB at 2.45 GHz frequency. Suitable magnetite content can decrease microwave reflectivity and improve microwave absorbing ability. The *MHE* of asphalt mixtures increases with the increase of magnetite contents when magnetite content is below 80%. Optimum magnetite aggregate content can evidently shorten the *MDT*. However, the *MDT* increases with the decrease of surrounding temperature. In a word, magnetite can be used as aggregates and microwave-absorbing materials in asphalt mixtures to achieve microwave deicing function.



## 1. Introduction

Nature reserves rich magnetite materials, whose main component is $Fe_3O_4$ with excellent magnetic properties [1,2]. In addition, magnetite mostly possesses excellent mechanical properties, such as higher compressive strength, lower wear value, which are required for materials used as asphalt and concrete aggregate [3,4]. Therefore, magnetite materials can be used as low-cost microwave absorbers and replacement of conventional aggregates in construction and building materials [5].

Microwave absorbing material can directly transfer microwave energy into heat. Energy transfer efficiency of microwave heating method is higher than that of infrared heating, so instantaneous heating can be achieved by a microwave power system [6]. In addition, microwave heating is evidently different from conventional heating technique. For the former, heat is generated from dielectric loss and magnetic loss of materials under microwave radiation [7]; while for the latter, materials are heated from the outside to the

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inside through conduction, convection and radiation. Microwave heating is characterized by its uniformity and non-pollution. In a word, microwave heating technique possesses many advantages over conventional heating methods in heating efficiency and energy utilization.

For the issue of road deicing in winter, the current commonly used road deicing techniques are deicer method [8,9] and mechanical method [10,11]. For the former, its operation is simple and the cost is low, but it can result in serious environmental pollution and severe corrosion for structure steels. For the latter, many vehicles are required and the pavement structure can be destroyed during deicing operation. For the rapid and effective removal of snow and ice on pavement, the novel road ice melting techniques are explored. Microwave deicing technique is one of them. However, the problems are that the traditional paving material for microwave absorption heating efficiency is low; ice melting speed is slow and the continuous and the rapid deicing performances are difficult to realize. Therefore, if the magnetite is used in asphalt mixtures, ice and snow on pavement can be removed easily under radiation of microwave pavement maintenance vehicles.

There are many literatures relating to microwave technology for asphalt pavement. For example, magnetite was found enormously beneficial for microwave heating and microwave heating efficiency of asphalt pavement was studied [12,13]. Microwave deicing vehicles have been used in asphalt pavement maintenance [14] and microwave measurement could be utilized for snow and ice detection on road surface [15]. Sweeping microwave asphalt radar was developed for pavement deicing [16] and directivity of coupled antennas for microwave heating of asphalt mixture was improved [17]. Roller mountable asphalt pavement density sensor with microwave was developed [18]. Crumb rubber pretreated by microwave irradiation can improve asphalt blending efficiency [19]. In addition, improving the short-term aging resistance of asphalt by addition of crumb rubber radiated by microwave was investigated [20] and technical viability of heating asphalt mixtures with microwaves to promote self-healing was conducted [21]. In theory, heat transportation in asphalt mixtures was studied based on multiphase fluid thermal physics transfer of microwave heating [22].

On the other hand, some waste materials, such as recycled taconite [23], waste engine oil residues [24] and reclaimed asphalt pavements [25] are widely used for recycling in asphalt pavement construction. The asphalt mixtures with microwave absorbing materials can be used in asphalt pavement recycles [26]. The microwave vehicles used for deicing can also be used for asphalt reclaimed applications because the generated microwave energy is just the required heat of hot mixing asphalt pavement maintenance. Therefore, asphalt pavement with damages, such as cracks, rutting, etc., can be reheated and repaved after the microwave radiation. So asphalt pavement can be reconstructed in relatively short duration. There is no air pollution in these recycled processes [27].

Of course, it is challengeable to melt ice with large areas with the increase of today's energy prices for microwave heating technology. It may be used in very sensitive and small applications of asphalt pavement deicing. However, the above mentioned study results show that it is performable using microwave technology in asphalt pavement. The key of promoting this technology is to improve microwave absorbing ability of materials and heating efficiency of asphalt mixtures under microwave radiation. Therefore, this study used magnetite aggregate as microwave absorbers in asphalt mixtures for pavement deicing. So, six different mixture designs were conducted to study influences of magnetite aggregate on surface temperature of asphalt mixtures. The microwave reflections under different microwave frequency were studied to explain the temperature changes. The primary aim of this work is to use magnetite aggregate successfully as microwave-absorbing materials in asphalt mixtures and enormously improve heating efficiency of asphalt mixture under microwave radiation so as to decrease damages of chemical and physical deicing methods to asphalt pavement.

## 2. Experimental

### 2.1. Raw materials

Magnetite and basalt were used as aggregates in asphalt mixtures, whose properties were shown in Table 1. The SBS (styrene-butadiene-styrene) modified asphalt was adopted as binder and its properties were given in Table 2. Hydrated lime with 2.743 g/cm$^3$ density and 78.4% (CaO + MgO) contents was used to improve asphalt-aggregate interfacial adhesion. The mineral fillers were limestone fillers with no agglomeration, whose density is 2.895 g/cm$^3$ and hydrophilic coefficient is 0.55.

### 2.2. Preparation of specimens

The aggregate gradation was shown in Fig. 1. 20%, 40%, 60%, 80% and 100% basalt aggregate were replaced by magnetite aggregate in the same volume. A mixer was used for mixing at the temperature of 165 °C. The aggregate, asphalt binder, hydrated lime and

**Table 1**
Properties of aggregates.

| Properties | Magnetite | Basalt |
|---|---|---|
| Crushing value (%) | 9.5 | 15.3 |
| Abrasion value (%) | 9.9 | 13.7 |
| Apparent specific density (g/cm$^3$) | 3.774 | 2.851 |
| Water absorption rate (%) | 0.23 | 0.78 |
| Adhesion with asphalt ( ≮ ) | 5 | 5 |
| <0.075 mm particle content (%) | 0.1 | 0.1 |

**Table 2**
Properties of asphalt.

| Properties | Results | Specification [28] |
|---|---|---|
| Needle penetration (25 °C, 100 g, 5 s) (0.1 mm) | 54 | 40–60 |
| Ductility (15 °C, 5 cm/min) (cm) | 45 | ⩾25 |
| Soften point (°C) | 85.1 | ⩾70 |
| Density (25 °C, g/cm$^3$) | 1.038 | – |
| Wax content (%) | 1.3 | – |

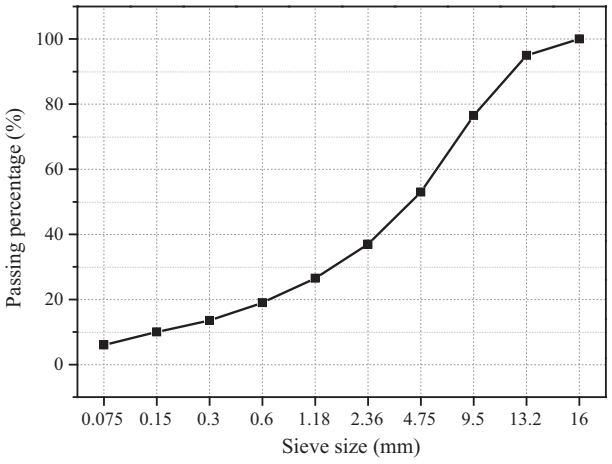


**Fig. 1.** Chart of aggregate gradation.