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Investigation on snow-melting performance of asphalt mixtures incorporating with salt-storage aggregates

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HIGHLIGHTS

- Salt-storage aggregates (SSA) were prepared.
- Asphalt mixtures with different SSA contents were prepared.
- Engineering properties of asphalt mixtures were tested.
- Salt-release performance of asphalt mixtures with SSA was investigated.
- Field snow-melting test was conducted by outdoor experiments.

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ABSTRACT

Chloride salts are the most commonly used chemicals that serve as snow-melting agents for winter highway maintenance due to their abundance and low cost. However, the heavy use of chloride-based deicers has caused a series of environmental problems, because the deicers are directly spread on the pavement surface before snowing. Therefore, how to decrease the damage of chloride salts on pavement and environment is very important. Thus, introduction of the deicer into the asphalt mixtures and making the deicer slow release has brought a recent scientific and industrial interest. In this work, salt-storage aggregates (SSA) were innovatively prepared. Asphalt mixtures incorporating 0%, 5%, 10%, 15% and 20% SSA by volume as limestone aggregates (LSA) were prepared and their engineering properties were tested, such as high temperature stability, crack resistance at low temperature and water stability. In addition, salt-release performance of asphalt mixtures with SSA was investigated. Finally, field snow-melting test was conducted by outdoor experiments of the asphalt mixtures. The results show The SSA possesses excellent water stability, high mechanical strength and salt-storage function. The properties of asphalt mixtures with SSA can meet the requirements of specification, but the influence of SSA on water stability of asphalt mixtures should be noticed. The electrical conductivity of asphalt mixtures increases with the increase of SSA content. Salt precipitation amount per unit area increases and then gradually becomes stable with the increase of soaking time. Salt precipitation amounts from asphalt mixtures increase with the standing time and the SSA content. The asphalt pavement with SSA can possess satisfied snow-melting performance in reference to the simulated field tests.

1. Introduction

In winter, snow can reduce asphalt pavement surface friction coefficient, which seriously affects driving safety. In addition, the condensation of snow on pavement causes enormously economic loss every year [1,2]. In order to clear the snow on pavement surface, the common ways contain snow melt agent method and mechanical method. For the former, the snow melt agents should be spread every time when it snows. It needs to spend a lot of manpower, materials and financial resources [3]. Mechanical methods are so easy that they can cause pavement structure damage [4–6]. Sodium chloride (NaCl) is the earliest materials with the largest amounts due to its rich resources, low cost and high effect, although the pavement is subjected to chloride ion corrosion damages [7,8]. Is it possible not to use chlorine salt in deicers? The answer to this question is affirmative. Some organic compounds,

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such as ethylene glycol and its derivatives, have perfect ice melting effect and less corrosive, limited harm to plants, but they are mostly used in deice for airport [9], air conditioning [10], solar energy [11], etc. Heated pavement is a sustainable, environment-friendly, and efficient alternative to substitute NaCl snow agent method, such as heating wire [12], heating fluid [13], self-heating element [14], etc. But this method does not present widespread application eventually in practice due to complex operation and high economic costs. Thus, it is no doubt that the cost is too high for they are used as road snow melting agent. Therefore, in the absence of snow melting agents with environmental protection function and low cost, the chloride salts are widely used for melting snow worldwide.

Fortunately, more and more attention is paid to materials for snow-melting performance of asphalt pavement. For example, Starck, et al. [15] studied the influences of deicing salt on visco elasticity of asphalt mixtures by using dynamic mechanical analysis and stress sensor and analyzed stress-strain changes of different asphalt mixtures soaking in deicing salt solutions. Shi, et al. [16] analyzed the corrosion mechanism of acetic and formic acid deicers on asphalt pavement structures, which was a comprehensive effect of chemical reaction, emulsification, distillation and additional stress in asphalt mixtures. In addition, the effects of water and snow-smelting salt on performance of asphalt mixtures were compared and analyzed by Hassan, et al. [7]. Furthermore, Tan, et al. [17] tested surface bonding strength between ice film and asphalt mixture to evaluate the binding capacity between asphalt mixtures and ice. Zhang, et al. [18] studied engineering properties and construction performances of salt-storage asphalt pavement with salt anti freezing materials and analyzed the impacts of salt additives on asphalt-aggregate ratio, volume indexes of asphalt mixtures.

Surely, asphalt mixtures incorporating snow melting materials possess the effect of melting snow on pavement. In 1960s, Switzerland, Germany and other countries developed kinds of salt-storage pavement by adding anti-freezing agents [19]. In 1973, snow melting material was prepared by Dubois [20]. Until 1990s, there was a great progress in the research of salt-storage materials. This method can reduce the freezing point of pavement to −20 °C, thus achieve the good effect of delayed icing on pavement. However, the salt release rate in salt-storage materials has not been well controlled and results in less snow melting effect after few years. Therefore, the slow release of composite salt fillers was studied in Japan at the end of 1970s [21]. Although these snow-melting materials have some effects, the price is too high, it is not suitable for large-scale utilization.

In this work, self-prepared SSA was added to asphalt mixtures for replacing the LSA to pursuit the achievements of snow-melting performance of asphalt pavement. Four different mixture designs were conducted to study the effects of SSA on the engineering properties and the salt-release performance of asphalt mixtures. The primary scope of this study is to successfully use SSA as aggregate in asphalt mixtures to melt snow in winter in special areas of asphalt pavement, such as ramp and steep slope, and greatly reduce disadvantages of conventional snow-melting methods, such as severe environmental pollution and high economic consumption.

2. Experimental

2.1. Raw materials

The styrene-butadienestyrene (SBS) modified asphalt was adopted as binder. Its properties were tested in reference to the *Standard Test Methods of Asphalt and Asphalt Mixtures for Highway Engineering* [22] and are summarized in Table 1. LSA and SSA were used in asphalt mixtures. Mineral filler was limestone powder with <0.075 mm particle sizes. Properties of LSA and mineral filler were tested in accordance with the *Testing Specifications of Aggregate for Highway Engineering* [23] and were shown in Table 2 and Table 3, respectively.

Table 1
Properties of asphalt binder.

Properties	Specification [26]	Testing results
Needle penetration (25 °C, 100 g, 5 s) (0.1 mm)	80–100	86
Ductility (5 °C, 5 cm/min) (cm)	≮40	49
Soften point (°C)	≮50	55.1
Density (15 °C, g/cm^3)	–	1.039
Wax content (%)	–	1.3
Flash point/°C	≮230	279

Table 2
Properties of LSA.

Properties	Specification [26]	Testing results
Crushing value/%	≯ 26	11.6
Apparent specific density/(g/cm^3)	≮2.5	2.701
Needle and plate particle content/%	≯ 15	9.65
Los Angeles abrasion value/%	≯ 28	7.9
Water absorption/%	≯ 2.0	1.25
Adhesion with asphalt	≮4	5

Table 3
Properties of mineral filler.

Properties	Specification [26]	Testing results
Apparent specific gravity/(g·cm^{-3})	≮2.45	2.928
Water content/%	≯ 1	0.51
<0.075 mm percentage/%	75–100	15.326
Hydrophilic coefficient	<1	0.478
Appearance	No agglomeration	No agglomeration

In this work, SSA was prepared by cementitious materials (CMs), water resistant modifier and sustained-release materials. The CMs are composites of magnesium chloride solution ($MgCl_2$, Baume Degrees 26) and magnesium oxide (MgO, activity ≥60% and free-CaO ≤2.0%). The water resistant modifier is hydrophobic silicone powder. The sustained-release materials (SRM) are made from sodium chloride (NaCl, purity ≥ 90%), glass powder (smelting temperature 700–800 °C and particle size ≤0.15 mm), and maifanite powder (particle size ≤0.15 mm).

2.2. Preparation of SSA

The flow chart of preparing SSA is shown in Fig. 1. NaCl, glass powder and maifanite powder were mixed in the proportion of 4.5:1:1, milled for 30 min in the ball mill, calcined for 60 min in muffle furnace at the temperature of 750 °C, crushed when they were cool, and milled for 30 min in the ball mill. Finally, some powder was obtained, which was named salt-release materials (SRM). Then, MgO, $MgCl_2$, SRM, and hydrophobic silicone powder were mixed in the proportion of 3:1:2:0.01 and stirred to uniform mixtures by a mixer. The mixtures were poured into steel molds and were pressed for 2 min with 2.0 MPa stress by a press machine to prepare SSA specimens. Then, the specimens were placed in a curing room with the temperature of 20 °C. After 28d curing ages, the specimens were broken into particles passing through 9.5 mm sieve and then were sieved with 0.075 mm–4.75 mm sieves to obtain the SSA. The morphology of SSA is shown in Fig. 2.

2.3. Preparation of asphalt mixtures

The aggregate gradation of the asphalt mixtures was shown in Fig. 3. The specimens incorporating 0%, 5%, 10%, 15% and 20% SSA by volume as substitute of LSA were prepared. The optimal asphalt-aggregate ratio of the asphalt mixtures was determined by Marshall test and the process is shown in Fig. 4. Preparation of asphalt mixtures with salt-storage aggregates was carried out at the temperature of 170 °C. LSA, SSA, asphalt binder and limestone fillers were added in order. The mixer rotated with 75r/min speed for 3 min. the asphalt mixtures were modeled within 2 min for specimens with different dimensions. They were placed in a room with the temperature of 20 ± 2 °C for use. The prepared asphalt mixtures and the laboratory tests were shown in Table 4.