Ice melting properties of steel fiber modified asphalt mixtures with induction heating

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Abstract. In this paper, the ice melting performance of asphalt concrete with steel fibers was studied. Steel fiber modified asphalt mixtures were prepared, five different fiber amount of steel fiber modified asphalt mixtures were mixed to study their induction heating rate. The samples covered with different thickness of ice were heated with induction heating to study their ice melting efficiency. It was proved that the induction heating of steel fiber modified asphalt mixtures could significantly improve their ice melting efficiency compared with the natural condition. And it was found that the thickness of the ice had little influence on the induction heating rate of the asphalt concrete.

Keywords: asphalt mixtures, steel fiber, ice melting, induction heating

1. Introduction

In most areas of the earth, the chemical salt was used to solve the pavement icing problem in winters [1]. The snowfall, sleet and freezing rain would usually lead to the formation of ice on the surface of road, which could result in serious transportation safety problems [2]. Eliminating ice effectively is important for traffic safety. From the late 1940s, deicing salts have been applied extensively in the North American countries [3]. By far, over 30 million tons of chemical salt were produced and applied all over the global world [4]. Unfortunately, this traditional method to melt ice will result in concrete corrosion and environmental pollution, and this problem has been paid much attention by International Energy Agency (IEA) and World Health Organization (WHO) [5]. And ice will not be melted by the most popularly used salt (sodium chloride) if the temperature falls below -3.9 ºC [6]. On the other hand, hydronic and heating with electric cable has been used for a number of decades as a means of controlling snow and ice formation on a variety of pavement surfaces [7,8]. However, the low energy efficiency of the old technologies limited their application and promotion. In recent years, the study of induction heating was more and more popular. Induction heating is a heating method based on electromagnetic induction and Joule heating [9,10]. It has been applied in many fields such as self-healing techniques. For instance, induction heating was applied to increase the temperature of the asphalt concrete in order to enhance its self-healing capacity [11-13]. As far as I know, few researches had been studied on the feasibility of using induction heating for ice melting.

The objective of this research was to study the ice melting properties of asphalt concrete with steel fibers through induction heating. The influence of steel fibers amount to the rate of induction heating was investigated. Marshall samples of asphalt concrete with different steel fibers content were
prepared with this purpose. And the ice melting properties of the asphalt concrete with steel fiber were studied.

2. Materials
AC-13 asphalt mixtures based on Marshall design procedure was used in this research. The raw materials involved andesite aggregates, limestone mineral filler, AH-70° base bitumen and steel fibers. Five different percentages of steel fibers were added to the asphalt mixture by volume of asphalt: 2%, 4%, 6%, 8% and 10% respectively. The properties of AH-70° base bitumen and steel fibers were shown in table 1-2.

| Tests                                  | Results | Specification |
|----------------------------------------|---------|---------------|
| Penetration (25 °C, 100g, 5s) [0.1mm]  | 68      | 60-80         |
| Softening point (ring and ball) [°C]   | 49      | 44-54         |
| Ductility [cm]                         | >150    | ≥100          |

Table 1. Properties of AH-70° base asphalt.

| Properties                         | Results |
|------------------------------------|---------|
| Length [mm]                        | 4.2     |
| Equivalent diameter [μm]           | 70-130  |
| Oil content [%]                    | <0.2    |
| Melting point [°C]                 | 1530    |

Table 2. Properties of steel fibers.

3. Experiments

3.1. Heating test of asphalt specimens with different steel fibers content
Marshall Specimens with different steel fibers content were prepared in this study, including 0%, 2%, 4%, 6%, 8% and 10% respectively. The influence of steel fibers content on the heating rate of asphalt mixtures with induction heating was measured. The asphalt-aggregate ratio of all specimens was kept at 5.3% in this test.

3.2. Ice melting test of asphalt specimens
In this test, only the specimens with 6% steel fibers content were used to investigate the ice melting property of mixture. As shown in figure 1, different thickness of ice was attached to the top surface of asphalt specimens by freezing. The height and weight of the specimens were measured before the melting test.
The ice melting performance of asphalt specimen in the natural conditions was also conducted for comparison purpose. All these tests were conducted at the indoor temperature of 9 ºC.

An induction heating machine with a maximum output of 2.7 kW and at a frequency of 123 kHz (seen in figure 2) was applied in this stage. The asphalt specimens were placed under the center of coil of the induction heating machine. The gap between the coil and the surface of asphalt specimen for ice melting was kept at a constant distance of 15 mm. Then, each specimen was heated for several times, each time included 30s of induction heating and another 30s of rest. During this stage, the surface temperature of the samples was recorded. When the ice could separate from the asphalt specimen with its own weight, the melting test would come to its end.

3.3. Ice melting test with different thickness of the ice

Different thickness of the ice were prepared in this stage, including 2.0mm, 3.0mm, 4.5mm and 5.5mm respectively. The ice melting experiment was also performed by using the induction heating machine mentioned before. The samples were placed as the same the position in 3.2. Each studied sample was heated for 30s and then rest for another 30s. While the induction heating machine was turned off, the temperature of both the surface and flank side of the test sample were measured. Each temperature was tested for three times, and the average data were recorded. Then the sample was turned upside down to test the bonding state between the ice and the asphalt specimen. The heating test was continued until the ice could separate from asphalt specimen and fall down due to its own gravity.

4. Results and discussion

4.1. Induction heating properties of mixtures with fibers

As shown in figure 3, the surface temperature of specimens with different steel fibers mix ratio was tested. It can be seen that the temperature of specimen without fibers did not increase in this condition. It was also clear that the surface temperature of samples increased as the heating time or the amount of steel fibers in the mixtures was increased.

![Figure 3. Effect of heating time on the surface temperature of test samples due to induction heating.](image)

In figure 3, it can be observed that the induction heating rate of each content of steel fibers is a kind of linear relationship. With the increase of the mix ratio of steel fiber, the heating rate of asphalt mixture was also increased. From Figure 3, it is calculated that the heating rates of asphalt mixtures were 0 ºC/min, 9.2 ºC/min, 20.5 ºC/min, 25.1 ºC/min, 35.9 ºC/min, and 49.0 ºC/min of the 0%, 2%, 4%, 6%, 8% and 10% mix ratio of steel fibers respectively. It is obvious that the mixtures with higher percentage of fibers showed higher heating performance of heating rate. While the andesite asphalt mixtures without steel fiber couldn’t be heated by the induction heating. The reason may be that the principles of induction heating are electromagnetic induction and Joule heating. This kind of heating needs a closed circuit in a changing magnetic field. In this condition, the more steel fiber mixed, the
more closed circuit formed. The increase mix ratio of steel fiber will result in the increase of heating rate as a consequence.

4.2. The ice melting performance in natural condition

![Figure 4. Evolution of specimen temperature in natural condition.](image)

Figure 4 showed the temperature variation of the specimen in natural condition of 9 °C. It took about 100 min until the failure of the bonding state between the ice and the Marshall Specimen. It can be seen that the final temperature of the ice surface was kept steadily at 1.2 °C. Compared with the result of induction heating shown in figure 5, it is clear that the induction heating for deicing was much more efficiency.

4.3. The ice melting performance with induction heating

![Figure 5. Ice melting performance with induction heating.](image)

![Figure 6. The flank surface temperature of the test specimen.](image)

As mentioned in 3.3, different thickness of the ice were prepared on the surface of the Marshall Specimen. The evolutions of temperature in surface of ice during induction heating were shown in figure 5. From figure 5, it can be observed that the induction heating time with four different thickness of ice until bonding state between the ice and the Marshall Specimen failure was the same. And after four times of discontinuous heating (120s of heating in total), the surface temperature of ice was increased from subzero temperature to above freezing, this is mainly because heat transfer through the interface area to the ice.

In the figure 5 it was also clear that the final temperature of the four different samples were almost the same (1.6 °C ), and during the ice melting process, the heating rate of ice surface was stayed at 0 °C/min. In this condition, the low heating rate and 1.6 °C can be regarded as the bonding failure moment between the ice and the asphalt mixtures. This may be because that when ice layer was about to failure, a large amount of ice in contact with the sample melted into water and retains in the interface area, so a lot of heat transferred to the water in this moment. As a result, the ice surface temperature tends to be the same.
Besides, the flank surface temperature of each sample during the induction heating was also recorded. As shown in figure 6, it can be seen that the heating rate of four different samples was almost the same. And the heating rate of each specimen was around 6 °C/min. The reason for this is that the steel fiber content of each sample was the same.

From figure 5 and figure 6, it was also obvious that the thickness of ice has no or little influence on the induction heating rate of the asphalt concrete. In other words, the thickness of ice has no or little influence on the ice melting efficiency when suffered with induction heating.

5. Conclusions

Based on the experimental results, the following conclusions can be drawn:

- The andesite asphalt mixtures without steel fiber couldn’t be heated by the induction heating. But with the amount of steel fibers in the asphalt mixture increases, the heating rate of asphalt mixtures increases under the induction heating, the heating rate of asphalt mixtures with 10% steel fibers can reach as high as 49.0 °C/min. And the induction heating rate of each content of steel fibers is a kind of linear relationship.

- Compared with the ice melting in natural condition, the use of induction heating for deicing is much more efficiency. The heating rate of samples with different thickness of the ice is almost the same, the thickness of ice has no or little influence on the ice melting efficiency when suffered with induction heating.

- The temperature of 1.6 °C was regarded as the bonding failure temperature between ice and asphalt mixtures. It is feasible to use this temperature to determine the induction heating time needed in the actual road deicing.

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