# Ice-Breaking and Skid Resistance Performance Evaluation of Asphalt Pavement Groove-Filled with Elastomer

**Tengfei Yao, Sen Han, Changpeng Men, Jianchao Zhang, Jianrong Luo, and Yang Li**

**Abstract** Icing on roads in cold regions seriously affects vehicle driving safety. Therefore, this study aims to propose a pavement surface treatment technology with groove-filled elastomer. Through theoretical analysis, the ice-breaking mechanism of groove-filled elastomer asphalt pavement was clarified. Then, through the indoor ice-breaking test, the ice-breaking performance of the asphalt pavement groove-filled with elastomeric materials under three filling forms of above, level and lower than the asphalt pavement surface and different ice thickness were studied. The results show that the filling form where the elastomer material is flush with the asphalt pavement has the best ice-breaking effect, and the groove-filled elastomer asphalt pavement still has an excellent ice-breaking effect when the thickness of the ice layer is less than 2 mm. Finally, through BPN and friction coefficient test, the skid resistance performance of groove-filled elastomer asphalt pavement under dry, wet and icing conditions is verified. Compared with AC-13 asphalt mixture, the skid resistance of groove-filled asphalt pavement is improved by 4.5, 10.8 and 24.6%.

**Keywords** Groove-filled asphalt pavement · Elastomer · Ice-breaking performance · Skid resistance performance

## 1 Introduction

In the cold winter, many highways and urban roads are often affected by rain, snow and freezing weather. When the snowfall is heavy or the ambient temperature continues to decrease, the road surface may be covered by ice for a long time,

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resulting in a serious lack of skid resistance of the pavement. The research data show that the traffic accident rate of the frozen section is twice as high as that under the normal climate conditions, and the casualty rate is as high as 70% [1, 2]. Especially in special sections such as tunnel entrances and exits, long steep slopes and bends, the accident rate is higher. The anti-skid problem of the road surface in icy and snowy environments has become a key problem restricting safe road construction [3, 4].

First of all, traditional passive deicing methods on pavement include manual and mechanical deicing or spraying snow melting agents, but these methods are time-consuming and laborious, and deicing agents such as chloride pollute the environment and corrode road ancillary facilities [5]. Thermal snow melting method has less pollution to the environment and high snow melting efficiency. However, there are problems such as high construction difficulty, high energy consumption, and high maintenance costs in the later period, which are difficult to popularize and use on a large scale [6]. The super-hydrophobic anti-icing pavement is mainly made by preparing a layer of super-hydrophobic material on the surface of the pavement. This super-hydrophobic structure could reduce the surface energy of the pavement and weaken the adhesion between the ice and the pavement so that the ice on the road surface is easy to remove [7, 8]. However, the super-hydrophobic structure of this layer may lead to a decrease in the initial skid resistance performance of the pavement and the wear resistance of the hydrophobic material needs further study. Self-stressing elastic paving technology could be divided into elastic-filled pavement and inlaid paving pavement. It mainly adds a certain amount of elastic material to the pavement material to cause uneven deformation of the pavement under the load of the wheel, thereby causing the ice layer to generate self-stress to break the ice [9]. Kiyoshi Takeichi paved a variety of inlaid pavements on urban roads respectively. Through long-term observation, it was found that the grooved filled elastomer pavement had good snow removal ability and skid resistance performance, but the interfacial bond durability between elastomer and pavement still needs further study [10].

Polyurethane (PU) is a kind of polymer material with repeated carbamate segments (-NHCOO-) in its molecular structure, which is famous for its high strength, excellent elasticity, oil resistance and low-temperature resistance [11]. Polyurethane elastomer (PUE) is composed of a rigid hard segment and a flexible soft segment block among them, the hard segment is formed by diisocyanate and small molecular diol or diamine (chain extender), and the soft segment is oligomer polyol [12]. The thermodynamic incompatibility of the soft and hard phases in the chain segment causes the polyurethane to appear microphase separation, that is, the hard segment phase is evenly distributed in the soft segment phase to play a role of elastic crosslinking. This structural feature makes PUE possess extremely excellent performance [13]. Many scholars have introduced polyurethane into the research of pavement engineering materials. Sun et al. [14] prepared a polyurethane mixture with a skeleton chain structure. The properties and functional groups of PU were evaluated by Brookfield rotational viscosity test, Fourier transform infrared spectroscopy (FTIR) and Dynamic mechanical analysis (DMA), and the pavement performance of the polyurethane mixture was evaluated. Gao et al. [15] used different types of rubber particles and polyurethane to prepare rubber particle mixtures, and evaluated the high-temperature resistance, aging resistance, and skid resistance of the rubber particle mixtures. Cong et al. [16] studied the effect of polyurethane hard segment content on polyurethane properties. They tested the hardness, elongation, elastic modulus and other properties of polyurethane and studied OGFC13 through freeze–thaw splitting test, rutting test, friction coefficient test, and three-point bending test. In order to improve pavement performance, polyurethane with 41% to 51% hard chain segment content is recommended. Wang et al. [17] used polyurethane as cement to prepare porous elastic pavements, and evaluated their road performance and acoustic properties. The applicability of this kind of pavement in urban roads in cold regions has also been verified.

This study aims to propose a pavement surface treatment technology with groove-filled the elastomer. Through theoretical analysis, the ice-breaking mechanism of groove-filled elastomer asphalt pavement was clarified. Then, through the indoor ice-breaking test, the ice-breaking performance of the asphalt pavement groove-filled with elastomeric materials under three filling forms of above, level and lower than the asphalt pavement surface and different ice thickness were studied. Finally, through BPN and friction coefficient test, the skid resistance performance of groove-filled elastomer asphalt pavement under dry, wet and icing conditions is verified.

## 2 Mechanism and Experiment Procedure

### *2.1 Ice Breaking Mechanism of the Asphalt Pavement Groove-Filled with Elastomer*

As shown in Fig. 1, the basic ice breaking principle of the asphalt pavement groove-filled with elastomer is that under the action of vehicle load, the difference of modulus

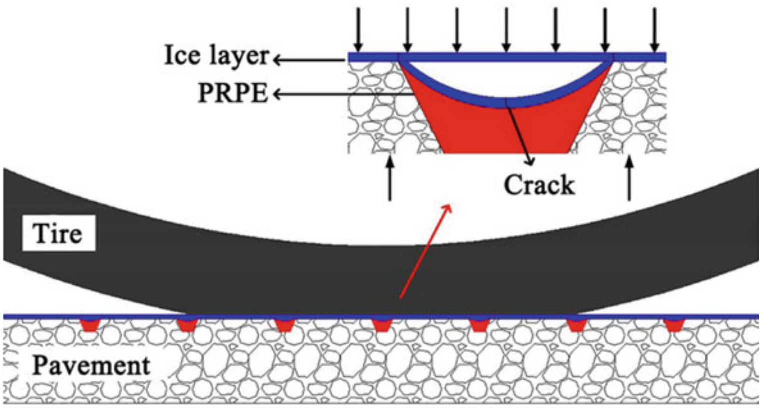


**Fig. 1** Ice breaking mechanism of the asphalt pavement groove-filled with elastomer

between road material and elastic material causes the stress concentration in the ice layer at the junction of the two. The self-stress generated would be much greater than the internal stress of the ice layer under the normal pavement structure. When the stress value is greater than the strength of the ice layer, the ice layer would automatically break. The edges and corners of the groove would be exposed at this moment, which could immediately play a certain anti-skid effect. With the vertical compressive stress and transverse shear stress of the tire, the ice layer located on the upper part of the asphalt concrete between the grooves would gradually be worn by the tire, thereby achieving the effect of the overall road surface ice layer being broken and the original road surface exposed.

## *2.2 Preparation Process of Groove-Filled Asphalt Pavement Specimens*

In this study, referring to related papers [18], rectangular grooves with a width of 10 mm and a depth of 10 mm were selected, and the groove spacing is 50 mm. The elastomer material is made of polyurethane and rubber particles in a certain ratio. The filling container is a 400 ml hose, and the filling equipment is an electric glue gun. The specific preparation process is as follows:

a. Form the specimen plate. The 30 cm × 30 cm × 5 cm AC-13 asphalt mixture specimens were formed in the laboratory.
b. Groove. The sample plate was grooved with a grooving machine in the laboratory according to the size of 10 mm × 10 mm × 50 mm, and then the dust in the groove was washed. After washing, it was placed in a ventilated place to dry.
c. Stick antifouling tape. In order to prevent the pavement from being polluted by the elastomer material, the plastic tape was pasted on the groove edge of the filling front edge.
d. Preparation of the elastomer. The elastomer was prepared according to the optimum ratio of elastomer material determined by the experiment.
e Filled with the elastomer. Put the prepared the elastomer into the hose, install the nozzle and the back cover into the electric gun, set the filling speed of the gun at 0.5–1 m/min, and slowly and evenly fill along the groove edge.
f. Compaction. First, lay a non-woven fabric along the filled groove, and then manually compact it with a steel pipe with an outer diameter of 30 mm.
g. Curing. After the compaction is completed, tear off the non-woven fabric strip and tape, and place the test piece plate at room temperature for 24 h.

## *2.3 Evaluation of the Ice-Breaking Performance of Groove-Filled the Elastomer Asphalt Pavement*

This test uses a self-developed pavement ice-breaking simulation tester. The equipment is shown in Fig. 2. The whole system is mainly composed of a wheel mill and a refrigeration system. The refrigeration system could automatically and accurately control the temperature in the equipment, and the wheel rolling device could simulate the stress situation of the road under the repeated action of the wheel dynamic load. The wheel rolling device is a smooth tire, and the interaction mode with the road surface is pure rolling. The main parameters of the experimental instrument are as follows: rubber wheel width: 50 mm; rubber wheel grounding pressure: 0.7 MPa; walking times: 42 times/min; temperature control range: 0 ~ −5 °C; temperature control accuracy: ± 0.5 °C; specimen size: 300 mm × 300 mm × 50 mm. The test operation process is as follows:

a .Firstly, the corresponding ice thickness was frozen in the refrigerator.
b .Turn on the power and set the test temperature to—5°C. After the temperature is constant, the frozen specimen is placed on the test platform for 30 min, so that the temperature of the specimen is consistent with the temperature in the equipment.
c .Start the wheel rolling system to roll the test piece, observe the ice surface breaking condition of the test piece at all times, take out the test piece according to different rolling times, take photos of it, and record the corresponding rolling times.

This section mainly explores the influence of three kinds of the elastomer filled height on the ice-breaking performance of groove-filled structure through the ice-breaking test. The filled height is 1 mm lower than the groove height, flush with the groove and 2 mm higher than the groove(Abbreviation: the elastomer and groove level, the elastomer lower than groove and the elastomer higher than groove) as

**Fig. 2** Pavement ice-breaking simulation tester

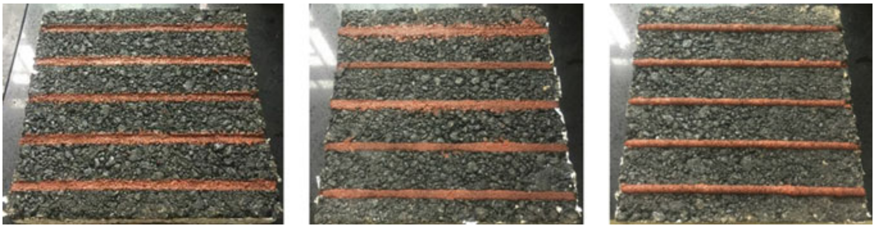

**Fig. 3** Grooving filled elastomer specimen plates

shown in Fig. 3. Under the test temperature of—5 °C, the ice layer thickness (1 mm, 2 mm, 3 mm, 4 mm) was changed to explore the change of ice-breaking performance of different structures.

### *2.4 Evaluation of Skid Resistance of Groove-Filled the Elastomer Asphalt Pavement*

In order to verify the skid resistance performance of the grooved asphalt pavement filled with the elastomer, the BPN and friction coefficient of the groove-filled the elastomer asphalt pavement were tested under dry, wet and icing conditions respectively. The pendulum friction tester is used for the BPN test, and the walking friction coefficient tester (WFT) developed by ourselves is used for the friction coefficient test. At the same time, the common asphalt pavement, grooved pavement (unfilled) and groove-filled asphalt pavement were tested and compared.

As shown in Fig. 4 is a picture of WFT. It has two rear wheels and one front wheel. The front wheels are test tires. The diameter of the three wheels is the same, which is 400 mm. The center distance between the front and rear wheels is 540 mm,

**Fig. 4** The Walking Friction Tester (WFT) [19]

and the center distance between the two rear wheels is 580 mm. The front wheels are solid smooth rubber tires with a width of 60 mm. The density of the tested tire rubber is 1.15 g/cm3 and the shore hardness is 75. A constant vertical load of 196 N is maintained on the test wheel, and the corresponding contact area is 19.775 cm2. The contact pressure is about 99.2 kPa. WFT is equipped with a speed sensor to measure the test speed in real-time, and a torque sensor is used to record the torque of the test wheel. According to the measurement principle of WFT and the friction coefficient calculated theoretically, the calibration is carried out. The friction coefficient measured by WFT is calculated as follows:

$$\mu = \frac{M}{R \times N}. \tag{1}$$

where M is the measured torque, R is the radius of the test wheel, and N is the vertical load on the test wheel. The data recorder of WFT calculates the friction coefficient at 0.2 s intervals to provide continuous recording of the friction coefficient values at close range. The test speed could be maintained at the normal walking speed.

## 3 Results and discussion

### *3.1 Ice Breaking Performance*

As shown in Fig. 5, it shows the ice-breaking effect picture and the binary refinement image of the elastomer and groove level specimen, 2 mm ice thickness, and −5 °C groove filling. After binary refinement image processing, different types of specimens are obtained, and the calculation results of ice fragmentation rate of specimens with different ice thickness are shown in Table 1 and Fig. 6. When the thickness of ice layer is 1 mm, both the elastomer and groove level and the elastomer lower than groove specimen have a good ice-breaking effect, and the ice fragmentation rate of the elastomer and groove level specimen is significantly higher than that of the elastomer lower than groove specimen. This is because when the thickness of the ice layer on the pavement is 1 mm, the actual thickness of the ice layer on the upper part of the elastomer lower than the groove specimen could be close to 2 mm, and the actual strength of the ice layer at this time is far greater than that of the 1 mm thick ice layer of the elastomer and groove level specimen. Similarly, when the thickness of the ice layer on the pavement surface is 2 mm, the ice fragmentation rate of the elastomer higher than the groove is also less than that of the elastomer and groove level specimen. The reason is that when the elastomer is covered with a 1 mm thick ice layer, the actual road surface ice thickness is 3 mm. The integrity of the road surface ice layer is good, and the wheel load is difficult to damage its structure. Similarly, when the surface of the bituminous pavement is covered with 1 mm ice, the thickness of the ice inside the groove has reached 10 mm, which makes the ice

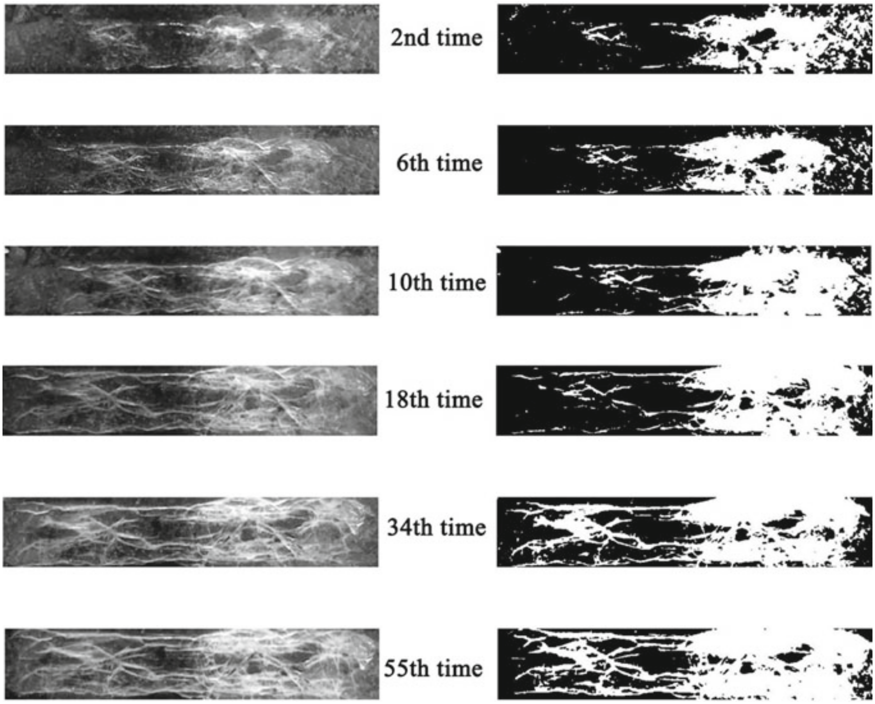


**Fig. 5** The ice-breaking effect picture and binary processing image of the groove at different rolling times

**Table 1** Results of ice fragmentation rate of different pavement types under different ice thickness

| Pavement type | Ice thickness/mm | | | |
|---|---|---|---|---|
| | 1 (%) | 2 (%) | 3 (%) | 4 (%) |
| Grooved pavement (unfilled) | 35.4 | 20.3 | 9.1 | 5.8 |
| The elastomer and groove level | 69.8 | 57.7 | 40.5 | 15.3 |
| The elastomer lower than groove | 65.3 | 55.6 | 32.8 | 7.2 |
| The elastomer higher than groove | 40.2 | 25.4 | 10.2 | 5.1 |

layer firmly solidified with the asphalt pavement. Therefore, the ice-breaking effect of the groove asphalt pavement is the worst. The results show that the ice-breaking effect of the four kinds of specimens is as follows: the elastomer and groove level > the elastomer lower than groove > the elastomer higher than groove > the grooved pavement (unfilled).

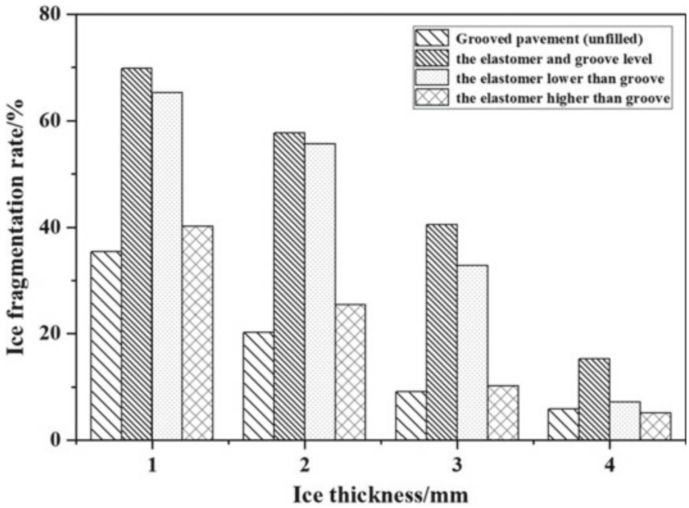


**Fig. 6** Ice fragmentation rate of different pavement types under different ice thickness

## *3.2 Skid Resistance Performance*

The test results are plotted as a histogram as shown in Fig. 7 and 8. Firstly, it could be seen that the BPN and friction coefficient data are consistent. In the dry state, the BPN and friction coefficient of the three pavement types have a few changes, and the groove-filled pavement slightly increases. Secondly, the skid resistance of AC-13 pavement decreases under the wet condition, while the skid resistance of

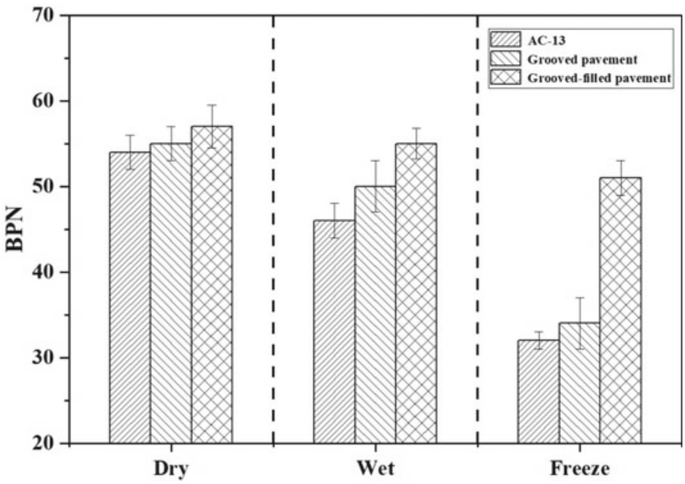


**Fig. 7** BPN test results in different environments

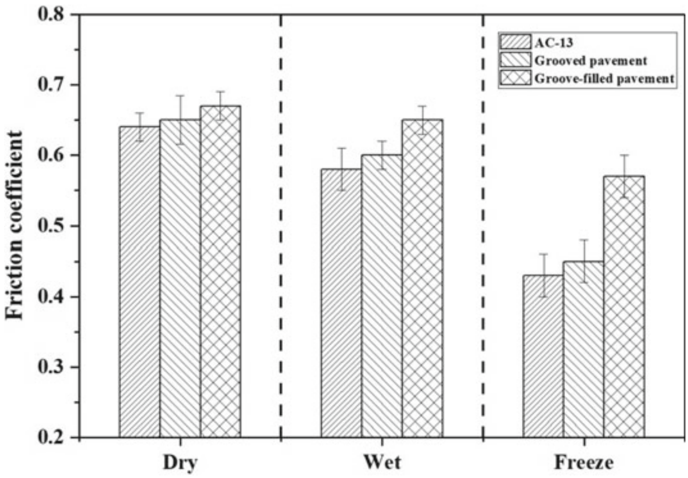


**Fig. 8** Friction coefficient test results in different environments

grooved asphalt pavement and grooved filled pavement decreases slightly. Then, under the condition of icing, the skid resistance of AC-13 and grooved asphalt pavement decreases greatly, while the skid resistance of groove-filled asphalt pavement only slightly decreases, which indicates that the groove-filled asphalt pavement still has excellent skid resistance performance when the pavement is frozen. The main reason is that the groove-filled pavement could provide a large mechanical contrast with the asphalt pavement at the groove. Under the wheel rolling, the local area of the ice layer has a certain unbalanced stress, which makes the ice more easily broken so that the skid resistance performance of the pavement would not be greatly reduced. Compared with the common AC-13 asphalt mixture, the skid resistance of groove-filled pavement increases by 4.5%, 10.8% and 24.6% respectively under dry, wet and icing conditions. In the environment of ice and snow, the groove-filled pavement has obvious advantages.

## 4 Conclusions

In this study, a pavement surface treatment technology of groove-filled the elastomer was proposed. Through theoretical analysis, the ice-breaking mechanism of groove-filled the elastomer asphalt pavement was clarified. Then, through the indoor ice-breaking test, the ice-breaking performance of the asphalt pavement groove-filled with elastomeric materials under three filling forms of above, level and lower than the asphalt pavement surface and different ice thickness were studied. Finally, through BPN and friction coefficient test, the skid resistance performance of groove-filled elastomer asphalt pavement under dry, wet and icing conditions is verified.

It was verified the obvious advantages of the asphalt pavement of groove-filled the elastomer in ice-breaking and anti-skid. The ice-breaking performance of different pavement types is verified through the ice-breaking test. The results show that the ice-breaking effect of the four pavement types is as follows: the elastomer and groove level > the elastomer lower than groove > the elastomer higher than groove > the grooved pavement (unfilled). Finally, through the BPN and friction coefficient test, the skid resistance of the three types of pavement is verified under dry, wet and icing conditions, and the groove-filled asphalt pavement has the best skid resistance performance. Compared with the common AC-13 asphalt mixture, the skid resistance performance of groove-filled pavement increases by 4.5%, 10.8% and 24.6% respectively under dry, wet and icing conditions.

Although the the ice-breaking and skid resistance performance of groove-filled the elastomer asphalt pavement have been verified, the wear resistance of groove-filled asphalt pavement and determination of groove parameters still need to be further studied.

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