Review of Reflection Cracking Preventive Technologies on Asphalt Pavement with Semi-Rigid Base Course

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Abstract. Semi-rigid base course is widely applied in pavement construction. However, because the inorganic binder tends to be affected easily by environmental factors (temperature, moisture), the cracking of semi-rigid base course is a serious problem, which causes reflection cracks on the surface layer. That is one of the main damage types of this kind of pavement structure. In view of the above problems, scholars all over the world have carried out researches on the cracking mechanism and the causes of cracks. Combined with engineering practices, various kinds of reflective crack prevention technologies have been proposed. In this paper, the author systematically investigates the existing retarding methods. According to their characteristics, it is mainly divided into three categories: surface anti-cracking treatment, base anti-cracking treatment and stress absorption structure addition. Meanwhile, the main principles and effects of these three categories of measures are analysed and summarized to provide the reference for subsequent study and design.

1. Introduction
Semi-rigid base is the most popular type of base in China. In addition to its high strength and integrity, it also has good water stability and frost resistance ability. Meanwhile, there are many kinds of alternative materials for semi-rigid base, and China has rich experience in design and construction of semi-rigid base. However, due to the high stiffness and environmental sensitivity, the reflection cracks caused by the semi-rigid base shrinkage cracking become one of the main diseases of the road. Reflection cracks greatly reduce the life of the road, as well as increases the difficulty and cost of road maintenance. With the aggravation of the reflection crack problem, there are various approaches with different effects and principles were applied to retard the development of reflection crack. Based on the brief summary of the causes of reflection cracks, this paper summarizes and analyzes the current mainstream methods.

2. Study on the Cause and Mechanism of Reflection Cracking
Scholars have done a lot of research on the mechanism of reflection cracks by means of lab test [1], finite element simulation [2] and test road construction [3]. The results show that although the semi-rigid base material has high strength, it is easy to deform and contract under the change of temperature and humidity, resulting in transverse contraction cracks. When the crack occurs, due to the large rigidity, the driving load will produce serious stress concentration at the crack tip, which will result in the damage of the surface layer [4].
3. Summary and Analysis of Prevention Technology

According to the above analysis, the development of reflection crack can be divided into mainly 3 steps: cracking caused by vehicle and environmental load in base layer; B stress concentration at the bottle of surface layer; C down-top surface cracking. Therefore, according to the disposal materials and principles, the generation of control reflection cracks can also be summarized as the following three categories: (1) anti-cracking treatment at the bottom of surface layer; (2) adding stress absorption layer between layers; (3) anti-cracking design of base material.

3.1. Treatment Technologies of the Surface Layer

In the early stage, it is a common method to increase the tensile strength of asphalt surface by the use of scrap rubber [5], fibre [6, 7], asphalt modifiers [8]. Later, for asphalt type, some studies shows that compared with AH-70 and AH-50 asphalt, high elasticity asphalt has longer fatigue life and higher impact ductility, which is useful to resist reflection cracking [9]. Recently, Shafabakhsh tried to add natural zeolite and hydrated lime into crumb rubber modified (CRM) asphalt binder in order to prevent the propagation of reflective cracks [10].

However, with the increasing of traffic load, enhancing tensile strength of surface layer without increasing its depth is becoming less useful in the prevention of reflection crack. This kind of measures can mainly be used in low traffic volume road.

3.2. Pavement Structure Optimization

The second type of approach is adding an interlayer between base and surface to stop the propagation of reflection crack. This interlayer will be absorbing the concentration stress at crack tip to prevent further cracking.

3.2.1. Geotextile Interlayer. In 2000, based on the elastic fracture mechanics and the finite element method, Zhou Zhigang analysed the mechanical response of the geosynthetic reinforcement material after the base cracking under the symmetrical load, and confirmed that under the premise of the reinforcement material and the structural layer fully bonded, the addition of the geosynthetic layer can effectively reduce the stress concentration at the crack tip and then alleviate the reflective crack cracking [11]. In addition to the influence of driving load, scholars also analysed the influence of temperature change on stress transfer at the crack based on viscoelastic theory and heat transfer, and proposed that polymeric fibre geotechnical material is more conducive to prevent reflection crack cracking [12]. After that, scholars have done a lot of research on the preparation, construction technology and anti-reflection crack effect of different types of geotextile materials, such as filament singeing geotextile [13], glass fibre grid [14], etc. At the same time, some scholars have proposed that geotextile can better promote the interlayer bonding and delay the generation of reflection cracks [15, 16].

Early geotextile theoretical studies were mostly based on digital simulation techniques such as finite element analysis, and the anti-reflective cracking ability of geotextiles was confirmed on the assumption that the interlayer connections were good. Zamora-Barraza established a simple two-layer test specimen in the room to simulate the road surface, and added geotextiles, geotextiles, or other crack-resistant layers between the two layers to carry out dynamic load tests to explore its crack resistance. Tests show that this method can be used to determine the type and amount of viscous layer oil under different intermediate layer materials, and it can also be used to quantitatively evaluate the anti-reflective cracking effect of the intermediate layer [17]. Qian Jinsong et al. Used MMLS3 equipment to perform accelerated loading tests on a 1/3 scale pavement structure model to simulate the combined bending, tensile, and shearing effects caused by vehicle loads. The results show that the corresponding loading times of the pavement structure with the paving geotextile during the initial surface cracking and crack penetration are 3.55 times and 3.25 times that of the control group, respectively, confirming the anti-cracking effect of the geotextile in the real pavement structure [18]. At the same time, while the performance of the geotextile itself has improved, scholars have also paid
more attention to the bonding effect between the overlay material and the layer, such as the type, shape, thickness of the geotextile, and the selection of the tack coat oil [19, 20].

3.2.2. Inverted Structure. Inverted structure is also a method to prevent reflection cracking through adding stress absorption layer. The stress at the crack tip is released by adding a low modulus flexible base such as graded crushed stone between the pre surface layers of semi-rigid base. Compared with adding geotextile interlayer, due to the thickness and material similarity to the other layers, this type of measure will have better bonding among layers, as well as better continually.

Scholars have done a lot of research on the stress response under load by using the finite element software, and the conclusion shows that the flexible layer can be effectively decrease the deflection of road surface, the shear stress of graded crushed stone layer and the tensile stress of semi-rigid base [21]. At the same time, scholars have done a lot of research on grading design, thickness design and construction scheme of graded crushed stone to ensure its performance [22, 23]. In addition, four point fatigue tests were carried out by forming two composite beam specimens with different semi-rigid material structures, which confirmed that the inverted structure can improve the overall crack resistance of the material [24].

3.2.3. Stress Absorbing Layer. Since granular material such as graded stone cannot meet the requirements of high class road. Different kinds of bonded stress absorption layer are applied to resist refection crack. Following table shows the Comparison among several types.

| Number | Layer/Material                                      | Characteristic                                                                 |
|--------|----------------------------------------------------|--------------------------------------------------------------------------------|
| 1      | High Viscous Asphalt Stress Absorbing Layer [3]     | ● abundant asphalt and fine aggregates gradation;                              |
|        |                                                    | ● flexible at low temperature;                                                  |
|        |                                                    | ● recover rapidly;                                                             |
|        |                                                    | ● high anti-fatigue ability and strength;                                      |
| 2      | Stress-Absorbing Waterproof Interlayer [25] (Sawi) | ● higher fatigue life;                                                        |
|        |                                                    | ● good interlayer bonding capability;                                          |
|        |                                                    | ● strong reflection crack resistance;                                           |
|        |                                                    | ● low modulus;                                                                |
|        |                                                    | ● high toughness and elasticity;                                               |
|        |                                                    | ● good seepage-preventing capability.                                          |
| 3      | Interface Self Absorbing Composite Intermediate Layer [26] (Isac) | ● consist of fiberglass grid upper layer and polyester cloth interlayer;   |
|        |                                                    | ● a good capacity of preventing the formation and development of reflective cracking. |
| 4      | Engineered Cementitious Composites [1] (Ecc)       | ● higher tensile strength and ductility;                                       |
|        |                                                    | ● higher fatigue life.                                                         |
| 5      | Tack Coat [27]                                     | ● lower tack coat modulus is better.                                           |
| 6      | Open-Graded Large Stone Asphalt Mix (OLSM) [28]    | ● voids in OLSM can change the cracking propagation path to prolong pavement life |
| 7      | Large Stone Porous Asphalt Mixture(LSPM) [29]      | ● Rubber powder modified asphalt mixture is good for improving anti-reflection cracking in long-term freeze-thaw area |
3.3.  Treatment Technologies of the Base Layer
The crack of base course is the origin of reflection crack. If the crack can be solved from the source, the reflection crack can be reduced. There are mainly 2 types of approaches to eliminate base cracking effect.

3.3.1.  Anti- Cracking Design of Base Material. The first type or method is reducing shrink cracking by material modification. The research results show that the large-size skeleton dense gradation can reduce the stress of the base material when it shrinks and then reduce its cracking [30]. Meanwhile, the anti-cracking ability can also be increased by adding different types of additives. Polypropylene fibre was proved to be useful in improving the performance of cement stabilized macadam [31]. Meanwhile, many other fibres such as polyester fibre [32], polyvinyl alcohol fibre [33] also have similar effect. In addition to fibres, adding proper expansion agent can also considerably reduce mixture deformation in dry and humid environment [34]. Some scholars also proved that Cement Emulsified Asphalt Stabilized Crushed Stones has smaller temperature shrinkage coefficient and recommended optimum cement content is 4% with emulsified asphalt content is less than 3% [35].

3.3.2.  Pre- Cracking of Base Layer. Another type of approach is pre-cracking of the base layer to reduce its shrinkage effect. One of the main reason of reflection crack is high modulus of semi-rigid base. The shrinkage of semi-rigid base is unavoidable, if the shrink cracking occurs with large width, higher modulus will result in higher stress concentration. The application of pre-cracking can effectively reduce its shrinkage. Early in 2005, Sebesta applied micro-cracking to cement-treated base after 2-3 days of curing, the result shows that such approach effectively reduced shrinkage cracking of base layer without diminish its inservice modulus [36]. Researches also built such pre-cracking simulation model with Finite Element Method to prove that, compared with wide crack, thin cracking can mitigate stress concentration [37].

4.  Existing Problems and Development Trend in the Future
(1) The way of adding stress absorbing interlayer between base and surface has gradually become an important approach to solve the reflection crack. This method can be used not only in the construction of new semi-rigid base pavement, but also in the reconstruction and overlay of old road. But for the new road, increasing the absorption layer means higher cost.

(2) For the semi-rigid base material anti-cracking itself, the overall effect is not too bad, and adding fiber, using skeleton dense grading will increase the requirements of construction technology. If the construction quality cannot be guaranteed, the effect of such materials will be greatly affected.

(3) The pre-cracking of semi-rigid base may reduce its strength and modulus, but it could also reduce its environmental sensitivity to effectively alleviate its shrinkage cracking problem. The research of this type of research is becoming popular since its low cost compared with other methods.

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