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Preparation, microstructure and rheological properties of asphalt sealants for bridge expansion joints

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HIGHLIGHTS

- Asphalt sealants were modified by large amount of various modifiers.
- Network microstructure between polymer and bitumen was captured.
- Significant plateau region of master curves and black diagrams indicated improved rheology.
- Asphalt sealant's properties related well to mixture performance.
- Meso-scale finite element modelling was able to simulate the mixture response.

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ABSTRACT

The service performance of asphaltic plug joints (APJs) is unsatisfactory. Premature cracking, rutting and debonding of APJ filling mixture is strongly related to the relevant properties of the used asphalt sealants. Better understanding on the sealant properties and their relation to the mixture performance is thus needed. In this paper, asphalt sealants were highly modified with a large amount of styrene–butadiene–styrene block copolymers (SBS), crumb rubber (CR), polypropylene (PP) and a combination of the above modifiers. Fluorescence microscopy analysis confirmed the formation of continuous polymer-rich phase, the swelling of crumb particle and the compatibility between the modifier and bitumen. Fundamental research into rheological behaviours was carried out by using viscosity test, dynamic modulus test, creep test and relaxation test. The significant plateau region of rheological master curves and black diagrams demonstrated an extraordinary effect of modification. Asphalt sealant's properties were found to well relate to APJ mixture performance. Finite element (FE) modelling at meso scale provided a favourable result and allowed bridging the gap between sealant properties and mixture performance. The provided test results could be used as a database for the selection and optimization of asphalt sealant.

1. Introduction

Expansion joints are used to accommodate the complex movement of bridge decks. The joints are not only the critical element for bridges but also the weak element. The service life of the bridge expansion joints is relatively shorter than expected and thus results in high maintenance cost. A survey done by Lima indicated that the maintenance cost for expansion joints reached 25% of the costs of maintaining bridges in Portugal [1]. Leaky expansion joints usually result in a serious problem on steel corrosion and thus influence the durability of concrete bridge. The damaged joints also dramatically reduce driving comfort and safety.

There are various types of bridge expansion joints, which can accommodate movements from 30 to 1000 mm. Among them, asphaltic plug joints (APJs) are popular in many countries for short concrete bridges with a relatively small joint movement less than 50 mm. The advantages of APJs include low cost, easiness for installation, maintenance and repair [2,3]. Due to increasingly strict requirements on traffic noise reduction, innovative silent APJs have been tested and applied in the Netherlands [4]. In order to broaden APJ's application, new APJ systems for large movements

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up to 100 mm have been developed in Switzerland by embedding a row of springs in the conventional APJ mixture [5].

Literature review shows that the filed performance of APJs varies significantly worldwide. The reported service lives in different nations showed a very wide range and were not satisfactory [6]. APJs have a simple structure but they are subjected to various damages due to different mechanisms, in which traffic loading, joint open and close, temperature fluctuation are believed to play an important role [7,8]. Various defects in APJs have been identified in field including rutting and shoving in summer, cracking through the joint filling material, and debonding at the joint-pavement interface in winter [3,6].

The APJ filling material is a special mixture that consists of asphalt sealant plus single-grade coarse aggregates. This mixture differs strongly from traditional hot mix asphalt used for asphalt pavements. The amount of asphalt sealant that used in an APJ mixture can reach 20–40% by volume. Coarse aggregates don't form a strong stone skeleton compared to conventional asphalt mixtures. A large amount of asphalt sealant used allows the APJ mixture being flexible to deal with the joint opening at low temperatures, while such a bitumen-rich mixture is susceptible to rutting and shoving due to traffic loading at high temperatures. For this reason, asphalt sealants are required to have a significantly high softening point to resist flow at high temperatures and a large elongation to accommodate joint movements at low temperatures. Furthermore, strong adhesion is a guarantee to prevent debonding between APJ and the existed pavement. Highly modified bitumen is thus needed to meet all of the above mentioned requirements on sealant properties.

Many countries have established a standard specification for asphalt sealant used for APJs. A typical one can be found in ASTM D6297-01 [9]. The specification issued by UK Bridge Joint Association is based on the following indexes including cone penetration, softening point, flow resistance, and extension test [10]. It should be noted that the indexes listed in most of the existing specifications are empirical and thus poorly related to the joint performance in field. After a tremendous amount of researches, the Swiss Guidelines of the Swiss Federal Road Office (ASTRA) released a new guideline on APJs in 2005 [11]. Compared with other specifications, the Swiss guidelines are successful to establish performance based material specifications and sophisticated test methods. The proposed technical indexes fully consider the characteristics of highly modified asphaltic sealant and more relevant to the field performance of APJs. Some important technical tests include elastic recovery, aging resistance, and storage stability. Dynamic rheological analysis, examination on polymer dispersion state and change of polymer content before and after aging are first presented for material specification. A five-year monitoring project on 18 joints in Switzerland demonstrated the proposed technical requirements in the Swiss guidelines related well to the durability of APJs [3].

It should be noted that material property testing on asphalt sealant in laboratory can't provide sufficient and convincing proof of APJ performance. In order to determine the performance of the filling material and APJ structure as a whole, Federal Institute for Materials Research and Testing (BAM) in Germany has developed a sophisticated joint movement simulator as a functional test. Effects of joint open and close due to temperature fluctuation and repeated traffic loadings on crack resistance are evaluated. Besides Germany, the joint movement simulator test at low temperatures is acceptable for APJ performance evaluation in many countries including Switzerland, the Netherlands, USA, and so on. Furthermore, the performance validation on real full-scale APJ systems was carried out by means of LINTRACK test facility at Delft, the Netherlands [4].

Apparently there is a gap between simple material testing on asphalt sealant and APJ performance in field. It is time-consuming and expensive to perform joint simulation testing. Furthermore this type of test facility is not affordable. Numerical simulation has been increasingly used as a tool to bridge the gap between material property and service performance. The principle is to put material property, structural geometry and loading together into a simulation tool to calculate the stress and/or strain of material components. Stress and/or strain analysis allows evaluating the performance of a structure by considering material strength and fatigue life. Based on the principle mentioned above, APJ system can be simulated at macro-scale, while APJ joint filling mixture can be simulated at meso-scale by considering a composite structure that consists of coarse aggregates and asphalt sealant, as illustrated in Fig. 1. Similarly, this meso-scale simulation can translate the visco-elastic response of asphalt sealant into stress and/or strain, which can be used for performance evaluation purpose. By combining material property testing, numerical simulation at macro and meso scales, importance of material's relevant properties that relate to performance can be well ranked. For example, the sealant's elongation and relaxation at low temperatures is related to joint cracking, while the creep resistance is corresponding to mixture rutting and shoving at high temperatures. Aging resistance will account for the durability of APJ. Meso-scale simulations have been demonstrated to be useful to get insight into the problem of raveling, cracking, and rutting of asphalt mixtures [12–14]. Therefore, it is believed that the cracking, rutting and durability of APJ systems could be evaluated by this means.

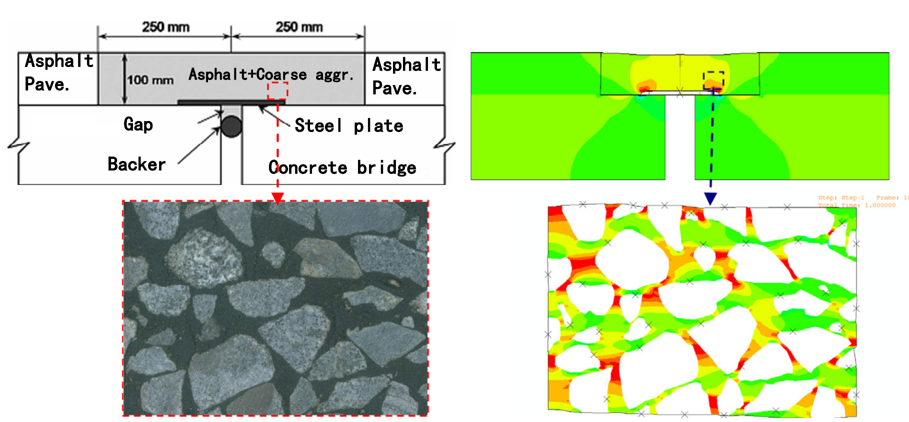

Fig. 1. Insight into the stress and strain of the asphalt sealant by the combination of numerical simulations at macro and meso scales.