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Assessment of effectiveness of rejuvenator on artificially aged porous asphalt concrete

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HIGHLIGHTS

- Porous asphalt concrete was prepared from an artificially aged loose asphalt mixture.
- The aged porous asphalt concrete specimens were immersed in a rejuvenator.
- The rejuvenator didn't change stiffness modulus of the aged porous asphalt concrete.
- The rejuvenator didn't change fracture properties of the aged porous asphalt concrete.
- No rejuvenation of the rejuvenator was detected in this research.

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ABSTRACT

The service life of porous asphalt pavements is limited due to raveling. Preventive maintenance to porous asphalt pavements by means of spraying rejuvenators on the pavement surfaces is considered as cost-effective. In the research of this paper, a loose asphalt mixture was artificially aged and then compacted. A rejuvenator was applied to the prepared porous asphalt concrete specimens. The stiffness modulus and indirect tensile strength of the specimens were measured using the indirect tensile tests. The results show that the application of the rejuvenator did not change the stiffness modulus and indirect tensile strength of the porous asphalt concrete specimens.

1. Introduction

Since 1972, research has been carried out in the Netherlands to assess the advantages of porous asphalt (PA) wearing courses in relation to conventional pavement structures [1]. Based on the results of a cost/benefit analysis of using PA as a wearing course on roads, the Dutch Ministry of Infrastructure and the Environment decided in 1987 to apply PA wearing courses on a large scale. In 1990 it was decided that the entire main highway network qualifies for PA wearing courses [2]. Since then, the application of PA on the Dutch highway network increased substantially. At the end of 1996 about 36% of the main highway network had PA as a wearing course. In 2005 about 65% of the main highway network had been surfaced with PA wearing courses and this value was around 90% in 2010 [3,4].

In the Netherlands, a typically used PA mixture is the standard PA 0/16 mixture. According to the Dutch construction specifications [5], the standard PA 0/16 mixture consists of about 85% crushed stones with sizes between 16 and 2 mm, about 10.5% crushed sand with sizes between 2 and 0.063 mm, 4.5% mineral filler with sizes less than 0.063 mm and a bitumen with a penetration grade of 70/100 0.1 mm. The mineral filler is requested to contain hydrated lime with a content of at least 25% by mass. The content of the bitumen is 4.5% by mass of 100% mineral aggregates. The single design criterion for the PA concrete is that the air voids content of a compacted PA mixture has to be at least 20%.

Because of the high air voids content PA wearing courses are effective in reducing traffic noise and avoiding splash and spray during wet weather. However, the high air voids content results in a high sensitivity to damage due to traffic and environmental effects. The most occurring form of damage on PA wearing courses is raveling [2,4]. Raveling is the loss of stone particles from the pavement surface. Due to raveling, the average service life of PA wearing courses is lower than that of dense asphalt surfacing layer. It is reported that the average service life of typical PA wearing

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course in the Netherlands is 11.8 years [6]. Aging is believed to be the main reason for raveling failure in PA wearing courses [7]. Due to the open structure of PA concrete, the bituminous binder is strongly exposed to the effects of oxygen, ultraviolet radiation in the top and changes in temperature. This causes rapid aging of bituminous binder in PA concrete. After 3 years of service in the field, the bituminous binder in PA concrete starts to behave brittle at temperatures above 0 °C, which increases the sensitivity to cohesive failure of the bituminous binder [7].

In 2010, the Dutch Ministry of Infrastructures and the Environment launched a research project entitled "Lifespan Extension Maintenance of Porous Asphalt Concrete (LVO-ZOAB in Dutch)" to investigate the possibilities of applying preventive maintenance to PA wearing courses by means of spraying rejuvenators on the pavement surfaces [8]. The purpose of rejuvenators is to penetrate into somewhat the asphalt concrete and soften (rejuvenate) the bituminous binder [9]. Till the LVO-ZOAB project, no Dutch experience about using rejuvenators on PA wearing courses has been reported. In the U.S., only few research of using rejuvenators on dense asphalt surfacing layers has been reported. The first independent study [10] reported that some of the rejuvenators penetrated into the dense asphalt concrete pavement surface to a depth of approximately 9.5 mm and provided some rejuvenation to the bituminous binder. It was measured by extracting the bituminous binder from the asphalt concrete cores and measuring the penetration and viscosity. Another independent study [11] found that a rejuvenator significantly reduced the resilient modulus of the laboratory prepared asphalt concrete samples with air voids contents of 10–12%. It was recommended that rejuvenators should not be applied on asphalt concrete pavements with air voids contents below 7–8%. A specification for bituminous pavement rejuvenation has been published by the U.S. Federal Aviation Administration [12]. It is specified that an asphalt pavement rejuvenation product is required to have an ability of rejuvenation of the upper 9.5 mm of aged bituminous binder in the asphalt pavement surfaces. The rejuvenation product has to be capable of achieving at least some certain changes in the properties of the recovered bituminous binder, such as decrease of the viscosity and complex shear modulus.

In the LVO-ZOAB project, potential rejuvenation products from the market were applied on PA wearing courses in the field trial sections on Dutch main highways. The feasibility of those potential rejuvenation products to extend the service life of the PA wearing courses was determined by laboratory tests [13]. The authors of this paper were also involved in the LVO-ZOAB project. It has been found that the applied rejuvenation products increased the bending stiffness of the PA concrete beams from the field trial sections. The fracture properties of those PA concrete beams were not changed due to the application of the rejuvenation products. This might indicate that the rejuvenation products did not have rejuvenation effect. If for instance the rejuvenation products rejuvenate the aged bituminous mortar in the PA concrete beams, this could reduce the bending stiffness of the PA concrete beams. It should be noted that those PA concrete beams had micro cracks already. In the case of that the rejuvenation products fill the micro cracks in the PA concrete beams, it will cause an increase of the bending stiffness of the PA concrete beams. Furthermore, it has been found that the raveling resistance of the PA concrete cores from the field trial sections seems to be improved by the applied rejuvenation products because of adding extra fresh bituminous binders. The rejuvenation effectiveness of the applied rejuvenation products is not clear based on the results of those laboratory tests on the PA concrete samples from the field trial sections.

In this research, a rejuvenator was applied on an artificially aged porous asphalt concrete. The purpose of this research is to get a general opinion of the rejuvenation effectiveness of the rejuvenator on the artificially aged porous asphalt concrete. The indirect tensile tests were performed to measure the stiffness modulus and indirect tensile strength the artificially aged porous asphalt concrete with and without the rejuvenator.

2. Materials and methods

2.1. Porous asphalt concrete specimens

In this research, the standard porous asphalt 0/16 mixture was selected because it has been widely used in the single-layer porous asphalt wearing courses in the Dutch main highway network. The crushed Norwegian aggregates (Bestone®), Wigro 60 K filler and Q8 70/100 Pen bitumen were used to prepare the asphalt mixture. The specifications of the Q8 70/100 Pen bitumen and Wigro 60 K filler are given in Tables 1 and 2 , respectively. Table 3 illustrates the composition of the prepared porous asphalt 0/16 mixture. The apparent density of crushed stone and sand was measured according to the European standard EN 1097-6 [14]. For mineral filler, it was measured according to the European standard EN 1097-7 [15].

The specified compaction method for the porous asphalt mixture is the Marshall compaction method using 50 blows on each side of the mixture in a cylindrical mold with a diameter of 100 mm. In order to reduce the variation in air voids content in the porous asphalt concrete specimens, the porous asphalt 0/16 mixture was compacted using a Shear Box Compactor in this research. The Shear Box Compactor was designed to manufacture prismatic blocks with sizes of 150 mm in width, 450 mm in length and 145–185 mm in height in the laboratory [16]. It has been proven that by means of the Shear Box Compactor homogeneous specimens with a small variation in air voids content can be produced [17]. Fig. 1 shows pictures of the Shear Box Compactor and its cylindrical mold. The length and width of the mold are set constant at 450 mm and 150 mm, respectively. Throughout the compaction phase, a vertical force is continuously applied on the mixture filled in the mold. The vertical force results in a constant vertical stress of 0.75 MPa. Together with the vertical load, cyclic shear forces are applied by the frame in horizontal direction to reach a maximum shear angle of 4 degree. The shear loading cycles are finished after the predefined target height of the mixture is reached.

In this research the target air voids content for porous asphalt concrete was set at 20%. The theoretical maximum density of the mixture was calculated according to the European standard EN 12697-5 [18], based on its composition listed in Table 3. It was 2531 kg/m^3. So it can be obtained that the target bulk density for the porous asphalt concrete should be 2024 kg/m^3. According to the target bulk density and the dimension of the compaction mold, the resultant target height for 20.5 kg porous asphalt 0/16 mixture was found to be 150 mm. Fig. 2(a) shows a picture of the porous asphalt concrete block compacted using the Shear Box Compactor. From such a porous asphalt concrete block, a cylinder with a diameter of 100 mm was drilled and then sawn to a height of 50 mm (see Fig 2(b)). From each block, seven specimens with a diameter of 100 mm and a height of 50 mm can be obtained for testing.

One porous asphalt concrete block was made from the fresh porous asphalt 0/16 mixture. From it seven fresh porous asphalt concrete specimens for testing were obtained. Their specimen codes are from F1 to F7. Another porous asphalt concrete block was made from an artificially aged mixture. The artificially aged mixture was prepared by aging the loose fresh porous asphalt 0/16 mixture in an oven at 135 °C for 4 h and further at 85 °C for 7 days. In the first aging phase, at each hour the loose mixture was overturned once and stirred for 1 min. In the second aging phase, at each day the loose mixture was overturned once and stirred for 1 min. In both aging phases, approximately 10 kg loose mixture was placed in one pen box with a length of 36 cm and a width of 25 cm in order to keep the thickness of loose mixture between 5 and 6 cm. This artificially aging protocol was proposed and investigated by Partl et al. [19]. Seven aged porous asphalt concrete specimens for testing were obtained as well. Their specimen codes are from A1 to A7. The bulk density of the fresh and aged porous asphalt concrete specimens for testing was determined by measuring their dimensions according to the European standard EN 12697-6 [20]. It was known that the calculated theoretical maximum density of the prepared porous asphalt 0/16 mixture was 2531 kg/m^3. Therefore, the air voids contents of the porous asphalt concrete specimens can be calculated.

2.2. Rejuvenators

A rejuvenator (coded as rejuvenator I in this paper) was applied on the aged porous asphalt concrete specimens. This rejuvenator is a cationic rapid setting bituminous emulsion with a binder content of 53–57% by mass. It's viscosity is

Table 1
Specification of the Q8 70/100 Pen bitumen.

Penetration at 25 °C	Softening Point R&B	Density at 25 °C	Flash Point C.O.C.	Solubility in Xylene	Viscosity at 60 °C
0.1 mm	°C	kg/m^3	°C	by mass	Pa s
70–100	43–51	1029	230	99%	160