Performance Characteristics of Epoxy Modified Open Graded Friction Course (OGFC) By Post-doping Methods

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Abstract. To improve drainage properties and increase driver’s safety in wet weather, epoxy modified Open Graded Friction Course (OGFC) by post-doping methods was proposed. The predominant focus of this paper evaluated the performances of epoxy modified Open Graded Friction Course (OGFC) such as rutting resistance at high-temperature, crack resistance at low-temperature, friction, moisture resistance and coefficient of permeability. For comparison, the same NMAS Open friction course with epoxy asphalt which was supplied courtesy of ChemCo Systems Ltd and SK High-Viscosity Asphalt were cited. In addition, the harsh construction requirements and application limitations caused by the residence time of epoxy asphalt were solved by the post-mixing process which was produced by two steps, First step, component B of epoxy asphalt was produced in the backyard plant, then suitable amount of component A was added and mixed evenly while paving in site, affecting the holding time only in the two links of paving and rolling, and the time was easy to control. The results show that epoxy modified Open graded friction Course reinforced with Basalt fiber produced by post-mixing methods has good friction resistance and permeability while retaining satisfactory performance and mechanical properties.

1. Introduction

Porous friction courses (PFC), or Open-graded friction courses (OGFC) defined by the Texas Department of Transportation (TxDOT), is a large interconnected air void content mixture with a special gap-graded. In general, the voids content is 18% to 25%. Similar porous asphalt (PA) mixtures with voids contents as high as 25% are successfully applied in Europe. The advantage of good drainage capacity allows water to quickly drain away from the surface by flowing through the mixture itself. So would greatly increase driver’s safety in wet weather than normal mix designs and avoids to the potential for hydroplaning. The porosity of an OGFC can also significantly reduce tire-pavement noise and splash and spray potential of the pavement surface [1, 2].

However, due to air void content, these materials also exhibit poor strength and durability so that greatly restricted its applications. There are two common problems that have caused inconsistency in OGFC.
performance: ravelling and binder drain down [3-5]. In order to increase the durability of the porous asphalt mixtures, some efforts have been made including using fibers in the mixture to allow more binders to be added in the mixture [6,7], some modifiers such as styrene butadiene styrene (SBS), ethylene-vinyl acetate (EVA), styrene butadiene rubber (SBR), polyethylene (PE), and rubber binders were used to improve the mechanical properties and durability of the binders [8-10]. High viscosity modified asphalt is a better way to improve the performance of OGFC, and OGFC has been used more and more. But the application is still very limited due to heavy duty loads and short service life.

Above all, we need to use innovative materials to solve these problems. Epoxy asphalt is an excellent thermosetting material with good ductility at low temperature and high strength at high temperature which was first used to pave the steel deck of the San Mateo–Hayward Bridge in 1967 with 49-year service life [11,12]. Using epoxy asphalt instead polymer modified asphalt is a good way to modify the durability of OGFC, some researchers focus their attention on the use of epoxy asphalt in porous asphalt mixtures for long service life [13-20]. On the other hand, mainstream epoxy asphalt products such as ChemCo made in American and TAF made in Japan is expensive, in addition, there must be in short time to complete the whole construction process. So it is worthwhile to investigate the performance characteristics of Open graded friction Course with Self-produced epoxy asphalt and new production process.

2. Objective
Rutting resistance, crack resistance at low temperature, moisture resistance, friction, and permeability and anti-skid ability were conducted to assessment performance of Epoxy Modified Open Graded Friction Course (OGFC) reinforced with basalt fiber produced by post-doping methods, the purpose of adding the reinforced fier of basalt mineral fiber was to increase crack resistance and self-healing ability of OGFC. For comparison, the same NMAS Open friction course with epoxy asphalt which was supplied courtesy of ChemCo Systems Ltd [15] and SK High-Viscosity Asphalt were cited [14].

3. Materials and Methods

3.1 Materials
For the main laboratory study, basalt coarse aggregates, limestone fine aggregates which were produced in quarry located in Yunnan Province, China.

Conventional bituminous binders are thermoplastics; they become soft when heated and harden when cooled. The epoxy asphalt Self-developed is also a two-part product, Part A (used at 12.1% by weight) is epoxy resin with E51, Part B (87.9%) consists of acid liver curing agent, 70 penetration grade bitumen (supplied Shell), toughening agents such as resin and rubber etc. The product is free from solvents.

Basalt fiber was produced by Hebei Shengzhang energy saving technology Material Co., Ltd., the diameter of fiber is 16.6 micron, the Fracture strength is 0.41N/tex.

3.2 Mixture design and manufacture
The typical target air-void content is around 18% to 25%, in order to considering larger permeable and lower noise to forming a highly porous structure, larger voids with 23% was considered in this study. The nominal maximum aggregate size (NMAS) is 13.2 mm and the aggregate gradation shown in Fig. 1, tow-part epoxy asphalt binder self-produced were used. For comparison, epoxy asphalt and High-Viscosity asphalt from SK in Korea OGFC mixtures were cited, the epoxy asphalt was obtained from U.S. manufacturer which used widely in China and the U.S.

The optimum epoxy asphalt content of OGFC is typically determined based on optimal Cost-effective and the philosophy of epoxy asphalt content as much as possible in the mixture without excessive drain down during transportation and placement in constriction. Marshall Specimens of the five trial binder contents were also prepared by post-mixing methods and tested after full curing for further check of the selected binder content. It was found that specimens compacted at 5.0% binder content had an average air-void content of around 23%, and had the cost-economic stability value than specimens compacted at other binder contents. So in this study the optimum epoxy asphalt binder content (OBC) is 5% (by mass of aggregates), the fiber content is 0.3%.
3.3 Test methods

3.3.1. Marshall Stability
Epoxy asphalt OGFC’s Marshall Stability was evaluated following a procedure Chinese test Specification Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering [21]. The epoxy asphalt mixture was manufactured by post-mixing process which mixed with two steps. First, part B of epoxy asphalt was added into aggregate and filler to mix 120s, then the part A was added to mix again 120s. Specimens were prepared according to the standard Marshall method. The diameter of the specimen is 101.6 mm and nominal thickness is 63.5 mm, and the number of compaction cycles is 50 blows. Five parameters were measured, namely, bulk specific gravity, air voids, voids in mineral aggregates or VMA, Marshall Stability and Marshall Flow value. The dimension and specifications of the Marshall apparatus were explained in ASTM D 1559. Before tested, all specimens were cured at 120°C for 4h.

3.3.2. Rutting resistance at high temperature
Rutting resistance of epoxy asphalt mixture of OGFC was evaluated by dynamic stability measured in a slab rutting test, following a procedure in Chinese test specifications Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering [21]. The slab with sizes of 300 mm in width, 300 mm in length, and 50 mm in thickness was compacted by a roller compactor to the desired air-void content, then cured for 4h or more at 120°C. The rutting test of OGFC with epoxy asphalt binder was then conducted at 60°C by a solid rubber tire with 0.70 MPa of contact pressure and 42 passes per minute for 60 minutes. The dynamic stability (DS) is defined by

\[
DS = \frac{(t_2 - t_1) \times N \times C_1 \times C_2}{d_2 - d_1}
\]

Where \( t_1 \) and \( t_2 \) are testing times, 45 min and 60 min, respectively; \( d_1 \) and \( d_2 \) are corresponding rut depths; \( C_1 \) and \( C_2 \) are parameters specific to tester and specimen type respectively; \( N \) is speed of the test wheel (42 passes/min). As can be seen from the definition, DS represents the number of wheel passes that are needed to cause one millimetre of rut depth.

3.3.3. Moisture resistance
A soaked Marshall Stability tests and indirect tensile strength ratio (TSR) tests similar to that in AASHTO T 283 were conducted to evaluate Moisture resistance [22]. In this test, three sets of specimens (three specimens in each set) were conditioned in a 60°C water for different durations, i.e., 0.5h, 48h respectively, and then measured for their Marshall Stability values. The residual Marshall stability was calculated for the 48 h conditioned specimens as the ratio of the average Marshall Stability of the second set of specimens and the average Marshall Stability of the first set of specimens.
3.3.4. Crack resistance at low temperature
The stiffness and flexural strength at failure of OGFC-13 with epoxy asphalt was conducted to evaluate the crack resistance ability at low temperature by a three-point flexural beam test following a procedure in Chinese test specifications Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering [22]. The size of beam specimen is 250 mm ± 2 mm in length, 100 mm ± 2 mm in width, and 50 mm ± 2 mm in thickness, and was loaded at the mid-span at a rate of 50 mm/min until failure at temperature of -10℃. Calculations of these parameters such as flexural strength, flexural strain, and flexural stiffness at failure can be achieved based on elementary beam theory, which will not be detailed here.

3.3.5 Anti-skidding
British pendulum number (BPN) and mean texture depth (MTD) were conducted to assess the anti-skidding ability respectively with a British Pendulum Tester (BPT) and the sand patch method following a procedure in Chinese test specifications Field Test Methods of Subgrade and Pavement for Highway Engineering [23].

4. Results and discussion

4.1 Marshall Stability
Marshall Stability measures the maximum load sustained by OGFC of self-produced epoxy asphalt materials at a loading rate of 50 mm/minute. The test load is increased until it reaches a maximum. Beyond that, when the load just starts to decrease, the loading is ended and the maximum load (i.e. Marshall Stability) is recorded. During the loading test, dial gauge is attached which measures the specimen’s plastic flow owing to the applied load. The flow value refers to the vertical deformation when the maximum load is reached.

Marshall Stability is related to the resistance of bituminous materials to distortion, displacement, rutting and shearing stresses. The stability is derived mainly from internal friction and cohesion. Cohesion is the binding force of binder material while internal friction is the interlocking and frictional resistance of aggregates. As bituminous pavement is subjected to severe traffic loads from time to time, it is necessary to adopt bituminous material with good stability and flow. The average Marshall Stability results were summarized in Table 3.

4.2 Rutting resistance at high temperature
The dynamic stability (DS) of Epoxy asphalt OGFC with an air-void content of around 23% were tested in the rutting test. The average results and cited results were summarized in Table 1. The commonly adopted acceptance criterion for DS should be greater than 3000 passes per millimetre. It can be seen that OGFC of self-produced epoxy asphalt DS was more than four times the DS of the same mix but with high-viscosity asphalt made by SK. Compare to OGFC with epoxy asphalt from ChemCo Systems Ltd the deformation is very slow. So the OGFC-13 mixture with self-produced epoxy asphalt has excellent rutting resistance due to the thermosetting property and good compatibility of the epoxy asphalt, which does not soften as much as conventional binders at high temperatures.

Table 1. Rutting test results at 60℃.

| OGFC mixture                  | Air-void content (%) | Rut depth at 45 min (mm) | Rut depth at 60 min (mm) | DS (mm⁻¹) |
|------------------------------|----------------------|--------------------------|--------------------------|-----------|
| OGFC-13 of self-produced EA  | 23.8                 | 0.598                    | 0.628                    | 21000     |
| OGFC-13 cited                | 21.2                 | 0.593                    | 0.629                    | 17500     |
| OGFC-13 SK high-Viscosity Asphalt | 20.8             | /                        | /                        | 4526      |

4.3 Moisture resistance
OGFC Marshall Specimens with an air-void content of around 23% were tested in the TSR test, the results and cited were summarized in Table 2. As can be seen, the TSR values of the OGFC-13 of self-
produced epoxy asphalt are around 85%, which is higher than the minimum values (75% or 80%) typically required for porous asphalt mixtures [24]. To evaluate the long-term moisture effect on the OGFC mixture, a soaked Marshall test was also conducted. The results and cited were summarized in Table 3. As can be seen, the Marshall stability of the OGFC—13 of self-produced epoxy asphalt remained higher than 20.0 kN even after 48h moisture conditioning at 60℃, which is significantly larger than the specified minimum value of 3.5 kN for unconditioned specimens. The 48h moisture conditioning only slightly reduced the Marshall stability of EA OGFC from 27.53kN to 23.31kN. This further verifies the excellent resistance of epoxy asphalt mixtures to moisture.

4.4 Crack resistance at low temperature
The slabs of OGFC-13 of self-produced epoxy asphalt with around 23% air-void content were tested in three-point flexural beam test for their stiffness and flexural strength at a low temperature (-10℃). The results were summarized in Table 4. As can be observed from Table 4, the use of thermosetting toughness epoxy asphalt does not make much difference in the asphalt behaviour at low temperatures. And have good ability of low temperature crack resistance.

4.5 Friction
The BPN values and the MTD values of OGFC-13 of self-produced epoxy asphalt were summarized in Table 5, Based on MTD (0.55 mm or 1.0 mm) (45) [23,24] and the minimum acceptable values of BPN [23,24], the OGFC-13 of self—produced mixture satisfies both criteria. It can also be observed that OGFC of self-produced epoxy asphalt is significantly better than Cited both BPN and MTD. Since BPN reflects friction at low speeds while MTD reflects friction at high speeds on wet pavements, a combination of them reflects the overall friction performance of the mixture.
Table 5. BPN and MTD values from sand patch test.

| Mixtures                          | Air-void content (%) | BPN   | MTD (mm) |
|-----------------------------------|----------------------|-------|----------|
| OGFC-13 of self-produced EA      | 23.8                 | 80.4  | 2.13     |
| OGFC-13 cited                     | 20                   | 78.8  | 1.77     |
| OGFC-13 SK high-Viscosity Asphalt| 20.7                 | 65    | /        |

5. Road Trial

In order to confirm the findings of the laboratory evaluation the performance of epoxy modified open graded friction course (OGFC) reinforced with basalt fiber produced by post-doping Methods. A field trial was laid on left half with three lanes in tunnel of Yunnan wutangxun expressway on December 28, 2020, the length is 534m.

5.1 Materials

The epoxy bitumen used was produced in site as described earlier. Subject to field materials, the grading was adjusted to OGFC 16. Compaction of 100 mm diameter specimens for testing was by Marshall Hammer (50 blows per side) and carried out at site laboratory of contract Section II of pavement. Production testing of the mixes gave the results shown in Table 6.

Table 6. Field trial mix grading

| Mix              | Passing (%) sieve size (mm) | Bitumen content (%) | Air voids (%) |
|------------------|----------------------------|---------------------|---------------|
|                  | 16  | 13.2 | 9.5  | 4.75 | 2.36 | 1.18 | 0.6  | 0.3  | 0.15 | 0.075 | 100  | 79.8 | 50.3 | 22.4 | 15.3 | 10.7 | 9.2  | 6.8  | 5.7  | 4.5  | 5.0  | 20.5 |
| production       | 100 | 82.0 | 51.1 | 20.0 | 14.8 | 10.9 | 8.6  | 7.1  | 5.1  | 4.0  | 5.0  | 21.2 |

5.2 Manufacture and construction

A drum-mix plants was used to manufacture the EOGFC. The component B was prepared and heated to 130-150°C, then in order to clean the plant, the pumps and lines used to introduce the epoxy bitumen component B were connected from the plant and drained and flushed about half an hour. The epoxy component B mixtures with 4.4% content were manufactured first; there are a few general tips about the production process as follows:

- The moisture content of the aggregate leaving the dryer is better less than 0.2%, at least should not be higher than 0.5%;
- The mixtures were manufactured at a temperature of 125°C–140°C, must not be higher than 150°C;
- The fiber mixing time shall not be less than 15s before adding epoxy B component;
- Epoxy Asphalt B component mixture evenly mixed shall not appear white material.

After the mixed mixture is transported to the site, the special paver with high-power, anti-segregation and large-width is adopted for paving. When paving, add 0.0061kg epoxy resin per ton of mixture and mix evenly before spreading. Construction and compaction by a standard tandem steel-wheel vibratory roller and tire roller. Before tire roller, after double steel wheel, keep up with the rolling in time, and completed Rolling within 20 minutes before the epoxy asphalt mixture becoming “dry”and not adhesive. During the rolling process, plants were sprayed on the rolling wheel to prevent sticking materials without adding water.

5.3 Results and analysis of road trial

For acceptance checking, the inspection department carried out on-site road performance tests, such as, thickness, compaction degree, water permeability coefficient, friction coefficient, structure depth and flatness on the 3 cm thick epoxy asphalt concrete pavement. The results were summarized in Table 7. Show.
| Test index                  | Number of samples | Average/representative value | Design value and requirements |
|---------------------------|-------------------|------------------------------|-------------------------------|
| Marshall stability        | 6                 | 25.4KN                       | ≥8                            |
| Flow value                | 6                 | 28.6(0.1mm)                  | 20～50                        |
| Dynamic stability of rutting | 2               | 262,500 times / mm           | ≥10000                       |
| Marshall residual stability| 4                 | 96.8%                        | ≥90%                          |
| Thickness                 | 8                 | 32.3mm                       | ≥30mm                         |
| Water permeability coefficient | 5 sections    | 6950ml/min                   | ≥5000                         |
| Coefficient of friction   | 7                 | 85.1                         | ≥55                           |
| Structure depth           | 7                 | 2.14mm                       | ≥0.55                         |
| Flatness                  | 7                 | 0.71m/Km                     | ≤2.0m/Km                      |

It can be seen from Table 6 that paving a 3 cm thick epoxy asphalt concrete above the asphalt concrete foundation could make the test road to meet the requirements of design and specification. Such material and technology are feasible and effective for tunnel pavement.

6. Conclusions
With the socio-economic development, we need to focus on long life, durable, sustainable pavements research that are more environmental and user friendly. Through laboratory experiments and road trial of Epoxy Modified Open Graded Friction Course (OGFC) reinforced with basalt fiber produced by post-doping methods and controlled, the following findings are obtained:

1. OGFC with epoxy asphalt’ DS is about 4 times the DS of the same mix but with high-viscosity asphalt made by SK.

2. The Marshall stability of OGFC-13 with self-produced epoxy is respectively 3.0 times, 2.48 times which with epoxy asphalt, high-viscosity asphalt, the indirect tension strength of OGFC-13 with self-produced epoxy is respectively 3.04 times, 2.02 times which with epoxy asphalt, high-viscosity asphalt, and the OGFC-13 with epoxy asphalt have good ability of low temperature crack resistance. So even the voids is higher, yet the OGFC reinforced fiber with self-produced epoxy asphalt’ performance is much better than the same mixture but with epoxy asphalt widely used in USA and China made by ChemCo Systems Ltd[15] and can be used for heavy duty highway.

3. The epoxy asphalt of Self-produced and the epoxy asphalt from ChemCo Systems Ltd are both a two-part product, Part A is epoxy resin with E51, Part B is compounds with asphalt, curing agents, etc. The OGFC with self-produced epoxy asphalt’s optimum binder content is about 5% consider performance and economy.

4. The fixed mix ratio of Component A and Component B of self-produced epoxy asphalt and from ChemCo Systems Ltd was respectively 100:942 and 100:585[12, 19], the amount of epoxy resin of self-produced is more less, economy than the epoxy resin ChemCo Systems Ltd, is more economy and better performance.

Acknowledgments
This paper was financially supported by Transportation Science and Technology Project of Yunnan province under approval number of No.35 [2017]. The authors would like to thank those who have given us technical advices and help in experimental design and construction.
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