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RESEARCH ARTICLE

LABORATORY PERFORMANCE OF COLD-MIX ASPHALT USING EPOXY RESIN MODIFIED-ASPHALT EMULSION

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ABSTRACT

As a newly developed road material, epoxy resin modified-asphalt emulsion (ERMAE) shows great promise of being applied to cold-mix asphalt. In this paper, the cold-mix asphalt using ERMAE (hereinafter referred to as the Subject) is evaluated in terms of Marshall Stability, moisture resistance, high-temperature performance and low-temperature performance with a series of tests, all of which are proven satisfactory. Its Marshall Stability is approximately equal to that of the hot-mix asphalt, and far greater than the traditional cold-mix asphalt. Its moisture resistance has reached the requirement for the hot-mix asphalt. Its performance at low temperatures is similar with that of the hot-mix asphalt while the performance at high temperatures even matches that of polymer-modified hot-mix asphalt. Also it is found that its optimum laboratory performance comes with a dosage of 30% of curing agent.

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INTRODUCTION

A new kind of road material named epoxy asphalt emulsion has been developed recently by putting epoxy resin and curing agent together to modify asphalt emulsion. The robust epoxy asphalt emulsion, which may show great promise of being applied to the cold-mix asphalt, was pioneered by a research group from Guangdong University of Technology (He, 2008; He and Zhang, 2007) and was further developed by the researchers of Chang'an University (Chen *et al*., 2015). It performs exceedingly well at both high and low temperatures and is adhesive enough to hold aggregate together. Therefore it can be used in a humid environment at a low temperature to provide timely repairs to damaged asphalt pavement. Li *et al*. (2010) tested the influences of varying gradations of aggregate on the performance of epoxy asphalt emulsion. Efforts were also made to investigate its ability to hold aggregate together by Li *et al*. (2010). Building on previous researches (Cubuk *et al*., 2009; Motamedi *et al*., 2017; Kang *et al*., 2015), this paper aims to analyze the serviceability of the Subject in repairing damaged asphalt pavement. By testing the Marshall Stability, moisture resistance and performances at high and low temperatures of the Subject this paper may proven to be of great significance to the modification of cold-mix asphalt.

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MATERIALS AND METHODS

Selection of Raw Materials: The Subject was made mainly by a mixture of epoxy asphalt emulsion, curing agent, graded aggregate and the filling. For starters, epoxy resin and asphalt emulsion was mixed together in a ratio of 5:95 to make epoxy asphalt emulsion. While making the asphalt emulsion, 6% of water was added to the mix. A range of 20% to 35% of curing agent was subsequently adopted to cure the epoxy resin in the epoxy asphalt emulsion, as shown in Table 1. For aggregate and the filling, crushed limestone and fine limestone powder was selected respectively as the raw material. Both the crushed limestone and the fine limestone powder were carefully chosen to meet the requirements of Technical Specification for Construction of Highway Asphalt Pavements (JTG F40-2004).

Design of Mixes: The experiment was conducted by using three types of the mix as shown in Fig. 1. The optimum asphalt content (OAC) of each aggregate gradation was determined by the conventional Marshall method (JTG F40-2004).

Test Methods

Marshall Stability (MS): Since cold-mix asphalt is always compacted in a humid environment at an ambient temperature, the strength of the Subject would go through two phases: the initial phase of a low strength just after compaction and the final phase of a high strength after repeated compaction by traffic loads and the evaporation of moisture. The initial low strength was caused by excessive moisture left in the compacted mixture. After the repeated compaction of the openings and the evaporation of the excessive moisture, the strength of the Subject would gradually increase to a high level as in the final phase. The Marshall Stability tests were selected to evaluate the strength according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011). In the Marshall Stability tests, the specimens were split into two subsets: a wet one for the initial phase and another dry one for the final phase. To test the initial strength, the specimens were stored in the curing device at an ambient temperature (20 ℃) in a humid environment (80% humidity) for 3 h, and then tested by the Marshall Test machine. As for the final strength, the specimens were stored in the curing device at a high temperature (60 ℃) in a dry environment (30% humidity) for 3 h before the Marshall tests.

Moisture Resistance: After compaction, there would be some moisture left in the openings and permeable channels of the compacted mixture. After the evaporation of the excessive moisture, however, water that may accumulated on the surface can still easily penetrate into the openings and permeable channels, making the Subject more vulnerable to possible damages. Water resistance should therefore be regarded as an important aspect of the Subject. The Marshall Immersion test and freeze-thaw splitting test were selected to evaluate the moisture resistance in the paper. In the Marshall Immersion tests, the residual Marshall Stability (MS_0) was selected to quantify the moisture resistance:

$$MS_0 = \frac{MS_2}{MS_1} \times 100\% \quad (1)$$

where MS_1 – Marshall Stability of samples immersed in water for 30 min at 60 ℃ ± 1℃ (kN); MS_2 – Marshall Stability of samples immersed in water for 48 h at 60 ℃ ± 1℃ (kN). In the freeze-thaw splitting tests, the specimens were also split into two subsets: one dry subset and one wet subset. The wet specimens were conditioned following the freeze-thaw cycle procedures described in the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011). The ability of the Subject to resist moisture damage was quantified with an indirect tensile strength ratio (*ITSR*):

$$ITSR = \frac{ITS_2}{ITS_1} \times 100\% \quad (2)$$

where ITS_1 – indirect tensile strength of the dry subset (MPa); ITS_2 – indirect tensile strength of the wet subset (MPa).

High-temperature Performance: The pavement repaired with poor cold-mix asphalt may generate significant permanent deformation in cases like high temperature or repeated vehicle loadings. Its performance at high temperatures should therefore be made an important requirement for the Subject. To this end, this paper selected the rutting test. The compacted samples (300 mm both in length and width, and 50 mm in height) were stored in the curing device at a high temperature (60 ℃) in a dry environment (30% humidity) for 6 h before rutting tests. In the rutting test, the dynamic stability (*DS*) was selected to quantify the high-temperature performance:

$$DS = \frac{t_2 - t_1}{D_{t_2} - D_{t_1}} \times N \quad (2)$$

where t_1 – the initial time to record deformation (min); t_2 – the final time to record deformation (min); D_{t_1} – the deformation at t_1 (mm); D_{t_2} – the deformation at t_2 (mm); N – times of loading per minute (times/min). In this paper, t_1 is 40 min, t_2 is 60 min, and N is 42 times/min.

Low-temperature Performance

Voids of the cold-mix asphalt are usually greater than that of the hot-mix asphalt, resulting in poorer low-temperature performance. As a result, the cold-mix asphalt is more likely to generate cracks under low temperature conditions, which means its low-temperature performance is also an important aspect of the Subject. The bending test (JTG E20-2011, T 0715) was selected to evaluate this performance in this paper. In the bending test, the failure strain ε_B was selected to quantify the performance:

$$\varepsilon_B = 6\frac{hd}{L^2} \quad (2)$$

where h – height of cross section at the midpoint of span (m); d –deformation at the midpoint of span when fail (m); L – span of sample (m).

RESULTS AND DISCUSSION

Marshall Stability (MS): Fig. 2 illustrates the results of Marshall Stability tests conducted with three types of mix, all of which have a same dosage of 30% of curing agent. The initial and final strengths were tested according to the procedures described in Section 2.1. Based upon the testing results, the MS values of Subject are found to be approximately equal to that of the hot-mix asphalt and still far greater than the traditional cold-mix asphalt. According to JTG F40-2004, the MS values of hot-mix asphalt and the cold-mix asphalt should be greater than 8 kN and 3 kN respectively. Differences may also occur among different types of mix. It is noted that the AC-16 mix has greater strength than that of the AC-13 and AC-10 mixes.

Tests also find that the final strength is greater than initial strength, indicating an increase in the strength of the Subject after the evaporation of the moisture. Fig. 3 illustrates the results of Marshall Stability tests conducted by using one type of mix, the AC-13, with varying dosages of curing agent. It is found that the Subject exhibits the greatest initial strength when given a dosage of 30% of curing agent. If the dosage is less than 30%, the curing of epoxy resin would be insufficient, resulting in lower initial strength. If the dosage is more than 30%, the excessive curing agent could develop an adverse effect on the initial strength. Therefore, it is concluded that the optimum initial strength would be produced if given a dosage of 30% of curing agent. However, there is no apparent indication that the dosage of curing agent might affect the final strength, which shows a less important role of curing agent in a dry environment at high temperatures.

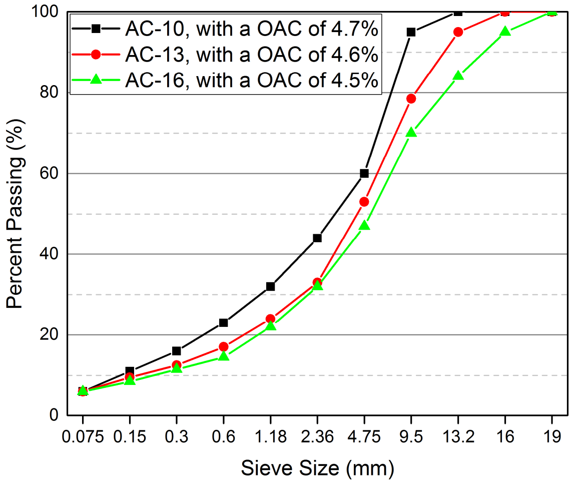

Fig. 1 Aggregate gradations and corresponding optimum asphalt content

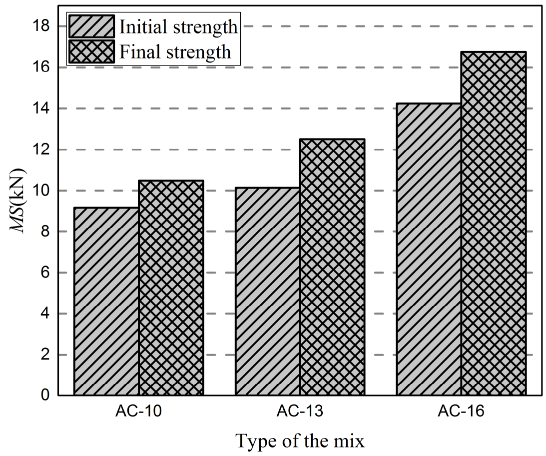

Fig. 2. The results of Marshall Stability tests

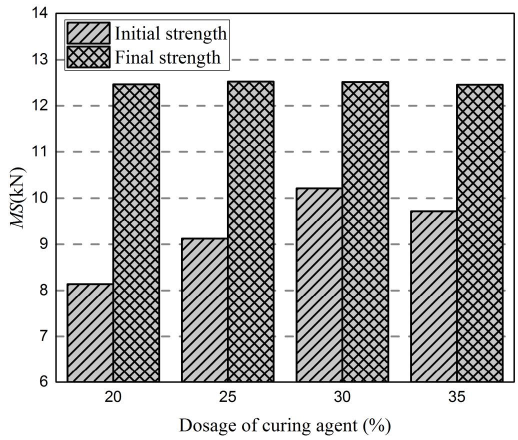

Fig. 3 Influence of the dosage of curing agent on Marshall Stability

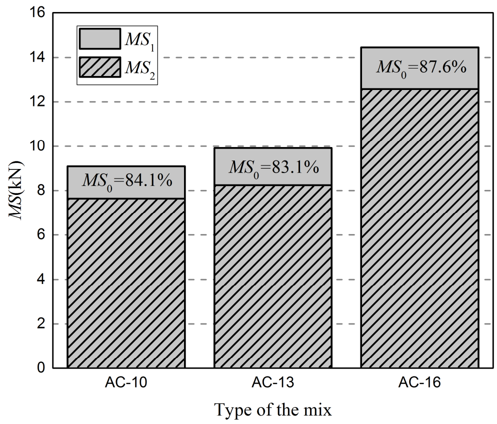

Fig. 4 The results of Marshall Immersion tests

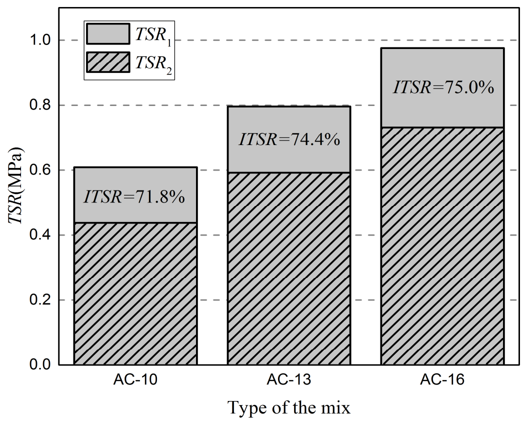

Fig. 6 Influence of dosage of curing agent on MS_0 values

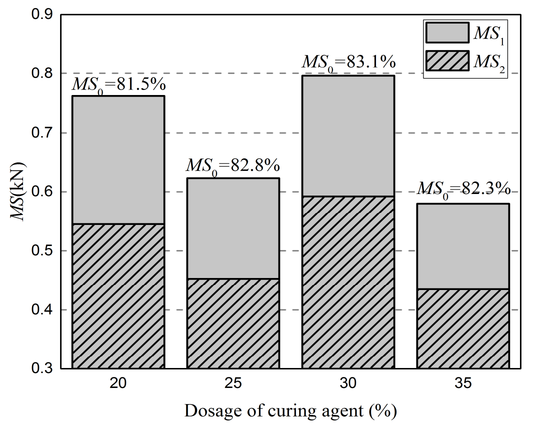

Fig. 7 Influence of dosage of curing agent on *ISTR* values

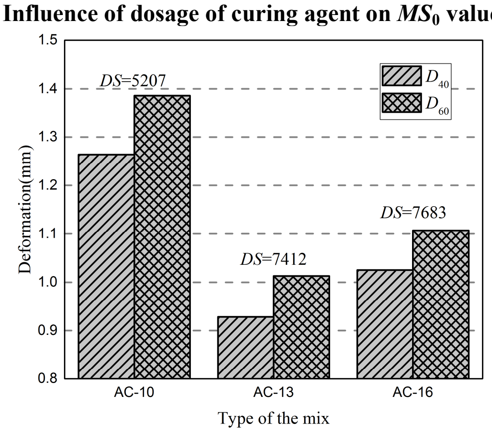

Fig. 8. The results of rutting tests

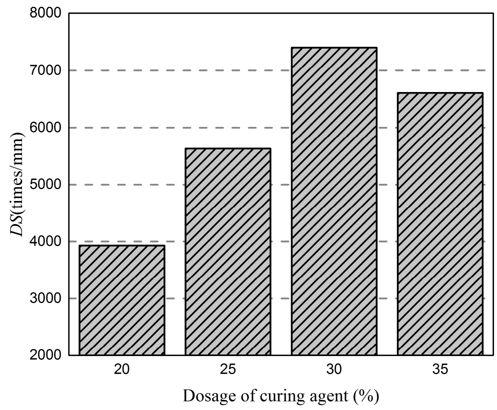

Fig. 9. Influence of dosage of curing agent on *DS* values

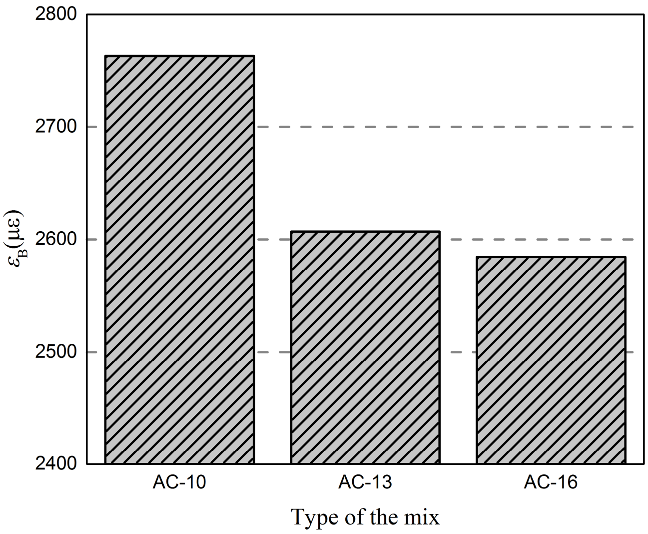

Fig. 10 The results of bending tests

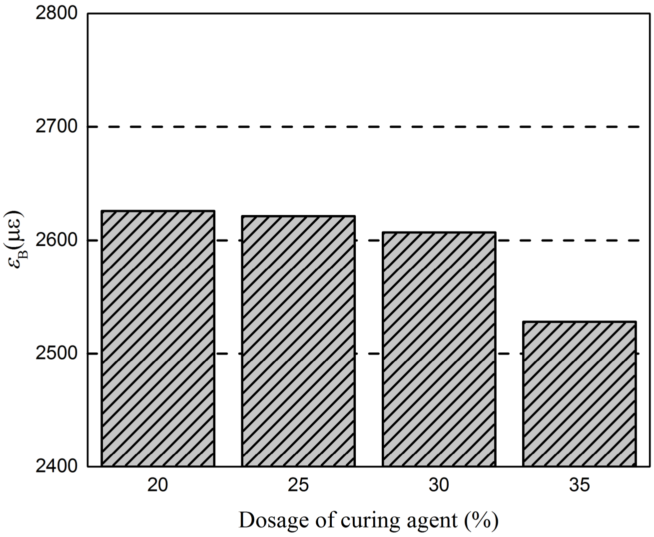

Fig. 11 Influence of dosage of curing agent on failure strain

Table 1. Main properties of the epoxy asphalt emulsion with varying amount of curing agent

Amount of curing agent (%)	20	25	30	35
Penetration, 25 ℃, 100 g, 5 s (0.1 mm)	78	75.1	74.2	75.2
Softening point (℃)	49.9	51.8	52.4	51.4
Ductility, 15 ℃ (cm)	31	28.6	24.8	23.6

Moisture Resistance: Fig. 4 and 5 illustrates the results of moisture resistance tests conducted with three types of mix that have a same dosage of 30% of curing agent. The MSR and ISTR values are calculated according to the procedures described in Section 2.2. Based upon the test results, the AC-16 mix seems to have more potential to resist moisture damage than the AC-13 and AC-10 mixes. The MS0 values of all gradations of the aggregate meet an 80% limit as required by the specifications (JTG F40-2004). It could be concluded that the MS0 values of the Subject has reached the requirement for the hot-mix asphalt. The ISTR values also meet the requirement of JTG F40-2004, though slightly lower compared the Marshall Immersion tests (ranging from 71.8% to 75.0%). According to JTG F40-2004, the ITSR values of the cold-mix asphalt should be greater than 70%. The test results of moisture resistance by using one gradation of aggregate, the AC-13, with varying dosages of curing agent are shown in Fig. 6 and 7. Based upon the test results, it is found that given a range of dosages of 20% to 35%, all of the MS0 values of the specimens are more than 80% and the ISTR values more than 70%. Both the MS0 values and the ISTR values see nonlinear increases if the dosage increases from 20% to 30%. However, between 30% and 35%, the growth of MS0 values and ISTR values becomes less obvious. Therefore adding an appropriate amount (30%) of curing agent could contribute to the resistance to moisture damage.

High-temperature Performance: Fig. 8 illustrates the results of the rutting tests conducted with three types of mix having the same dosage of 30% of curing agent. Based upon the test results, the DS values of the Subject are approximately twice as much as that of the polymer-modified hot-mix asphalt. According to JTG F40-2004, the DS values of polymer-modified hot-mix asphalt should be greater than 2800. In addition, it is noted that the AC-13 and AC-16 mixes have smaller deformation and DS values compared with the AC-10 mix, giving it better performance than the other two at high temperatures. Fig. 9 illustrates the results of rutting tests by using one type of mix, the AC-13, with varying dosages of curing agent. Based upon the test results, the dosage of curing agent has a great influence on performance at high temperatures. When the dosage is 30%, the Subject has the smallest DS values and therefore the best high-temperature performance.

Low-temperature Performance: Fig. 10 illustrates the results of the bending tests conducted with three types of mix that have a same dosage of 30% of curing agent. Based upon the test results, the εB values of the Subject are slightly lower than, though pretty close to, that of the hot-mix asphalt. According to JTG F40-2004, the εB values of the hot-mix asphalt should be greater than 2000 in the warm region and 2600 in the cold region. Besides, the AC-10 mix seems to have greater εB values and therefore more potential to resist low-temperature cracks than the AC-13 and AC-16 mixes. The bending test results of the same mix type, AC-13, with varying dosages of curing agent are shown in Fig. 11. Based upon the test results, the εB values see nonlinear decreases if the dosage increases from 20% to 35%. Increasing from 20% to 30%, the εB value would decrease gradually from 2626 με to 2607 με, though still approximately equal to that of the hot-mix asphalt (2600 με). When the dosage increases from 30% to 35%, the εB value would decrease sharply from 2607 με to 2528 με, and further fall below the critical value of 2600 με. It indicates that adding curing agent may make the cold-mix asphalt more brittle, thus reducing its low-temperature performance.

Conclusion

In this paper, the laboratory performance of cold-mix asphalt using epoxy resin modified-asphalt emulsion is evaluated by using the Marshall Stability, Marshall Immersion, freeze-thaw splitting, rutting and bending tests. Based upon those tests, the following conclusions could be drawn: The Marshall Stability of the cold-mix asphalt using ERMAE is approximately equal to that of the hot-mix asphalt, and far greater than the traditional cold-mix asphalt. The optimum Marshall Stability would demand a dosage of 30% of curing agent. In addition, the evaporation of moisture and improvements in curing temperature would be beneficial to improve its Marshall Stability. The moisture resistance of the cold-mix asphalt using ERMAE has reached the requirement for hot-mix asphalt. The optimum moisture resistance would demand a dosage of30% to 35% of curing agent. The high-temperature performance of the cold-mix asphalt using ERMAE is approximately twice as much as that of the polymer-modified hot-mix asphalt. Its optimum performance would demand a dosage of 30% of curing agent. The low-temperature performance of the cold-mix asphalt using ERMAE is slightly lower than, though pretty close to, that of the hot-mix asphalt. Its optimum low-temperature performance would demand a dosage of 20% to 30% of curing agent.

Conflicts of Interest: The authors declare that there have been no conflicts of interest.

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