Experimental investigation of the road performance of terminal blend rubber asphalt mixture with different dry-way additives

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Abstract. Using wet-way composite modification method may result in the amount of ground tire rubber (GTR) in terminal blend rubber asphalt (TB) undetectable. So, it is of great interest to find out if dry-way modification method can substitute for wet-way composite modified asphalt to address the shortcomings of TB mixture. A laboratory experiment was developed for performance evaluation of TB asphalt mixtures with dry -way use polymer additives. The results showed that: (1) 5 hours was recommended as optimum processing time, since no obvious difference existed after TB asphalt modifying for 5 h and 7 h. (2) The incorporation of anti-rutting agent PLAST.S, GTR, polyester fiber (PF) and styrene-butadiene-styrene block copolymer (SBS) improved the rutting stability, resistance against low-temperature cracking, moisture stability and fatigue life of TB asphalt mixture, especially when PLAST.S and PF were used. (3) The use of GTR and PF brought obvious increase of mixing torques, resulting in more challenges to the workability of TB asphalt mixture, whereas mixture with PLAST.S did not have a statistically significant difference with TB asphalt mixture. Therefore, according to the results obtained, PF can be used to replace TB/SBS composited modified asphalt since the two shared the most similar improvement of the properties of TB asphalt mixtures, while PLAST.S and GTR were also considered as good choices for modifying the TB asphalt mixture in dry-way.

1. Introduction
Recently, a new kind of asphalt rubber named terminal blend rubber asphalt (TB) has been recognized as a promising alternative to the traditional one because of its construction connivance [1-3]. The production is a smooth and homogeneous asphalt processed at temperature of 210°C or higher for 16 h~24 h, ensuring the ground tire rubber (GTR) particles in asphalt matrix are totally depolymerized. Therefore, TB asphalt can be transported to an asphalt concrete mixing plant or a job site and stored in the storage tank without agitation just as the polymer modified bitumen PMB [2]. Taking advantage of compatibility and homogeneousness in asphalt matrix, TB asphalt shows many benefits at pumping, mixing, storage stability, which make it more suitable for asphalt plant to produce. What’s more, it shows great advantage in the application for dense graded mixture when compared with traditional asphalt rubber (AR) [4-6]. On the other hand, due to the desulfurization of GTR in asphalt, the reduction of rubber elasticity tends to slightly weaken the high temperature rutting resistance of the asphalt pavement [7,8].

Currently, several techniques are used to make up for the reduction of elasticity of TB asphalt. One
of the most widespread techniques is adding polymers to the TB asphalt during the modifying process [9-11]. Unfortunately, after introducing the polymers into TB, such as styrene-butadiene-styrene block copolymer (SBS), the viscosity of asphalt increases with an obvious amplitude which makes more challenges for pavement construction as traditional AR faces. In addition, wet-way composite modification method cost more time and money, and sometimes precipitation problem in asphalt appeared [12-14]. Besides, some researchers [14] suspected that when using wet-way composite modification method, some suppliers are probably to add either less GTR or more polymers to meet the performance requirement, which makes the exact amount of GTR undetectable. At the same time, incorporating polymer additives directly to the asphalt concrete mixer drum with plain TB asphalt (dry-way) is easy handing and economical since it requires neither the storage tank nor pumping equipment remoulded.

However, it is unclear whether the TB asphalt mixtures with dry-way polymer additives have the similar performance to TB/SBS asphalt mixture. Therefore, it’s of great interest to conduct a comprehensive study on the effect of dry way polymer additives on TB asphalt mixtures.

2. Objective
The objective of this paper is to determine whether dry-way use polymer additives can substitute for TB/SBS asphalt to address the shortcomings of plain TB asphalt mixture. Processing time for plain TB asphalt was determined through conventional performance tests and fluorescence microscopy test, the engineering properties of TB asphalt mixtures were evaluated through high temperature wheel tracker test, low temperature three point beam flexure test, Marshall immersion test, modified Lottman tests, three point bending fatigue test, and mixture workability test.

3. Materials and testing methods

3.1. Materials
In this investigation, 90# base asphalt was used for modifying TB asphalt. Crushed gneiss aggregate were brought from a local quarry in Shaanxi Province in China. Three kinds of polymer additives used in dry way modification were selected, as shown in figure 1.

![Figure 1. Polymer additives (a) GTR powder; (b) coarse GTR; (c) PLAST.S (d) PF.](image)

The GTR powder was homogenously ground at ambient temperature without particles larger than 40 mesh (69 μm). The coarse GTR was obtained from the same way, which was utilized to replace some fraction of aggregates within the size range from 0.3 mm to 4.75 mm. The selected GTRs were shown in figures 1(a) and 1(b). A commercial anti-rutting agent named PLAST.S, mainly composed of recycled polymer [15], was used to mainly improve rutting resistance of TB asphalt mixture. A commercial polyester fiber mainly comprised of polyethylene terephthalate was employed, as shown in figure 1(d).

3.2. Preparation of TB asphalt
During the process, the 190°C base asphalt was mixed with 20% fine GTR powder using a high speed stirring mixer with a speed of 4500 rpm. A kind of catalyst was introduced into the asphalt right after the GTR powder incorporation step, which aimed to accelerate the degradation speed of GTRs in asphalt...
and lower the process temperature. To determine the economical and effective mixing time, TB asphalt modifying 1 h, 3 h, 5 h and 7 h respectively (TB1, TB3, TB5, TB7) was evaluated through conventional performance tests. A composite-modified TB asphalt (TB/SBS) was manufactured by adding 3.0% SBS into the prepared TB5 asphalt matrix and shearing with high speed for 0.5 h at 180°C [7].

Figure 2. Convention performance test results: (a) 25°C Penetration, (b) Softening point, (c) 5°C Ductility, (d) 135°C Viscosity, (e) 177°C Viscosity, (f) Elastic recovery.

Figure 3. Fluorescence micrographs: (a) TB0 (magnification: X40); (b) TB5 (magnification: X100) (c) TB7 (magnification: X100).

Figure 2 shows that after a drastic change in the first 3 h modification, no obvious differences existed between the properties of TB5 and TB7. It means that all conventional engineering properties of TB asphalt achieved stability after a high speed of mixing for 5 hours. The fluorescence micrographs of TB5 and TB7 in figure 3 show the GTR particles had broken down into extremely small size and remained homogeneously in liquid phase of asphalt after modifying 5 h, while large rubber particles isolated in the TB0 matrix during the first period of modification. As a result, the TB5 was selected for further TB asphalt mixture investigation based on less time consumption in production.

It can be seen from the figure 2 that all conventional performances for TB asphalt were promoted by the addition of SBS except the kinematic viscosity at 135°C and 177°C, while still met the 3.0 Pa·s
limitation. At the same time, the TB5 asphalt had considerably higher ductility and elastic recovery values as compared to the 90# base asphalt. This indicated the low temperature performance of base asphalt was improved by the fully degraded GTR polymer. In addition, the TB5 had a higher softening point value than that of 90# base asphalt, which means the high temperature performance of base asphalt was also improved. The 135°C viscosity value of TB5 was much higher than that of base asphalt, but far below the maximum viscosity limitation of 3.0 Pa·s for pump ability demand issued by CALTRANS [16]. It can be deduced that terminal blend asphalt produced in this study has a good temperature performance and shows great construction possibility.

3.3. Mixture design
Mixture design was carried out by using Marshall design method with a target air void of 4.0%. Based on the research of predecessor that TB asphalt was more suitable for dense graded mixture than the gap graded one [5], a dense asphalt concrete (DAC) gradation with the 13.2 mm nominal maximum aggregate size was selected. The synthesis aggregate gradations of all TB type mixtures were kept the same throughout the whole lab evaluation of TB asphalt mixture, as detailed in Table 1. The experimental dosages of PLAST.S and PF were 1.5‰, 3.0‰ and 4.5‰ by weight of the aggregate, while the experimental dosages of GTR were 1%, 2% and 3% by weight of the aggregate.

Table 1. Synthesis aggregate gradation of mixtures.

| Sieve (mm) | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|------------|------|-----|------|------|------|-----|-----|------|-------|
| Passing (%)| 96   | 76  | 47   | 30   | 20   | 16  | 11  | 9    | 6     |

The higher value of Marshall Stability is, the better high temperature rutting resistance the asphalt mixture will get. According to the test results, the recommended dosages of GTR and PF were 1% and 3.0‰, because TB asphalt mixture obtained the highest Marshall stability values at these dosages respectively, while 3.0‰ was selected for PLAST.S under the economical consideration since there is no significant improvement after the dosages increased from 3.0‰ to 4.5‰.

3.4. Pavement performance testing method
Wheel tracking test was performed at 60°C to evaluate the high temperature rutting resistance of the TB asphalt mixture by the dynamic stability (DS). The low temperature cracking resistance of TB asphalt mixtures were evaluated using a three-point flexural beam test at -10°C by the failure flexural strain and failure strain energy. Marshall Immersion test and modified Lottman test were performed to evaluate propensity of the asphalt mixtures to moisture induced damage by the residual Marshall stability (MS0) and the residual tensile strength (TSR), on the Marshall specimens. All procedures of the aforementioned tests follow the standard test methods in China test specification JTG E20-2011 [17]. The mixture workability test was performed to look into the work yield on placing asphalt mixture using an asphalt mixture workability device (AWD), which was according to the NCAT’s research [18]. The torques, needed to keep a propeller rotating with a constant rate of 45 rmp in hot loose mixture weighing 4 kg, were measured. Asphalt mixtures with lower torque values were considered easier to be placed or had better workability.

4. Results and discussions

4.1. High temperature rutting resistance
Wheel tracking test was performed at 60°C to evaluate the high-temperature deformation resistance of mixtures. Figure 4 showed the TB asphalt mixture had the lowest dynamic stability (DS) and highest rut depth (RD) among the five mixtures tested, which indicated the rut resistance of TB asphalt mixture could be improved through the composite modified asphalt and dry-way polymer additives. Furthermore, mixture with TB/SBS asphalt, PLAST.S, GTR and PF were acceptable for use in any road without limitation in consideration of rutting resistance, since all of their DS met the supreme
specification requirement of 3000 (cycle/mm) [19]. Mixture with PLAST.S exhibited the best rutting resistance with the minimum rut depth of 1.672 mm, and the PF could reduce the rut depth of the plain TB mixture (2.136 mm) by 14%, while coarse GTR reduce by 4%. It is clearly presented that the ranking of modification effect on mixture rut resistance was PLAST.S > TB/SBS asphalt > PF > GTR, that is, the TB asphalt mixture modified with PLAST.S through dry-way process had the best anti-rutting property, followed by TB/SBS asphalt and dry-way PF, and dry-way GTR in the least.

![Figure 4. Wheel tracking test results.](image1)

![Figure 5. Three point bending beam test results.](image2)

4.2. Low temperature cracking resistance
The evaluation of low-temperature cracking resistance of the mixtures was carried out by using three point bending beam tests at -10°C. Figure 5 summarized the average values for failure strain (FS) and flexural strain energy density (FSED).

According to JTG E20-2004 [19], asphalt mixture is considered suitable for cold winter region in China when the failure strain value of three point bending beam is higher than criteria of 2800 μm, as represented by the red dash line in figure 5. It can be noted that each mixture type had great anti-low temperature cracking property since all the failure strain results passed the red dash line. Results for both of the failure strain and flexural strain energy density revealed that incorporation of either TB/SBS asphalt or dry-way additives can improve the low temperature cracking resistance of TB asphalt mixture. The PF helped to increase the FESD of the plain TB asphalt mixture from 14.74 kJ/m³ to 21.53 kJ/m³, and increased the low temperature flexural strain by 27%. While the anti-rutting agent PLAST.S and GTR helped to increase the low temperature flexural strain of the plain TB asphalt mixture by 14%, 7% respectively. As compared to the plain TB asphalt mixture, the mixtures with TB/SBS asphalt performed the best, followed by TB asphalt mixture blended with additives PF in dry-way in the second position, the anti-rutting agent PLAST.S in the third and GTR in the last position.

4.3. Moisture susceptibility
Marshall Immersion test and modified Lottman test were conducted to evaluate the moisture damage resistance of the asphalt mixtures. The test results were presented in figure 6.

The average values of Marshall Stability (MS) for all the mixtures in unconditioned group were around 10 kN, and the unconditioned indirect tensile strength (ITS) remained around 1.0 MPa, which were similar to previous findings [20]. It can be seen that the TB/SBS asphalt, PLAST.S and PF showed excellent benefits to improve the structure strength of TB asphalt mixture, since asphalt mixture with the modifier mentioned had much higher MS and ITS values than that of the plain one. While, the addiction of coarse GTR impaired the structure stability of the TB asphalt mixture. The reason probably could be the decrease in the contact strength of mineral skeleton caused by replacing stone-stone structure with stone-coarse GTR-stone structure.
Figure 6. Moisture susceptibility test results: (a) Marshall Immersion test, (b) Modified Lottman test.

On other hand, Marshall Stability (MS) and indirect tensile strength (ITS) of all asphalt mixture suffered declines after the environment simulation effect. All the asphalt mixture presented good moisture resistances since MSR and TSR values were all higher than the minimum specifications required according to JTG F40-2004[19], namely 85% for MSR, 80% for TSR. TB/SBS composite asphalt increased the MSR and TSR values of the plain TB asphalt mixture by 7.09% and 10.36%. The PF helped to increase the MSR and TSR of the plain TB asphalt mixture from 87.05% to 94.17%, 82.01% to 90.12% respectively. While the anti-rutting agent PLAST.S and GTR helped to increase 5.44% and 2.21% for MSR of the plain TB asphalt mixture, 7.62% and 4.62% for TSR respectively. As a result, composite-modified TB/SBS asphalt was the most effective way to improve the moisture damage resistance of TB asphalt mixture, followed by PF, PLAST.S and GTR in order.

4.4. Fatigue cracking resistance

Figure 7. Three point bending fatigue test results: (a) Fatigue life, (b) Linear regression formula.

The evaluation of fatigue cracking resistance of the mixture was performed by employing three point bending fatigue test in stress controlled mode. The curves of fatigue life and fatigue stress for each mixture, generated by test values of fatigue life (Nf) at each stress ratio, were shown in figure 7. The regression equations of fatigue curve complied with a linear relationship in denary logarithm, in which K was the slope and b was the intercept. It can be seen that TB asphalt mixture had the largest K and smallest b among the five mixtures tested, which indicated the mixture had the highest fatigue sensitivity and would result in the shortest fatigue life (in cycles) at the same applied load respectively. Conversely, the fatigue stress required to promote a crack for TB asphalt mixture was lowest for equal fatigue lives [21]. Taking the stress ratio of 0.3 as an example, mixture with PLAST.S exhibited the longest fatigue...
life, and the TB/SBS asphalt increased fatigue life (Nf) of the plain TB mixture by 222.1%, while PF coarse GTR increased Nf by 170.6% and 90.3% respectively. This suggested that the incorporation of composite-modified TB/SBS asphalt and dry-way additives PLAST.S, GTR and PF improved the fatigue life of TB asphalt mixture. And the rank of modification effect was PLAST.S > TB/SBS asphalt > PF > GTR, that is, the TB asphalt mixture with PLAST.S had the best anti-fatigue cracking property, followed by TB/SBS asphalt and PF, and with GTR backmost.

4.5. Workability performance
For workability evaluation, asphalt workability device was employed to test the mixing torque of each loose mixture. Figure 8 depicted the average values of mixing torque obtained in the test. It can be noted that each loose asphalt mixture showed lower mixing torque when the test temperature was increased from 135°C to 177°C. On the other hand, an obvious increase of mixing torque in TB asphalt mixture was observed after the incorporation of TB/SBS asphalt and dry-way additives except the PLAST.S, which slightly reduced the mixing torque of the TB asphalt mixture. It clearly proved that the TB asphalt mixtures with PLAST.S had better workability than that with TB/SBS asphalt or with other dry-way additives. This was probably because the TB/SBS asphalt had higher viscosity than that of TB asphalt, and at the same time, the intact GTR and PF increased the viscosity of TB asphalt for absorbing large amount of asphalt, while the PLAST.S melted completely with a viscosity far below the TB asphalt at the mixing temperatures, and consequently, lowest torque.

![Figure 8: Asphalt mixture workability test results.](attachment:image.png)

5. Conclusion
Dry-way additives directly mixed with heated aggregate before the incorporating TB asphalt was an easier way to produce asphalt concrete when comparing with wet-way production, since wet-way production faced more challenges in TB composite asphalt processing, pumping and asphalt mixture mixing. Based on the comprehensive laboratory testing results, the following conclusions can be summarized:

- Based on conventional performance results and morphologies in fluorescence micrographs, the optimum laboratory processing time at 190°C with catalyst for terminal blend rubber asphalt was determined to be 5 hours.
- Mixture with PLAST.S exhibited greater dynamic stability (DS) and longer fatigue life but higher sensitiveness to low-temperature cracking and moisture damage than that of mixture with TB/SBS composite asphalt, while still increased 14% low temperature flexural strain and 7.62% TSR as compared to the plain TB asphalt mixture. No statistical difference existed in workability between the mixture with PLAST.S and the plain one.
- The positive effect of GTR incorporated was far junior to TB/SBS composite asphalt, while still slightly increased the resistance against rutting deformation (4%), low-temperature flexural strain (7%), TSR (4.62%) and fatigue life (90.3%) of the plain TB asphalt mixture. Besides,
mixture with GTR had the highest mixing torque, indicating a worst workability.

- PF got the most similar effect to TB/SBS modified asphalt on enhancing road performances of mixture, since the incorporation of PF increased 14% the resistance against rutting deformation, 27% low-temperature flexural strain, 8.11% TSR and 170.6% fatigue life of the original mixture, which were close to 17%, 43%, 10% and 13% of improvements respectively provided by TB/SBS composite asphalt. Although mixture with PF faced more challenges in mixing.

It seems more practicable to use PF as surrogates to TB/SBS mixture, which were close to 17%, 43%, 1% and 13% of improvements respectively provided by TB/SBS modified asphalt on enhancing road performances of asphalt. Although mixture with PF faced more challenges in mixing.

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