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A case study of the comparison between rubberized and polymer modified asphalt on heavy traffic pavement in wet and freeze environment

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ABSTRACT

Ground tire rubber (GTR) usage in asphalt pavement with the dry process has gained more prominence in recent times. The objective of this work is to investigate the pavement performance of GTR-modified asphalt pavement and polymer-modified asphalt pavement on heavy volume of traffic conditions in Michigan's wet and freeze environment. A suite of laboratory tests was done to evaluate the pavement performance of GTR-modified and polymer-modified asphalt mixtures. To reveal the strain and stress relationship under different frequencies and temperatures, the dynamic modulus test was applied. The Hamburg wheel tracking device (HWTD) was used to assess the high-temperature deformation resistance. The disc-shaped compact tension (DCT) test was used to evaluate the low-temperature cracking characteristics. The characteristics of the asphalt binder were assessed by the dynamic shear rheometer (DSR) for high-temperature properties and the asphalt binder cracking device (ABCD) for low-temperature properties. After the construction, a field noise test was conducted. The experimental results stated that the polymer-modified asphalt mixture and GTR-modified asphalt mixture showed higher dynamic modulus and better ability to prevent cracking than the conventional asphalt mixture at low temperatures, as well as better permanent deformation and stripping resistance than the conventional asphalt mixture. The fracture energy of the GTR-modified hot mix asphalt (HMA) is 13–16 % larger than the polymer-modified HMA. The number of passes to the stripping point of GTR-modified was 510–518 % higher than the conventional HMA. When compared to the field core, the lab-compacted HMA offers superior pavement performance. The extracted asphalt binder test results show the GTR-modified asphalt has better rutting resistance and cracking resistance than polymer-modified asphalt, and the results in the noise test demonstrated that the rubber-modified asphalt pavement mitigated the noise level by 2–3 dB on the road at different vehicle speeds. Moreover, the pavement condition was noticeably enhanced after the reconstruction of the surface course. The total number of passenger tires to be used in this project is about 2270. To summarize, better rutting and cracking properties in asphalt pavement are shown by the project's utilization of rubber technology. And the GTR-modified HMA is comparable to

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polymer-modified HMA. Therefore, it may be appropriate to utilize rubber technology on high-traffic volume asphalt pavement in Michigan's wet and freeze climate.

1. Introduction

Ground tire rubber (GTR) is a troublesome waste product because it cannot decompose. GTR can be recycled by being used as a foundation material for new pavement. Research organizations and the road industry have given GTR a lot of attention because of the impact it contributes on lowering incorrect trash disposal and boosting environmental sustainability [1,2].

GTR was first used in the asphalt pavement by dry process in the 1960s [3]. The wet process, dry process, and terminal blend process are the three methods used to include rubber particles in asphalt mixes that are widely accepted. The dry process technique without requiring changes to the asphalt plant attracts more and more attention. The dry process adds the rubber particle together with the aggregates into the asphalt drum yield GTR modified asphalt mixtures. Numerous researchers have applied GTR in the asphalt pavement by dry process in recent decades. Some scientists study the GTR-modified HMA high-temperature performance. Hernández et al. [4] and Chen et al. [5] stated that GTR used in Open-graded HMA would increase the stiffness and resistance to deformation when compared to control HMA. Nguyen and Tran [6] showed that compared to traditional HMA, GTR and polymer-modified HMA have superior rutting resistance. Lastra-González et al. [7] found that The GTR-modified HMA might provide a 30 % increase in deformation resistance over traditional HMA. Some researchers investigated the performance of GTR-modified HMA at low temperatures. Sangiorgi et al. [8] addressed that the stiffness could be decreased and the cohesiveness between the asphalt binder and aggregate could be improved by adding GTR. Yang et al. [9] proposed that compared to traditional HMA, asphalt with rubber added may exhibit better low-temperature properties. Dias et al. [10] evaluated the resistance to deformation of GTR-modified HMA, he found the same rutting performance level in both the wet and dry processes. Other studies have also concentrated on the GTR-modified HMA's fatigue properties. Silva et al. [11] mentioned that compared to a standard gap-gradation mixture, the lifetime of an asphalt mixture treated with GTR is 20 times longer. Picado-Santos et al. [12] found that after eight years of service, rubber added to asphalt pavement exhibits high quality, which shows an excellent performance throughout fatigue life.

Polymer-modified asphalt is a typical material that has been used for flexible pavements in the past few decades [13,14]. A number of researchers have studied laboratory performance and field performance. Some researchers have focused on polymer-modified asphalt pavement's high-temperature performance. Greene et al. [15] stated that the rutting depth of polymer-modified asphalt mixture was reduced by 29–49 % compared with conventional asphalt pavement. Yan et al. determined that high-content

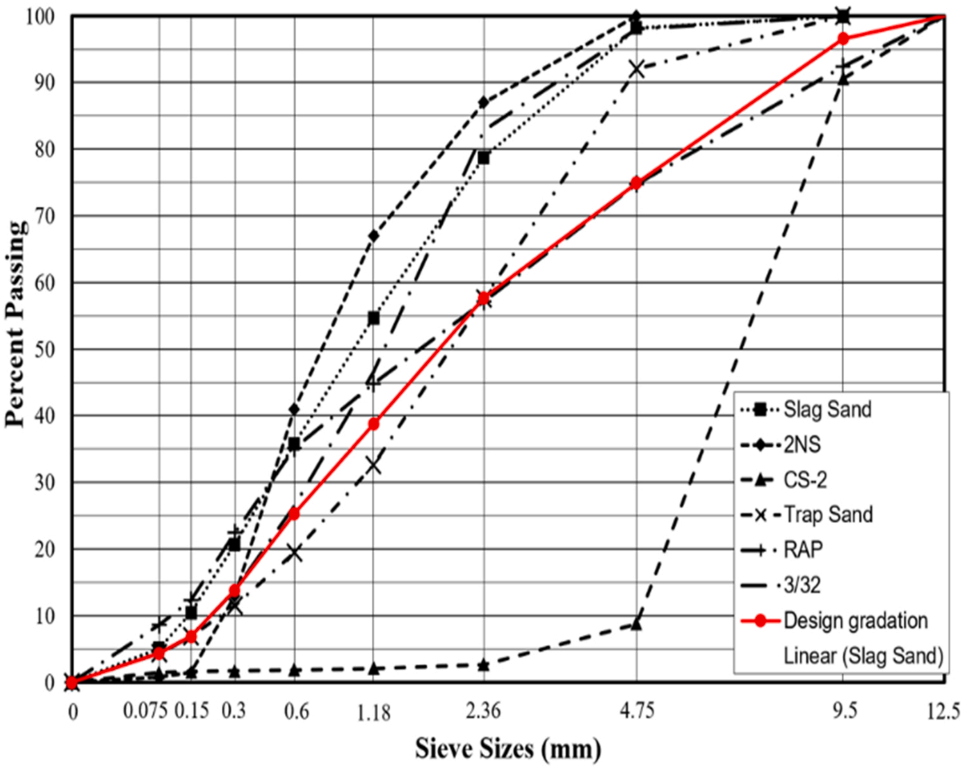


Fig. 1. The aggregate gradation detail in the project.

polymer-modified asphalt improved the rutting performance compared with conventional asphalt. Some researchers have focused on low-temperature cracking and fatigue evaluation. Blazejowski et al. [16] and Yan et al. [17] observed that polymer-modified asphalt binder increased the low-temperature cracking resistance and fatigue life. Zhou et al. [18] found that polymer-modified asphalt mixture showed better cracking energy, while reclaimed asphalt pavement (RAP) would decrease fatigue performance. Polymer-modified asphalt is a very reliable material for heavily trafficked roads; however, GTR asphalt has not been widely proven to be as good as polymer-modified asphalt. Hence, it is necessary to compare the road performance between polymer-modified asphalt and GTR-modified asphalt.

The objective of this research is to investigate the application of GTR-modified asphalt pavement in Michigan high-traffic volume roads. The permanent deformation and moisture susceptibility predictions could be evaluated by the HWTD test, and the cracking resistance properties could be estimated through the DCT test. The dynamic modulus test was applied to reflect the master curve of hot mix asphalt (HMA). The asphalt binder properties were estimated by the DSR and ABCD tests. The anticipated number of equivalent tires was estimated based on the consumption usage of rubber particles. And the field noise level was evaluated after the construction.

2. Raw materials and test program

2.1. Raw materials and project description

2.1.1. Aggregate gradation and asphalt binder

The aggregate used for this project in Kent County is shown in Fig. 1. Based on the Michigan Department of Transportation (MDOT) specification, 5E10 was used as the aggregate gradation. Six types of aggregate were used in this gradation. Two asphalt binder types were applied in this study. One is polymer-modified asphalt binder (PG 70-28), of which the optimum asphalt content (OAC) is 5.07 %. The rubber-modified asphalt by the dry process is asphalt (PG 58-28) contained 10 % weight rubber particles, and the OAC is 5.25 %. The conventional asphalt mixture with the same aggregate gradation and 5.07 % asphalt binder (PG 58-28) was used in this study. The content of reclaimed asphalt pavement (RAP) is 20 % of the total weight of the asphalt mixture. Styrene-butadiene-styrene modifier was mixed with PG 58-28 asphalt binder to produce the polymer-modified asphalt (PG 70-28), which was obtained directly from the plant. The basic characteristics of the asphalt binder met all of the requirements of the specification (AASHTO M320). The details are shown in Table 1 below.

2.1.2. Treated crumb rubber

Treated crumb rubber was used in the project. The specific gravity of the treated crumb rubber is 1.15, As displayed in Fig. 2. The rubber content is around 10 % of the asphalt binder by weight.

2.1.3. Project description

This project is located at Cascade Road between Burton Street and 28th street, near I-96 in Kent County, MI, as shown in Fig. 3(b). The current average daily traffic (ADT) is 16,500, which makes it a highly trafficked main road. The 10-year projected ADT is over 20,000. There are around 7 % commercial ADT. Approximately two inches of existing asphalt layer was cold-milled, and two inches of HMA was placed. The most commonly used equivalent load in pavement design in the U.S. is 18,000 pounds (80 kN). That means the new design will carry up to 10,000,000 standard 18,000 pounds trucks. The average minimum and maximum temperatures in Kent County are − 9 ℃ and 28 ℃. Temperature variations and repeated heavy traffic load lead to severe pavement distresses. Fatigue cracking caused by the fatigue failure of the asphalt overlay under repeated traffic loading is shown in Fig. 3(a). The total construction length of this project is 0.7 miles (1.1 km). 1153.2 tons of loose mixture were used in paving two lanes of polymer-modified asphalt pavement. Similarly, 1729.7 tons of loose mixture were used in paving three lanes of GTR-modified asphalt pavement, as shown in Fig. 3(c).

Paving materials were sourced from the fixed asphalt plant located at 2020 Chicago Drive, Wyoming, MI. There are no special requirements for tanks, pumps, and filters to produce GTR asphalt mixtures. At the asphalt plant, the GTR particles could be directly mixed with aggregates and then asphalt binders, as shown in Fig. 4. The aggregate feeding system was also used to send the six types of aggregates with the specified gradation to the drying drum. The rubber feeding system was also connected to the drying drum, and rubber particles were injected into the heated drying drum and blended with heated aggregate and asphalt to produce the hot asphalt mixture following the job mix formula requirement. Finally, the materials were moved to the mixture storage silo tank and then sent to the field construction site by truck.

2.2. Test methods

This section focuses on the laboratory mixture experiments, which include the low-temperature cracking resistance test, the high-

Table 1
Technical specifications of the two types of asphalt used in this study.

Asphalt types	Viscosity/Pa S (@ 135 °C, max 3 Pa S)	G*/sin (δ)/kPa (min 1 kPa)	G*sin (δ)/kPa (max 5000 kPa)
PG 58-28	0.38	2.9	2563
PG 70-28	1.2	3.04	3010

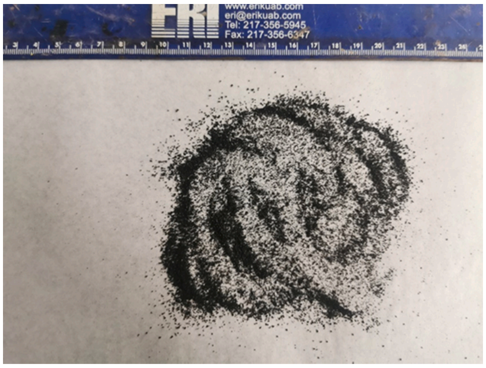


Fig. 2. The treated crumb rubber utilized in the research.

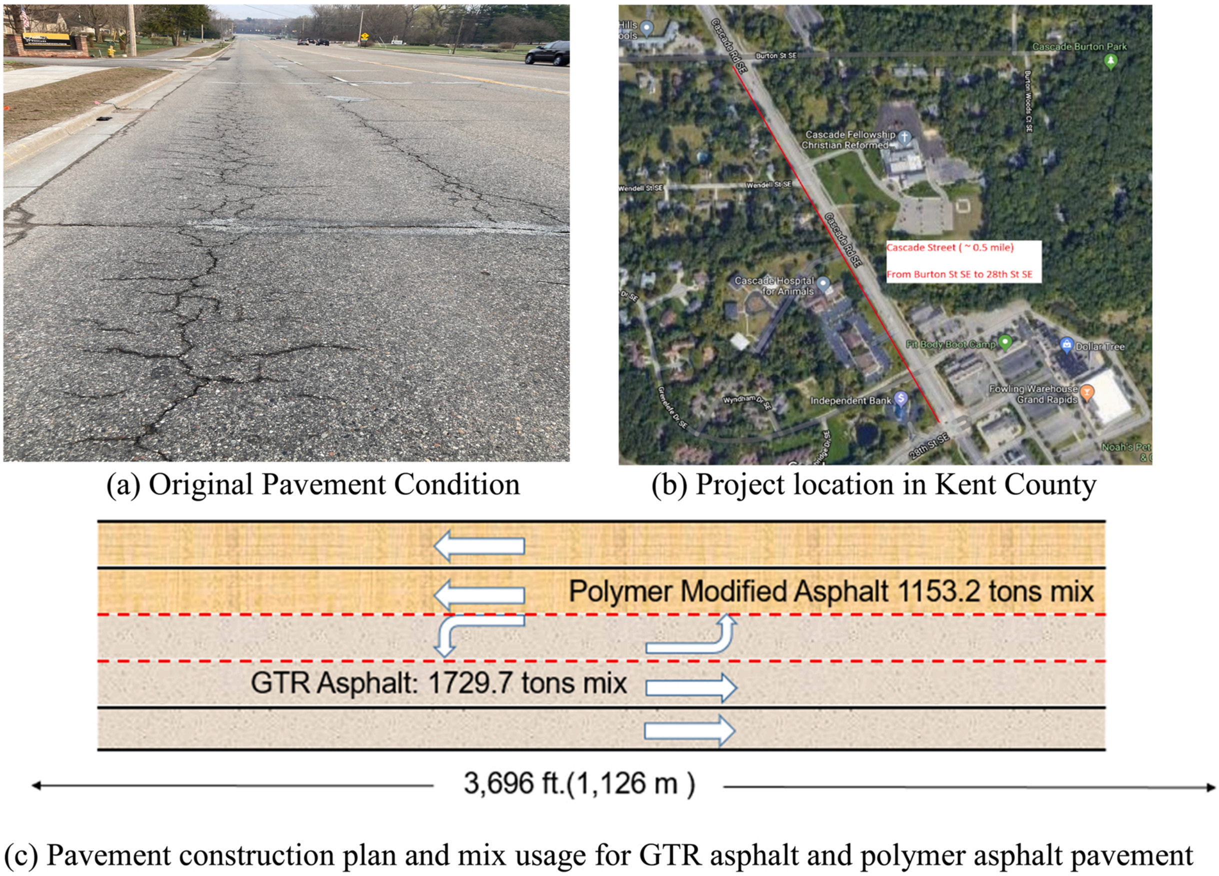


Fig. 3. Project location condition and pavement construction plan.

temperature rutting test, and the dynamic modulus test for the three types of asphalt mixture. The characteristics of the extracted asphalt binder at high and low temperatures were assessed using a dynamic shear rheometer and an asphalt binder cracking device. The pavement construction process is recorded, materials consumption is estimated, and after construction, the level of field noise was evaluated. The research flow diagram is illustrated in Fig. 5.

2.2.1. HWTD test

The features of rutting and moisture susceptibility are crucial for in-service performance. The possibility for rutting and stripping of GTR-modified HMA, polymer-modified HMA, and conventional HMA was estimated using the HWTD test. the submerged asphalt mixture was put under the steel wheel. A number of displacement measurements were used to measure the rutting depth. The rutting test was conducted at a temperature of 50 °C. Three replicates mixture were conducted for this test. During the test procedure, the four

Fig. 4. Asphalt plant applied to supply the GTR-modified HMA and the polymer-modified HMA.

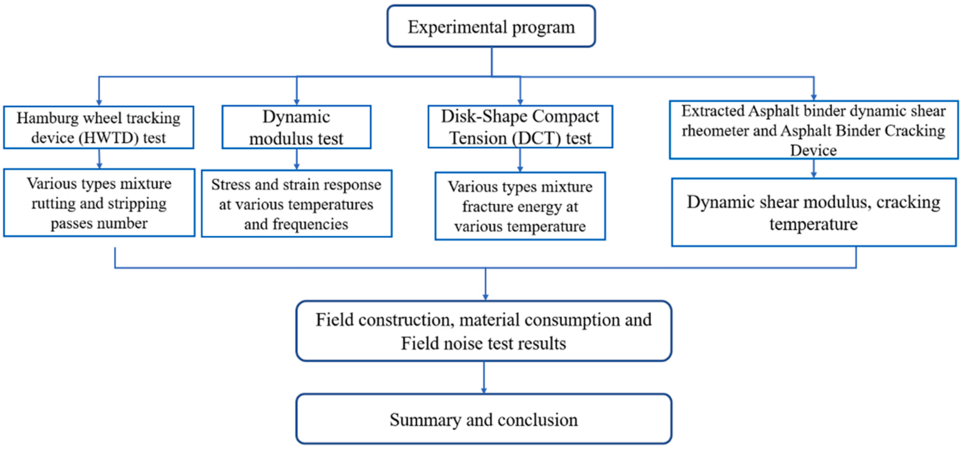


Fig. 5. Research flow diagram used in this research.

vital parameters were used to reflect the mixture's performance. The post-compaction consolidation condition was used to reveal the rutting depth at 1000 cycle loads caused by the continued consolidation. The creep slope was located at the point that occurs after consolidation by compaction while ahead of the stripping point. It was used to evaluate the potential of rutting without moisture damage. The stripping point was intercepted between the stripping slope and the creep slope. It could be used to reflect moisture susceptibility. After this point, the sample would start stripping, and it would cause an increased rate of rutting deformation. Generally, the high cycle number of wheels passing at stripping points indicates good resistance to moisture damage. The stripping slope would be used to reflect the accumulation of moisture damage. Different mixtures show different values of creep slope, stripping point, and strip slope.

2.2.2. Disc-shaped compact tension (DCT) test

The original road condition shows the existence of several fatigue cracks and thermal cracks on the surface overlay, and the minimum temperature is − 9 ℃ during winter in Kent County. This indicates that low-temperature performance is a critical parameter that affects the service life of the road [19–21]. The cracking resistance among GTR-modified HMA, polymer-modified HMA and conventional HMA was assessed using the DCT test. According to ASTM D6373, the sample is a cylinder with a thickness of 45 mm and a diameter of 150 mm. To demonstrate the test temperature on the characteristic of GTR-modified HMA, polymer-modified HMA, and conventional HMA, the samples were tested at − 24 and − 18 °C, respectively. Three replicates mixture were conducted for this test.

2.2.3. Dynamic modulus test

The dynamic modulus test was carried out using the Universal Testing Machine (UTM-100). The samples were exposed to different loads and frequencies. Throughout the test, the axle strain was measured, and the load and displacement data were documented. Dynamic modulus results were calculated by the AASHTO T 342. Three replicates mixture were conducted for this test. The $|E^*|$ master curve was collected when the dynamic modulus values at specific reference temperature (T_{ref}) was obtained and then shifted $|E^*|$ horizontally. It should be mentioned that the moving space varies at specific temperatures based on the coefficients of shift factor $a(T)$. Eqs. (1) and (2) was applied to establish the relationship between T_{ref} and $a(T)$.

$$\text{loglog}(a(T)) = a_1\left(T^2 - T_{ref}^2\right) + a_2(T - T_{ref}) \quad (1)$$

$$\text{loglog}(|E*|) = b_1 + \frac{b_2}{1 + e^{-b_3 - b_4 \log(f_R)}} \tag{2}$$

Where a_1 and a_2 are the polynomial fitting coefficients of the temperature shift factors; b_1, b_2, b_3, b_4 are the sigmoid coefficients; T_{ref} is reference temperature; T is the test temperature; and f_R is the reduced frequency.

2.2.4. Dynamic shear rheometer

The dynamic shear rheometer was used to determine the viscoelastic characteristics. The extracted asphalt from the loose asphalt mixture based on the standard solvent extraction method, specified in ASTM D8159-19, were used in this study. The complex shear modulus (G*) and phase angle (δ) were obtained from the DSR test. The test temperature was 34, 40, 46, 52, 58, 64, 70, 76, 82 °C for Rolling Thin-Film Oven (RTFO)-aged asphalt binder. The test temperature was 13, 16, 19, 22, 25 °C for Pressure Aging Vessel (PAV)-aged asphalt binder. The test frequency was 0.1, 1, 1.59, 3, 5, 10 Hz.

2.2.5. ABCD test

The asphalt binder cracking device test was used to estimate the cracking temperature and cracking stress in low temperatures. The ABCD system comprises of refrigerator cooled by air and its temperature range should cover from + 25 °C to − 60 °C, while it should be able to be cooling the asphalt at a rate of 20 °C/h. When the asphalt specimen is cracked, the strain decreases instantly as the thermal stress built up, and the temperature is recorded until breaking occurs.

3. Test result analysis

3.1. HWTD test

The results of the HWTD test for different HMAs are illustrated in Fig. 6. The rutting test of conventional asphalt mixture stopped after the rutting depth up to 2 cm, and the rutting test of GTR- modified and polymer-modified asphalt mixture stopped before the pass number reached 20,000. It could be found that the GTR-modified and polymer-modified asphalt mixture have better rutting performance. The number of passes for the conventional, GTR-modified, polymer-modified asphalt mixtures, GTR-modified field core, and polymer-modified field core is 5620, 18,590, 20,000, 14,940, and 20,000, respectively. With the same gradation, the polymer and rubber incorporated with the asphalt binder enhance the stiffness of the asphalt binder. It may reduce the possibility of the rutting deformation of the asphalt mixture and improve the resistance of permanent deformation ability. While the lab compacted HMA has superior rutting properties than the field core. The main reason may be caused by the different conditions, the lab sample is compacted and surrounded by a steel mold while the field is surrounded by asphalt pavement.

The HWDT test results of different types of HMA are shown in Fig. 7. The slope for creep and stripping of polymer-modified and GTR-modified HMA reduced significantly. Compared with conventional asphalt mixture, the creep slope of GTR-modified and polymer-modified asphalt mixtures were 8.9 % and 8.4 %, respectively. The stripping slope of GTR-modified and polymer-modified asphalt mixtures were 36.4 % and 21.8 %, respectively. This indicates that the GTR-modified and polymer-modified HMA would cause less rutting and moisture damage compared with conventional HMA. This is due to the fact that the dispersion of rubber and polymer would improve the asphalt binder stiffness and improve the interface property between aggregate and asphalt binder. Generally, the stripping point would reflect moisture damage potential to the asphalt mixture. The higher the stripping point passes, the better resistance of moisture damage. Meanwhile, it could be seen that the GTR-modified and polymer-modified HMA shows superior resistance to moisture damage when compared to the conventional HMA. The rubber and polymer incorporated asphalt strengthen the anti-stripping properties. The percentage of the wheel passes number at the stripping point of GTR-modified and

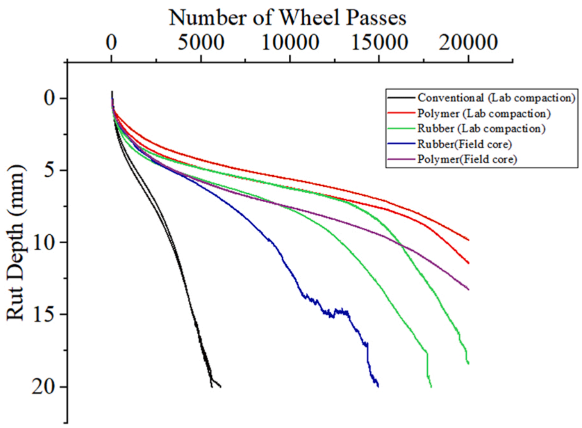


Fig. 6. HWDT test results of HMA.

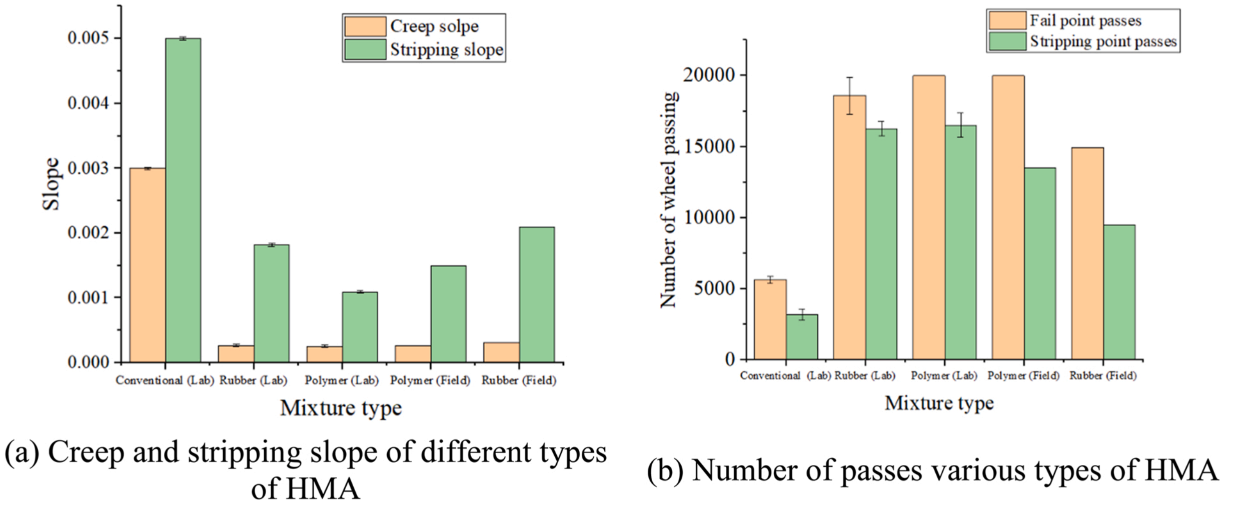


Fig. 7. The slope and wheel passes number of the various types of HMA.

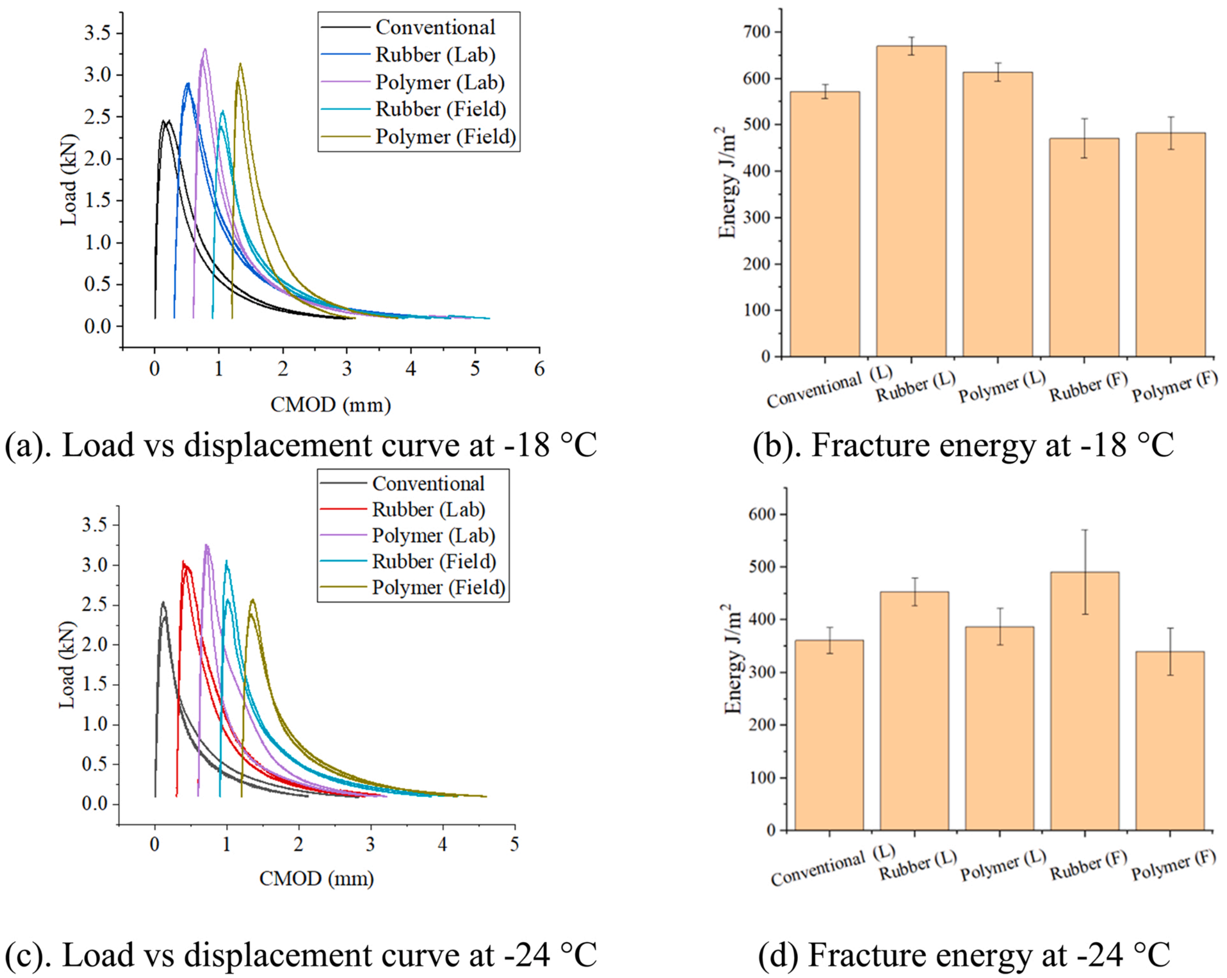


Fig. 8. DCT test results of conventional HMA, GTR-modified HMA, polymer- modified HMA.

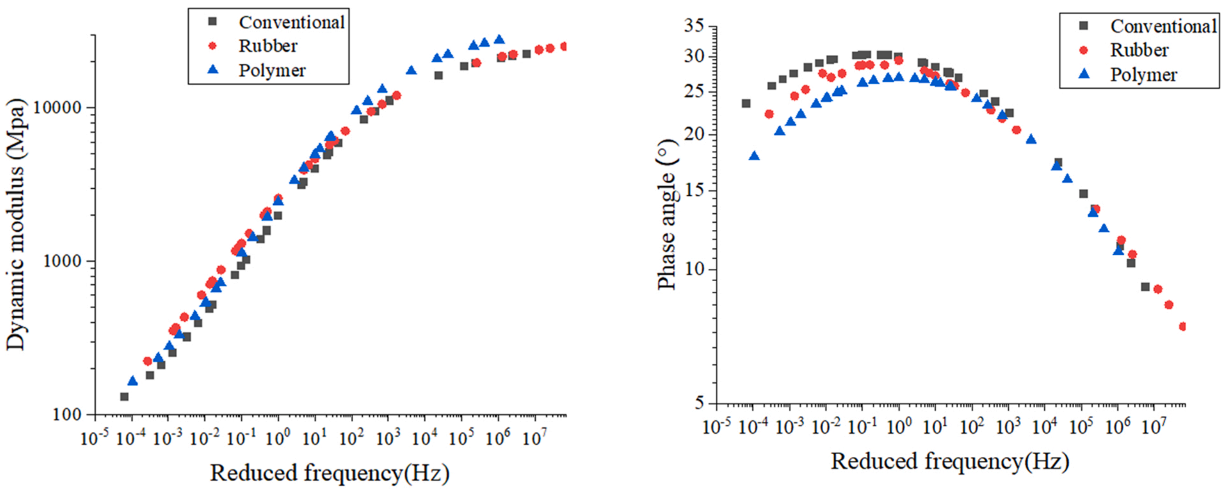
polymer-modified HMA was 510 % and 518 %, respectively, compared with conventional HMA. Moreover, when compared to the field core, the lab-compacted HMA offers superior moisture resistance.

3.2. DCT test

For assorted types of asphalt mixture, the DCT test result at different temperatures is shown in Fig. 8. In order to prevent the test results from being influenced by air voids, the samples were compacted to 7 % air voids. To find the influence of temperature on the cracking performance of three types of asphalt mixture, the tests were conducted at − 18 °C and − 24 °C, respectively. The fracture energy calculated from the load and displacement curve (CMOD) would be applied to reflect the asphalt mixture's cracking performance. The high value of fracture energy would have a better cracking resistance at low temperatures. The fracture energy of conventional, polymer-modified, and GTR-modified asphalt mixtures at − 18 °C is 480 J/m^2, 561 J/m^2, 652.5 J/m^2, respectively. Compared with conventional asphalt mixtures, the GTR-modified and polymer-modified HMA have better low-temperature cracking performance. The rubber and polymer as an additive into asphalt binder would enhance the interface properties between aggregates and asphalt binder. It should be mentioned that the polymer-modified asphalt mixture shows the maximum peak load value in the DCT test results in Fig. 8(a). It was observed that the polymer-modified asphalt mixture requires a high load to cause the breaking in the HMA, while the GTR-modified asphalt mixture has maximum CMOD. The deformation occurred during the low-temperature cracking process. Therefore, the GTR-modified HMA presents better low-temperature cracking resistance than polymer-modified HMA. Both GTR-modified HMA and polymer-modified HMA have greater low-temperature fracture resistance when compared to conventional HMA. The DCT test at − 24 °C was performed, and the test results are shown in Fig. 8(c) and (d). From the figures, the fracture energy of conventional, GTR-modified, and polymer-modified asphalt mixtures was 361 J/m^2, 376 J/m^2, and 425.5 J/m^2, respectively. The anti-cracking properties decreased as the test temperature decreased, as indicated by the asphalt mixture becoming brittle. The GTR-modified HMA had the best low-temperature cracking performance, and both the GTR-modified and polymer-modified HMA had better low-temperature resistance compared with conventional HMA. Moreover, when compared to the field core, the lab-compacted HMA offers better crack resistance.

3.3. Dynamic modulus test

The dynamic modulus and phase angle master curve of the three types of HMA at 21 °C are displayed in Fig. 9. The polymer-modified HMA shows higher dynamic modulus (E*) values at low temperatures than the GTR-modified HMA. The polymer incorporated with asphalt enhances the elasticity of HMA. The rubber particle incorporated with asphalt could also enhance the stiffness of the HMA compared with the conventional HMA. However, the rubber particles that are unincorporated with asphalt binder are softer than the aggregate particle. This may be the main reason that the polymer-modified asphalt mixture shows a higher dynamic modulus than the GTR-modified asphalt mixture at low temperature and high frequency, while the GTR-modified asphalt mixture shows a higher E* than the conventional HMA. For example, the E* of polymer-modified HMA, GTR-modified asphalt mixture, and conventional asphalt mixture at − 10 °C and 25 Hz are 26,966 MPa, 25,611 MPa, and 23,913 MPa, respectively. It was observed that the GTR-modified asphalt mixture shows a higher dynamic modulus at high temperatures than the polymer-modified HMA and conventional HMA. The rubber-incorporated asphalt would increase the stiffness of the asphalt mixture at high temperatures, and the polymer-incorporated asphalt would also enhance the elastic component of the HMA which increases the dynamic modulus at high temperatures. Taking 54 °C and 0.1 Hz as an example, the dynamic modulus of polymer-modified asphalt mixture, GTR-modified



(a). The dynamic modulus master curve @ 21 °C (b). The phase angle master curve. @ 21 °C

Fig. 9. The dynamic modulus and phase angle master curve of three types of asphalt mixture at 21 °C.

asphalt mixture, and conventional asphalt mixture are 212 MPa, 224 MPa, and 131 MPa, respectively.

The master curve of the phase angle of three assorts of asphalt mixture is displayed in Fig. 9(b). HMA would have a more elastic property and less viscous property as the phase angle decreased. Moreover, a low reduced frequency refers to a high temperature, and a high reduced frequency corresponds to a low temperature. It was found that the asphalt angle decreased with the increase of the reduced frequency, and the decrease rate was low until the reduced frequency reached 10 Hz and then dropped down fast to the maximum reduced frequency. The reason behind this is that as the reduced frequency enlarged, the elastic manner of HMA increased while the viscous behavior decreased. Polymer-modified asphalt mixture shows a higher phase angle than the GTR-modified asphalt mixture at high temperatures, even though the dynamic modulus of the GTR-modified asphalt mixture is higher than the polymer-modified asphalt mixture. This is due to the fact that the rubber particles in HMA enlarged the elastic component. However, the GTR-modified asphalt mixture still shows a lower phase angle than the conventional asphalt mixture, which means that the rubber particle incorporated with the asphalt mixture would enlarge the stiffness of the HMA and decrease the phase angle of the HMA.

3.4. Dynamic shear rheometer test

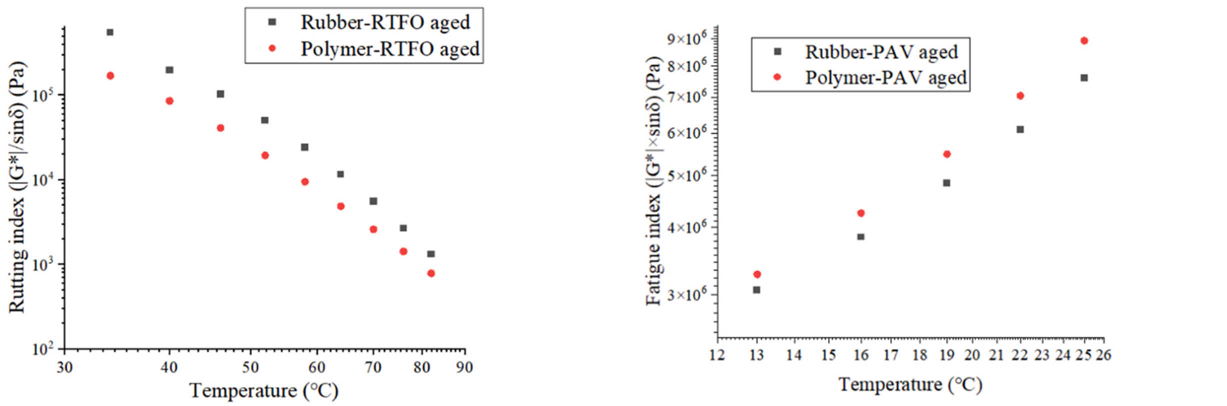
The dynamic shear rheometer was used to evaluate the high-temperature and medium-temperature behaviors of the asphalt binder, as shown in Fig. 10. the asphalt binder was extracted based on the standard extraction process from the loose asphalt mixture. Then the short-term aging and long-term aging process were applied to the asphalt binder and the viscoelastic of the asphalt binder was evaluated by the dynamic shear rheometer. The rutting indicators of the GTR-modified asphalt are higher than the polymer-modified asphalt. It means GTR-modified asphalt has a higher resistance to deformation than polymer-modified asphalt. The GTR-modified asphalt has a lower value of the fatigue indicators compared with the polymer-modified asphalt. It indicated that the fatigue potential of the GTR-modified asphalt is better than the polymer-modified asphalt.

3.5. ABCD test results

The ABCD test results of extraction asphalt binder from the GTR-HMA, polymer modified HMA and conventional asphalt (PG58-28), and polymer asphalt (PG 70-28) are shown in Fig. 11. The cracking for rubber asphalt extraction, conventional asphalt, polymer asphalt extraction, and polymer asphalt is − 44.7 °C, − 37.8 °C, − 45.1 °C, and − 46.6 °C, respectively. The cracking temperature for both rubber asphalt and polymer asphalt is lower than conventional asphalt. It means the rubber and polymer-modified asphalt could improve the low-temperature cracking resistance. And the cracking temperature of the polymer asphalt is lower than the polymer-modified asphalt extraction. The main reason behind this is that the extracted asphalt binder from RAP may reduce the cracking resistance. The strain jump of extraction asphalt binder from the GTR-HMA, polymer modified HMA and conventional asphalt (PG58-28), polymer asphalt (PG 70-28) is displayed in Fig. 11(b). the rubber asphalt shows the lowest fracture stress, while the polymer asphalt has highest strain jump. It means the rubber particle incorporated with the asphalt binder would help to release the stress of the asphalt binder.

4. Field construction

The construction project was conducted by Kent County Road Commission (KCRC) on Cascade Road, Michigan, in June 2021. The old road condition is displayed in Fig. 12(a). It could be seen that there are a series of interconnected cracks caused by fatigue failure of



(a). The rutting indicators of asphalt binder vs. temperature at 10 rad/s

(b). The fatigue indicators (|G*|×sinδ) of asphalt binder vs. temperature at 10 rad/s

Fig. 10. DSR test result of RTFO and PAV aged asphalt binder.

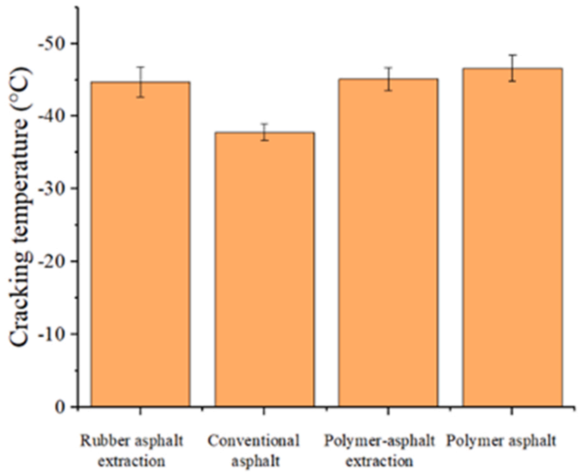


Fig. 11. The ABCD test results of different types of asphalt binder. (a). Cracking temperature results.

the surface overlay under repeated traffic loading, and block cracking divided the pavement up into rectangular pieces. It indicated the poor condition of the top surface layer before being milled. The overlay was milled, and the asphalt emulsion was used on the surface of leveling layers before the new overlay was paved, as shown in Fig. 12(b). The GTR-modified asphalt pavement by the dry process was paved on the left three lanes, and then the surface overlay was compacted into a 2-in. depth. The polymer-modified asphalt pavement was paved after the GTR-modified asphalt pavement construction was completed. Then, the surface layer was compacted; the detail is shown in Fig. 12(c–f). The final condition before and after construction is shown in Fig. 12(g). It could be seen that the pavement condition was enhanced after the reconstruction of the surface course.

5. Field noise test results

In this study, a noise meter that meets ANSI S1.4 Type 2 and IEC 61672-1 Class 2 requirements were used to evaluate the noise of asphalt pavements. The noise meter was calibrated to 1 kHz and 94 dB. The resolution of the noise meter is 0.1 dB, and the accuracy is ± 1.5 dB. The distance between the noise meter and the vehicle during the measurement was 15 feet. The noise on different roads was measured, as shown in Fig. 13. The noise measurement vehicle was a light truck, and the noise measurement was performed at five different speeds: 20MPH (32 km/h), 30MPH (48 km/h), 40MPH (64 km/h), 50MPH (80 km/h), and 60MPH (96 km/h). A total of four noise data were collected at each speed. During the measurement, the temperature was 18 °C, the average humidity is 41.5 %, the wind speed was 10 km/h, and the background noise was 53 dB.

The noise test results are shown in Fig. 14, and the field noise level results outside of the truck are shown in Fig. 14(a). As the speed increased from 10 mph to 60 mph, the noise level increased from 60.35 dB to 84 dB. Meanwhile, the noise level of rubber-modified asphalt pavement is 2 dB lower than poly-modified asphalt pavement outside of the truck. And the noise level increased with the increased speed for both the rubber-modified and polymer-modified asphalt pavement. The field noise level results inside the truck are shown in Fig. 14(b). As the speed increased from 10 mph to 60 mph, the noise level increased from 46.25 dB to 62.25 dB. Meanwhile, the noise level of rubber-modified asphalt pavement is 1 dB lower than poly-modified asphalt pavement inside of the truck. And the noise level increased with the increased speed for all types of asphalt pavement.

6. Conclusions

This research concentrated on characterizing the pavement performance of GTR-modified HMA and polymer-modified HMA. The dynamic modulus, the rutting performance, the low-temperature properties were assessed. The asphalt binder properties were assessed by the DSR and ABCD tests. The findings of this investigation are summarized below:

(1) The DCT test showed that the GTR-modified HMA and polymer-modified HMA have better low-temperature fracture energy compared with the conventional HMA. The energy of the GTR-modified HMA is 13–16 % larger than that of the polymer-modified HMA. Lab-compacted HMA showed stronger fracture resistance than the field core.
(2) The HWDT test showed that the GTR-modified HMA and polymer-modified HMA have better resistance to rutting than the conventional HMA. Compared with conventional HMA, The stripping slope of GTR-modified and polymer-modified HMA were 36.4 % and 21.8 %, respectively. And the lab-compacted HMA offers superior moisture resistance and rutting resistance compared to the field core.
(3) The DSR and ABCD test results showed that the GTR-modified asphalt has better cracking resistance, rutting resistance, and fatigue properties when compared to the polymer-modified asphalt.

(a) Original pavement condition

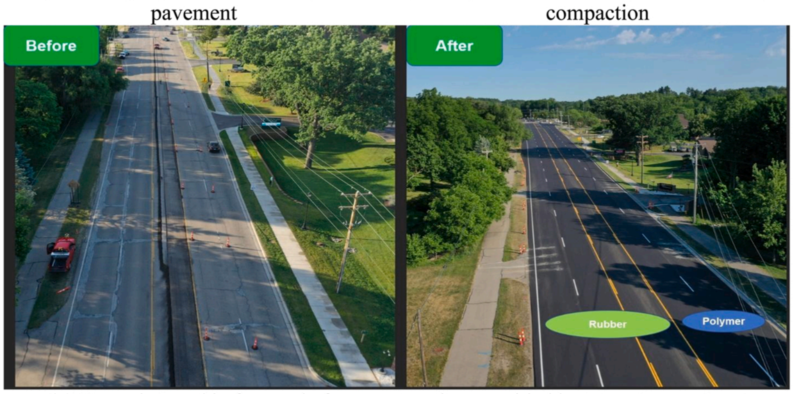
(b) Surface layer milling and emulsified asphalt application

(c) Paving GTR-modified asphalt pavement

(d) GTR-modified asphalt surface layer compaction

(e) Paving polymer-modified asphalt pavement

(f) Polymer-modified asphalt surface layer compaction



(g) Cascade Road before and after construction provided by Kent County Road Commission

Fig. 12. Pavement construction procedure on the Kent project.

(4) The pavement condition was obviously enhanced after the reconstruction of the new surface overlay, the noise level of rubber-modified asphalt pavement is 2 dB lower than poly-modified asphalt pavement outside of the truck and 1 dB lower than poly-modified asphalt pavement inside of the truck, and the total number of passenger tires required for this project is estimated to be 2270.

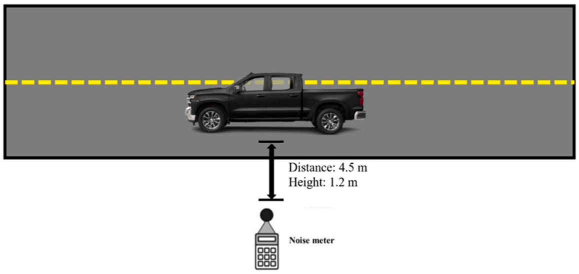


Fig. 13. Demonstration of Cascade Road noise test.

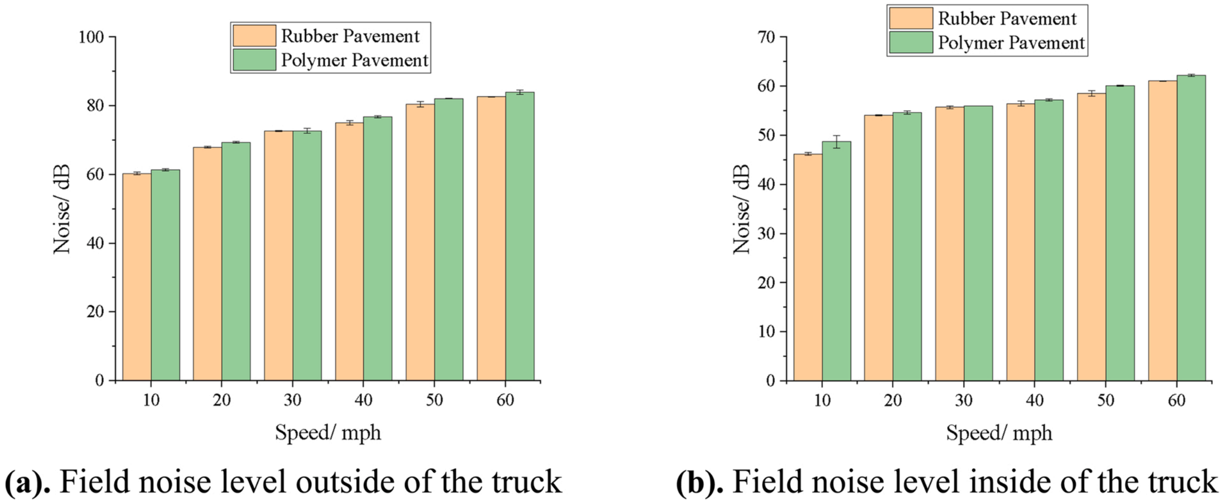


Fig. 14. Field noise test results.

In conclusion, the cracking and rutting resistance in asphalt pavement was improved by the application of rubber technology in the project. Moreover, the GTR-modified HMA is comparable to polymer-modified HMA. Therefore, it may be appropriate to utilize rubber technology on high-traffic volume asphalt pavement in Michigan's wet and freeze climate.

CRediT authorship contribution statement

The authors confirm contribution to the paper as follows: study design and conception: Dongzhao Jin, Zhanping You; data collection: Dongzhao Jin, Kwadwo Ampadu Boateng, Dongdong Ge, Tiankai Che; analysis and interpretation of results. Dongzhao Jin, Dongdong Ge, Lei Yin, and Zhanping You; Sources: Wayne Harrall, Zhanping You. Draft manuscript preparation: Dongzhao Jin, Kwadwo Ampadu Boateng, Tiankai Che, Lei Yin and Zhanping You. Writing – review & editing, Dongzhao Jin, Dongdong Ge, Wayne Harrall, and Zhanping You. All authors reviewed the results and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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