Performance Assessment

of

Asphalt Mixtures Containing Mine Tailings

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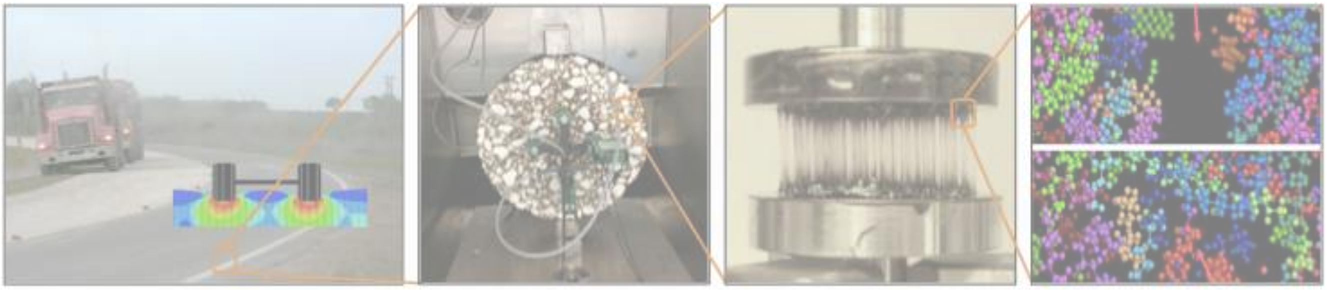

Executive Summary

A typical dense graded asphalt mix design from the central Texas region was used as a control or baseline to compare the performance of asphalt mixtures that incorporate mine tailings sampled from two different locations of a stockpile in Burnet, Texas. Test specimens were fabricated in the laboratory and their performance was assessed for rutting, cracking, and moisture damage using test methods similar to the standard tests used by the Texas Department of Transportation.

Results based on the Hamburg wheel-tracking device show that mixtures that incorporate mine tailings exhibit improved resistance to rutting compared to the control mixture. Results based on the indirect tensile strength of unconditioned specimens also show that mixtures that incorporate mine tailings had an average tensile strength that was similar or slightly greater than the average tensile strength of the control mixture. However, indirect tensile strength test of specimens after moisture conditioning show that specimens that incorporate mine tailings had a reduced resistance to moisture induced damage. Based on the results from this study it appears that mine tailings may be used as a partial replacement of fine aggregates in a dense graded asphalt mixture if its resistance to moisture induced damage can be increased possibly with the use of anti-stripping agents.

1. Overview

The purpose of this study was to investigate potential use of graphite mine tailings as fine aggregates in an asphalt mix. In order to achieve the goals of this study a typical dense graded asphalt mixture design used in the central Texas region was used as a baseline or control. Test specimens with mine tailings were prepared by substituting the fine aggregates in the control mix with equivalent mass fraction of mass tailings. The rutting, fracture and moisture damage resistance of the control and test mixtures were assessed using standard test methods. This report presents a summary of the materials used, test methods adopted, results from these tests and recommendations.

2. Materials

A typical dense graded asphalt mix used for pavement applications comprises coarse aggregates, fine aggregates and asphalt binder. Behavior and performance of an asphalt mixture depends on proportions and properties these constituents along with the temperature and compaction procedure during asphalt mix preparation.

For this study, three types of test specimens were fabricated as listed below.

1. **Control specimen**: Prepared following a typical dense graded mixture design using mineral limestone aggregates from a source in Buda, Texas.
2. **Top specimen:** Prepared using partial replacement of the limestone aggregates with sand from the top of the graphite tailings stockpile.
3. **Bottom specimen:** Same as Top specimens except the replacement sand was from the bottom of the stockpile.

Performance of the asphalt mix is dictated by the properties of the binder. Commonly used binder classification is called 'Performance Grading' (PG grade) which takes temperature susceptibility of asphalt binder as the grading criterion. The standard for PG grading is PG XX-YY where XX is average seven-day maximum pavement design temperature and -YY is minimum pavement design temperature (in Celsius). A binder with a given PG grade is qualified for use in projects where pavement temperature is within the range given in the PG grade. The asphalt binder used in this study was PG 64-22 sourced from Valero, Texas. This binder grade is one of the commonly used grades in the state of Texas (TxDOT, 2011).

3. Mixture Proportions

Asphalt specimens were prepared using a Type C mix formula for the given aggregate source. Type C is dense-graded hot asphalt mix, which is widely used in Texas. From the gradation of the graphite mine tailings, it was observed that the particles are mostly (more than 95%) fine aggregates smaller than 600 μm (ASTM No. 30 sieve). For this reason, in specimens with mine tailings, some portions of the fine Buda aggregates were replaced by correspondingly sized fine aggregates from mine tailing. Table 1 provides the aggregate gradation and binder content used to fabricate the Control, Top and Bottom mixes.

Table 1: Mix Proportions for specimen preparation

Sieve Size:	Cum. % Passing	Cum % Retained	Individual % Retained	Control mix Weight (gram retained)	Top mix replacement (gram retained)	Bottom mix replacement (gram retained)
1"	100.0	0.0	0.0	0		
3/4"	100.0	0.0	0.0	0		
3/8"	83.1	16.9	16.9	399.6		
No. 4	57.5	42.5	25.6	608.1		
No. 8	38.7	61.3	18.9	449.6		
No. 30	23.6	76.4	15.1	360.6		
No. 50	16.9	83.1	6.7	160.4	122.2+ (38.2g Buda)	59.82 (+100.2g Buda)
No. 200	5.7	94.3	11.1	265.7	265.7	265.7
Pan	0	100	5.7	138.6		
Binder %	4.7			117.25		
Total	100	100	100	2500	2500	2500

Figure 1 illustrates the curve for the selected aggregate gradation along with the maximum density line (Power 45 Curve), along with the lower and upper specification limits. Figure 2 shows different aggregate sizes used in this study.

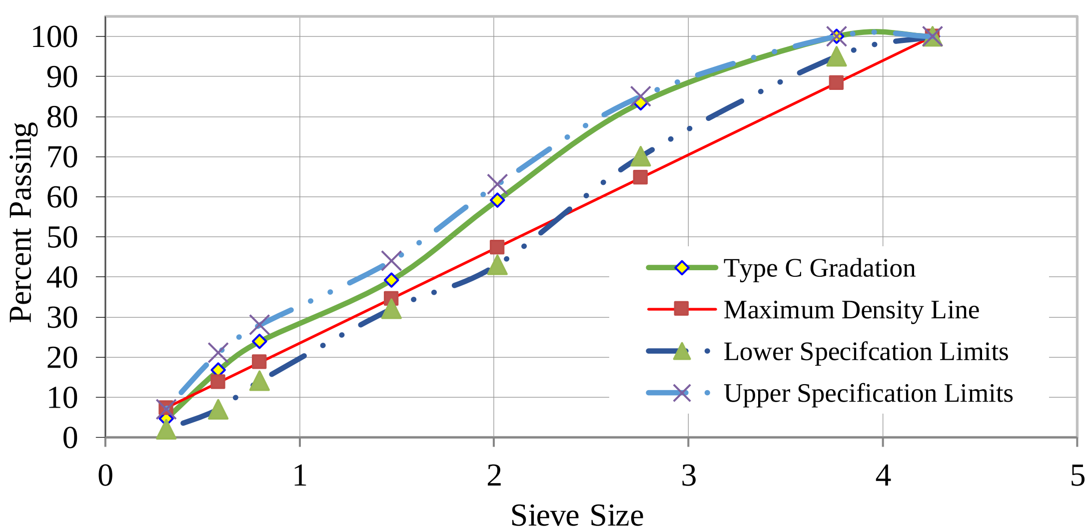

Figure 1: Percent Passing vs. Sieve size

Figure 2: Different sizes of aggregates used in this study (Buda aggregates with Top and Bottom mine tailings)

4. Experimental Procedure

4.1 Specimen Preparation

Test specimens were prepared using the Superpave Gyratory Compactor (SGC) following the TxDOT designated Tex-241-F procedure (TxDOT, 2010b). Tex-241-F specifies the mixing and curing time and temperatures of the loose mix. It also specifies the requirements of the Superpave Gyratory Compactor along with a detailed procedure for specimen preparation.

The following steps briefly describe the steps involved in the preparation of the test specimens:

1. The dry aggregates were weighed according to the gradation in Table 1 and mixed in accordance with Tex-205-F.
2. The aggregates and asphalt binder were heated to the required mixing temperature for the PG 64-22 binder (143ºC).
3. The aggregates and required amount of binder (Table 1) were mixed thoroughly in a pre-heated mechanical mixer.
4. The loose mix was then short-term aged in a force draft oven for 4 hours at 135ºC.
5. The loose mix was then weighed to achieve target density and placed in a preheated mold of 6 –inch diameter.
6. The loose mix was then compacted to the required height using the gyratory compactor.
7. The compacted specimen was then extruded from the mold.

Figure 3 shows the Superpave Gyratory Compactor with the mold and a compacted specimen used for this study. In all, total 22 specimens with 63±1 mm height and 150 mm diameter were prepared for the three types of mixes for further testing. Of these 22 specimens, 10 specimens were prepared using the control mix and the remaining 12 were made with mine tailings.

Figure 3: Superpave Gyratory Compactor with freshly compacted test specimen

4.2 Density of the Test Specimens

Prior to testing it is important to ensure that all test specimens have similar volumetrics, especially in terms of their air void content. To this end, bulk specific gravity and air void content of all the test specimens were measured. Bulk specific gravity (G_b) is the ratio of the compacted asphalt specimen weight to the bulk volume of the specimen. It is a measure of the degree of compaction or densification achieved. To measure G_b, the specimen weight is measured in dry condition, submerged condition and saturated surface dry condition. This is effectively a ratio of specimen bulk weight to weight of water of equal volume.

$$G_b = \frac{weight\ of\ dry\ spceimen\ in\ air, g}{weight\ of\ SSD\ specimen\ in\ air, g - weight\ of\ specimen\ in\ water, g}$$

Percent absorption, which is a measure of the water absorbed by the mineral aggregates, can be measured using following formula:

$$Percent\ Absorption = \frac{weight\ of\ SSD\ specimen\ in\ air, g - weight\ of\ dry\ spceimen\ in\ air, g}{weight\ of\ SSD\ specimen\ in\ air, g - weight\ of\ specimen\ in\ water, g} \times 100\%$$

Theoretical maximum specific gravity (G_{mm}) is similar to bulk specific gravity when the specimen is compacted to zero air void. It is also termed as ‘Rice gravity’. Tex-227-F specification was followed to measure G_{mm}.

For this study, a metal pycnometer with vibrating table was used. About 1500 gram loose asphalt mix was taken as recommended in Tex-227-F. Dry mix weight was measured and the weight of the pycnometer was measured in water with and without the loose mix in it. Before taking weight of the loose mix in pycnometer in water, a suction of 2.0 inch

Mercury pressure was applied to remove any residual air. Figure 4 shows the pycnometer and the suction pump. The theoretical maximum specific gravity was obtained as follows:

$$G_{mm} = \frac{A}{D + A - E}$$

Where, G_{mm} = theoretical maximum specific gravity

A = weight of dry sample in air, g

D = weight of pycnometer in water, g

E = weight of pycnometer containing sample while submerged in water, g

Relative density of the compacted specimens was measured as the ratio of bulk and maximum specific gravity.

$$\%G_{mm} = \frac{G_b}{G_r} \times 100$$

Where, $\%G_{mm}$= relative density

G_b= bulk specific gravity

G_{mm} = theoretical maximum specific gravity

Figure 4: Apparatus for measuring 'Rice Specific Gravity'

4.3 Hamburg wheel Tracking test

Rutting or permanent deformation is one of the forms of failure in an asphalt pavement. The Hamburg wheel-tracking test is designed to determine the rutting resistance of an asphalt mix. TxDOT Tex-242-F specification was followed for this test. Essentially, Hamburg wheel test is a performance test that involves numerous passes of a steel wheel on a pair of test specimens submerged in water at a high temperature to observe corresponding damage (permanent deformation) to the test specimens. The test does not yield any value that can be used for the thickness design of a pavement. However, the number of passes required to generate damage in form of rutting (usually 1/2-inch) gives general idea about the expected performance of the asphalt mix in the field.

The Hamburg wheel-tracking device used for this study had two steel wheels of 8-in dia and 158±5 lbs weight. The wheels make 50±2 passes per minute across the test specimens. The test specimens were prepared using the Superpave Gyratory Compactor or SGC, as described earlier. However, the specimens fabricated using the SGC were required to be cut along a chord separating a 16 mm thick minor segment. This was done to accomodate two test specimens in the mold as shown in Figure 5.

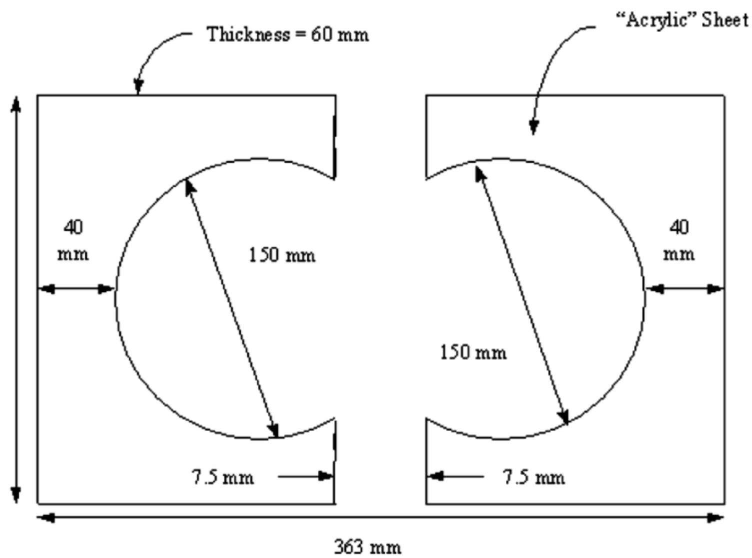

Figure 5: Specimen mold in Hamburg Wheel Tracking test.

The wheel and the test specimens are housed in a water bath where temperature of the water can be controlled. The test was done at 50±1ºC water temperature. An automated system measures the vertical location of the steel wheel as it passes over the specimen. Results were obtained in the form of rut depth after every 100 passes. Figure 6 shows test specimens in the Hamburg wheel-tracking test device.

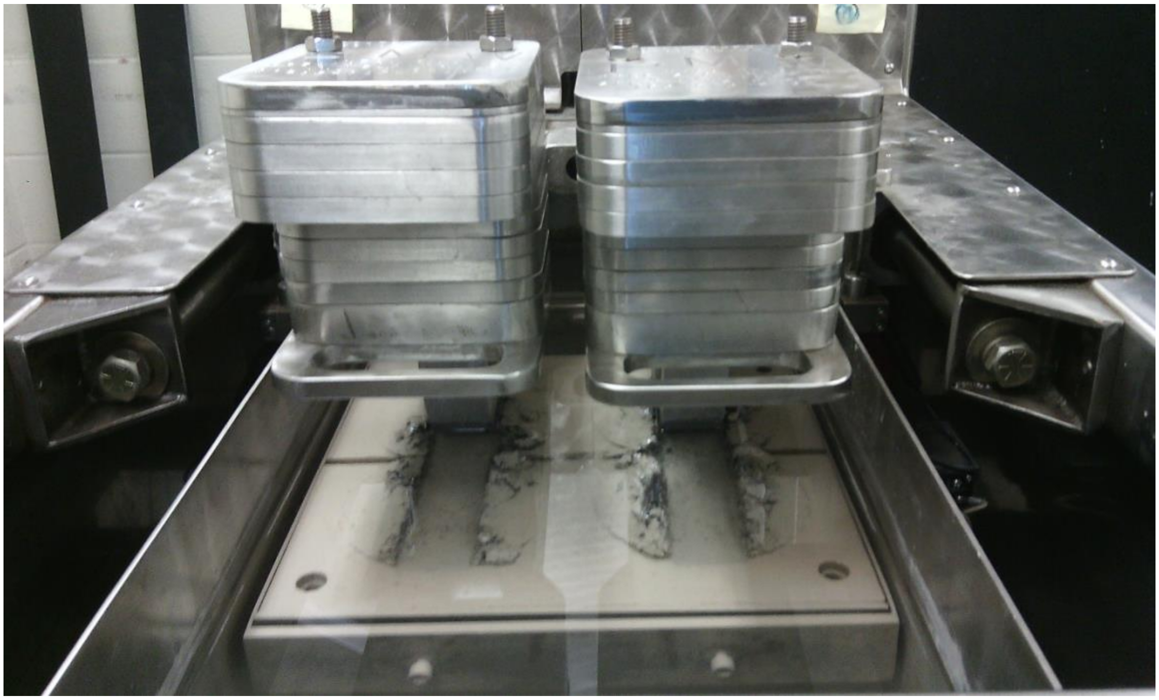

Figure 6: Hamburg Wheel Tracking test

4.4 Indirect Tensile Test

This test is used to estimate tensile strength of compacted asphalt mixtures. The tests were done as recommended by TxDOT in Tex-226-F specification. Indirect Tensile Test (IDT) involves applying a compressive load along the diametric axis of a cylindrical test specimen. A loading press is used to conduct this test with the specimen set using a loading strip. The loading strip applies a compressive load to the specimen at a deformation rate of 2 inch per minute. Figure 7 shows the test setup with a specimen being tested.

Figure 7: Indirect Tensile testing

Though the applied loading is compressive in nature, failure is achieved by a resulting uniform tensile stress along the loading axis (tensile stress direction is perpendicular to the loading axis). Figure 8 shows a qualitative stress distribution inside the specimen.

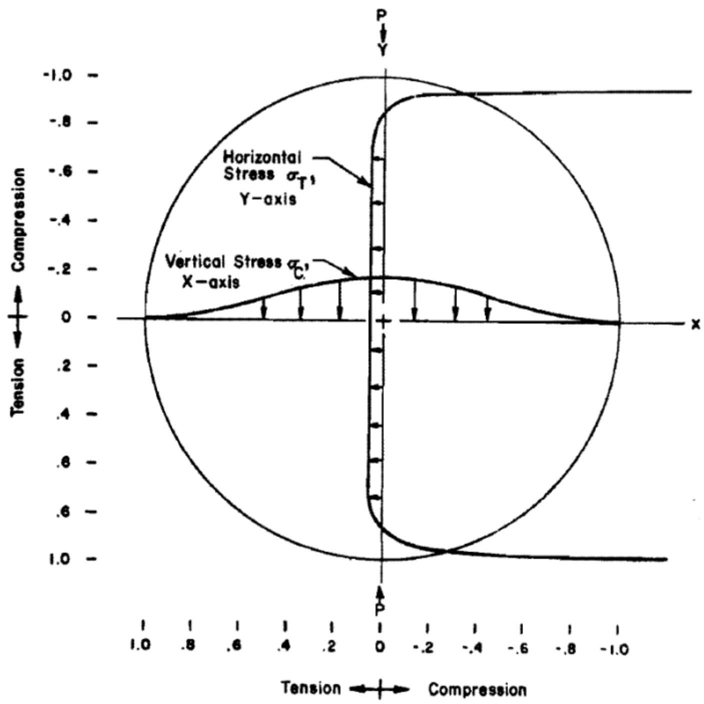

Figure 8: Stress Distribution during IDT (Kennedy & Anagnos, 1983)

Tensile strength of a tested specimen can be calculated as follows:

$$S_T = \frac{2F}{3.14hd}$$

Where,

S_T= Indirect tensile strength, psi

F= Applied compressive load at failure, lbs

h, d= Height and diameter of the specimen, respectively, inch.

However, in addition to testing the Control, Top and Bottom specimens, this study also involved evaluating moisture damage resistance of the mixes using Tex-531-C test procedure. All test specimens were divided into two equal groups. One half of the test specimens were tested as is without any kind of moisture conditioning. The other half of the specimens was placed under water. Vacuum was then applied to saturate the test specimens. The specimens were then conditioned at -18ºC for 15 hours and thawed in water at 60ºC for 24 hour before conducting the tensile strength test as before. The tensile strength ratio (TSR) was determined using results from the unconditioned and moisture conditioned tests as follows:

$$TSR = \frac{\text{Avg. Indirect Tensile Strength of Conditioned Specimens}}{\text{Avg. Indirect Tensile Strength of Dry Specimens}}$$

5. Test Results and Discussion

5.1 Density

Density measurements are required to estimate the degree of compaction achieved and also to ensure consistency in the test specimens. Bulk density reflects the weight-volume relationship of the compacted test specimens while maximum specific gravity estimates the density without any air void.

Bulk specific gravity of the specimens was found to be consistent. Bulk specific gravity for all specimens was in the range of 2.25 to 2.26 with average of 2.27. Water absorption of the specimens was close to 1.9%.

Theoretical maximum specific gravity was found to be 2.433 and the relative density of the specimen was calculated to be 93.4%. These values satisfy the requirements of the test procedures used in this study, namely, Tex-241-F, Tex-226-F and Tex-531-C, which specify that the specimen relative density should be 93±1%.

5.2 Rutting Resistance

Hamburg wheel test was conducted using the test method as described in Tex-242-F. For the binder grade PG 64-22, Texas Department of Transportation recommends minimum 10,000 wheel passes before the wheels create 0.5-inch rut when tested at 50ºC. The tests on control specimens and specimens with mine tailings reveal that specimens with mine tailings performed better than the control specimens. The results show that the control mix marginally reached 10,000 passes in one test and was close to this limit in a replicate test. On the other hand, specimens wherein some of the fine aggregates were replaced with mine tailings from bottom of the stockpile, performed significantly better with about 15,900 passes to result in ½-inch rutting. Specimens wherein tailings from the top of the stockpiles were used also showed better performance than the control specimens. These specimens required about 12,300 passes to result in ½-inch rutting. Figure 9 shows the number of wheel passes vs. rut depth relationship for two tests using the Control mix (four replicate specimens) and one test each for the Top and Bottom mix (two replicate specimens for each test).

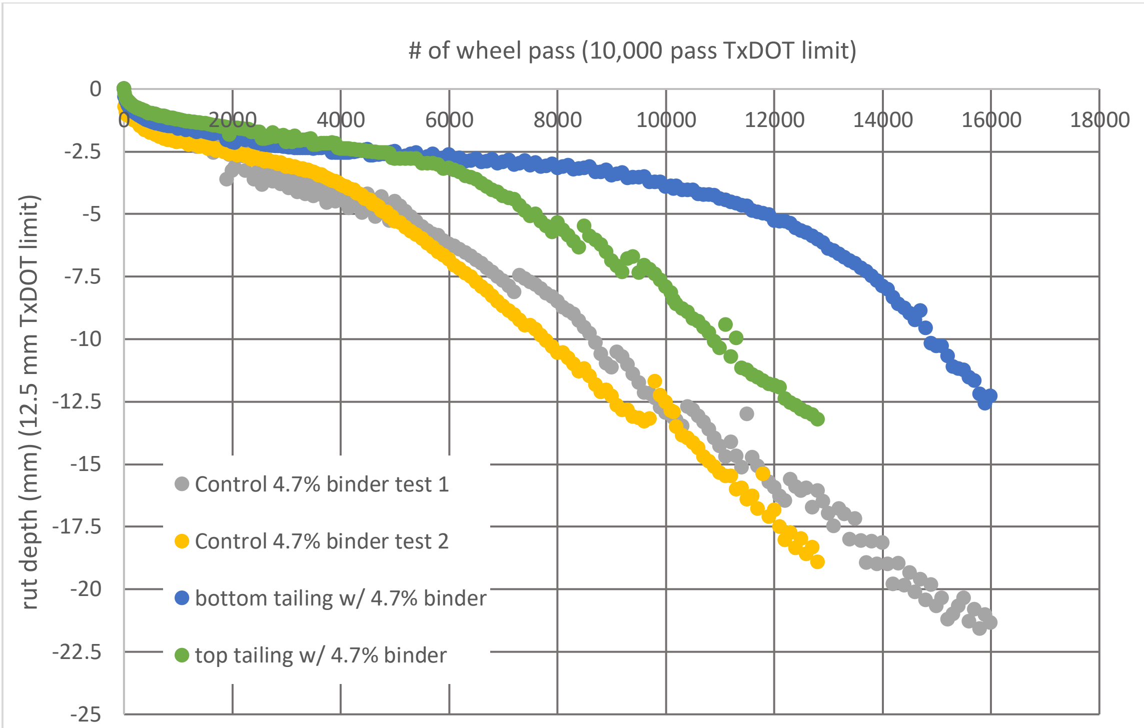

Figure 9: Hamburg Wheel test rut depth vs. # of wheel pass

5.3 Indirect Tensile Test

Indirect tensile test on the unconditioned and moisture conditioned specimens were conducted using the Control, Top and Bottom mixes. TxDOT recommended range of tensile strength for unconditioned specimens is 85-200 psi. Figure 10 shows a typical load vs time relationship for IDT test. The peak load from these tests was used to determine the tensile strength of the mixes. Table 2 summarizes the results from the IDT test for the unconditioned and moisture conditioned Control, Top, and Bottom mixes.

Table 2: IDT test results for dry and moisture conditioned specimens

	Avg. Dry Condition Tensile Strength (psi)	Avg. Moisture Conditioned Tensile Strength (psi)	Tensile Strength Ratio (TSR)
Control Specimen	417.13	357.76	0.86
‘Top’ Specimen	460.64	192.02	0.42
‘Bottom’ Specimen	429.22	260.16	0.61

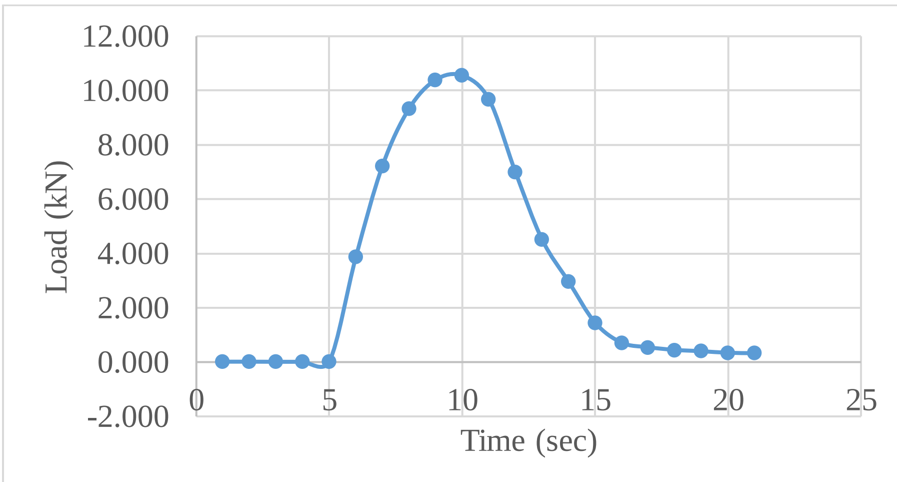

Figure 10: Typical load vs. time curve in IDT, the pick indicates maximum strength

It can be observed from Table 2 that mixes with mine tailing perform slightly better than the control specimens. All three types of mixes have a higher tensile strength than the TxDOT recommended value. However, after moisture conditioning, the control specimens were able to retain about 86% of dry strength whereas the ‘top’ and ‘bottom’ specimens were able to retain only 42% and 61% of their initial dry strengths, respectively. Despite the significant loss of strength for specimens with mine tailing after moisture conditioning, Bottom specimen strength is more than the specification recommended value and Top specimen strength is marginally below the recommended value and within the acceptable range. However, it should be kept in mind that the recommended values are intended for dry specimen only and commonly accepted minimum tensile strength ratio is 0.80, which was not met for the specimens with mine tailing. However, based on the results from the Hamburg wheel tracking test (which is also conducted under submerged conditions), it appears that the use of anti-stripping agents in the mixes with mine tailing may possibly reduce its moisture susceptibility as exhibited by the IDT.

6. Conclusion

Full replacement of #50 passing and #200 retained, and partial replacement of #30 passing and #50 retained aggregate was done with the same sized mine tailings. During the mixing process of aggregates and binder, no noticeable discrepancy was observed between the control mix and the mixes that incorporated mine tailings. However, an unpleasant odor was noticed during initial sieving of the tailing, potentially originating from the dampness of the pile. Density tests on compacted specimens showed that the required density (93±1%) was achieved for all test specimens during compaction using the Superpave Gyratory Compactor. Hamburg wheel test results indicate that specimens with mine tailings, especially with tailings from the bottom of the stockpile, perform substantially better than the control mix. For a target rut depth of ½-inch, specimens prepared with top and bottom mine tailings survived 12,300 and 15,900 passes which is greater than the required number of passes (10,000). Indirect tensile tests of dry specimens for the control mix and the mixes that incorporated mine tailing show that the strength values are close to each other though those with mine tailings are slightly higher than the control mix. However, mixes with mine tailings were more sensitive to moisture induced damage and retained 42 and 61% strength for ‘top’ and ‘bottom’ specimens, respectively, while the control mix retained 86% of its strength. We speculate that the use of anti-stripping agents might reduce the moisture sensitivity of the asphalt mixtures with mine tailings.

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