FHWA, Drilled and Grouted Micropiles State-of-Practice Review. July (1997). Report No. FHWA-RD-96-016/019 United States Department of Transportation, Four Volumes.

Hussein Elarabi and Amin Ahmed Abbas Soorkty, (2015). Building and Road Research Institute, University of Khartoum." Construction of Micropiles Using Pressure Techniques", Journal of Civil Engineering and Architecture 9 (2015) 45-50.

10th ISM Workshop on MicropilesSeptember 22-25, 2010, Washington, DC, USA'' Hollow Bar Micropiles for Settlement Control in Soft Soils'' Jonathan Bennett, PE, D.GE – Chief Engineer Earth Support Division.

10th ISM Workshop on MicropilesSeptember 22-25, 2010, Washington, DC, USA '' THE DESIGN AND EXECUTION OF DRILLED AND FLUSH-GROUTED TITAN MICROPILES IS GOVERNED IN EUROPEAN UNION (EU) BY NATIONAL TECHNICAL APPROVAL Z-34.14-209 (DIBT) Dipl.-Ing. E.F. Ischebeck.

7th ISM Work Shop on Micropile, Schrobenhausen. (2006). "Foundation Improvement of Historic Buildings by Micropiles", Museum Island, Berlin and st. Kolumba, Cologne. By Klaus Dietz, Andre Schurmann, pp.7 - 12.

Lizzi, F. (1982). Static Restoration of Monuments. Sagep Publisher. Genoa. Italy.

Jim Sheahan, April 1, 2009 P.E. HDR Engineering, Inc "Micropiles–AnOverview" Lowa Department of Transportation, AGC, FHWA, pp. 5-10.

Michael W. O'Neill, Richard A. Hawkins, and Larry J. Mahar (December, 1982) "Load Transfer Mechanisms in Piles and Pile Groups"

Wetman, A. (1981). "A Review of Micro Pile Types". Ground Engineering, May, pp.43-49.

Effects of Asphalt Concrete Gradation, Air Voids, and Test Temperatures on Rutting Susceptibility by Using the Hamburg Wheel Tracking Device (HWTD)

Matias M. Mendez Larrain, S.M.ASCE[1]; and Rafiqul A Tarefder, M.ASCE[2]

[1]M.Sc. Student, Dept. of Civil Engineering, Univ. of New Mexico, MSC01 1070, 1 University of New Mexico, Albuquerque, NM 87131. E-mail: mmendezl@unm.edu
[2]Professor, Dept. of Civil Engineering, Univ. of New Mexico, MSC01 1070, 1 University of New Mexico, Albuquerque, NM 87131. E-mail: tarefder@unm.edu

Abstract: This study analyses the effect of gradation in different Asphalt Concrete (AC) mixtures using the Hamburg Wheel Tracking Device (HWTD) destructive test. Eight Superpave III (SP III) mixtures with different gradations were collected in New Mexico and tested at three different temperatures (40 °C, 50 °C and 60 °C) and three different Air Voids (AV) contents range. Coarser and finer gradations were defined using the maximum density line. Three finer gradation and five coarser gradation mixtures were compared. Coarse gradation showed better results in all three different test temperatures and AV contents ranges. An AV contents range from 5 to 6.5 percent was considered as optimum for this study. A relation between AV contents and temperature test was not observed.

INTRODUCTION

Hamburg Wheel Tracking Device (HWTD) test is a destructive method that determines the rutting resistance and moisture damage (stripping) of a certain asphalt mixture while a steel wheel rolls across an asphalt concrete surface in a hot water bath. Throughout many years, the use of HWTD in laboratory testing for moisture and rutting susceptibility has been extensively evaluated by some Department of Transportations (DOT's). Cylindrical samples are commonly compacted in the Superpave Gyratory Compactor (SGC). Generally, four cylindrical specimens with a 62±1 mm. (2.4 in.) height and a 150 mm. (6 in.) diameter are submerged in a water bath at 50 °C (122 °F). Two 158 lb. (702 N) wheels roll at approximately 52 Revolutions per Minute (RPM) over two connected cylindrical samples. Each set of specimens is tested at 20,000 wheel load cycles or until 12.5 mm. (0.5 in.) deformation is reached. Some state agencies increase the maximum deformation criteria for research purposes.

BACKGROUND

HWTD test method measures the rut depth and number of passes to failure. In addition, it describes the procedure for testing rutting and moisture susceptibility of Warm Mix Asphalt/Hot Mix Asphalt (WMA/HMA) Asphalt Concrete (AC) samples in the HWTD. HWTD results are expressed in post-compaction consolidation, creep slope, stripping inflection point and stripping slope shown in Figure 1. The post-compaction consolidation is the rut depth at the first 1,000 wheel passes and occurs at the very beginning of the test. It is called post-compaction consolidation because the load applied by the wheel increase the density of an asphalt mixture. Creep slope is related to the permanent deformation (rutting) of the asphalt mixture. Stripping slope is related to the moisture damage (stripping) of an asphalt mixture. The Striping Inflection Point (SIP) is the number of wheel passes that intersects the creep slope and the stripping slope. This mark is related to the resistance of the asphalt mixture to moisture damage. Once the stripping inflection is reached, moisture damage starts to dominate the performance of the mixture.

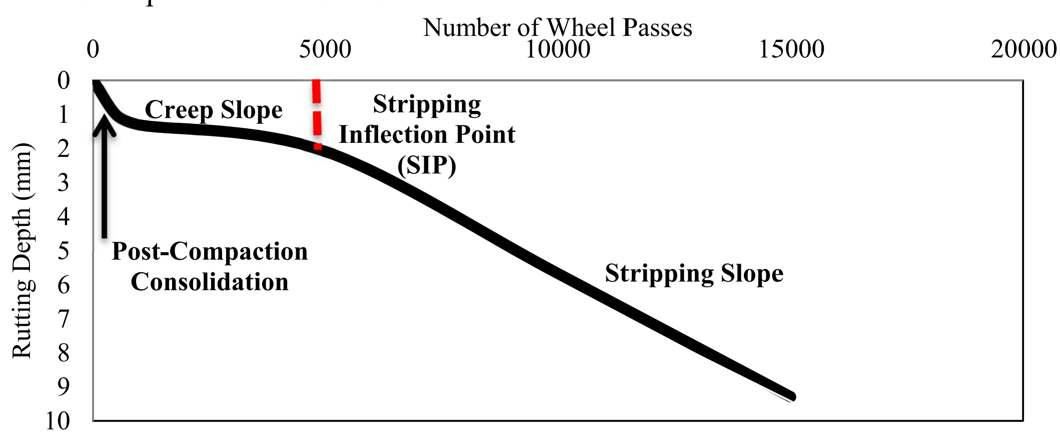


FIG. 1. HWTD result curve.

HWTD results are affected by different mixture design properties and test inputs. Throughout the past of years, research to understand coarse and finer gradation for rutting and stripping distresses was performed. Kandhal and Cooley defined gradations below and above the restriction zone to define finer and coarser mixtures. Mixtures tested in three different rutting susceptibility tests showed no significant difference between gradations. Gokhale et al. used the accelerated pavement testing and asphalt pavement analyzer to evaluate coarse and fine superpave mixtures. Same findings as Khandal and Colley were observed. Golalipour et al. defined three variations in mixtures gradation. Better rutting results were observed in upper limit variations (coarser gradation). In addition, a variation in testing results was observed when AV contents changed. Manal and Attia tested three different types of aggregates using the wheel tracker test. Results shown improvement when coarse gradation was used in the AC mixture. Differently, Habbeb et al. found less rutting when finer gradation mixtures were tested in the wheel tracker test. Kanitpong et al. found that finer and coarser mixtures permanent deformation performance is related to the type of aggregate. In addition, finer mixtures appear to have greater stripping resistance. Studies showed mixtures with lower AV performed better. Permanent deformation and other distresses were sensitive to AV contents. Tarefder and Zamman observed that AV contents and gradation are important rutting factors in AC mixtures using the asphalt pavement analyzer. Results showed an improvement in rutting resistance for lower AV contents and coarser gradations. Aschenbrener and Curier tested 4 types of mixtures at different AV contents using the HWTD. Based on the results, a recommendation of 5 to 7 percent AV contents range was defined. Kassem et al. stated that AV contents are less sensitive to HWTD results.

MATERIALS AND SAMPLE PREPARATION

Materials used in this study were collected in the state of New Mexico. Eight HMA/WMA mixtures with SP III gradation were collected. Gradations with higher area above the maximum density line were considered as finer mixtures. Otherwise, were considered as coarser mixtures as shown in Figure 2.

AC mixtures were differenced in five coarser SP III and three finer SP III mixtures.

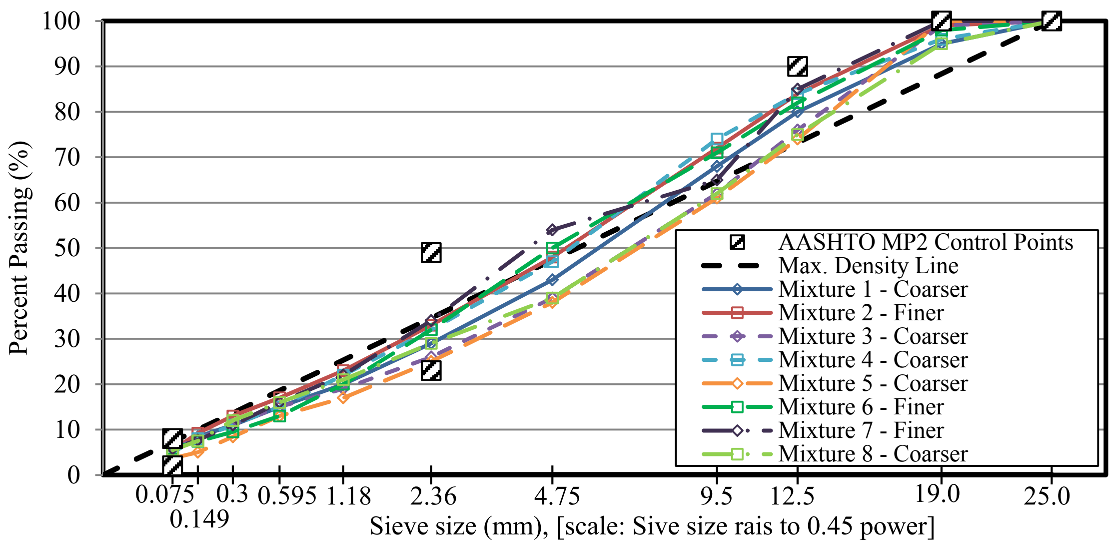


FIG. 2. Mixtures gradation according the maximum density line

HMA/WMA mixtures were collected in warm bulk condition from different sites. Samples were heated at plant mix temperature and SGC was used to compact cylindrical samples. Specimens were compacted at 150 mm in diameter and 62±1 mm height with target AV contents of 6±1 %. Theoretical Maximum Specific Gravity (G_{mm}), Bulks Specific Gravity (G_{mb}) and AV contents of each specimen were determined.

HWTD TEST AND RESULTS

HMA/WMA mixtures were tested at three different temperatures (40 °C, 50° C and 60°C) to observe the effect of temperature for the two different gradations. In addition, three ranges of AV contents were defined to observe the effect of this parameter in the tested samples. Range 1 (R1), Range 2 (R2) and Range 3 (R3) were defined as 5.0 - 5.5 %, 5.5 – 6.5 % and 6.5 – 7.0 % AV contents accordingly. Rutting depth along 11 points in each pair of specimen was measured; average of results from the fifth to the ninth point was used. The following table shows HWTD results for finer and coarser gradations along with the respective AV contents range and test temperature.

TABLE 1. Summary of AC HWTD Results

Gradation	Temperature (° C)	Tests	Air Void Range	Rutting Depth (mm)	N° Passes
Finer	40	1	R1	4.10	20,000
		2	R2	2.28	20,000
		3	R3	2.61	20,000
	50	7	R1	11.11	16,823
		5	R2	8.92	17,561
		4	R3	15.83	13,915
	60	4	R1	11.31	13,066
		1	R2	19.13	3,942
		1	R3	13.89	4,612
Coarser	40	2	R1	1.24	20,000
		2	R2	1.41	20,000
		4	R3	1.98	20,000
	50	3	R1	2.13	20,000
		18	R2	3.30	20,000
		10	R3	2.90	20,000
	60	3	R1	7.81	16,638
		8	R2	6.00	18,350
		1	R3	3.94	20,000

Previous results showed higher rutting depth for finer mixtures than coarser mixtures in all three test temperatures. The effect of test temperature in finer mixtures showed significant effect with higher rutting depths at higher temperatures. Finer mixtures tested at 40°C reached the 20,000 wheel passes with rutting depths not higher than 4.5 mm. as shown in Figure 3(a). The effect of AV contents showed lower rutting depths for R2. For this test temperature test, lower AV contents showed higher rutting depths. The number of test performed in R1 is a restriction to this assumption. From Figure 3(a), the optimum AV contents range for finer mixtures tested at 40 °C is 6 to 7 percent.

HWTD results of finer mixtures at 50 °C showed higher average rutting depths than mixtures tested at 40 °C. Mixtures in R1 and R2 did not reach the maximum rutting depth (12.5 mm) adopted for most of transportation agencies. Mixtures in R3 performed the worst exceeding the maximum rutting depth. R2 showed better results in terms of rutting depth and number of wheel passes with non-significant difference between R1. In Figure 3(b) two regions of rutting depths were observed, rutting depths higher than 12 mm and lower than 8 mm. This difference can be related to the type of aggregate and binder PG in the mixtures. For this temperature, the optimum AV contents in the samples are 5 to 6 percent. Mixtures above this range collapsed earlier and showed higher impression.

Finer mixtures tested at 60 °C rapidly collapsed and exceed the maximum rutting depth for R2 and R3. Impressions from 13 to 20 mm were observed at no more than 5,000 passes. The effect of AV contents for R2 and R3 for finer mixtures is significant when samples are tested at 60°C as shown in Figure 3(c). Only one test was performed in these two ranges and results may behave differently if numbers of test are increased. R1 showed good results in relation to other ranges. A close gap to finish the test was observed and samples experienced impression not higher than 12 mm. The optimum AV contents for this test temperature are in R1. Excluding the effect of AV contents in AC mixtures at different temperatures, the effect of test temperature in finer mixtures is critical when water baths reaches the 50 °C temperature. From Figure 3(b) and (c) it can be observed that 15 test of 22 failed when temperature was 50 °C or higher. Whenever test temperature was between 50 °C and 60 °C results showed better performance of the samples when R1 was the AV contents range.

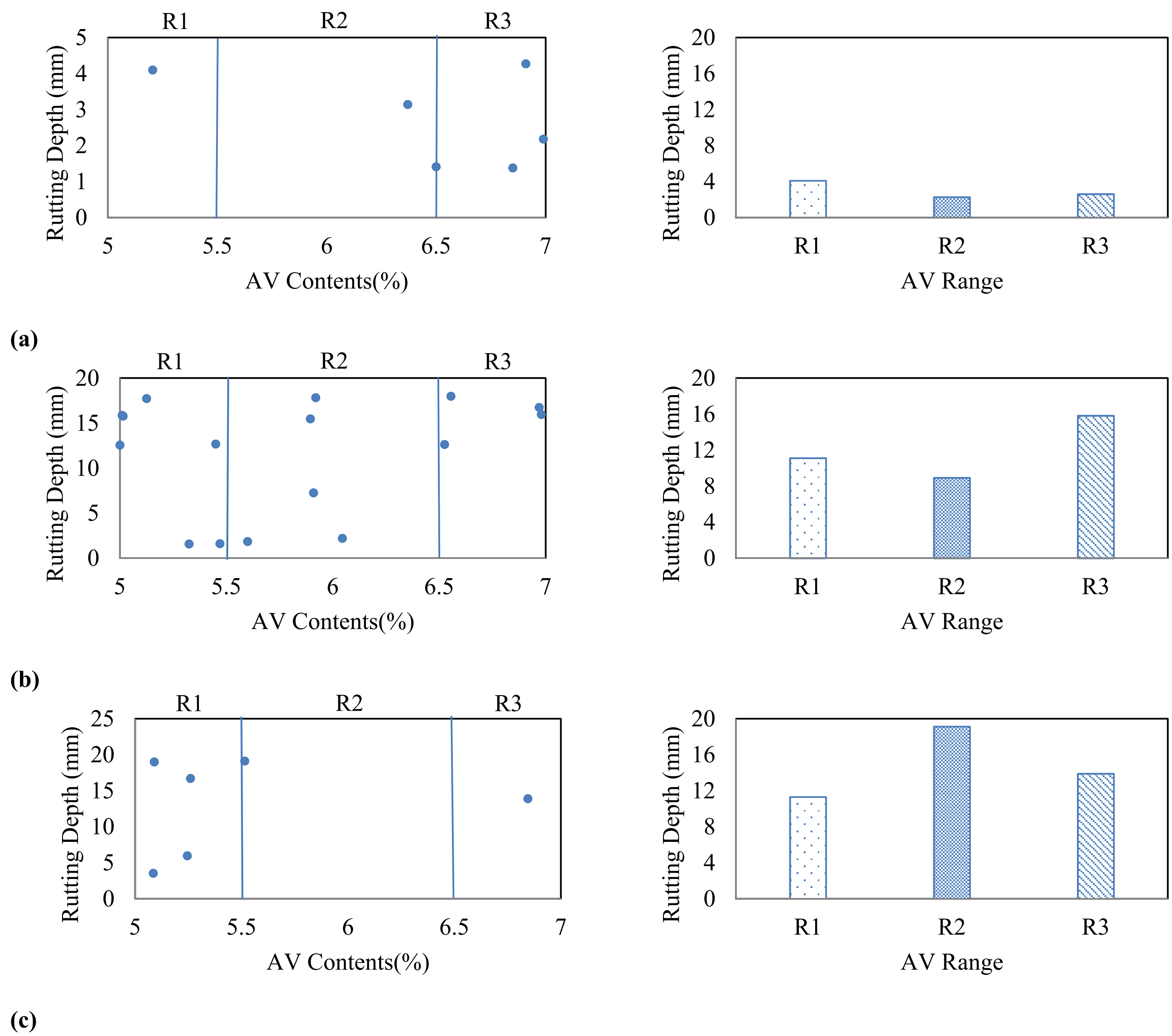
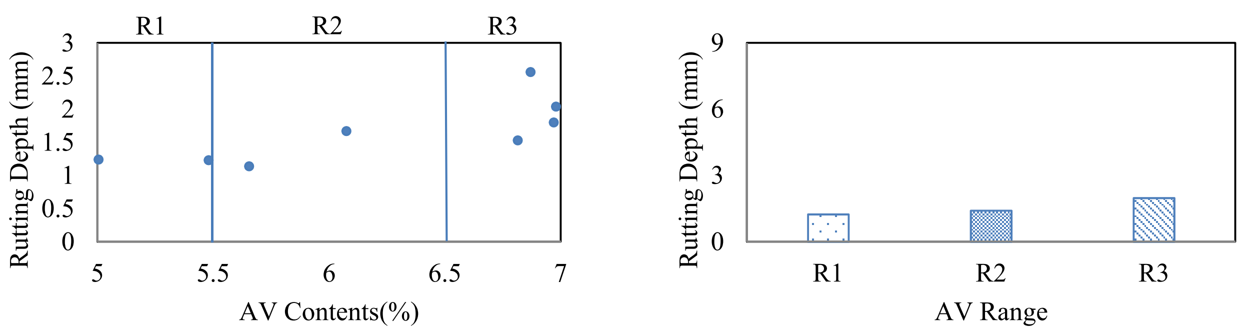


FIG. 3. Rutting depths Vs air void contents for finer mixtures at different test temperatures (a) 40 °C (b) 50 °C (c) 60 °C

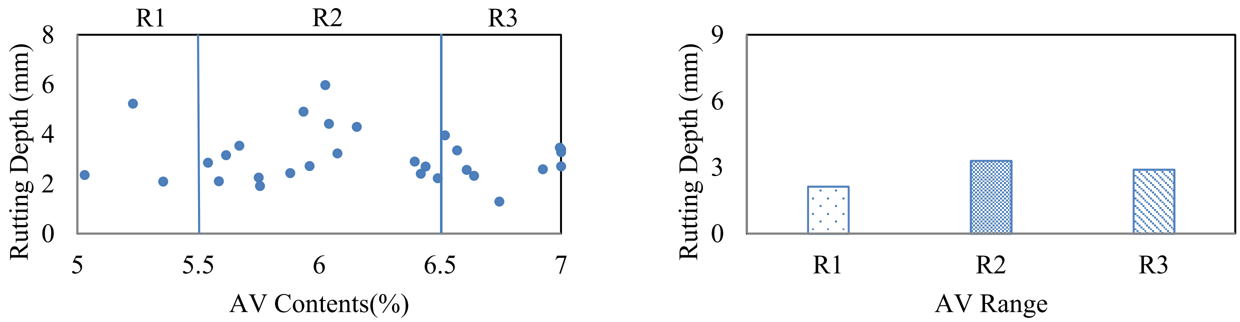
Coarser mixtures showed a significant improvement in HWTD results compared to finer mixtures. As shown in Table 1, the critical effect of test temperature starts at temperatures higher than 60 °C. At lower temperatures, coarser mixtures reached the 20,000 passes in all the tests and did not show impressions higher than 3.3 mm. In other words, coarser mixtures performed well at 40 °C and 50 °C as shown in Figure 4. Coarser mixtures tested at 40 °C experienced rutting depths not higher than 2.5 mm. and 20,000 passes as shown in Figure 4(a). The effect of AV contents range is non-significant due the low impression in the testing results. R1 and R2 showed better results than R3. The effect of this temperature in coarser mixtures is insignificant.

HWTD results for coarser mixtures tested at 50°C shown in Figure 4(b) experienced rutting depths oscillating from 1.3 to 6 mm. and none of the tests collapsed before the 20,000 passes. R1 showed better result but the amount of tests performed at this range may be a restriction. A difference of 0.4 mm was observed for rutting depths between R2 and R3. In Figure 4(b), two ranges of rutting depths were observed in the three ranges. Ranges oscillate from 2 to 4 mm and 4 to 6mm. with 26 test in the first range and 5 in the second. Due the amount of tests and results in the first region, coarser mixtures at 50 °C performed well and non-signs of stripping were observed. As shown in Figure 4(b) and the number of test performed R3 is the best region of AV contents for this temperature.

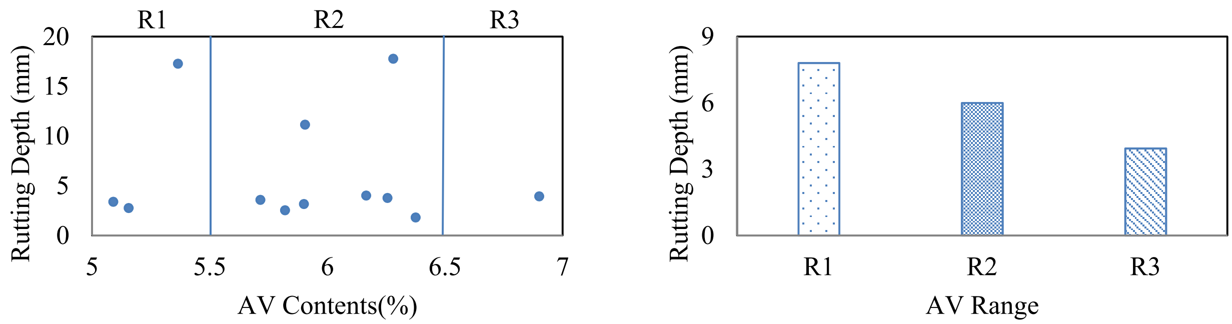
The effect of test temperature at 60 °C showed high variability in the results depicted in Figure 4(c). Coarse mixtures experienced high rutting depths in 3 of the 12 tests. In terms of wheel passes, two tests did not reach the 20,000 passes and impressions above 17 mm were observed. These results can be related to a change in properties in the mixtures design such as type of aggregate, binder PG and so on. Rutting depths between 1.8 and 4 mm were the most representative HWTD results at this test temperature. From this 9 test, no difference was observed in the three AV contents ranges but 6 of the 9 test were in R2. Excluding the three test above the 10 mm, coarse mixtures at 60 °C did not show critical performance in the HWTD test. Due the amount of test in R2 and the HWTD results obtained, R2 is the optimum range of AV contents for coarser mixtures.



(a)



(b)



(c)

FIG. 4. Rutting depths Vs air void contents for coarser mixtures at different test temperatures (a) 40 °C (b) 50 °C (c) 60 °C

The effect of test temperatures is mostly related to the gradation of the mixtures. From Figure 3 and Figure 4, HWTD results shown that finer mixtures collapsed easily and rapidly at different temperatures. When temperature of the test increases the results are critical and the tendency of reach stripping is higher. In addition, AV contents in range 1 performed better for this gradation. Difference between finer and coarser mixtures rutting depths at 40 °C was not significant. The effect of this temperature did not show signs of stripping for finer gradation and coarser mixtures performed better and barely rut. For 50 °C test temperature, finer mixtures showed stripping and rutting depths reached the maximum rutting depth defined by most of the transportation agencies. Coarser mixtures did not show a considerable increment in rutting at this temperature. Finally, HWTD results showed that finer mixtures poorly performed at 60 °C and this gradation is not adequate. Differently, coarse mixtures showed good results at this test temperature.

CONCLUSIONS

From this study the following conclusion can be drawn:

- Coarser gradations perform better than finer gradation in HWTD for different test temperatures. This finding may be related to the stone-stone contact in coarse aggregate particles.
- Finer gradations and coarser gradations showed better results for AV contents in range 1 and range 2 (5.0 – 6.5 %).
- No relationship between AV contents and test temperature was observed.

ACKNOWLEDGMENTS

The authors would like to appreciate the research funding provided by the New Mexico Department of Transportation (NMDOT) and Southern Plains Transportation Center (SPTC).

REFERENCES

Aschenbrener, T., and Curier, G. (1993). *Influence of Testing Variables on the Results from the Hamburg Wheel-Tracking Device*. Publication No. CDOT-DTD-R-93-92. Colorado Department of Transportation.

Gokhale, S., Choubane, B., Sholar, G., and Moseley, H. (2006). *Evaluation of Coarse and Fine Graded Superpave Mixtures under Accelerated Pavement Testing.* Publication No. FL/DOT/SMO/06-494. Florida Department of Transportation.

Golalipour, A., Jamshidi, E., Niazi, Y., Afsharikia, Z., and Khadem, M. (2012). "Effect of Aggregate Gradation on Rutting Asphalt Pavements." In *Procedia Social and Behavioral Sciences. Vol 53,* pp. 440-449.

Habeeb, H., Chandra, S., and Nashaat, Y. (2012). "Estimation of Moisture Damage and Permanent Deformation in Asphalt Mixture from Aggregate Gradation." In *KSCE Journal of Civil Enginering, Vol. 18(6),* pp. 1655-1663.

Kanitpong, K., Charoentham, N., and Likitlersuang, S. (2012). "Investigation on the Effects of Gradation and Aggregate Type to Moisture Damage of Warm Mix Asphalt Modified with Sasobit." In *International Journal of Pavement, Vol. 13:5,* pp. 451-458.

Khandal, P., and Cooley, A. (2002). *Coarse Versus Fine-Graded Superpave Mixtures Comparative Evaluation of Resistance to Rutting.* Publication No. NCAT Report 02-02. National Center for Asphalt Technology.

Kassem, E., Masad, E., Lytton, R., and Chowdhury, A. (2011). "Influence of Air Voids on Mechanical Properties of Asphalt Mixtures." In *Journal of Road Materials and Pavement Designs*, Vol. 12, pp. 493-524.

Manal A.., and Attia, M. (2013). "Impact of Aggregate Gradation and Type of Hot Mix Asphalt Rutting in Egypt." In *International Journal of Engineering Research and Application, Vol. 3, Issue 4,* pp. 2249-2258.

Tarefder, R. and Zaman, M. (2002). *Evaluation of Rutting Potential of Hot Mix Asphalt Using the Asphalt Pavement Analyzer.* Publication No. Final Report Item 2153; ORA 125-6660. Oklahoma Department of Transportation.

Mixture Ratio Design of a Porous Concrete Base in a Tunnel Pavement Based on the Orthogonal Test

Xinjun Feng[1]; Fuqiang Liang[2]; Hong Jiang[3]; and Jianbo Yuan[4]

[1]Professor, School of Traffic and Transportation Engineering, Changsha Univ. of Science and Technology, No. 960, 2nd Section, Wanjiali South Rd., Hunan 410004, China. E-mail: fxjasphalt@aliyun.com
[2]Graduate, School of Traffic and Transportation Engineering, Changsha Univ. of Science and Technology, Hunan 410004, China. E-mail: lfq31@foxmail.com
[3]Lecturer, School of Traffic and Transportation Engineering, Changsha Univ. of Science and Technology, Hunan 410004, China. E-mail: jianghon_2022@qq.com
[4]Professor, School of Traffic and Transportation Engineering, Changsha Univ. of Science and Technology, Hunan 410004, China. E-mail: yuanjb01@163.com

Abstract: Porous concrete due to its high porosity and permeability is considered as an alternative to tunnel pavements base. Based on orthogonal test method, an optimized coarse aggregates gradation with good packing state and uniformity is put forward. Three factors of cement content, sand ratio and water-cement ratio are considered in an orthogonal test with four levels adopted in every factor. The results show the most effective factor affecting 7-day compression strength is cement content, then sand ratio and water-cement ratio. The most effective factor affecting effective porosity is cement content, then water-cement ratio, the least effective factor is sand ratio. A series of regression relationships of 7-day compression strength and effective porosity of porous concrete base are derived on the basis of range analysis of the test results. According to the orthogonal test, the optimum proportion of porous concrete base in tunnel pavement is determined.

INTRODUCTION

In recent years, with the rapid development of highway construction in China, the number of highway tunnels continuously increase. In southern China, there are universal water damages in the tunnel pavements serviced several years. Humid climate and heavy rainfall contribute abundant underground water in tunnels. The water that entered in the pavement structure and could not be drained out is the main reason that causes water damage of the pavements. In view of this, it is proposed to set permeable base in tunnel pavements to discharge underground water from both sides