Accelerated Laboratory Polishing Device for Hot Mix Asphalt

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ABSTRACT: This paper presents a newly developed accelerated polishing device used in the laboratory as a screening tool for selecting high polishing-resistant and high-friction aggregates and for optimizing the mix design to ensure satisfactory field performance in terms of preventing premature loss of friction due to vehicle tire-pavement surface polishing and wearing actions. The accelerated polishing equipment can test two types of Hot Mix Asphalt (HMA) specimen sizes: one is the 15.24 cm diameter gyratory compacted specimen, and the other one is the 45.72 cm by 45.72 cm by 5.08 cm slab specimen made by a roller compactor. The repeatability of the test results was confirmed through a series of testing and statistical analysis. Also, the polishing and friction performance of HMA specimens made by different aggregates and compaction methods (gyratory vs. roller compaction) was compared.

INTRODUCTION

The primary cause of polishing and loss of friction of asphalt concrete pavement can be attributed to loss of microtexture and macrotexture of the pavement surface through prolonged abrasive action between vehicle tires and pavement surface. Lack of adequate skid resistance of the pavement surface can create serious safety concerns to vehicles traveling at high speed, especially when the vehicle is braking suddenly on a wet pavement surface where hydroplaning can occur. It is desirable to have the ability to screen the polishing and friction characteristics of a hot mix specimen during the mix design stage. The main objective of this paper is to present a laboratory-scale accelerated HMA polishing device for the purpose of screening the polishing and friction performance of the HMA mix.

POLISHING DEVICES FOR HMA

There are four existing laboratory-scale accelerated polishing devices for polishing the HMA surface: The North Carolina State University (NCSU) Wear and Polishing Machine (ASTM E660, 2005), the National Center for Asphalt Technology (NCAT) Device, the Wehner/Schulze Polishing Device (Do, et. al, 2007), and the Penn State Reciprocating Polishing Device (Nitta et. al, 1990, ASTM E1393, 2005).

DEVELOPMENT OF NEW POLISHING DEVICE

The guiding principle of the new laboratory-scale accelerated polishing device is that the friction loss of asphalt pavement surface can be accurately measured and replicated in short test durations. The abrasive action between a rubber vehicle tire and asphalt concrete pavement surface was enacted in the accelerated polishing device by using polishing shoes (pads) made of Styrene-Butadiene-Rubber (SBR). Two specific specimen dimensions can be tested: a 45.72 cm by 45.72 cm by 5.08 cm high roller compacted slab specimen or a 15.24 cm diameter by 10.16 cm high Superpave gyratory compacted specimen. For the gyratory compacted specimen, a solid rubber disk of 15.24 cm diameter and 3.81 cm thick was used. For the slab specimen, a rubber ring of approximately 33.02 cm outside diameter and 22.86 cm inside diameter was used to fit with the required measurement area for the Dynamic Friction Tester (DFT) and Circular Texture Meter (CTM). The DFT device consists of a disk fitted with three spring-loaded rubber sliders. The disk is initially suspended above the pavement surface and is driven by a motor until the desired tangential speed of the sliders (about 90 kph) is attained. The rotating disk is then dropped onto the wet surface. The friction force and speed of the rotating disk are continuously measured and recorded as the disk slows down to stop (zero speed). The CTM uses laser techniques to measure the surface texture profile of an annulus surface area. A photograph of the completely fabricated accelerated polishing device is shown in Fig. 1. Fig. 2 shows the details on mounting the two different specimen sizes.

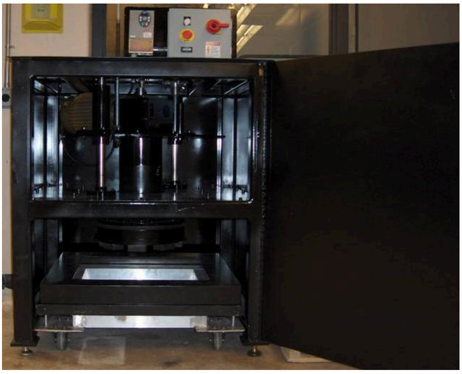
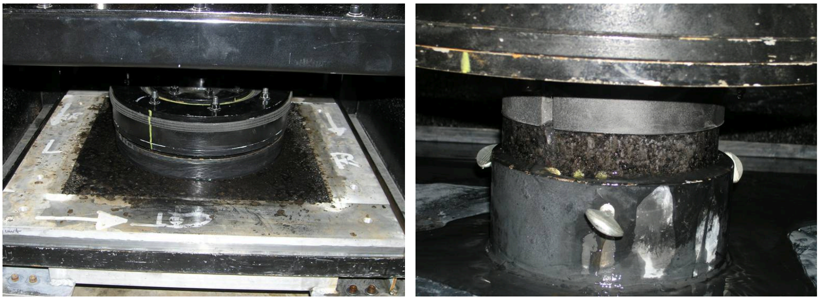


FIG. 1. Overall view of the accelerated polishing machine using rubber shoes



(a) Details on slab specimen mounting (b) Gyratory-compacted specimen mounting

FIG. 2. Specimen mounting with the developed accelerated polishing machine

Different combinations of operation conditions were tried. The final selected operation conditions are as follows: (a) vertical force = 84 kg for 15.24 cm specimen and 127 kg for the large square specimen, and (b) the rotation speed at 30 rpm. These optimum operation conditions were selected to ensure that rubber pad would not experience rocking motion, and that more or less a flat contact surface between the rubber pad and the specimen was maintained. The water spray was used to wash off rubber debris and to prevent overheating during polishing action.

REPEATABILITY OF THE ACCELERATED POLISHING DEVICE

The repeatability of the polishing results using the developed accelerated polishing device was examined. For each set of specimens made of the same mix formula (aggregate source, aggregate gradation, optimum binder content, binder type, and compaction method and effort), three replicate specimens were tested. Both British Pendulum Test (BPT) and Mean Texture Depth (MTD) measured by the sand patch method were used. The British Pendulum tester (ASTM E303-93) consists of a rubber slider attached to the end of a pendulum arm. As the pendulum swings, it is propelled over the surface of the specimen. As the rubber slider contacts the surface of the specimen, the kinetic energy of the pendulum decreases due to friction. This energy loss is measured and reported as the British pendulum number (BPN). The Sand Patch Method (ASTM E965-96) is used to measure macrotexture of the specimen surface. This method involves taking a known volume of a spreadable material and spreading it out in a circle on the surface of the specimen. Measuring the diameter gives the area of the circle. The MTD is determined by dividing the volume by the area.

The friction values obtained from BPT and the MTD measured by the sand patch method from the three replicates were statistically analyzed using the techniques of Homogeneity of Variance (Levene statistic), one-way Analysis of Variance (ANOVA), and Multiple Comparisons to check for the repeatability of test results. The statistical analysis results are summarized in Table 1. It can be seen that the difference between the variances and the means of the results for the three replicate specimens was insignificant for all cases when considering the friction values (British Pendulum Number, BPN) and insignificant for the vast majority of the cases when considering the macrotexture values (MTD). The repeatability of the polishing action provided by the accelerated polishing device was acceptable.

TABLE 1. Repeatability Tests for the Limestone and Gravel HMA Mixes

Aggregate Source	Factor	Homogeneity of Variances		1-Way ANOVA Table		Multiple Comparisons	
		Levene Statistic	Significance[a]	F	Significance[a]	Group	Significance[a]
Possible Medium Polish (Columbus Limestone)	BPN	0.167	0.847	0.280	0.758	1 2	0.982
						1 3	0.853
						2 1	0.982
						2 3	0.755
						3 1	0.853
						3 2	0.755
	MTD	0.384	0.685	5.705	0.009	1 2	0.964
						1 3	0.027
						2 1	0.964
						2 3	0.015
						3 1	0.027
						3 2	0.015
Possible low Polish (Stocker Sand & Gravel)	BPN	0.484	0.622	1.068	0.359	1 2	0.854
						1 3	0.334
						2 1	0.854
						2 3	0.640
						3 1	0.334
						3 2	0.640
	MTD	0.884	0.426	93.006	0.000	1 2	0.304
						1 3	0.000
						2 1	0.304
						2 3	0.000
						3 1	0.000
						3 2	0.000

a. significant at the p-value smaller than 0.05

COMPARING POLISHING BEHAVIOR BETWEEN HMA SURFACE AND AGGREGATE SURFACE

In a previous study (Liang and Chyi, 2000), different aggregates sources were tested for polishing and friction behavior using the accelerated British Polishing Wheel (ASTM E3319). The results of polishing behavior of two aggregates from Liang and Chyi (2000) and the current study of the HMA specimens made with the same two aggregate sources are statistically compared in Table 2 and Table 3 for Limestone and Sand and Gravel aggregates, respectively. It can be seen that the friction values of the aggregates, denoted by PV, are highly correlated to the friction values of the HMA made with the same aggregates, denoted by either BPN for the gyratory compacted specimens and FN_SPEED (where SPEED refers to the friction at the measuring speed) for the roller compacted slab specimens. The fact that aggregates constitute more than 90% by weight of the HMA leads us to believe that aggregate would be a dominant controlling factor on friction of HMA surface. The high correlation observed in Tables 2 and 3 supports this. Based on the comparisons presented in this section, the developed laboratory-scale accelerated polishing device was shown to be able to polish the HMA surface and provide similar test trend as if the polishing tests were performed on the aggregates only.

TABLE 2. Simple Linear Regression between Aggregate Friction Values in (Liang and Chyi, 2000) and HMA Friction Values (This Study) for Columbus Limestone Mixes

Correlation Variables	Model Equation	R^2 (%)	ANOVA Table	
			F-value	P-value
PV vs. BPN	PV = 8.322 + 0.462 BPN	91.6	76.04	<0.0001
PV vs. FN_0	PV = 19.112 + 0.257 FN_0	92.0	80.17	<0.0001
PV vs. FN_10	PV = 19.516 + 0.347 FN_10	95.8	160.84	<0.0001
PV vs. FN_20	PV = 10.688 + 0.649 FN_20	93.9	107.34	<0.0001

TABLE 3. Simple Linear Regression between Aggregate Friction Values in (Liang and Chyi, 2000) and HMA Friction Values (This Study) for Stocker Sand and Gravel Mixes

Correlation Variables	Model Equation	R^2 (%)	ANOVA Table	
			F-value	P-value
PV vs. BPN	PV = -22.166 + 0.876 BPN	98.5	259.35	<0.0001
PV vs. FN_0	PV = -22.956 + 0.603 FN_0	72.7	10.64	0.0310
PV vs. FN_10	PV = -8.717 + 0.574 FN_10	74.2	11.49	0.0275
PV vs. FN_20	PV = -117.545 + 2.768 FN_20	92.5	49.08	0.0022

POLISHING TREND OF HMA SAMPLES PREPARED BY TWO COMPACTION METHODS

The friction values of the two types of specimen sizes, each compacted with different compaction method (i.e., roller compaction vs. gyratory compaction) were found to be correlated and the coefficients of determination were significant, as indicated in Tables 4 and 5 for Limestone and Sand and Gravel aggregates, respectively. Based on the ANOVA analysis shown, the overall significance of the models, as presented by the F-value and P-value, was found to be significant at the 0.05 significance level.

TABLE 4. Simple Linear Regression between Friction Values of Gyratory Compacted Specimens and Friction Values of Roller Compacted Slab Specimens (Limestone aggregate)

Correlation Variables	Model Equation	R^2 (%)	ANOVA Table	
			F-value	P-value
BPN vs. FN_0	BPN = 23.686 + 0.550 FN_0	98.7	522.07	0.0000
BPN vs. FN_10	BPN = 25.566 + 0.723 FN_10	97.3	248.48	0.0000
BPN vs. FN_20	BPN = 8.262 + 1.327 FN_20	91.4	74.60	0.0000

TABLE 5. Simple Linear Regression between Friction Values of Gyratory Compacted Specimens and Friction Values of Roller Compacted Slab Specimens (Sand and Gravel aggregate)

Correlation Variables	Model Equation	R^2 (%)	ANOVA Table	
			F-value	P-value
BPN vs. FN_0	BPN = -4.074 + 0.723 FN_0	81.3	17.38	0.0140
BPN vs. FN_10	BPN = 13.815 + 0.677 FN_10	80.3	16.27	0.0157
BPN vs. FN_20	BPN = -103.208 + 3.056 FN_20	87.8	28.71	0.0059

SUMMARY AND CONCLUSIONS

In this paper, an accelerated laboratory-scale polishing device that is capable of mimicking the polishing of the HMA pavement surface due to vehicle tires in an accelerated manner was developed. The accelerated polishing device was capable of testing two different sizes of HMA specimens: the 45.72 cm by 45.72 cm by 5.08 cm high slab specimens compacted using the roller compactor and the 15.24 cm diameter and 10.16 cm high cylindrical specimens compacted using the gyratory compactor. The design principles of the testing device, together with the optimized operation conditions, were presented in this paper. Results of a series of testing and comparisons can be summarized below.

- Repeatability of the accelerated polishing device was checked and affirmed using one-way ANOVA test.
- The polishing effect and trend of polishing produced by the new polishing device was ascertained through examination of the test results conducted on HMA mixes made of Limestone and Sand and Gravel aggregates, respectively.
- Good correlation of the polishing and friction behavior was found between aggregate specimens tested with standard test methods and the HMA specimens made with the same aggregates tested with the new polishing device. Therefore, it was reasonable to conclude that the new accelerated polishing device can accomplish the intended tire/pavement wearing and polishing mechanisms.
- Good correlation was found between the two specimen sizes using different compaction methods.

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Effect of Aggregate and Asphalt on Pavement Skid Resistance Evolution

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ABSTRACT: When designing pavement, engineers must optimize some requirements such as user safety (skid resistance), environmental impact (noise, rolling resistance…)... However, this skid resistance evolves during the entire pavement life. So it is a common practice to perform laboratory tests to forecast the evolution of skid resistance. Previous works done in the French Laboratory of Bridges and Roads (Laboratoire Central des Ponts et Chaussées, LCPC) have identified phenomena such as binder removal, aggregate polishing and seasonnal variations to be responsible of these variations. This paper focuses on the polished stone values of aggregates and the aging of asphalt on the evolution of pavement skid resistance. Skid resistance of different specimens of nude aggregates and asphalt mixes that are submitted to polishing and aging was studied. On skid resistance point of view, aging of aggregates can be neglected in comparison to those of asphalt. Rocks with high polishing resistance offer less variation of skid resistance. Aging of asphalt tends to increase skid resistance until 12 month and remains this latter constant after.

INTRODUCTION

Skid resistance is one of the fundamental requirements that provide a safe road (Diringer and Barros 1990; Roe and Hartshorne, 1998). But, unfortunately pavement skid resistance evolutes during the whole pavement life due to change on pavement surface characteristics. In the case of asphalt pavements, skid resistance is governed by, among other factors, asphalt types and aggregate properties (Michelin Company, 2000].

Research has been launched at LCPC since 2004 to investigate the polishing phenomenon of asphalt pavement. As results of this investigation, two parts was clearly observed from the evolution tendencies (see FIG.1): the friction coefficient increases firstly until reaching a maximum then decreases (Minh-Tan Do et al, 2007).

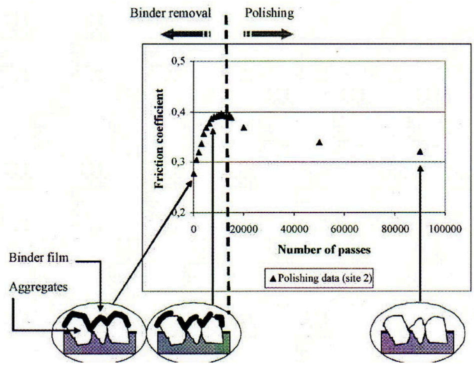

FIG. 1. Friction coefficient versus number of passes with WS machine

Comparing skid resistance evolution of asphalt mix specimen and specimen of nude aggregate (see FIG.2), the most important point is that the aggregate and asphalt curves coincide after the asphalt has reached the maximum friction. This result was explained by the fact that once the binder layer of asphalt pavement is removed, the aggregates are exposed little by little, and the surface of asphalt pavement behaves as the aggregate in this moment. For summarizing, it can be said that the skid resistance evolution is controlled by the aggregates after the binder removal [Tang, 2007; Minh-Tan Do et. al. 2008; EN 1097-8. 2000; Y. Brosseaud and V. Le Turdu., 2005].

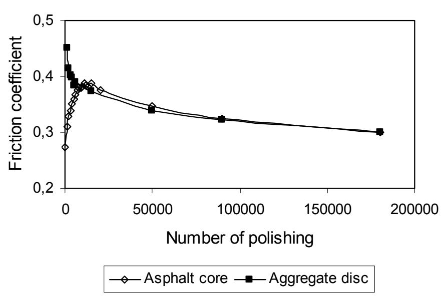

FIG. 2. Friction coefficient evolutions simulated by WS machine of asphalt and aggregate

In this paper, the effects of asphalt and aggregates characteristics on the evolution of skid resistance are analyzed. The experimental program is based on two parts. The first one focuses on the aggregate effects whereas the second consists on studying the effect of the asphalt.

EXPERIMENTAL PROGRAM

Wehner-Schulze machine

The experimental program is based on a set of tests with the Wehner-Schulze machine. This machine contains two stations for respectively performing polishing and measuring friction (see FIG.3).

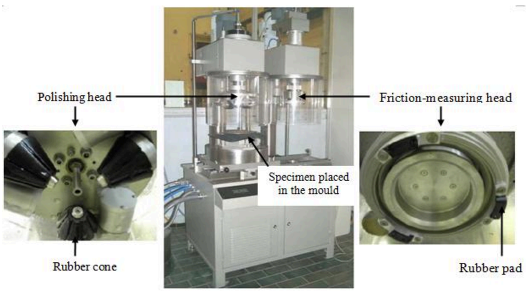

FIG. 3. Wehner-Schulze machine

The polishing station contains three rubber cones mounted on a rotary disc and rolling on the specimen surface. Test parameters of this station are:

- load on all polish cone rolls is 40kg;
- revolution of polishing head is 500 r.p.m;
- flow of abrasive water mixture is 5 l/min;
- surface is polished on a ring of roughly 16 cm diameter and 6 cm width;
- temperature of abrasive water mixture is 20°C;

The friction measuring head composes of three small rubber pads (4 cm^2 area for each pad) disposed at 120° on a rotary disc. Test parameters at measurement station of friction coefficient with friction-measuring head:

- load on all measurement rubber is 26kg;
- start velocity of measurement rubbers is 100 km/h;
- flow of water is 20 l/min;
- contact surface is 82 cm^2;
- temperature of water is 12°C;

Specimens are cores of 22.5cm diameter.

Aggregate specimens

Six types of aggregates characterized by their Polished Stone Value (PSV - see Table 1) were used in this study. The used procedure for performing the polishing process can be found in the following reference (Tang, 2007).

Circular specimens are prepared in laboratory with 7.2/10 aggregate size (see FIG.7 (b)). They are fabricated by placing manually the aggregates in a single layer as closely as possible, with their flattest faces lying on the bottom of a mould, then filling the