

Polishing Machine Based on High-Pressure Water Jet

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Abstract— The design of high pressure water jet based polishing equipment and its fabrication conducted in this study is reported herein, together with some preliminary test results for assessing its applicability for HMA surface polishing. This study also provides preliminary findings concerning the test variables, such as the rotational speed, the water jet pressure, the abrasive agent used, and the impact angel that were experimentally investigated in this study.

The preliminary findings based on four trial tests (two on large slab specimens and two on small size gyratory compacted specimens), however, indicate that both friction and texture values tend to increase with the polishing durations for two combinations of pressure and rotation speed of the rotary deck. It seems that the more polishing action the specimen is subjected to; the aggregate edges are created such that the surface texture values are increased with the accompanied increase in friction values. It may be of interest (but which is outside the scope of this study) to investigate if the similar trend exist for HMA prepared with aggregate source that is sand and gravel.

Keywords—High-pressure, water jet, Friction, Texture, Polishing, Statistical Analysis.

I. INTRODUCTION

ASPHALT pavements tend to lose friction when subjected to traffic loading and environmental effects. Pavement friction or skid resistance is defined as the ability of pavement surface to maintain traction with vehicle tires to enable efficient braking as needed, which will, in turn, reduce skid-related accidents dramatically. Pavement is mainly controlled by the surface texture and roughness including the macro and micro scales. In order to investigate the polishing and wearing processes in a laboratory setting, small accelerated polishing devices along with friction and texture measuring devices are needed to successfully complete the simulation of the interaction between pavement surface and vehicles' tires.

Most of available polishing devices can polish aggregate specimens only with specific specimen sizes. Furthermore, there is none that is compatible with the SuperPave standards; meaning no existing device can polish the SuperPave gyratory compacted specimens. Therefore, there is a need to fabricate a new accelerated polishing device that can handle asphalt specimens compacted using the SuperPave gyratory compactor, which is the main objective of this study. Additionally, with the advent of adopting the Dynamic Friction Tester and the Circular Texture Meter friction and texture measuring devices, the new machine will be manufactured to represent a companion to these two widely used pieces. This would, definitely, make the newly developed machine more comprehensive to be used for different

scenarios.

The design concept of accelerated polishing devices is usually based on the requirements of time efficient (test duration should be no longer than one day for test to be completed), testing Hoot Mix Asphalt specimens rather than just aggregate samples (thus, providing more authentic indicator of the performance of HMA in the field), ease of operation, and repeatability of test results.

In addition to mechanical polishing devices developed over the years, a completely new polishing concept using the high pressure water jet is also explored in this study. The use of high pressure water jet in polishing HMA can be traced to the work conducted jointly by the French LRPC (Laboratoire Ponts et Chaussées) and Quebec MTQ (Ministère des Transports du Québec). In their work, the machine referred to as "GRAP" was shown to achieve the polishing action by projecting a stream of water and very fine abrasive agent under pressure (around 1450 psi) with a given angle of incidence. Fig. 1 provides a photograph of the prototype machine in the laboratory. The test method is well described in [1]. The polishing concept of the GRAP polishing machine is illustrated schematically in Fig. 2. The water supply should be around 11.7 liters per minute (3 gallons per minute) to provide the required water pressure. The surface is swept by displacement of the projection nozzle due to a cross motion table. Polishing is obtained after twenty sweep cycles (2 hours and 45 minutes including preparation of specimens and friction measurements; however, the actual polishing time is 45 minutes) of rectangular shape. The machine is composed of projection housing, volumetric powder measurer, generator for water under pressure, water-abrasive projection nozzle, cross motion table, retrieval tray and electric control panel with programmable controller. Results from [1] showed that the limit polishing states achieved by the GRAP is comparable to that achieved by the Accelerated British Polishing Equipment. Reference [2] also reported similar reasonable test results from GRAP. The success reported by [1] and [2] provides an inventive idea for an independent investigation of the water jet based approach to polish HMA surface. There are studies, on the other hand, that used the same principle of high-pressure water jet to enhancing pavement surface properties rather than smoothening the surface. In general, there are number of existing methods for restoring the skid resistance of a pavement surface as an alternative to resurfacing or overlaying; most of these have focused on recycling the existing surface and removing excess binder from the surface such as mechanical retexturing, waterblasting and ultra-high-pressure watercutting. Only one of these methods, ultra-high-pressure (UHP) watercutting, is capable of restoring both the microtexture and the macrotexture on polished surfaces. Reference [3], for example, concluded that high water

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pressure retexturing can be used successfully in order to improve the texture depth of asphalt mixtures especially for coarse graded mixtures, gap graded mixtures and SMA mixtures and the effect is long lasting. It could, however, be a temporary solution when used on dense graded mixtures. Reference [4] studied the conditions that affect the performance of texture restoration utilizing ultra-high-pressure (UHP) watercutting, and concluded that the effectiveness of the UHP watercutting is variable but can be up to five years in some situations. It is stated in [5] that the initial testing of the polished sites before and after the watercutting process confirmed that watercutting a polished surface results in an increase in both macrotexture and microtexture of the surface. Also, watercutting process was found to be capable of increasing skid resistance to acceptable levels. Essentially similar results were also established by many other studies such as [6]-[8].

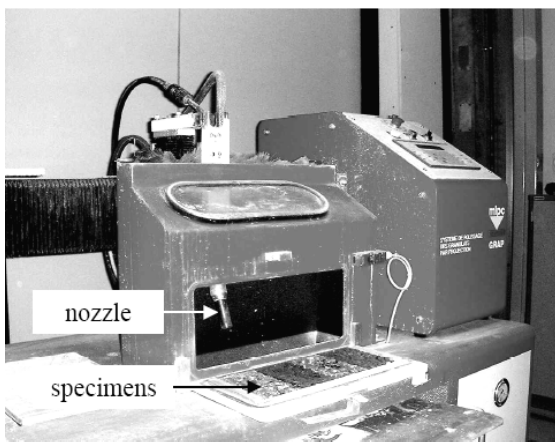


Fig. 1 GRAP polishing machine

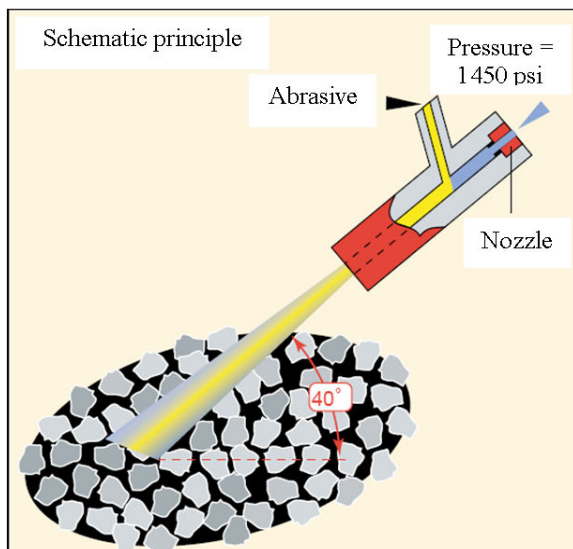


Fig. 2 Schematic depiction of GRAP polishing machine concept

The design of high pressure water jet based polishing

equipment and its fabrication conducted in this study is reported herein, together with some preliminary test results for assessing its applicability for HMA surface polishing. This study also provides preliminary findings concerning the test variables, such as the rotational speed, the water jet pressure, the abrasive agent used, and the impact angel that were experimentally investigated in this study. It is very important to note that the GRAP polishing equipment was designed to polish aggregate specimens. Specimens are 100 mm by 150 mm (4 inch by 6 inch) rectangular plates. These specimens are made of coarse aggregates of similar sizes and fixed in a resin matrix, as shown in Fig. 3. The new device developed in this study, however, aims at polishing HMA surfaces with different sizes.



Fig. 3 GRAP aggregate specimen

II. EQUIPMENT DEVELOPMENT, DESCRIPTION, AND OPERATIONAL PROCEDURE

The guiding principle of the laboratory-scale accelerated polishing equipment using high-pressure water jet is that the evolution history of friction loss of the HMA surface can be simulated and measured in realistic short test duration. The design of the polishing equipment allows for projecting high-pressure water (around 1450 psi) and fine abrasive agent onto the specimen surface at the desired angle (usually 40 degree). A picture illustrating the proposed concept of the high-pressure water jet accelerated polishing machine for HMA testing is shown in Fig. 4. It should be noted that the polishing device is designed to accommodate two specific specimen dimensions: an 18 inch by 18 inch by 2 inch high roller-compacted slab specimen or a 6 inch diameter by 4 inch high SuperPave gyratory-compacted specimen. As a result of different specimen sizes, the spray nozzle can polish different patterns (suitable for the different friction and texture measuring devices) as the rotary platform rotates different specimens with different dimensions. Therefore, the friction and texture properties of the HMA specimen surface are determined by two approaches for the two specimen sizes: (a) the dynamic friction tester and circular texture meter for 18 inch by 18 inch slab specimens, and (b) British pendulum tester and sand patch method for 6 inch in diameter gyratory compacted specimens.

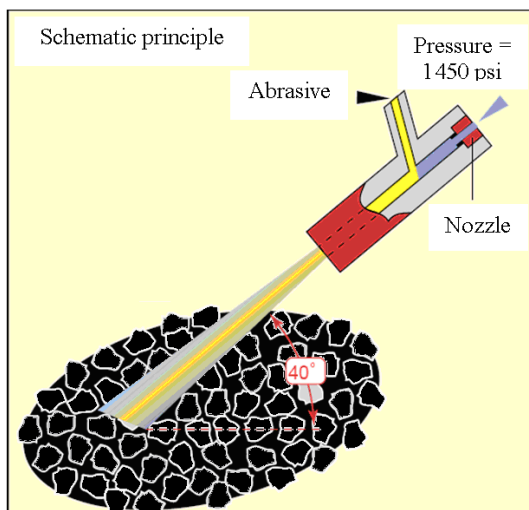


Fig. 4 Schematic depiction of the concept of the high-pressure water jet polishing machine using HMA specimens

The high pressure asphalt polisher includes the equipment components. The tester includes a tubular steel frame, approximately 77 inch by 52 inch by 32 inch high, to support a drum deck and a top deck. A rotary deck is inside the drum. The top deck is double hinged which allows the deck to be lifted for access to the rotary deck. The test specimens are placed and registered on the rotary deck for testing. The rotary deck is inside a 45.5 inch diameter cylindrical drum that is used to help contain the water and debris spray. The water spray nozzle is hosed inside the protection drum. Floor levelers with antiskid pads are included for positioning the machine. A winch type system is used to raise and lower the samples onto the rotary deck. The polisher is equipped with a high pressure pump/5HP motor assembly, rated for 2000 PSI max, and set at approximately 1450 PSI with 11.7 liters per minute (3.0 gallons per minute) of water flow. The water pressure can be adjusted through a pressure gage. A nozzle which sprays a 2 inch minimum fan type pattern and draws grit into the spray is used. The nozzle is supported in such a way that it can be adjusted for use for either the 18 inch square specimen or the 6 inch in diameter specimen. A 56.7 liter (15 gallon) grit tank and grit suction system is provided as well. The amount of grit mixed into the flow can be adjusted as needed. An auxiliary spray nozzle is provided to washout residual grit from the tank. A 2 inch NPT drain with fittings and a 2 inch hose are designed and fabricated to drain water from the drum. A 1/2 HP variable speed drive motor with a gear reducer is used to rotate the rotary deck at a speed of approximately 10 rpm. The speed can be varied between approximately 6 to 16 rpm. Electrical circuit box housing: Emergency-Stop, On Push Button for the sample rotation and the pump, and Time Meter is provided. A motor drive to control the motor speed is also included.

A photograph of the completely fabricated accelerated polishing device using high-pressure water jet with all components labeled is shown in Fig. 5. The photograph of the

drum (chamber) used to hold either specimen size (18 inch by 18 inch by 2 inch high roller-compacted slab specimen or 6 inch diameter by 4 inch high Superpave gyratory-compacted specimen) is shown in Fig. 6. The close up view of the specimens of the two sizes being subjected to high pressure water jet polishing is shown in Figs. 7 and 8, respectively.

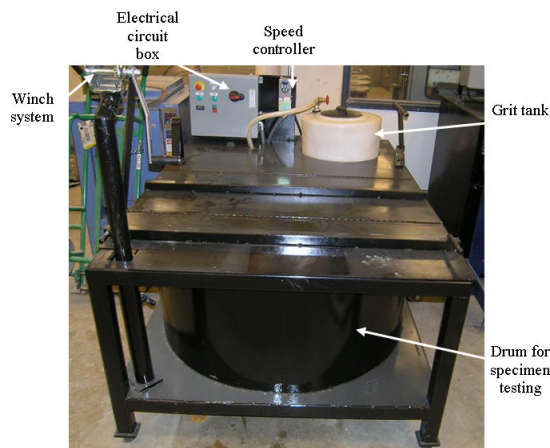


Fig. 5 Overall view of the accelerated polishing machine using high-pressure water



Fig. 6 Drum (chamber) for placing the test specimen



Fig. 7 Details on slab specimen mounting in the drum



Fig. 8 Details on gyratory compacted specimen mounting in the drum

III. EQUIPMENT CHARACTERISTICS AND VALIDATION

In this section, the investigation results of using the developed polisher to polish HMA surface are presented.

A. Materials

In the evaluation study of the developed polishing device, a limestone aggregate source and the asphalt binder grade (PG 70-22) were used to compact the roller-compacted slab specimens or the Superpave gyratory-compacted 6 inch specimens. The gradation curve of the aggregate used for HMA is shown in Fig. 9. The optimum binder content of 5.9% used for compacting the HMA specimens was determined using the Marshall Mix Design method.

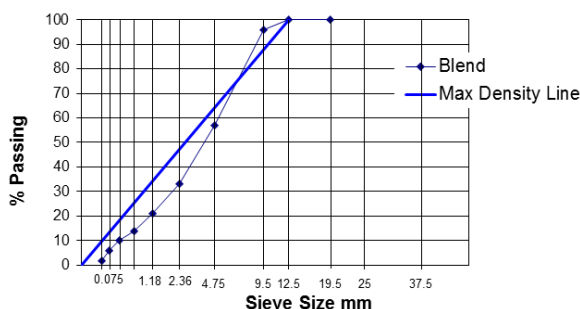


Fig. 9 Aggregate gradation curve

B. Sample Preparation Procedure for HMA Specimens

The mixing procedure of the loose mix is as follows. First, the aggregates are separated by dry sieving into the desired sizes using the mechanical shaker. The aggregates are then washed and heated to about 330°F. Aggregates are weighed and blended according to the gradation curve shown in Fig. 9. The weighed aggregate mix is then put in the oven at 330°F for 3 hours for achieving a uniform aggregate temperature. The mixing bowl and the mixing paddle are also heated to 300°F. The asphalt binder is heated in the oven at a temperature of 350°F for 2-3 hours. At this point, the aggregate is placed in the mixing bowl and blended quickly with the asphalt binder until a uniform blending is obtained.

The gyratory compactor is used to compact the loose mix into a 6-inch cylindrical specimen, while a roller compactor is used to compact the loose mix into an 18 inch by 18 inch by 2

inch slab specimen.

C. Friction and Surface Texture Measurements

Different types of measuring techniques are used to measure friction and texture of the HMA surface for the two types of specimen sizes. For the 18 inch by 18 inch by 2 inch roller-compacted specimens, the dynamic friction tester [9] and the circular texture meter [10] are used for measuring friction and texture, respectively. For the 6 inch cylindrical gyratory-compacted HMA specimens, the British Pendulum Tester [11] and the sand patch method [12] are used for measuring friction and surface texture, respectively.

D. Work Plan

The work conducted in the development stage of the high pressure water jet based accelerated polishing machine included the polishing of laboratory prepared HMA specimens (i.e., roller-compacted HMA specimens and gyratory-compacted HMA specimens) at variable rotational speed of the rotary deck housed inside the protection drum. Also, the water pressure varied in the work plan. The water jet that impacts onto the specimen surface is set at an angle of 40 degree to the horizontal specimen surface. The fine grit was used. A summary of the trial test program designed to investigate the feasibility of the developed machine is shown in Table I.

TABLE I
WORK PLAN SUMMARY OF THE LABORATORY WORK

Slab Specimens		
Trial No.	Rotation Speed (rpm)	Water Pressure (psi)
1	10	1450
2	10	400
6 inch specimens		
Trial No.	Rotation Speed (rpm)	Water Pressure (psi)
3	10	1000
4	10	500

IV. RESULTS AND DISCUSSION

The polishing effect of the accelerated polishing machine is examined in this section.

For the HMA slab specimens made with limestone aggregate, the friction values (FN) obtained from the DFT at different measuring speeds versus the polishing duration for the trial number one (10 rpm rotation speed and 1450 psi of water pressure) are shown in Fig. 10. For the same test (Trial No. 1), the MPD measured by the CTM is plotted versus duration of polishing in Fig. 11. It can be seen from Fig. 10 that friction increases with polishing duration. Corresponding to the friction increase, there is a similar trend of MPD increase with polishing duration as well. This polishing behavior is opposite to what is expected. A similar trend is observed for trial number two (10 rpm rotation speed and 400 psi of water pressure) when the slab specimen was tested. Figs. 12 and 13 show the increasing trend of both friction and texture values with the polishing duration for trial number 2 test results.

For the 6 inch HMA gyratory-compacted specimens made

with limestone aggregate, the friction values (BPN) obtained from the BPT and the MTD measured by the sand patch method when the rotation speed was 10 rpm and the water pressure was 1000 psi (trial number 3) are plotted against the polishing duration in Figs. 14 and 15, respectively. It can be seen that both the friction values and the MTD increase as the polishing duration increases.

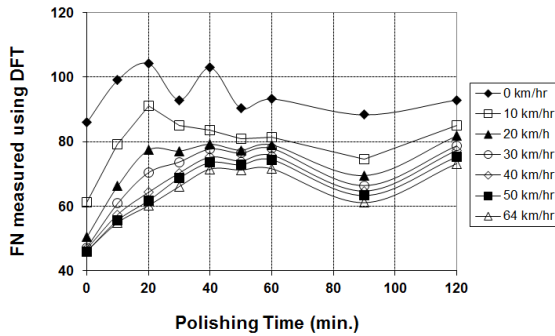


Fig. 10 Friction values for trial number 1 (at 10 rpm and 1450 psi) at different speeds

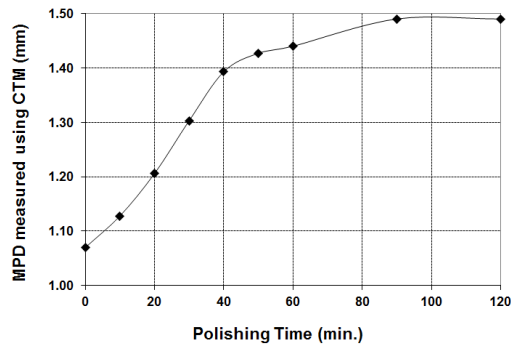


Fig. 11 MPD trend for Trial number 1 (at 10 rpm and 1450 psi)

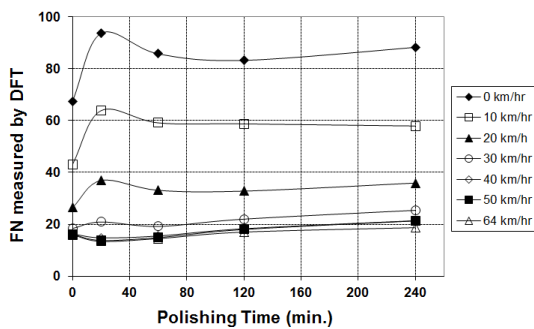


Fig. 12 Friction values for trial number 2 (at 10 rpm and 400 psi) at different speeds

The test results of HMA specimens at 10-rpm rotation speed and the water pressure of 500 psi (trial number 4) are shown in Figs. 16 and 17. The similar trend as trial number 3 is observed. Furthermore, one can see that the polishing behavior for large slab specimens and gyratory-compacted specimens is similar.

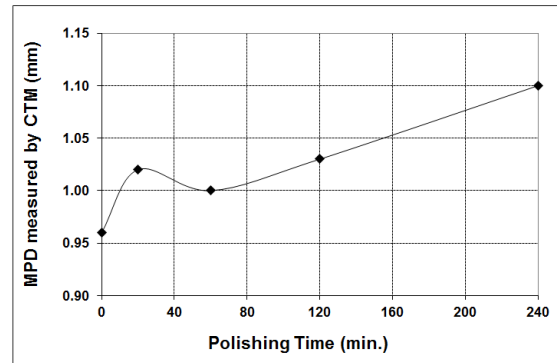


Fig. 13 MPD trend for trial number 2 (at 10 rpm and 400 psi)

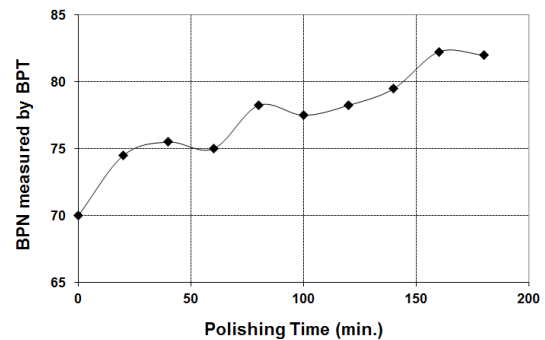


Fig. 14 Friction values of trial number 3 (at 10 rpm 1000 psi)

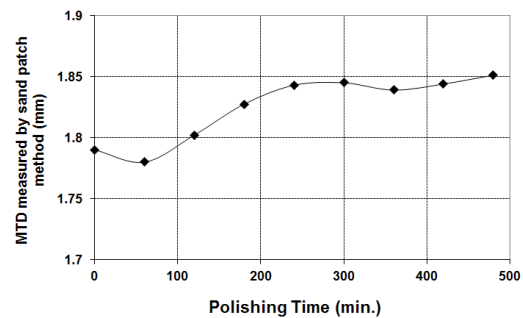


Fig. 15 MTD trend for trial number 3 (at 10 rpm 1000 psi)

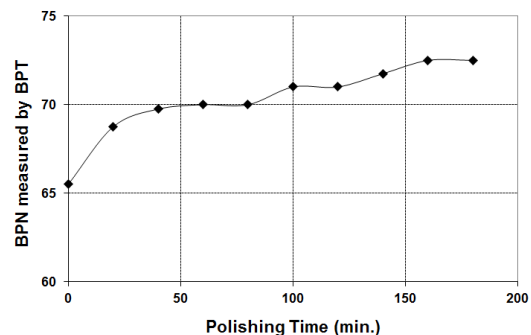


Fig. 16 Friction values for trial number 4 (at 10 rpm 500 psi)

The photographs of the tested HMA specimens are presented in Figs. 18 and 19 for the roller-compacted and gyratory-compacted specimens, respectively. It is strikingly

clear that high pressure water jet appears to have the effect of rejuvenate and renew the surface such that there is the accompanied improvement of friction values.

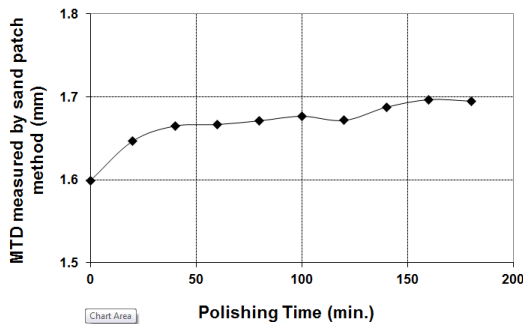


Fig. 17 MTD trend for trial number 4 (at 10 rpm 500 psi)



Fig. 18 Tested HMA roller-compacted slab specimen surface



Fig. 19 Tested HMA gyratory-compacted specimen surface

V. CONCLUSION

Presented in this chapter is the development of an accelerated laboratory-scale polishing machine using the concept of high-pressure water jet to polish HMA surface in a short duration, with the intention to use this equipment for screening the aggregate source and mix design formula to

ensure adequate friction (or skid resistance) of the HMA over the expected life span of the pavement surface. The accelerated polishing machine is designed such that it is capable of testing two different sizes of HMA specimens: 18 inch by 18 inch by 2 inch high slab specimens compacted using the roller compactor and 6 inch diameter and 4 inch high gyratory-compacted HMA specimens. The design principles of the testing device, together with the evaluation results of the capability of the developed polishing machine to simulate the real polishing action, are described in detail in this study.

The preliminary findings based on four trial tests (two on large slab specimens and two on small size gyratory compacted specimens), however, indicate that both friction and texture values tend to increase with the polishing durations for two combinations of pressure and rotation speed of the rotary deck. It seems that the more polishing action the specimen is subjected to; the aggregate edges are created such that the surface texture values are increased with the accompanied increase in friction values. It may be of interest (but which is outside the scope of this study) to investigate if the similar trend exist for HMA prepared with aggregate source that is sand and gravel.

One interesting side effect from the finding observed in this study is the concept of using controlled high pressure water jet to rejuvenate (create) the desirable rough surface texture for restoring the surface friction of those worn surface course made of limestone aggregates. If this found to be technically feasible to carry out in the field with confirmed friction restoration benefit, then it can be used to improve the friction of the existing asphalt pavement surface, rather than the conventional approach of resurfacing or reconstructing the pavement surface course. A substantial cost saving can be realized in this approach of using high pressure water jet in maintaining or improving surface friction.

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