Evaluation of the effect of diamond grinding and grooving on surface characteristics of concrete pavements

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ABSTRACT

Providing a smooth, safe, and quite riding surface is an ultimate goal for pavement engineers. To achieve this goal a balance between high friction level and low roughness and noise level is made. Diamond grinding and grooving is one of the techniques that can be used to improve pavement smoothness while increasing the drivers' safety by improving the frictional properties of the riding surface.

This paper evaluates the effect of diamond grinding and grooving on various surface characteristics of concrete pavements. Measurements for texture, friction, and smoothness have been collected on two continuously reinforced concrete pavements at the Virginia Smart Road. One of the sections was diamond grinded and longitudinally grooved while the other section was transversely tinned.

The results of the study show that diamond grinding and grooving increases the surface macrotexture which helps in improving the surface friction. Friction was measured using both smooth tire and ribbed tire locked wheel trailers. Smooth tire measurements confirmed that diamond grinding and grooving increases the friction, however, ribbed tire skid trailer did not show this effect. Several single spot laser profilers and a SURPRO reference profiler were used to measure the surface smoothness before and after grinding and grooving. Longitudinal grooving made the single spot laser profilers incapable of measuring the correct road profile. Power Spectral Density (PSD) analysis revealed that longitudinal grooving introduces artificial wavelengths in the profiles collected by single spot laser profilers. According to the reference profiler results, the smoothness of the concrete surface was increased after it was subjected to diamond grinding and grooving.

INTRODUCTION

Diamond grooving is a techniques that is used in order to improve the frictional properties of the pavement surfaces (*1*). Most of the developments in diamond grinding and grooving occurred in the state of California in the early 1960s (*2*). The main purpose of this practice was to restore the skid resistance of old concrete pavements (*2*). Friction of the pavement surface is an important factor contributing to road safety. Each year many people around the United States (U.S.) lose their lives as a result of car crashes. Due to the importance of friction in reducing the rate of car crashes, the Federal Highway administration (FHWA) has started to implement new policies that require the state Departments of Transportation (DOTs) to implement highway safety programs. Diamond grinding and grooving can be a good option for state DOTs to restore the frictional properties of old concrete pavement in their road network.

Along with friction, roadway smoothness is an important surface characteristic that affects the ride quality, operation cost, and vehicle dynamics. Currently, most state DOTs use laser inertial profilers to measure the road roughness. Measurements are summarized using the International Roughness Index (IRI) which was developed by National Cooperative Highway Research Program (NCHRP) and World Bank. Smoothness measurements can be used to evaluate the ride quality of existing road networks or as a quality check for newly constructed pavements. Due to the importance of ride quality to the road users, highway agencies have implemented smoothness based specification for newly constructed as well as rehabilitated pavements. The smoothness specification identifies an acceptable range of smoothness that the contractor must achieve to obtain full payment. All highway agencies assess penalties if the achieved smoothness is less than specified, while many highway agencies give bonuses to contractors who achieve a smoothness level that is higher than the specified level. Diamond grinding and grooving is one of the methods which can be used to improve the smoothness of both old and new pavement surfaces.

OBJECTIVE

The objective of this paper is to evaluate the effect of diamond grinding and grooving on surface characteristics of concrete pavement. In particular, the paper investigates the changes in macrotexture, friction, and smoothness of a tinned concrete pavement subjected to diamond grinding and longitudinal grooving. Measurements for this study were collected at the Virginia Smart Road during the 2010 and 2011 annual equipment round up (Rodeo 2010 & 2011).

BACKGROUND

One of the main goals of pavement engineers is to provide a smooth, safe and quiet riding surface for road users. In order to achieve this goal, a balance should be made between high level of friction and low level of smoothness and noise. Both, friction and noise are affected by pavement macrotexture. High macrotexture improves road safety by increasing the draining properties of the road surface. It also helps reducing the tire-pavement noise level (*3*). Several devices are available for measuring friction. Most state DOTs in the U.S. currently use the locked wheel friction trailer. The trailer can measure the longitudinal friction in fully locked condition (100% slip). Because Most of skidding accidents happen during wet weather condition due to friction deficiencies (*4*), the device is equipped with a water distribution system that sprays water in front of the tire during the test so it can measure the wet friction.

From the functional point of view, smoothness is an important roadway performance indicator since road users primarily judge the quality of a road based on its roughness and/or ride quality. According to the national highway user survey (1995 and 2000) (*5*), pavement roughness/ride quality was rated as one of the top three principal measures of public satisfaction within a road system. Earlier studies (*6*) have shown that rough roads lead to user discomfort, increased travel time due to lower speeds and higher vehicle operating cost. As such, road roughness is now widely recognized as one of the principal measures of pavement performance. Different techniques are available for measuring road smoothness, most of which measure the vertical deviations of the road surface along a longitudinal line of travel in a wheel path, known as a profile (*7*). Traditionally, the profilograph has been used to measure the smoothness of road pavements. The profile recorded by the profilograph is analyzed to determine the profile index (PI), which is the smoothness index that is used to judge the ride quality of the pavement. However, several inherent weaknesses were observed in the profilograph and PI for judging the ride quality of a pavement, and hence many state highway agencies have instead adopted the International Roughness Index (IRI) as the ride quality parameter for assessing the smoothness of new/rehabilitated pavements. Inertial profilers is used to obtain profile data to compute the IRI (*8*).

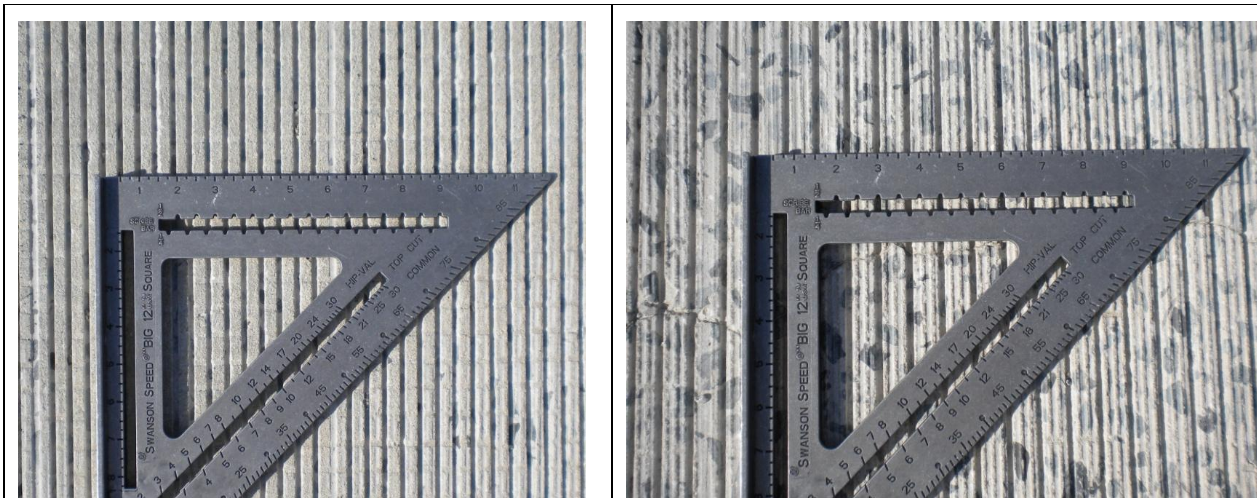
Diamond grinding and grooving is one of the rehabilitation practices that can be used on old concrete pavements in order to make the surface smoother. The method uses diamond infused steel cutting blades for grinding and grooving concrete pavement. For grinding, the blades are spaced close together so that they can cut the pavement's unevenness (megatexture) and leave a rough pavement surface (high microtexture). For grinding, the blades are further spaced out so they create channels on the pavement surface (high macrotexture). Diamond grooving is mainly used for new concrete pavement to texture the pavement which increases the friction by improving water drainage (*9*).

Several studies have recently been performed to investigate the effect of diamond grinding and grooving on the noise level of pavements. Research has shown that longitudinal diamond grinding is one of the quietest types of surface finishing for concrete pavement (*10*). In the U.S. most of the grooving on highways are longitudinal while transverse grooving is more common for runways (*1*).

DATA COLLECTION

The data for this study was collected at the Virginia Smart Road during the annual equipment roundup (Rodeo) in two consecutive years; 2010 and 2011. The Virginia Smart Road provides a 3.2 km (2 mi) controlled test track available for transportation research. The road consists of two lanes and it has various types of pavement surfaces. Each year several sate DOTs meet at the Virginia Smart Road with the purpose of equipment comparison on the available surfaces. This event is called the annual equipment Rodeo.

The road has three continuously reinforced concrete sections on both east-bound and west-bound directions that are transversely tinned. These sections were originally built and tinned in 1999, at the time when the Smart Road was constructed. In order to evaluate the effect of diamond grinding and grooving on Portland Cement Concrete (PCC) pavements, one of the sections located along the west-bound direction was ground and longitudinally grooved by International Grooving and Grinding Association (IGGA) in January 2011. The procedure included a Conventional Diamond Ground (CDG) followed by longitudinal grooving. Two different groove spacing were used for each half of the lane; ½ inch along the left wheel path and ¾ inch along the right wheel path (*11*). FIGURE 1 illustrates the close up of grooving on the PCC section.



(a) PCC left wheel path, ½ - inch groove spacing.

(b) PCC right wheel path, ¾ - inch groove spacing.

FIGURE 1 Grooving on PCC section.

To evaluate the effect of diamond grinding and grooving on surface properties, several measurements for texture, friction and smoothness were collected. The various tests used to measure the surface properties are explained below.

Texture

Texture measurements were obtained using the ASTM E-2157 CTMeter. This static device has a displacement sensor mounted on an arm at a radius of 142 mm (5.6 in) which rotates at a fixed elevation from the surface. The device reports the Mean Profile Depth (MPD) and Root Mean Square (RMS) according to ASTM E-2157 standard.

In order to determine the effect of diamond grinding and grooving on surface macrotexture, measurements were collected on both tinned and grooved PCC. The tinned PCC section is located along the east-bound lane while the grooved section is located along west-bound lane. All the measurements for both sections were collected in the left wheel path and overall three sets of measurements were obtained for each section. TABLE 1 shows the macrotexture data for each test section.

TABLE 1 Macrotexture Measurements Using CT-Meter

Section type	# of Measurements	Average MPD (mm)
Original tinned PCC	3	0.38
Diamond ground and grooved PCC	3	2.14

From the results of TABLE 1, it can be seen that diamond grinding and grooving has significantly increased the macrotexture of the PCC pavement (higher MPD). This high macrotexture can improve the skid resistance of the surface by significantly reducing the effect of hydroplaning.

Friction

Friction measurements were obtained using two locked-wheel skid trailers. One of the locked wheels used the ASTM E-524 smooth test tire while the other used the ASTM E-501 ribbed tire. Five sets of measurements were obtained on both original tinned and grooved PCC at three speeds; 25, 40, and 55 mph. All measurements were collect during Rodeo 2011. FIGURE 2 shows the layout of the test sections. The summary of the locked wheel measurements is presented in TABLE 2.

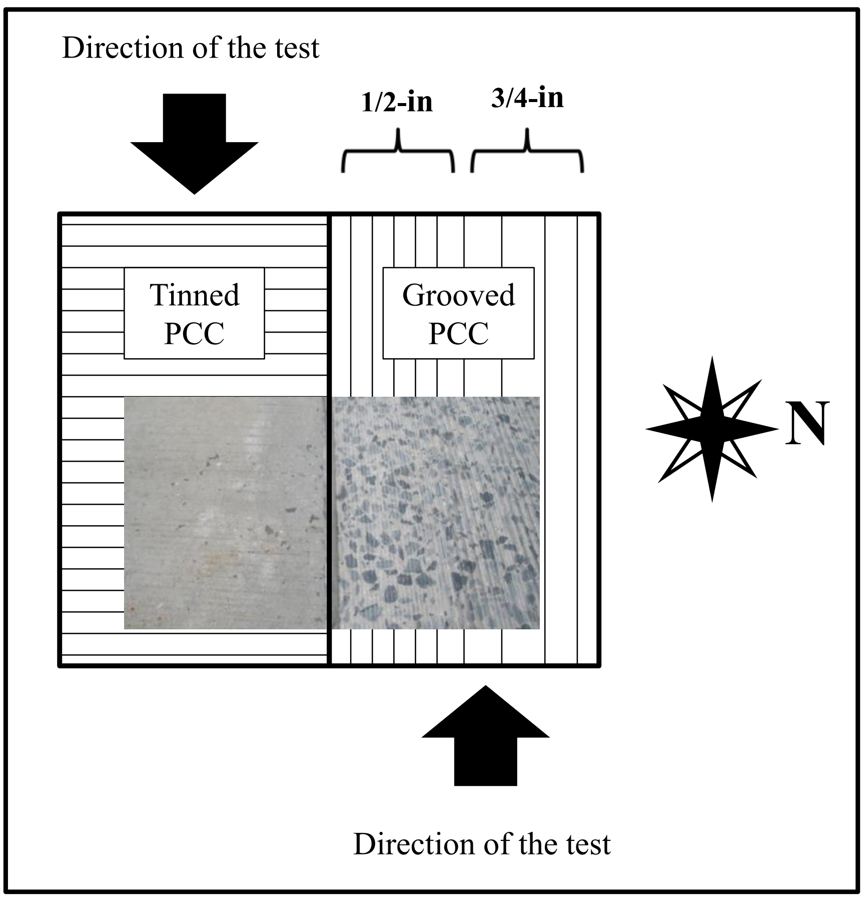


FIGURE 2 Test sections layout.

TABLE 2 Summary of Locked Wheel Skid Trailer Measurements

Unit #	Test tire	Test section	Test speed mph)	# measurements	Average skid number
1	Smooth	Original Tinned PCC	25	5	51.23
			40	5	36.60
			55	5	28.65
		Grooved PCC	25	5	58.90
			40	5	56.07
			55	5	44.97
2	Ribbed	Original Tinned PCC	25	5	67.77
			40	5	64.07
			55	5	53.10
		Grooved PCC	25	5	62.23
			40	5	59.65
			55	5	48.82

Smoothness

For smoothness assessment, longitudinal profile measurements were made before- & after-diamond grinding and longitudinal grooving was performed. The tested section was 528 feet long, and the wheel-path was marked every 10 feet with paint so that the operators could align the profilers when traveling at the required speed off 50 mph. The paintings would also help reduce possible wandering away from the wheel-path followed by the profilers (*12*). The left and right wheel paths were marked 34.5 inches from the center line. The test section also had paint-marked lead-in 150 feet apart starting going over a one-inch high electrical rubber cable cord protector that was placed as an artificial bump to indicate the start of the lead-in section. The bump produces a spike in the profiles measurements which would make it possible to determine the exact location of the test section (*13*).

Several high-speed inertial profilers participated in this study and prior to testing, all devices were subjected to block and bounce tests in order to calibrate their height sensors and accelerometers. For reference comparisons, an inclinometer-based ICC SURPRO walking-profiler was used. All the profiles were collected using the procedures mentioned in AASHTO PP-49: "Standards for Certification Inertial Profiling Systems" (*14*). TABLE 3 is a list of the profilers’ manufacturers, sensor types and the sampling intervals of all the profilers that participated in study conducted as part of Rodeo in 2010 and 2011 respectively.

TABLE 3 Summary of the Profiler Tests

Profiler unit	Manufacturer	Sensor type	Data Recording Interval	
			Rodeo - 2010	Rodeo - 2011
Unit 1	Dynatest	Single spot laser	1.00"	1.00"
Unit 2	Dynatest		0.998"	1.00"
Unit 3	ICC		1.248"	1.21"
Unit 4	ICC		3.1"	3.06"
SURPRO	ICC	Inclinometer	1.00"	1.00"

DATA ANALYSIS

Effect of Diamond Grinding and Grooving on Frictional Properties of PCC

In order to evaluate the frictional properties of the tested surfaces, the correlation between skid number and the test speed was calculated. In a previous study, the authors found a statistically significant linear relationship between skid number and speed of the test vehicle for the range of speeds from 20 to 60 mph (*15*). To verify that, test on the hypothesis of slope were conducted on the measurements. The null hypothesis for the test (H_0) is that there is no relationship between skid number and speed (slope = 0). Rejection of the null hypothesis indicates that there is a linear relationship between the two parameters (*16*). The analysis was done using the SAS software. 95% level of confidence was used for the test ($\alpha = 0.05$). The null hypothesis would be rejected if the p-value of the test is less than α. After conducting the test; all the possible linear correlations between skid numbers and speed were found to be significant with P-value less than 0.0001.

Once the linear relationship between skid number and speed was found to be significant, linear correlations were made for all measurements (FIGURE 3). Several observations can be made. Smooth tires results show a significant increase in the skid numbers of the concrete section subjected to diamond grinding and grooving. This agrees with the higher measured macrotexture achieved on concrete after grinding and grooving. Another interesting observation for smooth tires is the slope of the correlation line between skid number and speed for the sections. This slope is lower for ground and grooved PCC than it is for tinned PCC which suggests that friction is less sensitive to the changes of speed for this section. At lower speeds (25 mph) smooth tires measurements for both sections seem to be relatively close, however, at high speeds the difference is much more evident (40 & 55 mph). In general, the effect of hydroplaning is more pronounced at higher speeds; since the grooved section has a higher macrotexture, it is less sensitive to hydroplaning and consequently provides higher friction in high speeds.

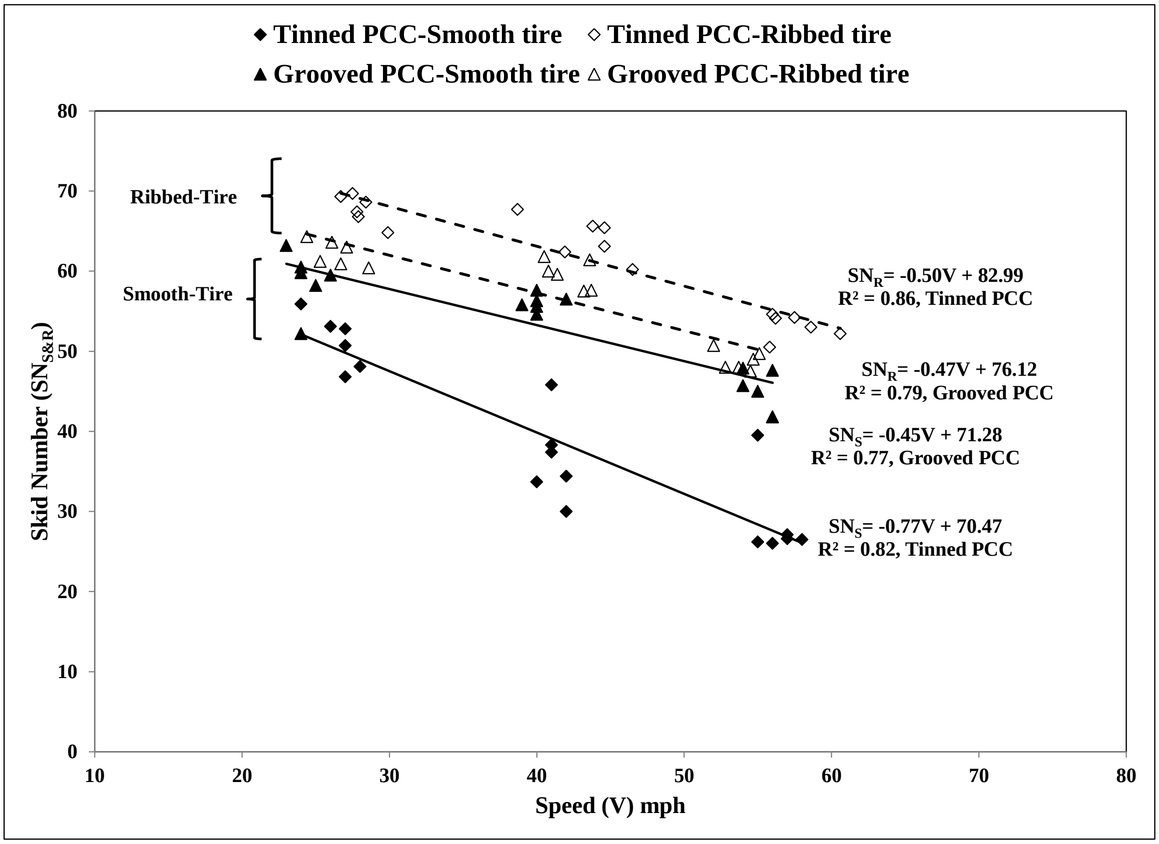
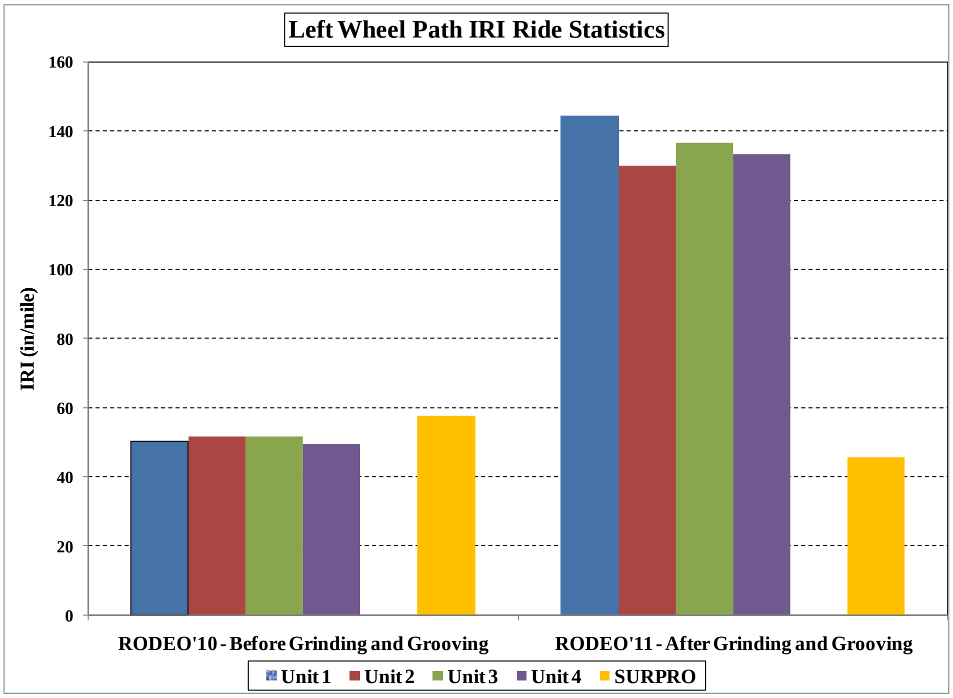


FIGURE 3 Correlation between skid number and speed.

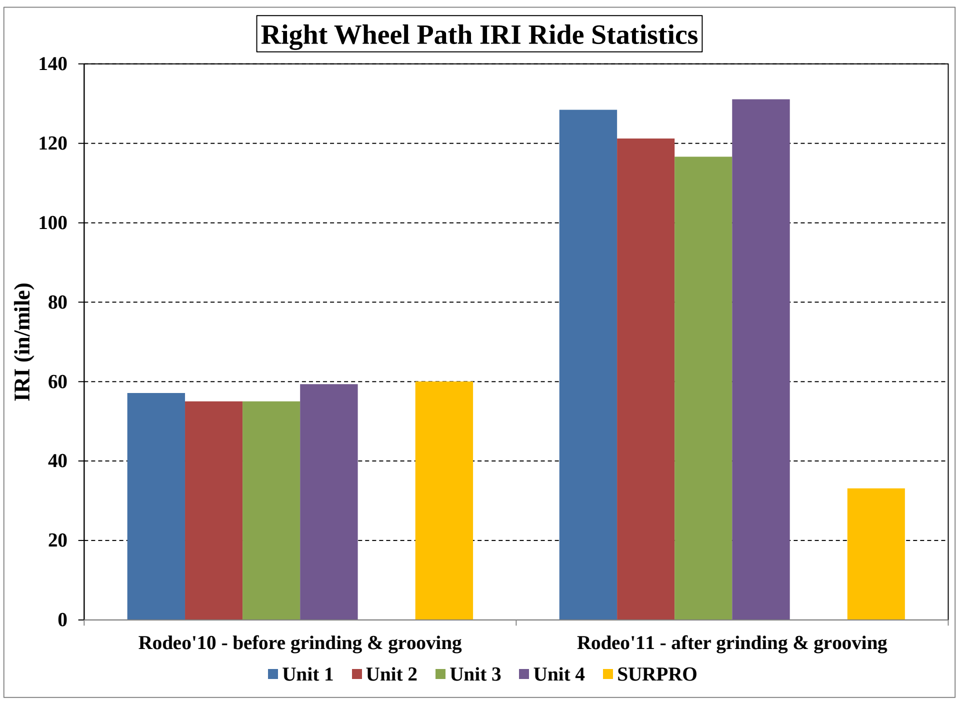
Ribbed tires results on the other hand do not show a significant difference in the skid values collected on the two test surfaces. The sensitivity of friction to speed is similar for both tinned and grooved test sections (parallel slopes). It is surprising that the ribbed tires skid numbers are slightly higher for tinned PCC than the grooved PCC. This seeming paradox between smooth tire and ribbed tire results might be explained by sensitivity of the test tire to the pavement surface texture and surface condition. Smooth tires are more sensitive to macrotexture while ribbed tires are more sensitive to microtexture. It can therefore be postulated that tinned PCC has a higher microtexture while grooved concrete has a higher macrotexture. Since the difference between ribbed tire measurements for the two types of PCC surfaces is not significant, grooved concrete is a preferred choice for pavement surface as it prevents hydroplaning at high speeds because it increases macrotexture. The lack of sensitivity of ribbed tires to the effect of macrotexture has been cited by other researches (*4*). There are evidences showing that pavement grooving significantly decrease the rate of wet-weather accidents; however, ribbed tires fail to show this effect. For that reason some researchers believe that smooth tires are a better choice for predicting skidding potentials (*4*).

Effect of diamond grinding and grooving on smoothness of PCC

In order to evaluate the effect of the diamond grinding and longitudinal grooving on the smoothness of PCC section, the IRI values of the profiles were computed using ProVAL. All IRI computations in ProVAL applied a 250 mm moving average filter. The IRI results from all the profilers on before- & after- diamond ground and longitudinally grooved PCC section is shown in FIGURE 4.



(a) Left wheel path IRI ride statistics.



(b) Right wheel path IRI ride statistics.

FIGURE 4 IRI ride statistics for PCC before- & after- diamond grinding and grooving

As expected, the SURPRO IRI measurements on ground and grooved PCC section were found to be lower than the transversely tined PCC section. On the other hand, a significant increase in the average IRI values was observed for profiles collected by the single spot laser profilers on PCC section after it was subjected to diamond grinding and longitudinal grooving. This is mainly caused by the wander of the inertial profiler as it travels along the road.

FIGURE 5 shows the continuous roughness plots for profile collected by Unit 2 on the left wheel path of diamond ground and longitudinally grooved PCC section against the corresponding SURPRO profile. The plot shows that there are significant differences in the roughness distribution among the profiles collected by the single spot laser profilers compared to the reference instrument. This difference is caused by the presence of longitudinal grooves on the pavement surface, which causes the height-sensor of the single spot laser profiler unit to obtain measurements at the bottom of the groove as well as on the pavement surface because of lateral wander.

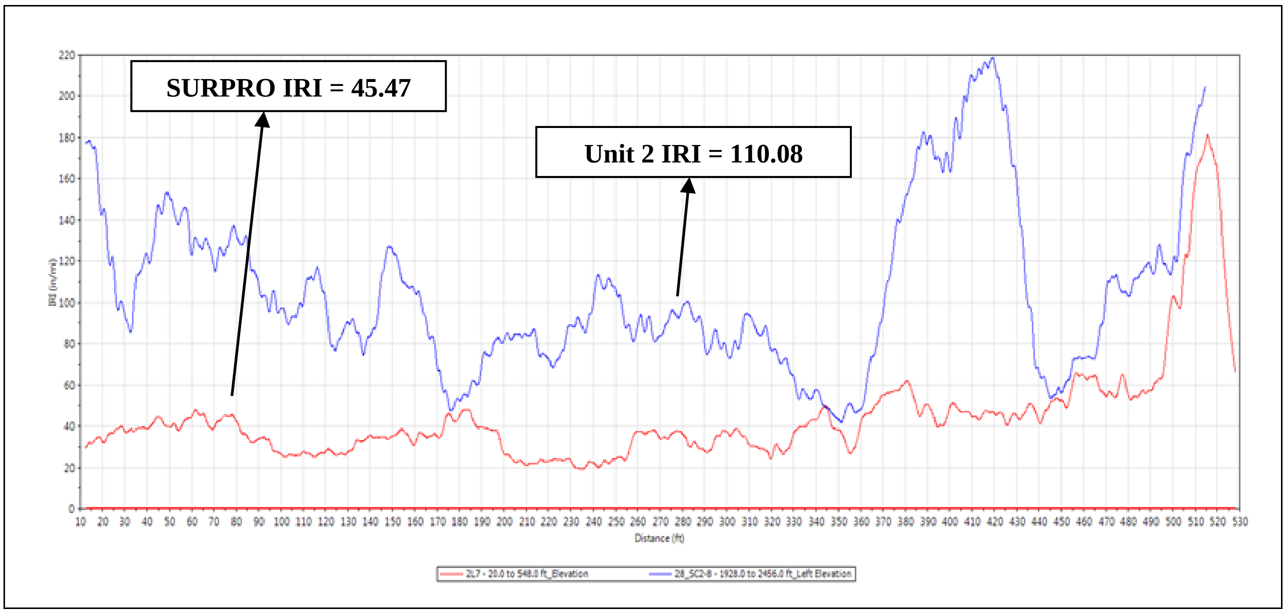
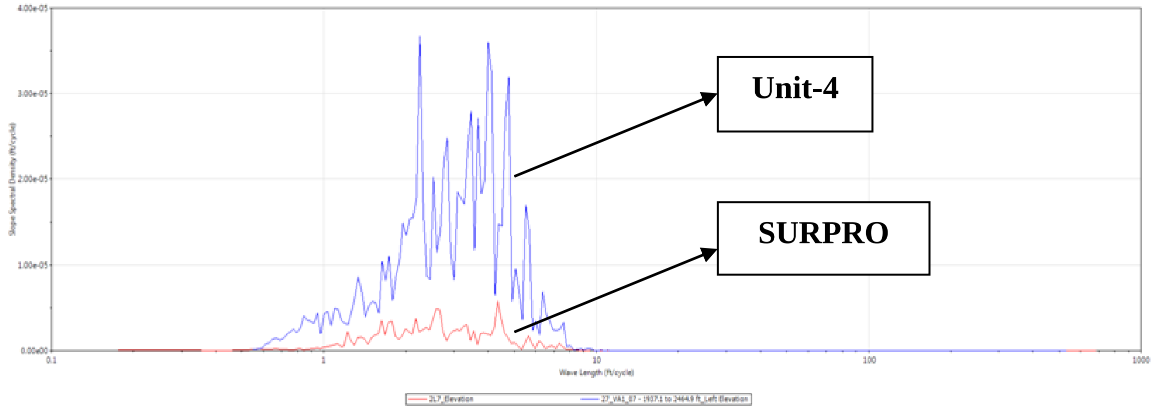


FIGURE 5 Continuous roughness distribution profile of Unit-2 and SURPRO on ground and grooved PCC section [Base-length = 25 feet].

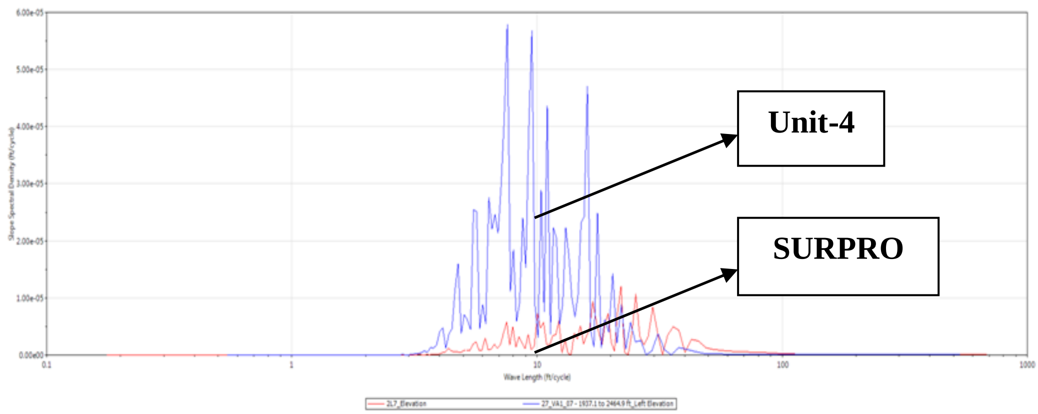
In order to examine how the presence of diamond grounded texture and longitudinal grooves contaminate the profile data collected by single-spot profilers, the Power Spectral Density (PSD) (*7*) analysis of the participant profile slopes and the reference profile slopes over different wavebands (long, short and medium) was carried out. The prominent wavelengths present in the profile produce marked spikes in the PSD plots.

FIGURE 6 show that there is very poor agreement between the participant profile and the reference profile at short, medium and long wavebands respectively. Since IRI is most sensitive in the wavelength range of 4 to 100 feet (*6*), the participant profiles produced IRI that were significantly higher than that measured by reference instrument.

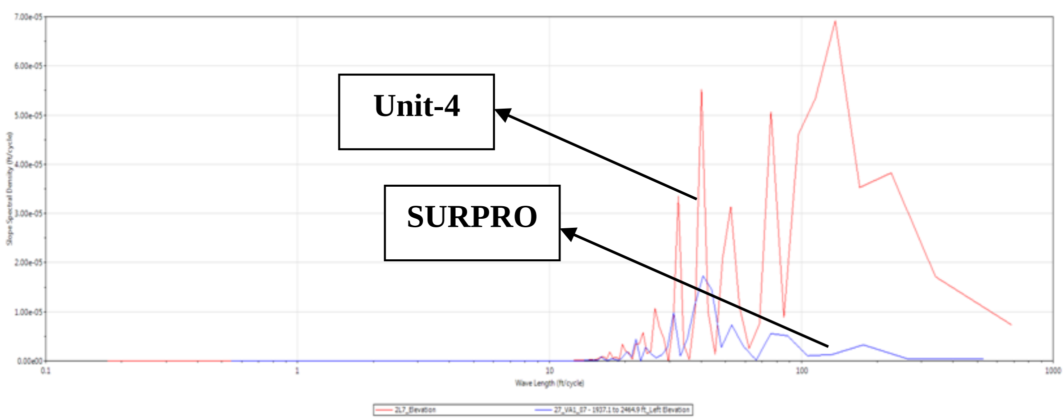


(a)

PSD plot for profiles passed through high-pass cutoff wavelength of 5.25 feet.



(b) PSD plot for profiles passed through high-pass cutoff wavelength of 26.2 feet and low-pass cutoff wavelength 5.25 feet.



(c) PSD plot for profiles passed through high-pass cutoff wavelength of 131.2 feet and low-pass cutoff wavelength 26.2 feet.

FIGURE 6 PSD plots of Unit-4 and SURPRO profile for short, medium and long wavebands.

The difference in PSD is attributed to the presence of the diamond ground texture and the longitudinal grooves on PCC section which resulted in incorrect recording of the profile data by the single-spot sensors of the participant units which introduced artificial wavelengths in the profile and over-estimating the IRI values higher than the 'true' IRI of the pavement section measured by the reference profiler.

FINDINGS AND CONCLUSIONS

The paper investigated the effect of diamond grinding and grooving on the surface characteristics of PCC. Improvements in macrotexture, friction, and smoothness for a PCC pavement subjected to diamond grinding and grooving was evaluated. Following is the summary of the findings and conclusions of the study:

- Diamond grinding and grooving has significantly increased the macrotexture of the PCC surface. High macrotexture can help in removing the water from the pavement surface which can cause hydroplaning and skidding problems during wet weather condition.
- Friction measurements revealed that the friction has increased after applying diamond grinding and grooving to the PCC surface, especially when using the smooth tire. This effect was found to be more significant in higher speeds.
- Ribbed tires skid trailers results did not show a significant difference in friction measurements on ground and grooved PCC compared to tinned PCC. This was expected, since ribbed tire measurements are not very sensitive to pavement macrotexture. This finding is in agreement with other studies that have cited that pavement grooving can help reducing the rate of wet crashes but ribbed tire skid trailers are incapable of showing this effect.
- SURPRO reference profiler results show a decrease in IRI values on the PCC surface after grooving. The improvement in smoothness was more substantial on the right wheel path with ¾ inches grooving compared to the left wheel path with ½ inches grooves.
- Compared to the reference profiler, single spot laser profilers over-predicted the IRI values on the ground and grooved PCC. This disagreement is due to grooves on the section, which makes the single spot profilers incapable to measure the correct profile. PSD analysis confirmed the presence of artificial wavelengths in the profiles collected by single spot laser profiler which is due to the longitudinal grooving.

The authors recommend using multi-footprint profiling systems in future research on pavement with longitudinal grooves to compare their performance to single spot laser profilers.

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