Long Term Skid Resistance of Exposed Aggregate Concrete Pavement

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ABSTRACT: Exposed aggregate and transverse tining concrete pavement have gained their popularity due to improvement of skid resistance. At early age, transverse tining concrete surface provided a better skid resistance than exposed aggregate surface. Transverse tining surface is composed of both binder and aggregate, however, cement binder is not durable as aggregate. Thus, skid resistance may be reduced due to the loss of cement binder when pavement ages. Additionally, aggregate's angularity and wearing resistance have an importance role in pavement's skid resistance. Exposed aggregates on the surface may also be polished and consequently the reduction of aggregate physical properties will decrease the skid resistance before the end of design life. Therefore, this research aimed to compare and quantify the loss of long term skid resistance of exposed aggregate pavement compared to transverse tining surface texture based on the data that was surveyed from the acceleration wheel testing in laboratory. Moreover, polishing resistance of various aggregates for exposed aggregate concrete was also evaluated.

1 INTRODUCTION

Concrete pavement is a strong and durable structure compared to asphalt pavement, however, its skid resistance is still a concern. One related factor of road accidents are found to be induced by inadequate skid resistance of the pavement surface (Davies et al. 2005 and Kudrna 2006). Microtexture of the material is a main key to generate the skid resistance of the surface with which tire is in contact (Roe and Hartshorne 1998). To meet the required skid resistance, surface texture of concrete pavement has to be modified (Liu et al. 2013). These upgraded surfaces include longitudinal/transverse tining, exposed aggregate, transverse broom, aggregate chips and open graded concrete. Up today, transverse tining (Figure 1a) has been used in some states of U.S.A (Hoerner et al. 2003). Transverse tining can effectively improve the skid resistance of concrete pavement due to the quick water removal from driving lane to shoulder (FHWA 2005). Exposed aggregate texture, as shown in Figure 1b, is interestingly constructed in European countries (Wasilewska et al. 2017 and Hoerner et al. 2003). This texture requires the removal of surface mortar of concrete to expose the aggregate. There are two exposure techniques: (1) watering and brushing the fresh concrete surface with rotary brush and (2) spraying the set retarder on surface immediately after placement and removing unset mortar by mechanical brush after 24 hours (Descornet et al. 1993).

(a) (b)

Figure 1. (a) Transverse Tining and (b) Exposed Aggregate Texture of Concrete Pavement

Researches on the evaluation of skid resistance of tining and exposed aggregate texture have been conducted over the years (Liu et al. 2013 and Kuemmel et al. 2000). Liu et al. (2013) used lateral friction coefficient test vehicle to estimate the skid resistance of various concrete surface textures. The study found that exposed aggregate and longitudinal grooved textures were better than other textures. Also, a similar purpose of study was conducted by Kuemmel et al. (2000). They indicated that friction number (FN_{40s}) of tining textures provided a higher skid number than that of exposed aggregate. Concrete surface must provide not only the safety in braking of vehicle during early service but also adequate skid resistance throughout the pavement life. Many studies indicated that the loss of long term skid resistance was generated by traffic, pavement age, surface texture, aggregate mineralogy, and climate situation (Luo 2003; Lee and Chon 2008; Hofko et al. 2017 and Wasilewska et al. 2017).

Since, loss of skid resistance for each surface textures was reported, long-term skid resistance of concrete texture has become a concern for safety of vehicle traveling on the aged pavement. Therefore, the present study aimed to evaluate the long term skid resistance of EACP by comparing to that of transverse tining texture. Also, polishing impact of different aggregate types on skid resistance of EACP was investigated.

2 RESEARCH METHODOLOGY

Long term skid resistance of EACP was investigated in this study. Skid resistance loss of EACP was compared with that of transverse tining texture. The degradation of skid resistance under traffic loading of the two textures was simulated by accelerated roadway-surface wearing tests in laboratory. Reduction rate of skid number (SN_{40}) for each surface texture was compared. Additionally, the polishing effect of five aggregates on skid resistance of EACP was investigated in laboratory. Durability of each rock was initially characterized with Los Angeles abrasion test. Further, aggregate samples for accelerated polished test were prepared and the initial BPN of these non-polished aggregate samples was measured using British Pendulum Test (BPT) device. Subsequently, polishing test was conducted on each aggregate sample using Accelerated Polished Machine (APM) and the terminal BPN was recorded. The reduction of BPN was used to evaluate the effect of aggregate type on skid resistance loss of EACP.

3 COMPARISON OF SURFACE TEXTURE DURABILITY

3.1 Laboratory Setup – Accelerated Surface Wearing Test

Skid resistance loss of exposed aggregate texture was compared with that of transverse tining textures. Three specimens of each texture were molded with 600×300×200mm dimensions for accelerated wearing test. Mixture design of each texture was described in Table 1. Road pavement required a low slump mixture; hence, water/cement ratio was selected as 45% as shown in Table 1.

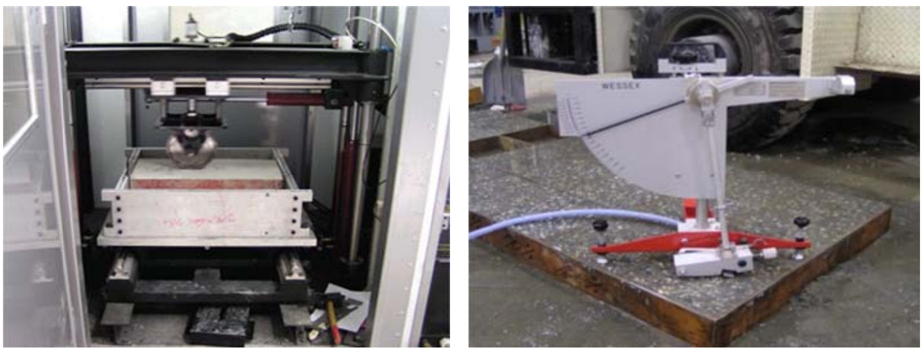
Table 1. Mixture Proportion of Tining and Exposed Aggregate Textures

Surface Texture	Coarse Aggregate Size	S/A %	w/c %	Unit Weight: kg/m^3				Air Content %
				W	C	S	G	
Tining Method	25 mm	41	45	175	389	699	1078	1
Exposed Aggregate	19 mm	45	45	185	411	748	980	1.8

S/A - fine aggregate ratio; w/c - water/cement; W - water; C- cement; S - sand, G - gravel

For transverse tining specimens, grooving was made with 25mm spacing, 3mm in depth and in width. This dimension follows the Korean standard. The specimens of exposed aggregate texture were sprayed by set retarder with water/retarder ratio of 1:1. After 24 hours, the unset mortar was removed by steel brush to expose aggregates to the surface. Each specimen was placed in the wheel tracking chamber to accelerate the wearing on surface texture as shown in Figure 2a. A 60-kg steel wheel with 50mm in width was repeatedly running on the concrete specimen. As indicated in Figure 2b and Figure 2c, BPN value of each surface texture was measured by BPT following the ASTM E303-93 *"Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester"* (ASTM 1997a) and MTD (Mean Texture Depth) was determined by the volumetric method of ASTM E965-15 *"Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique"* (ASTM 2015) after wheel passing 1 - 2,500 - 5,000 - 10,000 - 20,000 - 40,000 - 80,000 - 100,000 and 10^8 cycles. Afterward, BPNs were converted to SN_{40} based on Eq. 1 (Henry 1986) and data in Table 2. Hence, comparison of skid resistance for each surface texture was evaluated by SN_{40}.

$$\mathrm{SN}_{40} = 0.884 \times BPN + 5.16 \times MTD - 17.8 \tag{1}$$



(a) Accelerated Wheel Tracking Chamber (b) British Pendulum Test (BPT) on EACP

Figure 2. Test Procedure for Comparing Skid Resistance of Tining and Exposed Aggregate Texture

Table 2. Conversion Example of SN_{40} from BPN and MTD of Each Surface Texture

	Transverse Tining			EACP-19mm		
CVP	SN_{40}	BPN	MTD	SN_{40}	BPN	MTD
2000	54.22	72.89	1.47	52.05	74.17	0.83
5000	52.27	71.44	1.34	51.02	73.41	0.76
10000	52.11	71.67	1.27	50.24	72.71	0.73
20000	48.98	68.53	1.20	49.46	72.35	0.64
40000	47.99	68.12	1.08	48.68	71.59	0.62
80000	47.68	68.35	0.98	47.90	71.05	0.56
100000	47.37	68.24	0.94	47.65	71.00	0.52

3.2 Comparison of Skid Resistance Loss

Figure 3 showed the comparison of skid resistance in transverse tining and exposed aggregated texture after subjected to numbers of wheel passing. The two textures provided the same trend between skid resistance and number of wheel passing. Initial SN_{40} of transverse tining (SN_{40} =69.38) was higher than that of exposed aggregate texture (SN_{40}=60.6). Both textures provided an acceptable initial skid number (SN_{40}>35) (Jayawickrama et al. 1996). SN_{40} was significantly decreased due to the increase of cumulative traffic volume on the road which it validated the findings of previous researches (Grady and Chamberlin 1981). Slope of skid number loss of transverse tining (4.51) were higher than that of EACP (2.59). This showed the rapid decrease of skid number for tining texture compared to EACP. This was due to the strong wearing-resistance of aggregate particle exposed to tire-surface contact, while cement binder on the surface of tining methods had a weak durability against wearing. Therefore, exposed aggregate texture did not only provide adequate initial skid resistance at early age but also maintained the long term surface durability to secure the sufficient friction of tire-surface contact. This advantage may prolong the time of surface restoration and reduce the life cycle cost.

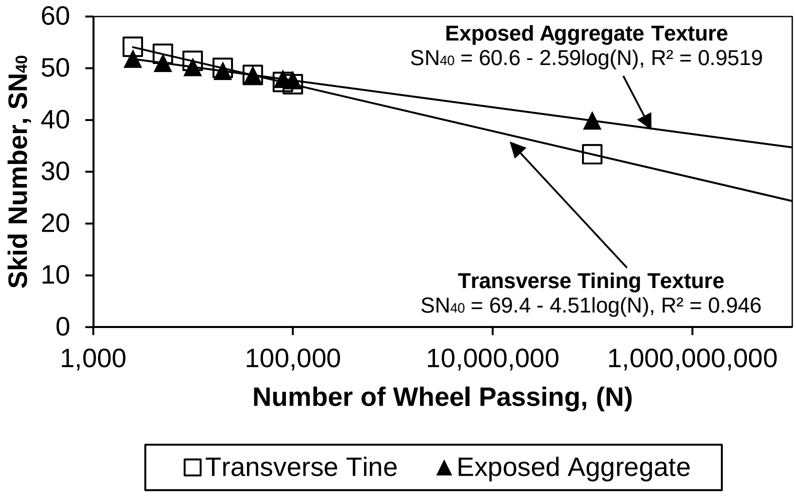


Figure 3. Comparison of Skid Resistance in Tining and Exposed Aggregate Texture under Accelerated Wearing Test

4 EFFECT OF AGGREGATE TYPE ON LONG TERM SKID RESISTANCE OF EACP

4.1 Laboratory Setup

Polishing effect on skid resistance of EACP was investigated on five rocks: (1) Granite, (2) Andesite, (3) Sandstone, (4) Gneiss, and (5) Limestone. Physical properties of the aggregates were listed in the Table 3. Initially, the abrasion test in Figure 4a was conducted on each rock to verify their quality for concrete pavement. The experiment was based on KS F 2508 *"Method of test for resistance to abrasion of coarse aggregate by use of the Los Angeles machine"* (KS 2007). Percentage of loss due to abrasion for each aggregate is computed by Eq. 2. Afterward, accelerated polish test was conducted on each aggregate based on ASTM D 3319-90 *"Standard Test Method for Accelerated Polishing of Aggregates Using the British Wheel"* as shown in Figure 4c (ASTM 1997b). Each aggregate specimen was arranged and glued in the mold as shown in Figure 4b. Initial skid resistance (BPN_0) of exposed aggregate surface was measured based on BPT, Figure 4d (ASTM 1997a). After conducting the polish stone test by APM (Accelerated Polish Machine), terminal skid resistance (BPN_T) of each aggregate was measured. R (in percentage, %) was the percentage of loss due to Abrasion. m_1 and m_2 (in grams, g) were the original and final mass of aggregate retained on the 1.7mm (No. 12) sieve.

$$\mathrm{R} = \frac{m_1 - m_2}{m_1} \times 100 \tag{2}$$

Table 3. Physical Properties of the Five Aggregates for Exposed Aggregate Texture

Aggregate Type	Granite	Andesite	Sandstone	Gneiss	Limestone
Specific Gravity	2.59	2.46	2.65	2.66	2.52
Density [kg/m^3]	1,557	1,491	1,589	1,592	1,513

(a) Los Angeles Abrasion Test


(b) Specimen Preparation


(c) APM Device

(d) BPT Device

Figure 4. Test Procedure for Investigation of Aggregate Effect on Skid Resistance

4.2 Result and analysis of polished aggregate on skid resistance

4.2.1 Results of abrasion test

Abrasion test was conducted to select the satisfied rocks for concrete pavement construction. Lost percentage for each aggregate due to abrasion was described in Figure 5. Among the five rocks, Andesite provides the lowest loss and Limestone gave the highest loss due to abrasion. All aggregates had a satisfactory abrasion resistance (R<40%). Therefore, these five aggregates can be used for the concrete mixture of pavement construction.

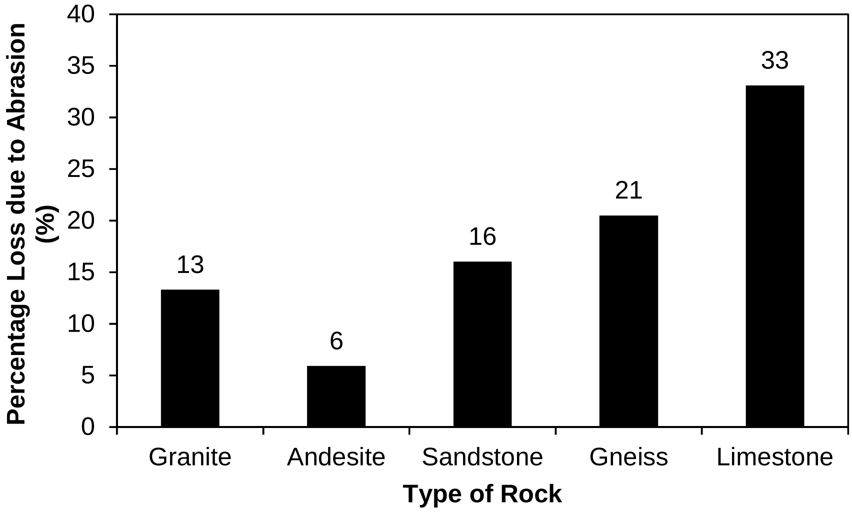


Figure 5. Percentage of Loss for Each Aggregate due to Abrasion

4.2.2 Results of skid resistance reduction of each aggregate

The study selected the five aggregates to evaluate its polishing effect on long term skid resistance of exposed aggregate texture. $\%BPN_{reduction}$, percentage of BPN reduction after accelerated polishing process), was described in Figure 6. Granite, Sandstone, and Gneiss provided a low BPN degradation around 21, 23 and 20%, respectively; while Andesite induced a high reduction of BPN up to 51%. The result of this investigation pointed out that decision of rock selection for exposed aggregate method was important since various rocks provided different anti-polishing quality for long term skid resistance. Granite, Sandstone, or Gneiss was recommended for exposed aggregate concrete due to its low rate of skid resistance reduction under polishing by repetition of traffic. Also, this study indicated that hard rock with high abrasion resistance provided the low polished resistance under traffic loading. This result validated the findings in previous literature that rocks, wore by the loss of mineral grains from a relatively soft matrix, had high polishing resistance. In contrast, rocks with the same hardness wore uniformly, may provide a low polishing resistance (Roe and Hartshorne 1998). Therefore, this study suggested that L.A abrasion test for aggregate hardness cannot determine the polishing resistance for EACP and APM should be included in the concrete mixture design procedure.

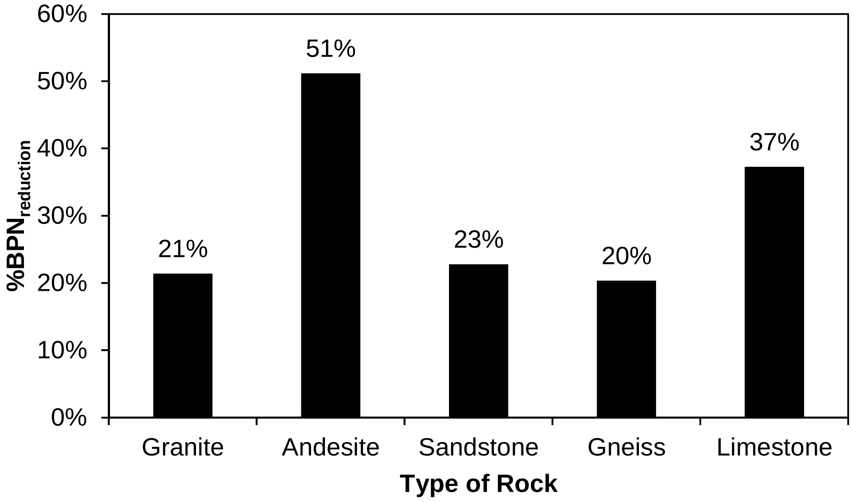


Figure 6. Reduction of BPN of Various Rocks for EACP Mixture after Polishing

5 CONCLUSIONS

This study presented a laboratory test to compare the long term skid resistance of transverse tining and exposed aggregate texture in concrete pavement. Also, skid resistance of exposed aggregate method depended mainly on the surface of aggregate particle. This led to the evaluation of polish effect of different aggregate on long term skid resistance of EACP. This present study provided significant findings as following:

- Compared to transverse tining texture, EACP can maintain both initial and long-term skid resistance against wearing caused by traffic loading.
- Granite, Sandstone and Gneiss are recommended for exposed aggregate concrete due to their high resistance against polishing by traffic.
- Mixture design of EACP should be revised by adding the APM test in the test procedure to evaluate polish resistance of aggregate.

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