LTPP data를 이용한 타이닝 콘크리트 포장의 미끄럼저항 감소 예측식 개발

Development of Prediction Equation for Skid Resistance Loss of Tinned Concrete Pavements Based on LTPP Friction Data

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1. INTRODUCTION

Low skid resistance was reported as the cause of 25% of traffic accidents among the investigated by Chelliah, et al (2). The skid resistance is influenced by various characteristics of pavement surface and tire. Skid resistance between a rubber tire and pavement surface is consisted with the sum of two components – adhesion and hysteresis. Adhesion is the product of interface shear stress and contact area. Hysteresis is caused by damping losses with the rubber when it is flowing over and around the aggregate particles of pavement surfaces (3). When pavement is wet, water film occurs and it could result hydro planing that increase potential for accidents. The provision of artificial macro texture such as tinning increase the rate of water drainage from the pavement surface, thereby improve skid resistance at wet condition. Tinning is one of typical methods to build macro texture on a concrete pavement surface to minimize the development of water film so that adequate skid resistance at wet surface condition (4). The skid resistance of initial tined concrete pavement depends on direction, depth and width of tinning, content of aggregate and properties of aggregate. Tinning has been recognized as an effective method to generate good skid resistance on concrete pavement surface, however it may produce noise. Considerable study has been done to investigate appropriate tinning layout including longitudinal tinning and randomly spaced transverse tinning to satisfy in the aspects of noise reduction and provision of skid resistance (4). Pavement surface characteristics are changed due to wear and polishing by traffic, generally results a reduction of skid resistance. Adequate skid resistance should be maintained during the entire service life of the pavement to provide safe driving condition. Therefore, restoration of skid resistance at appropriate time is important in the aspect of pavement management. Rational estimation of the rate of degradation of skid resistance is essential part of to make the decision when the pavement surface should be retreated and to allocate funding for the surface restoration. However, reliable method to predict the rate of decrease of skid resistance has not been suggested yet. Decrease of skid resistance is caused by wear and polishing. Generally wear is much related to the

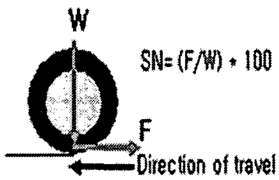

FIGURE 1. Mechanism of skid resistance development

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bond of aggregate particles and the rest of mix. Titus-Glover and Tayabji (3) noted that aggregate wear (loss of micro texture) is not identical to pavement surface wear (loss of macro texture) in case of PCC pavements. This is because hardness and other properties of PCC matrix (mortar and aggregate) are very different from those of either the mortar or the aggregate alone. Titus-Glover and Tayabji (3) considered the rate of initial wearing of tinned surface of PCC pavement depend on the properties of the mortar mix, since tinned surface of PCC pavement is done mostly in the mortar mix alone. Polishing can be defined as a reduction of micro texture. To maintain adequate skid resistance in the process of polishing, micro texture need to retain irregularities and sharp-edged shape (10). Development of reliable prediction equation for the rate of skid resistance loss in tinned concrete pavement is the objective of this study. The pattern of skid resistance loss and effects of the direction of tinning were investigated based on laboratory accelerated pavement-surface wearing test. Also the rate of skid resistance loss and influencing factors obtained from LTPP friction data were statistically analyzed. Finally, a reliable and simple equation to predict the rate of skid resistance loss for tinned concrete pavement is proposed. This equation may give useful information for pavement engineer to provide plan and budget to maintain appropriate skid resistance of tinned concrete pavements.

2.ACCELERATED PAVEMENT SURFACE WEARING TEST

2.1Purpose of Accelerated Pavement- Surface Wearing Tests

Accelerated pavement-surface wearing tests were performed to investigate following issues: First, Is it possible to find a simple generalized pattern for the rate of skid resistance loss per wheel path? Second, does the tinning direction influence the rate of skid resistance loss? The first issue needs to be examined for the systematic analysis of rate of skid resistance loss that can be obtained from LTPP friction data. Grady et al (1) reported the multiple-year measurement of skid resistance of tinned concrete for 110 sites in New York State. All skid test in Grady's study were made at 40 and 55 mph, according to ASTM E 274-77 and the tests employed a ribbed tire that meet the requirement of ASTM E-501-76, and a smooth tire that meets those of ASTM E 524-76. Grady's made an interesting conclusion that skid resistance decrease linearly with cumulative vehicle pass in log-log scale. And the variation of skid resistance can be expressed as the equation (1).

$$\text{Log (SN)\_V(mph)} = \text{Log } (SN_0)\text{\_V(mph)} \quad \text{K Log (CVP)} \qquad \text{Eq(1)}$$

Where: SN_0 = Initial Skid Resistance Number at V mph,
CVP = Cumulative Vehicle Pass
K: Skid Resistance Loss-Rate Parameter

Then K may be related various factors including mortar strength, heavy vehicle ratio, climatic condition and so on. The effects of tinning direction on the skid resistance rate have not been systematically studied yet. Transverse tinning may or may not show higher rate of skid resistance loss than longitudinal tinning. Higher rate of skid resistance require shorter surface-restoration period and may increase the life cycle cost of concrete pavement. Therefore, rate of skid-resistance loss may need to be considered in the selection of tinning direction. Accelerated pavement-surface wearing tests were performed at a given environmental condition. Therefore possible effects of climatic condition on skid resistance loss could be eliminated from the wearing and polishing due to tire and pavement texture.

2.2 Test Specimens, Set-Up and Procedure

Mix design details are for concrete is summarized in table 1 and 28 days compressive strength is recorded as 382 kg/cm^2. Mix design listed in table 1 is realistic concrete mix design used at Jungbu-Highway in Korea. Transverse tinned and longitudinal tinned concrete specimens of 600mm$X$ 300mm$X$200mm were provided. Spacing and depth of tinning is set to 25mm and 3mm for transverse tinned and longitudinal tinned concrete specimens.

TABLE 1. Mix proportions

Coarse Aggregate Size	S/A (%)	W/C (%)	Unit weight (kg/m^3)				Air content (%)
			W	C	S	G	
32mm	41	45	175	389	699	1078	2

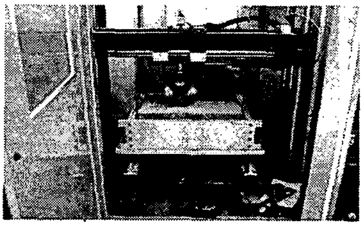

FIGURE 2. Accelerate concrete surface wearing test

A large-size wheel tracking equipment is used to accelerate wearing of tinned concrete specimen. Sixty kg wheel-load is continuously applied on the surface of tinned concrete. The wheel-path width is set to 50mm and 100,000 cycle of wheel movement was applied on the surface of transverse and longitudinal tinned concrete specimens. Mean texture depth (MTD) were measured by sand patch method according to ASTM 295 and SN_{40-wet} were measured by British Pendulum Test (BPT) at the cycle of 0, 10,000, 20,000, 40,000, 80,000, 100,000.

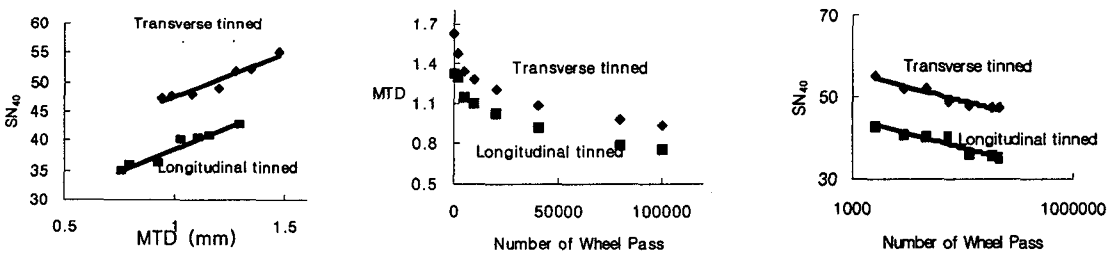

FIGURE 3. SN_{40-wet} vs MTD vs Number of wheel pass for tinned texture

2.3 Results and Analysis of Accelerated Pavement-Surface Wearing Tests

As the number of wheel path increased, skid resistance and MTD of both transverse and longitudinal tinned surface decreased. Skid resistances of transverse tinned surface were higher than that of longitudinal tinned surface at equal level of MTDS and number of wheel path applied. An interesting finding is the difference between the skid resistance of transverse tinned surface and longitudinal tinned surface kept constant all along the repetition of wheel path and skid resistance decreased with the MTD and decreased linearly with number of wheel pass in log-log scale for both cases as shown in figure.2 From this result obtained from the accelerated concrete surface wearing test, followings can be concluded: Grady's conclusion (1) that skid resistance decrease linearly with cumulative vehicle pass in log-log scale is valid and the direction of tinning does not make significant difference of rate of skid resistance loss.

3. ANALYSIS OF SKID RESISTANCE DATA OF LTPP SURFACE FRICTION DATA

3.1 Purpose of Analysis of Skid Resistance Data in LTPP Surface Friction Data

Titus-Glover and Tayabji (3) made comprehensive investigation on availability, characteristics, and quality of LTPP surface friction data. The LTPP surface friction data were reported as skid number (SN) that were obtained based on ASTM E-274 procedures. Also, the availability of related pavement characteristics was assessed including traffic, climate, wear, polishing, aging, contamination and wetness. Titus-Glover and Tayabji (3) suggested PCC mixture that would obtain adequate skid resistance by having following:

- The fine aggregate material should be of high quality (gritty).
- The mortar used for texturing the pavement surface should be durable.
- The proportion of fine aggregate in the mix should be near the upper limit of the range that permits proper placing, finishing and texturing.
- Siliceous particle content in the mix should not be less than 75 percent.
- Entrained air must be used to protect the textured surface to protect the effects of freezing and thawing
- The concrete mixture must be durable (having adequate amounts of Portland cement, water cement ratio, air contents and aggregates)

Titus-Glover and Tayabji's(3) recommendation is a plausible guide for the mix design of concrete to maintain long-term skid resistance, however it may not realistic for practices since concrete mix design is generally controlled by strength development and skid resistance concept is not considered in mix design. Considerable amount of existing concrete pavement need restoration of pavement surface due to the lack of skid resistance before the pavement-life designed based on structural capacity. However it is difficult to make network-level pavement management plan when the surface restoration should be done. If we can predict the change in skid resistance of pavement surface at a given condition, it can be used for adequate management of pavement surface. The LTPP surface friction data contains a total of 2441 measurements of SN for various pavement surface conditions under different history of traffic and environmental conditions. Among them multi-year measurements of skid resistance for 41-tinned concrete surface are included. The rate of skid resistance loss and factors influencing the skid resistance loss will be systematically interpreted in order to develop the reliable prediction model of the rate of skid resistance loss.

3.2 Development of A Model for Rate of Skid-Resistance Loss in Tinned Concrete Surface from LTPP Database

Multi year-measurements of skid resistance for tinned concrete surface at 41 LTPP GPS sections are included in Datapave program. Skid resistance loss in a short duration may be not represent the wearing and polishing since the loss in a short duration is not large enough comparing to the measurement error. Also Skid resistance data showing no correlation with cumulative vehicle pass and increase with age or traffic were considered as questionable data in the previous study of Titus-Glover and Tayabji (3). Titus-Glover and Tayabji (3) indicated that the possibility of error in skid resistance is quite high, and the sources of error can be random, such as operator error, or systematic, such as equipment error or distress and surface contamination. Therefore, these questionable data are excluded for the development of a model for rate of skid-resistance loss in tinned concrete surface. Therefore, 13 sections that showed relevant relationship between skid resistance and cumulative vehicle pass were selected for the investigation of the relationship between the ratio of skid resistance loss and related factors. The result of the linear regression analysis [Log $(SN_N)\_40$ = Log $(SN_0)\_40$ K Log (CVP)] for the skid resistance loss in log scale and the cumulative vehicle pass in log scale are expressed for the investigated LTPP sections are summarized in table 2.

TABLE 2. Linear regression analysis for the skid resistance loss in log scale and the cumulative vehicle pass in log scale: Log $(SN_N)\_40$ = Log $(SN_0)\_40$ K Log (CVP)

SECTION	Number of Measurements	Measurement Periods	K	R^2
13-3007	9	9	0.0211	0.6097
13-3011	9	9	0.0179	0.5481
13-3017	9	9	0.0698	0.8204
18-3031	8	8	0.1377	0.5589
24-5807-1	9	9	0.0987	0.8443
24-5807-2	9	9	0.077	0.8663
32-3010	7	7	0.259	0.9321
39-4018	9	9	0.0969	0.5085
39-5003	9	9	0.1573	0.8541
48-3003	7	7	0.1302	0.594
48-3569	7	7	0.077	0.3432
51-5009-1	9	9	0.0915	0.8134
51-5009-2	9	9	0.0915	0.8134

The linear relationship [Log $(SN_N)\_40$ = Log $(SN_0)\_40$ K Log (CVP)] for the skid resistance loss in log scale and the cumulative vehicle pass in log scale that were shown in accelerated pavement-surface wearing test are demonstrated again. K values are ranged from 0.0179 to 0.1573. This large difference of K among sections means that the rate of skid resistance loss respect to the number of cumulative vehicle is influenced by other factors as well as polishing and wearing of tire-pavement contact. The potential factors influencing the ratio of skid resistance loss to the cumulative vehicle pass can be categorized in three parts, concrete material characteristics, climatic conditions and traffic characteristics as shown in table 3. The value for K and potentially related factors including water cement ratio, truck ratio, freezing index and snow cover day for each investigated section is summarized in table 4.

TABLE 3. Potential factors influencing the ratio of skid resistance loss to the cumulative vehicle pass for tinned concrete texture.

Potential Factors	Possible Mechanism
W/C Ratio	Mortar is the major part of tinned texture. And the strength of mortar is influenced by W/C ratio.
Truck Ratio	Heavy vehicle may result much wearing and polishing than light vehicle.
Freezing Index	Aggregate that undergo freezing and thawing over long periods of the time tend to weaken and disintegrate. This procedure may accelerate the loss of skid resistance
Snow Covered Day	Snow removal process may accompany considerable damage in surface texture. This process leads substantial reduction of skid resistance. Also Snow cover day is greatly related with the amount of de-ice agent used.

TABLE 4. K value and Potential Related Factors

SECTION	K	W/C	Truck ratio	Freezing Index	Precipitation	Snow Covered day
13-3007	0.0211	0.49	8	63.7	1488.9	1.75
13-3011	0.0179	0.49	21.6	5.9	1189.3	0.16
13-3017	0.0698	0.47	20.6	16.5	1227.3	0.71
18-3031	0.1377	0.33	19.3	230.5	1165.4	19.9
24-5807-1	0.0987	0.41	39.2	120.9	1028.8	14.24
24-5807-2	0.077	0.41	39.2	120.9	1031	14.24
32-3010	0.259	0.51	45.2	494.9	278.9	67
39-4018	0.0969	0.5	10.5	336.9	1009.8	28.45
39-5003	0.1573	0.49	16.6	381.8	944	54.47
48-3003	0.1302	0.37	10.3	26.4	927.1	1.46
48-3569	0.077	0.57	25.9	54.8	696.5	2.97
51-5009-1	0.0915	0.52	22.1	69.8	1103.6	9.67
51-5009-2	0.0915	0.52	22.1	69.8	1103.6	9.67

The range of water cement ratio of investigated sections is from 0.33 to 0.51, which covers conventional water cement ratio of concrete pavement. No significant relationship between K value and water cement ratio is not found as shown in figure 4. Truck ratio ranged from 8% to 45.2%. Truck ratio is not significantly related with K value as shown in figure 5.

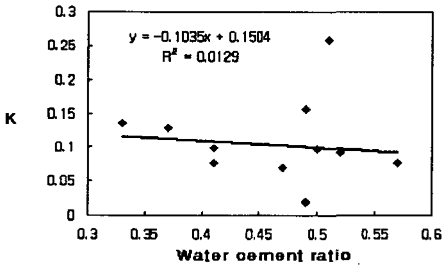

FIGURE 4. Relationship between K and water cement ratio.

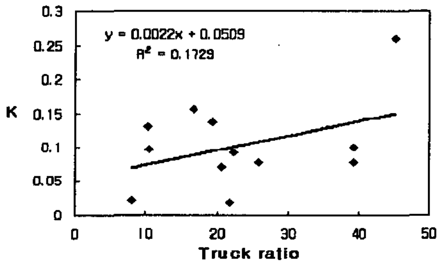

FIGURE 5. Relationship between K value and truck ratio.

Wide range of climatic condition such as freezing index (5.9−494.9) and Snow Cover Day (0.71−54.47) are included in the investigated section. As shown in figure 6,7 K value are greatly influenced by these climatic conditions.

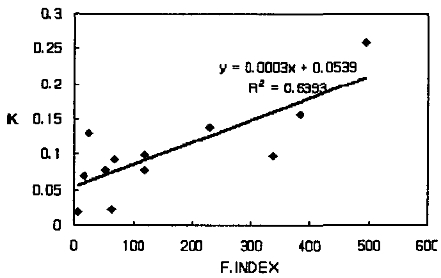

FIGURE 6. Relationship between K value and freezing index.

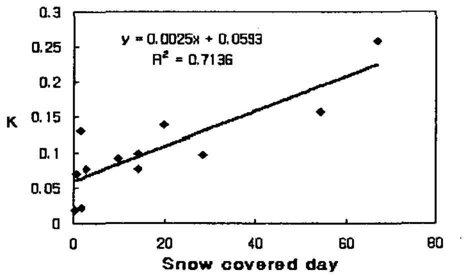

FIGURE 7. Relationship betwee K value and snow covered day

The results of statistical analysis for the relationship between single variable (potential factors) and K value are summarized as shown table 5. Statistically it was indicated that K is not significantly related with truck ratio and W/C ratio. And it showed that K increased with higher freezing index, higher snow covered day. However, freezing index and snow cover day have high correlation (0.97), only snow cover day which shows higher relation with K are used in prediction model.

TABLE 5. Results of single variable analysis for the correlation between K and Potential Related Factor

Potential Factors	R2	Adj R2	P-value
W/C Ratio	1.3	0.0	0.711
Truck Ratio	17.3	9.8	0.158
Precipitation	63.8	60.5	0.001
Freezing Index	63.9	60.7	0.001
Snow Covered Day	71.4	68.8	0.000

Finally, the skid resistance after N pass of traffic can be expressed as follows:

$\mathrm{Log}(SN_N)\_40 = \mathrm{Log}\ (SN_0)\_40 \quad K\ \mathrm{Log}\ (CVP)$ Eq(2)

SN_N = SN after N pass of cumulative vehicle

SN_0 = Initial SN after construction

CVP = Cumulative vehicle pass

K = 0.0593+0.00247*Snow Cover Day (R^2=0.71)

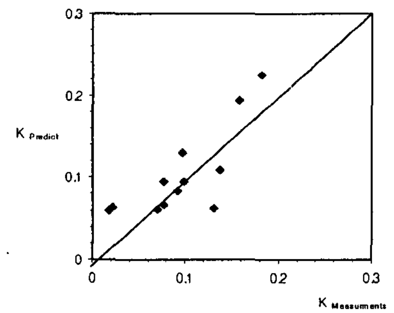

FIGURE 8. Comparison between predicted K and measured K for 13 LTPP sections.

As shown in figure 8, a good agreement between predict K by Eq (2) and measured K shown in table 3 for 13 LTPP sections is indicated. Therefore it is believed that Eq (2) would give reliable prediction of future SN for a given tinned concrete pavement. Eq (2) may be use valuable method to estimate the timing of pavement surface restoration

4. CONCLUSIONS

Results of accelerated pavement-surface wearing test indicated that Log (SNN) decrease linearly with Log (cumulative vehicle pass in log scale) and the direction of tinning does not influence the rate of skid resistance loss. Based on the analysis of multiyear − measurement skid resistance data and potentially related factors obtained from LTPP data, a reliable equation to predict future skid resistance is suggested.

$\mathrm{Log}(SN_N)\_40 = \mathrm{Log}(SN_0)\_40 \quad (0.0593+0.00247 \times \text{Snow Cover Day}) \times \mathrm{Log}\ (C)$ Eq(3)

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