Health & Safety

Effect of Aggregate and Pavement Types on Skid Resistance Evolution

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Abstract

Skid resistance is an important safety factor for highway pavement that is accounted for in proper materials selection, design, and construction. In this research, Skid Resistance values are collected from different pavements with different aggregates. Skid resistance performances were measured by both Friction Tester and Laser Profilometer. Field tests are conducted several times during more than 10 years for some pavement sections. Skid resistance performance values are observed and evaluated. These assessments are used to predict friction change during the lifetime of a pavement would aid in predicting pavement performance and identifying the appropriate time for any treatment and rehabilitation. The results of this study help to choose the most suitable aggregates and pavement types allowing to reach and to maintain a relevant skid resistance level according to the demand on the roads in the Turkish Highway Network.

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1. INTRODUCTION

Skid resistance is an important parameter for highway designs, construction, management, maintenance and safety. Skid resistance describes the contribution that the road makes to tyre/road friction. Essentially, it is a measurement of friction obtained under specified, standardized conditions, generally chosen to fix the values of many of the potential variable factors so that the contribution that the road provides to tyre/road friction can be isolated [1]. ASTM E-867 defines friction resistance as 'the ability of the traveled surface to prevent the loss of traction' [2].

A pavement with higher skid resistance minimizes the skidding thus increase the road safety. It was found that higher percentage of crashes occur on roads with low friction while fewer crashes happen on roads with high friction. Many researchers have developed models to predict the association between car crashes and friction. Most studies confirm the association between high rates of car crashes and low levels of pavement friction[3].

Several factors affect highway safety including pavement surface friction, road geometry, traffic conditions, vehicle speed, and environmental conditions.

Skid resistance plays the key role in ranking roads according to their safety wet conditions [4]. Many studies have been conducted to contribute to the issues related to slid resistance. Some of these studies aim for a correlation between lab-based polishing simulation and skid resistance measurement and evolution of the skid resistance under traffic in the field. Thus, the developed procedures can be used to predict the remaining life-time of a surface layer before critical skid resistance values will be reached [5]. As is well known, the assessment of evolution of skid surface performance plays a fundamental role in road pavement management and is useful in order to allocation of maintenance resources.

The aim of this work is to produce an inventory on skid resistance performance indicators for road pavements used across Turkey, taking into account different aggregates and pavement types. And also it is need to choose the most suitable pavement types, aggregates and to predict a skid resistance. This research has attempted to closely evaluate these aspects to aid highway engineers in selecting the pavement type and aggregate with appropriate skid resistance. Thus, it will be helped to make preliminary estimation in maintenance and repair with respect to skid resistance performance and to allocate budget accordingly.

This study was conducted on three types of road. These are Motorway, State Highway, Provincial Road under control of General Directorate of Highways [Karayolları Genel Müdürlüğü (KGM)]. Three kinds of road pavement were measured: stone mastic asphalt, wearing course and concrete. Tests were performed on eight pavement sections. Eight pavement sections were made from different aggregates and bitumens. And they had different aggregate – bitumen combinations. One pavement section was made concrete.

Several surface performances were measured by two different devices (Friction Tester and Laser Profilometer). We made many measurements performed to understand pavement skid resistance and its evolution during service. Skid resistance measurements have been started since the new construction of the pavements. Some pavements over 11 years age have been monitored for over 10 years.

2. FACTORS AFFECTING ON SKID RESISTANCE AND RELEVANT RESEARCHES

Researchers declared that there are several factors that affect the available pavement surface friction. These factors can be categorized as follows: a) Pavement surface factors: surface texture (microtexture and macrotexture), type of surfacing, age of the surface. b) Tire factors: Speed, cornering angle, slip ratio, tread wear, tire groove depth and tread pattern, tire inflation pressure and load. c) Load factors: equivalent number of vehicle traffic loadings, road geometry, traffic flow conditions. d) Environmental factors: temperature, water film, seasonal variations [6].
Reduction in skid resistance under traffic and environmental conditions that causing polishing, bleeding, and raveling is usual, and there are many factors such as type of pavement, physical and mechanical properties of aggregates, the properties and amount of bitumen affect to the pavement long term skid resistance performance [7,8]. Texture deterioration rate is difficult to be estimated because it is affected by many factors, including aggregate properties, binder properties and aggregate-binder combination, road geometry and traffic, as discussed below. The ability of an aggregate to resist the polishing action of traffic depends on several parameters: hardness, mineralogical composition, crystalline structure, shape, angularity, resistance to abrasion, resistance to polishing, petrographic nature. It is a common practice to assume that aggregates with lower Los Angeles abrasion loss, lower sulfate soundness loss, lower freeze-thaw loss, lower absorption, and higher specific gravity have better resistance to polishing [8, 9].

The effect of pavement surface texture on pavement skid resistance has been reported in early skid resistance studies [10]. The pavement surface texture according to its size is divided into the two categories of microtexture and macrotexture [2]. The complete frictional characteristics of the road can be found if both the microtexture and macrotexture are known. Early on it was established that good microtexture is important at low speeds and good macrotexture is important at high speeds [11].

The microtexture category contains surface asperities of less than 0.5 mm in height, while the macrotexture category refers to asperities greater than 0.5 mm (between 0,5 and 50 mm) in size [12, 13]. Macrotexture refers to the coarse-scale texture irregularities of the pavement surface that affects the hysteresis component of the friction. These irregularities are associated with the void area between aggregate particles. The magnitude of this component will depend on the size, shape, and distribution of coarse aggregates used in pavement construction, the nominal maximum size of aggregates and the particular construction methods used in the implementation of the pavement surface layer [14, 15, 16, 17]. Microtexture refers to fine-scale texture irregularities in the surface of the aggregate particles that are measured at the micron scale of harshness and are known to be mainly a function of aggregate particle mineralogy [13, 14]. Stone particles smoothness or harshness depends on these irregularities. The magnitude of microtexture depends on initial roughness of the aggregates surface and the resistance of the aggregates against the polishing action of traffic and environmental factors [14]. The adhesion component of the friction is influenced by microtexture (13, 14).
Earlier research indicated that skid trailer measurements conducted using a ribbed tire (ASTM E501) are more sensitive to the microtexture properties of the pavement surface than to macrotexture; thus, they are good estimators of pavement microtexture [13, 19].

The study carried out by Pranjić et al. (2018) gives a brief analysis of pavement surface macrotexture characteristics important for skid resistance realization [12]. However, some researchers believe that the microtexture of the aggregate is important at all speeds [18 ,19].

Microtexture results show some differences in the evolution trends, especially in the phase of early life skid resistance; this variability is probably due to the composition parameters (aggregates and binder type) of the mixtures [17].

The study carried out by Vaiana et al. [9], microtexture results show some differences in the deterioration behavior of the 4 mixes, probably related to the petrographic nature of aggregate and to the binder type, confirming how the combination of aggregate and bitumen has a significant effect on skid resistance, especially during pavement early life. In particular, aggregates with lower Polished Stone Values (PSV) (limestone) have a lower resistance to the stripping phenomenon, becoming immediately more exposed to traffic actions. In the case of mixes with aggregates characterized by higher values of PSV, few months after the surface laying (around 6 months), the binder coatings are smoothed but not removed from the aggregate, determining a lower early life skid resistance [9].

The study carried out by Do et al. (2015) deals with the relationship between road surface texture and skid resistance. Mechanisms underlying the tire/wet road friction are first described. Definitions of road surface irregularities scales are given. The rest of the paper is then focused on the macrotexture and microtexture scales and their respective roles in what happens at the tire/road interface. Their results showed that micro-texture is more significant feature than the macro-texture in skid resistance [20].

Gökalp et al. (2016) reported that the study is to investigate skid resistance performance of surface coatings which were produced at laboratory with different aggregate types, particle sizes and polishing levels. Six natural aggregates within three different origins such as limestone, basalt and boulder and four by-products including Electric Arc Furnace and Ferrochrome slags were used to prepare chip seal and slurry seal samples. Macro-textures of surface coating samples were determined with sand patch and outflow meter tests according to ASTM E 965, and ASTM E 2380 standard methods, respectively to determine the known effects of surface texture over skid resistance of the surface coatings. To identify the skid resistance of each surface coating sample, British Pendulum Tester, which is a widely known test device was utilized according to ASTM E 303 standard method. With regard to all analyses, the effect of macro and micro textures on skid resistance of chip seal samples produced with polished and unpolished aggregate was evaluated. As a results of all analyses, micro-texture was found out a significant decisive feature in skid resistance performance evaluations [8].

In the study by Gökalp et al. (2017) sand patch method and British Pendulum Test method were used to measure the surface macro-textures and skid resistance performance of each chip seal sample according to ASTM E 965 and ASTM E 303, respectively. Skid resistance performance of each chip seal sample was evaluated with macro and micro textures. The results showed that micro-texture is more significant feature than the macro-texture in skid resistance [21].

Yager and Buhlmann (1982) examined the correlation between the British pendulum tester (BPN) and surface texture depth. The study concluded that the variation of BPN is independent of surface texture depth [10]. Liu (2004) however found that BPN depends on both surface microtexture and macrotexture [22]. Corley- Lay (1998) also found that the variation of BPN from section to section resembles the variation of SN [23].

Ahammed (2011) reported that the limited skid testing using both the British Pendulum and skid trailer on the same AC pavement surfaces indicated that British Pendulum Number (BPN) fairly resembles the Skid Number (SN). This finding proved that BPN is an indicator of both microtexture and macrotexture, not just only the microtexture on pavement surfaces [17].

Luce et al. (2007) evaluated the aggregate texture and its relationship with skid resistance using the data collected from several pavements in Texas. The aggregate type (gravel, sandstone, and quartzite) was shown to be statistically significant for the variation in skid resistance. The aggregate gradation however was shown not to explain the difference in skid resistance among the AC mixes [24]. Goodman (2009) however found a good correlation of texture and skid resistance with aggregate gradation as well as asphalt mix properties. Although Goodman (2009) performed a comprehensive analysis of texture and skid resistance, the author concluded that the developed models need further validation [17, 25]. These indicate that there is still disagreement about the British Pendulum's ability to account for the variation in pavement surface microtexture and macrotexture [17].

Himeno et al. (2000) found that pavement surface friction decreases with an increase in the mean profile depth (MPD), a laser based measure of texture depth, leading to a conclusion that MPD is not an effective factor for evaluating the skid resistance [26]. Flintsch et al. (2003) also found that MPD values are device specific. These findings indicate that further examination of the laser based methods for measuring or correlating (with other methods) the pavement surface features such as the texture, roughness, and rutting is required [17, 27].

Guan et al. (2018) evaluated the influence of macrotexture and microtexture on the skid resistance of four types of aggregates. For this purpose, fractal dimension (D), root mean square height (R_q), and Polished Stone Value (PSV) were tested. The results showed that the PSV development was approximately divided into 3 stages including accelerated attenuation stage, decelerated attenuation stage, and stabilization stage. There is a critical point of the entire polishing cycles. When the number of the polishing cycles exceeds this critical point, microtexture replaces macrotexture to play a major role in the skid resistance of aggregates. In summary, macrotexture has significant influence on the early skid resistance performance of aggregates, and microtexture has significant influence on the long-term skid resistance performance. Due to the fact that polishing of the aggregate in the pavement is the long-term process, microtexture is more important for long-term skid resistance of aggregates. R_q is a suitable indicator to evaluate the long-term skid resistance of aggregates. Due to the highest value of R_q in the stabilization stage, bauxite had higher skid resistance during the long-term polishing process, and it was suitable for the wearing course, especially high friction surface treatment [28].

3. METHOD AND METHODOLOGY

The main texture parameters that influence pavement surface friction are microtexture and macrotexture [19].
In this study focuses on the changing of microtexture and macrotexture performance of asphalt pavement in actual road during service. Microtexture and macrotexture measurements were carried out by Friction Tester and Laser Profilometer. The field data collection is elaborated, which covers 7 types of asphalt surfaces and 1 concrete surface. The degradations of skid resistance performance were evaluated using the Mean Profile Depth (MPD) for 3 asphalt pavement surfaces and Skid Number (SN) for 8 pavement surfaces (asphalt and concrete). The road pavements were monitored periodically since they were laid SN and MPD indicators were determined.

Measuring Devices and Methods:

Skidding resistance measurements were made on pavement surfaces by two different devices and methods; 1) 1295 Friction Tester-Locked Wheel Testing- ASTM E 274 2) Laser Profilometer-Pavement Surface Texture Profiler-LP ISO 13473-3.

Friction testing performed with the Locked Wheel Friction Tester.
The 1295 Pavement Friction Tester measures both fully locked wheel and peak friction on paved surfaces. The 1295 consists of a fully instrumented tow vehicle and test trailer, and utilizes the manufacturer two-axis transducer to provide real time vertical load and horizontal tractive force measurements.The trailer will spray water under the

selected tire, lock the wheel, and measure the vertical and horizontal forces imparted by the pavement. The skid number is calculated as the average coefficient of friction across the test interval [29].

Skid number measurement was conducted using the 1295 Pavement Friction Tester (PFT) in accordance with ASTM E 274, "Specification For Skid Resistance Using A Full Scale Tire." [30]. Standard tire used as test wheel ASTM E 501 [31]. Water was delivered ahead of the test tire and the braking system was actuated to lock the test tire. The resulting friction force acting between the test tire and the pavement surface and the speed of the test vehicle were recorded using the on-board instrumentation. The skid number of each pavement section was measured at 64 km/h test speed. A measurement was taken approximately every 200 m. Measurements were made by locking the right and left wheels. SN measurements taken from on the road direction of right lane. The right lane was chosen because of carrying the heavy traffic. The mean values were used in the evaluations.

Road surface macrotexture as MPD was determined using the laser profilometer.
The Road Surface Profilometer (RSP) test system is a road surface profiler. The test system is able to measure, display, store, and calculate longitudinal-transverse road profile and roughness data in both wheel paths, including rut data, MPD data in both wheel paths and speed. The RSP is able to operate at speeds up to 120 km/h. The information is collected and is stored in a data file. The data file is then imported into a software program.

RSP consists of a mechanical/electrical transducer beam (rut bar) mounted on van vehicle. The system consists of cameras, accelerometers, laser sensors, a distance measuring instrument and a computer system. The vehicle has a global positioning system. The laser sensors, accelerometers and inertial motion sensor unit for the system are mounted in rigid aluminium housing (rut bar) at the front of the vehicle [32]. The rut bar consists of seventeen laser displacement sensors and two accelerometers. Two of the sensors are used for identification of macrotexturing. These two sensors operate at speeds up to 32,000 Hz. The remaining eleven sensors operate at speeds up to 16,000 Hz. The equipment meets the ASTM E950 Class 1.
Class 1 measurement resolution: less than or equal to 0.1 mm.
Inertial motion sensor, specify a 0.3 deg. accuracy, which is 0.5%.
Sampling interval of longitudinal profiling: 2mm reported at 25mm
Reporting sampling interval of longitudinal profiling: 25mm
Large wavelength cutoff (-3dB) of longitudinal profiling: user selectable between 10-199m
Vertical sensor resolution: 0.05mm
Vertical sensor resolution of transverse profiling: 0.05mm
Macrotexture:
Vertical resolution = 0.04mm
a standoff distance of 260 mm and a measuring range of at least +/- 77mm
Acquisition sampling interval = <1mm at speeds up to 110kph
Reporting sampling interval = >25mm
Laser measurement range 155mm
Spot size = ~1mm

The mean profile depth data was collected with RSP device in both wheel paths. MPD was measured according to ASTM E 1845-01 “Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth” and ISO/CD 13473-1 “Characterization of Pavement Texture Utilizing Surface Profiles” [33, 34].
The measurements were made at a speed of 70 km/h. Mean profile depths were measured on the pavement of the road direction of right lane and computed every 100 mm. The mean values were used in the evaluations.

4. PAVEMENT TYPES, AGGREGATES AND OTHER MATERIALS USED IN THE STUDY

The measurements of the skid resistance carried out on the eight different pavement surfaces of our country highway network. Pavement types are Stone Mastic Asphalt (SMA), Asphalt Concrete (AC) and Concrete.
Different types of agregates used in construction of pavements. These were basalts, limestones and granodiorite. All aggregates used were of different origin. Other materials used in pavements were fly ash and boron mineral.

Basalt is a basic volcanic rock, with a large compressive strength, low water absorption, and good wear resistance. Limestone has satisfactory physical properties, such as good workability, excellent sturdiness, and good cementation. However, it is generally not used on the surface of asphalt pavement, due to its lower strength than volcanic rocks, such as basalt [35]. Limestone has a greater tendency to polish than most other types of aggregates [36]. It is not sufficiently resistant against polishing. It is shown that carbonated aggregates are among low resistance stones against polishing and their usage is limited in the wearing surface [37]. To avoid reducing skid resistance of the asphalt surface, it is essential to implement a hard and polish-resistant coarse aggregate [37]. Aggregates composed of a hard mineral and a weak mineral behave differently: the softer mineral mass wears quickly, exposing the hard grains to the traffic loads, keeping good frictional properties for extended periods of time [2, 9, 10].

Fly ash in asphalt pavements: Fly ash can be used as a cost-effective mineral filler in asphalt paving applications. Where available locally, fly ash may cost less than other mineral fillers. Also, due to the lower specific gravity of fly ash, similar performance is obtained using less material by weight, further reducing the material cost of asphalt. Mineral fillers increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements. Mineral fillers also help reduce the amount of asphalt drain down in the mix during construction, which improves durability of the mix by maintaining the amount of asphalt initially used in the mix. Fly ash will normally meet mineral filler specification requirements for gradation, organic impurities and plasticity. Also, fly ash is hydrophobic (non-water wettable), reducing the potential for asphalt stripping; the presence of lime in some fly ashes may also reduce stripping. Mineral fillers have become more necessary as mixture gradations have become coarser.[38, 39].

Boron in concrete pavements: Utilization of by-products or waste materials in concrete production are important subjects for sustainable development and industrial ecology concepts [40]. Topçu et al. (2009*)* investigated impact of boron waste on the workability and strength of concrete. They reported that the use of boron as mineral admixtures or fine aggregates improve the durability properties of concrete and thus increase the economic and environmental advantages for the concrete industry [40].
Asphalt roads provide better traction and skid resistance for vehicles. Asphalt tends to help keep roads free from rain and snow [41].

Four different SMA constructed with different aggregates: Basalt-1, basalt-2, basalt-3 (including 4% fly ash) and limestone-1
Three different dense graded wearing courses were designed with different aggregates: Basalt-4, 50% basalt-5+50% limestone-2 and granodiorite.
Concrete pavement including boron [Jointed Reinforced Concrete Pavement (JRCP)]: Boron added cement was used in concrete.

Coarse aggregate characteristics like angularity and resistance to wear, have a substantial role in providing sufficient skid resistance in pavements. Using hard and irregularly shaped coarse aggregates is a key to attaining and retaining the desired texture [35]. Asphalt pavements with coarse gradations are increasingly being designed because they perform well under heavy traffic conditions [38]. Fine aggregates show their significant role only when used in relatively large quantities [37, 42].

Table 1 shows the asphalt and concrete mixtures with different aggregates, pavement types, construction years, locations and other information on roads.

Table 1: Road and Pavement Information

No	Road Number and Name	Type of Pavement Surface and Aggregate	Construction year	Testing Location From-to
1	O 4-34 İstanbul-Ankara Motorway	SMA Basalt-1	2017	26+000-30+700
2	O 51-10 Mersin-Tarsus Motorway	SMA Basalt-2	2015	20+000-21+000
3	O 52A-15 Gaziantep Ring Road	SMA Basalt-3 Including fly ash	2011	25+700-34+000
4	O 51-07 Mersin-Tarsus Motorway	SMA Limestone-1	2016	9+500-10+000
5	O 52-16 Gaziantep-Nizip Motorway	Wearing course Basalt-4	2006	0+000-15+000
6	010-18 Samsun-Ordu State Road	Wearing course 50% B+50% L	2007	13+750-17+550
7	010-19 Ordu-Giresun State Road	Wearing course Granodiorite	2006	11+600-15+000
8	855-01 Ordu-Ulubey Provincial Road	Concrete (including bor)	2007	5+000-6+000

5. RESULTS AND DISCUSSION

5.1. Field Measurement Results

In this work, macrotexture and microtexture of asphalt and cement concrete pavement surface have been investigated in the field using two different methods which are Locked Wheel Testing and Surface Texture Profiler.
Different eight pavement types using different origin aggregates were measured.
Skid resistance performance of the pavements, which have been in service for approximately 3 to 11 years, was monitored. The measurements were made several times on different dates. All measured roads have still been in service and monitoring.

SN measurements were made on all pavements. MPD measurements were only made on three SMA pavements. SN lower specification limit of the pavement is 30 for Turkey. SN values of all pavements were found to be over 30. Pavement SN performances were observed to be good from the results obtained. However, MPD results did not achieve the same performance. These results are tabulated in Table 2.
Macrotexture evolution shows a progressive decrease over time because of the occlusion of the voids due to both the migration phenomenon of the bitumen and the dust and oil accumulation. In addition, under the effect of prolonged post-compaction action due to the traffic, the aggregates are embedded in the asphalt matrix with a further reduction of the average texture depth [9, 20].

Table 2: Pavement Information, Skid Number and Mean Profile Depth Data

No	Type of Pavement Surface	Construction Year	Measurement Date	AADT (Vecihle /Day)	SN (Right Lane)	MPD (Right Lane)
1	SMA Basalt-1	2017	2019	–	52	0,65
			2018	22622	45	0,64
			2017	22794	37	0,70
2	SMA Basalt-2	2016	2019	–	49	0,67
			2018	24595	48	0,78
			2017	26090	41	0,82
3	SMA Basalt-3 Including fly ash	2011	2017	9349	37	–
			2016	7673	39	–
			2014	5354	56	–
4	SMA Limestone-1	2016	2019	–	32	0,49
			2018	24595	36	0,53
			2017	26090	40	0,58
			2016	26090	41	0,81
5	Wearing course Basalt-4	2006	2017	14722	45	–
			2014	11929	52	–
			2006	New project	64	–
6	Wearing course %50 Basalt+%50 Limestone	2007	2018	16516	38	–
			2014	14356	44	–
			2008	8688	57	–
7	Wearing course Granodiorite	2006	2018	21035	43	–
			2014	15149	48	–
			2008	10212	54	–
8	Concrete Including bor	2007	2018	7934	39	–
			2014	5014	44	–
			2008	5644	61	–

5.2. Skid Resistance Evaluation

During the service life of an asphalt pavement the skid resistance varies. The aggregate type has a significant effect on skid resistance. Figure 1 shows the SN data measured in each SMA sections with different aggregates.

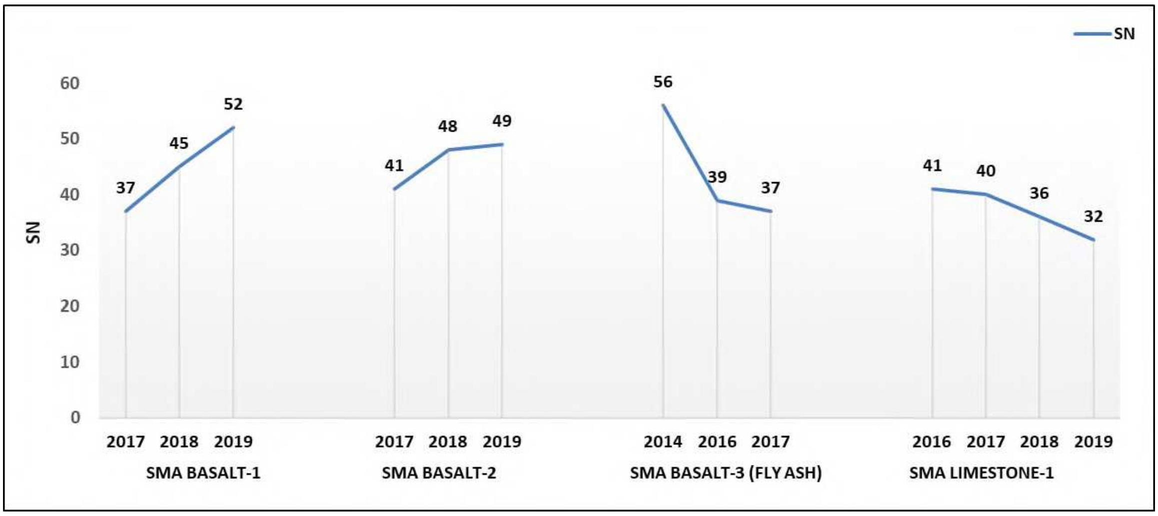

Figure 1. Variation of skid number values during service life for SMA pavements with different aggregates.

The initial skid resistance is not so high, due to the binder film for basalt-1 and basalt-2 pavements. The skid resistance increases as the bitumen on the surface of the aggregate is worn away. In the last stage, the polishing of the exposed aggregate influences the skid resistance. Friction will decrease during time after so many load cycles caused by traffic. The polishing resistance will be dependent on the type of aggregate and mixture composition [43].

Generally, the evolution of skid resistance is characterized by an initial increase in friction coefficient that occurs in the months immediately after the laying of the road surface because of the actions due to vehicular traffic, the bitumen film is gradually removed from the aggregates surface. Each aggregate is more exposed to the contact with the tire and, consequently microtexture increases. This first phase is known as the "early life skid resistance". Once the binder has been completely removed, the skid resistance evolution curve reaches a maximum. Afterwards (after 2 million of vehicle passes or 2 years of pavement service life) this higher exposure causes a decrease in skid resistance due to the smoothing and polishing actions under traffic loads [11, 18].

The SN data were measured in each AC and concrete sections. Wearing courses and concrete pavement SN measurement data showed the same behavior. Change of skid resistance values are shown in Figure 2.

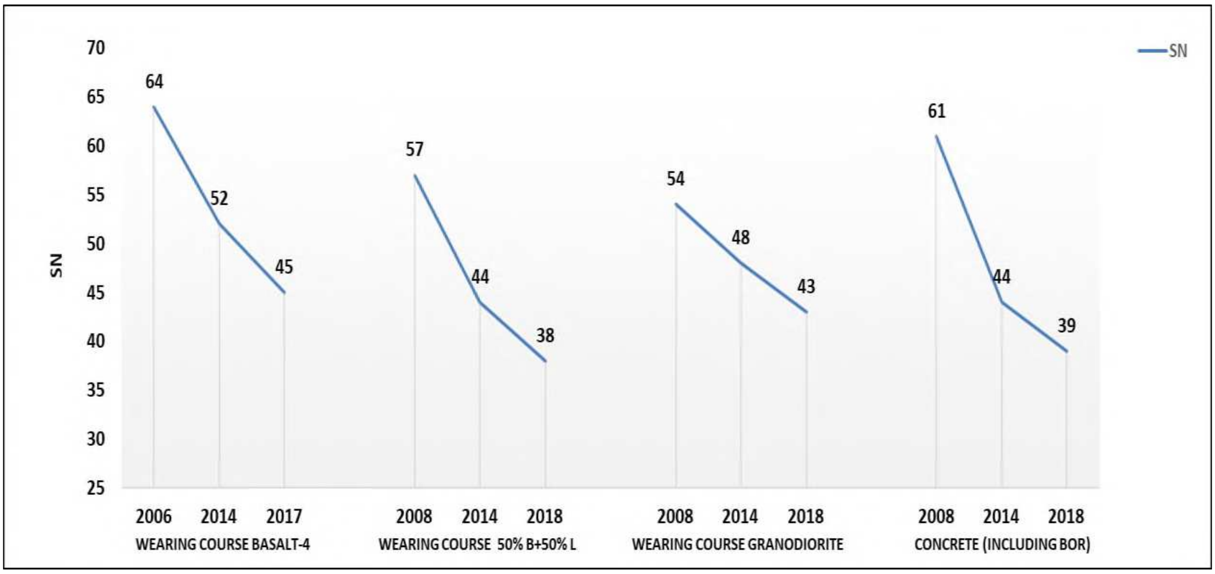

Figure 2.Variation of skid resistance values during service life for concrete pavement and wearing courses with different aggregates.

For a good skid resistance, using basalt and granodiorite are preferred than using limestone. However, in the mixture of 50 % basalt and 50% limestone, the use of 50% fine limestone aggregates shows less performance than all granodiorite and all basalt mixtures, but still gives good results.
The SN and MPD data were measured on three selected SMA sections. It is shown graphically in Figure 3. The variations of skid number and mean profile depth were shown to be different. SN and MPD results are similar for limestone pavement. However, it does not show similarities with MPD and SN performance for basalt pavements.

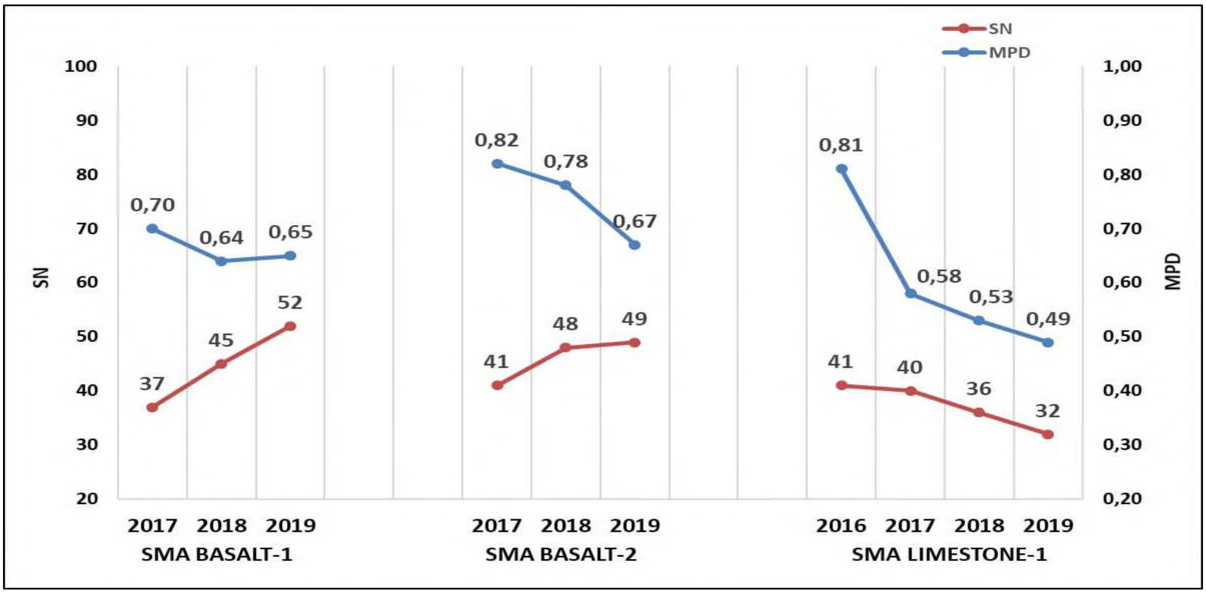

Figure 3. Comparation of skid number of SN and MPD for the SMA pavement with different aggregates.

5.2.1.Stone Mastic Asphalt

The trends for change in SMA pavements surface friction after an initial (early-life) values are shown in Figure 1, Figure 3.

SMA Basalt-1, SMA Basalt-2:
It is seen that the SN values of SMA-Basalt pavements have increased from the date of manufacture (about 3 years). The first SN values are low and the last values are high. The last SN values are 52 for SMA Basalt-1 and 49 for SMA Basalt-2. MPD decreased slightly since the date of manufacture. There is no similar relationship between SN and MPD. Figure 3.

SMA Basalt-3 including fly ash:
Three years after the manufacturing date, the SN value was good and measured as 56. In the sixth year of service period, SN value became 37. It has been observed that it remains within safe limits during its 6-year service period and is being monitored. Fly ash in the SMA is thought to have a positive effect on the skid number. Figure 1.
SMA pavement contains fly ash as filler. Because of the possible problems that can be faced with the distance of the source of the filler (calcite) and in the supplement of it, the fly ash was used.

SMA Limestone-1:
After the manufacturing, the SN value is 41 and the MPD value is 0.81. These values decreased to 32 and 0.49 respectively and both values decreased similarly over time. SN values approached to the lower limit in a period of 3 years and necessitate monitoring in near time periods.
In the first year MPD values fell faster and then they decreased slightly during the 2 years.
There is similar relationship between SN and MPD.
Skid resistance performance of SMA Limestone-1 is at the bottom when compared to other measured pavements. It shoud be due to the polishing of limestone. Figure 1, Figure 3.

5.2.2.Wearing Course

Wearing course Basalt-4, Wearing course PMB %50 Basalt-5+%50 Limestone-2, Wearing course Granodiorite: Wearing courses had the best values after the manufacturing. After 10 and 11 years long follow-up periods, SN values were observed to be in good condition. The best SN performance was found to be wearing course basalt-4 and wearing course granodiorite. Last measured SN values were found 45 for basalt, 43 for granodiorite and 38 for %50 basalt+%50 limestone mixture . Figure2.
Limestone is abundantly available and cheap in our country. It is easy to grind with less energy consumption. Therefore, 50% basalt and 50% limestone were used in the pavement.

5.2.3.Concrete (Including boron)

Concrete including boron had the good SN value after the manufacturing. It was 61. After 11 years of long follow-up period, SN values were observed to be in good condition. It was 39. However, the concrete road AADT (Vecihle / Day) values are less than other measured asphalts. Table 2, Figure2. Boron was used to increase the durability properties of concrete. Boron is thought to have a positive effect on the skid number.

6. CONCLUSIONS AND RECOMMENDATIONS

Pavement skid resistance performance varies depending on the types of pavement and aggregate.
As a result of this study, the effect of pavement type and aggregate on skid resistance was determined.

SMA pavements were monitored for approximately 3 years, wearing courses for 10-11 years, and concrete pavement for more than 10 years. During these times, the SN value of the SMA Limestone-1 pavement was close to the lower limit of the specification but was slightly higher than the lower limit. However, SN values of other pavements were well above the specification limit. Whereas MPD values were low.
In two SMA pavements, the SN values were lower at the first manufacturing date and increased with increasing time. However, MPD values were observed to be high and then decreased.
In contrast to some SMA sections, other pavements had the highest SN value as of the date of manufacture and had been observed to decrease over time. SN performances were found to be very good in Wear course Basalt-4 and Granodiorite pavements.
Generally, according to the skid resistance results obtained in this research same pavement types exhibited the similar behavior. In addition to this, wearing course and concrete pavement behaviors were similar.

Aggregate quality is one of the most important for good surface friction. It is shown that different aggregates have different effects on skid resistance.
The study confirmed that aggregate quality is the dominant factor for pavement skid resistance. The results of this research show that for a good skid resistance, using basalt and granodiorite are preferred than using limestone.

In the next step, measurements will continue until the SN value falls below the specification lower limit in order to determine the service life of the pavements. Prediction models will be established when sufficient data are available. And also prediction models will be developed for various aggregates and pavement types. Further study of this application is recommended with data from pavements with a wide range of skid resistance. This will lead to better judgment on the predictions.

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