Investigation of pavement skid resistance and macrotexture on a long-term basis

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Road safety has been connected with pavement skid resistance which often triggers the decision of pavement maintenance. So far, many laboratory studies have been conducted trying to find a link between skid resistance and macrotexture component. However, the findings cannot be extrapolated always in the field because of the multi-parametric nature of skid resistance. This nature triggered the present study that aims to identify some key aspects of skid resistance and its main textural components, macro and microtexture. The goal is twofold: to present and assess the effect of seasonal variation on a long-term basis focusing mainly on Mediterranean climate zone and to illustrate the effect of cumulative traffic on skid resistance and macrotexture in the field. To meet the objectives of this study, annual of skid resistance, macrotexture and road traffic data sets were analysed. Study findings showed that under the effect of cumulative traffic, macrotexture and skid resistance start presenting an inverse trend. Also, that trend seems to be related with the equilibrium phase of skid resistance performance, after which seasonal variation becomes less pronounced. In addition, the cumulative traffic in conjunction with the variations in weather data are proved to be critical for the microtexture component to which the drop-in skid resistance may be attributed, whereas macrotexture component increases. Ultimately, the findings of the present study result in awareness of constraints of using only macrotexture data to develop models for predicting skid resistance in field conditions.

Keywords: skid resistance; macrotexture; microtexture; GripTester; British Pendulum; sand-patch

Introduction

Skid resistance is provided by the surface layer of a pavement structure i.e. the wearing course and it combines pavement functionality and road safety. The lower level of skid resistance has been shown to directly influence the accident risk due to the reduced ability of drivers to effectively control their vehicle during emergency reactions requiring braking (Hall et al. 2009, Flintsch et al. 2012). Hence, frictional properties of a pavement are crucial and need to be extensively investigated for understanding their performance due to long-term effects of traffic and ageing over its service-life. These issues are considered by pavement engineers in an effort to improve pavements' long-term durability, while attempting to utilize materials and techniques that are appropriate from both the functional and sustainable related perspectives (Losa et al. 2008). Ultimately, a pavement structure should not only fulfill skid resistance aspects but also, should meet the long-term requirements for pavement sustainability.

Skid resistance depends on the macro and micro-textural characteristics of pavement surface (Hall et al. 2009, Kane et al. 2014, Li et al. 2018). Aggregate gradation, compaction levels achieved and binder properties mainly influence macrotexture levels, while aggregate mineralogy characteristics including asperities of the aggregates mainly affect microtexture levels (Masad et al. 2007, Plati et al. 2017). Both macro and microtexture seem to increase after the initial exposure of the aggregates to traffic, as traffic-polishing wears away the overlying film of asphalt binder that covers the asperities of the aggregates (Do et al. 2009). Skid resistance presents the same increasing trend, too. After this phase of increase, skid resistance has a tendency to decrease over the remaining pavement life as these exposed aggregates become increasingly more polished by the cumulative traffic passing along the pavement sections (Flintsch et al. 2012, Xie et al. 2019).

However, the performance of the textural characteristics is not uniform over the pavement service life; a range of factors such as volume and type of traffic and climatic conditions affect it. It has been noted that the initially achieved macrotexture level of the asphalt mixture can also influence the long-term polishing behavior of an asphalt road surface (Kane et al. 2012). According to this, the input of aggregate characteristics has been utilized by researchers to integrate into predictive models for skid resistance performance (Ergun 2005, Ueckermann et al. 2015, Chou et al. 2017, Alhasan et al. 2018). Also, beyond this factor, traffic characteristics as the composition of vehicles, have been incorporated for describing their influence on skid resistance performance (Mulry et al. 2012, Khasawneh et al. 2016, Hofko et al. 2019). In regards to the effect of climatic conditions, skid resistance is known to be affected by the “seasonal variations” mainly centred around rainfalls levels that may have a cleaning effect on the pavement surface and they have been described by many researchers, so far (Cenek et al. 1999, Wilson 2006, Plati et. al 2019). In general, skid resistance performance on a long-term basis, including the seasonal variations, may differentiate a lot among the nations due to the differences in the type of traffic, pavement materials and climatic conditions. So far, the majority of studies on these skid resistance aspects have been conducted in the north and central European countries (e.g. France, Germany etc.), US, New Zealand and Australia.

Nowadays – worldwide, multiple methods and techniques are available for measuring the coefficient of friction on site or more simply, skid resistance in field. However, each method or technique is based on different principles and the output data are not always on the same basis to make the measurements comparable. This is not an issue when measuring macrotexture as the methods involved do not differ dramatically. Hence, several researchers have attempted to utilize pavement texture measurements as a direct input in developing models for the estimation of skid resistance performance. The trigger of these researches is on the one hand to eliminate the necessity to measure skid resistance in field (Ergun 2005, Ueckermann et al. 2015, Chou et al. 2017, Alhasan et al. 2018) and on the other to avoid discrepancies among the available friction devices. Thus, many of these models were developed based on scaling laboratory data; it was subsequently attempted to extrapolate the prediction results to the field (Alhasan et al.

2018, Wang et al. 2018, Hofko et al. 2019). Although, a few of the developed skid resistance prediction-models appeared to work sufficiently with laboratory-based data, the same is not true when these models were applied to field based data (Liu et. al 2004, Alhasan et al. 2018). Therefore, the relationship of field texture and skid resistance measurements is still under discussion.

Obviously in the field, there are several factors influencing pavement performance and it is not possible to quantify them accurately in a laboratory setting. In addition, the fact that each road presents unique characteristics based on the combination of factors such as traffic and climate gives an extra weight on the difficulties in fully describing and assessing field pavement performance. On these grounds, efforts to appraise field pavement performance have centred around climatic and traffic effects in order to motivate road operators and provide them with necessary information for maintaining pavement performance and road safety (Bijsterveld and del Val 2016, Hofko et al. 2019, Plati et al. 2019).

Considering the need of road engineers to understand the field performance of pavement characteristics, the present study aims to identify some of key aspects in skid resistance and its main textural components, macro and microtexture. The goal is twofold: to present and assess the effect of seasonal variation on a long-term basis focusing mainly on Mediterranean climate zone that is characterized by dry summers and mild-wet winters, and to illustrate the effect of cumulative traffic on skid resistance and macrotexture in the field.

To meet the objectives of this study, annual measurements-based data of skid resistance, macrotexture and road traffic were analysed. The data come from two highways located in Southern Europe with similar pavement characteristics but different traffic as described in the followings.

Experimental program

Pavement characteristics

Skid resistance and macrotexture data sets that were utilized for the current investigation come from road sections as included in a) an 11- year annual database of an urban highway and b) a 7-year annual database of an interurban highway. For the first case, the two investigated sections (A and B) are approximately 10 km each, on straight/relatively straight alignment and slope less than 3%, and for the second case, the two investigated sections (C and D) are approximately 12 km each, on straight/relatively straight alignment and slope less than 3% too. During the period of measurements, the sections were structurally sound and there were neither surface distresses nor indications for rutting or hydroplaning problems that may affect the analysis or results of the present study. In addition, no resurfacing works had been taken in place.

It is worth mentioning that wearing course/antiskid surface of the sections investigated are of hot-mix asphalt (HMA) concrete, surfaced with an open-graded mixture given the O-5 mix designation according to the ASTM D3515 (2001) standard. Steel slag used into the mix design for wearing course with polymer-modified bitumen of 25-55/70 grade penetration. The asphalt mix contains 4.0% bitumen binder by mass of the mixture and has an 11.5% air void content.

At the area of the interurban highway, the possibility of raining is generally increased comparing with the urban highway both in summer and wither months. Additionally, according to provided information about the vehicle flow of both duty vehicles and passengers’ cars the traffic volume is lower in the interurban highway.

Data collection

As already mentioned, for the current investigation annual field database (macrotexture and skid resistance) were utilized and analysed. For the macrotexture data the measurements had been conducted in conformance to ASTM E1845 (2015) for the standard practice for calculating pavement macrotexture – Mean Profile Depth (MPD). A vehicle mounted laser profiler system (ASTM E1845, 2015) had been utilized with the sampling rate frequency being approximately 16 kHz and the derived MPD data were averaged over 10-meter intervals.

For the skid resistance data, a calibrated GripTester system (Findlay Irvine, 2002) had been utilized. In general, the GripTester device consists of a three-wheeled system and a wheel fitted with ASTM E1844 (2015) standard smooth-tread tire that is utilized for measurement purposes. The axle of the test wheel is connected to a chain-system that controls the test wheel's slip at 14%. The water system for the GripTester produces a 0.5 mm water-film depth. The constant slip of the test wheel, coupled with the water-film depth, allows the GripTester to continuously measure a wetted pavement surface, with the system reporting an average unit-less friction measurement, called the Grip Number (GN). For the current investigation, the utilized data for GN index were averaged over 10-meter intervals consistently.

Both skid resistance and macrotexture data sets come from measurements at three times per year (survey periods) along the outer right wheel path of the individual lanes of the sections as deterioration occurs in this lane more rapidly, mainly due to the effect of heavy vehicles passing this lane (Plati and Pomoni 2019). Taking into consideration the UK Standards (Design Manual for Roads and Bridges 2015) of skid resistance measurements, as well the main characteristics of the Mediterranean climate zone, the three survey periods are described as following:

I. Early dry period – Approximately one week after the main period of increased rainfalls/ wet months (based on the specific climate zone).

II. Middle dry period – Approximately two to three months after period 1 (mainly referred to the start of the dry months).

III. Late dry period – Approximately four to six months after period 1 (mainly referred to the end of the dry months).

Figure 1 presents a general overview of the anticipated skid resistance levels based on the aforementioned survey periods.

The skid resistance measurements were processed in order to determine the Mean Summer Skid Coefficient (MSSC) as defined in UK Standards (Design Manual for Roads and Bridges 2015) and get an indication of the annual skid resistance level, irrespective of the survey period of measurements. MSSC represents an equilibrium level of skid resistance by averaging the results of the three pre-described survey periods throughout a year.

Furthermore, with a view to having corresponding skid resistance and macrotexture data, the macrotexture data from the three survey periods were similarly processed and averaged to calculate a representative annual macrotexture index – MPD for each of the investigated years. In addition, the Annual Average Daily Traffic (AADT) volume was used to calculate the cumulative traffic volume of the investigation period for each highway section

Data analysis and results discussion

Seasonal variation and year-to-year deterioration

For the section A of the urban highway, seasonal variation effect was investigated based on the measurements from the pre-defined survey periods before calculating the MSSC. Figure 2 gives an overview of the skid resistance data per period. Although data of some survey periods were not available and not shown, the seasonal variation effect is obvious. Furthermore, when put the focus on the early periods' data, it seems that after a point ("early Y9"), skid resistance decreases constantly and then, the seasonal variation becomes less pronounced. This point indicates the start of the equilibrium phase in skid resistance performance as described in relevant studies (Wilson 2006, Choi 2011, Friel et al. 2013) and referred thereinafter as the equilibrium point (EP).

In addition, it has been estimated that a rough decrease in skid resistance from the early to late period can be considered around the value of 35% (drop) (Plati et al. 2019). Noticeably, this drop is applicable for the specific climate zone and it can be dependent on the type of road materials, as well. However, it may be important information in case this drop leads to undesirable levels of skid resistance and some maintenance actions should be applied well ahead.

Afterwards, annual macrotexture levels in terms of MPD and MSSC in terms of GN (MSSC_GN) were plotted versus the cumulative traffic of each year of analysis, for both highways. As observed in Figures 3 to 6, after a certain cumulative traffic volume for all sections, macrotexture (MPD) tends to increase and inversely the skid resistance levels (MSSC_GN) tend to decrease at a more rapid rate. For the sections C and D of the interurban highway though, this inverse trend starts for a lower volume of cumulative traffic than at the sections A and B (Figures 5 and 6).

An extensive analysis on that behaviour between the two functional characteristics has been already described by other researchers (Ahammed and Tighe 2012, Kouchaki et al. 2018, Plati and Pomoni 2019); they have shown that macrotexture and skid resistance although being related characteristics and their behaviour has been connected, similar trend is not always possible in the field. The explanation of their inverse trend has been attributed to the textural components of the pavement surface. In particular, the lack of fine aggregates after extensive polishing produces increased MPD measurements (macrotexture), however there is no microtexture to contribute to skid resistance. Thus, in conjunction with the polished coarse aggregates, skid resistance tends to decrease more rapidly. In other words, it seems that there is not any positive effect on skid resistance resulting from the increase in macrotexture. Contrariwise, this increase in macrotexture could be considered as an indication of pavement surface wear, for instance detachments of fine aggregates from asphalt. This indication in combination with the loss of skid resistance could support tentatively the decision for planning pavement resurfacing.

In an attempt to identify whether there is any common element between the phases a) when the inverse trend starts (i.e. after Year 8: Y8) and b) when seasonal variation effect becomes less pronounced (point EP), Figure 7 shows the seasonal variation in comparison to the year to year deterioration for the section A of the urban highway.

From Figure 7, it is obvious that there is an indication of a relation between the two phases. In other words, it seems that when the pavement surface is getting more polished (notably inverse trend after Y8), the seasonal effect becomes less pronounced. This remark seems to be rational, considering the pavement condition at the phase after the inverse trend between MSSC_GN and MPD, which was previously explained. Particularly, considering the loss of fine aggregates and the polished coarse aggregates, both dusty (occurring in middle and late dry periods) and clean conditions (occurring in early dry periods) are not so much critical for the textural characteristics and, therefore, the seasonal variations do not affect the skid resistance significantly.

Cumulative traffic volume effect versus climate effect

Comparing the data of the two highway sections, Figures 3 to 6 present that both skid resistance and macrotexture indices start from identical values i.e. around 0.50

MSSC_GN and MPD 0.55-0.70 mm respectively. However, skid resistance faces a remarkable all-round drop, albeit macrotexture does not variate so much and finally increases. Especially, at the interurban highway sections C and D, it reaches greater values than at the urban sections. This remark may be attributed to the differences in the amount of cumulative traffic and rainfalls occurrence between the two highways. More specifically, intense rainfalls in the interurban highway clean more effectively the texture depth resulting in higher macrotexture values.

To discuss the matter further, the amount of traffic volume when the inverse trend is occurring at the two highway sections is different. Specifically, the start of the inverse trend is occurring at a higher amount of traffic at the urban highway than in the case of the interurban one. However, in the area of the interurban highway, the possibility of raining (both in early and middle-late dry periods) is increased and the traffic volume is less than in the urban highway (both duty vehicles and passengers' cars). Hence, the trend discussed does not seem to be rational at first glance. This remark triggers the analysis of available early-life data from the interurban highway (data before the section was put in traffic). More specifically, the two components of skid resistance – micro and macrotexture are investigated. On this purpose, spotted data coming from measurements of macrotexture (Mean Texture Depth – MTD in mm) with the sand patch method (ASTM E965, 2015) and microtexture measurements (British Pendulum Number – BPN) with British Pendulum (ASTM E303, 2018) from the section D were analyzed. Figure 8 presents the trend and the correlation between macro and microtexture components for the section D of the interurban highway.

From Figure 8, it can be seen that the trend between two components of skid resistance i.e. microtexture in terms of BPN and macrotexture in terms of MTD is proportional before opening to traffic. However after Section D was put in traffic, it seems that skid resistance (MSSC_GN) and macrotexture (MPD) start presenting an inverse trend (Figure 9). Given this inverse trend, it may be deemed that skid resistance in terms of GN is affected more by microtexture component of an asphalt pavement surface rather than the macrotexture component.

However, the question is why microtexture is so susceptible to traffic-polishing at this area of highway compared to the case of the urban highway, given the same type of pavement materials in both highways. The explanation could be connected with the specific conditions of increased possibility of raining (both in early and middle-late dry periods) and low traffic volume at the area of the interurban highway that was previously mentioned as well. In other words, the loose debris from aggregate polishing are cleansed away due to rainfalls very often, acting against fine dust formation providing with an increase in macrotexture; on the other hand, that dust could be helpful under the traffic flow and load for roughening the asperities of the aggregates (Do et al. 2007, Dunford and Roe 2010). Nonetheless instead of that, the surface aggregates are not getting rougher but polished, decreasing microtexture component and the resulting skid resistance.

Conclusion

At the present investigation, a study in macrotexture and skid resistance was performed using field data from pavement sections of an urban highway and an interurban one. The emphasis is put on two elements. The first element involves the effect of seasonal variation and year-to-year deterioration in skid resistance performance. The second element is interpreted as the cumulative traffic volume leads to an inverse trend between skid resistance and macrotexture levels. The starting of this inverse trend seems to be related to the increase in macrotexture mainly due to the loss of the surface fine aggregates. Also, it is argued to be connected with the equilibrium phase in skid resistance performance. In particular, due to the loss of the fine aggregates, both dusty (occurring in middle and late dry periods) and clean conditions (occurring in early dry periods) do not affect significantly the textural characteristics; then the seasonal variations do not influence anymore the skid resistance significantly.

Further, the findings of this research produce evidence in support of the statement that cumulative traffic, albeit being critical for skid resistance and macrotexture relation, is not the only determinant factor. The pavement sections of the interurban highway with the increased possibility of raining (both in early and middle-late dry periods) and the low traffic volume, presented an inverse trend in skid resistance and macrotexture levels, at a lower volume of cumulative traffic compared with the urban highway. This remark triggered the investigation of available early-life macrotexture (MTD) and microtexture (BPN) data sets from the interurban highway before the section was opened to traffic. Early-life data analysis showed that both skid resistance components (micro and macrotexture) presented a proportional trend. However, after the effect of cumulative traffic under the specific weather conditions, skid resistance seems to decrease while macrotexture increases. Hence, it is argued that microtexture component affects more skid resistance in terms of GN. To that extent, it may be also considered that the microtexture component was more susceptible to the conditions of the interurban highway and determinant for the skid resistance performance.

To sum up, the increase in macrotexture after the inverse trend should be discriminated as an indication of pavement surface wear and not be interpreted as better macrotexture performance. Besides, when assessing pavement performance, macrotexture must reach conjunction with skid resistance. Also, it seems of utmost importance to consider pavement textural characteristics and skid resistance concerning weather conditions or locally provided data. However, at the equilibrium phase when the seasonal variation effect becomes less pronounced in skid resistance performance, weather conditions are not the key issue.

In the end, the findings of the present study result in awareness of constraints of using only macrotexture data to develop models for predicting skid resistance in field conditions. All in all, it is strongly recommended to use proper measuring devices to collect reliable and accurate skid resistance data, but it is important to mind the limitations and principles of the utilized measuring devices in the field.

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Figures list

Figure 3. MSSC_GN and MPD vs. cumulative traffic of the urban highway section (Section A).

Figure 4. MSSC_GN and MPD vs. cumulative traffic of the urban highway section (Section B).

Figure 5. MSSC_GN and MPD vs. cumulative traffic of the interurban highway section (Section C).

Figure 6. MSSC_GN and MPD vs. cumulative traffic of the interurban highway section (Section D).

Figure 7. Comparative illustration of seasonal variation and year to year deterioration (Section A).

Figure 8. Early-life BPN and MTD data sets of the interurban highway section (Section D).

Figure 9. In-service MSSC_GN and MPD data sets of the interurban highway section (Section D).