# EXPLORING AGGREGATE INFLUENCE ON LONG-TERM SKID RESISTANCE IN SOUTH AFRICA

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## ABSTRACT

Skid resistance is an integral part of the road conditions that influence road safety on paved roads. Amongst other factors, the aggregate type used to construct wearing courses significantly affects the skid resistance of flexible road surfacing. Understanding the influence of aggregate mineralogy on skid resistance provides an opportunity to enhance road safety and optimise material selection for wearing course construction. This paper presents the correlation between the characteristics of aggregates used to construct wearing courses in South Africa and their long-term skid resistance performance. In this study, some of the commonly used aggregate types in the construction of wearing courses in South Africa were assessed for their mineralogical properties and long-term skid resistance performance after simulated traffic polishing. This study established that the aggregate types with a higher hardness, which is a property primarily dependent on the mineralogical makeup of an aggregate, tended to retain their surface texture better than softer aggregates. The study's results also noted that further research must be invested in determining the worst accuracy level required to achieve credible aggregate microtexture data.

**Keywords**: Aggregate, Friction, Mineralogy, Polishing, Road Safety, Skid resistance, Surface Texture, Wearing courses.

## 1. INTRODUCTION

In South Africa, road safety poses an issue of concern since the country regularly experiences many road accidents, with some resulting in fatalities (Mona, 2022). Skid resistance, defined as the force developed when a tyre is prevented from rotating and slides on a road's surface (National Research Council (US), Highway Reasearch Board, 1972), is a key parameter for road safety. Skid resistance depends on various factors, including road surface characteristics, wherein surface texture is the primary parameter that governs the skid resistance performance of a given road surface (International Standardization Organization, 2002). The surface texture of a road can be divided into a range of delineations depending on the size of the wavelength and amplitude of the irregularities on the road surface; however, the significant categories of surface texture that affect skid resistance are micro and macrotexture (Sandberg, 1997).

The surface macrotexture refers to all irregularities on the road surface with an amplitude of 0.1 to 20 mm and a wavelength of between 0.5 to 50 mm (Permanent International

Association of Road Congress, 1987) and is regarded as an overall asphalt mixture characteristic, which primarily provides dispersion of excess water on the road surface during wet conditions and the dissipation of energy of tyres in motion (Kane et al., 2013). Surface microtexture is all irregularities on the road surface with an amplitude of less than 0.2 mm and wavelength of less than 0.5 mm, and its magnitude dramatically depends on the initial roughness of aggregate and its ability to retain its roughness after being subjected to traffic polishing action (Do et al., 2009). The microtexture primarily produces frictional resistance and disrupts the continuity of the water film between the tyre and road surface during wet conditions (Kane et al., 2013). Previous research has established a relationship between the initial aggregate microtexture, its evolution resulting from traffic polishing and the mineralogical composition of the aggregate used for fabricating wearing courses. (Tourenq & Fourmaintraux, 1971). Previous work has established relations that offer the potential to analyse an aggregate's ability to retain its microtexture as defined by its mineral composition (Kane et al., 2013).

This study aims to conduct experimental work that will facilitate the establishment of a relationship between the mineralogical properties of aggregates typically used for constructing wearing courses in South Africa and the long-term skid resistance performance of the aggregates.

As prevalent in most countries globally, South Africa has no official skid resistance testing standard. In addition, there is no official skid resistance predictive data that can be used to model the skid resistance behaviour of the aggregate used to construct wearing courses in the country. Predictive skid resistance performance of aggregate provides an opportunity for optimising road construction material used to construct wearing courses. Developing an understanding of skid resistance behaviour, as defined by aggregates used to construct wearing courses in the country, also allows for improving road maintenance since it will provide the potential to predict the long-term quality of wearing courses in the country. This paper aims to achieve its study objectives by satisfying the following:

1. To determine the skid resistance performance of aggregates typically used to construct wearing courses in South Africa.
2. To establish a correlation between the mineralogy of aggregates typically used to construct wearing courses in South Africa and the long-term skid resistance performance of the aggregates.
3. To establish a relationship between the evolution of the surface texture of aggregates used to construct wearing courses in South Africa and the mineralogy of the aggregates.
4. To establish a correlation between the evolution of the surface texture of aggregates used to construct wearing courses in South Africa and the long-term skid resistance performance of the aggregates.

In this paper, the first section outlines the mineralogy of the aggregates used in the study. The second section outlines the measurement of the surface texture and the polishing and subsequent friction test. The third section outlines the analysis of the results of the tests undertaken in the study. The section then outlines the analysis of the results and the development of the correlations between the mineralogy, long-term skid resistance performance, and the surface texture evolution of the aggregates used in the study.

## 2. EXPERIMENTS

### 2.1 Materials

In this study, three different aggregates, namely Andesite, Dolomite, and Granite, were used. The aggregates were selected due to their prevalence in use in the wearing course construction industry in South Africa. They were sourced from various quarries around the Gauteng province, the country's economic hub. The aggregates were also chosen according to the variability of their mineralogical composition. Andesite is an intermediate igneous rock generally containing intermediate silica content. Dolomite is a sedimentary rock primarily composed of Calcium Carbonate, and Granite is an intrusive igneous rock composed of interlocking crystals.

### 2.2 Mineralogical Characterization

The mineralogy of each of the aggregate types used in the study was determined through petrographic examinations using a high-power petrographic microscope. The aggregates were ground into a thickness of 30µm and embedded in a resin for examination. The samples were then examined in a high-power petrographic microscope capable of x600 magnification, wherein the main rock types and the relative proportions of the mineral composition in each aggregate was determined (See the mineral composition of the aggregates in Table 1).

**Table 1: Aggregates Mineral Composition**

| Aggregate Type | Mineral Type | Mineral Composition (%) |
|---|---|---|
| Andesite | Quartz | 4,5 |
| | Microcline | 14,4 |
| | Chlorite | 17,5 |
| | Actinolite | 23,6 |
| | Tectosilicate | 30,4 |
| | Dolomite | 1,9 |
| | Epidote | 7,8 |
| Dolomite | Quartz | 7,7 |
| | Dolomite | 92,3 |
| Granite | Quartz | 31,6 |
| | Muscovite | 9,8 |
| | Chlorite | 1,4 |
| | Microcline | 21,5 |
| | Tectosilicate | 35,7 |

### 2.3 Aggregate Mosaic Sample Preparation

Circular stone mosaics were prepared in accordance with SANS 3001: A11 / BS EN 1097-8 for each stone type (See Figure 1 for an example of one of the mosaic samples). For each stone type, 225mm diameter stone mosaics were fabricated in accordance with the following procedures:

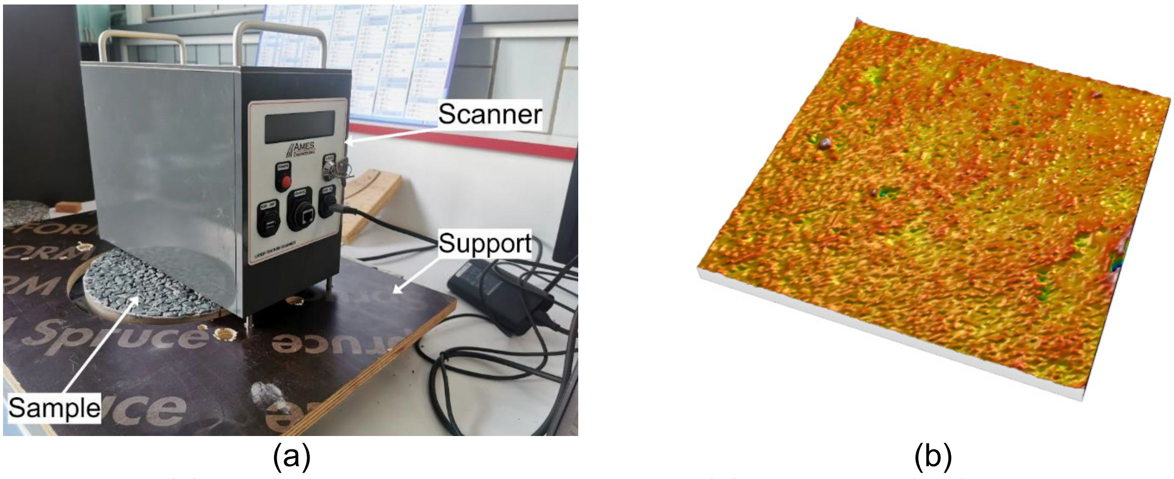
1. The stone samples were sieved through a 10 and 7mm sieve, where only the material retained on the 7mm sieve was retained for further testing.
2. The retained material from each sieve was run through a 7mm round bar flakiness gauge to eliminate flaky material from the sample. The material was then washed of dust and impurities.

3. The stones were then individually placed into a greased steel mould. They were placed in a single layer, with each stone lying on its flattest face.
4. A silica water paste was then poured into the mould such that the paste covered two-thirds of the stone layer, whereafter the paste was allowed to dry.
5. The mould was then filled with resin.
6. After the resin had completely set, the sample was then removed from the mould, and the silica paste was washed off from the top of the sample.

**Figure 1: Example of circular mosaics samples fabricated in the laboratory**

### 2.4 Surface Texture Measurement

For each of the different stone types, the mosaics were placed on a support designed to secure a surface texture scanner and ensure a uniform reference position of the samples throughout the study (See Figure 2 (a) for the laser texture measurement setup). An LTS 9500 scanner was then placed on the support, and the scanner was used to scan two 100 x 100mm zones along the region of the sample, which would most likely be polished in the subsequent friction tests, at a resolution of 50 µm. These surface texture measurements were conducted on all samples before any polishing was done, and they were subsequently done at the end of both 90 000 and 180 000 cycles of polishing during friction tests. Data from the scanner was retrieved and processed through the Mountains Map software to attain the roughness parameters of each sample (See Figure 2 (b) for a typical 3D surface topography obtained from the Mountains Map software).

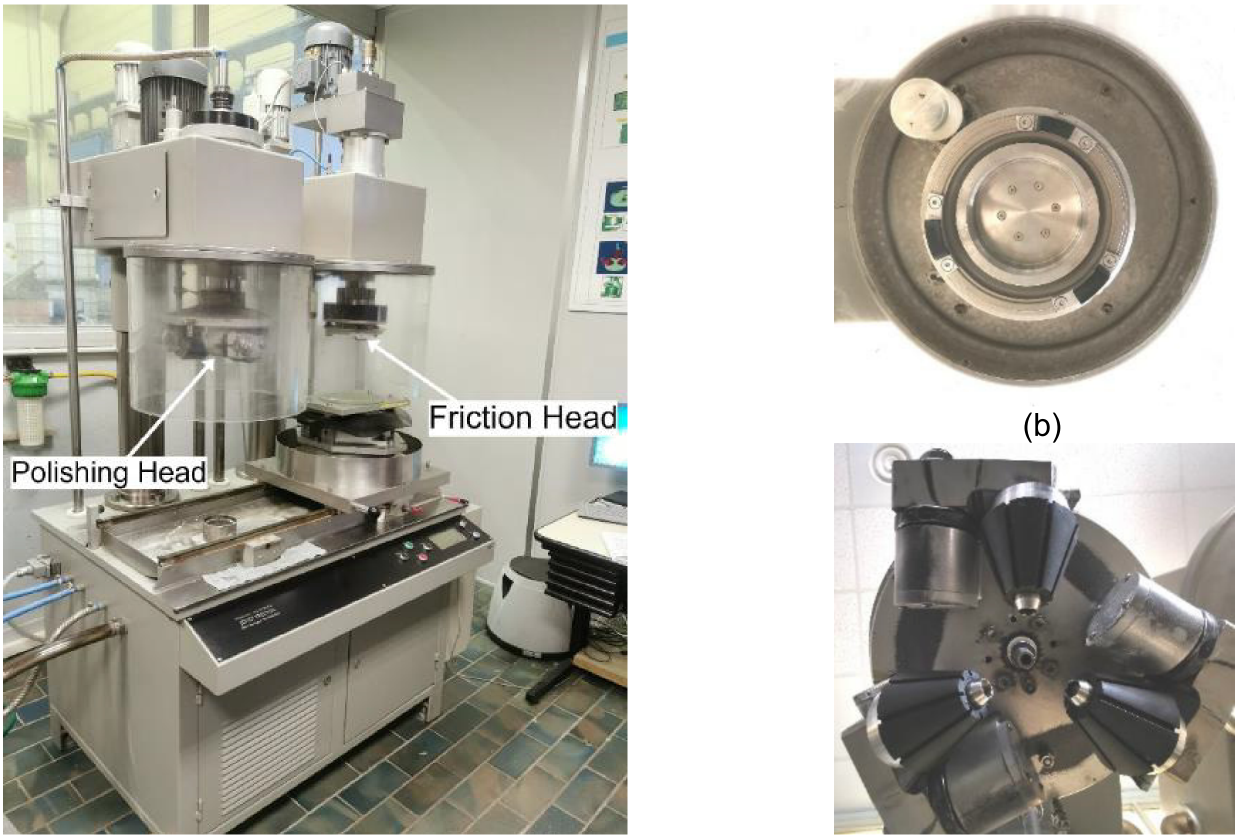


(a) (b)

**Figure 2: (a) Laser Texture Measurement setup; (b) Typical 3D Surface Topography from scanner**

## 2.5 Polishing and Friction Measurement

In this study, polishing and friction tests were performed with the Wehner-Schulze machine. This is a machine consisting of two rotary stations, with one dedicated to the polishing of samples and the other for measuring friction (See Figure 3 for the Wehner-Schulz Machine used for the experiments). The polishing station contains a rotary head which consists of three rubber cones whereas the friction measurement station contains a rotary head which consists of three rubber pads with a surface of 4 $cm^2$, positioned at an angle of 120º from each other. During polishing, a sample was secured in the mould of the machine where the mould was placed under the polishing head of the machine. The polishing head of the machine was then placed on the sample, and the sample was polished with the polishing head exerting an average pressure of 0.4 $N/mm^2$ on the sample. Throughout polishing, a mixture comprising of 5% quartz powder (Silica Powder <0.06mm) and 95% water was sprayed on the sample to accelerate polishing. After polishing was completed, the sample was washed before the mould was manually moved to the friction measurement station. In the friction measurement station, the rotary head was accelerated to a speed of 100 km/h, where water was then projected on the surface of the sample and the motor of the rotary head was stopped. The rotary head was then dropped onto the sample such that the rotation of the rotary head was stopped by the friction between the rubber pads and the surface of the sample. The friction time curve was recorded and the friction at 60 km/h was then noted down for analysis.



(a) (b) (c)

**Figure 3: (a) The Wehner-Schulze Machine; (b) Friction Head; (c) Polishing Head**

## 3. RESULTS AND DISCUSSIONS

### 3.1 Mineralogical Composition

The study established that the mineralogical composition of the aggregates that were elected for the study was highly variable. This variability offered a good chance of defining a good representation of the long-term skid resistance performance of South African aggregates with respect to the mineralogical composition of the aggregates.

In a previous study, Kane validated a relationship between the hardness of minerals in aggregates to the long-term skid resistance performance of road surfaces (Kane et al., 2013). In his study, Kane proposed an Average Hardness Parameter (AHP), which defines the hardness of aggregate in accordance with the mineralogical composition of aggregate (Kane et al., 2013). In an extension of the work done by Tourenq and Fourmaintraux (1971), where they had proposed the Average Hardness ($dm_p$) and the Contrast of Hardness ($C_d$) in their study to quantify the capability of aggregate to retain skid resistance when subjected to traffic polishing, Kane proposed that AHP is equivalent to the sum of the two aggregate hardness. In his work, Kane replaced Vicker's hardness with Moh's hardness scale.

$$dm_p = \sum_i dv_i \times p_i \tag{1}$$

$$C_d = \sum_i \left| dv_i - dv_p \right| \tag{2}$$

$$AHP = dm_p + C_d \tag{3}$$

Where: $dv_i$ is the hardness of each mineral constituting the aggregate, $p_i$ is the percentage by mass of each mineral, and $dv_p$ is the hardness of the most abundant mineral in an aggregate (Tourenq & Fourmaintraux, 1971).

The results in Table 2 revealed that aggregates containing an abundance of hard materials tended to have a superior hardness than aggregates containing soft minerals. Thus, it can be implied that aggregates containing minerals with a superior hardness tend to have a higher hardness than those containing soft minerals.

**Table 2: Mineral composition and Aggregate Hardness Parameter**

| Aggregate Type | Mineral Type | Mineral Composition (%) | $p_i$ | $dv_i$ | $dm_p$ | $\left\|dv_i - dv_p\right\|$ | $C_d$ | $AHP$ |
|---|---|---|---|---|---|---|---|---|
| Andesite | Quartz | 4,5 | 0,045 | 7 | 5,03 | 1,5 | 8 | 13,03 |
| | Microcline | 14,4 | 0,144 | 6 | | 0,5 | | |
| | Chlorite | 17,5 | 0,175 | 2 | | 3,5 | | |
| | Actinolite | 23,6 | 0,236 | 5,5 | | 0 | | |
| | Tectosilicate | 30,4 | 0,304 | 5,5 | | 0 | | |
| | Dolomite | 1,9 | 0,019 | 3,5 | | 2 | | |
| | Epidote | 7,8 | 0,078 | 6 | | 0,5 | | |
| Dolomite | Quartz | 7,7 | 0,077 | 7 | 3,77 | 3,5 | 3,5 | 7,27 |
| | Dolomite | 92,3 | 0,923 | 3,5 | | 0 | | |
| Granite | Quartz | 31,6 | 0,316 | 7 | 5,69 | 1,5 | 9 | 14,69 |
| | Muscovite | 9,8 | 0,098 | 2 | | 3,5 | | |
| | Chlorite | 1,4 | 0,014 | 2 | | 3,5 | | |
| | Microcline | 21,5 | 0,215 | 6 | | 0,5 | | |
| | Tectosilicate | 35,7 | 0,357 | 5,5 | | 0 | | |

## 3.2 Evolution of Surface Texture

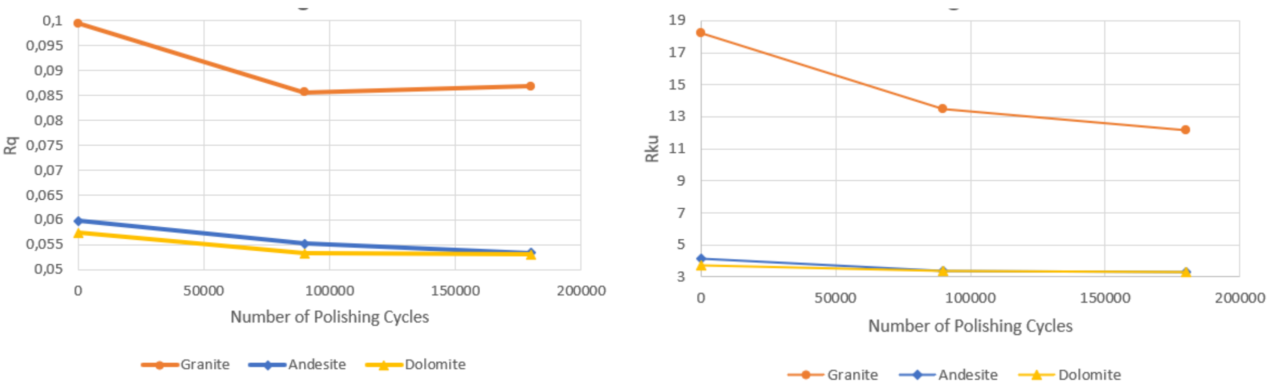
The surface texture in this study was quantified through laser scanning, which is one of the commonly used no-contact texture measurement methods. In the study, two roughness parameters, which are namely the height root mean square deviation (Rq) and the Kurtosis (Rku) were used to quantify the evolution of the surface texture of the aggregate surface subjected to traffic polishing. According to previous studies, Rq, which quantifies the height of asperities of a surface and Rku, which quantifies the shape of asperities of a surface, serve as good surface texture indicators (Vieira, 2014). Rku is a surface texture indicator which can either be one of the following cases (Evident, 2024):

- Rku = 3: Normal distribution,
- Rku > 3: The height distribution is sharp,
- Rku < 3: The height distribution is even.

For each mosaic specimen, two zones within the polishing track of the specimen were scanned, wherein, in each of those zones, surface data was extracted from three random individual aggregates. The extracted data was then processed through the Mountains Map software to determine the two parameters of the surface texture of the aggregates, using the following equations:

$$Rq = \sqrt{\frac{1}{\ell}\int_0^{\ell} Z^2\,(x)dx} \qquad (3)$$

$$Rku = \frac{1}{Rq^4}\left(\frac{1}{\ell}\int_0^{\ell} Z^4(x)dx\right) \qquad (4)$$



(a) (b)

**Figure 4: (a) Evolution of the Height Root Mean Square parameter; (b) Evolution of the Kurtosis parameter**

From the results depicted in Figure 4, it is evident that there was a correlation between the hardness of the aggregates and the Rq and the Rku parameters. The aggregates with a higher AHP tended to have a higher Rq and Rku both before and after each one of the polishing cycles. From the results, it is evident that Granite, which is harder than both Andesite and Dolomite had a much higher Rq and Rku and after each polishing cycle, the aggregate did show a much steeper decline of both the height and shape parameters, however, the parameters remained higher than the other aggregates at 180 000 cycles. From the results, it can also be observed that Granite had a decline in Rq up until 90 000 cycles of polishing, which was succeeded by an increase in Rq until 180 000 cycles. This observation can be attributed to differential polishing, which is a phenomenon proposed by Tourenq and Fourmaintraux in a previous study, where additional roughness is generated on aggregates after polishing due to the presence of a variety of minerals in an aggregate which have a varying hardness (Tourenq & Fourmaintraux, 1971). Dolomite, the softest aggregate, and the aggregate with the lowest mineral constituent variability exhibited the lowest height and shape parameters, and after each cycle of polishing, the aggregate still showed a decline in the height and shape parameters. Andesites, which had an intermediate hardness, displayed intermediate height and shape parameters; however, after each cycle of polishing, it was evident that the aggregate had a steep and consistent decline in the height and shape parameters. The observations in this study validated the findings in the previous study by Tourenq and Fourmaintraux, which proposed that during the polishing of aggregates, the evolution of the surface texture can either be a result of general polishing, which is just the removal of material, or differential polishing, which is a process which creates relief between hard and soft material (Tourenq & Fourmaintraux, 1971).

### 3.3 Evolution of Friction Coefficient

Figure 5 shows the friction results obtained from the Wehner Schulze machine for every aggregate at 0, 1 000, 2 000, 5 000, 10 000, 20 000, 50 000, 90 000 and 180 000 cycles of polishing. From the results, it can be observed that there was a decline in friction coefficient values for each aggregate after every round of polishing. In each aggregate type, there was a steep decrease in friction values from 0 to 20 000 cycles of polishing, and then the decline in friction coefficient values decreased and stabilized from 20 000 cycles up until terminal friction was reached at 180 000 cycles. The results also show that Andesite had a slightly higher initial coefficient of friction than all the other aggregates. Between 0 and 1 000 cycles, Andesite's friction declined much faster than that of Granite, resulting in lower friction readings than Granite throughout the rest of the test. On the other hand, Dolomite proved to have much lower friction coefficient values than the other aggregates, and it can also be observed that the decline in friction of Dolomite between 0 and 1 000 cycles of polishing was much higher than that of other aggregates. It can also be observed that Granite, which is the hardest aggregate, maintained superior friction values from 0 to 180 000 cycles than the other aggregate types, whereas Dolomite, which is the softest aggregate, yielded the lowest friction coefficient values throughout the test.

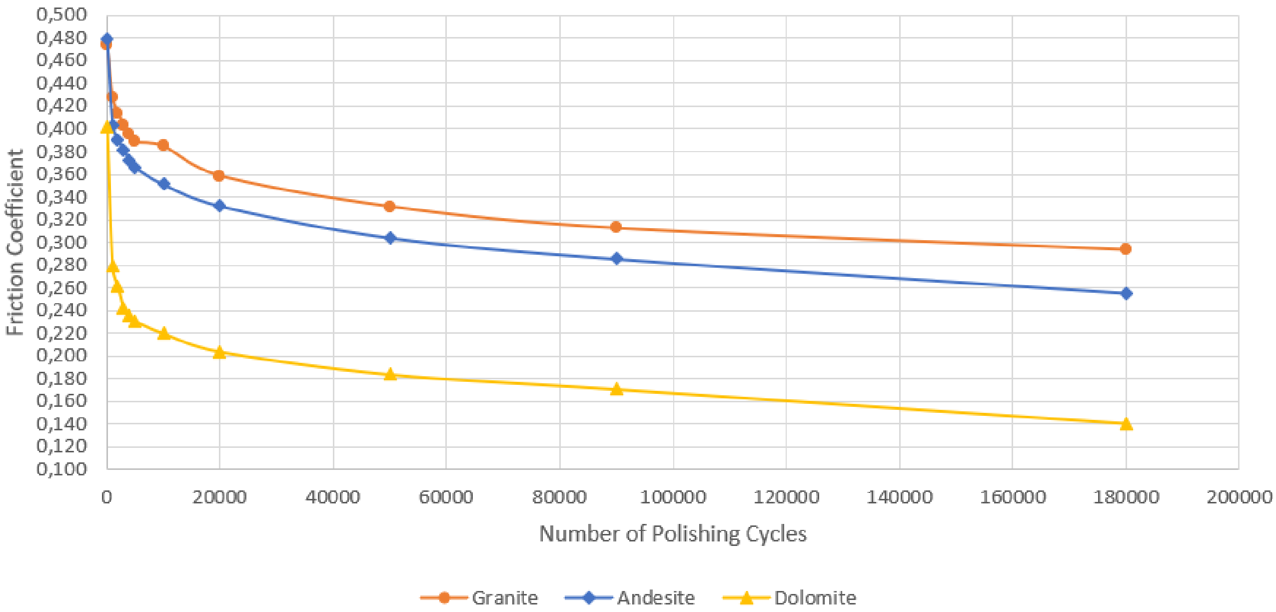


**Figure 5: Evolution of Friction Coefficient**

### 3.4 Correlation of Mineralogy, Surface Texture and Friction

From the results in Figure 6, it was observed that there was a correlation between the hardness of the aggregates and the evolution of the friction coefficient of the aggregates when subjected to traffic polishing. The results confirm findings from previous studies which have established that the long-term skid resistance performance of aggregate is directly proportional to the hardness of the aggregate (Kane et al., 2013). Such findings have strongly validated how much of an influence aggregate mineralogy has on the long-term skid resistance performance of wearing courses.

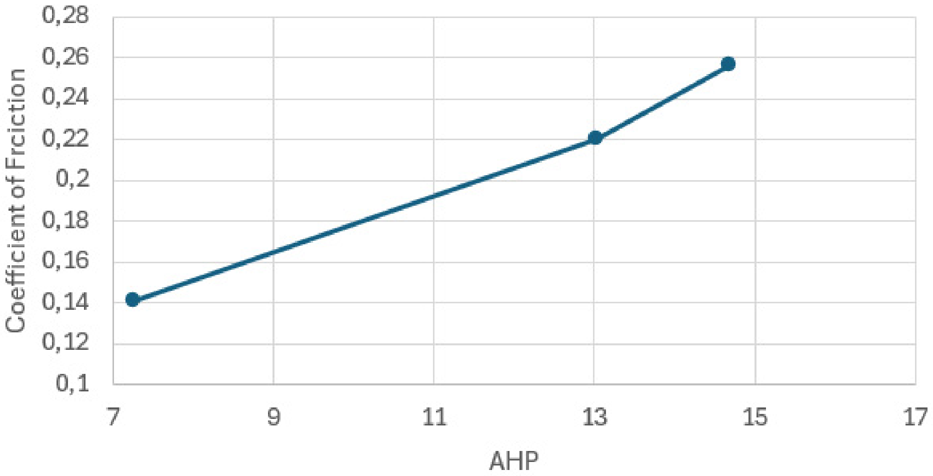
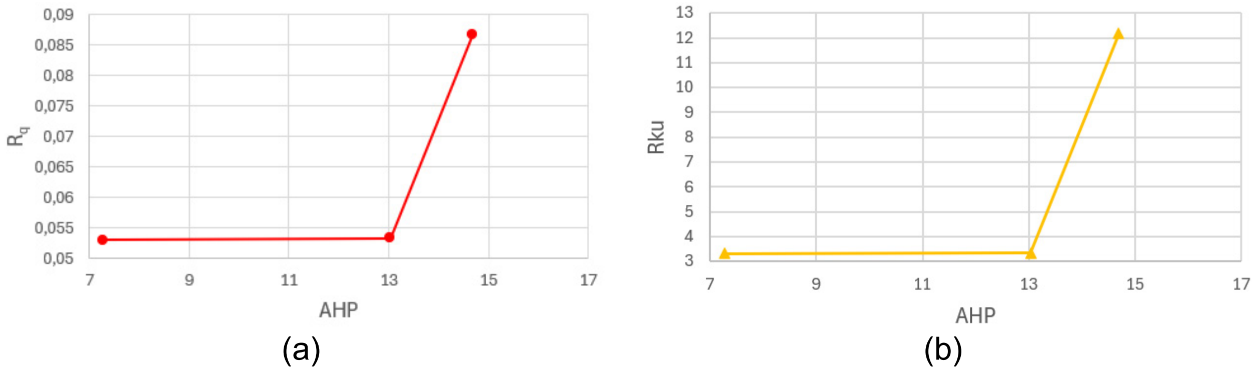


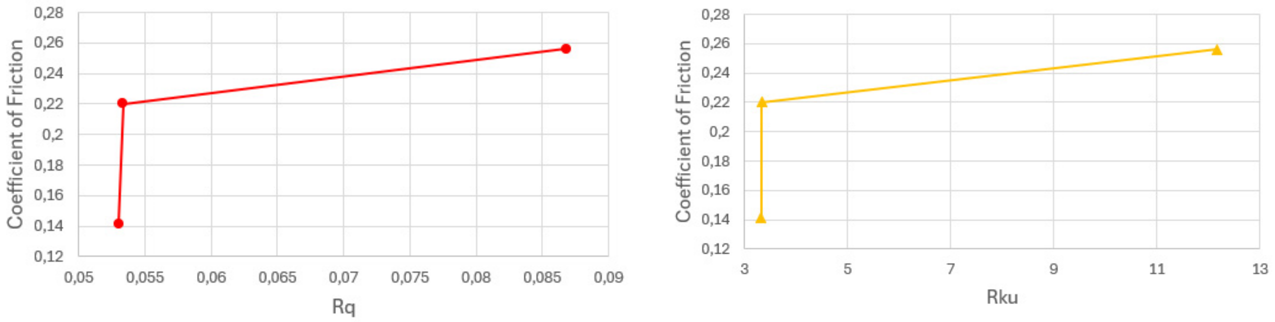
**Figure 6: Coefficient of Friction vs Average Hardness Parameter**



(a) (b)

**Figure 7: (a) Height Root Mean Square vs Average Hardness Parameter; (b) Kurtosis vs Average Hardness Parameter**

The results from Figure 7 have further shown that there was a correlation between the hardness and the surface texture of the aggregates. The results consistently showed that both the height and shape of irregularities of an aggregate surface greatly depended on the hardness and, consequently, the mineralogy of the aggregate. Results from Figure 8 further convey the relationship between the surface texture and the friction coefficient of the aggregates. From the results, it can be observed that an increase in both the height and the sharpness of the irregularities of the surface of the aggregates translates to increased values of the friction coefficient of the aggregates.



(a) (b)

**Figure 8: Coefficient of Friction vs Height Root Mean Square; (b) Coefficient of Friction vs Kurtosis**

## 4. CONCLUSIONS

This work explores the influence of aggregates on the long-term skid resistance of wearing courses in South Africa. Various aggregates commonly used to construct wearing courses were used throughout the study to establish relations that would quantify the relationship between mineralogy and the evolution of aggregate skid resistance.

From the work done in this study, the following can be concluded:

- The results from this study generally validated a correlation between the mineralogy of aggregates commonly used to construct wearing courses in South Africa and their long-term skid resistance performance.
- This work concludes that the skid resistance performance of a wearing course is directly proportional to the hardness of the aggregates used to construct the surfacing.
- It can also be concluded that the evolution of aggregates' surface texture is greatly dependent on their hardness.
- It can also be deduced from the study that aggregates' skid resistance diminishes with the surface texture reduction when aggregates are subjected to traffic polishing.

From this study, future work can be invested in varying the resolution used for surface texture measurements to deduce the level of accuracy needed to attain credible aggregate microtexture data.

## 5. ACKNOWLEDGEMENTS

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