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Modeling and testing of road surface aggregate wearing behaviour

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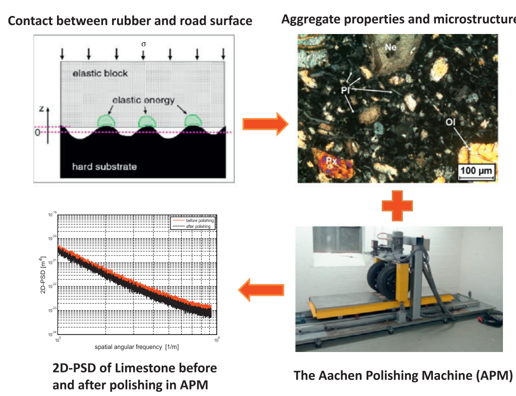
HIGHLIGHTS

- Nine sources of aggregates with different rock types and mineral contents were chosen for wearing analysis.
- Wearing tests with the Aachen Polishing Machine using real vehicle tires were conducted.
- We used the wearing model based on the tire-road contact theory of Persson.
- Based on a spectral analysis, the wave length corresponding to the wear of the surface was identified.

GRAPHICAL ABSTRACT



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ABSTRACT

The amount of urban dust and especially the particulate matter (PM) production is closely related to the wearing resistance of the aggregates on the road surface. In this research, the Aachen Polishing Machine (APM) was used to conduct wearing tests; the APM uses real vehicle tires. The obtained results were analysed with a rubber-road wearing model. Based on the spectral analysis of the texture, the wave length coinciding with the most wear of the specimen surface was identified. Findings show that the decrease of skid resistance can be ascribed to changes in the micro-texture up to 62.8 µm in the polishing test with the APM procedure. The final friction after polishing tests exhibits a positive correlation with the average hardness of the aggregate and the mass percentage of non-fissile mineral. A positive interdependence is observed for the quartz content whilst the calcite content exhibited a negative one. The average height induced by polishing is selected to determine and quantify the abrasion of aggregate. The results show a directly proportional relationship between the abrasion and the contact pressure.

1. Introduction

Minerals in aggregate develop fractures or may even be worn from the mineral matrix completely as a result of weathering and the mechanical load transferred onto the pavement surface through the tire [23,25]. The consequence is on the one hand the particulate matter (PM) emission from the wearing of the pavement. On the other hand, the skid resistance of road decreases due to polishing effects and may fall below values required to ensure sufficient braking distance in the course of pavement service life. Furthermore, the portion of fine wear particles which remains on the road surface will serve as polishing agents and speed up the wearing process of the pavement by traffic loading.

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PM is a common air pollutant and consists of very small particles in either solid or liquid states. A large number of scientific studies have found PM to be a major pollutant and that extensive exposure causes various adverse effects with regard to public health [2,3,13]. The investigation from Federal Environment Agency of Germany showed that the largest single source is from road traffic including automotive exhaust gases (mainly from diesel engine 29,000 t/year) and abrasion of vehicle components (brakes 7000 t/year and tires 6000 t/year) [22].

Generally it has to be said that the part of PM emission from wearing of the pavement is still undetermined. Based on the experimental investigations in the US, Finland and Sweden, the amount of urban dust and especially PM_{10} (particles with an aerodynamic diameter smaller than 10 μm) emissions are shown to be closely related to the wearing resistance of the aggregate on the pavement surface [1,6–11,18,19]. Since the water and polishing agents can significantly influence the generation and measurement of PM from the wearing process of road surface, the above mentioned tests were different from the traditional wearing tests in pavement engineering that needs water and polishing agents during the test program. Furthermore, the knowledge on wearing of road surface should be better understood based on the combination of phenomenological tests and tire-road wearing model.

This research project focuses on the wearing behaviour of pavements. Therefore the wearing tests with the APM were conducted on samples manufactured with aggregate from various sources to better identify the influential effects. The spectral analysis of texture was conducted to identify the wave length coinciding with the most wear of the specimen surface. The wearing model based on the tire-road contact theory of Persson allows for an observation of the road surface, which can distinguish frequencies ranging from the micrometer scale to the centimeter scale. This approach enables the linking of phenomenological characteristics with physical contact theory and thus constitutes to a more substantiated evaluation of the polishing and wearing resistance.

2. Literature review – polishing and wearing resistance of road surface aggregate

Traffic safety can only be provided under sufficient activation of frictional forces in the tire-road contact surface and therefore the long-term skid resistance; this is primarily affected by the polishing or wear resistance. The polishing or wearing effect may be described sufficiently by the angularity and the abrasion of the aggregate, which is illustrated in Fig. 1:

- The change of the aggregate's micro-texture in the course of polishing is referred to as the polishing resistance and is also used to describe the skid resistance
- The abraded material or the mass loss as a result of the polishing process is referred to as the wearing resistance.

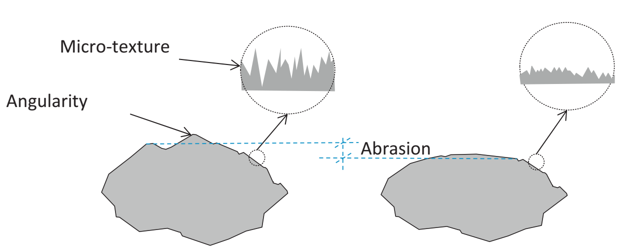

Fig. 1. Texture properties before and after polishing [27].

In Germany, the polishing and wearing resistance may be determined experimentally in part by means of the following test procedures:

- The polishing resistance of coarse aggregate can be described with the polished stone value (PSV), determined in accordance with EN 1097-8:2009. Cubic aggregate with a diameter of ca. 10 mm is mounted in mould segments which are assembled to a ring. These are fixed around the outside of a wheel and polished in for three hours with coarse emery and emery powder. The British Pendulum Tester (BPT) is used to evaluate the coefficient of friction at selected polishing stages. Aggregate with a higher skid resistance and polishing resistance exhibit higher PSV.
- Another means of determining the polishing resistance of pavements is the Wehner/Schulze test (W/S) in accordance with EN 12697-49. In analogy to the PSV test the polishing load is imposed by three conical rubber rollers under the addition of water and/or quartz sand or quartz powder. After polishing the activated friction is measured at 60 km/h by another measuring unit equipped with three rubber pads (grain sizes 0/2 mm, 2/5 mm, 5/8 mm and 8/11 mm).
- The abrasion of aggregate is measured with the Micro-Deval test (MD) according to EN 1097-1 and is quantified by the mass loss. A steel drum is filled with the aggregate, 5000 g of steel balls and 2000 ml tap water. The drum is then rotated with a speed of 100 min^{-1}. The mass loss to determine the MD coefficient is defined as the percentage of the aggregate to pass a 1.6 mm sieve. Aggregate with a high wearing resistance exhibit a low MD coefficient.

In PSV and W/S tests, the polishing resistance is characterized as the skid resistances of aggregate after the polishing process and can be measured with the pendulum tester or the W/S test. The wearing resistance (related to the abrasion of specimen surface) is not taken into consideration. The Micro-Deval test is characterized by its efficiency, reliability and accuracy whilst necessitating very simple equipment. If the polishing process is described by a contact-mechanic-based model the Micro-Deval coefficient (MDE) represents a wear coefficient to characterize the aggregate [14]. However, the MDE considers solely the weight loss and neglects the changes of the aggregate texture and angularity [29].

Generally the infinitesimal material abrasion (dz) is dependent on the polishing duration, the contact stress, the resistance of material against polishing. Kane [14] has developed a model to describe aggregate wear in W/S polishing process based on contact mechanics. The wear law can be formulated as such:

$$z_R(x, y, N, A) = \beta \times MDE(A) \times p(x, y, N) \quad (1)$$

where z_R represents the material removal at the location (x, y) after Nth polishing cycles in W/S. $p(x, y, N)$ is the contact pressure and the MDE is Micro-Deval coefficient.

In Wang et al. [28] samples were polished in a realistic manner with the Aachen Polishing Machine (APM). It was found that only the highest points of aggregate particles were polished during polishing with APM. Therefore, the penetration depth of tire rubber affects the result of polishing tests significantly.

3. Wear model based on tire-road contact theory of Persson

Previous research [15–17,26] has revealed that the normal and tangential force between tire and road depends primarily on the wavelengths and the amplitude of surface texture. The