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Influence of freeze–thaw on the polishing resistance of coarse aggregates on road surface

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HIGHLIGHTS

- We combined the freeze–thaw effect with the mechanical loading effect in process of polishing test.
- The change of the texture was taken as a link between the polishing effect and the skid resistance development course.
- The freeze–thaw susceptibility by the difference of the skid resistance development before and after the freeze–thaw.
- We related the skid resistance behavior to the mineralogical composition and structure of the specific aggregate type.

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ABSTRACT

The aggregates used for surface layers are of central importance for the skid resistance of a road as they are subjected to a combined load due to traffic and weather conditions. In this paper, different aggregates are selected and two plate specimens are produced using each aggregate. One of the test plates is subjected to solely polishing load and the other one was treated with a combined load of polishing and freeze–thaw cycles. By comparing the texture changes and the skid resistance development, a statement is derived on the impact of a freeze–thaw effect for the short-term and long-term development of skid resistance.

1. Introduction

Skid resistance of road surfaces is essential for traffic safety. Statistics show that the accident rate of road traffic decreases with higher skid resistance [1]. For both asphalt and cement concrete road surfaces, the skid resistance is mainly dependent on the aggregates in the surface layer in the long run [2,3]. Skid resistance of road generally decreases with the course of polishing effects on the aggregates due to traffic load [2–6]. Therefore, in European norm, the standard test method of polished stone value (PSV) was applied to determine the resistance to polishing (EN 1097-8: 2009). A high PSV indicates better polishing resistance and hence higher skid resistance of the road [7–9]. As a result, there is a minimum PSV required for aggregates of road surface materials in the standard specifications for road construction in Germany.

The material of the road surface layer is not only subjected to the mechanical load, but also affected by the weathering action; for example, in some cases freezing–thawing is a major cause of pavement damage [10–13]. On the one hand, water flow and freeze–thaw cycles can reduce the adhesion between binder (bitumen or cement) and aggregates, leading to cracking and raveling [10–12]. In the worst case, the structure of the pavement may be completely destroyed [13]. On the other hand, it can also change the aggregate properties, such as strength, compressibility, porosity and permeability [13,14]. The structure of the aggregates will be loosened or broken due to the expanding of water when freezing and the chippings will be flushed away. Frost durability is one of the most important properties of building materials [14]. Therefore, the resistance to freezing and thawing (RFT) of aggregates is evaluated by the mass loss after repeated freezing and thawing (EN 1367-1: 2007) in the standard specifications. Lower mass loss means better quality. The mass loss of the aggregates for high-rank road surfaces in Germany must be under 1%.

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Even for aggregates with a mass loss of lower than 1%, freeze–thaw can affect the structure and particularly the micro-texture of the aggregates, further affecting their resistance to polishing, and causing problems with skid resistance and traffic safety. However, this effect of freeze–thaw is still not known, as the influence has not yet been considered either in the PSV test or the RFT test.

In this paper, a combined traffic and weathering effect is simulated in laboratory. A first general statement should be made whether freeze–thaw alterations (FTA) exert an impact on the texture and the skid resistance and how this impact can be assessed quantitatively. Therefore, the selection of aggregates was deliberately limited to a few aggregates which are frequently applied in surface layers (basalt, diabase, granite and greywacke) and two plate specimens are produced for each aggregate type. For each pair, one of the test plates is subjected to solely polishing load and the other one is treated with a combined load of polishing and freeze–thaw cycles. By comparing the results of the texture and skid resistance measurements, it was found that freeze–thaw affects the micro-texture of the aggregates to different wavelength scales and further influences the short-term and long-term development of the skid resistance. These influences depend on the type of the aggregates and the mineralogical properties, such as crystal sizes and the content of the sensitive minerals to freeze–thaw, like mica.

2. Experimental program

The research strategy is illustrated in Fig. 1. First of all, plates with a dimension of 32 cm x 26 cm × 4 cm were produced in mosaic-laying method from different aggregate types with a grain size of 8/11, as shown in Fig. 2. Two test series are planned in the experiments. In test series 1, the polishing effect of traffic in real terms is simulated under laboratory conditions using the Aachen Polishing Machine (APM). For test series 2, the test specimens are subjected not only to a polishing but also to a freeze–thaw effect. The simulation of the freeze–thaw effect in the laboratory is carried out according to EN 1367-1 (2007). The sample plates are soaked with water under atmospheric pressure and then exposed to ten freeze–thaw alterations (FTA) with the addition of sodium chloride in the climatic chamber. This involves cooling to −17.5 °C in dry air followed by thawing in a water bath at about 20 °C. In order to study the changes of the surface, the surface topography and skid resistance were measured after each loading phase to indicate the influence of the freeze–thaw and the polishing. Details of the test methods are described in a later section.

2.1. Selection and property of the aggregates

Different aggregate types, such as basalt, diabase, granite and greywacke, were selected for the tests based on the findings in the reference [15]. These aggregates are typically used in the surface layers of roads with heavy traffic in German federal highways. With freeze–thaw mass loss lower than 1% according to EN 1367-1 (2007), they are deemed as highly frost resistant. The great variance in the mineralogical composition of granite from the major granite quarries in Germany makes it an ideal choice for studying the influences of different minerals on the polishing and friction behavior [15]. The mineralogical properties were examined in the Institute of Clay and Interface Mineralogy (CIM) of the RWTH Aachen University. The composition is shown in Fig. 3 and a description of the mineral structures as well as the crystal size of each aggregate type is listed in Table 1 [15]. In addition, the polished stone value (PSV) according to EN 1097-8: 2009 was tested, which is also shown in Table 1.

Fig. 2. Test plate of the aggregates [15]. The aggregates are laid over the entire surface of the test plates. Quartz sand is sprinkled into the gaps between the individual grains and concrete is poured over the whole plate. A centimeter-wide rim of the plate is covered with epoxy resin to ensure stability of the edges.

2.2. Topographic description

The texture measurement is performed with the optical surface measurement device from the Fries Research & Technology (FRT) GmbH. The highest accuracy for a measurement in vertical direction is 6 nm, so that even the smallest texture information in the micrometer scope can be captured. On every aggregate test plate, three square areas of 10 mm × 10 mm are measured, as shown in Fig. 4. Each square area is comparable to an aggregate grain of the size 8/11. In a measuring lattice with the interval of 2 μm in x-direction and 25 μm in y-direction, two million points will be measured, ensuring a detailed depiction of the micro-texture of the aggregates.

An evaluation of the surface characteristic was performed on basis of the spectral analysis of the surface profile. Through Fourier transformation, the height information of the surface profiles can be transferred in the spatial frequency domain. The function $C(q)$ denotes the two-dimensional power spectral density (2D-PSD) of the pavement surface:

$$C(q) = \frac{1}{(2\pi)^2} \int d^2x \langle h(x)h(0) \rangle e^{-iqx} \quad (1)$$

Here, $h(x)$ is the surface height measured from the average plane with $x = (x, y)$ and $\langle h \rangle = 0$. The statistical properties of the texture are assumed to be isotropic so that $C(q)$ only depends on the magnitude $q = |q|$ of the wave vector q.

2.3. Skid resistance test using the Wehner/Schulze machine (W/S)

The W/S machine (Fig. 5, left) has two stations, one for polishing and the other for measuring friction. The polishing unit for accelerated traffic load simulations consists of three conical rubber rollers (Fig. 5, middle) that rotate at a speed of 17 km/h and have a contact pressure of 0.4 N/mm^2 (draft EN 12697-49). A mixture of 5% quartz powder (<0.063 mm) and 95% water is added at a rate of 5 l/min as the

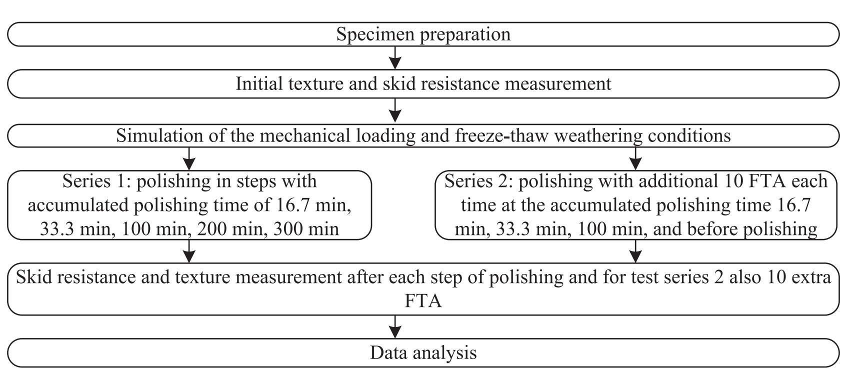

Fig. 1. Schematic illustrations of research strategies.