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Investigation of synthetic, self-sharpening aggregates to develop skid-resistant asphalt road surfaces

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ABSTRACT

The primary objective of this research was to investigate and develop a "self-sharpening road surface" that exhibits a consistently high skid resistance throughout the polishing process which occurs in the course of normal pavement use. High-strength shale ceramsite (HSSC) is made by heating high-strength shale to about 1200 °C in a rotary kiln. It was laboratory-tested to measure its wear and polishing behavior. Subsequently, asphalt specimens were prepared using coarse HSSC aggregates and tested for their polishing resistance, high temperature rutting, low temperature cracking and water stability. The results of tests on the HSSC aggregates showed that their honeycomb-like structure can lead to the continuous regeneration of the texture in the course of polishing, and thus a positive effect on the skid resistance. Data from tests of the HSSC asphalt mixture led to a recommendation that 60% HSSC was the best composition for manufacturing roads that exhibit long-term skid resistance whilst still satisfying other pavement performance requirements.

1. Introduction

The skid resistance of a road surface mainly depends on its aggregate's mineralogical composition, morphology, and mechanical properties [1–5]. The effects of imposed loads and weathering, as determined by the polishing resistance of the aggregates, cause the initial skid resistance to decrease continually to a worn-in level [2,5]. Different test methods, for example the polished stone value (PSV, EN 1097-8:2009) [2,8,11–15], the Wehner/Schulze machine (W/S, EN 12697-49) and the Aachen Polishing Machine (APM) [6–10] were developed to simulate the polishing and wearing process occurring on road surfaces. Based on these aggregate tests and the obtained knowledge for a given set of laboratory conditions, numerous prediction models for asphalt roads have been developed [11–23].

The force imposed on the road surface by the tire leads to the fracturing of minerals on the surface of an aggregate or even the wearing of complete minerals from the compound material [1,2, 8–10]. Depending on the petrographic parameters of the aggregate, this can lead to either rougher or smoother surface characteristics. The aggregate can be referred to as a self-sharpening material, if it maintains the roughness under continuous polishing. BREYER (1954) [8] has presented an overview of an aggregate's petrographic requirements for "becoming smooth" and "staying rough" (see Table 1). An inhomogeneous structure, a low abrasive hardness, and a low crystallinity could prevent the polishing of aggregates [8]. Minerals with a different hardness within the aggregate can exhibit selective breaking-out of particles due to wearing processes and result in the reconstruction of the aggregate's texture and relief [8]. This effect depends on the crystal size, the form of minerals as well as the polishing behavior of adjacent minerals. Furthermore, aggregates containing many cavities can lead to the continuous emergence of new rough surface textures with a high angularity. This regeneration of the micro and macro-texture can have a profoundly positive effect on sustaining skid resistance characteristics on the long term [8].

2. Aims

In order to maintain a sufficient and long-lasting skid resistance of a road surface, it is necessary to optimize the corresponding aggregate components of the road surface layer. The overall objective of this research is the development of a "self-sharpening road surface" that permanently exhibits high and consistent skid resistance properties during the polishing process; this is to be achieved by the use of several aggregates with specifically selected hardness

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Table 1
Overview of the petrographic requirements for aggregates “becoming smooth” and “staying rough” [8].

	Aggregates becoming smooth	Aggregates staying rough
1	Glassy fine structure	Grainy fine structure
2	Combination of glassy minerals	Combination of glassy and non-glassy minerals
3	Homogeneous fine strukture	Inhomogeneous fine strukture
4	High density	porous
5	high abrasive hardness	Low abrasive hardness
6	High material strength	Low material strength
7	strong grain bond	Loose grain bond
8	High crystalinity	Low crystalinity
9	High wearing resistance	Low wearing resistance
10	Fresh state	Weathered state
11	Clay like fine abrasion	Quartz-like grainy abrasion

differences and structures. The conceptual approach is based on the incorporation of high-strength shale ceramsite (HSSC). This is a type of material which exhibits a high polishing resistance due to its porous/ honeycomb-like structure and low hardness in comparison to conventional natural aggregates. Although an imposed traffic load may wear and abrade a high amount of HSSC material, the skid resistance will be maintained due to the aforementioned characteristics and can be determined using

- British pendulum number (BPN) according to EN 13036-4 to describe the micro-texture.
- Mean texture depth (MTD) according to EN 13036-1 to describe the macro-texture and drainage of road surface.
  Asphalt road surfaces are continuously and simultaneously exposed to stress induced by traffic and weathering. To assess their suitability to withstand such an exposure the asphalt specimens prepared with coarse HSSC aggregates were analyzed with regard to the following properties:
- the polishing resistance to describe the long-term skid resistance;
- rutting resistance at high temperature;
- cracking resistance at low temperature; and
- moisture susceptibility.

The combination of the findings shall result in the recommendation of the best dosage of HSSC for manufacturing roads which exhibit long-term skid resistances whilst still satisfying the pavement performance requirements.

3. Test procedure

The implementation of this approach and the procedure in the laboratory is described in the following.

3.1. Selection of the aggregate

Five aggregate sources (three andesites and two limestones) typically used for surface layers on highways were chosen from major quarries in North China. Additionally, one type of HSSC was chosen from the ceramsite industry (see Fig. 1). Basic ceramsite is frequently used as a lightweight aggregate (LWA) to replace natural aggregates in the building industry. LWA are covered in ASTM C330 (for structural concrete), C331 (for masonry units), and C332 (for insulating concrete) whereby all require a composition consisting predominantly of lightweight-cellular and granular inorganic material. Incorporating the LWA improves the thermal efficiency of buildings and thus reduces heating and cooling loads, offers a higher fire resistance due to the honeycomb-like structure and reduces the costs of the project due to its availability. The predominantly used LWA for construction are expanded clay, shale and slate. The uses include numerous structural elements such as panels, tiles, partitions, etc. as well as structural backfills against foundations and abutments whereby the use increases the ground stability by reducing settlement and deformations. Several studies established the possible use of those recyclable aggregates from the ceramic industry waste in the construction of landfills, subbase courses on secondary roads and Hot Mix Asphalt (HMA) [24–26].

Fig. 1. HSSC gains 9.5/13.2 mm.

HSSC is an aggregate made by heating high-strength shale to around 1200 °C in a rotary kiln. The yielding gases expand the high-strength shale by inducing the emergence of thousands of small bubbles during heating, producing a honeycomb-like structure. Due to the polishing effect, this structure could lead to the continuous regeneration of the aggregate texture and thus have a positive effect on the skid resistance. As opposed to conventional expanded clay aggregates which are spherical, the processing of high-strength shale leads to highly angular, broken grains with superior compressive strengths. An important attribute is the decreases weight of the aggregates due to the porosity of the microstructure allowing for a density of 559 kg/m³. However, it is important that the aggregates exhibit sufficient compressive strengths >25 MPa, as specified in the Chinese guideline GB/T 17431.1-1998.

3.2. Polished Stone Value (PSV) tests on the aggregate

In the context of interdisciplinary research, different rock types are examined regarding their mineral and topographic characteristics. As the long term skid resistance is the main objective, the aggregates' polishing and skid resistance behavior must be analyzed. For this purpose the standard PSV test is used to determine the polishing resistance of aggregates in their initial state.

The PSV test is widely used throughout the world to predict aggregate polishing resistances in the laboratory. Test specimens consist of cube-shaped 9.5/13.2 mm sized aggregate chippings (see Fig. 2) and are fixed to the curved molds using an epoxy binder where after 14 samples are bolted around the polishing wheel of the accelerated polishing machine. The polishing stage has two phases of three hours polishing each with coarse emery and fine emery powder as the polishing agent. The coefficient of friction is determined after selected polishing stages using the British Pendulum Tester (BPT). The mean value of the results yields the laboratory assessed Polished Stone Value (PSV). A high PSV indicates better polishing resistance and hence a higher skid resistance of the road [1,2,12]. As a result, there is a minimum PSV requirement for aggregates of road surface materials in the standard specifications for road construction in Germany [2].