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Accelerated laboratory testing of aggregate friction properties

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A B S T R A C T

This paper presents a thorough analysis of an experimental method for measuring aggregate friction properties. The second-generation Aggregate Image Measurement System (AIMS) is used to measure coarse aggregate surface texture before and after polishing in a modified Micro-Deval (MD) test procedure, in addition to Variable Speed Friction Test (VST) samples. Investigating the relationships between AIMS-MD angularity and texture, a weak relationship was found between VST friction values and AIMS angularity after MD polishing for 105 min (AMD-105). Furthermore, the strong correlation between AIMS AMD-105 texture and the surface texture of VST friction samples indicated that MD is a viable option for replacing VST as a polishing mechanism. Finally, cluster analysis was conducted to obtain threshold for classifying aggregate angularity and texture into acceptable and non-acceptable zones (i.e., defining the criteria for qualifying aggregates for friction purposes).

Introduction

Asphalt pavement performance is highly affected by its aggregate properties such as: gradation and size, particle shape and surface texture, porosity, cleanliness, toughness and abrasion resistance, durability and soundness, expansive characteristics, polishing and frictional characteristics, and mineralogy and petrography. Properties of aggregates impact asphalt pavement permanent deformation, fatigue cracking, frictional resistance, thermal cracking, and raveling (Kandhal and Parker, 1998). Aggregate shape properties significantly affect the performance of the unbound/bound layers of highway/airfield pavements, as well as railroad ballast, in terms of shear strength, modulus, and permanent deformation characteristics (Kandhal and Parker, 1998; Masad et al., 2007; Tutumluer and Pan, 2008; Indraratna and Salim, 2005). The influence of aggregate shape characteristics on asphalt pavement performance was highlighted in a research study conducted under National Cooperative Highway Research Program NCHRP 4-30A (Masad et al., 2007). The study revealed that shape, angularity, and texture were all significant characteristics for predicting pavement performance.

Frictional resistance, known as skid resistance, is considered as one of the most important performance parameters of asphalt pavement. The importance of pavement frictional resistance stems from its impact on travel safety; thus, a minimum acceptable safe limit must be maintained (Bloem, 1971). Skid resistance of asphalt pavements depends primarily on the microtexture and macrotexture of the surface (Dahir, 1979). Microtexture depends primarily on aggregate shape characteristics, while macrotexture is a function of the mix properties, compaction method, and aggregate gradation (Kandhal and Parker, 1998; Crouch et al., 1995; Luce et al., 2007; Forester, 1989). Skid resistance of asphalt pavement surfaces is presumably adequate right after pavement construction and after the pavement is opened to traffic; aggregates that resist polishing and wear are therefore desired (Bloem, 1971).

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Aggregate polishing resistance is often tested to evaluate aggregate materials before they are used in hot-mix asphalt (HMA) surface courses.

Several methods have been developed to simulate aggregate polishing; one of the most widely used method is the combination of British wheel/pendulum method ASTM E303 and ASTM D3319. However, in a study conducted by Won and Fu (1996) it was shown that British pendulum results depend on many other factors besides aggregate texture, such as particle arrangement, and number of pendulum swings. Recently, several studies evaluated the use of the Micro-Deval test along with imaging systems to measure the effect of the test on aggregate shape characteristics (Mahmoud, 2005; Luce, 2006; Mahmoud and Masad, 2007; Lane et al., 2011; Moaveni et al., 2014; Ortiz and Mahmoud, 2014). Mahmoud and Ortiz (2014) used AIMS along with the Micro-Deval test to measure aggregate polishing, abrasion, and breakage. Aggregate polishing was characterized at several Micro-Deval polishing times by measuring the texture index, while abrasion and breakage were characterized by angularity and weight loss measurements. The study illustrated the capability of Micro-Deval along with AIMS to measure aggregate polishing characteristics.

This paper presents important findings from a recently completed research project sponsored by the Illinois Department of Transportation (IDOT) with a goal towards implementing aggregate imaging techniques along with MD as an accurate, practical, and repeatable methodology for measuring aggregate polishing properties. IDOT current protocol for aggregate polishing is based on an IDOT modified ASTM standard E660-90 "Accelerated polishing of aggregate or pavement surfaces using a small-wheel, circular track polishing machine" along with the British pendulum. This system is referred to as Variable Speed Friction Test (VST) by IDOT. The circular track polishing machine has the capability to achieve aggregate terminal polishing. However, it's very time-consuming to prepare and polish the samples. MD capabilities to replace the circular track polishing machine was investigated, and strong correlations between aggregate surface texture measurements of both equipment proved MD as a strong candidate to replace the circular track polishing machine. Additionally, it was necessary to develop aggregate friction specification based on the new proposed method, this was achieved by performing statistical cluster analysis to detect natural grouping in aggregate shape properties.

Objectives and scope

The main objectives of this paper were to demonstrate the efficacy of modified AIMS-MD polishing procedure (Mahmoud and Ortiz, 2014) as an aggregate polishing and terminal friction measurement protocol and to establish friction specifications for AIMS-MD procedure results. This was achieved by performing the following tasks:

- 130 aggregate sources were collected from sources typically utilized by IDOT.
- Aggregates were polished in MD, and VST.
- Aggregate particles were scanned with AIMS before and after polishing in MD, polished VST samples were also scanned.
- Clustering were performed to provide guidelines for aggregate friction specifications.

Materials and testing procedures

The aggregate materials used in this study were selected from a wide range of mineralogical properties and various quarries in different geographical regions in the state of Illinois and neighboring states. All aggregate materials were washed, oven dried, and sieved to obtain particle sizes passing the 1/2 in. (12.5 mm) sieve and retained on the 3/8 in. (9.5 mm) sieve. Table 1 lists the types and number of samples of all aggregate materials tested. Testing procedures in this study are: AIMS, AIMS-MD Polishing, and VST. The following subsections provide a brief description of each of the procedures.

Second generation Aggregate Image Measurement System (AIMS-II)

The new version of the Aggregate Image Measurement System (AIMS-II) was used to obtain aggregate shape properties before and after polishing in the MD. *For simplicity, AIMS-II will be referred to as AIMS in this paper.* AIMS is a computer automated system that captures real-time digital images of aggregate particles, in addition to an analysis software that process and analyzes aggregate images to obtain their shape characteristics. The main shape characteristics used in this study are: aggregate angularity, and texture.

Angularity index (Gradient method)

The gradient method is used to measure aggregate angularity index. The method is based on quantifying the change in the gradient vector along a particle boundary. The gradient vector changes slowly along smooth and rounded corners boundaries, while it changes more rapidly at sharp corners. The index is calculated mathematically using Eq. (1).

$$\text{Angualrity Index (Gradient Method)} = \frac{1}{\frac{N}{3}-1}\sum_{i=1}^{N-3}|\theta_i - \theta_{i+3}| \quad (1)$$

Table 1
Aggregate material type and number of samples.

Aggregate type	Number of samples
Dolomite	44
Limestone	39
Lower gravel	10
Lower crushed gravel	3
Upper gravel	13
Upper crushed gravel	8
ACBF slag	2
Steel slag	4
Sandstone	4
Granite/diabase/quartzite	3
Total samples	130