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Machine vision based characterization of particle shape and asphalt coating in Reclaimed Asphalt Pavement

Maziar Moaveni [a,1], Sedat Cetin [b,2], Alexander S. Brand [a,3], Sachindra Dahal [a,4], Jeffery R. Roesler [a,5], Erol Tutumluer [a,*]

[a] Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 205 North Mathews, Urbana, IL 61801, United States
[b] Department of Civil Engineering, Afyon Kocatepe University, Gazligöl Yolu, 03200 Afyonkarahisar, Turkey

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ABSTRACT

Reclaimed Asphalt Pavement (RAP) particles are created from the impact removal and/or reprocessing of existing asphalt layers. RAP particles contain a combination of asphalt and aggregates with varying degrees of coating and morphology. Particle size and shape properties, amount of asphalt coating the RAP particles, and the binder content of the RAP are among the important engineering properties that control the performance of this material. This paper introduces an innovative machine vision-based inspection system to quantify the percentage of asphalt coating in different RAP aggregate sources. The Enhanced-University of Illinois Aggregate Image Analyzer (E-UIAIA) is used to acquire the color RGB images of RAP particles from six different sources with sizes between 1/4 in. (6.35 mm) and 1/2 in. (12.5 mm). The influence of asphalt coating percentage on the RAP particle size and shape properties are quantified in this paper. Then, using the advanced color image thresholding scheme incorporated in the E-UIAIA, the corresponding segmented binary images of RAP particles are generated. A newly defined image mean property is used as an automatic variable threshold limit to segment the bright areas in the associated grayscale version of RAP images to detect the uncoated areas on each particle. A relationship was found between the results of the proposed image processing technique in terms of asphalt coating percentages and the asphalt content of the RAP. Furthermore, the asphalt surface coating percentages could be successfully correlated to the fracture energies of concrete specimens containing these RAP particles blended with other virgin aggregates.

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Introduction

Considering limited sources of virgin aggregates and asphalt binder and the ever increasing material and construction costs, the utilization of Reclaimed Asphalt Pavement (RAP) as a recycled alternative in sustainable construction of highway pavements has increased significantly during the last two decades (Al-Qadi et al., 2007; Howard et al., 2009; Brock and Richmond, 2007). RAP is acquired through milling and processing deteriorated asphalt pavement layers. RAP particles can be

* Corresponding author. Tel.: +1 (217) 333 8637.
E-mail addresses: moaveni1@illinois.edu (M. Moaveni), scetin@aku.edu.tr (S. Cetin), abrand2@illinois.edu (A.S. Brand), sdahal2@illinois.edu (S. Dahal), jroesler@illinois.edu (J.R. Roesler), tutumlue@illinois.edu (E. Tutumluer).
[1] Tel.: +1 (217) 778 2503.
[2] Tel.: +90 (217) 819 9220
[3] Tel.: +1 (630) 930 3856.
[4] Tel.: +1 (479) 276 2653.
[5] Tel.: +1 (217) 265 0218.

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agglomerations of smaller aggregates and binder and larger aggregates that are partially-coated with asphalt. RAP materials can be reused as recycled aggregates in unbound aggregate base/subbase layers (Scheartle and Edil, 2009), new pavement layers consist of hot and warm mix asphalt (Vavrik et al., 2008) as well as concrete mixtures (Brand et al., 2013; Brand and Roesler, 2014a,b).

The common methods to produce RAP include: hot recycling at the asphalt plant, hot in-place recycling, cold in-place recycling and full depth reclamation (West, 2010; Copeland, 2011; Kandhal and Mallick, 1997). Milling machines scratch the pavement with milling teeth mounted on a drum, and this impact tears and crushes the pavement layer into smaller size particles which creates uncoated surfaces around individual particles. RAP materials extracted from the roadway possess different properties corresponding to the source and type of virgin aggregate, binder content, and the Performance Grade (PG) of the binder. RAP aggregates may have different particle shape properties and asphalt coating percentage also depending on the crushing, fractionation and pulverizing processes.

According to NCHRP 452 report (McDaniel and Anderson, 2001), the binder content and physical properties of RAP aggregates including the size distribution and particle shape, texture and angularity, need to be determined for their proper use in the desired mixture design. These factors also control the performance of RAP in terms of stiffness, crack resistance, modulus and deformation characteristics. When used in asphalt pavements, the aged binder in RAP can cause pavement cracking failure because of the increased stiffness and viscosity of the binder and decreased ductility (Al-Qadi et al., 2007). This general expected increase in stiffness can lead to over conservative design in terms of selection of more costly, softer asphalt binder grades and/or limiting the RAP content in a mixture (Hill et al., 2013). When RAP contributes with a higher percentage of asphalt content than target designed value in the mix, it causes higher total achieved asphalt content in the mixture. Therefore, the mixture becomes soft and is prone to higher plastic deformation (Howard et al., 2009). Conversely, if RAP contributes less asphalt than expected to the mixture, the final mix will have lower total asphalt content value which eventually makes the pavement susceptible to cracking, raveling, and moisture damages (Shirodkar et al., 2011). Incorporation of RAP into cement-based materials alters the interface between cement matrix and RAP thereby affecting the bonding (Brand and Roesler, 2014b). However, Huang et al. (2006, 2005) state that this asphalt coated aggregate might be useful in resisting the crack propagation along the interface which allows more energy to be dissipated. Recently, this finding has been confirmed by Brand et al. (2013).

As clearly substantiated through the reviewed literature, accurate determination of asphalt coating percentages on the RAP particles is both needed as a quality indicator, and at the same time, for the sustainable utilization of various RAP sources. Several standard methods such as centrifuge, vacuum, or reflux extractor are currently used to measure the asphalt content in RAP (ASTM D6847, AASHTO T164). However, these techniques are time consuming, require expensive equipment, and the solvents and chemicals used in the process can be hazardous to both the environment and the operators (Garcia et al., 2007). Additionally, the asphalt content values in RAP may not necessarily be an accurate representation of the existing asphalt coating and film thickness on individual particles. The coating on RAP particles is a function of asphalt absorption by aggregate, particle size and shape, methods of milling/crushing during RAP production, and resistance of virgin aggregate to breakage and/or degradation. A close look at the literature shows that currently limited research exists related to characterization of RAP particles in terms of particle shapes and the effect of asphalt coating on changing the shape properties. This can possibly be related to the lack of a standard procedure that can objectively and reliably quantify the shape properties of RAP particles rapidly and accurately.

Machine vision (MV) is the technology used to develop imaging-based systems for applications such as automated inspection systems, process control, and robot guidance. Digital image processing techniques, such as morphological filtering, thresholding, pattern recognition and segmentation, are used to process the acquired images in developed imaging systems (Sinha, 2012). More recently, machine vision technologies and image analysis have been utilized as an objective and accurate inspection system for quantifying virgin aggregate particle size and shape properties in a rapid, reliable, and automated fashion when compared to traditional manual methods (Tutumluer et al., 2005; Al-Rousan et al., 2007). This methodology holds the potential to be applied for morphological characterization of RAP materials as well as evaluating the level of asphalt coating on particles. Implementation of this technology provides the opportunity for optimized RAP selection and utilization, which will provide sustainable benefits to the transportation infrastructure resources.

This paper describes the application of advanced image processing methods to determine asphalt coating percentage on RAP particles and investigates the changes in RAP aggregate size and shape properties influenced by the asphalt coating. The Enhanced University of Illinois Aggregate Image Analyzer (E-UIAIA) and its imaging-based shape and size indices, including Angularity Index (AI), Surface Texture Index (STI), Flat and Elongated Ratio (FER), and volume (V) (Moaveni et al., 2013; Rao, 2001; Pan and Tutumluer, 2010; Pan, 2006), are applied to characterize the morphological properties of RAP aggregates from six sources obtained from pavement surface courses in northern Illinois. These shape indices will be further elaborated in this paper. Binary images of RAP materials generated by the E-UIAIA are used to develop an innovative computational algorithm to estimate the amount of asphalt coating on each RAP particle.

Objective and scope

The primary objective of this research is to develop a robust and accurate image processing algorithm to quantify the asphalt coating percentage on RAP particles. A combination of image processing and enhancement

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