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Evaluation of morphological properties of railway ballast particles by image processing method

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ABSTRACT

The properties of individual ballast particles affect the behavior of ballast layer under train loading. One of the most important individual properties is the morphological characteristics of ballast particles represented by surface texture and angularity. In the present study, the morphological properties of ballast particles are quantified by developing surface texture (ST) index and angularity index (AI) determined on two-dimensional aggregate images. For this purpose, four different types of fresh ballast aggregates (basalt, marl, dolomite and trachyte), rounded river aggregate and degraded ballast sample obtained from railway track are analyzed for each specific sieve size fraction by developed image processing method. Comparison of the developed method in the present study for determination of ST and AI with the previously developed morphological indices shows that there is a reasonable correlation between them. In addition, the results obtained from the air void contents of aggregates in loose condition validate that the developed indices for the evaluation of morphological properties of aggregates can characterize the angularity and surface texture of each individual ballast particle properly.

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Introduction

Railway network is one of the efficient methods for transportation of passengers and goods. In ballasted railway tracks, the ballast layer forms the track bed upon which the railway sleepers are laid. Ballast is usually comprised of hard and strong angular particles derived from high strength rocks [19,7]. The major role of ballast layer are distributing stresses transmitted by the sleepers to the underlying layers as well as facilitating rainwater drainage [16].

In general, the main factors that can affect the mechanical response of ballast are the characteristics of the individual particles (such as parent rock type, particle shape, particle size, angularity

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and surface roughness), bulk properties of the granular assembly (including particle size distribution, void ratio, etc.), loading characteristics (e.g. train speed and loading frequency) [6,7]. These factors have a main influence on ballast particle degradation which can occur due to the breakage of angular corners and abrasion of sharp edges during the railway operation.

The physical and mechanical characteristics of individual particles significantly influence the behavior of ballast under both static and cyclic loading. Amount of ballast degradation could be very different for ballast with various individual properties. In the research conducted by Koohmishi and Palassi [8], the strength of single ballast particles was evaluated by conducting point load test on ballast particles of various size fractions and particles shapes. It was found that the strength of single ballast particle is decreased by increasing the particle size. In work carried out by Wnek et al. [23], ballast degradation and durability were analyzed by Los Angeles abrasion (LAA) test and it was concluded that the durability of more-angular aggregates is less due to increased breakdown potential of the aggregates from their angularity. Therefore, to evaluate the degradation mechanism of ballast aggregates under static and cyclic loading, it is important to accurately characterize the morphological properties of ballast particles.

Imaging technology provides an accurate measurement of aggregate profiles and has been successfully used in the last two decades for quantifying aggregate morphology [22]. Researchers have distinguished between different aspects of the shape of granular particles. The shape of a particle can be fully expressed in terms of three independent properties, i.e. form, roundness (or angularity), and surface texture [10]. In the research conducted by Masad and Button [10], the properties of the fine aggregates including angularity and surface texture were measured by a unified imaging approach. Rao et al. [17] proposed an image-based angularity index to describe aggregate angularity using the University of Illinois Aggregate Image Analyzer (UI-AIA). The system involved three cameras to capture images from three orthogonal planes. In this relation, a unified computer automated system for characterizing the shape of fine and coarse aggregates was designed to measure aggregate shape properties referred to as Aggregate Imaging System (AIMS) [3]. Zhang et al. [24] developed an indicator to characterize the combined effect of the angularity and surface texture of coarse aggregates and analyzed its statistical distribution. Also, in the work conducted by Chen et al. [2], the aggregate angularity was characterized using processing the edge of particle image with a gradient method. It should be mentioned that evaluation of the available test methods for characterizing aggregate shape, texture and angularity was carried out based on accuracy, repeatability, cost, applicability for the different aggregate sizes and etc. as reported by Masad et al. [12]. According to this study, AIMS was recommended for measuring characteristics of both fine and coarse aggregates.

Some researchers developed correlation between aggregate morphology and pavement performance. Masad et al. [11] quantified the shape characteristics of fine aggregates and their relationship to the rutting resistance of hot mix asphalt. Pan et al. [14] investigated morphological properties of coarse aggregates on the resilient modulus of hot mix asphalt. According to this study, an imaging based angularity index was found to be more closely related to the resilient modulus than an imaging based surface texture index. In another similar work, the effect of aggregate morphology on the resilient behavior of unbound granular materials was investigated [15].

The image processing method has also been used to consider morphological properties of railway ballast aggregates. In the work conducted by Tolppanen et al. [21], degradation of ballast particles was analyzed by using a combination of three-dimensional (3D) laser technique and the LAA testing machine to assess the degradation behavior of railway ballast. In another study, the effect of coarse aggregate morphology on the shearing resistance of railway ballast was investigated [4,5]. Also, Okonta [13] carried out a research in which the ballast particles were progressively abraded using the LAA device and were analyzed after each cycle of abrasion by digital image processing method.

The ballast particles are large sized crushed aggregates with high angularity, rough surface texture and irregular shape and it is easily possible to define schematic shape for each specific particle. The main purpose of the present study is to evaluate the morphological properties (shape, surface texture and angularity) of single ballast particle for various rock types and sieve size fractions using image processing technique. For this purpose, two imaging based indices are introduced by modification and extending the methods proposed by Zhang et al. [24] and Masad and Button [10] for quantification of surface texture and angularity, respectively.

Methodology

In this research, the morphological properties of ballast aggregates are evaluated by developing an image processing method. The ballast samples have been collected from four quarries and include rock types of basalt, marl, dolomite and trachyte. In addition, uncrushed river aggregate (sandstone) is used as non-angular (rounded) sample. The general descriptions of obtained aggregates are summarized in Table 1. To consider the morphological properties of ballast particles, an image processing method is developed to determine the surface texture and angularity indices of each particle. A flowchart of the process of validation of the developed image processing method is presented in Fig. 1. As shown, a comparison between the developed procedure in the present study and previous methods is carried out to evaluate the accuracy of the proposed method for evaluation of the morphological properties of aggregate. Also, the proposed method is validated in an indirect manner by testing the void contents of different sized ballast aggregates in loose condition. Finally, a comparison between fresh crushed ballast stones and ballast aggregates used under the railway track for a long period of time is made.

Imaging based morphological properties of ballast aggregates

The two main morphological properties of ballast particles are angularity and surface texture. Angularity or roundness reflects variations at the corners; while, surface texture describes the surface irregularity at a scale that is too small to affect the overall shape. The main difference of the two morphological properties is that the angularity is a macro-property of the outline of the coarse aggregate image while the surface texture is a micro-property. In this study, the imaging based surface texture index is determined by modification and extending the index proposed by Zhang et al. [24]. Also, the imaging based angularity index is evaluated by modification of the method presented by Masad and Button [10].

In present study, the 3D shapes of the ballast aggregates are assumed to be hexahedron, pentahedron, tetrahedron and flat as shown in Fig. 2. Therefore, several two-dimensional (2D) images are taken from various views for each aggregate particle to determine the morphological properties of ballast particles.

Surface texture

Zhang et al. [24] developed an indicator called angularity and surface texture (AT) index to characterize the combined effect of the angularity and surface texture based on 2D aggregate images.