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Ballast degradation: Effect of particle size and shape using Los Angeles Abrasion test and image analysis

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HIGHLIGHTS

- Using laser-based technique to evaluate ballast shape characteristics.
- Degradation analysis of individual ballast particle based on 3-D images.
- Quantified assessment of ballast degradation based on 3-D image.
- Influence of ballast morphology (particle size and shape) on ballast degradation.

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ABSTRACT

Ballast track is the most widely used track for the railway transport, and ballast bed plays a significant role to provide resistances during train operation. Generally, the ballast bed consists of crushed stones. To achieve the mitigation of ballast degradation, the first priority is to describe the degradation development and to study its effect factors.

The influence of ballast morphology (particle size and shape) on ballast degradation is examined here using the Los Angeles Abrasion (LAA) test in combination with 3-D image analysis. LAA tests are used to obtain the deteriorated ballast. Then, based on the 3-D images, the changes of ballast particles after the tests were analysed. To quantify the ballast degradation (abrasion and breakage), the Abrasion Depth based on the analysis of 3-D images were proposed, while ballast breakage was estimated using the broken particles ratio.

The results have shown that ballast degradation is directly related to the ballast morphology. The proposed image-based procedure can effectively be applied to assess ballast degradation. The results can be used for ballast material standardization, modelling of ballast degradation process and maintenance cycle prediction.

1. Introduction

Ballast bed used in railway track design (Fig. 1) traditionally consists of crushed hard rocks with average particle size range of 20 mm–65 mm under the sleeper, with high density, toughness, hardness, and high resistance to weathering. Ballast shear strength is influenced by ballast compaction, particle state and particle size distribution, and generally fresh ballast particles contribute more to ballast resistance.

A main problem of the traditional railway tracks is geometry deterioration, which is mainly related to the track settlement. Most of the settlement is caused by the permanent deformation of the ballast layer [1], which results from densification or dilation, distortion, and degradation, as concluded in [2]. Because ballast undergoes gradual and continuing degradation due to the cyclic loadings and the maintenance operations, researchers keep developing methods (examples in [3–5]) to study ballast bed degradation. Nevertheless, some issues are still controversial, such as the effects of shape and size on degradation and deformation.

As the research in [2,6], it was demonstrated that the particle's shape and roughness influences the ballast resistance and shear

Abbreviations: LAA test, Los Angeles Abrasion test; LAA loss, Los Angeles Abrasion loss; DEM, Discrete Element Method; FI, flakiness index; EI, elongation index; AAD, Average Abrasion Depth; MAD, Maximum Abrasion Depth; SLAV, Single LAA loss calculated with volume.

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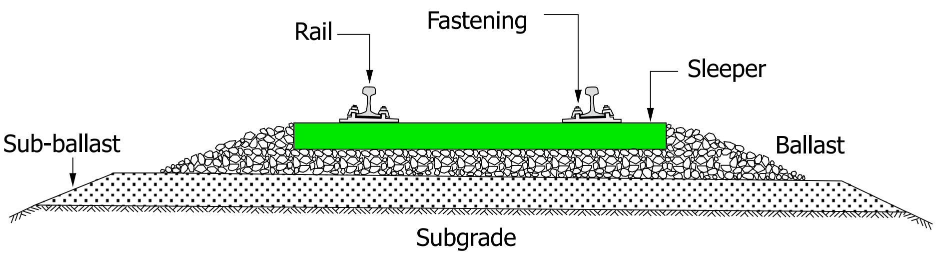

Fig. 1. Traditional railway track.

strength, and comparing to the rounded particles, the angular ones contribute to lower permanent deformation [7]. However, higher particle angularity is related with the increasing of breaking strain and the reduction of the ballast stiffness. Another study on particle shape shows that flaky or elongated particles at a limited percentage could increase the shear strength, and reduce the settlement for the lower rate of settlement accumulation [8]. However, it was also reported that flaky or elongated particles would lead to increased particle degradation and higher deformation [9]. Likewise, there is no general consensus on the effect of particle size [10]. It was found that particle size has little influence on shear strength in [11]. Yet, it was concluded in [12] that the shear strength increases when the particle size reduces. Conversely, the shear strength increases as the particle size increasing according to the research in [13].

It is difficult to obtain unified principles of ballast study for it is granular material. Plenty of effect factors will contribute to the final results causing no trends, if the ballast is only treated as a whole sample. For instance, when studying how the ballast size influences the shear strength, the compaction and bulk density might be the key factors [14]. However, during the adding normal stress or the shearing process, the ballast breakage will change the compaction and also the contacts. It may become a key factor, if ballast breakage is very severe [15]. For that, it needs to study from the granular level other than analysing the trends according to the test results of the whole sample. Therefore, it is significant to develop a method to estimate individual ballast particle degradation, and based on that, the effect of the factors, such as the shape, and the size, could be quantified accurately.

In order to obtain the deteriorated ballast the Los Angeles Abrasion (LAA) test was used. Generally, it is used for measuring toughness of grain materials .For this part, several laboratory tests, for instance, the Los Angeles abrasion test (LAA), mill abrasion test, Deval abrasion test, were used for the studies of ballast degradation and generation of fouled ballast [5,16]. However, the mill abrasion test cannot simulate the impact during train passing. And the abrasion results after the micro-Deval tests did not exerts any relationship with the degradation of ballast under repeated loading [17]. Although LAA test may not fully simulate the effect of field loading conditions [18], it was found that results of LAA test are well-correlated with ballast box test results when tamping was considered in their experiments [19,20].

During the test the material samples and a set of steel spheres are tumbled inside a closed, hollow, steel cylinder (Fig. 2), which is rotated around a horizontal axis. The LAA test is an effective and simple way to obtain deteriorated ballast and the fouling, and for this purpose it was used in [16,21–23].

A comprehensive tests were performed in [17], finding that the LAA results correlated fairly well with ballast breakage of the full scale track model test. It also concluded that the LAA test can distinguish high-quality material and the poor material clearly. It was proposed in [24] that, the sieve analysis that is used in the LAA test for determining how the particles reduce in size, is not precise

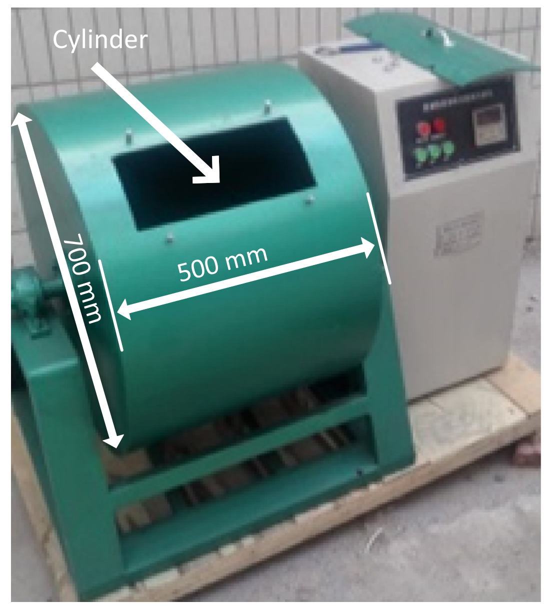

Fig. 2. Los Angeles Abrasion (LAA) test machine.

enough to estimate the ballast degradation, especially for the purpose of numerical simulations e.g. using Discrete Element Method (DEM).

Recently, ballast degradation was studied and determined from the digital or X-ray images system by various researchers [16,25–27]. Detailed measurements of particle's shape and roughness using the image analysis method have been successfully used for quantifying particle morphology [28,29]. Ballast particle abrasion and breakage by LAA tests with fouling index, and a relationship between the fouling index and the flakiness and elongation index change, sharp corner loss and surface texture reduction of the ballast particles, and the ballast shape factors evolution in different LAA test stages were studied in [16]. However, how individual ballast particles with various morphology deteriorate have not been systematically studied. Moreover, the digital or X-ray image is a cross section of an individual particle, and reflects the morphology of ballast particles roughly. As proposed in [27], only when the number of cross-sections is sufficiently large, the morphology of ballast particles can be more accurately accessed, however, it is quite time consuming.

As a consequence, this paper describes a study to measure and evaluate how an individual particle morphology (size and shape) changes during degradation. It is studied with LAA tests, as well as 3-D image analysis. Based on the 3-D images, quantifications of individual particle changes in detailed parameters are proposed and studied. 3-D image analysis is an ideal and accurate tool for quantifying particle size and shape properties in a rapid, reliable and automated fashion when compared to traditional manual