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Three-dimensional laser scanning technique to quantify aggregate and ballast shape properties

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HIGHLIGHTS

- CSIR using laser-based technique to evaluate aggregate/ballast shape properties.
- Improvements in aggregate/ballast shape properties measurement demonstrated.
- 3-D laser scanning method provides accurate aggregates aggregates/ballast shape properties.
- Volume-based flakiness index equation validated for aggregates/ ballast particles.
- Reliable flakiness data can now be obtained for aggregates and ballast materials.

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ABSTRACT

There is a need to improve the measurements of shape characteristics of aggregates and ballast materials used in the construction of road, airfield, and railway track infrastructures. The fundamental shape properties of aggregate and ballast, including form (roundness, flatness, elongation, sphericity), angularity, and surface texture (roughness) have not been accurately quantified because of their irregular and non-ideal shapes. Current developments are shifting from manual and subjective methods towards a more accurate and automated techniques to quantify aggregate shape properties. This paper validates a new flakiness index equation using three-dimensional (3-D) laser scanning data of aggregate and ballast materials obtained from different sources (quarries) in South Africa. The new equation uses volume ratio instead of the traditional mass ratio to determine flakiness index of aggregates and ballast materials. It is concluded that the validated equation can be used with confidence to determine flakiness index of aggregate and ballast materials.

1. Introduction

The use of imaging and scanning techniques for quantifying the shape and surface properties of aggregates in pavement layers and ballast in railway track structures has recently emerged as an attractive and viable option over the current standard (manual) test procedures. The major advantages of these techniques include their ability to evaluate the shape and surface properties of the aggregates/ballast in a quick and accurate manner, and allowing automation of the measurements. This is in contrast with the existing standard test procedures, which are subjective in nature, time consuming and laborious.

Shape and surface characteristics of rock aggregate and ballast are well known to influence the performance of asphalt and concrete pavements, and railway track structures. The pavement and railway track structures are influenced by roundness, flatness, elongation, sphericity, angularity and surface texture of the aggregate/ballast. At the same time, these properties must meet specifications. The bond between bituminous binder and aggregates in asphalt and spray seals, the cement/aggregate bond in concrete and the interlocking ability to resist shearing and deformation in unbound materials are also affected by angularity and surface texture. A peculiar problem of ballast is linked to excessive number of repeated loading under the train. The breakage of sharp corners of ballast, repeated grinding and wearing, as well as crushing of weaker particles under heavy repeated loading cause differential track settlement and unevenness of the surface.

Although researchers have made frantic efforts to develop methods/procedures for measurement of aggregate shape properties, the process has been hampered by the fact that aggregate/bal-

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last particles have irregular and non-ideal shapes and variable surface textures. A major problem is that the current standard test methods for quantifying the shape properties of aggregates and ballast are tedious and involves a process in which the results are mainly based on the judgment of a technician. Thus, there is lack of confidence in the inter-laboratory results to be used on a daily bases for quality control and quality assurance. The problems associated with the use of the traditional methods are widely reported by some researchers [1–3].

The Council for Scientific and Industrial Research (CSIR) in South Africa is currently undertaking a research project to automate the quantification of shape and surface properties of aggregate and ballast materials used for construction of roads, airfields and railway track structures. The project employs modern three-dimensional (3-D) laser scanning technique to effectively address a number of difficulties associated with characterization of aggregate/ballast surface and shape properties, as well as the influence of these properties on the performance of pavements and railway track structures. This paper validates a new equation proposed for the computation of flakiness index of aggregate/ballast particles. Aggregate materials from seven sources, and ballast materials from two sources were scanned in a 3-D laser system to determine their flakiness properties. These materials are mainly used for construction of roads, airfields and railway track structures in South Africa.

2. Review of automated methods to quantify aggregates shapes

The shape properties of aggregates used in asphalt and concrete pavements, as well as ballast in railways track structures have a significant influence on their engineering properties [4–7]. As mentioned earlier, the form, angularity, surface texture, surface area and volume of aggregate particles influence their mutual interactions and interactions with any binding or stabilising agents, and are related to performance of the pavement [8,9].

The recent state-of-the-art has attempted to analyse aggregate shape properties using imaging techniques/video imaging systems [10–12]. These techniques are generally fast, efficient and provide additional benefits of automation that eliminates the subjectivity associated with the traditional manual methods. However, most of these methods capture a two-dimensional (2-D) image of the aggregates and provide only 2-D information about the geometry of the aggregate particles, which makes it difficult to measure the shape properties in terms of mass or volume.

An accurate way of evaluating 3-D shape properties of an aggregate particle is through the use of X-ray computed tomography (CT) technique. The sophisticated X-ray CT technique is expensive for routine use in this study. Moreover, X-ray equipment has stringent safety and radiation monitoring requirements. Recently, 3-D laser scanning technique for quantifying aggregate shape characteristics has received much attention as a more viable and cost effective alternative to both imaging and X-ray CT [13,14]. The 3-D laser scanning technique has been used for characterizing the roughness of rock fracture surfaces and railway ballast materials [15,16]. Hayakawa et al. [17] and Tolppanen et al. [18] reported that digital modelling of gravel particles based on laser scanning could be useful, reliable, repeatable and relatively fast to evaluate the properties of ballast material. Pan and Tutumluer [19] used 3-D laser scanning to validate surface area factors of crushed and uncrushed natural aggregates for asphalt mix designs. The use of 2-D tomographic images to reconstruct 3-D surface area of an irregular shaped aggregate particle has also been proposed [20–23].

Advanced technologies to quantify the shape and surface properties of aggregates and ballast in pavements and railway track structures is relatively new. In the United States for instance, efforts to use imaging techniques to characterize aggregate shape properties have been made through collaborative research by state departments of transportation, research institutions, the industry and the academia. For example, a national pooled fund imaging project was pursued by National Center for Asphalt Technology (NCAT), and eight state highway agencies in collaboration with University of Illinois [24]. Recently, CSIR researchers have demonstrated that modern three-dimensional (3-D) laser scanning technique could be adapted and used to accurately determine aggregate and ballast shape and surface properties [25–28]. Fig. 1 presents shape and surface properties defined for a typical scanned aggregate particle by the CSIR researchers [27].

3. Flakiness index of aggregates

3.1. Flakiness index and performance

The flakiness index parameter gives an indication of the flatness of a sample of aggregate particles, and computed from their dimensions (length, width and thickness). Low flakiness index value is an indication that the aggregate is close to cubical shape, which is a preferred shape for aggregates used in pavements and railway track structures.

Flaky aggregate particles have a tendency to lie flat in pavements, creating slippage planes and reducing interlock and overall performance. Flaky and elongated particles tend to lower the workability of concrete mix, which may impair the long-term durability. Aggregates particles that break during production and construction will reduce the durability of the asphalt mixes in the asphalt layer leading to raveling, pop-outs, and potholes. In addition to the influence on workability, Siswosoebrotho et al. [29] found that flaky aggregates affect stiffness, as well as the volumetric properties (voids in mineral aggregate, air voids content) of asphalt mixes. In seal (surface dressing) pavements, good embedment properties are generally, the desirable characteristics for the aggregates. The flakiness index value indicates how well the aggregates will be embed in the bitumen sprayed surface of the seal.

Similarly, flaky particles are not desired in railway track structure since they break easily under repeated train loading. Traditionally, angular, crushed hard rocks, which are uniformly graded and free from dust aggregates enhance performance in the track structure.

3.2. Flakiness index test procedure

The current test methods are performed on coarse aggregates (size > 4.75 mm). In South Africa, the flakiness index of aggregates is determined using procedures described in the South Africa

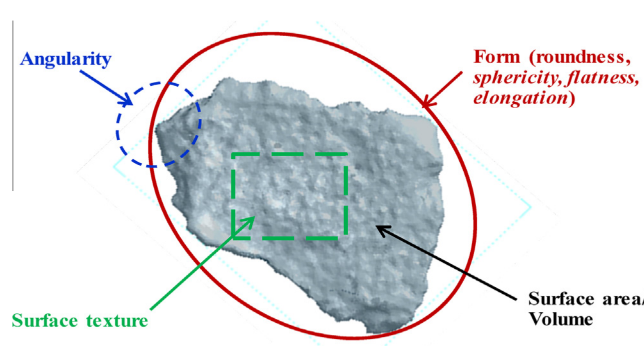

Fig. 1. Surface and shape properties of typical aggregate particle.