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The best of shape

3-D scanning in S. Africa gives aggregate a closer look

All roads, airfields and railroads use rock aggregates in one or more layers within the pavement structure.

Aggregates, therefore, play an important role in the performance of the pavement structures including load transfer and drainage functions. The existing pavement design methods and models were developed using classical continuum theory, which does not consider the effect of aggregate particle morphological (shape) properties including the form, angularity and surface texture as well as the surface area on the performance of the pavement structures.

Aggregate shape/surface characteristics are well known to influence the performance of asphalt and concrete pavements. Angularity and surface texture govern the friction properties and compacted density of the overall aggregate matrix, which significantly affect the overall performance of pavements. 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 also are affected by angularity and surface textures of aggregates. Furthermore, macro and micro textures provided by aggregates on pavement surfaces are necessary to provide wet friction at low and high vehicle speed conditions for safety, while the aggregate form influences the stiffness of the pavements. The performance of pavements, therefore, depends largely on the characteristics of aggregate materials. Complete and accurate quantification of these properties is thus essential for understanding their influence on pavements and will lead to proper selection of aggregates that produce long-lasting pavements.

For several decades efforts have been made by engineers and researchers in pavement design to develop methods and procedures for accurate quantification of aggregate shape and surface properties. The difficult part of the process has been the fact that aggregate particles have irregular and nonideal shapes, resulting in poor approximations.

The author of this article is leading a research team from the Council for Scientific and Industrial Research (CSIR) in South Africa on a three-dimensional laser-based application in pavement engineering. The team employs a modern 3-D scanning device to effectively address the difficulties associated with the characterization of shape and surface properties of natural, recycled and marginal aggregates used in roads, airfields and railroads in South Africa.

Serving all aggregates

There is a substantial amount of natural rock aggregates worldwide that have a restricted usage in pavement and building construction industries due to their smoothness and rounded macrostructure. Recycled concrete aggregate (RCA) from demolition rubble can potentially be reclaimed and converted to aggregates for use in pavement construction. The use of RCA in pavements would help mitigate potential depletion of high-quality rock aggregate sources and provide a means of dealing with various environmental issues regarding demolition rubble, i.e., harmful gas and dust emissions, as well as cost-effective and environmentally acceptable disposal of the rubble after demolition activities.

There are currently no standard test methods for direct and objective measurements of aggregate shape and surface properties. The current methods used in practice have several limitations including use of a manual approach, which is subjective in nature, and lack a direct relationship with the fundamental properties governing the performance of pavements. These limitations impact on the quality of pavements and could lead to specifications that may overemphasize the need for superior aggregate properties or allow the use of inferior aggregates without a clear relationship to their influence on the performance of pavements. Proper characterization of "all aggregates—natural, recycled and marginal" will help engineers predict their influence on the performance of pavements.

Preliminary investigations carried out by the author of this article and co-researchers indicated that the use of 3-D laser-based scanning technology better quantifies the actual surface area of "all aggregates" that have potential use in pavement design and construction. It is therefore imperative for researchers in pavement engineering to seek and implement improved techniques and reliable methods for accurate characterization of aggregate shape and surface properties.

Looks irregular

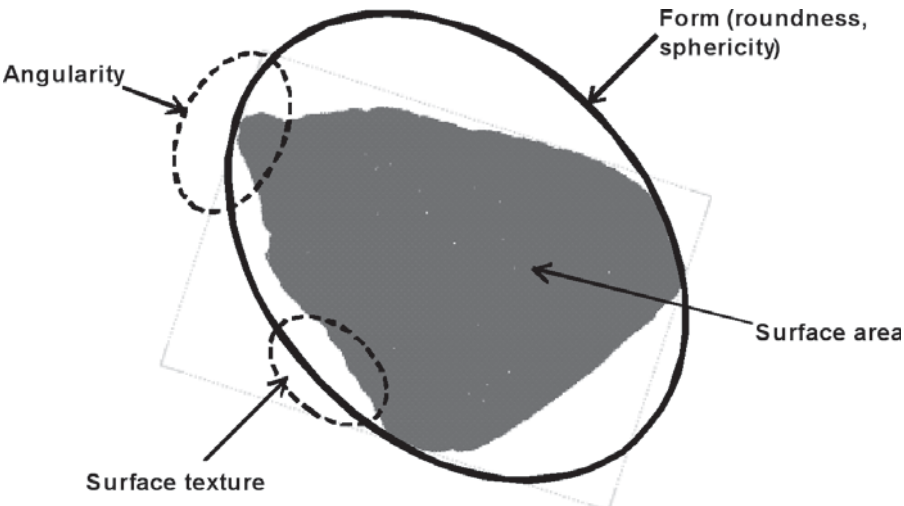
Since 1942, the standard method for determining the surface area of coarse aggregate particles (particle sizes greater than 4.75 mm, or No. 4 sieve size) for asphalt mix design worldwide considers aggregates as spherical in shape. The assumption that all aggregate particles are spherical clearly introduces inaccuracies in the computation of surface areas, and subsequently bitumen (asphalt) film thickness. A more rational approach will be the use of direct measurements to compute the aggregate particle surface area.

The current work at the CSIR by the author of this article and co-researchers has demonstrated that modern 3-D laser applications could be adapted and used to accurately measure the surface area of rock aggregates. These researchers have developed surface area factors (surface area factors are used to compute surface areas) for coarse aggregates used in five typical South African asphalt mixes. It was found that the standard method underestimates the surface area of the aggregate particles by 10% to 30% depending on the type of the asphalt mix. This may have large implications for the calculation of the correct bitumen film thickness of these asphalt mixes.

It is imperative to note that aggregate particles have irregular shape . . . they are not spherical.

So the key research questions were the following:

- How do shape and surface properties of aggregates determined by using 3-D laser scanning techniques relate to pavement performance?
- How can the ability to measure shape and surface properties of individual aggregates and their variability be improved?
- How are aggregate characteristics related to their packing and performance?
- What are the comparative properties of conventional, recycled and marginal aggregates? and
- Given the very scarce skills in this field, how should technology transfer in the application of laser-based technology be enhanced through innovative research?



Shape and surface properties of a typical South African aggregate particle.

Answering these questions will help to optimize the design and evaluation of aggregate properties in all pavement layers.

Potential in 3-D

The use of imaging and scanning techniques for shape and surface analysis of aggregates has recently emerged as an attractive and viable option over the use of the current standard

Actual aggregate particles (left) and scanned and processed particles of a typical South African asphalt mix.

(manual) test procedures. The major shortcoming of the standard methods is the lack of an effective approach to accurately capture profiles of the irregularly shaped aggregate particles. Also, these methods approximate the aggregate particles as spheres for determining bitumen film thickness and other engineering properties, which influences durability and performance of asphalt pavements significantly.

Several attempts have been made to develop and evaluate image analysis systems as alternatives to the manual test procedures. A number of video imaging systems developed for determining aggregate properties is currently available either commercially or as tools in research laboratories. These systems 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 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 of an aggregate particle is through the use of X-ray computed tomography (CT). The sophisticated X-ray CT technique is expensive for this purpose (portable X-ray CT costs more than $1.4 million). Moreover, X-ray equipment has stringent safety and radiation monitoring requirements. The use of 3-D laser-scanning technology for quantifying aggregate shape and surface characteristics has received much attention lately as a more viable and cost-effective alternative to 2-D imaging systems. However, the application of laser scanning of aggregates in pavement engineering is very limited worldwide.

To date, no direct and objective standard methods are available to offer accurate measurements of aggregates used in construction, which leads to poor pavement conditions including potholes, cracking, bleeding and rutting. A 3-D laser-scanning device has been acquired by the CSIR to conduct scientific and applied scanning research of aggregates. The laser-scanning device offers a direct measurement of aggregate properties. The funding for the laser-based research was obtained by the author of this article through the CSIR R&D call for a proposal in 2010 on "Strategic Basic & Applied Research." The device has potential use in the following areas:

- Reference device for accurately measuring the shape and surface properties of rock aggregates used in pavements;
- Verification tool for the current conventional test methods including flakiness index, grading, angularity and other physical tests related to rock aggregates;
- Analysis tool for establishing rock aggregate database to efficiently rank and utilize the sources of aggregate stockpiles and rank different aggregates crushers;
- Appropriate device to overcome and improve the limitations associated with the conventional test methods provided in existing standard specifications;
- Tool for providing test data that can be numerically analyzed and modeled to characterize the properties of common aggregates used in pavements; and
- Tool for investigative studies by evaluating performances of aggregates used in in-service pavements.

Being partial

The ongoing research in 3-D laser-based application in pavement engineering at the CSIR in South Africa offers partial solutions to the cost, renewal and aggregate sourcing problems. The research provides innovative science, engineering and technology solutions for improvement of pavement performance through better characterization of natural, marginal and recycled aggregates, as well as railroad ballast and their packing properties.

Through this research, the CSIR will introduce the latest technology into private industry and national road/airfield agencies, ensuring that aggregate resources are used in the most efficient and economical manner. Knowledge dissemination and technology transfer remain important outputs of this research.

The current research aims at strengthening the existing cooperation of the CSIR with local and international universities, research centers and industry and build new ones through possible collaborations on laser-based characterization of aggregates for pavement infrastructure. R&B

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For more information about this topic, check out the Asphalt Road Zone at www.roadsbridges.com.