Quantifying effect of stress levels on aggregate degradation using an abrasion test in a model rotating drum

M.B. Mgangira & A. Sambo
Council for Scientific and Industrial Research, Pretoria, South Africa

ABSTRACT: This paper presents the results of a study of aggregate particle degradation by quantifying changes to aggregate particle shape due to different levels of applied stress. Proof of concept of the experimental system, developed to provide some insights into aggregate degradation solely due to particle-to-particle interaction mechanism is introduced. The aggregate particle degradation process is created within a customised rolling small model drum, in which the aggregate assemblage is subjected to different stress levels created through simulated increased gravitational forces by testing in the geotechnical centrifuge. The aim of this study is to establish consistency of the experimental system with expected results on the influence of stress levels on aggregate degradation. This is achieved through the quantification of the number of generated fines. The determined generated fines show consistency with expected results of the influence of stress level on the degradation of quartzite, fresh and weathered aggregate samples and therefore validating the experimental system.

1 INTRODUCTION

Understanding the aggregate particle degradation process due to applied stresses is an important input for quantifying aggregate durability and suitability, not only for the structural stability of unbound materials in the upper structural layers, but also for performance as coarse material for asphalt mixtures.

There are several commonly used test methods to determine the durability and therefore the suitability of rock aggregates for use in pavements. The most commonly used mechanical tests (Paige-Green 2007, Lui 2017), measure resistance to abrasion under load.

The most commonly used test in South Africa involving the abrasion of aggregates to determine their durability is the abrasion resistance of coarse aggregates, as described in the South African National Standard in SANS 5846:2006 and the American Standard Test Method in ASTM C131. In order to induce the aggregate wear, a charge of steel balls is used. In the Los Angeles abrasion (LAA) test, the interior of the drum is mounted with a shelf which picks up and drops the aggregates and the steel balls as the drum rotates. Essentially, the particles are subjected to external force, resulting in the particle degradation.

The overall objective of this study effort are to: (i) establish appropriate experimental system for quantifying aggregate degradation that is solely dominated by particle-to-particle interaction mechanism and (ii) compare and evaluate the influence of stress levels on the magnitude of aggregate degradation, to establish consistency of the experimental system with expected trend on the influence of stress levels on aggregate degradation to validate the experimental system.

A proof of concept of the experimental system, developed to assist in the evaluation of aggregate quality, using a customised rolling model drum, is discussed. The experimental system consists of rolling an aggregate assemblage in a rotating model drum, in a high acceleration field, by testing in the geotechnical centrifuge. The basic principle in geotechnical centrifuge testing is that a model experiences increased self-weight, providing body forces that will be applicable in a prototype by using applicable scaling laws for testing in a high acceleration field (Schofield 1980, Garnier et al. 2007).

The assumption is therefore made, that if an aggregate assemblage in a small model drum is subjected to external forces, that are imposed by the increased self-weight of the aggregate particles themselves due to increased gravitational forces, there should be no need of using steel charge to induce wear on the aggregates, when testing in the high acceleration field.

However, as a result of the testing, changes in aggregate shape characteristics or amount of generated fines, should be significant to be able to quantify aggregate degradation and be consistent with expected results of the influence of stress level, to validate the testing system.

2 EXPERIMENTAL TESTING SYSTEM

Several factors guided the design of the system. The first requirement was that the experimental system fulfils the principles of granular material flow in rotating drums, in the absence of radial baffles and steel ball charge to induce wear on the particles. Secondly that all the components of the system will endure the increased self-weight due to high gravitational forces as a result of testing in the high acceleration field in the geotechnical centrifuge. While the model drum system should be able to endure the increased self-weight, the third consideration was the weight and the portability of the system. Several models were investigated by the Mechatronics Group of the CSIR, responsible for the development of the system. The final model was proof tested before the actual aggregate degradation testing programme was initiated.

The device, referred to as the aggregate abrasion test device (AATD) is a motor driven model drum, shown n Figure 1.

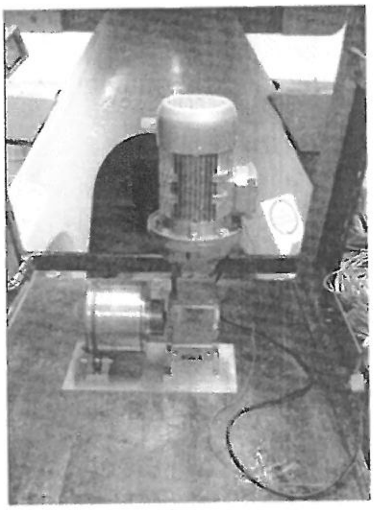

Figure 1. Model drum on the geotechnical centrifuge model platform

The model drum is rotated to a desired rotational speed by the use of the VFD. The University of Pretoria geotechnical centrifuge is classified as a 150 G-ton instrument. It is thus, capable of accelerating a model weighing up to 1 ton, to 150 times the earth's gravity. The centrifuge model platform measures 0, 9 m x 0, 8 m with unobstructed headroom of 1, 3 m. The radius, measured from the centrifuge axis to the model platform, is 3 m.

3 MATERIALS

The material used in the test were a quartzite aggregate, and to assess influence of aggregate weathering, fresh and weathered dolerite samples were also tested. At this stage, only a single particle size range, a representative aggregate sample of material passing the 26.5 mm sieve but retained on 19 mm sieve, was obtained for the investigation. 30 randomly selected particles created the sub-samples.

3.1 *Test procedure*

The total mass of the aggregate sample was determined before being loaded into the model drum. The AATD was then mounted on the centrifuge model platform. During geotechnical centrifuge testing, the model drum is spun around the central axis at a high rotational speed, thereby increasing the body forces acting on the aggregates. Thus no steel charge was used in the experiment to induce the impacts. The centrifuge's acceleration was increased to a desired gravitational acceleration, controlled by using one of the computers from the control room, before each of the abrasion test could begin. Once the desired acceleration was reached and stabilised, the model drum was rotated at a rotational speed of 100 rev/min in all the tests. The abrasion tests were run at centrifuge acceleration of 10g and 20g, for a period of 5 minutes in both cases, which according to the scaling laws represents 50 and 100 minutes respectively, in a dynamic test environment. All samples were subjected to the same test conditions.

At the end of each test, the material was carefully removed from the drum and weighed before sieving on the 2 mm and 0.075 mm sieves, to determine the degradation value and fines generated.

4 RESULTS AND DISCUSSION

The results of the abrasion test for the different samples tested at centrifuge acceleration of 10g and 20g are presented and discussed below. The testing was only aimed at demonstrating that the system provides results that are consistent with expected results on the influence of stress level on aggregate degradation and therefore validate functionality of the system and its potential to quantify aggregate resistance to abrasion.

The expectation is that as the particles make repeated contacts with each other during the course of the test as a result of the rolling and tumbling in the model drum, the particles should generate more fines.

The degradation value was determined as a mass loss of the sample through a 2 mm sieve per mass of the initial particle assemblage and generated fines was determined as the mass passing the 0.075 mm sieve. The amount of the generated fines was normalised to the initial mass of the aggregate assemblage and expressed as mg/g. Figures 2 and 5 show the degradation values and the generated fines proportions under the same drum rotation speed of 100 revolutions per minute. It can be seen that increasing the test acceleration level led to increasing degradation values and increase in the generated fines, showing the influence of increased self-weight as should be expected.

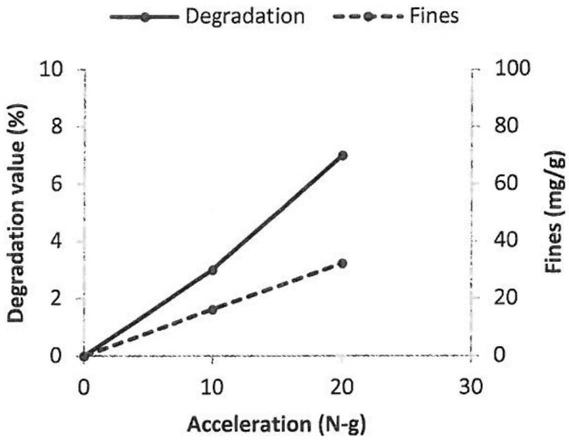

Figure 2. Degradation and fines generation, Barmac

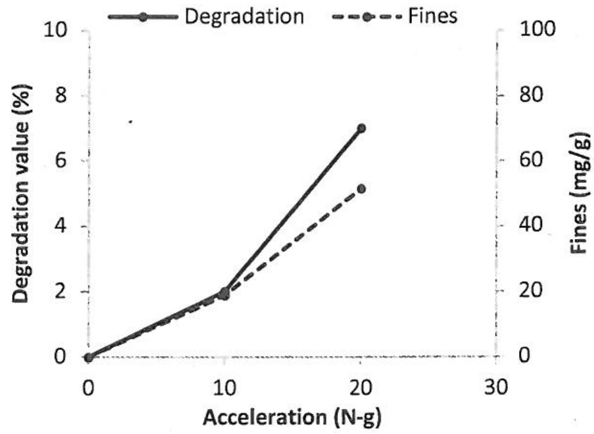

Figure 3. Degradation and fines generation, Cone

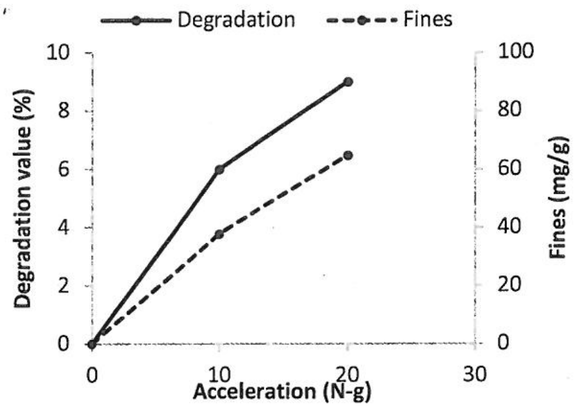

Figure 4. Degradation and fines generation, Osborn

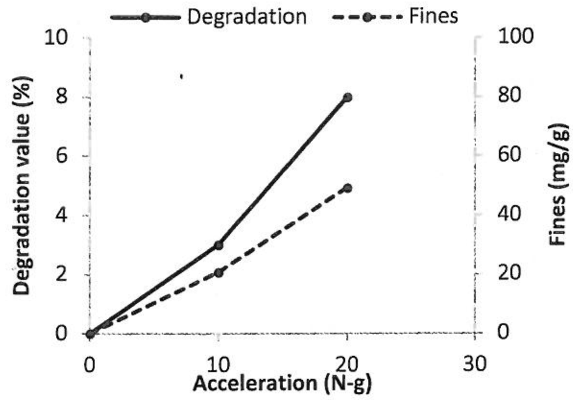

Figure 5. Degradation and fines generation, Jaw

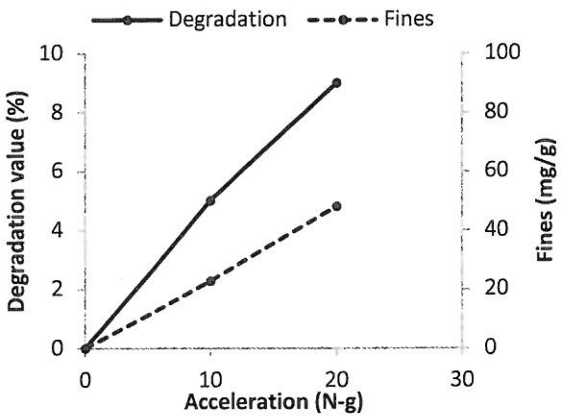

Figure 6. Degradation and fines generation, fresh dolerite

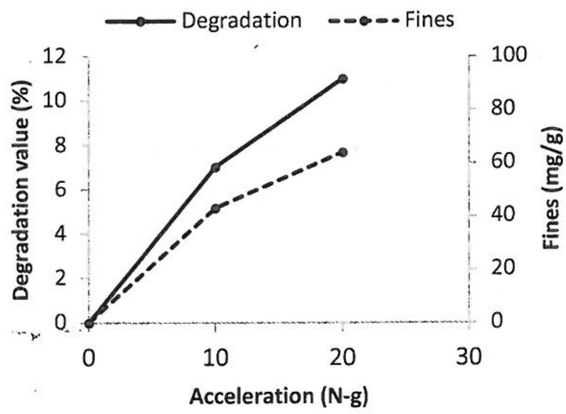

Figure 7. Degradation and fines generation, weathered dolerite

Figures 2 to 5 represent results of the quartzite but as products from different crushers. Figures 6 and 7 show the results of the testing on a fresh dolerite sample and a weathered dolerite sample.

It can be observed form the results presented in Figures 2 to 5 that the amount of fines material generated with increasing g-level, varies with crusher type. While this is an initial study, on the basis of the generated fines, clearly exhibiting particle-to-particle abrasion, confirms that the abrasion mechanism is to an extent influenced by the production process (Bouquety et al., 2007). The testing programme clearly shows the effects of the stress level rolling conditions that the amount of fine material generated increased with increasing g-level.

The results presented in Figures 6 and 7 show that the weathered dolerite sample generated more fines than the fresh dolerite. Thus, the difference in the quality of the same material can be determined using the testing system.

The study is continuing, aimed at exploring the quantification of the effect of stress level conditions on the degradation of aggregate particles and therefore durability, solely on the basis of particle to particle interaction mechanisms, created in a small model drum as a result of simulated increased gravitational forces, by conducting the test in the centrifuge.

There are a number of research questions to be investigated. From the physical properties point of view the next phase of the investigation will focus on: (i) the influence of test duration and particle degradation, (ii) effect of drum rolling velocity on particle degradation and (iii) effect of the mean initial particle mean diameter on degradation.

The testing of mixtures of various particle sizes, with the ultimate goal of modelling changes in the mean particle diameter in such mixtures, as well as investigations on the influence of wet and dry test conditions and different types of rock samples, will form part of the future test programme.

5 CONCLUSIONS

The quantification of degradation of aggregate assemblage has been demonstrated using an experimental system, consisting of small scale model drum in a centrifugal acceleration field, in which the observed particle abrasive or fragmentation is solely dominated by particle-to-particle interaction mechanism.

The effect of stress level on aggregate abrasion/wear is demonstrated through the quantification of fines generated following rolling of the samples in the model drum. The results of the number of generated fines are consistent with expected influence of stress level.

The outcome of the study has demonstrated the operational and functionality of the system and testing platform and its potential to quantify aggregate durability, solely dominated by particle-to-particle interaction mechanism.

6 ACKNOWLEDGMENTS

The technical support provided by Mr. Rikus Kock and the coordination by Prof SW Jacobsz at the Geotechnical Centre of the University of Pretoria. This work was supported under the CSIR Parliamentary Grants (B1iE201 and B1JE222).

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