Evaluation of Railway Ballast Degradation Using Different Approaches

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Abstract

The structural performance of ballasted railway tracks is adversely affected by the level of degradation of the ballast particles. The aggregate particles of the ballast bed undergo gradual degradation which results to an axial deformation of the railway track during the service operation. However, the study of ballast degradation has been very complex and to date, there has not been a single method that is universally accepted to quantify ballast degradation. Hence, in an attempt to adequately quantify the degradation of ballast, this study compares the two most common methods used for the evaluation of ballast degradation; Fouling index (FI) and Marsal's index (Bg). The degraded ballast material was prepared in the laboratory using the Los Angeles abrasion (LAA) method. The Los Angeles abrasion (LAA) test was conducted eight (8) times continuously on the same sample at an interval of 250 turns of the LAA test drum. A Series of sieve analysis was conducted after each test run and the changes in ballast gradations were evaluated. Based on the results obtained a strong correlation was observed between the two approaches with a coefficient of determination of 99.24%. Hence, both Marsal's breakage index and the fouling index can be used for the evaluation of ballast degradation. However, Marsal's breakage index is recommended due to its ability to give the breakdown of the particle size variations.

Keywords
Ballast degradation; fouling; Los Angeles Abrasion; gradation; breakage index

1. Introduction
Ballast bed is one of the most important component of ballasted railway track system, whose deterioration affect the structural performance of ballasted railway tracks. The deterioration of the ballast bed leads to failures of the track system (Ngo and Indraratna, 2016). Ballast is a non-cohesive granular material that is angular in shape and uniformly graded. It is usually placed under and between the sleepers, to provide stability for the sleepers and transfer stresses from the sleepers bearing area to the surface of the supporting ground as well as providing rapid drainage for the ballasted rail track (Lu and McDowell, 2010). It is used to provide stability, resilience, and distribution of stress from the track superstructure to its substructure (Anbazhagan *et al.,* 2012; Danesh *et al.,* 2018a, 2018b; Ngo *et al.,* 2014; Selig and waters, 1994). For a ballast layer to perform its designed function properly, it must be free from any form of deformations and the voids between its aggregate particles be clean in order to drain water at any point in time.

2. Literature Review
Ballast degrades due to the accumulation of traffic loadings and maintenance activities. Although, the attrition of angular asperities of ballast particles begins at the construction stage due to tamping which produce pulverized ballast particles. This continues after the railway is open to traffic and subjected to environmental conditions that cause ballast degradation and fouling of the ballast voids (Ionescu, 2004). This leads to the rearrangement of the particles and reduction in the volume of voids, hence resulting in settlement of the rail track system (Boler *et al.,* 2012). Fouling refers to the situation in which the voids in the unbound granular layer of the railroad ballast are filled with ballast aggregate broken particles and/or other fouling agents e.g., such as coal dust from coal trains wagon spillage and intrusion of subgrade soil (Qian *et al.,* 2017). Fouling is one of the fundamental factors that affect the performance of the railroad; it is associated with poor drainage and reduces the lateral stability of the rail track system. The Association of American Railroads (AAR) conducted a field study to assess railway ballast fouling using petrographic assessment method and reported that ballast particles breakage contributed about 75-90% of the fouling material after transporting 300 million gross tones (Chrismer, 1990). Similarly, Selig and Waters, (1994) stated that ballast particles degradation contributes largely to the fouling of the railway ballast layer by an approximate percentage of 76. However, to assess ballast field performance associated with degradation associated with particle to particle attrition of angular asperities and

breakage, a considerable amount of experimental studies have been carried out by numerous researchers to generate deteriorated ballast materials from ballast degradation processes in the laboratory using standard empirical methods such as the Los Angeles abrasion (LAA) test, micro-Deval abrasion test, Deval abrasion test, mill abrasion test, aggregate crushing test, and impact load test were used to assess ballast degradation. Researchers (Aursudkij, 2007; Lim, 2004; McDowell *et al*., 2005; Nålsund *et al*., 2013; Qian *et al.*, 2014; 2017) reported that the LAA test method correlates well with the real situation in the field than all the other test methods. However, the study of ballast degradation has been very complex and to date, there has not been a single method that is universally accepted to quantify ballast degradation. Hence, in an attempt to adequately quantify the degradation of ballast, this work compares two most common methods used for evaluation of ballast degradation; Fouling index (FI) and Marsal's index (B_g).

3. Material and Methods

3.1 Material and Sample preparation

The ballast material used for this study is 100% crushed granite and the different aggregate sizes were carefully selected, washed, oven-dried, and air-dried at room temperature. It is well-known that the new Nigerian standard gauge rail line is designed and constructed by Chinese companies. Hence, the sample was prepared by proportioning the aggregates as per People's Republic of China Railway Industry-standard gradation (TB/T 2328.14-2008) requirements as shown in Figure 1.

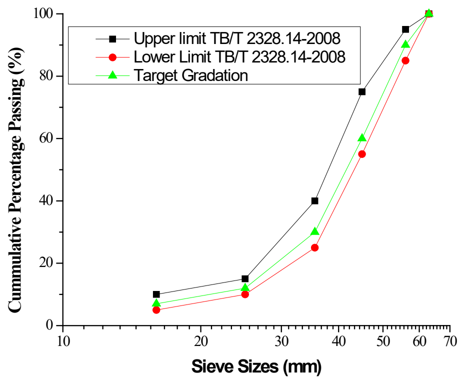

Figure 1: Gradation of crushed granite ballast material (TB/T 2328.14-2008, 2008)

3.2 Methods

This study is purely experimental and the methods employed are as highlighted in the following sub-sections. During testing, strict quality control and quality assurance measures specified by the relevant standard codes of practice were followed to obtain realistic and reliable results.

3.2.1 Ballast material characterisation

The sourced ballast material was characterized in terms of their physical and mechanical properties in the laboratories in accordance with the relevant codes of practice. The tests carried out include specific gravity (ASTM C128 – 15, 2015), Abrasion test (ASTM C535, 2012), crushing test (ASTM D5731, 2002), impact test (BS EN 1097-2) and water absorption (BS EN 1097-2, 2020), test. The aforementioned tests were conducted to determine the suitability of aggregates for use as ballast materials.

3.2.2 Ballast degradation

Los Angeles abrasion test is used to assess the wearing resistance and strength properties of granular materials. In this study, the Los Angeles abrasion (LAA) test was conducted to produce the deteriorated ballast in accordance with ASTM C535 (2009) in which 10 kilograms of clean ballast materials and 12 number steel balls were placed in the LAA drum. The drum was set to rotate at an average speed of 33 revolutions per minute, and the test was conducted eight times repeatedly on each sample at an interval of 250 turns of LAA test drum. Afterward, the drum was allowed to stand still for some minutes to let the dust settle before the evacuation of the material. The tested materials were sieved and cleaned thoroughly to collect dust and fine material using a sieve shaker. Material passing each sieve was collected and recorded.

3.2.3 Ballast degradation Evaluation

To evaluate the ballast degradation, different methods were used in this study to quantify the ballast degradation; Marsal's breakage index (B_g), LAA value and Fouling index (FI).

I. Breakage index

Marsal's breakage index (B_g), as proposed by Marsal (1967) is determined as the summation of positive values of the difference in percentage by mass of total material retained on the same sieve size after the test. The differences in percentage retained on each sieve size (ΔW_k) is determined as follows;

$$\Delta W_k = W_{ki} - W_{kf} \qquad (1)$$

Where W_{ki} and W_{kf} are the percentages by mass retained on sieve size k before and after the test respectively. Marsal's breakage index (B_g) was adopted for this study because of its simplicity and accuracy.

II Fouling index (FI)

The commonly used Fouling indices are the fouling index (FI) proposed by Selig and Waters (1994), and the void contamination index proposed by Feldman and Nissen (2002). However, the void contamination index is usually used when the fouling agents of different material with the ballast. Hence, in this study fouling index by Selig and Waters was adopted because the ballast and fouling material are of the same material.

The fouling index (FI) is express as the summation of ballast material passing sieve No. 4 and No. 200 in percentage by mass, as shown in Eq. (3).

$$FI = P_{0.075} + P_{4.75} \qquad (3)$$

$P_{0.075}$ and $P_{4.75}$; are the percentages by weight of ballast samples passing sieve sizes 0.075 mm, and 4.75mm respectively.

Eq. (3) was derived based on the fact that most North American railway systems use gradations with particle sizes varying from 4.75 mm to 51 mm. However, Eq. 3 can be modified to suit the railway's ballast gradation requirement of one's country of residence (Anbazhagan *et al.*, 2012; Ionescu, 2004). Therefore, the fouling index for the People's Republic of China Railway Industry-standard gradation (TB/T 2140–2008) requirement for a new track system, with a minimum particle size of 12.5mm can be estimated using Eq. (4). Although, the least sieve size for TB/T 2140–2008 gradation is 12.5mm but considering the aggregate range of size 4.75mm to 12.5 mm is wide and may have proper permeability and bearing capacity. Therefore, the fouling index for TB/T 2140–2008 ballast is taken as the summation of ballast material passing sieve size 9.5mm and 0.075mm in percentage by mass of the samples.

$$FI = P_{0.075} + P_{9.5} \qquad (4)$$

$P_{0.075}$ *and* $P_{9.5}$; are the percentages by weight of ballast samples passing sieve size 0.075 mm, and 9.5 mm, respectively.

4. Results and Discussion

4.1 Ballast material characterisation

The results for the preliminary tests conducted and the standards used on the ballast material are as presented in Table 1. The results show that the aggregates satisfied all the codes requirements, therefore the aggregates are suitable for use as ballast materia

Table 1. Results of Preliminary Test conducted on Ballast Aggregates

Test Conducted	Code Used	Test Result	Code Limit
Aggregate Crushing Value (%)	BS 812 Part 112	21.0	Max. 25
Aggregate Impact Value (%)	BS 812 Part 111	20.6	Max. 25
Specific Gravity	ASTM C127	2.66	2.55 – 2.75
Density (kg/m^3)	ASTM C127	1512	>1450
LAA value (%)	ASTM C535	14.52	20

4.2 Ballast degradation

The results for the sieve analysis after each of the series of LA abrasion tests is as presented in Figure 2. The results show the degradation trends in terms of change in initial particles size distribution curves. It can be observed that with an increase in the number of LAA test drum cycles the gradation keeps changing to well-graded. The change in the initial sample gradation is attributed to the breakage and smoothening of the larger particles to smaller ones. The degree of the ballast degradation is as estimated below using the approaches mentioned in section 2.2.3.

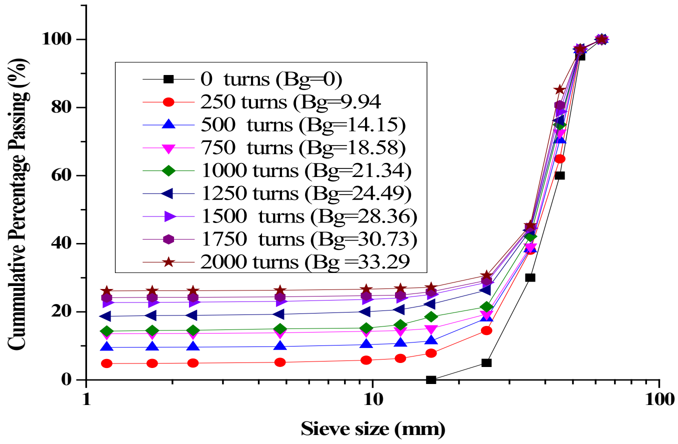

Figure 2: Gradation changes of ballast specimen after LAA test

4.2.1 Breakage index

The results for the breakage index obtained after the series of the LAA tests are presented in Figure 3. The ballast degradation was evaluated based on Marsal's breakage index (B_g). It is clearly shown that with an increase in the number of LAA drum turns, the breakage index (B_g) values increases. The increase in breakage index can be attributed to the breakage and splitting of larger particles into smaller particles which become rounded due to the abrading of the particles' sharp edges with an increase in the number of LAA drum turns. This consequently decreases the ballast shear strength, particle to particle interlock, and drainage capacity and increases axial deformation of the ballast layer. Therefore, ballast degradation in the field is attributed primarily to the breakage of sharp corners during service. This agrees with the works of (Indraratna *et al.,* 2014, Indraratna *et al.,* 2013, Qian *et al.,* 2017).

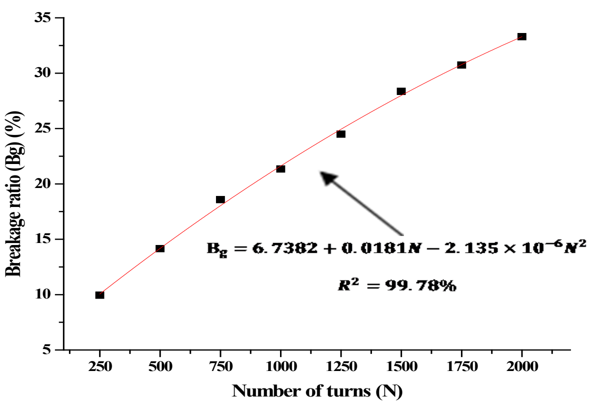

Figure 3: Breakage index values Against Number LA abrasion tests.

4.2.4 Fouling Index

The fouling index values obtained are as parented in Figure 4. It can be observed that with an increase in the number of LAA drum turns, the fouling index increases. The increase in fouling index is due to continuous abrading of the sharp edges and the breakage of the ballast particle and consequently, changes the ballast initial gradations (degradation) of the ballast samples. Figure 5 shows the relationship between the fouling index and breakage index. A strong correlation with coefficient of determination (R^2) of 99.24% can be observed between the two parameters. Hence, it is a clear indication that the two indices can be used to quantify ballast degradation.

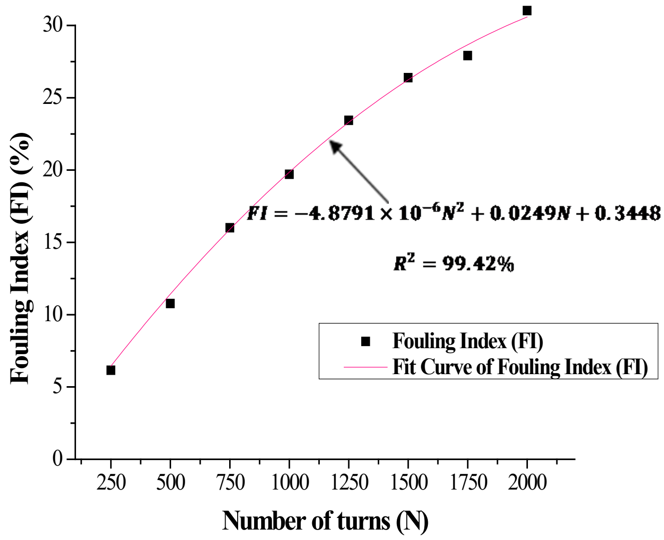

Figure 4: Fouling Index (FI) against the number of turns of LAA test drum.

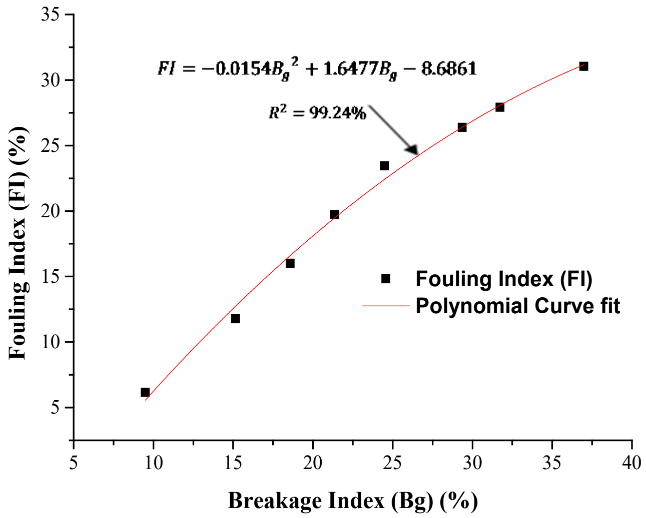

Figure 5: the relation between fouling index and breakage index

5. Conclusions

This paper presents an experimental study on railway ballast degradation evaluation. The ballast particle gradations were analysed during the degradation process, from 0-2000 turns at intervals of 250 turns of the LA abrasion test drum. Series of sieve analysis were conducted and the changes in ballast gradations were evaluated. At the end of the experiment, the following conclusions were drawn.

The preliminary test results showed that the material satisfied all the relevant code requirements and hence, the material is suitable for use as ballast material. The ballast degradation in terms of breakage index (B_g) , and the fouling index increases with an increase in the number of LA abrasion drum turns.

The increase in the ballast degradation is attributed to the chopping off of sharp edges, surface abrasion, and breakage of larger particles into smaller sizes. Based on results obtained from the ballast degradation analysis, both Marsal's breakage index and the fouling index can be used for the evaluation of ballast degradation. However, Marsal's breakage index is recommended due to its ability to give the breakdown of the particle sizes variations.

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Biographies

Ashiru Mohammed is a PhD candidate at the department of Civil Engineering, Ahmadu Bello University, Zaria, working on railway ballast degradation. He obtained his Master's degree from Sharda University, India in 2015. He has published 15 research articles in peer-reviewed journals and conference proceedings at both local and international level.

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