Comparative Evaluation of Railway Ballast Degradation

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Abstract- Ballast bed is one of the most important components of ballasted railway track system. Over a period of service, it undergoes axial deformation due to the accumulation of train cyclic loading. However, there has not been a universally accepted method of evaluating ballast degradation, hence, this study focused on comparing two most common methods namely; Marsal breakage ratio (B_g) and fouling index (FI). The degraded ballast material was prepared using Los Angeles abrasion (LAA) method at an interval of 250 turns of the LAA test drum, from the fresh ballast to degraded ballast at 2000 turns of the LAA test drum. Series of sieve analysis were conducted and the changes in ballast gradations were evaluated. A strong correlation was observed between the results obtained using the two approaches with a coefficient of determination of 99.24%. Based on the results obtained from the ballast degradation analysis both Marsal's breakage ratio 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, breakage ratio, fouling, gradations, Los Angeles Abrasion

1 INTRODUCTION

The structural performance of traditional railway tracks is profoundly affected by the level of degradation of the ballast particles through attrition and breakage during service operations. Ballast is an essential component of ballasted railway track substructure whose deterioration leads to failure of the track system (Ngo and Indraratna, 2016). Ballast is made up of 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 provide rapid drainage for the ballasted rail track (Lu and McDowell, 2010). It provides 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, 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 must be clean in order to drain water at any point in time. 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).

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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 tonnes (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 the behaviour of ballast bed associated with degradation, particle to particle attrition of angular asperities and breakage, a considerable number of experimental studies have been carried out by numerous researchers to generate deteriorated ballast materials from ballast degradation processes in the laboratory (Qian *et al.*, 2014).

Such experiments used 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 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, better 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 breakage ratio (B_g).

2 MATERIAL AND METHODS

2.1 MATERIAL AND SAMPLE PREPARATION

The ballast material used for this study was 100% crushed granite and the different aggregate sizes were carefully selected, washed with clean water, oven-dried at a temperature of 110˚C, 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.

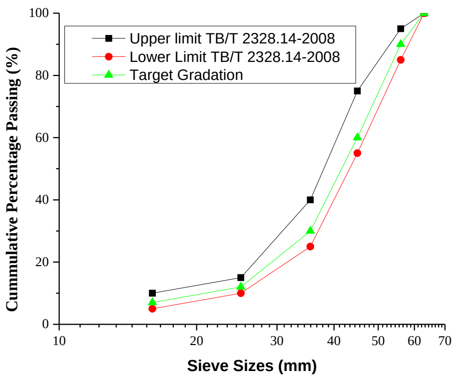

Fig. 1: Gradation of crushed granite ballast material (TB/T 2328.14-2008, 2008)

2.2 METHODS

This study was 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.

2.2.1 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 test (BS EN 1097-2, 2020). The aforementioned tests were conducted to determine the suitability of aggregates for use as ballast materials.

2.2.2 Ballast Degradation

Los Angeles abrasion test was 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.

2.2.3 Ballast Degradation Evaluation

Different methods were used in this study to quantify the ballast degradation namely Marsal's breakage ratio (B_g), LAA value and Fouling index (FI).

A. Marsal's Breakage Ratio

Marsal's breakage ratio (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 (ΔW_k) was 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 with size k before and after the test respectively. Marsal's breakage ratio (B_g) was adopted for this study because of its simplicity and accuracy (Indraratna and Salim, 2002).

B. LAA Value

The LAA value is the ratio by mass of material passing sieve 1.7mm to the overall mass of the sample, as expressed in Eq. (2).

$$LAA\,Value = \frac{W_i}{W_{total}} \qquad (2)$$

W_i is the Mass of ballast sample passing sieve size 1.7 mm and W_{total} is the total mass of the sample.

C. 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 are 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 the same. 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).

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

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$P_{0.075}$ and $P_{4.75}$; are the percentages by weight of ballast samples passing sieves with 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 4.75 mm 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 with 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 sieves with sizes 0.075 mm, and 9.5 mm, respectively.

3 Results and Discussion

3.1 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 specified requirements, therefore the aggregates are suitable for use as ballast material.

3.2 Ballast Degradation

The results for the sieve analysis after each of the series of LA abrasion tests are 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 kept 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.

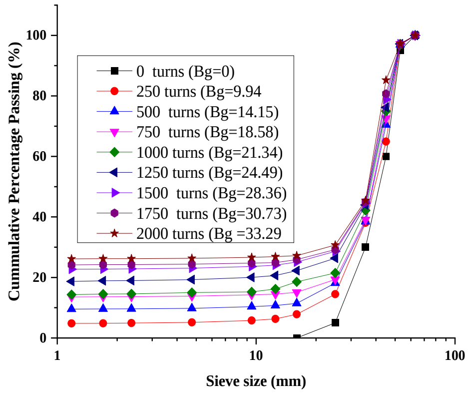

Fig. 2: Gradation changes of ballast specimen after LAA test

3.2.1 Breakage Ratio

The results for the breakage ratio obtained after the series of the LAA tests are presented in Figure 3. The ballast degradation was evaluated based on Marsal's breakage ratio (B_g). It is clearly shown that with an increase in the number of LAA drum turns, the breakage ratio (B_g) values increased. The increase in breakage ratio 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 increased 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), and Qian *et al.* (2017).

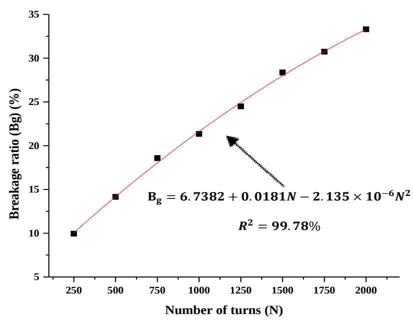

Fig. 3: Breakage ratio values Against Number of LA abrasion tests

Table 1. Results of Preliminary Tests 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

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3.2.2 LAA Value

The results for the LAA value test are presented in Figure 4. It can be observed that with an increase in LAA test drum turns, the LAA value increased. The increase in the LAA value is attributed to the continuous wearing of ballast particles surface and breakage of the sharp edges of the aggregates. The LAA value indicates the percentage of fines produced through the particles' attrition, hence the value will aid in evaluating the percentage reduction void. Reduction in percentage of voids has an adverse effect on the ballast bed drainage capacity.

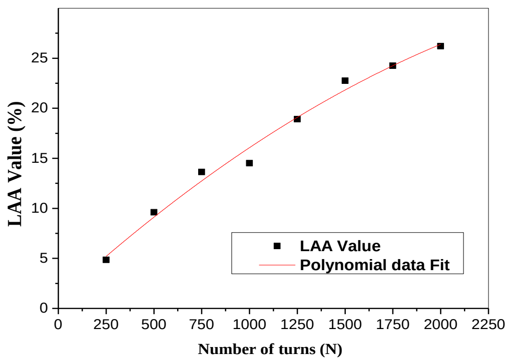

Fig. 4: LA abrasion Value against Number of LAA test drum turns

3.2.3 Relationship between Ballast Degradation and LAA Value

Figure 5 presents the relationship between the ballast degradation index in terms of Marsal's breakage ratio (B_g) values and LAA value. It can be observed that the two quantities are proportional to each other and are perfectly correlated with a coefficient of correlation of 99.02%. Hence, it can be said that ballast degradation can be estimated from the LAA value of the ballast sample.

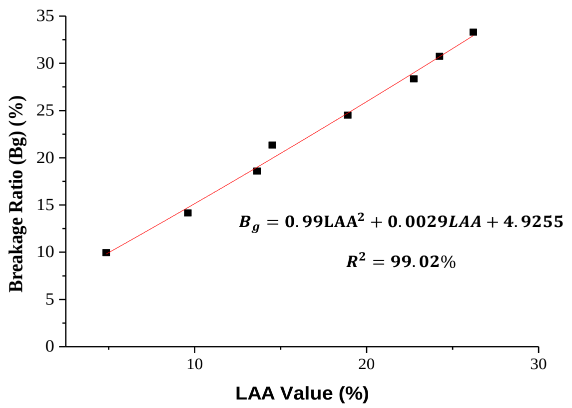

Fig. 5: Breakage index values Against LA abrasion Value

3.2.4 Fouling Index

The fouling index values obtained are as presented in Figure 6. It can be observed that with an increase in the number of LAA drum turns, the fouling index increased. The increase in fouling index is due to continuous abrading of the sharp edges, breakage of the ballast particle and consequently, changes in the ballast initial gradations (degradation) of the ballast samples. Figure 7 shows the relationship between the fouling index and breakage ratio. 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.

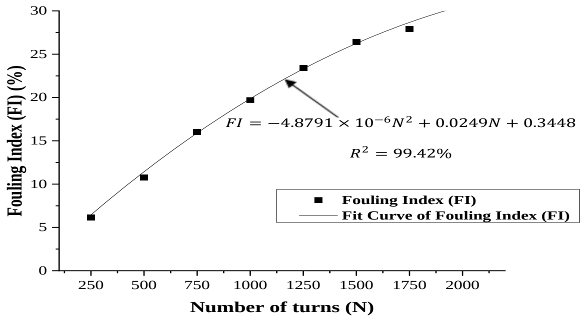

Fig. 6: Fouling Index (FI) against the number of turns of LAA test drum.

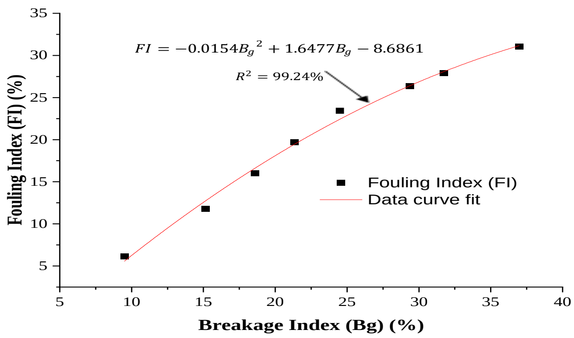

Fig. 7: Relationship between fouling index and breakage index

3.2.5 Relationship between fouling index and LAA Value

The relationship between fouling index (FI) and LAA Value is as presented in Figure 8, it can be observed that the two quantities are proportional to each other and are perfectly correlated with a coefficient of correlation of 99.02%. Hence, it can be said that ballast degradation can be estimated from the LAA value of the ballast sample.

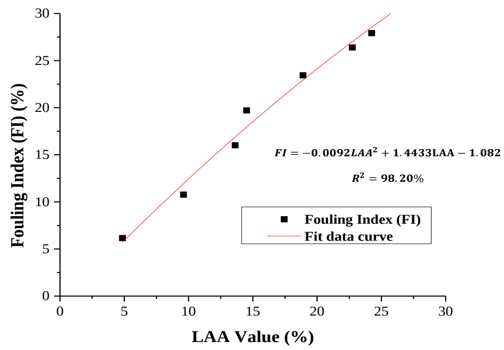

Fig. 8: Relationship between fouling index and LAA Value

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4 Conclusion

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 ratio (B_g) , the fouling index and LAA values increased 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.

Also, a relationship between ballast degradation and LAA values was developed and it was found to follow a polynomial with a correlation coefficient of 99.02%. The relationship between the ballast degradation index and LAA value can be used to quantify the ballast degradation level from the LAA value of the ballast sample. Lastly, 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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