Iran University of Science and Technology

International Journal of

Railway Research

ISSN: 2423-3838

A New Technique for Quality Assessment of Railway Ballast Materials

Masoud Fathali[1], Fereidoon Moghadas Nejad[2*], Morteza Esmaeili[3]

[1,3]School of Railway Engineering, Iran University of Science & Technology, Tehran, Iran

[2]Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran

ARTICLE INFO

Article history:

Received: 21.08.2018

Accepted: 25.10.2018

Published: 15.12.2018

Keywords:

Rail track

Ballast materials

Quality index

Laboratory tests

Abrasion number

A B S T R A C T

The influence of main quality tests on the overall quality of railway ballast materials is assessed in this study. The need to integrate all acceptance tests in a unified manner for precise evaluation of ballast quality is identified, and a technique of performing this is proposed. Using this approach, a new ballast quality index (BQI) is defined in which, the main acceptance tests including abrasive strength, abrasive hardness, fragmentation strength under external loads and weathering resistance, are considered. For the development of the new BQI, all tests results are combined, assigning justified coefficients to each test value according to its contribution on overall quality. Moreover, the comparison of the new index versus the Abrasion Number (AN) as a proposed approach of the Canadian Pacific Railroad for ballast selection is investigated. A practical use of the new index is finally presented with regard to the laboratory investigations on different ballast rocks, to indicate its capability and applicability.

1. Introduction

The ballast layer is an important part of the rail track which supports the sleepers against vertical, lateral and longitudinal displacements. It provides resiliency for the track, transfers the train loading to the substructure, simplifies drainage of water, and retards the growth of vegetation [1]. Typical ballast material is gravel size crushed rock (nominal 20 to 60 mm diameter) with durable particles. The source of ballast varies from country to country depending on the quality and availability of rocks, environmental regulations, and economic considerations. Therefore, a wide variety of materials such as basalt, limestone, granite and dolomite are used throughout the world [2].

While it is expected to be cheap and in ready supply, ballast has to be capable of performing the engineering functions under dynamic loading with minimum maintenance and repair activities, such as tamping or stone blowing [3]. Otherwise, ballast particles become quickly degraded under cyclic loadings. This causes increase of the overall compressibility [4], impeding of drainage [5], and fast deterioration of the geometry quality [6]. So, the replacement of the layer or its modification by methods such as geosynthetic reinforcement will be necessary, which in turn leads to higher costs [7].

In order to meet the performance requirements of ballast materials, railway organizations have proposed different quality tests to control and accept its specifications. Different aspects of ballast properties are individually evaluated by current railway standards and compared with their allowable limits. However, there is no integrated approach in which the priority of each ballast test as well as its place in the overall quality of materials can be recognized. This is very hard because of the variety of effective parameters in accepting or rejecting the quality of ballast particles. For

*Corresponding author, Professor

Email address: moghadas@aut.ac.ir

[DOI: 10.22068/IJRARE.5.2.53]

example, researchers such as Lim [8] and Abateneh [9] have shown that single conventional ballast abrasion tests, such as the wet attrition value, Los Angeles abrasion, and micro-Deval attrition give conflicting results and often fail to represent actual field performance of ballast materials. There is therefore a need for better and more consistent ballast assessment techniques that provide results reflecting the accurate quality of different ballast materials. Different tests potentially measure different features of the rock and so the interpretation of all tests should be considered in a unified manner to provide a more realistic image of ballast quality.

Consequently, a new approach should be developed that enables the evaluation of ballast quality in an integrated manner which is the purpose of current research. To obtain this goal, a new evaluation index is created in which, the values of main quality tests are combined by assigning justified coefficients according to their allowable limits. The allowable limits are determined by extensive survey of acceptance criteria for various types of ballast materials in different railways. Considering this index, the ranking (e.g. quantifying the total quality of ballast) as well as the unified comparison of various ballast materials will be able to provide. The comparison of the new index is also followed via the abrasion number (AN) approach in the Canadian Pacific Railroad. Finally, extensive laboratory tests are conducted to investigate the application of the new technique besides the correlation between different ballast rocks.

2. Current Ballast Quality Measures

Various tests have been proposed by different railway organizations to qualify the ballast materials, as the general scheme of the main categories is presented in Figure 1. The tests written in bold italic are the main universally accepted ones which directly determine the durability of ballast particles.

A comparison between the durability specifications of ballast (i.e. the allowable limits) used in Australia [10], Canada [11], England [12], Germany [13], India [14], Iran [15], and USA [16] is given in Table 1. The standard test method for each experiment is also pointed out in this table.

From Table 1 it can be concluded that there is no unified approach for quality control of ballast materials with universal acceptance. Additionally, the importance of each quality test against the others and its contribution to the overall quality level is not distinctive.

3. Development of New BQI

The development of ballast quality index is attempted in this section.

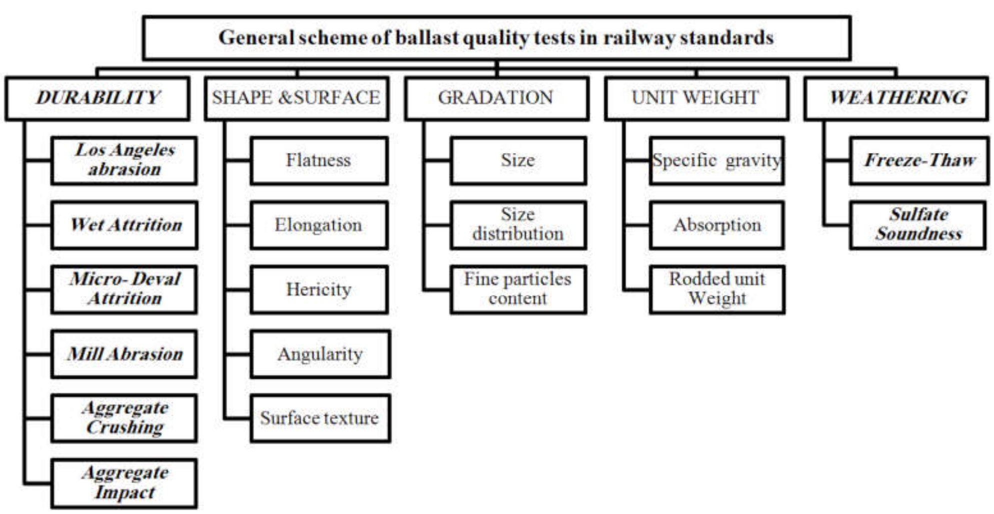

Figure 1. General scheme of ballast quality tests in railway standards

[DOI: 10.22068/IJRARE.5.2.53]

Table 1. Comparison of ballast durability specifications in various railways (%)

	Los Angeles Abrasion (LAA)	Wet Attrition (WA)	Micro-Deval Attrition (MDA)	Mill Abrasion (MA)	Aggregate Crushing (AC)	Aggregate Impact (AI)	Sulphate Soundness (SS)
Australia	25 AS 1141	6 AS 1141			25 AS 1141		
Canada	20-30 CN			14 Selig & Boucher(1990)			7-10 CN
England	20 BS EN 13450	4 BS EN 13450	7 BS EN 13450		22 BS EN 13450		
Germany	*8.7-23 BS EN 13450	*5.9-13.8 BS EN 13450				*10-23 BS EN 13450	
India	*30-35 IRS-GE-I					*20-30 IRS-GE-I	
Iran	30 IR301	10 IR301	*10-14 IR301				5 IR301
USA	*25-40 AREMA			14 Selig & Boucher(1990)			5 AREMA

*Note: The recommended range is introduced according to different ballast classes or rock sources

3.1. General Form of BQI

The most important quality tests on ballast particles can be classified in four main categories, which are widely accepted by different references [17-18]. The first category measures the rock particle strength or particle toughness through abrasive behavior, hereinafter called abrasion value. The main tests of this category are the Los Angeles abrasion (LAA) and wet abrasion (WA) experiments. The second category is the representative of rock particle hardness, hereinafter called attrition value. The micro-Deval attrition (MDA) and mill attrition (MA) tests are the main samples of this group. Particle fragmentation under external loads (gradually or sudden) is the third set of durability tests, called here fragmentation value. The aggregate crushing (AC) and aggregate impact (AI) values are the representatives of this group. The last one which is called weathering value, evaluates the aggregate resistance to disintegration from weathering conditions. The main tests of this category are the sulphate soundness (SS) and freeze-thaw breakdown.

All of the tests values can be put together in a suitable manner to form a general BQI, indicating the overall ballast quality condition. The combination of the above test values can be made by assigning an appropriate coefficient to each test which indicates its contribution to the overall ballast quality condition. This is made in this research as follows:

$$BQI = \left(\frac{a(abrasion)+b(attrition)+c(fragmentation)+d(weathering)}{(a+b+c+d)}\right) \quad (1)$$

where the BQI is the overall ballast quality index, and a, b, c, and d are the importance coefficients. From this equation, the smaller the BQI value shows a better ballast quality and the higher corresponds with poor ballast quality. Considering n number of readings in a test, the average amount can be expressed in BQI.

3.2. Determination of Importance Coefficients

To calculate the importance coefficients, the unified acceptable ranges of each test value (previously presented in Table 1) were served as expressed in Table 2. This table which presents

Table 2. Unified limiting values of durability tests for ballast material (%)

Quality Level	Abrasion Value		Attrition Value		Fragmentation Value		Weathering Value
	LAA	WA	MDA	MA	AC	AI	SS
Excellent	0-10	0-5	0-5	0-5	0-10	0-10	0-5
Good	10-20	5-10	5-10	5-10	10-20	10-20	5-7
Poor	20-30	10-15	10-14	10-14	20-25	20-25	7-10

the acceptance values of ballast durability tests in different conditions, is concluded from the most well-known standards of AREMA [16], EN BS [12], AS [10], CN [11], and IR301 [15]. As seen from this table, three quality classes for ballast are here proposed to integrate the acceptance values in a unique and quantitative manner. Class 1 (i.e. excellent level) can be considered as crushed rock ballast for use primarily on main line track (with high operational importance), class 2 (i.e. good level) for use on main line track (with moderate operational importance), and class 3 (i.e. poor level) for use only on other than main line track (with low operational importance). It should be noted that the choice of three quality levels for ballast materials is done here based on different operating conditions of rail track which is observed in some railway regulations such as AREMA and EN. This table provides an integrated image of the overall quality of ballast materials and shows the importance of each main test result in reaching the final quality. Generally, the lower the allowable amount of the test, the greater will be the impact of that test on BQI and vice versa. Notably, the influence of a test result (towards the BQI) is inversely related to the size of its accepting value. This concept is used in the calculation of the importance coefficients for test categories (a, b, c, and d in Equation (1)). Here, the coefficient for the test with the lowest value is considered to be 1, and the coefficient of every other test is calculated through dividing that test value by the lowest value. This concept can be served here due to the similar nature of the test results, i.e. generated percentage of finer particles in every durability tests.

3.3. The Proposed BQI

In this section, the proposed BQI is presented according to its previous general form (see Equation (1)). For this purpose, the selected test of each category should be decided on. Here, the LAA, MDA, AC, and SS tests are considered because of wide applications as well as their complementary concepts for quality control of different aspects of ballast material. For example, while LAA evaluates the dry particle strength of the materials, MDA assesses the wet hardness strength, AC determines the effects of gradually exerted pressures on ballast layer (especially important for interaction of ballast material with sleeper), and finally SS determines the weathering resistance in critical simulated climate condition. The amounts of importance coefficients are tabulated in Table 3 for selected tests. As explained in section 3.2, the coefficient for the test with the lowest value (here 10 for SS) is considered to be 1, and the coefficient of every other test is calculated through dividing that test value by the lowest value (i.e. 30/10=3 for LAA). As presented in Table 3, the calculated importance coefficients of the MDA and AC tests can be considered for MA and AI tests respectively because of their similar allowable tolerances in different quality levels.

Table 3. Importance coefficients of proposed BQI

Proposed BQI Tests	LAA	MDA/MA	AC/AI	SS
Importance Coefficients	A	b	C	d
	3.00	1.40	2.50	1.00

Entering the importance coefficients in accordance with Table 3, the BQI formula can be expressed as follows:

$$BQI = \left(\frac{3.00(LAA)+1.40(MDA/MA)+2.50(AC/AI)+1.00(SS)}{7.90}\right) \quad (2)$$

[DOI: 10.22068/IJRARE.5.2.53]

To categorize ballast materials based on their durability according to their BQI values, the quality ranges of ballast for different classes (i.e. excellent, good, and poor) have to be correlated. For this goal, Table 2 was used to define different ranges for proposed BQI and relate them to the condition of ballast materials. This table introduces different quality levels, which provides the boundary values for each test. For the determination of a ballast quality, boundaries for each measure were considered and taken as input for Equation (2). As a result, the ranges for BQI are obtained as presented in Table 4, indicating different conditions of ballast quality. For example, in class 1 (i.e. excellent range), the upper acceptable values of LAA, MDA, AC and SS are 10, 5, 10, and 5 respectively which are placed in Equation (2); thus, the BQI score will be 8.48 as seen in Table 4.

Table 4. Different qualities of ballast condition, based on the BQI

Class1(Excellent)	Class 2 (Good)	Class 3 (Poor)
$0 \leq \mathrm{BQI} < 8.48$	$8.48 \leq \mathrm{BQI} < 16.58$	$16.58 \leq \mathrm{BQI} \leq 23.05$

As the current proposed BQI is developed according to the limiting values of ballast quality tests, it may vary from one railway to another. In other words, the BQI can be established for any railway by applying the current developed technique and by using the allowable values of the quality tests defined in that railway.

3.4. Comparison of the BQI with Abrasion Number (AN)

The Canadian pacific Railroad characterized a combined index for selection of ballast materials called abrasion number (AN) as following equation [19]:

$$AN = LAA + 5MA \tag{3}$$

To compare the new presented technique, the correlation of BQI and AN is followed in this section. For this goal, the different ranges of limiting values for every quality levels is placed both in the AN and BQI equations. It should be noted that the selected tests here are LAA and MA from abrasion and attrition categories, respectively. Hence, the values of other tests (i.e. AC and SS in the BQI) are considered equal to zero. According to the limiting values of these tests, the quality range of each index can be determined according to the Table 5. To make the comparison of the results between two indexes possible, the BQI range of numbers should be converted to the AN range (i.e. in hundred). For this purpose, the amounts of BQI are multiplied by the conversion coefficient of 7.21 as presented in Table 5. From the obtained results, very close correlation of both equations can be concluded which shows the validity of the BQI equation. Moreover, the Canadian Pacific Railroad has proposed the minimum AN amount of 65 as a lower acceptance limit of ballast quality [20]. This limit is more close to the poor boundary of BQI (i.e. 67.52) compared with AN itself (i.e. 70).

Table 5. Correlation of the quality ranges of the BQI versus AN

	Excellent	Good	Poor
AN	$0 \leq \mathrm{AN} < 35$	$35 \leq \mathrm{AN} < 70$	$70 \leq \mathrm{AN} \leq 100$
BQI	$0 \leq \mathrm{BQI} < 4.68$	$4.68 \leq \mathrm{BQI} < 9.37$	$9.37 \leq \mathrm{BQI} \leq 13.87$
BQI (in 100)	$0 \leq \mathrm{BQI} < 33.76$	$33.76 \leq \mathrm{BQI} < 67.52$	$67.52 \leq \mathrm{BQI} \leq 100$

4. Practical Use of BQI

To show the application of new technique, the quality evaluation of three main ballast types is presented in this section by applying the new proposed BQI. The parent rock properties of the selected ballasts as well as the samples of ballast particles are presented in Figure 2.

4.1 Durability Tests

The durability of ballast is here assessed by the Los Angeles Abrasion (LAA), the Micro-Deval attrition (MDA), the Aggregate Crushing (AC) and the Sulphate Soundness (SS) tests. The equipments, specimens, and reference test methods are illustrated in Figure 3. The final results are also presented in Table 6.

[DOI: 10.22068/IJRARE.5.2.53]

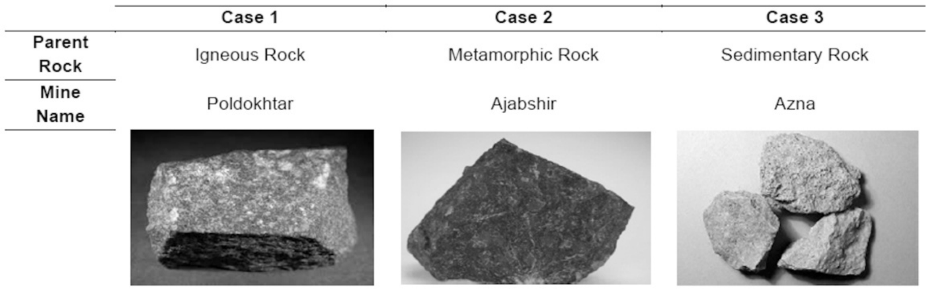

Figure 2. Three samples of parent rocks for ballast materials

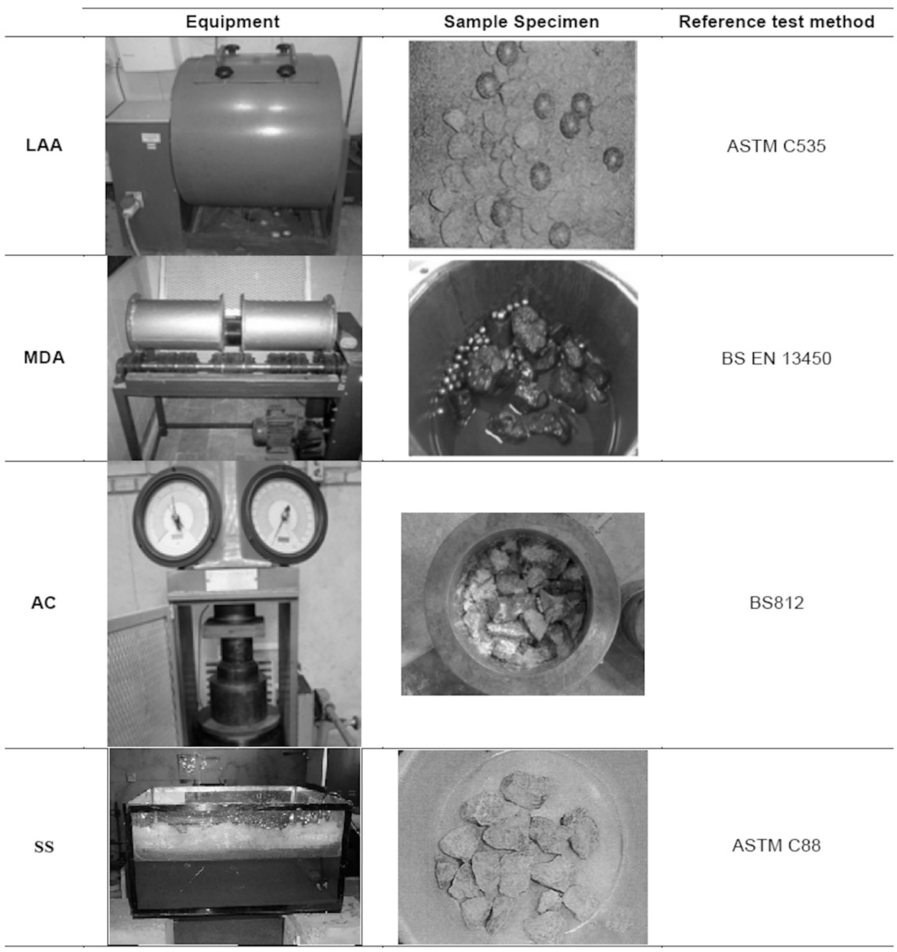

Figure 3. The equipments and specimens of selected durability tests

4.2 Discussion of BQI Results

The results of BQI for different ballast types are given in Figure 4. To obtain these results, the Equation (2) was calculated based on the results of quality tests and then the quality level was determined with regard to the Table 4. As it is illustrated in the figure, the BQI for igneous rock has reached to the highest quality level (i.e. excellent rank) in comparison with the other kinds of materials. Additionally, the metamorphic rock was put in the good quality level with the score of 10.17. However, the sedimentary ballast was put in a poor quality level and its score shows about 13 percent difference from good quality rank. These results have very good compatibility with the suggestion of different standards about the type of parent rock materials for ballast aggregates [18 & 21].

Table 6. The values of durability tests for different ballast types

	Igneous	Metamorphic	Sedimentary
LAA	12.50	16.42	31.72
MDA	2.58	5.08	13.46
AC	4.12	8.31	10.22
SS	0.20	0.15	3.46

This proves that the new index is sensitive to the condition of the ballast types, as it provides different quality levels for various parent rocks. Moreover, the difference between the levels of quality is determined in a quantitative manner, which could not be recognized by current test approaches.

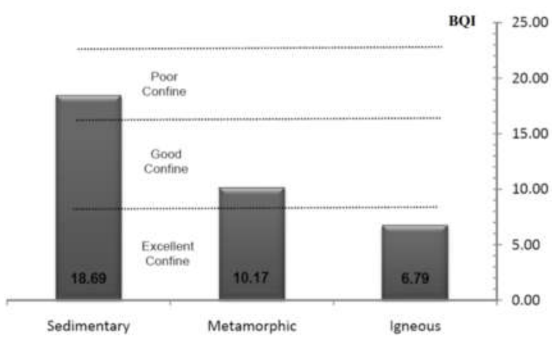

Figure 4. The comparison of durability indexes for three types of ballast material

5. Conclusions

In this research, the quality evaluation of ballast materials in an integrated manner is investigated. Identifying a need for the incorporation of all measuring tests for ballast aggregates, a new approach for the establishment of a BQI to be developed. To formulate new index, main durability tests for ballast particles including abrasive strength test, abrasive hardness test, fragmentation strength under external load, and weathering resistance are considered.

The new BQI is developed by the combination of the ballast test measures. This is achieved by assigning justified coefficients to each measured values. These coefficients are calculated with reference to the role of each test in the overall quality condition of ballast materials. The importance (role) of each test criterion is determined by allowable limits, which have been determined form deep survey of railway standards on ballast properties. Thus, the newly proposed index not only provides an indication of the conditions of individual tests but also yields a numerical representation of the overall ballast quality condition. This provides us with the possibility of being able to make a ranking about different ballast materials in a quantitative manner. Moreover, it facilitates identifying the priority of tests, which have more important role in the qualifying conditions of ballast materials. A practical use of the new index with regard to the extensive laboratory investigations on different types of ballast materials has been presented, and the ranking results for three different rocks of igneous, metamorphic and sedimentary are tabulated.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

List of symbols

a	Importance coefficient for abrasive strength
AC	Aggregate crushing
AI	Aggregate impact
AN	Abrasion number
b	Importance coefficient for abrasive hardness
BQI	Ballast quality index
c	Importance coefficient for fragmentation strength
d	Importance coefficient for weathering resistance
LAA	Los Angeles abrasion
MA	Mill abrasion

[DOI: 10.22068/IJRARE.5.2.53]

MDA	Micro-Deval attrition
n	Number of readings in a test
SS	Sulphate soundness
WA	Wet attrition

References

[1] D. Mishra, H. Kazmee, E. Tutumluer, J. Pforr, D. Read, E. Gehringe, Characterization of railroad ballast behavior under repeated loading, Transportation Research Record: Journal of the Transportation Research Board, 10.3141/2374-20, (2013), pp. 169-179.

[2] B. Indraratna, W. Salim, C. Rujikiatkamjorn, Advanced rail geotechnology–ballasted track, University of Wollongong, Wollongong City, NSW 2522, Australia, (2011).

[3] S. Lobo-Guerrero, L.E. Vallejo, The effectiveness of geosynthetic reinforcement, tamping, and stoneblowing of railtrack ballast beds under dynamic loading: DEM analysis, Geomechanics and Engineering, Vol. 2, No. 3, (2010), pp. 161-171.

[4] B. Indraratna, S. Nimbalkar, Stress-strain degradation response of railway ballast stabilized with geosynthetics, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 139, No. 5, (2013), pp. 684-700.

[5] N. Tennakoon, B. Indraratna, C. Rujikiatkamjorn, S. Nimbalkar, T. Neville, The role of ballast fouling characteristics on the drainage capacity of rail substructure, Geotechnical Testing Journal, Vol. 35, No. 4, (2012), 1-4.

[6] Y.H. Byun, W.T. Hong, J.S. Lee, Characterization of railway substructure using a hybrid cone penetrometer, Smart Structures and Systems, An Int'l Journal Vol. 15, No. 4, (2015), pp. 1085-1101.

[7] S. Saride, S. Pradhan, T.G. Sitharam, A.J. Puppala, Numerical analysis of geocell reinforced ballast overlying soft clay subgrade, Geomechanics and Engineering, An Int'l Journal Vol. 5, No. 3, (2013), pp. 263-281.

[8] W.L. Lim, Mechanics of Railway Ballast Behaviour, Ph.D. dissertation, The University of Nottingham, (2004).

[9] Y.A. Abateneh, Survey of railway ballast selection and aspects of modelling techniques, Dissertation, Division of Highway and Railway Engineering, Royal Institute of Technology, SE-100 44 Stockholm, (2011).

[10] AS 1141, Methods for sampling and testing aggregates, Standards Australia, NSW, Australia, (1996).

[11] CN, Crushed rock ballast material specification, Canadian National Railways Specifications, 12-20C, (2003).

[12] BS EN 13450, Aggregates for railway ballast, British Standard, (2013).

[13] Das BM., Retrieved 05 20, from Geotechnical Engineering Handbook, (2011).

[14] IRS-GE-I, Specification of Track Ballast, India, (2004).

[15] IR301, Railway track superstructure, general technical specifications, Iran Ministry of Roads and Transportation, Ministry Publication Service, (2005).

[16] AREMA, The American Railway Engineering and Maintenance of Way Association, Manual for Railway Eng. Vol.1, ch.1, Roadway & Ballast, part 2, (2014).

[17] M. Fathali, F. Moghadas Nejad, M. Esmaeili, Influence of tire-derived aggregates on the properties of railway ballast material, ASCE Journal of Materials in Civil Engineering, (2016), Vol. 29, No.1 , (2017).

[18] F. Moghadas Nejad, F. Azari, Laboratory investigation on technical specifications of ballast materials, Dissertation, Amirkabir University of Technology, Iran, (2005).

[19] E.T. Selig, J.M. Waters, Track geotechnology and substructure management, Thomas Telford, London, (1994).

[20] E.T. Selig, D.L. Boucher, Abrasion tests for railroad ballast, ASTM Geotechnical Testing Journal, GTJODJ, Vol. 13, No. 4, (1990), pp. 301-311.

[21] Y. Ozcelik, Predicting Loss Angeles abrasion of rock from some physical and mechanical properties, Scientific Research and Essays Vol. 6, No. 7, (2011), pp. 1612-1619.

[DOI: 10.22068/IJRARE.5.2.53]