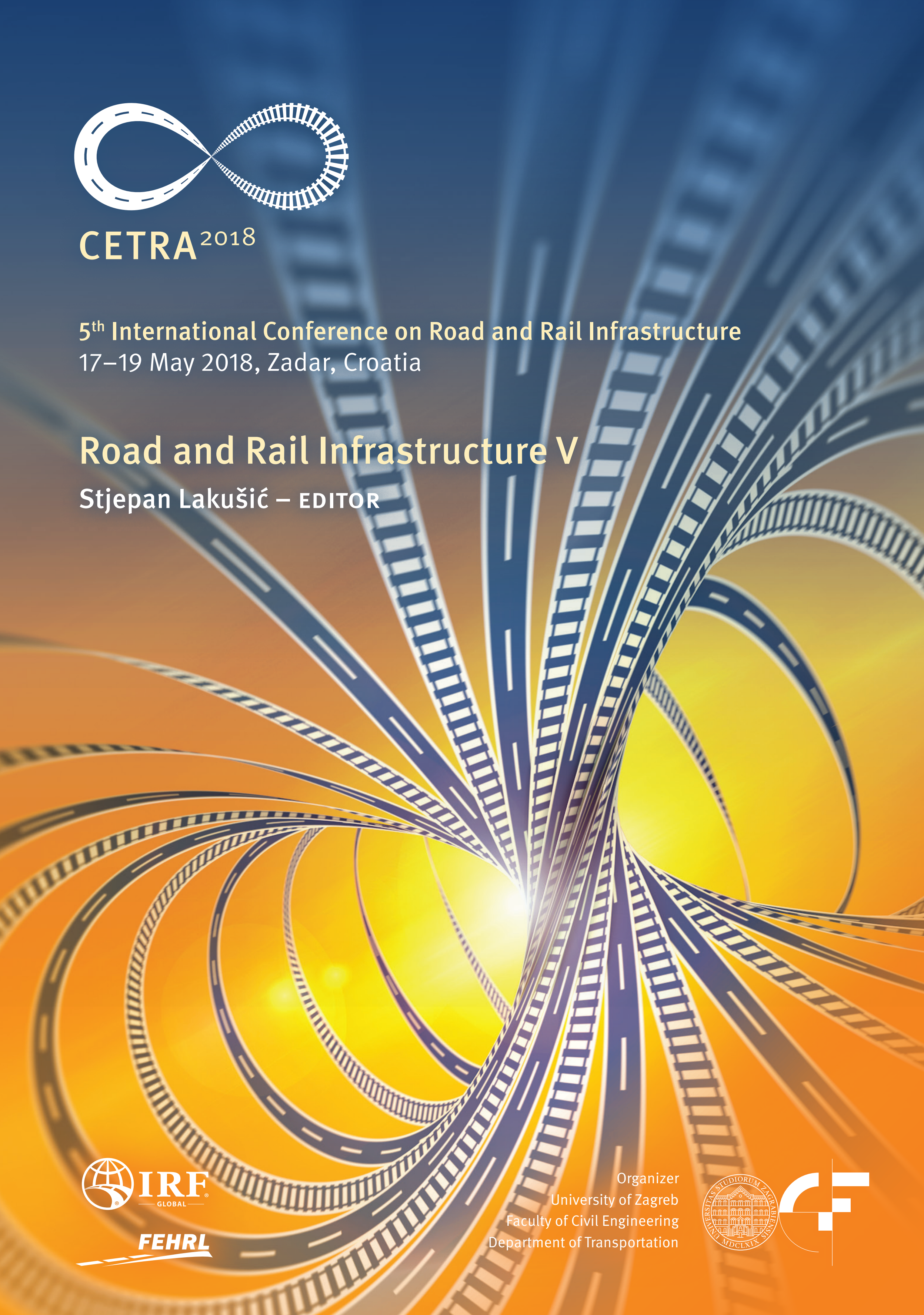

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – **EDITOR**

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EVALUATION OF BALLAST MATERIALS USED IN BRAZILIAN RAILWAYS BASED ON THEIR RESISTANCE TO WEAR

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Abstract

Most railways constructed today in Brazil and across the world are built on a ballast layer, which is usually comprised of granular materials of rocky origin. Ballast is a very important element in the absorption of vertical stresses caused by train traffic and it has, among other roles, the function of ensuring the vertical and longitudinal alignment of the track and drainage of water. Being the top layer of the track foundation, ballast is constantly subject to mechanical deterioration, weathering and to action of other external agents. Problems stemming from ballast degradation impact both cargo and passenger traffic, resulting in costly track maintenance routines and causing operational inconveniences, in addition to facilitating the occurrence of accidents. In that context, the objective of this study is to assess the characteristics of different rocky materials used as railway ballast in the main cargo exportation and passenger corridors in Brazil, particularly regarding their resistance to wear. Results from several studies conducted in different parts of the country were assembled and compared. Simultaneously, tests were carried out on a sample of ballast material collected at an important rail corridor near Campinas, south-east Brazil, and its Los Angeles abrasion, shape evaluation, specific density, and water absorption indexes were obtained. Results retrieved from previous studies and from the original tests were all compared to international standards enforced in Australia, USA and Brazil, countries where heavy-haul cargo is most relevant. It was possible to notice that, in spite of Brazil having and using rocky aggregates from very diverse geological origins, being the continent-sized country that it is, they meet most international standards and recommendations regarding resistance to wear, according to the indexes analysed in this research. It could also be observed that the studied diabase is adequate for use as ballast material.

Keywords: railway ballast, ballasted track, ballast abrasion, ballast properties

1 Introduction

1.1 The ballasted track

Railways can be built on different foundations depending on the desired properties to be obtained. Most rail tracks, however, are of the traditional ballasted type, from heavy-haul freight lines to high-speed passenger trains such as the French TGV. Nonetheless, the traditional rail foundation consisting of one or two granular layers overlying soil subgrade has become increasingly overloaded due to the utilisation of faster and heavier trains, demanding more frequent maintenance cycles [1]. Given that scenario, it is critical that engineering solutions are developed to enhance stability and safety of the railway, thus allowing further increases in passenger and freight demand.

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Among the many functions performed by the ballast according [2], the most important are: keeping the track in its original position by resisting lateral, longitudinal and vertical forces; working as a resilient and energy-absorbing layer; providing voids among particles in order to allow the storage of fouling material and drainage of water; facilitating levelling and lining maintenance operations by allowing tamping of the ballast particles; reducing vertical pressures from the sleeper contact area to the underlying layers; inhibiting the growth of vegetation; providing electrical resistance between rails.

Particles' gradation will change throughout the ballast's service life due to mechanical degradation during maintenance work and under traffic loading, as well as weathering from environmental changes and intrusion of fine particles from the subsoil or from the surface [2]. In fact, a common problem faced by ballasted tracks is the progressive deterioration of ballast with increasing traffic passage, when breakage of sharp corners, repeated grinding and wearing of aggregates, and crushing of weak particles under heavy cyclic loading may cause differential track settlement and unevenness of the surface [1]. Therefore, constant inspections and maintenance procedures are required.

1.2 Justification and objective

Being a non-renewable mineral resource, it is imperative that environmental concerns contribute to the choice and usage of ballast materials. The more durable they are, the lesser the impact on natural quarries. Therefore, research on the properties of ballast material contributes also to the preservation of natural resources. This article reviewed recent research studies conducted on the most important railways from North to South of Brazil, where ballast from different types of rocks was analysed. Simultaneously, an experimental procedure was run in order to assess a sample of diabase quarried in the South-east area of the country, aiming to investigate its particle size distribution, particle shape, water absorption and porosity and Los Angeles abrasion index. The main purpose of this paper is to compare both literature and experimental results to the existing international standards, and to compare the original results to the average values of the reviewed studies.

2 Evaluating the properties of track ballast

The source of ballast aggregate, the so-called parent rock, varies greatly from place to place, and even among regions within a continent-sized country such as Brazil. No universal specification of ballast can ever be established for its index characteristics such as size, shape, hardness, friction, texture, abrasion resistance and mineral composition that will provide the optimum track performance under all types of loading, subsoil and track environments [1]. Therefore, a wide variety of materials can be used as ballast throughout the world, such as granite, diabase, basalt, limestone, dolomite and gneiss. That same diversity can be found in different regions of Brazil, as shown throughout this paper.

In order to perform properly during its service life, ballast must conform to a series of characteristics. Its mechanical behaviour derives from a combination of the physical properties of the individual ballast particles and its conditions in-situ, such as density and void ratio. Selig and Waters reinforce that no single characteristic controls ballast behaviour; instead, it is the net effect of combined characteristics [2]. The physical properties of particles can be measured by several indices such as: durability, represented by resistance to abrasion; particle size distribution; particle shape; specific density and water absorption.

3 Experimental phase

3.1 Material collection and sampling

The aggregate analysed during the experimental phase is quarried diabase ballast withdrawn from the stockpile of an operational heavy-haul freight railway in the Campinas area, southeast Brazil (coordinates for the quarry: 22°19'32.2"S 46°53'40.6"W). Around 500 kilograms of clean, new material were collected, in perfect condition and with sharp edges.

3.2 Particle size distribution and shape analysis

A significant sample of around 140 kg was quartered, as shown in Figure 1, and quartered once more in order to obtain 35 kg of material, which was then sieved in a mechanical sieve shaker in accordance with the Brazilian and ASTM specifications [3, 4]. Sieve sizes ranged from 12 mm (0.5 in) to 63.5 mm (2.5 in). There are two shape factors for the gradation curve that have been used in the United Soil Classification System (USCS) and are presented in ASTM standard D2487 [5]. USCS classifies gravel-sized particles such as railway ballast as "broadly-graded" if C_u is larger than 4 and if C_c is between 1 and 3.

Based on the proportion by mass of each size fraction retained in the sieving process, 100 particles of ballast were randomly chosen and measured with a vernier calliper. Three dimensions were measured in each particle, being "a" the longest (length), "b" the intermediate (width) and "c" the shortest (thickness). According to standards [3, 6], b/a is the elongation ratio, while c/b is the flatness (or flakiness) ratio. Those values were calculated for every particle, and their average result determined if that sample was composed mostly of flat, elongated, flat and elongated or cubic particles. Different standards adopt different limits to classify the shape of particles, so more than one classification could be achieved. The British Standard [7] considers a particle flat if the ratio of width to thickness is more than 1:1.67. ASTM provides a choice of three ratios: 1:2, 1:3 and 1:5. The Brazilian norm uses the 1:2 ratio to classify ballast particles as flat. Similarly, the definition of an elongated particle also varies among standards: for the British it must have a length to width ratio of more than 1:1.8 while ASTM and the Brazilian standard maintain the same ratios as for flatness.

3.3 Specific gravity, absorption and porosity

A sample of aggregate was immersed in distilled water for 48 hours, in order to fill its pores. It was then removed from the water, the excess water dried from the surface of the particles, and the mass determined. Afterwards, the volume of the sample was determined by the displacement of water method. At last, the sample was oven-dried for 48 hours and the dry mass was determined. Those values allowed to calculate relative density (specific gravity), water absorption and porosity according to standards, [3, 8].

3.4 Los Angeles abrasion test

Samples were subject to the LAA test according to ASTM C-535 standard, [9]. Procedure consisted of revolving 10 kg of dry material with 12 steel balls weighing a total of 5 kg in a large steel drum for 1000 revolutions at 33 rpm. Grading 2 was used for the ballast sample, which means half of it (5 kg) passed the 50 mm sieve and was retained in the 37.5 mm, and the other half passed the 37.5 mm and was retained in the 25 mm sieve. Material was then washed on a 1.7 mm sieve. The LAA value is the amount of material smaller than 1.7 mm as a percentage of the original sample weight. The aggregate's frailty to wear and breakage is proportional to that value. Two additional repetitions were conducted for statistical precision.

4 Results

4.1 Experimental results

4.1.1 Particle size distribution and shape evaluation

The particle size distribution of the tested sample was plotted in a gradation curve shown in Figure 1 (continuous line), together with the tolerance range set by the Brazilian standard (black dashed line) and gradation n° 24 (red dotted line) of AREMA, the American Railway Engineering and Maintenance-of-Way Association. The aggregate analysed in this study meets the granulometric distribution criteria defined by the Brazilian standard for railway ballast, and its gradation curve exceeds the boundaries set by the AREMA standard only at sieve gradations that are provided in the Brazilian norm, but that are not part of the American specification: 50.8 mm and 25.4 mm.

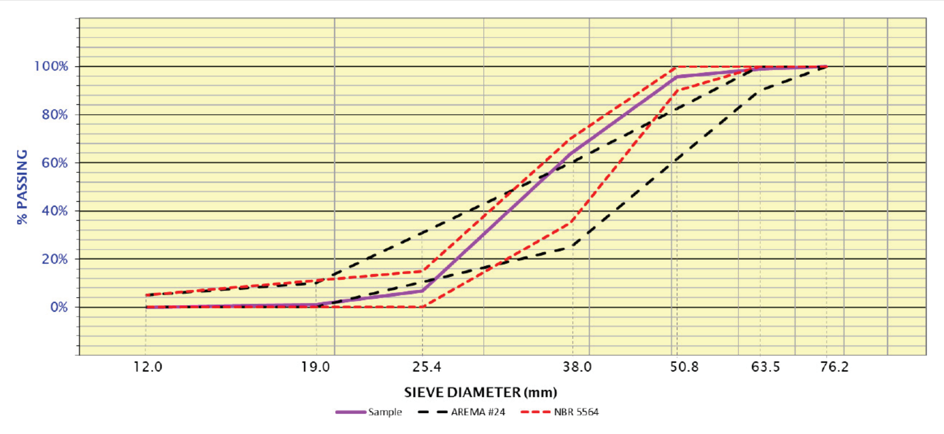

Figure 1 Particle size distribution of the aggregate in comparison to standards

The coefficient of uniformity (C_u) and coefficient of curvature (C_c) were found to be 1.43 and 0.96 respectively. According to the USCS [5] and as mentioned by Selig and Waters [2] those values indicate that the ballast material is very uniform.

Figure 2 shows the results for the evaluation of particle shape according to three different specifications. After measuring all dimensions of 100 particles, the mean value for “b/a” ratio (elongation) was 0,73 (σ = 0,14 and CV = 0,19) while the average “c/b” (flatness) was 0,62 (σ = 0,18 and CV = 0,29). Raymond’s Shape Factor [10], the average value between the longest dimension of each particle and its smallest dimension, is 2.3. It is noticeable that the classification of particle shape can vary greatly depending on the chosen standard.

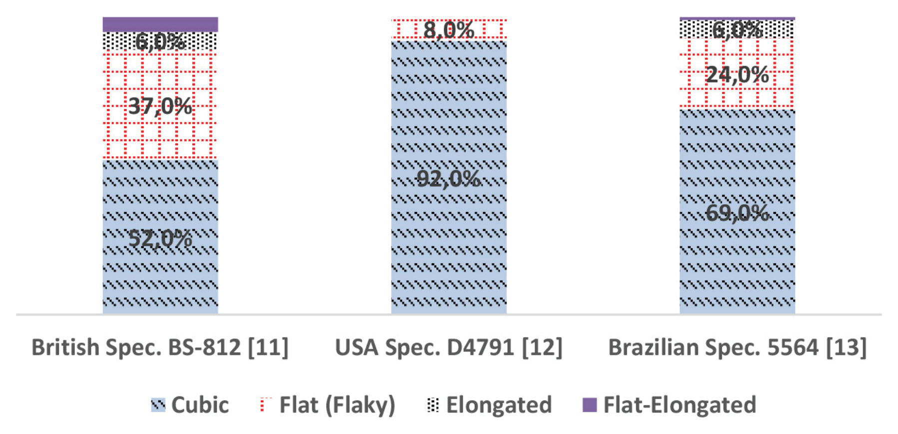

Figure 2 Proportion of particle shapes according to different specifications

4.1.2 Relative density, absorption and porosity

Relative density was found to be 3.01, while water absorption was 2.85 % and porosity was 0.95 %.

4.1.3 Los Angeles abrasion index

The average Los Angeles abrasion index found for the studied samples was 12.75 % with a standard deviation $\sigma = 0.0026$ and coefficient of variation CV = 0.02.

4.2 Literature review and comparison to international standards

Three international railway specifications, from Brazil [3], USA [17] and Australia [18] were used to evaluate the compliance of the different ballast materials to properties related to durability and shape, as shown in Table 1. The most restrictive or strict value is in bald letters, while the most tolerant is in italics.

Table 1 Specified values for ballast properties according to international standards

Standard	LAA (%)	Sulphate Soundness (%)	Specific gravity (kg/m³)	Water absorption (%)	Porosity (%)	Predominant particle shape	Non-cubic particles (%)
Brazil [3]	≤ 30.0	≤ 10.0	≥ 2500	**≤ 0.8**	**≤ 1.5**	Cubic	≤ 15
USA [17]	≤ 35.0	**≤ 5.0**	**≥ 2600**	≤ 1.0	-	Cubic	**≤ 5**
Australia [18]	**≤ 25.0**	-	≥ 2500	-	-	-	< 30

Six studies conducted in different regions of Brazil were reviewed. All works focused on the properties of ballast and analysed aggregates used in some of the most important railways in the country. A list of all those publications is presented in Table 2, along with the original results obtained in this study.

Table 2 Compilation of studies consulted in this review and original contribution

Sample	Type of rock	Location	Railway	Company	Reference
G1	Granite	Cariacica (ES)	E. F. Vitória-Minas	VALE S.A.	[11]
G2	Granite[1]	Barueri (SP)	CPTM	CPTM	[12]
G3	Granite[2]	Barueri (SP)	CPTM	CPTM	[12]
G4	Granite	Juiz de Fora (MG)	Ferrovia do Aço	MRS	[13]
B1	Basalt[3]	Quirinópolis (GO)	Ferrovia Norte-Sul	Valec	[14]
B2	Basalt[4]	Quirinópolis (GO)	Ferrovia Norte-Sul	Valec	[14]
B3	Basalt	São Carlos (SP)	Malha Paulista	Rumo	[15]
P1	Porphyry	Buriticupu (MA)	E. F. Carajás	VALE S.A.	[16]
P2	Porphyry[5]	Buriticupu (MA)	E. F. Carajás	VALE S.A.	[16]
D1	Diabase	Campinas (SP)	Centro-Sudeste	VLI S.A.	-

[1] *Aggregate from the secondary stage of quarrying (rougher, more elongated particles).*
[2] *Aggregate from the tertiary quarrying stage (more cubic particles).*
[3] *Aggregate from the most superficial layer of the quarry. Vesicular-structured basalt.*
[4] *Aggregate from the deeper layer of the quarry. Basalt with higher solidity and endurance.*
[5] *Recycled railway ballast. Washed clean of fine particles, but worn due to service life.*

The compiled results are shown on Table 3, as well as are indicated their compliance to specifications. Black printing in a white cell means compliance to all standards, black printing in a yellow cell means non-compliance to at least one specification and white printing in a red cell means non-compliance to all standards.

Table 3 Compilation of values reviewed in literature compared to original results.

Sample	LAA [%]	Sulphate Soundness [%]	Specific gravity [kg/m³]	Water absorption [%]	Porosity [%]	Predominant particle shape	Non-cubic particles [%]	C_u
G1	26.5 %	0.10 %	2796	0.35 %	0.9	Cubic	13 %	2.11
G2	16.2 %	-	2753	0.20 %	0.6	Cubic	13 %	-
G3	16.3 %	-	2753	0.30 %	0.7	Cubic	3 %	-
G4	19.7 %	-	2730	-	-	Cubic	-	-
B1	23.6 %	1.09 %	2865	1.94 %	5.73	Cubic	17 %	-
B2	14.3 %	0.87 %	2937	0.81 %	2.32	Cubic	6 %	-
B3	21.4 %	-	2910	0.23 %	0.68	Cubic	-	-
P1	14.0 %	0.03 %	2621	0.28 %	0.74	Non-Cubic	36 %	1.8
P2	10.0 %	0.02 %	2778	0.19 %	0.52	Cubic	33 %	1.7
Average	**18.0 %**	**0.4 %**	**2794**	**0.5 %**	**1.52**	**-**	**17 %**	
D1	12.8 %	-	3010	2.85 %	0.95	Cubic	31 %	1.4

It can be observed that the Los Angeles abrasion index of sample D1 is lower than all results from the literature, except for porphyry P2, and it is well within the most restrictive specification, which demands a value of less than 25 %, indicating that it has good resistance to abrasion. Its specific gravity is higher than every other sample in the literature, also in compliance to all standards. Porosity is well below the average among all reviewed samples and it is in compliance with the standard.

Water absorption of sample D1 was higher than any other value found in the literature, and five times the average. It was also three times the value limit established by the least restrictive standard. The predominant particle shape was cubic, but the proportion of non-cubic particles was 31 % according to the Brazilian parameters, which adopts a ratio of 1:2. Nonetheless, as mentioned in Section 3.2, different standards adopt different limits to classify the shape of particles, so more than one classification could be achieved. As shown in Figure 2, the proportion of non-cubic particles would be 8 % if the AREMA ratio of 1:5 was adopted, even though it would still be non-compliant to standards.

5 Conclusion

This research conducted a series of tests on an aggregate used as railway ballast by a railway in south-east Brazil, in order to investigate its particle size distribution, particle shape, water absorption, porosity and Los Angeles abrasion index. The obtained values were found to be within the same range as other ballast materials studied by other Brazilian authors in several regions of the country. Therefore, the tested diabase may be considered relevant for future studies. It must be noticed, however, that rocky materials used as aggregate in railway ballast are subject to constant weathering, which makes soundness studies as important as the assessment of geomechanical properties, considering the tropical weather of the region. Therefore, it is recommended to test the studied diabase for its natural alteration to weathering, as well as with a Soxhlet extractor and cycles of saturation/drying, thus complementing this work.

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