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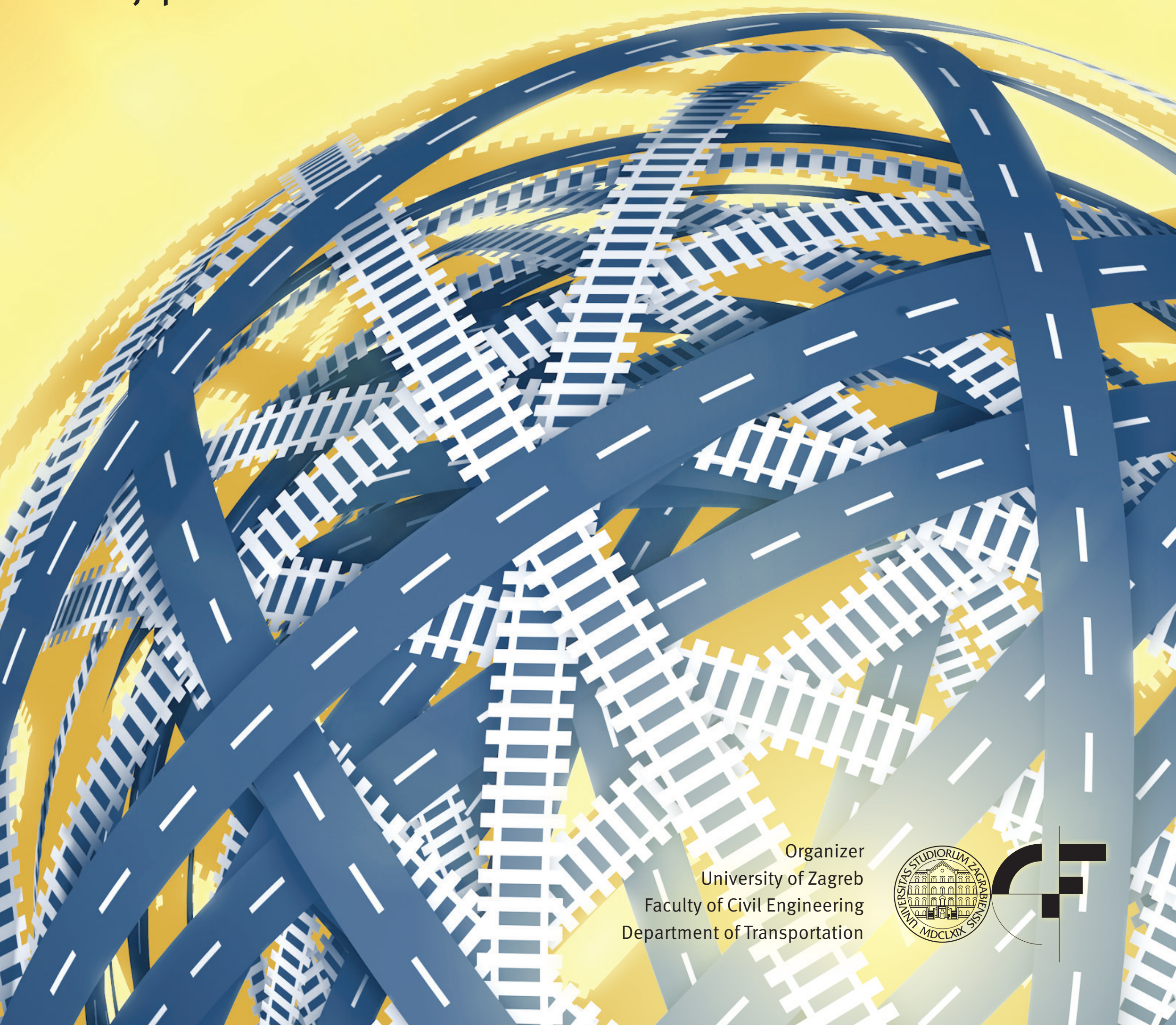
Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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RELATIONSHIP BETWEEN LIFESPAN AND MECHANICAL PERFORMANCE OF RAILWAY BALLAST AGGREGATE

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Abstract

As the lifespan is main criterion for selection of the aggregate for ballast and for planning the maintenance of the railroad, it is important to define relationship between the particle load resistant characteristics and ballast's lifetime in structure. Assessment of the quality of the ballast particles under dynamic and static loading should reflect both, the toughness and hardness, and these can be identified with the values of Los Angeles Abrasion and micro-Deval Abrasion. In order to predict the amount of loads, expressed in cumulated tonnes, the model formerly developed by Canadian Pacific Railroads was adapted. A number of different aggregate mixtures were tested in the laboratory including dolomite and granite rocks. The results were used to assess the gross tonnage possible to transport during the lifetime of ballast until repair or reconstruction should be done. The outcome of this study is the possibility to classify the requirements for aggregates' Los Angeles abrasion and micro-Deval abrasion values attributing them to designed traffic volumes.

Keywords: ballast, lifespan, Los Angeles, micro-Deval, aggregate selection

1 Introduction

The use of poor quality ballast leads to shorter tamping intervals, a shorter ballast lifespan, and thus to increased life cycle costs. Railway companies employ specific quality control testing methods [1] in order to ensure the desired mechanical behaviour (i.e. resistance to fragmentation and to abrasion). In part, such tests have been used without change for several decades. The tests are meant to simulate the loads acting upon the ballast in track. Some tests results are highly variable and often show poor repeatability. The reasons for this remain undefined. Several possibilities for improvement have been suggested, for example, use of alternative test evaluation methods, adjustment of test procedures, and even the use of completely new test methods [2]. Assessing the suitability of crushed stone to equipt ballast aggregate, it is usually required to determine the conformity of all its characteristics to standard requirements. However, seeking to select the suitable crushed stone, the mechanical properties of ballast aggregate become the most important, which most determine the functioning of all prism of ballast during operation. Aiming to classify the mechanical properties under the prospective cumulative traffic flows, the relation between mechanical properties and lifespan of ballast has to be identified. The usage of such classification will provide the opportunity to select the suitable mixture of crushed stone to equipt prism of ballast of the railway with respect to supposed cumulative traffic flow during design time.
Without exception, every ballast specification attempts to assess the quality of the ballast particles under loading. Ideally, this quality measure should reflect both, the hardness and toughness of the ballast particles. The typical tests that are performed on a mix of the particles

by railroads worldwide include impact testing, crushing value testing, Los Angeles Abrasion testing, and the like. Though, only toughness of the ballast aggregation is basically set by these tests, whilst hardness of minerals has very low influence to the results of these tests. For any couple of these tests (e.g. Los Angeles Abrasion and Impact Factor in accordance with EN 1097–2:2010 [3]) pretty strong correliation is received [4], so it is enough to perform one of these tests and Los Angeles Abrasion (LAA) test is most often chosen in practice.

The field break down from the harder mineral rock is often slower because less powdering occurs at the points of contact between particles, and the broken particles are more angular and coarser resulting in a slower rate of track fouling [5]. Comparing ballast aggregates, which values of LAA are equal, ballast, made of harder mineral grains, shows better results under the fieldwork [6]. Therefore, the comparison of materials, only assessing the values of LAA and resistance to dynamic crushing, which essentially specify toughness of rock, does not ensure selection of the most appropriate material. Rocks are made of minerals, having different hardness values, therefore the method, allowing to evaluate rock's overall hardness, has been needed. This has been achieved by application of Mil Abrasion test, generally used in mining industry [7]. The indicator, showing particles resistance to wear due to grinding, is measured by this test.

2 Resistance to fragmentation and wear

Resistance to fragmentation. The main reasons for ballast degradation are ballast fragmentation and wear. They destine settlement of a road and increase expenses for maintenance of trackway geometry. The indicator of particles resistance to fragmentation, coefficient of Los Angeles (LAA), is determined applying Los Angeles test under standard LST EN 1097–2:2010 [3]. It is intended to assess the strength of ballast particles and potency not to crack under sleeper. However, additional tests are needed to use in order to measure degradation of ballast concerning wear, which is influenced by particles grinding between. Inner interaction of particles is unavoidable mechanism of ballast degradation.

Resistance to wear. Ballast construction stability is reflected by MA test and particles resistance to wear due to grinding is determined by this test. The concept of MA test is based on micro-Deval (M_{DE}) test [8]. MA and Micro-deval assays equally allow to determine the resistance to wear avoiding fragmentation (or it is imperceptible). Particles resistance to fragmentation is better measured by LAA tests. It has been identified that MA partially correliates with results of Deval test [9]. MA is the test of wet particles wear because of grinding. This test is performed by spinning 3,0 kg of ballast aggregate (fraction 19/37,5 mm) and 3,0 l of water in a porcelain jar 10.000 times. Concerning the spinning of a porcelain jar, ballast particles wrestle one over other and wear avoiding significant fragmentation of particles, taking place at time of LAA test [10].

Alternatively, ballast aggregate could be assessed to analogical resistance to wear due to grinding, applying micro-Deval test, which is described in EN 1097–1:2011 [8] and ASTM D6928-10 [11]. M_{DE} test is performed by spinning of 10 kg ballast aggregate (fraction 31,5/50 mm) and 2,0 l of water in a metal jar 10.000 times. Spinning metal jar, ballast particles wrestle one over other and wear as in time of MA test, avoiding significant fragmentation of particles.

3 Prognostic model of ballast aggregate lifespan

Rocks having a predominance of hard minerals were noted to have low MA values. Rocks having similar minerals were also noted to have a variation in values based on their degree of induration or compactness, which added to the significance of the test in terms of assessing rock hardness [6]. These observations mean that operating the probable performance of ballast aggregate on a road needs to be assessed combining the results of LAA and MA tests. The study of ballast degradation has been performed by Canadian Pacific Railroads (CPR) order [12]. There has been determined that different rocks' relative performance, intended to ballast aggregate, could be represented by Abrasion Number (N_A), which is determined as the sum of LAA value and 5 MA values:

$$N_A = LAA + 5 \times MA \qquad (1)$$

Where:
N_A – Abrasion Number, %;
LAA – Los Angeles Abrasion value, %;
MA – Mill Abrasion value, %.

Procedures of MA test [9] and determination of N_A indicator have been included into CPR normative specifications. CPR has connected N_A values of used material for ballast aggregation with observed life of ballast, which is expressed in accumulated traffic flow MGT (Million Gross Tons) to result in breakdown to the point where the ballast needed renewal. Lifespan has been determined to ballast that is under wooden sleepers. Railway sections have not been included into the latter study, which were severely affected by environmental factors and/or heavily fouled by outside fouling sources. Furthermore, the model doesn't assess ballast fouling by fine particles due to ballast tamping under the sleeper, done during the routine repairs, seeking to rebuild the track geometry. However, the received results allow to prognosticate ballast lifespan under ideal operating conditions, whereas comparing lifespan indicators of different aggregates it is possible to select the suitable option from both the economic and engineering points of view.

$$Life = 10^6 \exp (8.08 - 0.0382\ N_A) \qquad (2)$$

Where:
Life – lifespan of the ballast, expressed in accumulated traffic flow MGT.

Seeking to adapt CPR model for use in Lithuania, correction coeficients are used. Description and assumptions, applied to calculations, are presented further.
Measurement units. Calculating by analysed model, the results are received by widely used mass measurement unit "Short ton" (marking ton): 1 ton = 0.9074847 t = 907.1847 kg. It is accepted in Europe that 1 t = 1000 kg, so correction coefficient: A = 1000/907,1847 has to be applied to calculation model of ballast lifespan. It is accepted that A = 1,102.
Axle load. CPR used model has been adapted to maximum axle load of 30 tones. Maximum axle load of 25 t is applied in Lithuania, so it is needed to determine correction coefficient B that will allow assessing the difference between permissible axle loads. The impact to ballast is approximately equal to half impact for track [13], and ballast degradation directly affects geometry of a road. Besides, 10 % increase in ballast stress conditions faster decrease of the road geometry quality from 1,2 to 1,5 time. The examined model is applied to greater axle load of 20 % than permissible axle load of 25 t in Lithuania. Therefore, ballast degradation, when maximum 25 t axle load is allowed, will be at least slower of B times: B = 1 + 0, 2 × 2 = 1,400. It is accepted B = 1,400.
Sleepers. Used model of CPR has been applied to prognosticate ballast lifespan, when wooden sleepers are used to superstructure. Therefore, correction coefficient C has to be determined, allowing to assess the influence of sleepers' type. Using concrete sleepers, dynamic loads and stresses in ballast are up to 25 % greater than using wooden sleepers [14], so ballast degradation under concrete sleepers will be at least C times faster (than at wooden tracks): C = 1 + 0,2 × 2,5 = 1,500. Correction coefficient, reverse to value C : C^{-1} = 1/1,500 = 2/3 is taken for adjustment of lifespan calculation model. It is accepted that C^{-1} = 0,667.

Determination of the resistance to wear. There were not found previous studies where the received results' relation is determined by MA and micro-Deval tests. However, it is known that MA test concept is based on micro-Deval (M_{DE}) test [6,12]. Indicators of the same rock MA and M_{DE} are usually very similar. So it is assumed that MA = M_{DE} and then Abrasion Number is is calculated by formula:

$$N_A = LAA + 5 \times M_{DE} \tag{3}$$

Where:
N_A – Abrasion Number, %;
LAA – Los Angeles Abrasion value, %;
M_{DE} – micro–Deval value, %.

Lifespan symbolizing "Life" is replaced by symbol $L_{G/B}$ because lifespan to ballast will be determined, when concrete sleepers are used. When concrete sleepers are used in construction, eqn (2) is adjusted using previously accepted coefficients of correction A, B, C and eqn (3): $L_{G/B} = A \times B \times C \times (106 \exp (8.08 - 0.0382\ N_A))$

$$\begin{gathered} L_{G/B} = A \times B \times C \times (10^6 \exp (8.08 - 0.0382\ N_A)) \\ L_{G/B} = 1.029 \times (10^6 \exp (8.08 - 0.0382 \times (LAA+5 \times M_{DE}))) \end{gathered} \tag{4}$$

Using eqns (3) and (4) it is possible to calculate prognostic ballast lifespan according to measured values of mechanical properties which is expressible by MGT.

4 Prognostic calculations results' assessment of ballast aggregate lifespan

Prognostic lifespan calculations are performed assessing indicators of Los Angeles and micro-Deval. Therefore, the received results by these calculations is complex evaluation of crushed stone mixture (mineral materials) most important mechanical properties. Seeking to determine and evaluate mechanical properties of different origin crushed stone from different suppliers, the experimental research has been performed in a laboratory. Two dolomite and three granite crushed stone mixtures from three different suppliers were selected and researched. Crushed stone mixtures of dolomite were encoded D1 and D2. Granite crushed stone mixtures have been encoded G1, G2 and G3. Abrasion Number N_A and prognostic lifespan of ballast aggregate $L_{G/B}$ for researched materials in a laboratory are calculated according (3) and (4). Calculations' results are presented in Table 1.

Table 1 Prognostic calculations results of ballast aggregate lifespan

Material	Indicators, dtermined in laboratory		Calculated indicators	
	LA, %	M_{DE}, %	N_A, %	$L_{G/B}$, MGT
D1	21,1	10,6	74,1	196
D2	22,7	12,4	84,7	131
G1	14,7	5,1	40,2	715
G2	9,2	4,9	33,7	917
G3	14,6	7,3	51,1	472

The determined results of particles resistance to wear and fragmentation and maximum permissible parameter values in Lithuania and another countries are given in Figure 1. It is seen that on the basis of existing regulatory documents in Lithuania the mentioned indicators of

all researched materials in laboratory are acceptible because maximum permissible limit of micro-Deval indicator is not exceeded, and Los Angeles Abrasion indicator is not rationed.
After comparison of performed calculation results of crushed stone mixtures G2 and D2, it seen that, dependently on mechanical indicators, lifespan of different materials can even differ seven times. Despite this, it is prognosticated that dolomite crushed stone mixture D1 has possibility to hold out almost 200 MGT of traffic loads. These results show ballast aggregate lifespan under ideal operating conditions. It is accepted that there is no fouling out of blanketing sand, subgrade and another external sources.
Seeing that 76% of ballast fouling appear due to its own degradation [14], it is possible to reduce the prognostic lifespan of 200 MGT for 24% and approximately receive prognostic lifespan of 150 MGT. Calculated by analogy lifespan $L_{G/B}$ of crushed granite mixture G2, 688 MGT is received. The latter parameter has already become closer to reality because there were 397 km of railway sections in 2015 where 595 MGT were transported through them at an average. Sections have been determined where more than 890 MGT (0, 9 km), 740 MGT (18, 3 km), and 690 MGT (42, 4 km) were transported through. Major repair has been delayed in all these sections. Intensive train traffic is in most of these sections, but road condition is good enough.

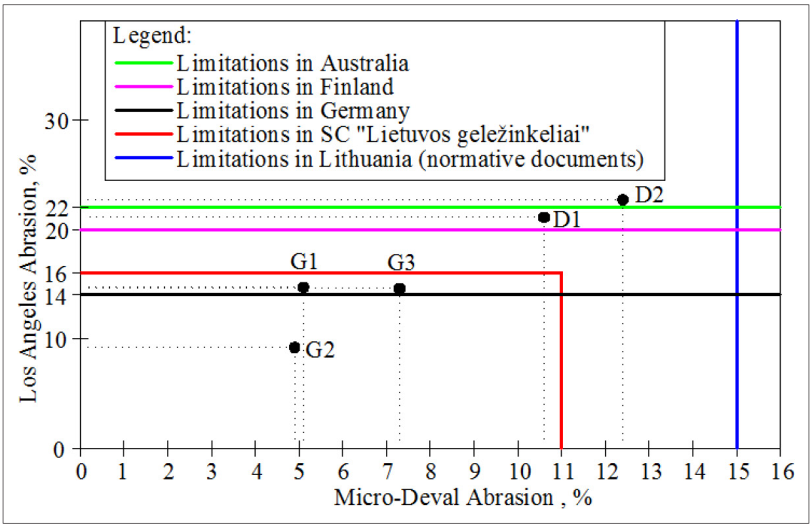

Figure 1 Determination results of particles resistance to wear and fragmentation and maximum permissible values of these parameters in Lithuania and abroad.

However, it should be mentioned that ballast degradation due to ballast tamping, performed during the time maintenance or routine repair, is not evaluated. While tamping ballast, the ballast degrades much faster and real lifespan mostly depends on times of ballast tamping. Besides, ballast fouling from outside or fouling due to sub-soil penetration can change. For example, fouling from outside sources on station's roads can be significantly higher and penetration of sub-soils can be stopped using geotextile for equipment of subgrade. Concerning the latter reasons, it has been decided to do lifespan prognostic calculations assuming that operating conditions will be ideal.
Graphic lifespan prognostic model of ballast aggregate is given in Figure 2, which is further used as the basis for classification of Los Angeles and micro-Deval indicators. Parameters values of classified mechanical properties are divided into five categories, as it is submitted in Table 2. Restriction limits, suggested to every category, are inscribed considering to the maximum permissible parameter values that are presented in Figure 1.

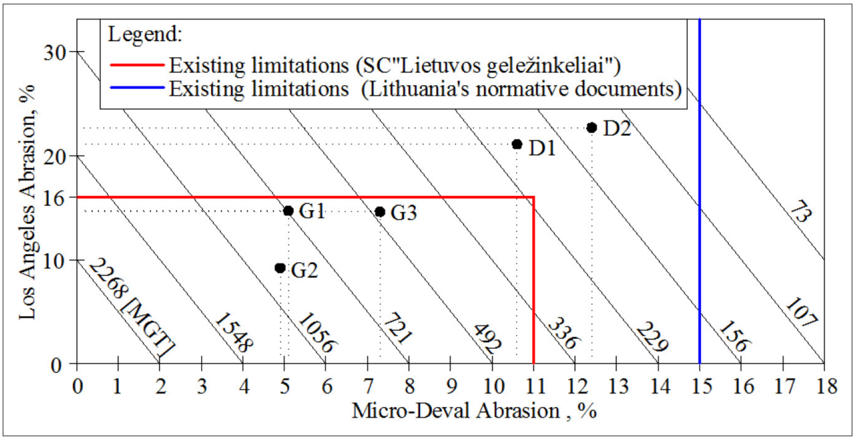

Figure 2 Lifespan prognostic graphic model of ballast aggregate as sleepers are made of concrete

Table 2 Division of ballast aggregate mechanical properties categories

Category of ballast mechanical properties	Category of the railway line	Anual traffic flow, MGT
K-1	GLK – Highway	–
	GLK – Intensive traffic	≥ 50
K-2	GLK-I	30 – 50
K-3	GLK-II	8 – 30
	GLK-III	
K-4	GLK-IV	≤ 8
	Another roads	2 – 8
K-5	Another roads	≤ 2

Rail access roads, local and connecting railway lines depend railway category “Another roads”, presented in Table 2. Highway rail lines for passenger trains to run from 160 km/h until 200 km/h are assigned to category K-1 of ballast mechanical properties.

5 Conclusions

Toughness and hardness of ballast aggregate particles directly influence residual life of ballast prism of the railroad. It is recommended to use such input parameters correction coefficients when the maximum permissible axle load is 25 t in Europe and concrete sleepers are used applying CPR model to determine lifespan:

- Measurement units: A = 1.102;
- Axle load: B = 1.400;
- Sleepers: C^{-1} = 0.667.

Two dolomite and three granite crushed stone tests‘ micro-Deval and Abrasion values have changed from 4,9 % to 12,4 % and satisfied the requirements of normative. Los Angeles Abrasion values have changed from 9,2 % to 22,7 %. However, the normative value for this indicator is not set. Toughness and hardness of the same origin rocks crushed stone are very different. The results show that LAA values of dolomite crushed stone mixtures differed 7,6 %, M_{DE} values differed 17 %. Granite crushed stone indicator values differed accordingly 59,8 %

and 49,0 %. The calculated Abrasion Number N_A differed 151,3 % and changed from 33,7 % (crushed granite) to 84,7 % (crushed dolomite).
The research has shown that when selecting ballast crushed stone it is necessary to evaluate not only the type of rock but also values of LAA and M_{DE} that directly influence Abrasion Number N_A.

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