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TESTING OF MECHANICAL-PHYSICAL PROPERTIES OF AGGREGATES, USED FOR PRODUCING ASPHALT MIXTURES, AND STATISTICAL ANALYSIS OF TEST RESULTS

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Abstract. In Lithuania, since 2007 the suitability of aggregates, used for producing asphalt mixtures, has been tested in accordance with the requirements of *TRA MIN 07:2007 The List of Technical Requirements for the Mineral Materials of Roads*. When analysing mechanical-physical properties of aggregates the tests of different type of aggregates of different manufacturers were carried out to determine the resistance of aggregates to freezing and thawing (*F* value), resistance to fragmentation by the Los Angeles Test (*LA* value) and the Impact Test (*SZ* value), the polished stone value *PSV*, resistance to wear M_{DE} and dry particle density ρ_{rd} value. Taking into consideration mineral materials, available in Lithuania and used in road building, the suitability tests were carried out and the requirements for their properties were described. When testing mineral materials, used in road building, the suitability of each test method was assessed for Lithuanian climatic conditions. Having made statistical estimations the hypotheses were tested on the correspondence of the same (mechanical-physical) quality indices of different type crushed rock (granite, dolomite and gravel). Having analysed the results of statistical estimations correlation dependencies were determined between the values of mechanical-physical properties *F*, *LA*, *SZ* and ρ_{rd} quality indices of aggregates of the same origin. Based on the histograms of frequencies of the impact test values and dry particle density values the hypotheses were tested whether the test data of these quality indices are distributed by normal distribution. It was determined that in Lithuania mechanical-physical properties of crushed gravel, used for producing asphalt mixtures, have not been sufficiently tested, therefore, it is necessary to carry out more comprehensive tests and analysis of crushed gravel of various fractions. The mechanical strength of mixture is simulated and experimentally validated by various techniques developed for sandy soils, namely: strength and deformation properties.

Keywords: aggregates, mechanical-physical properties, asphalt pavement, strength, asphalt mixtures, resistance to freezing and thawing, fragmentation, polished stone value, dry particle density, statistical estimations, normal distribution, hypothesis, correlation dependence.

1. Introduction

In order to improve road pavement properties as well as traffic conditions on roads the scientists of Lithuania and other countries carry out researches of structural pavement layers, analyze the effect of their properties on pavement performance, mechanical-physical properties of asphalt mixtures and materials used for structural pavement layers (Amšiejus *et al.* 2010; Amšiejus *et al.* 2009; Butkevičius *et al.* 2007; Ceylan *et al.* 2009; Petkevičius *et al.* 2009; Petkevičius *et al.* 2008; Radziszewski 2007; Sivilevičius *et al.* 2011; Vaitkus *et al.* 2009). Crushed rocks – granite, dolomite and gravel – differ by their size, shape and functioning conditions in structural pavement layers that depend on loading size and nature, temperature, environmental aggressiveness and other factors. In asphalt mixtures most commonly the more expensive but more durable aggregates (crushed granite and crushed dolomite) are used, therefore, the suitability of crushed gravel has not been sufficiently investigated. Using more strong aggregates the service life of road pavement structure becomes longer, pavement structure is more reliable and requires more thin structural layers, material expenditures are lower. The selected aggregates shall be inexpensive and easily obtained. In Lithuania the most commonly found is gravel, more rarely – dolomite. These rocks not always meet the requirements for mineral materials used in asphalt mixtures. Crushed granite is transported from the neighbouring countries; therefore, it is most expensive. In separate

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cases the mechanical-physical properties of crushed gravel are better than those of crushed dolomite, and in rare cases they come very approximate to the properties of crushed granite (Bhasin *et al.* 2009; Bulevičius *et al.* 2010).

In order to properly select aggregates the multipurpose decision-making methods shall be used (Sivilevičius *et al.* 2008; Zavadskas *et al.* 2008) and optimum solutions shall be applied for loads acting in circular plane and causing shear (Atkočiūnas *et al.* 2004). This article gives the statistical analysis of mechanical-physical properties of crushed granite, crushed dolomite and crushed gravel.

The articles studies normative quality indices applied for asphalt aggregates when performing tests in accordance with *LST EN 1097-6+AC:2003, LST EN 1097-6+AC:2003/A1:2005 „Determination of Particle Density and Water Absorption", LST EN 1097-1:2002, LST EN 1097-1:2002/A1:2004 „Determination of the Resistance to Wear (Micro-Deval)", LST EN 1097-2:1999, LST EN 1097-2:2001/A1:2006 „Methods for the Determination of Resistance to Fragmentation", LST EN 1097-8:2009 „Determination of the Polished Stone Value" and LST EN 1367-1:2007 „Determination of Resistance to Freezing and Thawing".*

2. Testing and analysis of mechanical-physical properties of aggregates

In the result of various tests of crushed granite, crushed dolomite and crushed gravel of different manufacturers the *LA*, *SZ*, *PSV* and *F* values were determined. The following results were obtained having analyzed the results of tests to determine resistance to fragmentation: 94% of all aggregate specimens, tested by the *LA* method, meet the requirements of LA_{20} for asphalt pavement, 88% of test results of crushed dolomite specimens gets between the requirements LA_{20} and LA_{25}. The limit of LA_{30} requirements is exceeded by 33% of all crushed gravel specimens. The requirements for asphalt pavement are satisfied by 69% of all aggregate specimens tested by the Impact test method. The limit of SZ_{18} is exceeded by 27% of the tested crushed granite specimens, the limit of SZ_{22} is exceeded by 36% of the tested crushed dolomite specimens, and the limit of SZ_{26} is exceeded by 23% of the tested crushed gravel specimens. The largest part (83%) of specimens, tested to determine the polished stone value, meets the requirements for PSV_{50} and PSV_{44} of asphalt pavement. All the crushed granite specimens meet the highest category of PSV_{50}. The limit of PSV_{44} requirements is exceeded by 17% of the tested crushed dolomite specimens. All aggregate specimens, tested to determine their resistance to freezing and thawing, 100% meet the requirements of F_1 and F_2 for asphalt pavement. 91% of test results of crushed granite specimens do not exceed 1/10, 80% of test results of crushed dolomite specimens do not exceed $\frac{1}{5}F_1$. All the results of crushed gravel tests get between the requirements F_1 and F_2 (Bulevičius *et al.* 2010).

3. Statistical analysis of mechanical-physical properties of aggregates

For all studied types of aggregates the statistical characteristics of their quality indices were calculated which are given in Table 1. For the analysis of aggregate properties, used in asphalt mixtures, the samples of statistical data of different quality indices were worked out. The sample of the *F* values of resistance to freezing and thawing quality index was made of 123 individual data (n = 123). The *F* values are given in Fig. 1. They are grouped by the type of rock.

Fig. 2 gives the *LA* values. The sample was made of 59 individual data (n = 59). In the Fig the *LA* values are grouped by the type of rocks. The dark points show the values rejected (due to strong difference) from further statistical estimations.

The *SZ* values are given in Fig. 3. The values are grouped by the type of rock. The sample of the *SZ* values was made of 238 individual data (n = 238). The dark points show the *SZ* values rejected (due to strong difference) from further statistical estimations.

In order to make a more detail as possible analysis of ρ_{rd} of aggregates, the data sample of 8/12.5 mm fraction was formed. Density of this aggregate fraction was determined by a pyknometer method according by *LST EN 1097-6+AC:2003, LST EN 1097-6+AC:2003/A1:2005.* Data on dry density measurements (fr. 8/12.5 mm) is given in Fig. 4. The sample of ρ_{rd} was made of 178 individual va-

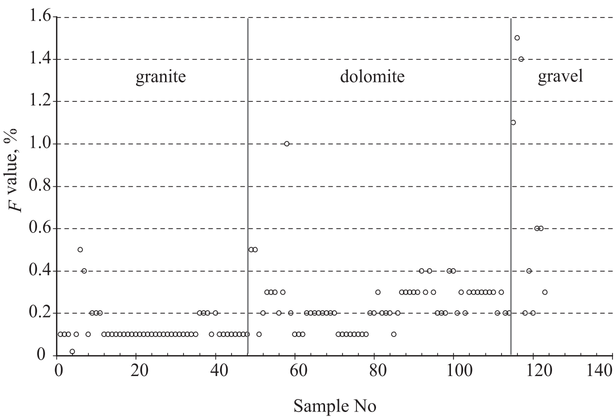

Fig. 1. *F* values of resistance to freezing and thawing of aggregates

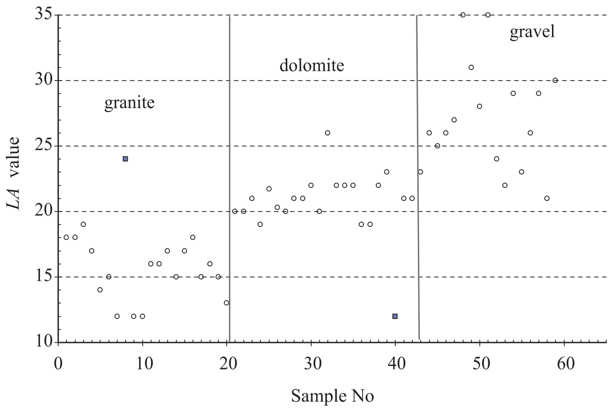

Fig. 2. *LA* values of resistance to fragmentation of aggregates

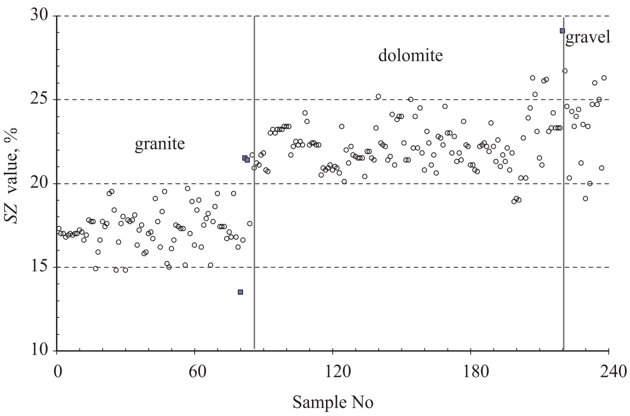

Fig. 3. *SZ* values of resistance to fragmentation of aggregates

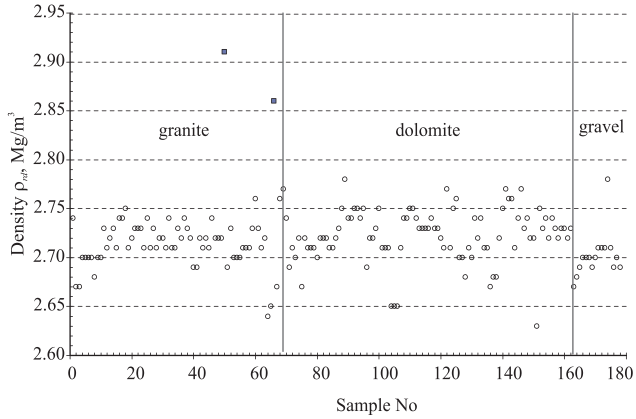

Fig. 4. ρ_{rd} values of dry density of aggregate particles

Table 1. Summary of mechanical-physical properties quality indices values

Statistics	Notation	Crushed rock	Quality index					
			F	*LA*	*SZ*	*PSV*	M_{DE}	ρ_{rd}
			Value					
Index *X*	X_{min}	Granite	0.50%	19	19.7%	50	9	2.64 Mg/m^3
		Dolomite	1w.00%	26	26.3%	41	16	2.63 Mg/m^3
		Gravel	1.50%	35	26.7%	–	20	2.60 Mg/m^3
	X_{max}	Granite	0.02%	12	14.8%	53	6	2.76 Mg/m^3
		Dolomite	0.10%	19	18.9%	47	14	2.78 Mg/m^3
		Gravel	0.20%	21	19.1%		14	2.65 Mg/m^3
Amplitude	$X_{max} - X_{min}$	Granite	0.48%	7	4.9%	3	3	0.12 Mg/m^3
		Dolomite	0.90%	7	7.4%	6	2	0.15 Mg/m^3
		Gravel	1.30%	14	7.6%	–	6	0.05 Mg/m^3
Mean	$\overline{X}$	Granite	0.13%	15.53	17.23%	51.47	6.76	2.713 Mg/m^3
		Dolomite	0.24%	21.10	22.23%	44.10	15.71	2.723 Mg/m^3
		Gravel	0.70%	27.05	23.47%	–	17.80	2.702 Mg/m^3
Standard deviation	S_x	Granite	0.078%	2.112	1.126%	0.884	0.750	0.022 Mg/m^3
		Dolomite	0.134%	1.556	1.356%	1.578	0.547	0.028 Mg/m^3
		Gravel	0.478%	3.992	2.189%	–	1.222	0.023 Mg/m^3
Corrected standard deviation	S'_x	Granite	0.079%	2.170	1.133%	0.915	0.768	0.022 Mg/m^3
		Dolomite	0.135%	1.594	1.361%	1.663	0.561	0.028 Mg/m^3
		Gravel	0.507%	4.115	2.253%	–	1.265	0.024 Mg/m^3
Dispersion	S_x^2	Granite	0.006 (%)^2	4.460	1.268 (%)^2	0.782	0.562	0.001 (Mg/m^3)^2
		Dolomite	0.018 (%)^2	2.419	1.838 (%)^2	2.490	0.299	0.001 (Mg/m^3)^2
		Gravel	0.229 (%)^2	15.938	4.793 (%)^2	–	1.493	0.001(Mg/m^3)^2
Sample asymmetry coefficient	g_1	Granite	12.410	–0.833	0.140	-0.484	2.336	1.683
		Dolomite	14.060	3.397	0.719	0.784	3.182	1.321
		Gravel	–1.202	–0.178	–0.655	–	6.312	8.432
Sample excess coefficient	g_2	Granite	3.280	–0.332	0.008	0.113	1.184	–0.942
		Dolomite	2.807	1.304	0.526	–0.014	–1.920	–0.821
		Gravel	0.708	0.587	–0.599	–	–1.769	2.450
Individual data sample	*n*	Granite	47	19	81	15	21	65
		Dolomite	67	21	135	10	21	95
		Gravel	9	17	18	–	15	16

lues ($n = 178$). The dark points show the ρ_{rd} values rejected (due to strong difference) from further statistical estimations.

Due to a low variety, i.e. a low dispersion, of values or due to insufficient number of investigation data no further estimations were performed for the polished stone value and Deval indices.

A statistical analysis of the values of mechanical [properties quality indices of the studied aggregates was carried out (Table 1). Dispersion of values of the resistance to repeated freezing and thawing of all 3 types of aggregates was not large: the corrected S_x varied from 0.079% to 0.507%. Especially small S_x of investigation data was represented by crushed gravel. This shows inconsiderable variation in test data of the resistance of aggregates to environmental impact. The means of crushed granite and crushed dolomite test data did not exceed 13% and 25%, respectively, of the max value of category F_1 (F_1 meets the mass loss up to 1%). The obtained low values of quality indices show that the tests of resistance to repeated freezing and thawing to determine aggregate suitability to asphalt mixtures are insufficient. The arithmetic means of F values of crushed granite and crushed dolomite differ insignificantly. The average value of test data of crushed gravel specimens was 5 times higher than that the arithmetic mean of crushed granite and 3 times higher than the arithmetic mean of crushed dolomite. This shows that crushed gravel is less resistant to the impact of ambient temperature compared to crushed granite and crushed dolomite. The values of arithmetic mean of *LA* and *SZ* of crushed granite and crushed dolomite are approximate. The highest values of S_x were represented by crushed gravel. This shows the highest variation in the quality indices of the studied physical properties of this type of aggregates and that the strength properties of the imported granite and dolomite are more stable compared to the properties of crushed gravel extracted in Lithuania.

S_x^2 and S_x of the polished stone value of crushed granite, compared to that of crushed dolomite, differ twice – this shows a larger stability of *PSV* of crushed granite.

The amplitude of values of M_{DE} of all 3 studied types of aggregates is approximate. This shows an approximate variation of results of studied property all 3 types of aggregates and an assumption could be made that this method is suitable to determine the values of M_{DE}. The arithmetic means of M_{DE} values of crushed dolomite and crushed gravel differ insignificantly, and this shows a low resistance of crushed dolomite, like that of crushed gravel, when testing specimens by this method (when rock is mechanically affected in water). Similarity of properties of the resistance of these types of aggregates to wear in water is proved also by approximate S_x of this quality index. S_x of M_{DE} values of all 3 types of aggregates are low – this shows a small data variation when testing specimens by Deval method.

A statistical analysis of the ρ_{rd} values was carried out too. The highest arithmetic mean of ρ_{rd} values was obtained for crushed dolomite, the lowest – for crushed gravel. The obtained means of ρ_{rd} values of the studied aggregates correspond to the DPD values of respective aggregates established by the list of technical requirements *TRA MIN 07:2007*. The amplitudes of ρ_{rd} values of the studied types of aggregates vary within narrow limits (0.05–0.15) Mg/m^3, this shows a small dispersion of the *DPD*. Standard deviations of ρ_{rd} values of all 3 types of aggregates are similar – this shows a similar variation of the values of this quality index. Therefore, it could be stated that physical properties of the specimens of the same rock are similar.

Asymmetry coefficient g_1 is a measure of symmetry of statistical frequencies distribution or a measure of histogram symmetry. The histogram is symmetrical when $g_1 = 0$. The sample excess coefficient g_2 is a measure of flatness (or sharpness) of the statistical distribution histogram. When $g_2 > 0$ the histogram is sharp, i.e. data dispersion about the mean is lower than that for normal (Gaussian) curve. When $g_2 < 0$ the histogram is flat and data dispersion about the mean is higher than that for normal curve. When the empirical asymmetry and excess coefficients are approximate to 0 the histogram could be treated as being approximate to the graph of density function of the normal distribution. When both coefficients are approximate to 0 it is up to the purpose to test a hypothesis that the sample of studied value is distributed by normal distribution.

4. Testing of hypotheses on the approximate of values of the same quality indices of different types of aggregates

When analyzing data of mechanical-physical properties quality indices of the studied types of aggregates (crushed granite, crushed dolomite and crushed gravel) the hypotheses were formulated on the correspondence of the means of *F*, *SZ* and ρ_{rd} (Table 2). The formulated hypotheses were tested using statistical estimations. When testing hypotheses on the approximate of means of the strength quality indices the following Eq was used for the statistical estimations:

$$T_{stat} = \frac{\overline{X} - \overline{Y}}{\sqrt{(n-1)S_x^2 + (m-1)S_y^2}} \sqrt{\frac{mn(m+n-2)}{n+m}}, \quad (1)$$

where $\overline{X}$, $\overline{Y}$ – means of the quality indices of aggregates being compared; n, m – samples of quality indices (number of data selected for testing); S_x^2, S_y^2 – dispersions of quality indices.

The hypotheses were tested when the significance level of the criterion $\alpha = 0.05$. Index g – indicates the value of quality index of crushed granite, d – of crushed dolomite and gr – of crushed gravel.

Table 2. Summary of zero hypothesis values

Hypothesis		Status	Quality index	Mean		Dispersion		Individual data sample		Value	
										Statis-tical	Critical
								n	m	T_{stat}	T_{crit}
$H_0 : \overline{X}_g = \overline{Y}_d$	F values of resistance to freezing and thawing means of crushed granite and crushed dolomite are approximate	rejected	F	$\overline{X}_g = 0.13$ (%)	$\overline{Y}_d = 0.24$ (%)	$S_g^2 = 0.006$ (%)^2	$S_d^2 = 0.18$ (%)^2	67	47	5.39	1.98
$H_0 : \overline{X}_g = \overline{Y}_d$	SZ values of resistance to fragmentation means of crushed granite and crushed dolomite are approximate	rejected		$\overline{X}_g = 17.23$ (%)	$\overline{Y}_d = 22.23$ (%)	$S_g^2 = 1.268$ (%)^2	$S_d^2 = 1.838$ (%)^2	81	135	–23.27	1.96
$H_0 : \overline{X}_g = \overline{Y}_{gr}$	SZ values of resistance to fragmentation means of crushed granite and crushed gravel are approximate	no rejected	SZ	$\overline{X}_g = 17.23$ (%)	$\overline{Y}_{gr} = 23.47$ (%)	$S_g^2 = 1.268$ (%)^2	$S_{gr}^2 = 4.793$ (%)^2	81	18	–1.77	1.96
$H_0 : \overline{X}_d = \overline{Y}_{gr}$	SZ values of resistance to fragmentation means of crushed dolomite and crushed gravel are approximate	rejected		$\overline{X}_d = 22.23$ (%)	$\overline{Y}_{gr} = 23.47$ (%)	$S_d^2 = 1.838$ (%)^2	$S_{gr}^2 = 4.793$ (%)^2	135	18	–17.92	1.96
$H_0 : \overline{X}_g = \overline{Y}_d$	ρ_{rd} values of dry density means of crushed granite and crushed dolomite are approximate	no rejected		$\overline{X}_g = 2.713$ Mg/m^3	$\overline{Y}_{gr} = 2.723$ Mg/m^3	$S_g^2 = 1.268$ (Mg/m^3)^2	$S_d^2 = 0.001$ (Mg/m^3)^2	65	95	–0.57	1.96
$H_0 : \overline{X}_g = \overline{Y}_{gr}$	ρ_{rd} values of dry density means of crushed granite and crushed gravel are approximate	no rejected	ρ_{rd}	$\overline{X}_g = 2.713$ Mg/m^3	$\overline{Y}_{gr} = 2.702$ Mg/m^3	$S_g^2 = 1.268$ (Mg/m^3)^2	$S_{gr}^2 = 0.001$ (Mg/m^3)^2	65	16	0.30	1.96
$H_0 : \overline{X}_d = \overline{Y}_{gr}$	ρ_{rd} values of dry density means of crushed dolomite and crushed gravel are approximate	rejected		$\overline{X}_d = 2.723$ Mg/m^3	$\overline{Y}_{gr} = 2.702$ Mg/m^3	$S_d^2 = 0.001$ (Mg/m^3)^2	$S_{gr}^2 = 0.001$ (Mg/m^3)^2	96	16	2.68	1.96

Table 3. Correlation dependencies between the values of quality indices of different crushed rocks

Correlation		Crushed rock	Individual data sample,	Mean		Standart deviation		Regression Eq	Correlation coefficient,
Dependency	Type		n						R
$r(X_{LA}, X_F)$	no at all	granite	11	$\overline{X}_{LA} = 14.91$	$\overline{X}_F = 0.16\%$	$S^2_{LA} = 3.537$	$S^2_F = 0.020(\%)^2$	$F = 0.1137 + 0.0030LA$	0.07
	very weak	dolomite	12	$\overline{X}_{LA} = 21.00$	$\overline{X}_F = 0.31\%$	$S^2_{LA} = 1.582$	$S^2_F = 0.014(\%)^2$	$F = -0.0067 + 0.015LA$	0.16
$r(X_{SZ}, X_F)$	very weak	granite	25	$\overline{X}_{SZ} = 17.00\%$	$\overline{X}_F = 0.15\%$	$S^2_{SZ} = 2.285(\%)^2$	$S^2_F = 0.010(\%)^2$	$F = -0.0366 + 0.0109SZ$	0.17
	weak	dolomite	38	$\overline{X}_{SZ} = 22{,}03\%$	$\overline{X}_F = 0.25\%$	$S^2_{SZ} = 1.176\ (\%)^2$	$S^2_F = 0.028\ (\%)^2$	$F = -0.4696 + 0.0325SZ$	0.26
$r(X_{\rho_{rd}}, X_F)$	weak	granite	26	$\overline{X}_{\rho_{rd}} = 2.722$ Mg/m^3	$\overline{X}_F = 0.15\%$	$S^2_{\rho_{rd}} = 0.003\ (\text{Mg/m}^3)^2$	$S^2_F = 0.010(\%)^2$	$F = 0.9565 - 0.2960\rho_{rd}$	0.15
	weak	dolomite	37	$\overline{X}_{\rho_{rd}} = 2.725$ Mg/m^3	$\overline{X}_F = 0.25\%$	$S^2_{\rho_{rd}} = 0.001\ (\text{Mg/m}^3)^2$	$S^2_F = 0.010(\%)^2$	$F = 4.3900 - 1.5185\rho_{\text{rd}}$	0.24
$r(X_{LA}, X_{SZ})$	average	granite	14	$\overline{X}_{LA} = 15.14$	$\overline{X}_{SZ} = 17.17\%$	$S^2_{LA} = 4.551$	$S^2_{SZ} = 1.491(\%)^2$	$SZ = 12.8798 + 0.2834LA$	0.50
	strong	dolomite	16	$\overline{X}_{LA} = 20.75$	$\overline{X}_{SZ} = 21.41\%$	$S^2_{LA} = 1.438$	$S^2_{SZ} = 1.549(\%)^2$	$SZ = 6.3913 + 0.7239LA$	0.70
	strong	gravel	10	$\overline{X}_{LA} = 25.50$	$\overline{X}_{SZ} = 23.07\%$	$S^2_{LA} = 8.650$	$S^2_{SZ} = 4.888\ (\%)^2$	$SZ = 7.0183 + 0.6295LA$	0.84
$r(X_{LA}, X_{\rho_{rd}})$	no at all	granite	11	$\overline{X}_{LA} = 15.50$	$\overline{X}_{\rho_{rd}} = 2.728$ Mg/m^3	$S^2_{LA} = 9.250$	$S^2_{\rho_{rd}} = 0.074\ (\text{Mg/m}^3)^2$	$\rho_{rd} = 2.7311 - 0.0002LA$	0.01
	average	dolomite	16	$\overline{X}_{LA} = 20.24$	$\overline{X}_{\rho_{rd}} = 2.728$ Mg/m^3	$S^2_{LA} = 5.592$	$S^2_{\rho_{rd}} = 0.002\ (\text{Mg/m}^3)^2$	$LA = 68.2585 - 17.3785\rho_{rd}$	0.47
	weak	gravel	10	$\overline{X}_{LA} = 25.50$	$\overline{X}_{\rho_{rd}} = 2.699$ Mg/m^3	$S^2_{LA} = 8.650$	$S^2_{\rho_{rd}} = 0.000\ (\text{Mg/m}^3)^2$	$LA = 201.5217 - 65.2174\rho_{rd}$	0.18
$r(X_{SZ}, X_{\rho_{rd}})$	average	granite	66	$\overline{X}_{SZ} = 17.31\%$	$\overline{X}_{\rho_{rd}} = 2.718$ Mg/m^3	$S^2_{SZ} = 2.23(\%)^2$	$S^2_{\rho_{rd}} = 0.001\ (\text{Mg/m}^3)^2$	$\rho_{rd} = 2.9154 - 0.0114SZ$	0.46
	no at all	dolomite	94	$\overline{X}_{SZ} = 22{,}32\%$	$\overline{X}_{\rho_{rd}} = 2.722$ Mg/m^3	$S^2_{SZ} = 2.115\ (\%)^2$	$S^2_{\rho_{rd}} = 0.001\ (\text{Mg/m}^3)^2$	$SZ = 31.1151 - 3.8319\rho_{rd}$	0.06
	weak	gravel	16	$\overline{X}_{SZ} = 23.20(\%)$	$\overline{X}_{\rho_{rd}} = 2.702$ Mg/m^3	$S^2_{SZ} = 4.588\ (\%)^2$	$S^2_{\rho_{rd}} = 0.001\ (\text{Mg/m}^3)^2$	$SZ = -51.9965 + 27.8312\rho_{rd}$	0.30

Table 4. Summary of hypotheses on the normal distribution of the values of quality indices

Quality index	Hypothesis status	Crushed rock	Individual data sample,	Number of intervals,	Length of intervals,	Mean	Standart deviation	Value	
								Statistical	Critical
			n	k	h			T^2_{stat}	T^2_{crit}
SZ	rejected	granite	81	5	0.98	$\overline{X}_{SZ}$ = 17.24(%)	S^2_{SZ} = 1.123(%)^2	7.77	5.99
	rejected	dolomite	135	5	1.48	$\overline{X}_{SZ}$ = 22.61 (%)	S^2_{SZ} = 3.583 (%)^2	37.91	5.99
ρ_{rd}	no rejected	granite	67	5	0.024	$\overline{X}_{\rho_{rd}}$ = 2.713 (Mg/m^3)	$S^2_{\rho_{rd}}$ = 0.001 (Mg/m^3)^2	4.11	5.99
	rejected	dolomite	93	5	0.03	$\overline{X}_{\rho_{rd}}$ =2.722 (Mg/m^3)	$S^2_{\rho_{rd}}$ = 0.001 (Mg/m^3)^2	9.96	5.99

5. Determination of correlation dependencies between the values of mechanical-physical properties quality indices of different types of aggregates

According to the *TRA MIN 07:2007 The List of Technical Requirements for the Mineral Materials of Roads,* for the same type of asphalt mixtures different permissible mechanical-physical properties quality indices of aggregates are set, therefore, it is necessary to test and determine correlation dependencies between the different quality indices of the studied aggregates. Correlation dependencies were determined according to the correlation coefficients given by Čekanavičius and Murauskas (2000): when correlation coefficient values is 0.00–0.19 – type of correlation dependency is very weak correlation or no correlation at all, when 0.20–0.39 – weak correlation, when 0.40–0.69 average correlation, when 0.70–0.89 – strong correlation and when 0.90–1.00 – very strong correlation. For statistical testing only those specimens were chosen for which from 2 to 5 quality indices, used for calculations, were studied. Correlation dependencies of mechanical-physical properties quality indices of crushed granite and crushed dolomite were determined between *LA* and *F*, *SZ* and *F*, ρ_{rd} and *F*, *LA* and *SZ*; *LA* and ρ_{rd}, and *SZ* and ρ_{rd} (Table 3). In Lithuania the most common aggregates, used for producing asphalt mixtures, are crushed granite and crushed dolomite. Due to the lack of values statistical estimations were carried out not for all quality indices.

Since the value LA_{24} of *LA* significantly differed from the remaining values it was rejected. Due to the same reason the value $SZ_{13.5}$ of *SZ* was also rejected. For further estimations the samples without those values were used. Having rejected the mentioned *LA* and *SZ* values the following results were obtained (Table 3). For the estimation of correlation dependencies between *LA* and *SZ* values 16 specimens of crushed dolomite were chosen (n = 16). In this sample the strongly different value X_{LA} = 12 was rejected. It was excluded from the later studied samples. If correlation dependence is very weak it could be stated that the studied indices have almost no influence on each other.

6. Testing of hypotheses on the normal distribution of data

Hypotheses that the frequencies of studied quality indices in histograms are distributed by normal distribution were tested having assumed the significance level α = 0.05. Hypotheses on the normal distribution of frequencies were tested only for those quality indices the frequencies of which were distributed in a tendency of normal distribution. If when drawing a histogram the curve takes an approximately symmetric shape of bell the hypothesis that data is distributed normally is usually proved. The more factors affect the value of quality index the higher probability that the data of quality index will be distributed by normal distribution (Вентцель 1969). Having accepted the hypothesis that data is distributed by normal distribution it could be stated that probability that any sample value will deviate from the sample mean at a distance not larger than $2S_x$ is 0.95. Consequently, the assumption on a normal distribution of studied data diminishes probability of the extreme variations of values. Summary of the values of hypotheses on the normal distribution of current data is given in Table 4.

The histogram of frequencies of *SZ* values was drawn without the significantly different values that were rejected (13.5, 21.4, 21.5). The histogram of *SZ* values of crushed granite is given in Fig. 5. The length of interval *h* was determined by the Eq (2):

$$h = \frac{X_{\max} - X_{\min}}{k}, \tag{2}$$

where h – the length of interval; $X_{\max}$ – max value of quality index; $X_{\min}$ – min value of quality index; k – the number of intervals.

The histogram of frequencies of *SZ* values was drawn for the sample where n = 135. Hypothesis was tested whether the results of resistance to fragmentation test are distributed by normal distribution. The histogram of *SZ* values of resistance to fragmentation of crushed dolomite by impact test method is given in Fig. 6.

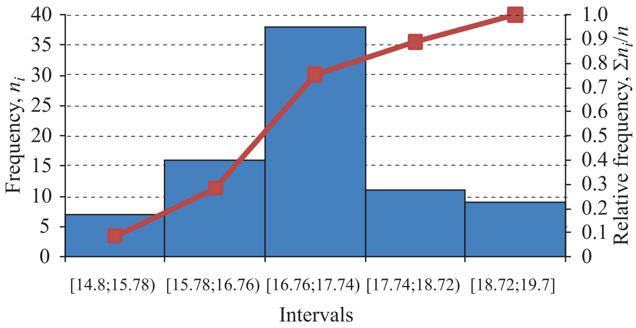

Fig. 5. Histogram of *SZ* values of resistance to fragmentation of crushed granite and distribution function

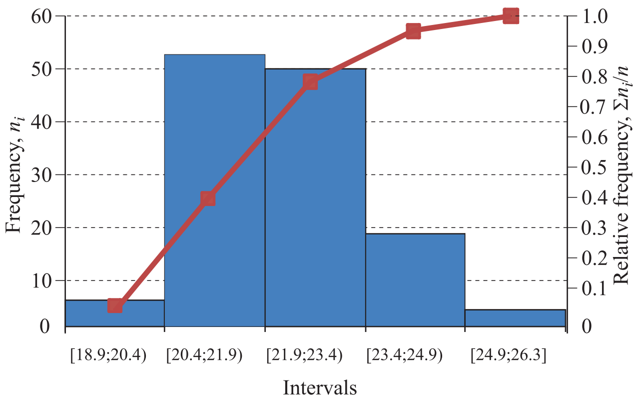

Fig. 6. Histogram of *SZ* values of resistance to fragmentation of crushed dolomite and distribution function

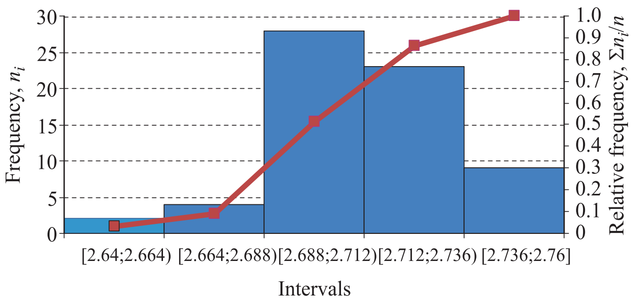

Fig. 7. Histogram of dry density ρ_{rd} of crushed granite (fr. 8/12.5 mm) and distribution function

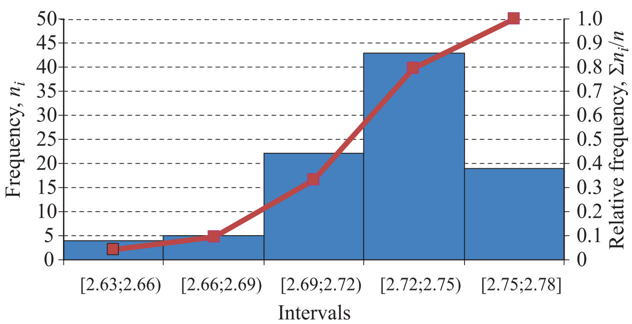

Fig. 8. Histogram of density ρ_{rd} of crushed dolomite (fr. 8/12.5 mm) and distribution function

Hypothesis was tested that the measurement results of ρ_{rd} value of crushed granite (Fig. 7) and crushed dolomite (Fig. 8) are distributed by normal distribution.

7. Conclusions

1. Having determined by statistical estimations the *PSV* and M_{DE}, a low dispersion of their values was obtained. The number of intervals being less than 5 it is beside the purpose to estimate histogram of the distribution of frequencies of values, therefore, hypothesis on the normal distribution of those values were not analyzed.

2. Tested hypotheses on different *F*, *SZ* and ρ_{rd} values means of crushed granite, crushed dolomite and crushed gravel shows there was no reason to reject hypotheses on the approximate of means of *SZ* values for crushed granite and crushed gravel. Further hypotheses on the approximate of means of *SZ* values for crushed dolomite and crushed granite, and for crushed dolomite and crushed gravel were rejected. Also, hypotheses were tested whether the means of ρ_{rd} values for crushed granite, crushed dolomite and crushed gravel are approximate. It was determined by statistical estimations that there were no reason to reject hypotheses on the approximate of means of ρ_{rd} values for crushed granite and crushed dolomite, and for crushed granite and crushed gravel. Hypothesis that the means of *DPD* of crushed dolomite and crushed gravel are approximate were rejected. Hypothesis that the means of *F* values of crushed granite and crushed dolomite are approximate were also rejected. Calculations showed that mechanical-physical properties of granite and gravel are approximate because of granite particles contained in gravel, whereas, the respective properties of gravel and dolomite are different.

3. Analysis of correlation dependencies of mechanical-physical properties quality indices of crushed granite, crushed dolomite and crushed gravel was carried out. The following dependencies between the *LA* and *SZ* values were obtained: of average strength – for crushed granite, strong – for crushed dolomite and crushed gravel. The obtained dependencies of these strength indices prove the identity of *LA* and *SZ* indices indicated in the list of technical requirements *TRA MIN 07:2007*. The following correlation dependencies between the *LA* and ρ_{rd} values were obtained: no dependency – for crushed granite, dependency of average strength – for crushed dolomite and very weak – for crushed gravel. The following dependencies were obtained between the *LA* and *F* values: no dependency – for crushed granite, very weak dependency – for crushed dolomite. The following correlation dependencies were obtained between the *SZ* and ρ_{rd} values: of average strength – for crushed granite, no dependency – for crushed dolomite and weak dependency – for crushed gravel. The following correlation dependencies were obtained between the *SZ* and *F* values: very weak – for crushed gravel and weak – for crushed dolomite. The following correlation dependencies were obtained between the *F* and ρ_{rd} values: very weak – for crushed granite and weak –

for crushed dolomite. Since correlation dependencies of the remaining indices are weaker than the average, the assumption that physical properties of the studied rocks have a strong influence on their mechanical properties is rejected.

4. Having made statistical estimations the hypothesis was tested whether the impact test data of crushed granite and crushed dolomite is distributed by normal distribution. Since it was obtained that $T^2_{stat} > T^2_{crit}$, this hypothesis was rejected. Also, the hypotheses were tested whether the histograms of ρ_{rd} values for crushed granite and crushed dolomite are distributed by normal distribution. It was obtained by the estimations of ρ_{rd} data that $T^2_{stat} < T^2_{crit}$, therefore, there was no reason to reject this hypothesis. Consequently, the assumption that the studied data is distributed by normal distribution diminishes probability of the extreme variations of values. For crushed dolomite the statistical value of this quality index was higher than critical, thus, the hypothesis was rejected.

5. In Lithuania mechanical-physical properties of crushed gravel, used for producing asphalt mixtures, have not been sufficiently tested, therefore, they need a more comprehensive investigation.

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