

Justification of the Optimal Granulometric Composition of Crushed Rocks for Open-Pit Mine Road Surfacing

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Abstract. The specific weight of the open coal mining method in Kuzbass is constantly growing due to higher hazard and low profitability of the underground mining method. It is possible to reduce the cost of open-pit coal mining using overburden rock in constructing temporary pit roads. The purpose of the work is to justify the possibility of using overburden rock for the construction of temporary technological roads. To this end, we set the tasks to determine the rational granulometric composition of crushed rock, dependences of its unit weight, static elastic modulus, and ultimate shear resistance. This study justifies the most efficient granulometric composition of crushed rock based on theoretical studies of the optimal structure of granular materials, taking into account the probability theory of particle-particle packing, laboratory studies of the dependence of the unit weight and the static elastic modulus on the content of particles of different sizes, and also the calculation of ultimate shear resistance of crushed rocks. As a result of the conducted studies, it has been established that the optimal granulometric composition of crushed rock, which at the same time ensures high values of unit weight, static elastic modulus and ultimate shear resistance, is achieved when the content of particles larger than half of the maximum is 40 to 55% and increases integrally with decreasing of the average particle diameter.

1 Introduction

Road surface is one of the most important elements of the pit road dressing, the average speed of pit transport and, consequently, its efficiency largely depend on the condition of roads. Taking into account that transportation costs make up 40 to 70% of total costs, improving the quality of road topping is one of the main ways to reduce the cost of mineral mining by the open-cast method.

The experience of coal mines operation in Kuzbass has shown that construction of asphalt-concrete and cement-concrete pavements is not justified economically when it comes to roads in a dynamically developing quarry space, where temporary roads make up to 80% of their total length. The most suitable for construction of road dresses of both permanent and temporary technological roads is crushed rock.

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The analysis of previous studies [1-11] shows that the crushed rock of the optimal granulometric composition should consist of various size particles taken in a certain quantitative ratio, which provides increased internal friction and adhesion between the particles, high unit weight and an insignificant intensity of the grain grinding process [12 - 15]. These conditions can be achieved with the largest possible number of coarse particles and minimal content of fine and silty particles necessary to create high unit weight and to ensure the cohesion of large particles.

2 Materials and methods

These conclusions which take into account the main theoretical provisions of A.V. Biryukov, B.S. Radovsky, and I.I. Kandaurov, were laid in the basis of the theoretical model of optimal packing of different-sized particles, the following assumptions and conjectures were introduced in it:

The entire crushed rock consists of N-components, and a certain fraction characterized by an average diameter is taken as a component. It is inconvenient to use the absolute values of the average diameters of the particles, so in the theoretical model, the average particle diameters of a certain fraction were replaced by relative dimensions, such as D_{max} , $D_{max} / 2$, $D_{max} / 4$, and so on. The particles of the largest component are evenly distributed throughout the volume, which allows us to consider not the entire set of particles (a macro object), but only one of them (a discrete object). All particles have the shape of a sphere. If we take the shape of the particles in the form of a cube, then theoretically the minimum voidness of a layer arranged from such a fragmented rock will tend to porosity of the rock itself, since individual particles can closely touch each other on all sides. It is difficult to consider a form in the form of a tetrahedron using random packing of particles, since grains can occupy one position, but they always have a different orientation in space. But the shape of particles in the form of a sphere satisfies both conditions: between particles there is always space (voids) that cannot be completely filled; regardless of the location of an individual particle, its orientation in space doesn't affect the package. To test the adequacy of the theoretical model, a laboratory study was made of the dependences of the unit weight and the static modulus of elasticity of crushed rocks of different granulometric composition. In addition, the ultimate shear resistance of that crushed rock was calculated.

All laboratory studies were performed on samples of crushed rock of different granulometric composition presented in Table 1.

Table 1. Selected grain size distributions of crushed rock

Blend #	Full residue, %, on sieves, mm:					
	10	5	2.5	0.63	0.16	0.05
# 1	9.70	24.09	33.08	48.91	56.64	71.83
# 2	12.93	28.91	46.90	55.70	66.86	77.47
# 3	33.95	48.33	61.82	61.82	81.14	85.48
# 4	48.50	58.09	62.58	66.54	69.63	80.92
# 5	29.10	43.48	61.47	69.39	77.11	83.63
# 6	19.40	38.58	52.07	67.90	79.49	83.83
# 7	38.80	57.98	66.97	66.97	86.29	88.46
# 8	58.19	72.58	81.57	89.49	93.35	93.35
# 9	48.50	58.09	67.08	75.00	78.86	85.37
# 10	58.19	67.79	76.78	80.74	83.06	88.26

3 Results

The proposed theoretical model was implemented by means of computer simulation. The simulation results are shown in Table 2.

Table 2. Optimal grain size distribution of crushed rock based on theoretical studies

Component dia., mm	D_{max}	$D_{max}/2$	$D_{max}/4$	$D_{max}/8$	$D_{max}/16$	$D_{max}/32$	$D_{max}/64$	$D_{max}/128$	$D_{max}/256$	$D_{max}/512$	$D_{max}/1024$	$D_{max}/2048$	$D_{max}/4096$	$D_{max}/8192$
The total content of the components (total residue), % by volume	52.4	58.95	64.68	71.12	74.97	77.71	80.66	83.43	85.76	87.87	89.61	91.03	92.31	93.07

The obtained results made it possible to determine the theoretical dependence characterizing the optimal granulometric composition of the crushed rocks:

$$V_D = 52.4 + \int_D^{0.5D_{max}} \left(\frac{30}{(D_{max} + 25)^{0.5}} + 1.84 \right) \frac{1}{D^{0.8}} dD, \quad (1)$$

where V_D – total content by volume of the i -th component and all the previous larger components, %; D – average diameter of particles of the i -th component, mm; D_{max} – average diameter of particles of the largest component, mm.

The results of the laboratory tests are shown in Figures 1 and 2 with reference to crushed rock rocks of coarse-grained sandstone with the maximum grainsize $D_{max} = 20$ mm.

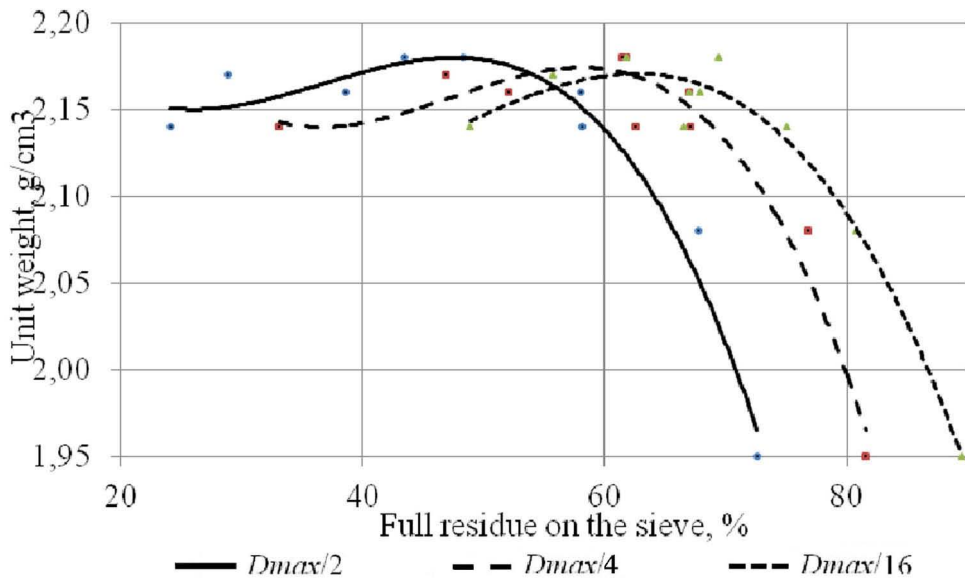


Fig.1. Dependences of unit weight on full residue of the sieves of a given size

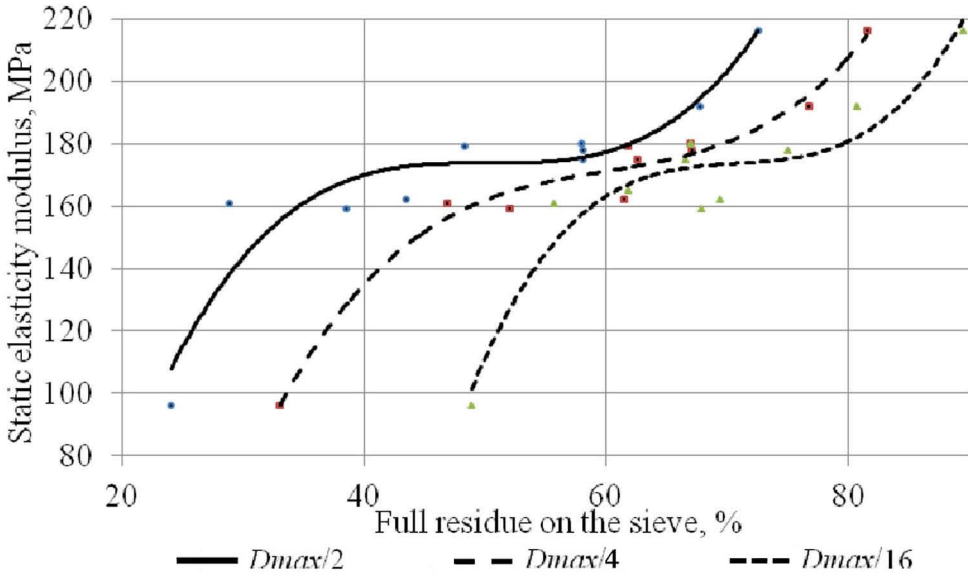


Fig. 2. Dependences of elasticity modulus on full residue on the sieves of a given size

The response functions of the unit weight (ρ) and the static modulus of elasticity (E) of the crushed rocks from the total residue on the sieve of a given size have the form (the values of the coefficients of the regression equations are given in Table 3):

$$\rho(V_D) = 0,79 \cdot \rho_0 \cdot \left[\cos\left(\frac{V_D^2 - k_1}{k_2}\right) \right]^2, \tag{2}$$

$$E(V_D) = \int_0^{V_D} k_3 \cdot V_D^{k_4} \cdot [1 - \cos(k_5 \cdot V_D)]^{k_6} dV_D + 40, \tag{3}$$

where V_D – content of particles over D mm in size in the crushed rock, %; ρ_0 – density of the initial rock mass, g/cm³; $k_1, k_2, k_3, k_4, k_5, k_6$ – coefficients of regression equations.

Table 3. Coefficients of regression equations

Average diameter	Regression equation coefficient value					
	k_1	k_2	k_3	k_4	k_5	k_6
$D_{max}/2$	800	9000	13.5	-0.537	0.091	0.721
$D_{max}/4$	1800	10000	0.838	0.223	0.075	0.822
$D_{max}/8$	2800	13000	0.032	1.06	0.070	0.700
$D_{max}/16$	3200	14000	0.0028	1.60	0.060	0.600

The DalNII has developed a technique for estimating the strength characteristics (ultimate shear resistance) for coarse clastic soils, which in fact differ little from fractured rocks. It is based on the dependence of the angle of internal friction and the specific cohesion of crushed rocks on the content of particles (debris) having a size of more than 2 mm. Further, according to the Coulomb law, the ultimate shear resistance is calculated. Graphical representation of the results of the performed calculation is shown in Figure 3.

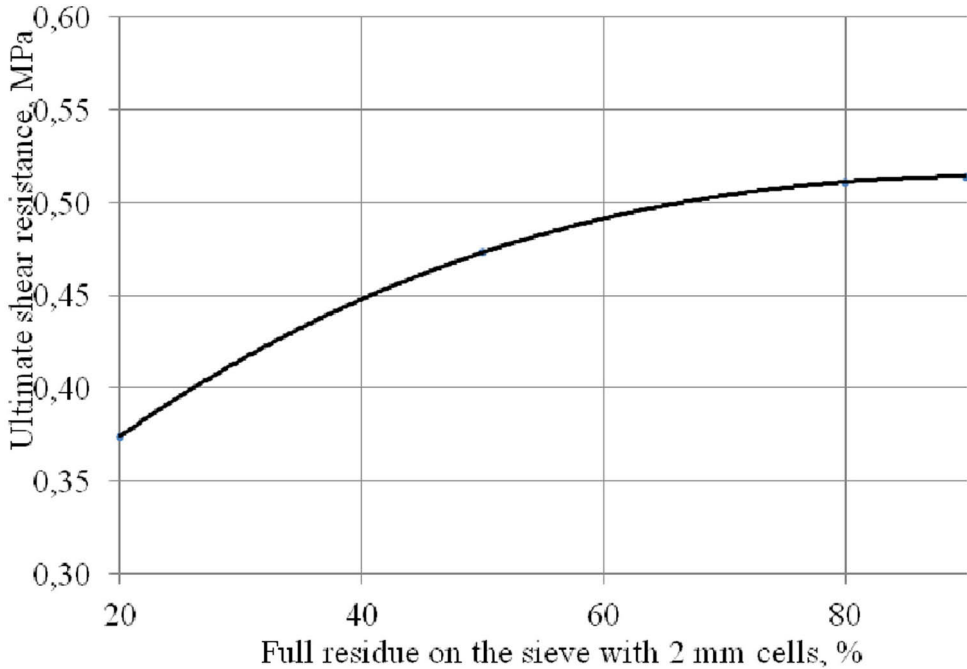


Fig. 3. Dependence of the ultimate shear resistance of crushed rocks on the content of particles over 2 mm in their composition

The obtained dependences of the volumetric mass, the static elastic modulus and the ultimate shear limiting resistance of the crushed rocks on their granulometric composition made it possible to optimize it.

Comparison of empirical data with the results of theoretical studies shows that they almost completely coincide. The difference is that according to the results of the experimental data, the optimum particle size distribution represents a region, and in theoretical studies, it is the only value in this optimal region. Consequently, the dependence characterizing the optimal granulometric composition of crushed rocks can be written in the form:

$$V_D = (40...55) + \int_D^{0.5D_{max}} \left(\frac{30}{(D_{max} + 25)^{0.5} + 1.84} \cdot \frac{1}{D^{0.8}} \right) dD. \quad (4)$$

4 Conclusions

The optimal granulometric composition of the crushed rock, which at the same time ensures high values of unit weight, static elastic modulus and ultimate shear resistance, is achieved when the content of particles larger than half of the maximum is 40 to 55% and integrally increases with a decrease in the average particle diameter.

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