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Determination of rock mass weakening coefficient after blasting in various fracture zones

Valentin Aleksandrovich Isheyskiy[a*] and Mikhail Anatolyevich Marinin[a]

[a]*Saint-Petersburg Mining University, 21 line, 2, Saint-Petersburg, 199106 Russia*

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A B S T R A C T

Quality of blast preparation for rock beneficiation influences both on integrity of mineral stock in particular and in economical performances of enterprise operations in general. While rock processing for obtaining of crushed stone the yield of screenings is high, its amounts depend on rock strength properties. Investigation into the influence of drilling and blasting parameters on strength properties of blasted rocks is an urgent research and practical task for mining companies producing building stones. This article discusses results of full-scale experiment aimed at determination of strength of blasted rocks in shotpile with accounting for fracture zones as a function of rock massif saturation with energy of explosive substance.

1. Introduction

Management of natural resources becomes more and more important upon development of resource intensive technologies. Reasonable management of natural resources as a system of scientific, industrial, and structural essence assumes the most complete use of mined natural resources and, as a consequence, decrease in amount of consumed resources, provision of recovery and reasonable use of natural resources (Bozhenov, 1994). Development of resource saving mining activities should be based on comprehensive investigation into mineral base, versatile estimation of destructed rocks and mined mineral resources. One of major issues in the field of aggregates is uncontrollable yield of screenings. For instance, upon production of gravel on the basis of granite, gabbro-diorite, basalt the average yield of screenings is 25%, and on the basis of carbonates is approximately 35% (Kharo et al., 2003).

* Corresponding author.
E-mail addresses: sheiskii@bk.ru (V. A. Isheyskiy)

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Blasting impact on fractured massif leads to decrease in strength properties of rocks, which influences significantly on the yield of screenings at processing stage. Numerous works are devoted to this aspect (e.g. Akande & Lawal, 2013; Inoue et al., 2014; Sasaoka et al., 2015, Yugo & Shin 2015). This article continues integrated studies discussed elsewhere (Paramonov et al. 2014; Isheysky & Yakubovskii, 2016; Isheysky, 2014). On the basis of simulations described by Paramonov and Isheysky (2014), a series of rock massif blasting with various specific consumptions was performed at Gavrilovskoe-1 open cast mine. Nitronit E-70 was used as explosive substance in all three series. Specific consumption was varied by means of narrower borehole pattern. Table 1 summarizes parameters of drilling and blasting in various series.

Table 1. Parameters of drilling and blasting activities

Description	Units of measurement	Values		
Blast No.	-	1	2	3
Diameter - d	mm	144	144	144
Subdrill depth - L_{sub}	m	1.4	1.4	1.4
Drill depth - L_{dr}	m	13.4	13.4	13.4
Distance between drills in a row - a	m	4.5	4.0	4.0
Distance between rows - b	m	4.5	4.5	4.0
Stemming length - l_{stem}	m	3.0	3.0	3.0
Loaded length - l_{load}	m	10.4	10.4	10.4
ES capacity in 1 m of drill - P	kg	16.4	16.4	16.4
Load weight in drill - Q	kg	220	220	220
Average yield g/m from drill - V_{drill}	m^3	243	216	192
ES specific consumption - q	kg/m^3	0.9	1.01	1.14

2. Experimental study

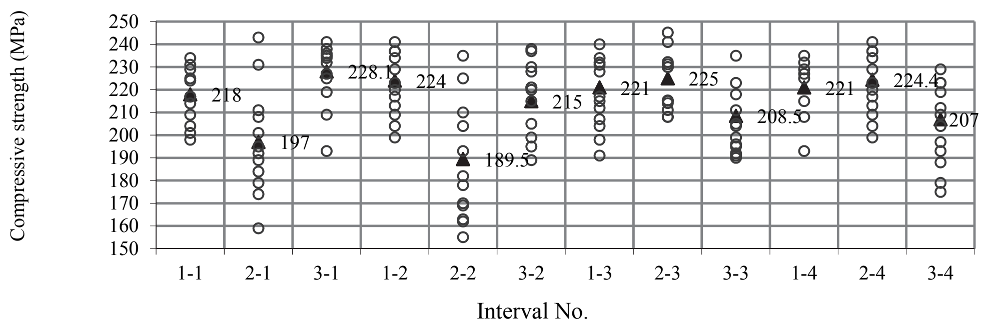
Strength properties of raw stock delivered to factory were estimated by strength of averaged rock from shotpile. In order to determine averaged rock the shotpile photo was taken was after each excavation. The shotpile was conventionally separated into 12 intervals. Planimetric analysis was performed using linear approach. The shotpile was outlined by measuring tape marked by black and white stripes. The tape is applied each 10 meters. Photos were taken from the distance of 10 meters to the shotpile using two cameras.

Table 2. Average rock size

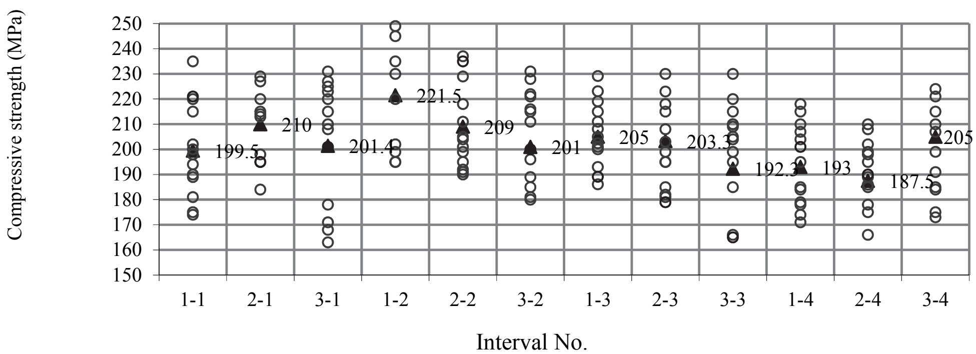
Sampling zone	Blast No.		
	№1	*№2*	*№3*
1-1	0.380	0.385	0.421
1-2	0.401	0.330	0.237
1-3	0.310	0.280	0.314
2-1	0.267	0.380	0.374
2-2	0.370	0.355	0.251
2-3	0.330	0.320	0.398
3-1	0.340	0.360	0.325
3-2	0.385	0.315	0.341
3-3	0.478	0.261	0.242
4-1	0.258	0.365	0.372
4-2	0.350	0.251	0.352
4-3	0.285	0.452	0.289
Avg.	0.346	0.337	0.326

Table 3. Average compression strength

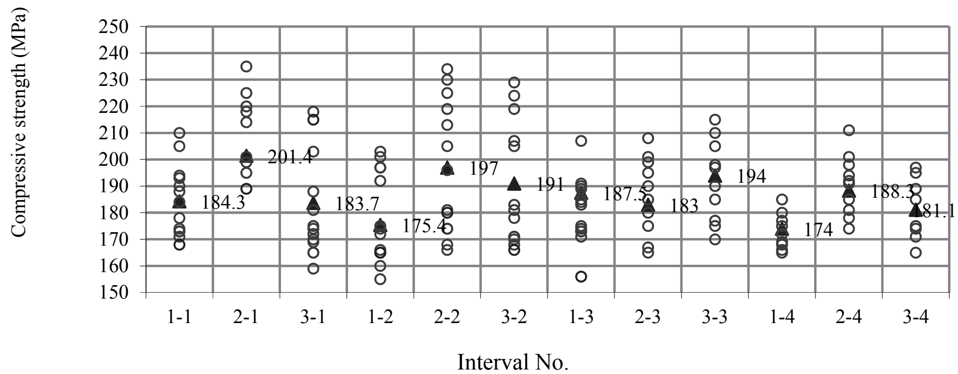
Sampling zone	Average compression strength. *MPa*		
	№1	*№2*	*№3*
1-1	218.0	199.5	184.3
1-2	197.0	210.0	201.4
1-3	228.1	201.4	183.7
2-1	224.0	221.5	175.4
2-2	189.5	209.0	197.0
2-3	215.0	201.0	191.0
3-1	221.0	205.0	187.5
3-2	225.0	203.3	183.0
3-3	208.5	192.3	194.0
4-1	221.0	193.0	174.0
4-2	224.4	187.5	188.3
4-3	207.0	205.0	181.1
Avg.	215.0	202.0	182.0



Blast No. 1



Blast No. 2



Blast No. 3

Fig. 1. Average strength of average size rock from various shotpile zones.

The obtained photos were initially processed using MapInfo GIS software and then using WipFrag software according to the procedure described elsewhere (Maerz et al., 1996; Maerz, 1996). Size averaged rock was taken after each excavation. Linear parameters of average rock were measured directly in mine. Length, height, and width were measured. The measured values were summarized in Tables 2 and 3. Spot sample was taken from various points. The sizes of average rock from various zones of shotpile are shown in Table 2. Samples for testing were prepared from mined rocks. Rock samples for laboratory studies were prepared by drilling of cores from sampled rocks after blasting and provision of required shapes and sizes using appropriate stone cut equipment (Broch & Franklin 1972).

Sizes and amount of prepared rock samples were selected individually for each batch taking into account optimum combination of requirements to sample representativity and its actual amount. Upon testing the samples with flat parallel edges, perpendicular to smooth side surface, were destroyed by compression using an MTS hydraulic press machine. The testing results are illustrated in Fig. 1 and summarized in Table 3. Specific consumption for various blasting series can be expressed by specific energy intensity using the following equation:

$$E = q \cdot Q, \text{ MJ/m}^3, \tag{1}$$

where Q is the specific energy, MJ/kg; q is the specific consumption of explosive substance, kg/m^3.
On the basis of Table 3 and using Eq. (1) let us plot strength variation of average rock as a function of specific energy intensity (see Fig. 2):

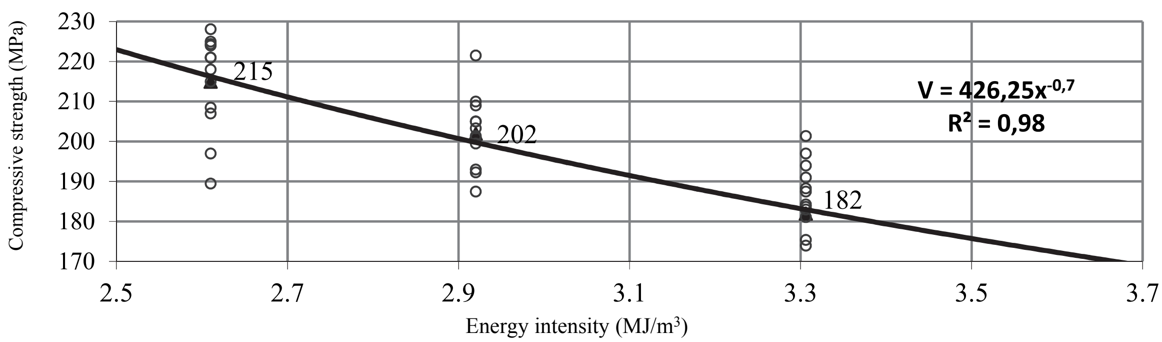


Fig. 2. Average rock strength as a function of specific energy intensity.

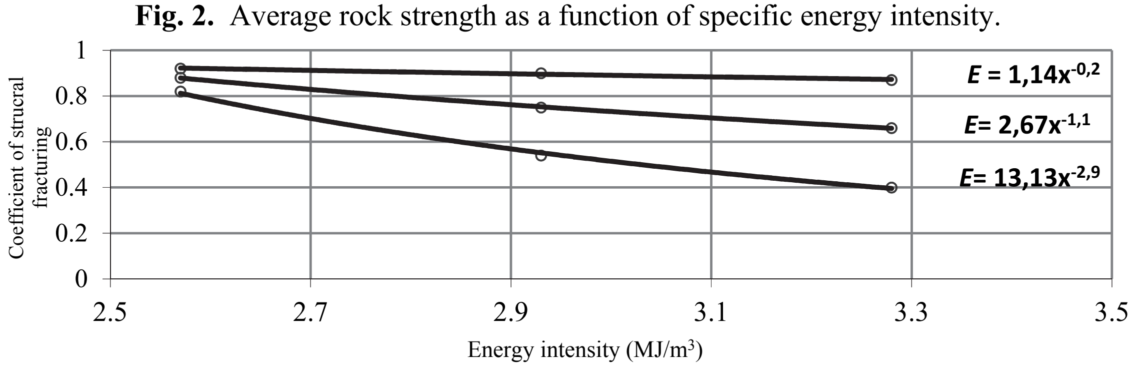


Fig. 3. Rock mass weakening coefficient as a function of specific energy intensity with regard to distance from blast source

3. Results and discussion

On the basis of plotting we obtained power law dependence which enables forecasting of compressive strength of averaged rock supplied to crushing as a function of specific energy intensity:

$$\left|\sigma_{comp}\right|_{avg} = 426.25\, E^{-0,7}, \tag{2}$$

where E is the specific energy intensity, MJ/m^3; $\sigma_{comp.avg}$ is the compressive strength of averaged rock, MPa. Taking into account the results in (Maerz, 1996; Kharo et al., 2003), and considering for the fact that the strength of averaged blasted rock is a function of distance to blasting source (Akande & Lawal, 2013), it is possible to express the rock mass weakening coefficient for uniaxial compressive strength of granite with regard to unbroken material in each zone as a function of energy intensity. The dependences of structural weakening in various zones are illustrated in Fig. 3. Therefore, the strength of averaged rock after blasting with consideration for fracturing zone can be expressed as follows:

$$\left|\sigma_{comp}\right|_{avg} = \sum_{i=1}^{n} \left|\sigma_{comp}\right|_{m} k_i \cdot \frac{V_i}{V_{tot}}, \tag{3}$$

where V_i is volume of destruction zone, m^3; V_{tot} is the volume of all zones, m^3; $\left|\sigma_{comp}\right|_{m}$ is the uniaxial compressive strength of rocks before blasting, MPa; k_i is the coefficient of strength weakening in a zone; n is the number of destruction zones.

Validation of Eq. (3) for the experimental conditions of the open cast mine was performed on the basis of blasting data and by comparison with the obtained Eq. (2). On the basis of results in Paramonov et al. (2014) and using MathCAD software the strength of averaged rock was calculated by Eq. (3). The example of output data for blasting No. 1 is illustrated in Fig. 4. The uniaxial compressive strength of granite for the considered conditions was 240 MPa. Specific energy intensity of the massif according to Eq. (1) was 2.61 MJ. Substituting the calculated data into equations of strength weakening for zones illustrated in Fig. 3 we obtain the uniaxial compressive strength for averaged rock in shotpile. The calculations were compared with the experimental curve shown in Fig. 5.

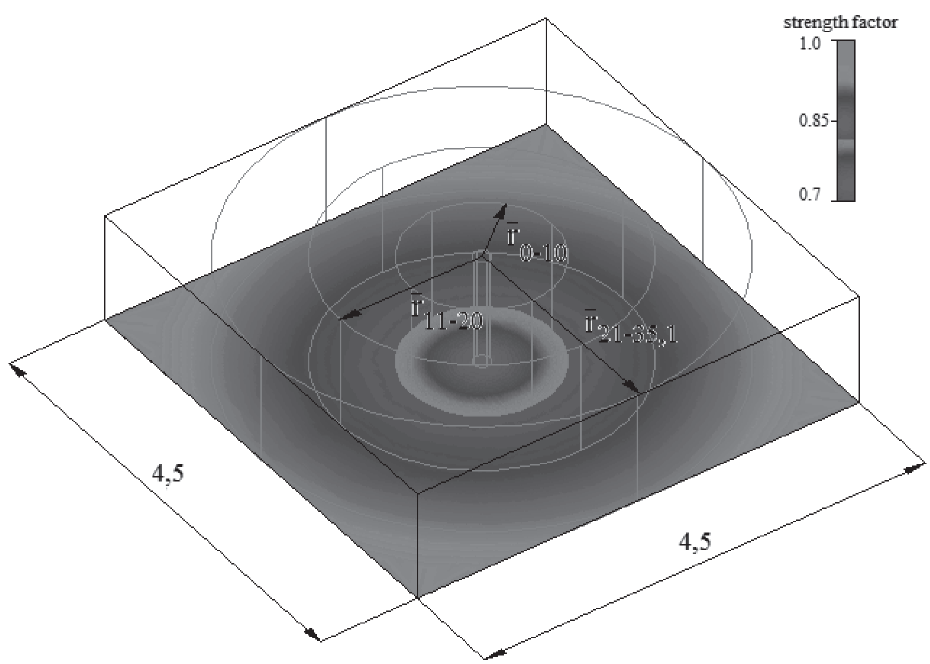


Fig. 4. Distribution of coefficients of structural weakening for specific energy intensity of 2.61 MJ (MathCAD)

4. Conclusion

On the basis of calculations and experiments ti has been established that variation of uniaxial compressive strength of average rock as a function of ES specific energy consumption in the range from 2.5 MJ/kg^3 to 3.5 MJ/kg^3 for the considered rocks is determined according to Eq. (2). It was demonstrated that this equation can satisfactorily approximates the experimental data and therefore is suitable for calculation of average rock strength in general and in individual fracture zones on the basis of ES specific energy consumption.

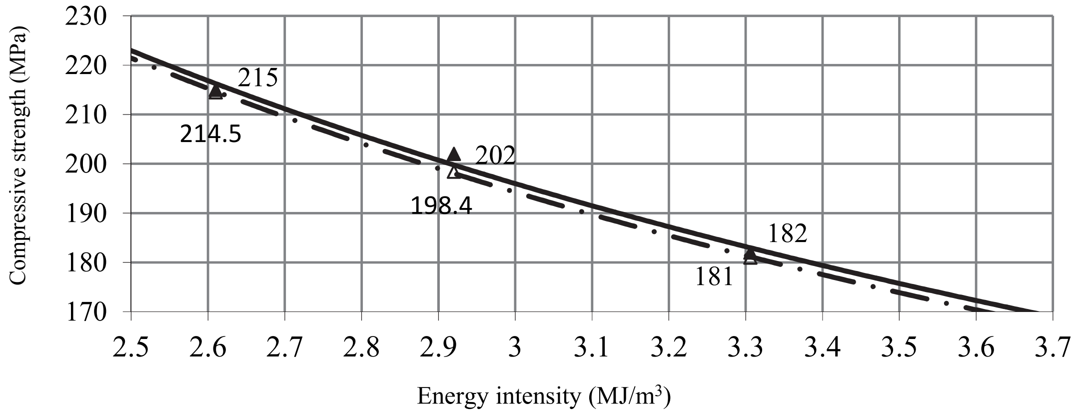


Fig. 5. Uniaxial compressive strength of average rock as a function of ES specific energy consumption for Gavrilovskoe-1 opencast mine: 1 – Experiments; 2 – Calculations according to Eq. (4)

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