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The influence of transverse profile of crusher jaws on comminution effects

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ABSTRACT: In estimation of comminution effects, apart from process efficiency, forces presented during comminution and comminution level, the grain composition and content of irregular grains in product are very important. The jaw crushers give disadvantageous results of grain symmetry of products, but the very high changeability of crushing forces and individual comminution energy was obtained, dependently on the compressing tool shape. In experimental jaw crusher of straight jaw movement, the jaws with longitudinal ruts of transverse triangular, trapezoidal or circular profile were used. Furthermore, the ruts of various teeth sizes, i.e. of various height (h) and scale (t), were applied. The best results were obtained for jaws with trapezoidal ruts, of proportionally low scale $t(t=1{,}1e)$ - where e is the output rift size – and high values of teeth height $h(h=0{,}8e)$. The industrial efforts confirmed the results given in laboratory scale.

1 INTRODUCTION

The practical aim of comminution processes is to obtain a product with demanded graining, while in many events is it also essential shape of grain. Other essential indicates are also the efficiency of comminution process and consumption of energy.

Grain shape in comminution of rock raw materials plays a crucial role in durability of concretes. While the increase in yield of flat grains has unfavourable influence on durability of concretes (anisotropic arrangement of such grains), the increase in yield of spherical and cubic grains (regular grains) improves durability of these concretes.

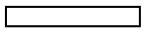
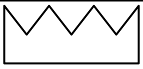
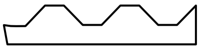
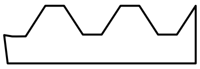
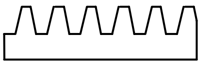
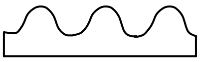
Three main dimensions of the grain, namely: length l, width b and thickness g are used to characterize its shape. Mutual relations of above values give coefficients used for suitable comparing of shapes for different grains.

Some of methods of describing the shape of the grain consist in comparison of real capacity or surface of grain of any shape with a model surface or capacity (regular shaped solid). Obtained in that manner globosity coefficient is function of main dimensions of the grain. Other methods of describing the globosity consist in analysis of either projection shape dimensions of grains on a plane, or their resistance in air tube or a character of falling.

In European Union a content of irregular grains in mineral aggregates is marked with using the method of Shultz's slide caliper or with using crack sieves – both methods are described in norms. The first method has application in natural and artificial aggregates with size 4÷63 mm. Single grains in the sample are classified based on relation of their length l to thickness g, measured with using Shultz slide caliper. Grain shape coefficient is computed as mass of grains with relation of l/g dimensions greater than 3, with reference to whole mass of investigated grains. Second method consists in sieving of narrow size grade of aggregate *(d, D)* through crack sieve with width of cracks *D/2*. Based on relation of mass of product passing through cracks to the whole mass of investigated grains, the flatness coefficient is computed.

In broken aggregates the grain shape depends on not only the type of mineral raw material but also the type of crusher and stage of comminution. In raw material processing plants on second stage of crushing there are usually used cone or hammer crushers. Progress in the field of materials technology allows employing of hammer crushers not only for crushing of sediment rocks, but also to magma rocks (granite, diabase).

Table 1. Experimental jaw covers used in investigations in jaw crusher

	Type of grooving of jaw covers		Grooving scale t [mm]	Height of teeth h [mm]	h/t	Comparative length of section line*	Number of refraction points in section line*	Transverse profile index (7+8)
	Name	Shape						
1	2	3	4	5	6	7	8	9
1	Plain		-	-	-	1	0	1
2	Low triangle		24	12	0,5	1,41	2,5	3,91
3	High triangle		24	17	0,7	1,75	2,5	4,25
4	Low trapezium		24	12	0,5	1,63	4,5	6,13
5	High trapezium		24	17	0,7	2,02	4,5	6,52
6	Condensed trapezium		17	12	0,7	2,04	5,5	7,54
7	Wavy (circular)		24	12	0,5	1,57	2,5	4,07

* Comparative length of section line is obtained through dividing the line of transverse section of grooves by the length of its horizontal projection, while the number of refraction points is computed on segment *t*

Jaw crushers (apart from jaw granulators) are mostly applied in initial crushing stages. These crushers are widespread and find application mostly in not large aggregate processing plants. Products of jaw crushers include up to 50 % of irregular grains, what is one of main disadvantages of theirs. In the event of cone crusher content of irregular grains is lower and cone granulators, with elongated crushing chamber, produce products with relatively small content of irregular grains (from several to a dozen or so percent). The lowest content of irregular grains is obtained from hammer crushers (usually several percent), but yield of finest grains is large, what in production of aggregates is frequently unfavourable effect.

Usually some quantity of aggregates is sifted in earlier stages of mineral processing process and they do not reach the last crushing stage in granulator. For that reason it is essential to obtain from crushing in jaw crushers the product with the lowest content of irregular grains. Such possibility creates an application of cover jaws with suitable transverse profile.

2 CHARACTERISTICS OF LABORATORY JAWS AND COMMINUTED MATERIALS

Among many factors influencing on comminution effects of rock materials in jaw crushers the most important are longitudinal section of crushing chamber and transverse profile of jaw linings. Surface of jaw linings in jaw crushers is usually grooved. In industrial solutions jaws with triangular grooved predominate. The height of teeth h equals $h = (0,3 \div 0,5)t$ (where t is scale of grooving).

In order to analyze the influence of jaw grooving on comminution effects, series of crushing experiments in laboratory jaw crusher with using of jaws with different types of grooving (different transverse profile) were made. In the Table 1 there are presented transverse profiles and dimensions of jaws grooving used in experiments.

The feeds in experiments were four rocky raw materials, namely: sandstone, limestone (concise), porphyry and diabase with graining 40÷63 mm, and there were marked main physio-mechanical parameters for each material (Tab.2)

Table 2. Basic physio-mechanical parameters of investigated materials.

Parameter	Porphyry	Diabase	Lime-stone	Sand-stone
Resistance to comminution, Los Angeles, [%]	18,4	16,9	25,0	36,8
Durability to squeeze, [MPa]	175	182	119	170

3 INVESTIGATIONS OVER INFLUENCE OF SHAPE OF JAW COVERS ON COMMINUTION EFFECTS

Comminutions of all materials were run in crusher with straight move of jaw for 7 sets of experimental jaws, at following crusher's work parameters:

- jump of moving jaw s = 8 mm,
- rotary speed of off-centre shaft n = 320min^{-1},
- outlet crack e = 15, 20, 30 mm.

There were made analyses of size analysis for products (Fig.1), crushing grades were also computed, and then for chosen size grades there were marked shape and plate indexes. In chosen samples crushing forces were additionally measured.

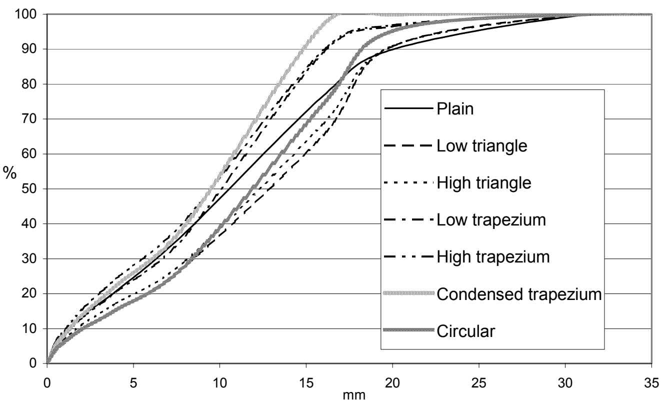


Figure 1. Size analysis of crushing products for porphyry with using various shapes of jaw surfaces (e = 15 mm, n = 320 rev/min, s = 8 mm)

In order to generalize results, approximations of size analysis curves (Tumidajski and others, 2006) were made with following formulas: cut Weibull's cumulative distribution function (a) and cumulative logistic distribution function (b):

a) $$\Phi(d) = 1 - \exp\left[-c\left(\frac{d}{d_{\max} - d} \right)^k \right], \quad 0 < d < d_{\max}$$

b) $$\Phi(d) = \frac{100}{1 + b \cdot e^{-ad}}$$

where: d – size of grain, $\Phi(d)$ – value of cumulative distribution function, d_{max}, k, c, a, b – parameters.

Although cut Weibull's distribution function is a distribution well describing products of coarse crushing in jaw crushers, it appeared that for crusher equipped with variously transverse formed jaws better approximations gives logistic distribution function (lower values of s_r, formula (1)):

$$s_r = \sqrt{\frac{\sum_{i=1}^{p_s} \left(\Phi_e(d_i) - \Phi_t(d_i) \right)^2}{p_s - 2}} \qquad (1)$$

where: p_s - number of sieves used with size of mesh d_i; $\Phi_e(d_i)$ and $\Phi_t(d_i)$ - values of empirical cumulative distribution function and the one obtained from approximation formula for grain size d_i, respectively.

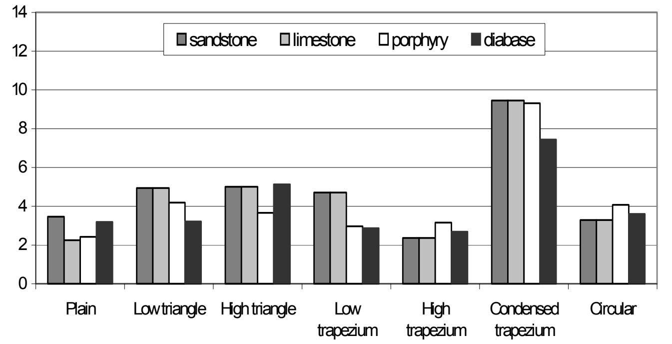


Figure 2. Values of rest deviations of product size analysis approximations for various types of jaws.

It is worth noticing that crushing process proceeds best when crushing plates with trapezoidal grooves are used. Average comminution stages for specific experiments are presented in Table 3.

Table 3. Average comminution stage for various jaws of jaw crusher and for various outlet cracks e (average values from crushing of four rock materials)

Type of jaws	Comminution stage for:	
	e = 15 mm	e = 20 mm
Plain	3,9	2,9
Low triangle(1)	3,6	3,0
High triangle (2)	4,1	2,8
Low trapezium (3)	5,0	3,5
High trapezium (4)	5,1	3,7
Condensed trapezium (5)	5,2	3,9
Wavy (6)	4,2	3,1

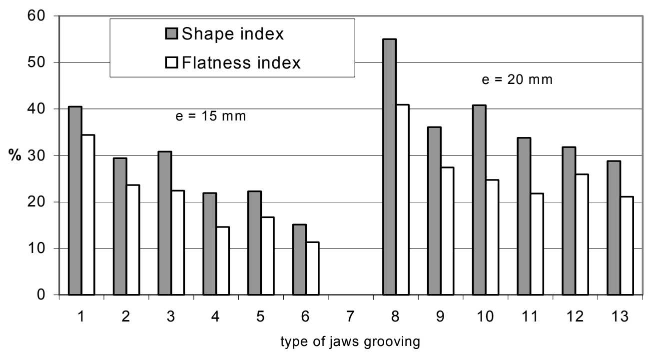


Figure 3. A participation of irregular grains in crushing products for various jaws.

During crushing process, in crushers where squeezing of material predominates (i.e. jaw, cone or cylindrical crushers), crucial role play cracks (material defects), which present a source of cracks spreading. In this connection it is also essential location, shape and size of grooves making possible arising of local deformations in crushing process of rock materials. In estimation of grooving of jaw linings it appeared a question: which value has greater influence on content of irregular grains in crushing products: a scale of grooving (for example dense grooves), a height of teeth (values *h* and *h/t*) or a shape of grooving. In the Table 4 there are presented crushing results obtained for jaws with various geometry of jaw linings' grooving and for these results there were computed regression equations.

Table 4. Results of comminution in crusher with various jaw profiles.

x_1	x_2	x_3	x_4	y_1	y_2	y_3
		15	1	32,8	46,0	3,9
		20	1	36,9	53,7	2,9
24	12	15	3,91	24,0	32,4	3,6
24	12	20	3,91	26,4	37,3	3,0
24	12	30	3,91	35,1		2,0
24	17	15	4,25	21,0	31,3	4,1
24	17	20	4,25	25,1	41,4	2,8
24	17	30	4,25	36,6		2,0
24	12	15	6,13	18,8	22,9	5,0
24	12	20	6,13	23,3	33,8	3,5
24	12	30	6,13	38,8		2,2
24	17	15	6,52	17,5	22,6	5,1
24	17	20	6,52	21,5	31,8	3,7
24	17	30	6,52	34,3		2,3
17	12	15	7,54	15,3	17,2	5,2
17	12	20	7,54	20,6	28,1	3,9
17	12	30	7,54	32,7		2,3
24	12	15	4,07	20,9	23,4	4,2
24	12	20	4,07	29,1	33,9	3,1
24	12	30	4,07	37,5		2,1

There were investigated sandstone, limestone, porphyry and diabase. In the table there are used average values for all materials. Following denotations were adopted in the table:

x_1 – scale of grooving,
x_2 – height of grooves,
x_3 – outlet crack of crusher,
x_4 – shape of grooving (index of profile according to Table 1),
y_1 – content of irregular grains (flatness index),
y_2 – content of irregular grains (shape index),
y_3 – comminution stage

$$y_1 = 5{,}49 + 0{,}3206x_1 - 0{,}2932x_2 + 1{,}0927x_3 - 1{,}0928x_4$$
$$[6{,}51] \quad [0{,}2286] \quad [0{,}1844] \quad [0{,}0631] \quad [0{,}4056]$$
$$R = 0{,}9810, \quad s_r = 1{,}67\%$$

$$y_2 = 3{,}23 + 0{,}0082x_1 + 0{,}6118x_2 + 1{,}8833x_3 - 2{,}7882x_4$$
$$[15{,}28] \quad [0{,}504] \quad [0{,}406] \quad [0{,}347] \quad [0{,}894]$$
$$R = 0{,}9396, \quad s_r = 3{,}00\%$$

$$y_3 = 4{,}4860 + 0{,}0321x_1 - 0{,}0113x_2 - 0{,}1531x_3 + 0{,}2946x_4$$
$$[1{,}328] \quad [0{,}046] \quad [0{,}038] \quad [0{,}013] \quad [0{,}082]$$
$$R = 0{,}9620, \quad s_r = 0{,}34\%$$

Numbers in square brackets denote errors of coefficients.

Above equations show that amount of irregular grains existing in aggregate obtained in individual crushing experiments with using of covers with various grooving, depends mostly on the shape of covers grooving. Most favourable results were obtained for plates with trapezoidal grooving with relatively low scale *t* and with comparative height of teeth *h/t* = 0,7. Moreover, content of irregular grains increases together with increase in width of outlet crack (when relation *h/e* diminishes, a range of teeth influence on crushing material downsizes). Results obtained in laboratory experiments confirmed industrial crushing conducted in jaw crusher with compound move of jaw. In industrial experiments there were investigated jaws with triangular grooving, showing significant level of wear, next brand new ones with triangular teeth with scale *t* = 25 mm and height *h* = 12,5 mm (*h/t*= 0,5), and finally jaws with trapezium grooves with scale *t* = 17 mm and with teeth of height *h* = 12 mm (*h/t* = 0,7). Figure 4 presents investigation results for jaw with circular (corrugated) covers (*h* = 6 mm, scale *t* = 25), for jaw with triangular grooving (*h* = 12,5 mm, scale *t* = 25 mm) and for trapezium jaws (h = 12 mm, *t* = 17 mm). Conditions of crushing process: graining of feed 10÷60 mm, jaw's jump *s* = 7,5 mm, width of outlet crack *e* = 8 mm.

Experiments results confirmed advantages of jaws with trapezium grooving. For these jaws the lowest contents of irregular grains were obtained.

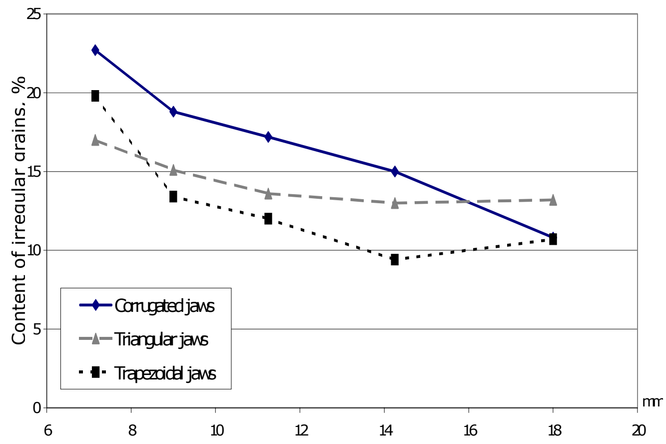


Figure 4. Content of irregular grains (flatness index, %) in various size grades of aggregates from L44.41 crusher, e = 8, *s* = 7,5, feed 10÷60 mm.

4 ANALYSIS OF CRUSHING FORCES FOR VARIOUS JAW COVERS

Crushing forces were measured during steady work of crusher, with using of extensometer placed on back of the plate of crusher and a computer with software registering course of crushing forces in time. Measure conditions: outlet crack e = 20 mm, revolutions: 320 min^{-1}, feed: 40÷63 mm, number of jaw's swings:100. Results are presented in Table 5.

Table 5. Results of measures of crushing forces for various materials in jaw crusher with variously grooved covers.

Type of jaw grooving	Crushed material	Average crushing force, [kN]		Maximum crushing force,[kN]	
		For material	For jaw	For material	For jaw
Trapezoidal	Lime-stone	6,4	6,2	64,3	57,1
Trapezoidal	Porphyry	6,5		62,5	
Trapezoidal	Diabase	5,6		44,6	
Triangular	Lime-stone	5,9	8,6	65,9	81,7
Triangular	Porphyry	11,4		107,0	
Triangular	Diabase	8,5		72,2	
Circular	Lime-stone	5,8	8,2	56,0	69,2
Circular	Porphyry	9,4		73,1	
Circular	Diabase	9,3		78,6	

Lowest crushing forces (averages and maximum values) occurred for trapezoidal jaws, while the highest – for triangular jaws (plain jaws were not investigated), now then material was easier comminuted when trapezoidal jaws were used. It has influence on decrease in both consumption of energy and the loading of crusher elements (jaws, bearing, and plate of crusher). Limestone was crushed the easiest, what is convergent with its relatively lowest durability qualities.

5 CONCLUSIONS

In crushing experiments there were investigated 7 pairs of jaws with various shape of crushing surface and with various dimensions of grooves. Jaws with following covers were investigated: plain, triangular, trapezoidal and circular. There were also used various grooving dimensions, namely a scale t and height of teeth h. Comminution efficiency was assessed by describing the size analysis of products and the content of irregular grains. There were also measured crushing forces. The size analysis was presented as a cumulative distribution function of size of grains in product. Shape of grains was described by presenting content of irregular grains in product determined by using Shultz's slide caliper (shape index) and crack sieves (flatness index).We can then denote following conclusions:

- The type of comminuted material has marginal influence on content of irregular grains in products. Greatest comminution stage appeared in crushing of limestone, while the lowest – in crushing of diabase. Above dependence is convergent with durability qualities of rock raw materials investigated.
- Grooving shape has essential influence on crushing stage and content of irregular grains in product. Most profitable jaws were with trapezoidal grooves. It is significant not only the shape of teeth, but also their height (relation h/t) and also a magnitude of scale t. Best results were obtained for jaws with congested trapezoidal grooves, with relatively lowest scale t and relation h/t = 0,7. Content of irregular grains described by flatness index was for trapezoidal jaws about 10% lower than for plain jaws. Shape index for jaws with congested trapezoidal teeth was about 30% lower than for plain ones. Positive influence of congested trapezoidal jaws on comminution effects results from the fact that these jaws have the longest line of transverse section and also have the most number of refraction points, where tensions during squeezing of materials accumulate.
- Width of outlet crack has noticeable influence on content of irregular grains in products. With increasing in width of outlet crack at fixed dimensions of grooves, content of irregular grains increases. In order to limit amount of irregular grains, the relation of teeth height to width of outlet crack should be possibly high (h/e about 0,7), while relation t/e should be comparable to one.
- Measures of crushing forces showed that material is comminuted easiest with using of jaws with trapezoidal grooving, while worst with using of triangular jaws (plain jaws were not investigated). For trapezoidal jaws lowest crushing forces were registered. Comparison of crushed materials shows that greatest crushing forces occurred in crushing of porphyry, and the lowest – in crushing of limestone. It corresponds with differences in squeezing durability and comminution immunity of investigated materials.

6 ACKNOWLEDGMENTS

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