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THE EFFECT OF THE WEAR DEGREE OF WORKING ELEMENTS IN A JAW CRUSHER ON THE OPERATING EFFECTIVENESS OF A TWO-STAGE GRANITE GRINDING SYSTEM

WPŁYW STOPNIA ZUŻYCIA ELEMENTÓW ROBOCZYCH KRUSZARKI SZCZĘKOWEJ NA EFEKTYWNOŚĆ EKSPLOATACYJNĄ UKŁADU DWUSTADIALNEGO ROZDRABNIANIA GRANITU

Key words: grinding, wear, mineral aggregates.

Abstract: The article presents an analysis of the influence of the wear degree of working elements in a jaw crusher on the crushing process and on the quality of the crushed material. The evaluation of the operating effectiveness of a technological system comprising two crushers was based on the quality indicator of the crushed product, i.e. on the share of irregular grains for a fraction with a mean grain size of 31.5/63 mm at each of the two stages of crushing. The wear degree was monitored by performing microscopic observations of the plates in the fixed jaw and by measuring the critical geometric characteristics of the crusher, e.g., tooth height, jaw size, and discharge opening size, during the entire service life of the crusher.

Słowa kluczowe: rozdrabnianie, zużycie, kruszywa mineralne.

Streszczenie: W artykule przedstawiono analizę wpływu stopnia zużycia elementów roboczych kruszarki szczękowej na przebieg procesu rozdrabniania oraz jakość uzyskiwanego surowca. Jako wyznacznik oceny efektywności pracy układu technologicznego dwóch kruszarek przyjęto wskaźnik jakości produktu rozdrabniania, tj. udział ziaren nieforemnych, dla frakcji o średniej wielkości 31,5/63 mm na każdym z dwóch stopni kruszenia. Stopień zużycia monitorowano, prowadząc obserwacje makroskopowe płyt szczęki stałej oraz wykonując pomiary krytycznych cech geometrycznych kruszarki – wysokości zębów oraz wielkości paszczy i szczeliny wylotowej w ciągu całego okresu ich eksploatacji.

INTRODUCTION

Jaw crushers are used for both coarse and fine grinding of rocks in extractive industry, and particularly in surface mining, in which crushing compact rocks and gravels is the basic technological operation. The working element responsible for grinding hard and large rocks comprises a pair of jaws which are either smooth or have a dedicated shape in the form of vertical grooves.

Jaws of an appropriate type and material allow the final product to have desired characteristics, such as, grain size and shape or the share of irregular grains **[L. 1]**. The effect of particular machines and technological systems on the results of crushing and processing mineral aggregates has been directly identified in numerous research projects, enabling manufacturers to produce aggregates of any predefined quality **[L. 2]**. Despite its random nature, which is, among other, things due to the

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varying characteristics and structures of rock raw materials, the grinding process is dependent on such parameters of grinding machines as the size of the discharge opening, the pressure actually reached, the number and shape of working elements, and their technical condition **[L. 3]**. This article focuses on the influence of the wear degree of working elements in a jaw crusher on the quality of the crushed material. Elements working in the jaw crusher are subjected to wear which can be described as impact fatigue and abrasion caused by the crushing of the feed material and its subsequent sliding towards the discharge **[L. 4**, **5]**.

The kinematic system of the jaw crusher comprises two jaws; one of them is fixed to the crusher frame and remains stationary with respect to the second moving jaw. The moving jaw, mounted to an eccentric shaft, performs a swinging movement, thereby crushing the feed introduced into the gap between the jaws by employing such crushing forces as compressive, percussive, abrasive, or breaking forces. Smooth surfaces of the jaws crush the feed material, while vertical grooves of the jaws facilitate its shearing or breaking. The system of two jaw surfaces forms an acute angle α, which is adjusted so as to prevent the material from being pushed upwards when the set angle is too high, and as to prevent the material from being extensively crushed when the angle is too low. The feed opening of the crusher, also referred to as the gape, determines the maximum grain size of the material to be crushed. The discharge opening, on the other hand, is also referred to as the sizing gap. Its size translates into the size of grain obtained in the crushing process **[L. 6**, **7]**. The grain sizes depend not only on the geometry of the crusher and the type of the working elements, but also on their wear degree, which increases together with the operating time.

The commonly appreciated advantages of jaw crushers include high capacity and simple design, as well as the ability to significantly reduce the grain size of the crushed material and to crush large size rocks **[L. 8–11]**. Macroscopic observations and measurements of the critical geometric characteristics of jaw crushers during their operation are fundamental procedures for improving the reliability and extending the service life of the working elements, and thus for satisfying the demands of the growing road construction and housing industries **[L. 12, 13]**.

RESEARCH OBJECT AND METHODOLOGY

This article presents an analysis of the crushing process at the Siedlimowice granite pit, which involves two stages: primary crushing in an R-120 jaw crusher and secondary crushing in an HP 400 cone crusher. The objective of the research was to identify how the changing shape of the jaw in a jaw crusher influences the efficiency of the granite crushing process.

The R-120 crusher used in the primary crushing process is fitted with a pair of jaws having deep semi-rounded sharp-ended tooth profile made of Hadfield steel, with one of the jaws being stationary. The secondary crushing process was performed in the HP 400 cone crusher, which comprises an inner cone located inside an outer cone. The operation of a cone crusher depends on the quality of the grinding process in the jaw crusher. The grain size of the material fed into the cone crusher determines the amount of energy required to further grind the feed material and, as such, accounts for the power consumption level at the secondary crushing stage. On the other hand, the size of the aggregate depends on the size of the discharge opening in the jaw crusher of the primary stage, and thus results directly from the wear degree of the crushing teeth.

The parameters recorded during tests of the granite crushing process in the R-120 jaw crusher and in the HP400 cone crusher included the following:

- The size of the feed opening “b” and the discharge opening “a” in the R-120 jaw crusher,
- The tooth height in the upper plate of the fixed jaw “h1” and in the lower plate of the fixed jaw “h2”,
- The power consumption of both crushers, and
- Laboratory tests of the material obtained from both primary and secondary crushing.

The measurements and observations were performed for the liners of the fixed jaw in a jaw crusher operated at the Siedlimowice granite pit within the period of 3 months from July 23, 2018, i.e. the day when the fixed jaw was installed, to October 19, 2018, i.e. one day before the jaw was uninstalled. The measurements were performed at analogical time intervals.

The laboratory tests were aimed mainly at identifying the quality of the aggregate, which determines its application scope and manner **[L. 14]**. The research works included identifying

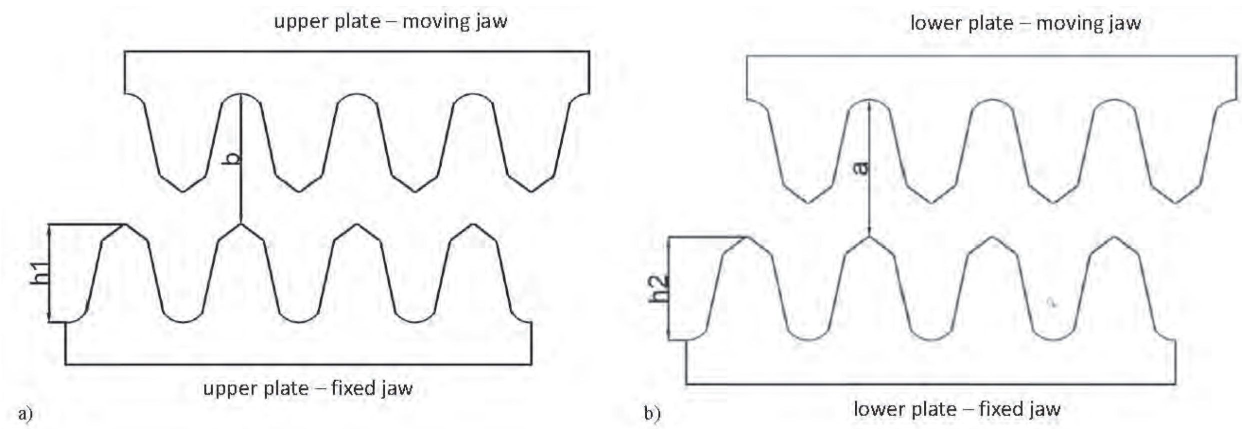

Fig. 1. Measurement methodology for the individual parameters: a) crusher gape (upper plate), b) crusher discharge opening (lower plate)

Rys. 1. Metodyka pomiaru poszczególnych parametrów: a) paszczy kruszarki (płyta górna), b) szczeliny kruszarki (płyta dolna)

the grain size distribution and the cubical shape of the material at both crushing stages, in accordance with PN-EN 933-1:2012 and PN-EN 13383-2:2003, and using sets of standardized laboratory sieves and the shape index gauge. The shape index, i.e. the percentage share of the mass of irregular grains in the analysed sample, was calculated for the mean grain size of 31.5/63 mm, which is optimal for observing changes caused by wear of crusher jaws, according to the following equation (1):

$$SI = \frac{M_2}{M_1} \cdot 100\% \tag{1}$$

M_1 – mass of the analyzed sample;

M_2 – mass of irregular grains, where an irregular grain is classified as each grain having the ratio of its length L (maximum distance between two grain planes parallel to each other) and thickness E (minimum distance between two parallel grain plates) is greater than 3.

RESULTS

Macroscopic observations were performed on the surfaces of the liners in the fixed jaw from the day when they were introduced into service (**Fig. 2**) to the day when they were withdrawn from service (**Fig. 4d**). **Figures 3a–b** and **4a–d** show increasing abrasive wear of the fixed jaw in the successive days of its service. In the initial phase, the teeth lost their semi-sharp profile, as the ends became rounded (**Fig. 3a–b**). Starting on day 29, the wear rate decreased for the outermost teeth. This tendency continued for the rest of the service life. On day 44, the plates were covered with numerous surface discontinuities, which took the form of cracks, fissures, and cavities, while the teeth in the area of the discharge opening lost their profile completely. In order to extend the service life of the fixed jaw, the positions of the upper plate in the crusher gape (with tooth height reduced by 32.9%) and of the lower plate in the discharge opening (with tooth height reduced by 88.2%) were reversed. Finally, after 89 days of service, and after 46 days since the repositioning of the plates, the fixed jaw was uninstalled as not fit for further operation. As the plates were repositioned, the teeth were completely worn due to abrasion in both the feed gape and the discharge opening. The least extensive wear was observed on the outermost teeth, which were largely not involved in the grinding process due to the cheek plates which limited the work area. The central teeth in the jaws are subjected to significantly higher compressive, abrasive, and percussive loads as the feed system is located centrally. Therefore, with completely worn central areas, the working elements were withdrawn from further service.

Table 1 shows the measurement results for individual geometric parameters of the pair of liners presented schematically in **Fig. 1**. After 15 days of service, the most extensive wear was observed on the lower plate, in which the tooth height was reduced by 50.6%. Eventually, the size of the opening “a” after 89 days of service increased by 43.2% of the original size, while the size of the gape “b” increased by 8.9% of the original size. In order to extend the service life of the liner in

Fig. 2. General view of the newly installed fixed jaw on the first day of service (to the right)
Rys. 2. Widok ogólny nowo zamontowanej szczęki stałej w pierwszym dniu eksploatacji (z prawej)

the fixed jaw, the positions of the lower plate and of the upper plate were reversed on September 4, 2018. At that moment, the teeth in the feed gape were smaller by 88.2% with respect to the original value, while the teeth in the discharge opening – by 32.9%. **Figure 5a** shows the relative height change of the teeth in the lower plate "h2" and in the upper plate "h1" with respect to the original value, while **Fig. 5** shows the relative size change of the feed gape "b" and of the discharge opening "a". The greatest reduction in the height of the teeth in the lower plate, and at the same time the greatest increase in the size of the discharge opening, was observed during the first 29 days of service.

The laboratory analysis was aimed at demonstrating the relationship between the wear degree of the fixed jaw and the amount of irregular grains (**Fig. 6**). Together with increasing operating time within the period from August 6 to September 3, 2018, the value of the shape index decreased in both the primary and the secondary crushing stage (**Table 2**). After the position of the lower plate was reversed with the position of the less worn upper plate, the shape index value increased, and subsequently decreased gradually with the operating time until the liner was uninstalled. The high value of the shape index observed after the fixed jaw was installed and later repositioned indicates that the more limited the wear degree of the fixed jaw in the area of the feed gape, the higher shape index value can be obtained for the aggregate leaving both the primary and the secondary crusher.

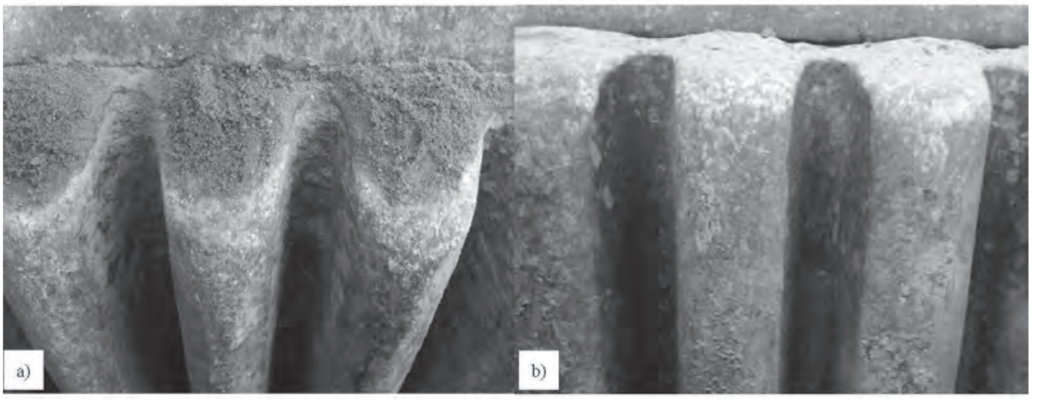

Fig. 3. General view of the teeth in the plate of the fixed jaw after: a) 15, b) 29 days of service
Rys. 3. Widok ogólny zębów płyty szczęki stałej: a) 15, b) 29 dnia eksploatacji

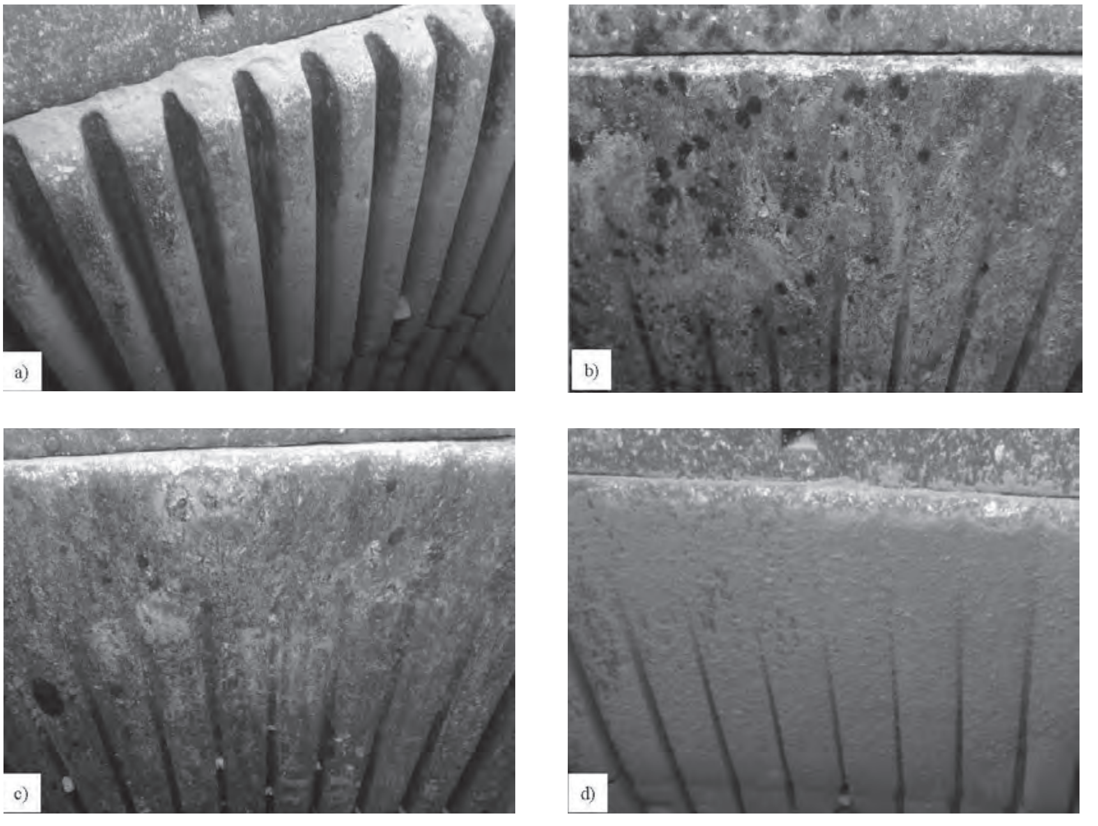

Fig. 4. General view of the upper plate in the fixed jaw after: a) 29, b) 44, c) 57, d) 89 days of service
Rys. 4. Widok ogólny płyty górnej szczęki stałej: a) 29, b) 44, c) 57, d) 89 dnia eksploatacji

The measurements also covered the power consumption by each of the crushers within the service life of the fixed jaw in the R-120 crusher. The power consumption of the cone crusher is higher than that of the jaw crusher in each measurement point. No relationship was observed between the

Table 1. Measured geometric parameters of the jaw crusher and their percentage change relative to the original value
Tabela 1. Wyniki pomiarów parametrów geometrycznych kruszarki szczękowej oraz ich procentowana zmiana względem wartości początkowej

Date of measurement	Jaw day of service	Size of opening "a"		Size of gape "b"		Teeth height in the upper plate "h1"		Teeth height in the lower plate "h2"	
		[mm]	[%]**	[mm]	[%]**	[mm]	[%]**	[mm]	[%]**
23.07.2018	1	190	0.0	910	0.0	85	0.0	85	0.0
06.08.2018	15	233	22.6	916	0.7	79	7.1	42	50.6
20.08.2018	29	256	34.7	922	1.3	75	11.8	19	77.6
04.09.2018*	44	265	39.5	940	3.3	57	32.9	10	88.2
17.09.2018	57	270	42.1	950	4.4	48	43.5	5	94.1
01.10.2018	71	270	42.1	969	6.5	25	70.6	0	100.0
19.10.2018	89	272	43.2	991	8.9	3	96.5	0	100.0

* The day when the upper plate and the lower plate were repositioned in order to extend the service life of the fixed jaw.

** Parameter change relative to the original value.

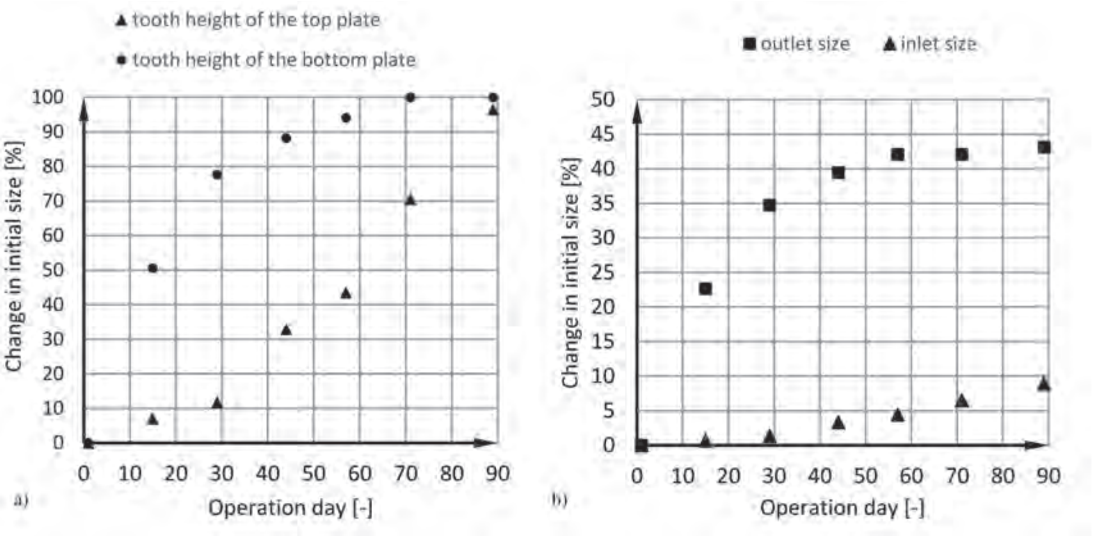

Fig. 5. Relationship between service time of the fixed jaw and: a) change of teeth height, b) change of feed gape size and of discharge opening size

Rys. 5. Zależność zmiany: a) wysokości zębów w czasie eksploatacji szczęki stałej, b) wielkości rozmiaru paszczy oraz szczeliny w czasie eksploatacji szczęki stałej

power consumption level at the primary crushing stage and the wear degree of the plates in the fixed jaw, the number of machine-hours, or the tonnage. The power consumption depends to the greatest extent on the amount and size of feed material, as well as on the stability and continuity of the feeding process. In the case of the cone crusher, the power consumption is also affected by factors which are further dependent on the size of the discharge opening in the primary jaw crusher, i.e. on the size of the crushed product. The larger the size of the opening in the jaw crusher, the larger the size of the feed to the cone crusher, and therefore, the more power is needed to grind it, as is illustrated in **Fig. 7**.

Table 2. Results of laboratory measurements and calculation of the shape index according to PN-EN 933-1:2012 for the primary and secondary crushing stage

Tabela 2. Wyniki pomiarów laboratoryjnych oraz obliczeń wskaźnika kształtu zgodnie z normą PN-EN 933-1:2012 dla pierwszego oraz drugiego etapu kruszenia

Date of measurement	I crushing stage			II crushing stage		
	Mass of the analysed sample 31.5/63 mm M_1	Mass of irregular grains in the analysed sample M_2	Shape index *SI*	Mass of the analysed sample 31.5/63 mm M_1	Mass of irregular grains in the analysed sample M_2	Shape index *SI*
	[g]	[g]	[%]	[g]	[g]	[%]
06.08.2018	4280.8	1540.2	35.98	35953.8	8952.5	24.90
20.08.2018	4467.9	1028.5	23.02	23029.4	3321.2	14.42
04.09.2018	7151.8	3434.2	48.02	10651.6	2907.7	27.30
17.09.2018	5679.2	2110.9	37.17	8577.4	2044.9	23.84
01.10.2018	12482.2	4051.7	32.46	13112.8	1977.4	15.08
19.10.2018	14176.8	4052.7	28.59	32378.9	3787.6	11.70

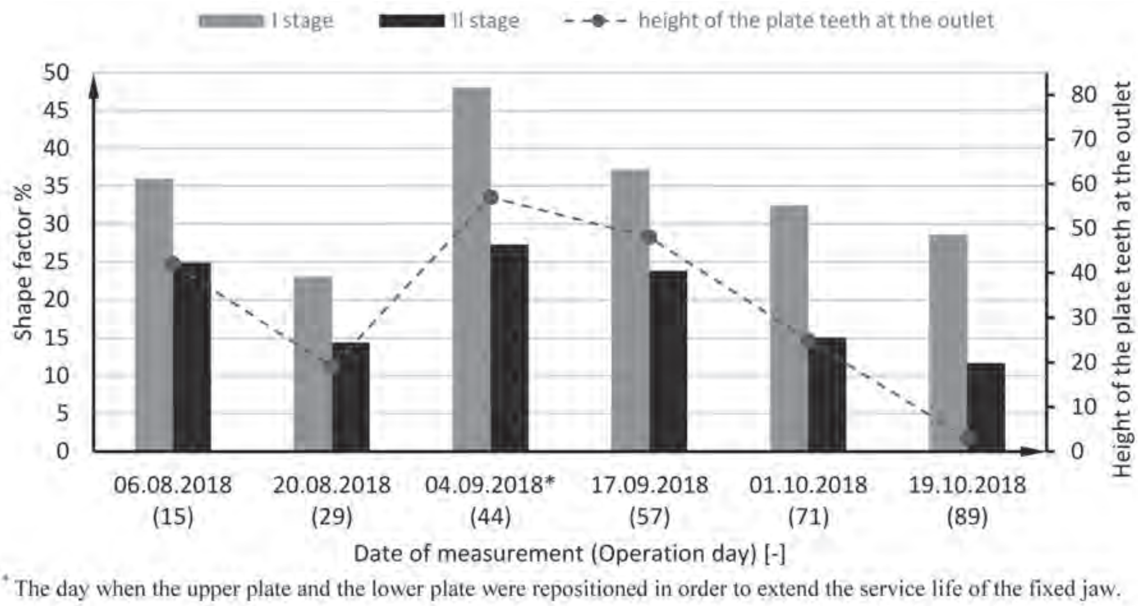

Fig. 6. Shape index for the primary and secondary crushing stage relative to the height of the plate teeth in the discharge opening of the jaw crusher

Rys. 6. Wskaźnik kształtu dla I i II etapu kruszenia względem wysokości zębów płyty w szczelinie kruszarki szczękowej

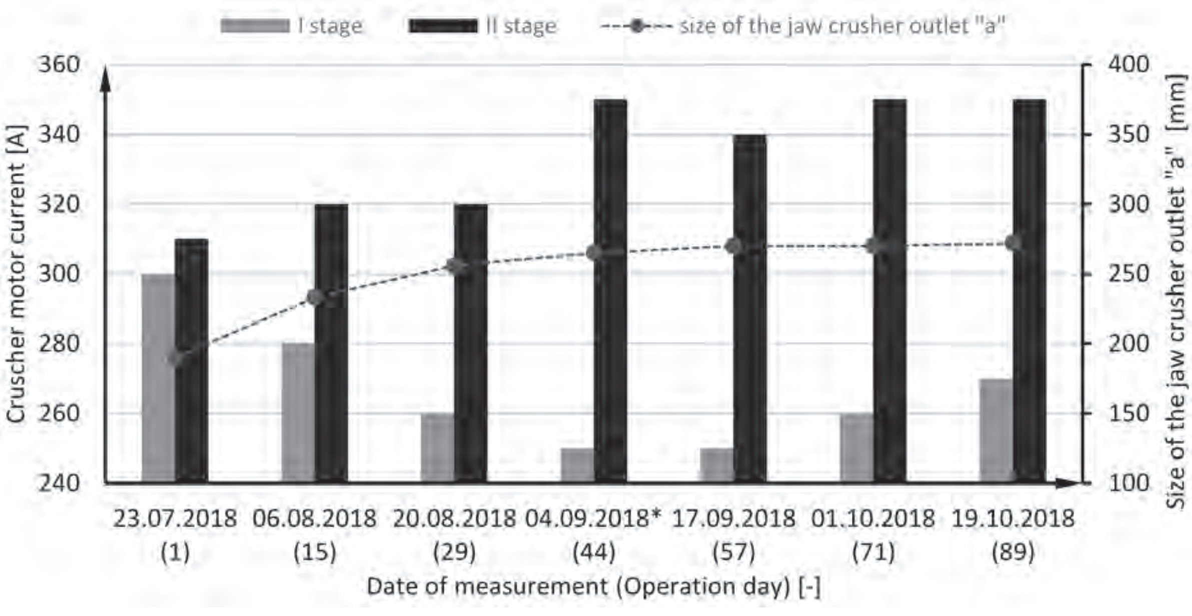

Fig. 7. Power consumption of the two crushers and the size of the opening "a" in the jaw crusher during successive days of service

Rys. 7. Pobór prądu obu kruszarek oraz wielkość szczeliny „a" kruszarki szczękowej w kolejnych dniach eksploatacji

DISCUSSION AND CONCLUSIONS

The research here presented allows a conclusion that an increasing abrasive wear of the working elements in the jaw crusher has a direct influence on the decreasing quality of the aggregate produced at both the primary and the secondary crushing stage in a technological system comprising two crushers: a jaw crusher and a cone crusher. The lowest quality of the aggregate was observed for the analysed grain size on August 20, 2018, i.e. after the fixed jaw had been in operation for 29 days and after the height of the teeth in the lower plate was reduced by 77.6%. Reversing the positions of the less worn upper plate with the lower plate is an advantageous technological procedure which improves the quality of the product and extends the service life of the jaw. The geometric measurements and quality tests indicate that the share of irregular grains is mostly influenced by the wear degree of the teeth in the discharge opening of the crusher. Moreover, the increasing size of the discharge opening causes the product of primary crushing to have a larger grain size, which is the reason for the ultimately higher power demand of a cone crusher, required to ensure appropriate crushing forces.

The research described in this article successfully used the identified share of irregular grains in the mean grain size of 31.5/63 mm over the successive service days for a system comprising two crushing units to serve as an indicator of the need for changes in the crusher operating settings. Laboratory analysis may be thus used to indirectly control indicators of the wear degree of working elements in crushers.

Further research on improving the materials for plates used in the working elements of jaw crushers should focus not only on extending their service life and limiting the processes of abrasive wear, but also on maintaining a stable teeth profile. The deteriorating profile of the working elements affects the processes of shearing and breaking of the crushed material and directly influences the quality of the aggregate.

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