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Influence of Natural Aggregate Crushing Process on Crushing Strength Index

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Abstract: Crushing is one of the most energy-consuming technological processes. The purpose of grinding is to achieve the desired grain size of mineral raw materials. The process of grinding consists of many factors, for example, the size and form of crushed grains, as well as their mutual arrangement inside the crushing machine chamber, the technological parameters of the crusher, the material properties, and the speed of the moving grains. One of the key parameters of the aggregate is its resistance to grinding. Resistance to grinding is related to the strength of the products made from aggregates subjected to grinding, which affects the overall quality of these products. Therefore, the aim of this study is to analyze the impact of the crushing of natural aggregate on the LA crumbling strength index. Two types of aggregates were analyzed—natural gravel and natural pebbles crushed in a crusher. Aggregates were acquired from two mines belonging to the plant Kruszgeo S.A. in Rzeszów, i.e., ZEK (Zakład Eksploatacji Kruszywa) Ostrów and ZEK Strzegocice II. The aggregate crushing process was carried out for 4–8 mm and 10–14 mm fractions using cone crushers of the 1044 type. Aggregate crushing was carried out in a Los Angeles drum, in accordance with the requirements of EN 1097-2:2020. The analysis showed that for grits of the 10–14 mm fraction, the lower values of the LA indices were obtained, which allows for obtaining a bigger index of crushing strength than in the case of crushing using the 4–8 mm fraction. This analysis showed how important the process of grinding aggregates is and, thus, the appropriate selection of fractions for the grit crushing process for the aggregate strength on grinding. Subjecting the aggregate to the grinding process results in an improvement in the crushing strength indicator, thus obtaining better strength parameters of the products manufactured from the aggregates subjected to the process of crushing (for example, concrete). The originality of the study is an analysis of key Polish aggregates and the crushing strength index.

Keywords: crushing; strength index; natural aggregate; mechanical engineering

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1. Introduction

Aggregates are an essential element in the development of infrastructure and contribute to our current standard of living, and maintaining this standard will require a huge amount of aggregates. The sustainability of aggregate production is linked to the solution of complex environmental, social and societal issues associated with the exploration, mining, processing, transportation and recycling of aggregated resources and the reclamation of mined-out aggregate deposits [1]. It is, therefore, necessary to research the processes involved in the production of aggregates. By researching these processes, where crushing processes play a very important role in terms of the final quality of aggregates, it is possible to achieve optimization of aggregate production and, thus, achieve a long-term sustainable supply of aggregates in the required quantities.

Crushing processes are applicable in various fields of raw material processing, where the activities are carried out depending on which mineral aggregates with a predetermined grain size are obtained or depending on which material is being brought to the state when the usable ingredient is released from the gangue. The purpose of crushing is to achieve the required grain size of the mineral raw materials. This process is complex and depends on many factors, including the size and form of the grains to be crushed, their mutual arrangement in the crushing chamber of the machine, the technological parameters of the crusher, the physicochemical properties of the material, the trajectory and speed of grain movement. Crushing processes are particularly important for enterprises of building and road areas because due to the crushing process, it is possible to achieve the high-quality aggregates desired by the customers [2–5].

Crushing is one of the most energy-consuming technological processes. The energy intensity of aggregate crushing is initially positively or negatively affected by the result of blasting [6]. The significant effects of blasting on crushing and grinding are the increased production through higher output and fewer delays due to bridging and jamming as a result of oversized products. Moreover, fragmentation is better suited to the crushing and grinding system, as it reduces energy consumption by these activities [7]. Therefore, it is important to carry out research into the influence of blasting parameters on the required fragmentation of the raw material and take the research results into account when designing blasting.

The selection of a suitable crusher also significantly impacts the energy consumption of crushing [8,9]. By selecting a suitable crusher, in addition to energy saving, it is also possible to achieve the required output quality of the aggregate in terms of the production program [10]. At the same time, some research is attempting to determine a method that would make it possible to predict the energy consumption of the crushing process [11]. The type of crusher can play a very important role in the production of aggregates with different shape parameters. The type of crusher, together with the types of rocks and mineralogical compositions, mainly influences the shape characteristics of the aggregate, especially the angularity and the shape of 2D [12]. Crusher settings also have a significant impact on energy consumption and aggregate quality. Research in this area shows that significant gains can be made both in terms of product yield and in terms of overall capacity by adjusting the operation of the crusher according to the conditions available [13]. At present, therefore, efforts are focused on optimizing the yield and increasing the capacity of crushing plants. Qualitative aspects of production depend on process optimization [14]. Many parameters affect product quality and production capacity. Optimization software must be used to control these parameters [15]. The design of a crushing plant by only relying on steady-state simulations will not generally provide the complete picture of the possible operating performance. The dynamics and variation between the equipment and stochastic events can significantly reduce predicted plant performance [16].

For this reason, it is necessary to use dynamic simulations of the crushing circuit using models of process equipment [17]. For optimal process control, it is then appropriate to use automated control systems. The complex automated system should provide an optimal level of automation for information collection and processing to form control signals and transfer them without loss and distortion to actuators in order to achieve efficient operation of the technological line for the crushing and screening plant [18].

To effectively control the crushing process, it is also very important to know the influence of the composition and properties of rocks on this process. Therefore, several studies address this issue, with the aim of achieving such control of the crushing process that will enable an efficient production of aggregates with the required properties. From these many studies of the influence of rock properties on their crushing and the resulting properties, it is possible to mention, e.g., research dealing with the study of rock crushability [19,20]; other research deals with the influence of rock composition, as well as the shape, texture and grain properties of rocks [21–25]. Many research tasks are currently also focused on the possibilities of replacing natural aggregates with recycled ones, comparing their properties and assessing their impact on the resulting properties of the final products [26–29]. In this context, the environmental aspects of their use are also assessed [30–32].

The development of the building industry as well as the road industry caused demand for broken aggregates, which are produced from high-quality rock raw materials, to increase significantly [33]. Various types of aggregates are used for the production of, e.g., concrete or mortar, and in the road industry for, e.g., the production of road surfaces. Portland and asphalt cement concrete mixes generally contain 75 to 85% by volume of aggregates. The quality of the aggregates is therefore of considerable importance in determining their suitability for any particular technical use [34]. This is why the method of carrying out the crushing process is so important, as well as the selection of the appropriate type of crushing, the selection of fractions for the type of aggregates and the desired quality requirements of the final product. Aggregates that have a low resistance to degradation can cause many problems for both Portland cement concrete and hot mix asphalt. The abrasive force of wheels can change the properties of the road and cause early failure of the pavement through consolidation, cracking, polishing and other problems [35].

The Los Angeles abrasion value test is the most widely used method for measuring aggregate resistance to abrasion. The test measures the resistance of an aggregate to wear due to attrition between rock particles and also to impact and crushing by steel spheres [36]. Other possible tests to assess the degradation of the aggregate may be the aggregate crushing value and aggregate impact value. The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact [37]. It is recommended [38] to use a combination of these three tests to assess the toughness/abrasion resistance of the aggregate.

The choice of topic for this study was influenced by the possibility of obtaining better strength parameters of the products manufactured from aggregates. Moreover, the quality of the product and the reduction of waste from production are important in sustainable product development [39–43]. The motivation was a lack of analysis and a need to determine the influence of the natural crushing process for key Polish aggregates on the crushing strength index. Additionally, another aim was to extend the current state of knowledge concerning aggregate abrasion based on the main Los Angeles index, whose verification is contained only in a few studies.

The aim of this study was to analyze the impact of the crushing of natural aggregate on the LA crumbling strength index. Two types of aggregates were analyzed—natural gravel and natural pebbles—crushed in a crusher. Aggregates were acquired from two mines belonging to the plant Kruszgeo S.A. in Rzeszów, i.e., ZEK (Zakład Eksploatacji Kruszywa) Ostrów and ZEK Strzegocice II. The Kruszgeo S.A., which is the largest producer of building aggregate, is in southeastern Poland [44].

The originality of the study is the presentation of the parameters of the crushing process and indices of crushing strength for key aggregates used in the construction industry in Poland, which have not been analyzed to date.

2. Literature Review

A review of the literature indicates that the process of crushing natural aggregate on the crushing index was analyzed. However, these analyses did not include the parameters selected for verification in this study. Several studies have looked at the effect of rock properties on abrasion resistance, as well as the correlation between the Los Angeles abrasion value test, aggregate crushing value, aggregate impact value, and rock properties [45–52]. These studies have shown that if we have one of these values determined by the test, it is possible to estimate another two related values based on the known correlations. The next example is article [53], in which dependence between the mechanical and geometric properties of aggregates was verified, i.e., aggregate (arches and mixtures) produced from sands of layers of Magura or Cergo. An analysis was carried out for dependence between the Los Angeles index, Micro-Deval index, and flatness and shape indicators. Moreover, in article [54], experimental research about the physical and mechanical properties of aggregate was described, i.e., phyllite and granite (conventional) aggregate concrete. The properties of the Los Angeles abrasion, water absorption, dry density, and aggregate impact value were analyzed. The sieve size was equal to 12 and 19 mm, and the aggregate size distribution was in the range of 5–20 mm. In turn, in article [55], it was shown that the Los Angeles index for gravel and tensile strength depends on the porosity of the concrete and granular mixture. For fraction < 2 mm, the natural gravel, thick natural gravel, and sand were verified. Another example is Reference [56], where the assessment of the possibility of predicting the degradation of Iranian carbonate aggregates was carried out. The strength tests of rocks and the dependencies between the properties of aggregate were realized. The properties of aggregate degradation by the Los Angeles index were obtained. Class B aggregate with a total weight of 5000 $\times$ 10 g for each sample was used. After 500 rotations, the weight loss of aggregates thicker than the mesh size from the 1.7 mm sieve was about 1 g. It was shown that it is possible to predict each range of aggregate degradation. In turn, in References [57,58], coarse aggregate was analyzed to determine the compressive strength of concrete. It was shown that the higher the Los Angeles (LAA) value, the lower the compressive strength of the concrete. In articles [59–61], fine granite, porphyrite, and quartzites were analyzed. The crumble strength of the aggregate was analyzed, e.g., the aggregate abrasion by the Los Angeles index (sieve 1.7 mm). Based on the LAA (25.22–34.55%) it was shown that granite has a good strength and hardness with a greater wear resistance. A similar analysis for the mentioned aggregates was carried out by the authors of article [62], in which the value of the Los Angeles index was achieved equal to 17.4–29.8%.

It was concluded that the research in the field of aggregates and their abrasion is still an open topic. The current state of knowledge includes a few studies in which there is still a search for different solutions to increase the quality of these products. It was also concluded that the impact of the natural aggregate crushing process on the crushing strength index with the parameters presented in this study was not analyzed. It was considered necessary to conduct an analysis on the aggregate mined in Poland. This resulted from the fact that the properties of concrete and other aggregate-based materials strongly depend on the properties of the aggregates obtained by the crushing process. Therefore, it is advisable to conduct research in this area. These analyses will allow an expansion in the information base regarding the quality of aggregates and other products derived from them.

3. Materials

Natural gravel aggregate and natural aggregate crushed from pebbles crushed in a crusher were examined (Figure 1).

The natural gravel aggregates from ZEK Ostrów that were analyzed were aggregates with a grain size of 2–8 mm and 8–16 mm. The material was determined as loose sedimentary rock in the form of grains, which is a combination of few minerals. It was characterized by high permeability with a good drainage of water. Additionally, gravel has relatively good adhesion to other components of the mortar. This material was taken from quaternary sedimentary rocks. Grains were characterized by the revolutions of the silica sandstones of the Carpathian flysch, as well as Magura sandstones with glauconite and sandstones with a silica binder with quartz grains and horn stones. The rocks were dominated by rocks such as quartz, feldspar, glauconite, and mica. The surface of the vast majority of grains was smooth or damp and slightly porous. This material is used in the production of concrete mixtures and prefabricates, generally for road and hydrotechnical construction. The majority of the aggregates were regular with different shapes (Figure 1c).

Natural gravel aggregates that came from ZEK Strzegocice II were well-sorted aggregates with a grain size of 2–8 mm and 8–16 mm, and they also originated from Quaternary sedimentary rock. Grains were well-weathered siliceous Carpathian sandstones, as well as silica sandstones that were colored with iron oxides. It was a loose sedimentary rock that was a combination of several materials. Few aggregates were characterized by good white grains of quartz, brown horn, and rough creamy sandstones. The aggregate was dominated by rocks: quartz, feldspar, mica, and glauconite. The surface of most grains of the aggregate was smooth or coated rough and slightly porous. Consequently, gravel has good adhesion to other components of the mortar. Moreover, this material has high water permeability. As in the case of the aforementioned material, it has applications in the production of concrete mixtures and prefabricates, generally for road and hydrotechnical construction. The grains were characterized by different shapes with a rather flat surface (Figure 1a).

The second type of aggregates from the Ostrów mine and the Strzegocice II mine that were subjected to examination were natural aggregates crushed in a cone crusher with a grain size of 2–8 mm and 8–16 mm (Figure 1b,d), which were obtained from larger pebbles with a grain size above 16 mm. The aggregates of this kind, from both plants, were characterized mostly by grains with sharp edges that resulted from crushing. These properties allow the grains to wedge well. Therefore, its application allows one to obtain a stable surface not very susceptible to rinsing. The origin and type of the dominant minerals were the same as in the case of the natural gravel aggregates. The difference was the aggregate grains. At the ZEK Ostrów plant, the aggregate was elongated, ellipsoid, partially rounded or flat. However, in ZEK Strzegocice II, the aggregate grains were elongated and flat.

Figure 1. Examples of natural gravel and grit aggregates: (**a**) gravel 2–8 mm from ZEK Strzegocice II, (**b**) grit 2–8 mm from ZEK Strzegocice II, (**c**) gravel 8–16 mm from ZEK Ostrów, and (**d**) grit 8–16 mm from ZEK Ostrów. Own study based on [44].

4. Methods

The crushing process was carried out in cone crushers type 1044, which are intended for the crushing of hard materials and rocks, e.g., granite, limestone, slate, basalt, flint, and sandstone, as well as other materials, if they are not contaminated with clay or loam.

The maximum size of crushed material is 160 mm (at the entrance to the crusher), and the range of the gap size adjustment ranges from 15 to 60 mm. Crushers of this type are used for the direct crushing of raw material in order to obtain the desired granulation or for the initial crushing, which precedes the further processing of the material.

Aggregate crushing was carried out in a Los Angeles drum, in accordance with the requirements of EN 1097-2:2020 [16]. Sieves with mesh sizes 10, 14, and 1.6 mm were used, and the material was weighed with an accuracy of 0.01 g.

In the first stage of the test, the grinding material was prepared by drying it at 105 °C to obtain its constant mass. In order to obtain a fraction of 10–14 mm and a fraction of 4–8 mm, the aggregates were sieved through the testing sieves. The 10–14 mm fractions and the 4–8 mm fractions were mixed separately to obtain modified grain sizes. In the Los Angeles drum, during the first crushing process, mixed fractions of 10–14 mm were placed along with 12 balls for the crushing of the aggregate, while in the second crushing process, mixed fractions from the range of 4–8 mm were placed along with 8 balls.

In the first and second shredding process, the drum performed 500 turns at a constant speed of 31 to 33 rotations per minute. After the shredding process was completed, the aggregate was sieved through a sieve with a 1.6 mm mesh size. The sieved material was weighed, and the Los Angeles coefficient (LA) was calculated; this determines the part of the mass of the analytical sample (used in a single test), expressed as a percentage, which is sieved through a 1.6 mm sieve (1).

$$LA = \frac{500 \times m}{50} \quad (1)$$

where m is the mass of material that remains on the 1.6 mm sieve, expressed in grams.

5. Results

5.1. Characteristics of Selected Facilities of Kruszgeo S.A.

The Kruszgeo S.A. company is the largest producer of building aggregate in southeastern Poland. Zakłady Eksploatacji Kruszywa, belonging to Kruszgeo S.A., extracts natural aggregates and produces sorted sands and gravels used in building and road construction. The aggregate extraction is carried out by 26 Zakłady Eksploatacji Kruszywa (ZEK), which is located in the Podkarpackie and Małopolskie voivodships, including ZEK Ostrów and ZEK Strzegocice II (Figure 2).

(**a**)

(**b**)

Figure 2. Picture of an extraction band: (**a**) ZEK Ostrów and (**b**) ZEK Strzegocice II. Own study based on [44].

In ZEK Ostrów, which is located nearby the Przemyśl, the basic assortment consists of washed sands and gravels, as well as crushed grits and broken sands resulting from the crushing of over-grain. In addition, natural aggregates from the deposit and aggregates left after the production process as over-grains are produced and sold at the plant.

The aggregate production processes at the Kruszgeo plants are constantly improving, and, therefore, these aggregates are considered the highest quality among the aggregates available on the market.

5.2. Analysis of the Influence of a Production Process on the Aggregate Crushing Strength Index

The results of the LA indices of crushing strength were analyzed from the period 2011–2017 for two plants—ZEK Ostrów and ZEK Strzegocice II. The indicators were ordered due to the type of fraction, i.e., 10–14 mm and 4–8 mm, grouping them into gravel and grits separately for both plants.

Depending on the type of aggregate, the LA index values for the crushing strength of the 10–14 mm fraction in ZEK Ostrów (Table 1) were characterized by large differences between the values for gravel and grit.

Table 1. LA index of crushing strength of aggregates with a fraction of 10–14 mm in ZEK Ostrów, (source: produced by authors).

		ZEK Ostrów	
Fraction	**Test Date**	**Gravel**	**Grits**
10–14 mm	VI 2011	30	25
	XI 2011	27	24
	VI 2012	29	24
	XI 2012	28	24
	VI 2013	28	24
	XII 2013	30	24
	VI 2014	30	24
	XII 2014	29	25
	VI 2015	29	24
	XII 2015	29	23
	VI 2016	30	24
	XII 2016	31	24
	VI 2017	31	24
	XII 2017	29	24

In Figure 3, differences in the LA index values for two aggregates can be noticed; in the case of gravel, the LA index values were obtained ranging from 27 to 31%, while for grit, they ranged from 23 to 25%. Differences between LA index values between the two aggregates were in the range from 3 to 7%. The LA index values of the analyzed aggregates were large. It was concluded that over the analyzed years for the 10–14 mm fraction, the grits have more stable values of the LA indicator, i.e., an average of 24%. The LA indicator for gravel was less stable, i.e., an average of 29%. The cause of the difference between the examined aggregates resulted from porosity, where aggregate with low porosity (in this example, grits) is characterized by a greater resistance to crushing. Moreover, these changes resulted from the shape and form of the aggregate.

As before, for the 10–14 mm fraction and for the same type of aggregates (gravel and grit), the LA index values of crushing were analyzed in the second plant ZEK Strzegocice II (Table 2).

It was noticed that the LA index values for grits and gravel, as in the case of ZEK Ostrów, differ significantly (Figure 4). In the case of grits, LA values ranged from 23 to 25%, where the most frequent value was 24%, while for gravel, these values ranged from 29 to 34% of the LA index. The LA index values for the analyzed aggregates were large. It was considered that for this fraction (10–14 mm) in the analyzed years, the grits had a more stable LA indicator, i.e., an average of 24%. The indicator of LA for the gravel was less stable, i.e., an average of 29%. It was noticed that there was no significant difference between the LA indicators for the analysis materials in the fraction equal to 10–14 mm.

Moreover, it was concluded, as before, that aggregate with low porosity is characterized by a greater resistance to crushing and that the shape and form of the aggregate were also significant.

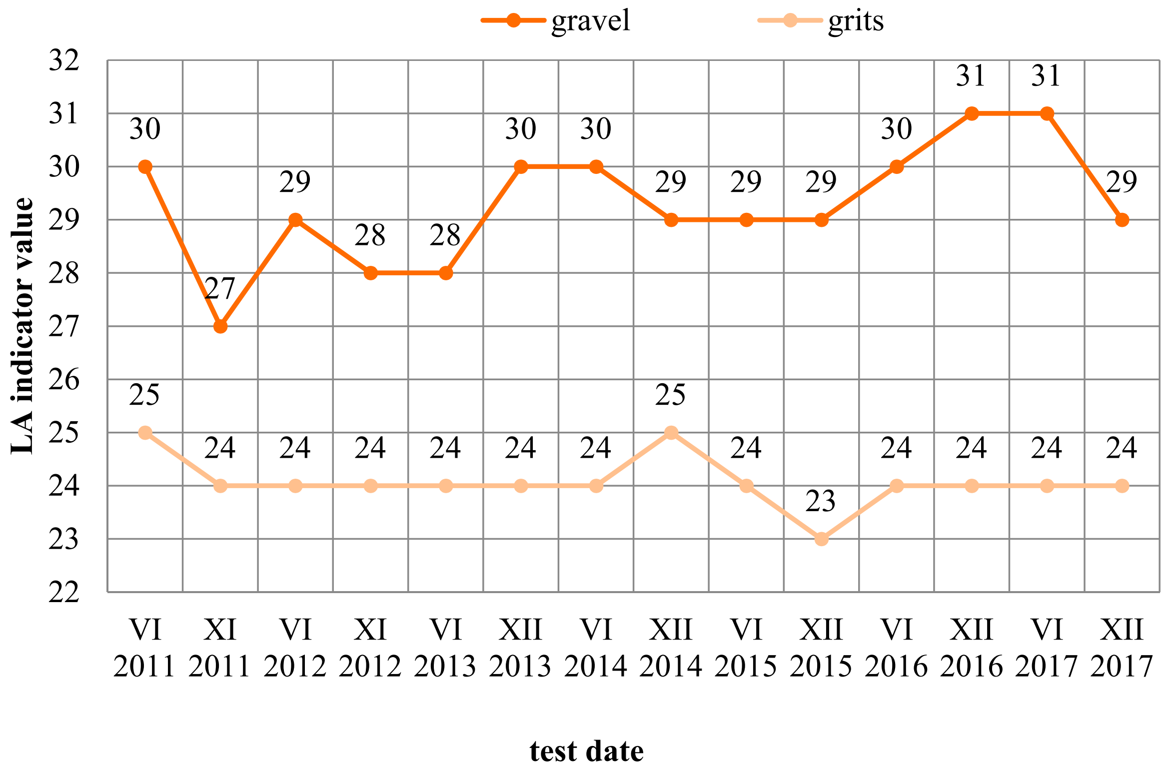

Figure 3. LA index value for gravel and grit at fraction 10–14 mm for aggregates from ZEK Ostrów. Own study based on [44].

Table 2. LA index of crushing strength of aggregates with a fraction of 10–14 mm in ZEK Strzegocice II (source: produced by authors).

		ZEK Strzegocice II	
Fraction	**Test Date**	**Gravel**	**Grits**
10–14 mm	IV 2011	30	25
	IX 2011	30	24
	III 2012	30	24
	XII 2012	29	24
	VI 2013	29	24
	XII 2013	32	24
	VI 2014	31	24
	XII 2014	32	25
	VI 2015	32	24
	XII 2015	31	23
	V 2016	34	24
	X 2016	33	24
	V 2017	33	24
	XI 2017	32	24

A subsequent analysis of the test results for aggregates of 4–8 mm fraction from ZEK Ostrów (Table 3 and Figure 5) was carried out.

The LA index values for the 4–8 mm fraction for gravel were in the range from 28 to 31%, while for grits, they ranged from 27 to 28%. It was noted that for this fraction for gravel and grit, the difference between the LA index values is small. Over the years, for grits, fewer differences in values of LA indicators were obtained, i.e., a greater stability has been achieved at about 27.8%. At this stage, it was possible to observe that for considered fractions 4–8 mm and 10–14 mm, the higher the fragmentation, the higher the LAA value. Additionally, it was observed that for smaller fractions, the porosity, shape, and form of the aggregate were not significant in the context of crushing.

Then, the LA index of the 4–8 mm fraction for the aggregates from ZEK Strzegocice II was similarly analyzed (Table 4). The same aggregates were analyzed as in ZEK Ostrów, i.e., grit and gravel.

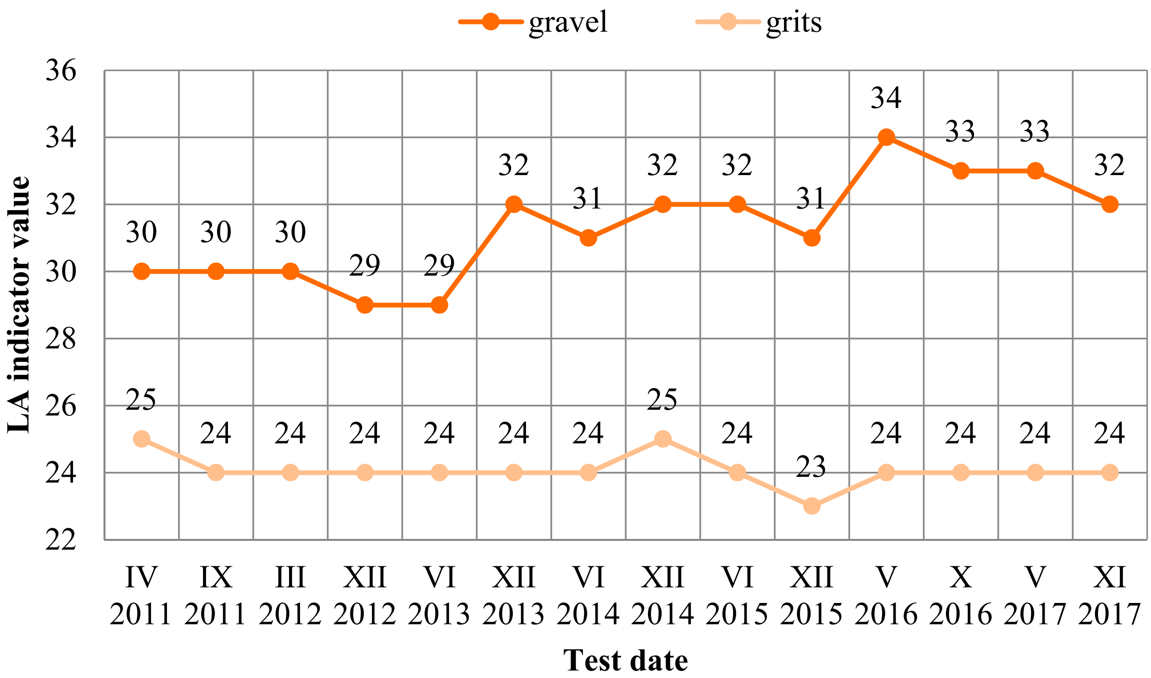

Figure 4. The value of the LA index for gravel and grit at the fraction of 10–14 mm for aggregates from ZEK Strzegocice II. Own study based on [44].

Table 3. LA index of crushing strength of aggregates with a fraction of 4–8 mm in ZEK Ostrów (source: produced by authors).

		ZEK Ostrów	
Fraction	**Test Date**	**Gravel**	**Grits**
4–8 mm	VI 2011	31	27
	XI 2011	29	27
	VI 2012	30	28
	XI 2012	30	29
	VI 2013	28	27
	XII 2013	29	28
	VI 2014	30	28
	XII 2014	30	27
	VI 2015	30	28
	XII 2015	29	27
	VI 2016	29	28
	XII 2016	31	29
	VI 2017	30	28
	XII 2017	29	28

In the case of gravel and also of grit, the LA values ranged from 28 to 31% (Figure 6). The differences between the indicators of these aggregates were much smaller compared to the values obtained from aggregates with a smaller grain size. The lack of differences between the examined aggregates resulted from the size of the fraction and the parameters of crushing, which allow the achievement of these results. It was observed, as before, that for smaller fractions, the porosity, shape, and form of the aggregate were not significant in the context of crushing. It was concluded that the higher the fragmentation, the higher the LAA value, e.g., in verified years, the average index value of the smaller fraction (4–8 mm) for the analysis aggregate was lower at about 4%. Moreover, in the case of grits, the lower the fraction, the higher the LLA index (about 24% and about 29%).

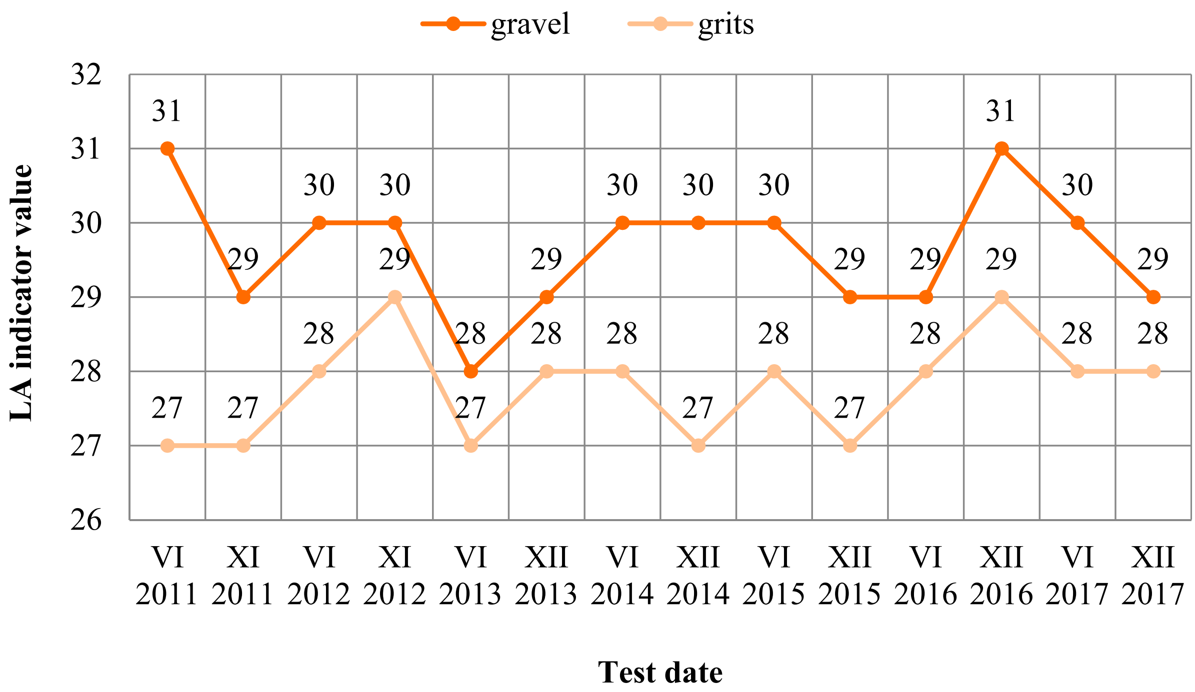

Figure 5. LA index value for gravel and grit at the fraction of 4–8 mm for aggregates from ZEK Ostrów. Own study based on [44].

Table 4. LA index of crushing strength of aggregates with a fraction of 4–8 mm in ZEK Strzegocice II (source: produced by authors).

		ZEK Strzegocice II	
Fraction	**Test Date**	**Gravel**	**Grits**
4–8 mm	IV 2011	31	29
	IX 2011	28	31
	III 2012	29	30
	XII 2012	29	29
	VI 2013	31	28
	XII 2013	30	28
	VI 2014	29	28
	XII 2014	30	29
	VI 2015	29	28
	XII 2015	30	28
	V 2016	29	29
	X 2016	30	30
	V 2017	30	29
	XI 2017	31	29

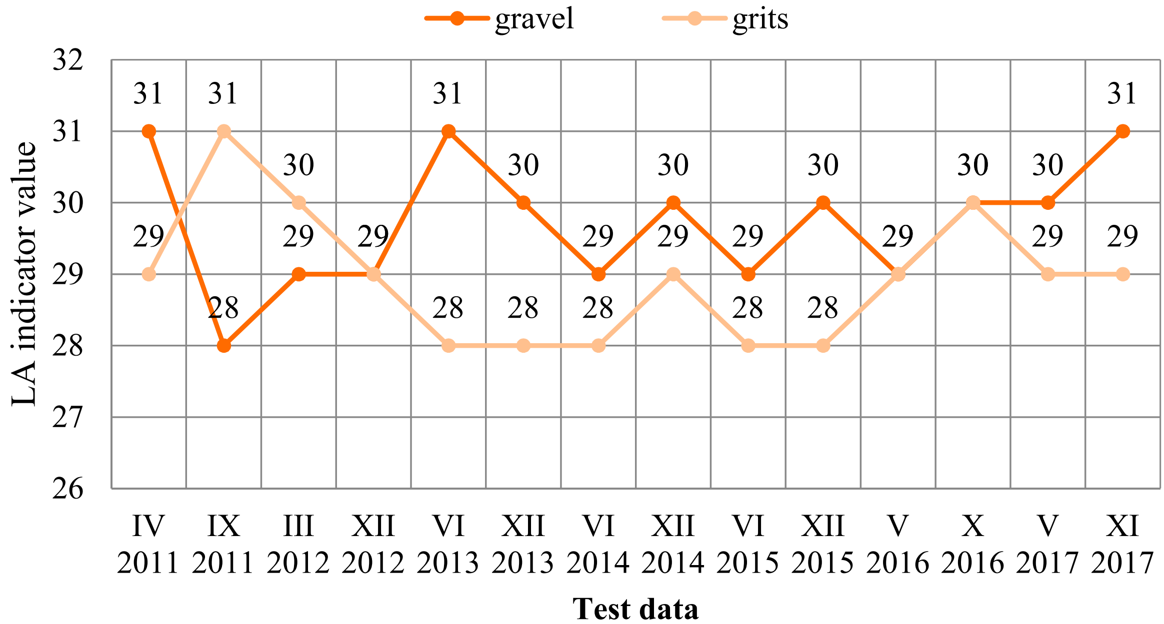

Figure 6. The value of LA index for gravel and grit at the fraction of 4–8 mm for aggregates from ZEK Strzegocice II. Own study based on [44].

6. Discussion

Due to the lack of studies representing the selected analysis aggregate and adopted crushing parameter process, it was not possible to compare the obtained results with earlier analyses. Based on the carried out analysis, it was possible to form several conclusions:

- In verified years for the selected fractions and plants, it turned out that for the different types of aggregate, the LAA index has different values in the range of 23–34%;
- For considered fractions 4–8 mm and 10–14 mm, the higher the fragmentation, the higher the LAA value, e.g., in verified years, the average index value of the smaller fraction (4–8 mm) for the analysis aggregate was lower at about 4%;
- In the fractions greater than 10–14 mm for grits, the LAA index has a high stability level, which is approximately 24%, irrespective of the plant;
- Grits are stable, independently from the plants, for the 4–8 mm fraction;
- Depending on the aggregate, the stability of the LAA index changed. For grits, it is more stable the bigger the fraction (10–14 mm), but for gravel, it is more stable the smaller the fraction (4–8 mm);
- In the case of grits, the lower the fraction, the higher the LLA index (about 24% and about 29%);
- The size of the fraction did not have a significant effect on the averaged crushing strength index for the gravel;
- The size of the fraction had a significant effect on the averaged crushing strength index for the grits; the smaller the fraction, the higher the LAA value.

The cause of the difference between the examined aggregates resulted from porosity, where aggregate with bigger fractions and with low porosity were characterized by a greater resistance to crushing [55]. Moreover, these changes resulted from the shape and form of the aggregate, where significant changes were observed for aggregate with a bigger fraction [53]. Additionally, these aspects were not concerned with aggregate with lower fractions, i.e., for smaller fractions, the porosity, shape, and form of the aggregate were not significant in the context of crushing. It is also important to pay attention to the source of the minerals and the fragmentation methods used (parameters and devices) to select the right aggregate for specialized works [53–57].

The main benefit of the analysis is extending the current scope of knowledge about the results of the influence of the natural aggregate crushing process on the crushing strength index for key Polish aggregates with parameters that have not yet been analyzed. Additionally, another advantage is the simultaneous analysis of the impact of the crushing process for two different aggregates and different fractions, which were mined in different Polish plants. Hence, this analysis is a new approach to the work conducted to date. It can be an important source of knowledge for further analyses to improve the strength of products.

The main limitation of the analysis is the lack of possibilities to compare the results with other works. Additionally, the disadvantage is the lack of verification with included size distribution curves of aggregates and their analysis.

Therefore, future analyses will be extended to verify distribution curves of aggregates. Moreover, as needed and possible, it is beneficial to perform statistical tests or produce other mathematical models to verify and supplement the obtained results.

7. Conclusions

Shredding is an energy-consuming technological process, whose goal is to achieve the desired granulation of mineral resources. It is important to carry out the comminution process in an appropriate manner to increase the strength of the raw material. Therefore, the impact of the process of crushing natural aggregate on the crushing strength LA (i.e., Los Angeles) index was analyzed. The aim was to analyze the impact of the crushing of natural aggregate on the LA crumbling strength index. The analysis was carried out for plants owned by Kruszgeo S.A.

After the analysis of the results of the LA crushing strength test for the selected aggregates, i.e., grits and gravel from two plants belonging to Kruszgeo SA, i.e., from Zakład Eksploatacji Kruszywa Ostrów and from Zakład Eksploatacji Kruszywa Strzegocice II, it was observed that as a result of subjecting aggregates to a crushing process and performing strength tests, a reduced LA value is obtained.

For grits of the 10–14 mm fraction, lower values of LA indices were obtained, and, thus, much larger differences between the values for both types of aggregates were noticed. Lower values of the LA strength index show that the strength properties of the analyzed aggregates improved.

However, in the case of smaller fractions (4–8 mm), the impact of the crushing process on the value of the crushing strength indicator is smaller, and, thus, the strength properties of the aggregates (gravel and grit) are less important than in case of the grits obtained as a result of crushing (fraction 10–14 mm).

After analyzing the results of the research, it was concluded that subjecting the aggregate to the grinding process results in an improvement in the crushing strength indicator, thus obtaining better strength parameters of products manufactured from aggregates subjected to the process of crushing (for example, concrete).

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