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Research paper

Alternative method for determining grain size distribution with use Doppler radar

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Abstract: Blasting mining is a set of activities that can be divided into a sequence of repetitive tasks. Primarily it is drilling, blasting, loading with the hauling and crushing. Drilling and blasting have the greatest impact on the economic indicator of the whole process. Their aim is to achieve the most optimal fragmentation of the blasting wall. It follows that an accurate and efficient fragmentation assessment process is one of the main indicators of blasting efficiency. Nowadays, sieve analysis is the most accurate method. However, this is a time-consuming and labour-intensive method. This is a predictive method, the disadvantage of which is the absence of the actual fragment size, which is also associated with inaccuracy. Currently, when the emphasis is on optimizing processes with environmental impact, finding a more efficient evaluation method that provides more accurate results than classical prediction procedures is even more relevant. The question of evaluating the grain size has been considered by many experts. This paper discusses the use of the reflection of flying fragments and their evaluation by Doppler radar directly during blasting. These measurements specify the size of the fragments and blasting speed up the process of evaluating the grain size of the muck-pile material.

Keywords: Doppler radar, fragmentation analyses, blasting, grain size distribution, measuring techniques

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1. Introduction

The quarrying process usually consists of a technological sequence, namely drilling, blasting, loading with the hauling and crushing. Drilling and blasting, which are the first steps of the overall process, that have the greatest impact on the productivity and costs associated with other operations. The focus of these two steps is to achieve optimal dividing of the blasting wall with safe and economical constraints.

The result of blasting is influenced by many parameters such as the natural material itself, the layering, the type of explosive, etc. Because of this, a quick and exact process is needed for evaluating its effectiveness. The evaluation process is also used to monitor blasting and its optimization design. One of the main indicators of blasting efficiency (outside shape of the wall after blasting and muck-pile distance from new blasting wall) is the resulting fragment size. Nowadays, sieve analysis is the most accurate method. However, this is a time-consuming and labour-intensive method. That led to the idea that blasting parameters and rock mass properties are used directly to determine of fragmentation [1].

Most quarries use blasting as the primary activity in breaking up the rock. The wrong blasting technique used results in unwanted destruction of the blasting wall or loss of stability. Extensive wall destruction and loss of stability requires additional excavation and, conversely, incomplete blasting is associated with secondary blasting and crushing.

Blasting represents the most significant cost factor, which, if incorrect design inputs are used, generates additional costs, reflected in the increased use of mechanization itself. Therefore, to determine the optimum cost value, it is important to confirm the combined of controllable parameters that meet the aim of the overall mining operation [2, 3]. This is usually achieved by defining a set of conditions that minimizes the total production cost per ton of blasted material. The process is described in the literature as non-linear, where the result is characterized by several parameters that are complicated to evaluate. In general, these parameters can be grouped into two categories: controllable (parameters of explosive material) and uncontrollable (environmental parameters).

Controllable parameters such as blasting, location and inclination of drilling, and setback settings have a major influence on the size and shape of the fragments. Therefore, the key to a method that quantifies fragment size quickly, safely and precisely is the proper management of the blasting operation [1, 4].

Drilling and blasting account for an estimated 55% of total mining costs. Consequently, these steps must be designed to minimize costs. Correct selection of explosives is most important for an effective blasting scheme design. This optimization is based on a reduction in investment in technological equipment, its operation and maintenance. Less material is manipulated, and so large volumes can be considered from 40 to 60% [5].

Rock fragmentation is one of the main parameters that influence the efficiency of loaders and transport equipment deployed in quarries. It is a relative term, and the values are specific for all equipment.

Because there are conflicting requirements (Fig. 1) for the drill-blast and load-haul systems, this situation presents a very difficult proposition. To develop an optimization plan, it is necessary to understand the level of the system and subsystem at which optimization is envisioned. If the system is considered as a whole, the scenario becomes rather complicated, especially when the costs of the different components of the system are considered [4, 6].

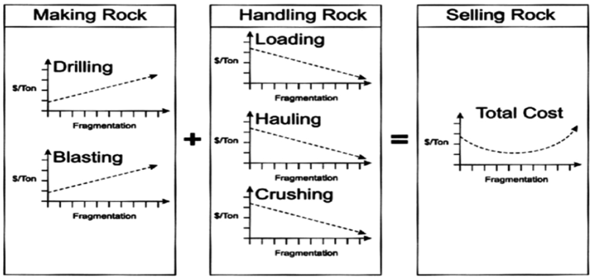

Fig. 1. Relation of individual system components in mine system and the optimum thereof [6]

Blasting is the first step to reducing the volume of mining, then follows crushing. The efficiency of these unit operations is directly related to the grain size of muck-pile. Therefore, its reliable determination is also a critical mining problem. Smaller debris generated by a properly designed blasting scheme, reduces the workload of primary crushers and increases their efficiency. This is automatically associated with a reduction in crushing costs and an increase in the crushing rate per hour (Fig. 2) [7, 8].

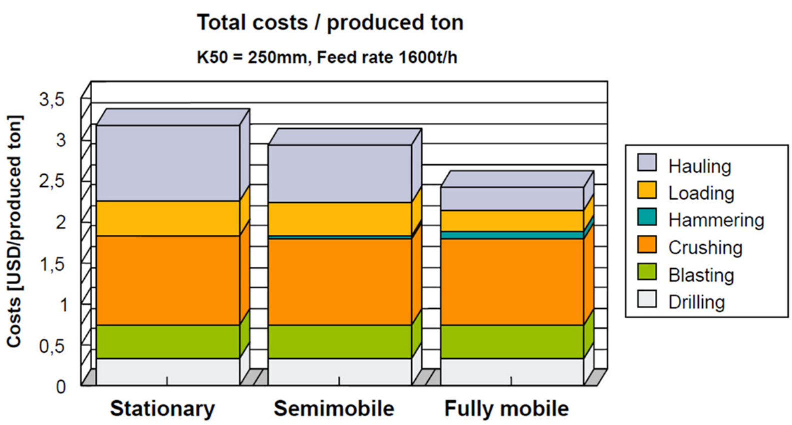

Fig. 2. Comparison of different crushing methods [9]

The whole problem described above can be reduced to a few words: quantification of grain size. However, the quantification of grain size encounters several problems, such as its dependence on material properties in conjunction with the design of the blasting scheme and the released energy that defines it. Although we have methods to control the grain size using blasting, there are no verification measurements. The grain size distribution of the whole muck-pile is very challenging due to the large volume, although new methods of collecting the necessary data using sensors and cameras mounted directly on the loaders have been developed.

Nobody evaluates grain size of the whole muck-pile, due to the large volume and production requirements. Finally, the application of visual techniques does not provide any engineering information, since the sampling method is not applicable in this case [6].

In approaching the general problems, the conventional use of Doppler radar for grain size determination has the potential to answer some of the questions [1].

2. Limits of the using a classical analysis technique for grain size distribution

In recent years, many investigations have been conducted to optimize blasting operations [2–4, 10]. The determination of grain size can be achieved in two possible ways [3]. In the first method, measurements are taken directly from the visible part of the muck-pile while the second method determines the fragmentation during loading and the volume is only a matter of estimation [11].

The first method is direct measurement. This relates to questions of what to measure and how to measure it, because the most important variable is information about the depth of the muck-pile. Currently, digital cameras are the most widely used and the result is a digital image with the possibility of adjusting the intensity for more accurate particle detection [11].

From the digital record, it is possible to see the particle boundaries, where the longest distance from the center determines its size. Thus, the assumption is that the particle is a sphere where their actual shape is neglected, and their size is determined by the relevant surface area (Fig. 3).

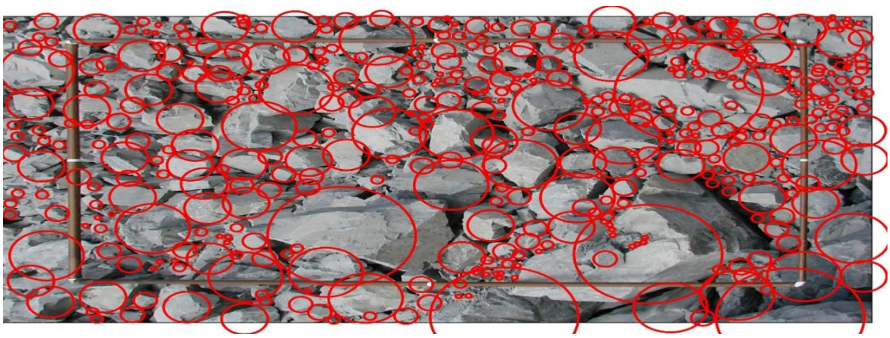

Fig. 3. Example of rectified photographs with a scale of 1 × 2 m [12]

The second method is associated with contour segmentation. This is solved by manual analysis, but the result is automatically influenced by subjective insight, and this is associated with a long time of evaluation. An option is to use alternative Land Surveyor measurement, but these do not reflect the specificity and character of the muck-pile [11] (Fig. 4).

This method is a quantitative estimation, and it depends on the sampling method. In general, it is the frequency of the occurrence of nominal fractions in the muck-pile.

Fig. 4. Land Surveyor measurement: left is cutout of the created orthophotomap and right are detected fragments of the muck-pile [13]

In principle, there are two problems that need to be solved to obtain a representative grain size distribution from the images. The first problem is that it effectively identifies a fragment over an area that may be incorrectly defined. The second problem is that imaging is a two-dimensional projection of fragments on the surface that is measurable, which distorts its true bulk size. This problem, especially in conditions where muck-pile is involved, is the strongest argument against imaging analysis [14, 15].

Some of the errors are directly related to the analysis of the digital image. It is the analysis directly after blasting where it is very difficult to accurately determine the size of the fragments, as the energy released has agitated the rock fragment so that it exhibits outward integrity and breaks down when it is moved [7, 11, 14].

Some of the above problems can be solved by deploying new sensors or the recently widespread drone imaging of the muck-pile. These automatic methods take full advantage of the computer settings, where they use stereological methods to determine volumetric values based on fragments contours (Fig. 5). Although automatic processing is faster than manual processing (automatic also reduces sampling errors), it creates additional measurement errors when contours are incorrectly determined.

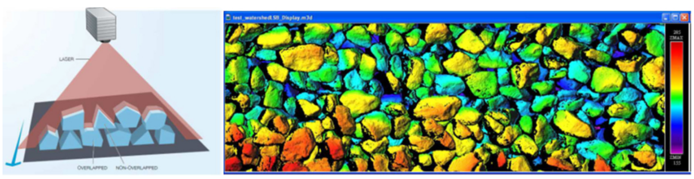

Fig. 5. Automatically measurements of limestone aggregate [16]

In the following section the potential of experimental use of Doppler radar and its ability to describe and evaluate the grain size of flying fragments during blasting will be discussed. This is an alternative method of grain size measurement where the primary aim is to minimize the subjective approach to evaluation and to provide effective measurement results in the shortest possible time.

The implementation of this work and the expected results for the entire stone industry is of importance for small and medium-sized quarries whose aim is to optimize processes without the need for large investments in new sensor and software equipment.

3. Fragment detection by Doppler Radar

The basic concept of radar is relatively simple, although its practical implementation is complex. Radar operates by emitting electromagnetic energy and detecting the response returned from reflecting objects (targets). The character of the echo signal provides information about the target. The range or distance to the target is determined by the time it takes for the beamed energy to travel to and from the target. The angular location is found using a directional antenna that senses the arrival of the echo signal. For moving targets, radar can infer their trajectory or path and predict future locations [1].

Reflectivity (Z) is an optical property of a material that describes how much light is reflected from the material in proportion to the amount that hits the material. It is defined as the unit volume of small dielectric spheres in a radar cross section. This volume is directly proportional to the number and size of the fragments [1].

For all measurements, the meteorological radar MRR-2 from METEK was used, designed to record the rainfall in the atmosphere, which was modified to a volcanic radar (Fig. 6).

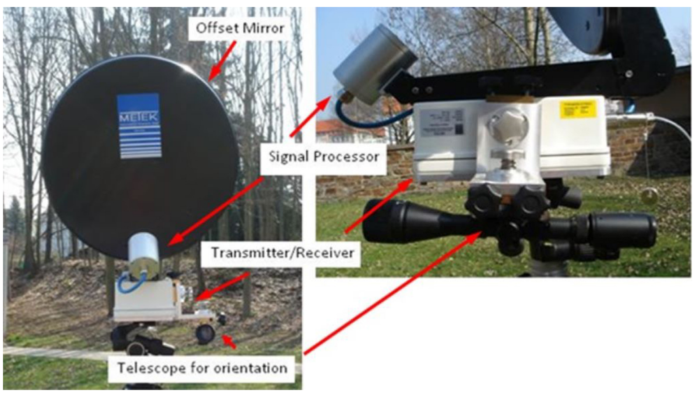

Fig. 6. Modified meteorological radar MRR-2

The basis of the first measurements was to find the physical dependence of the reflectivity and its associated fragments of different sizes. These measurements, be extended from two to more of varying fractions diameter. This would lead to the possibility of creating a picture of the progress of possible correlations and follow the equation.

By measuring in an ideal situation, with no disturbing factors (any moving object), it was possible to reduce the variables only to a change in the size of the fragments.

With this ideal state it is possible to determine the relationship between the measured reflectivity and size. From measured data it is obvious that the reflectivity progressively grows (red arrow on Fig. 7 and 8).

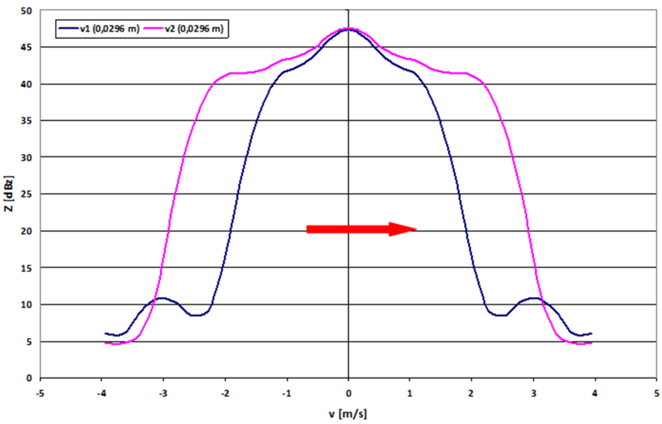

Fig. 7. Impact of the speed's changes on reflectivity for D = 0, 0296 m

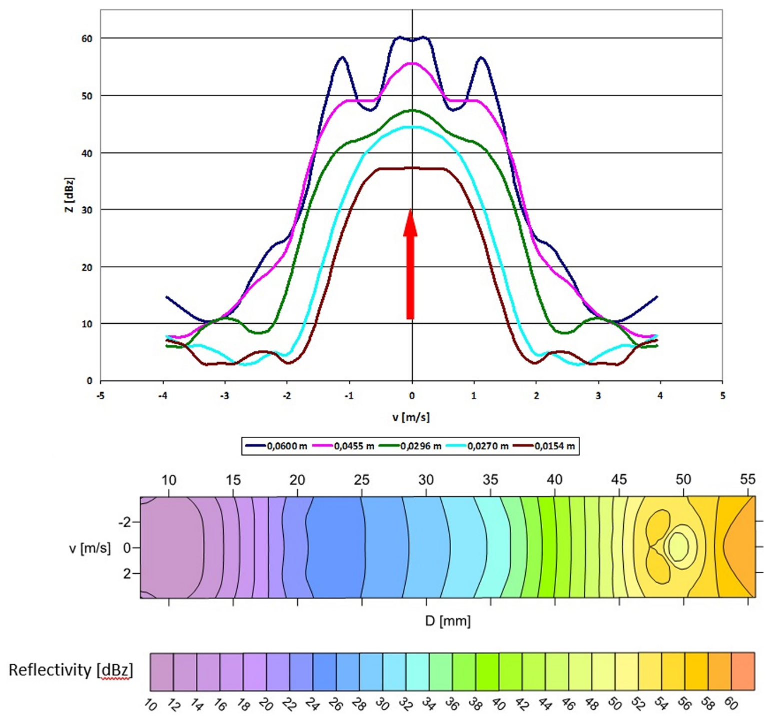

Fig. 8. First measurements with positive evolution, where is evident an increase in reflectivity with increasing fragment diameter

The main aim of these measurements was to find a direct dependence between the reflectivity and the size of the studies fragments. An interpretation of this dependence is in Figure 9. The blue and pink lines form the boundaries for the areas where a directly proportional increase applies, and the central value (dashed line) describes the granularity of the moving objects [1].

This proportional increase is described as:

$$Z_{\min} = 0.4071.D + 37.301 \text{ (blue line)} \tag{3.1}$$

$$Z_{\min} = 0.3547.D + 34.850 \text{ (pink line)} \tag{3.2}$$

where: Z is reflectivity and D is diametral

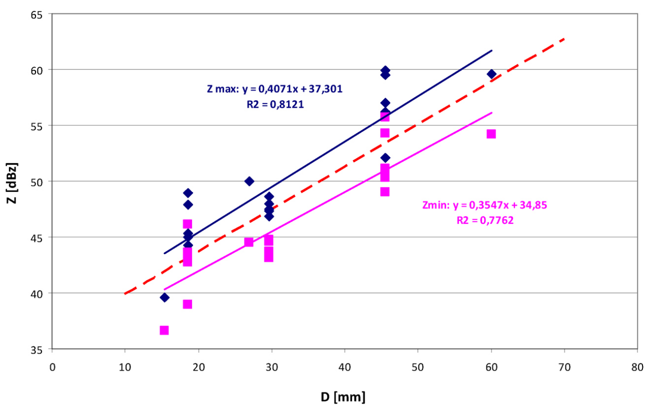

Fig. 9. Physical dependence describes the granularity of the moving objects

Transformation of equations (3.1) and (3.2) for in-situ measurement:

$$D_{i,\max} = \sum\_t = 1^{t+t_i} \left| \frac{Z_{\max,i} - -37.85}{0.4071} \right| \tag{3.3}$$

$$D_{i,\max} = \sum_{t=1}^{t+t_i} \left| \frac{Z_{\min,i} - -34.85}{0.3547} \right| \tag{3.4}$$

In the following sections, the impact boundary determination has in blasting mineral mining will be considered.

4. Results of use of Doppler radar to evaluate grain size distribution in quarry

In twelve natural stone quarries there were more than 60 blasting in-situ monitored and evaluated. The rock dynamic properties and the interface structure of the respective solid rock were statistically recorded. Doppler radar was used to determine the breakout velocity of the detonated explosive devices in the direction of the ejection.

Figure 10 represents a non-idealized blasting waveform that is recorded by the radar. There is a directed explosion, in which the particles at speeds 15 to 25 m/s and fly at an opening angle od ±50° to the radar. Each speed is represented at every angle. In the spectrum, only positive velocities can be found. The maximum speed can be described above as the real speed of the particles interprets that move exactly in the radar beam.

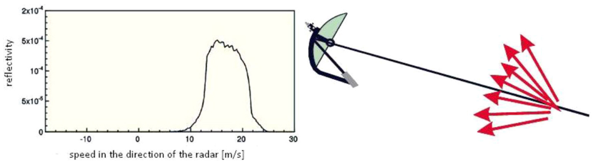

Fig. 10. Theoretical spectrum of a directed explosion [7]

In quarry at a safe distance of ≥ 300 m the radar sensor was placed before the blasting and the radar beam directed at the free surface before the blast (Fig. 11). Radar beams were projected on the wall as a circle whose diameter at a distance of 300 meters is 8 m.

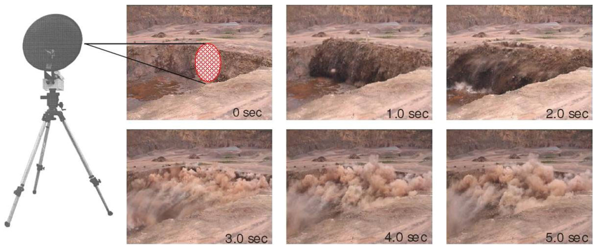

Fig. 11. Measuring the outbreak velocity by Doppler radar [7]

The following figure represented the deployment of Doppler radar directly in the quarry during the blast (Fig. 12).

Fig. 12. Position of Doppler radar short time for ignition in quarry

In the context of measurements and input parameters that affect grain size, joint body composition was also analyzed for each quarry.

In Figure 13, it is illustrated joint body composition for limestone, rhyolite and greywacke.

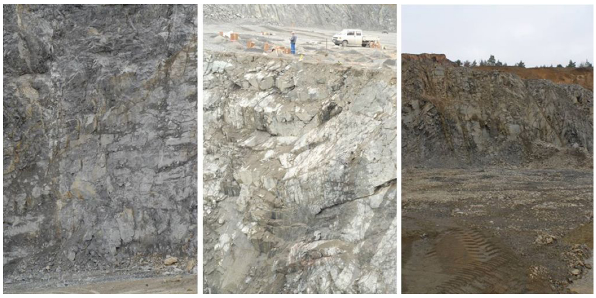

Fig. 13. Joint body composition for: limestone; rhyolite and greywacke

After the evaluation and comparison all in-situ measurements (due to the amount of data only selected quarries are shown) (Fig. 14 and 15) it was possible to convert re-corrections for the dependence of grain size and reflectivity.

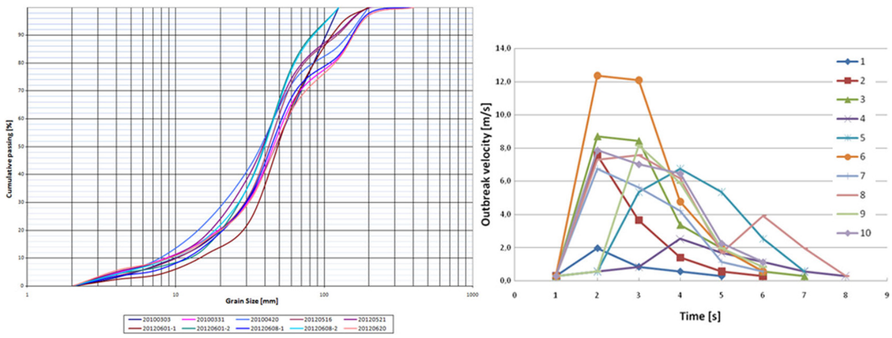

Fig. 14. Grain size distribution and outbreak velocity for quarry Oßling (Greywacke)

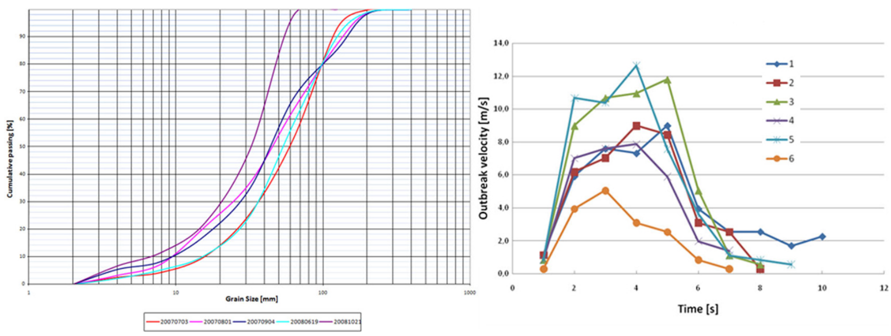

Fig. 15. Grain size distribution and outbreak velocity for quarry Elbingerode (Limestone)

The result of this correction is introduced in Figures 16–18. The graphs represent the different geological environments.

Comparative is in a log-linear coordinate system. The red line was measured by radar during the blast, the brown line is a measurement of surface grain size distribution with photo analysis, and the green line measurement by radar after equipment correction.

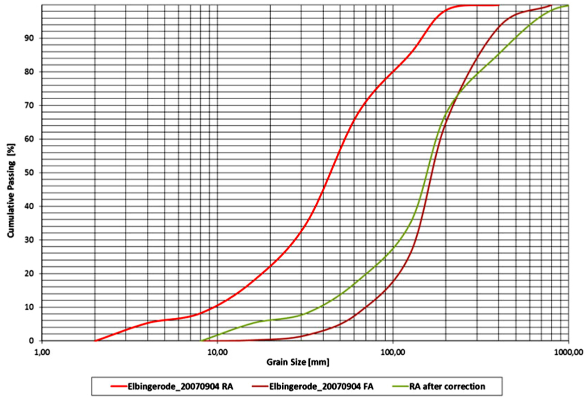

Fig. 16. Limestone

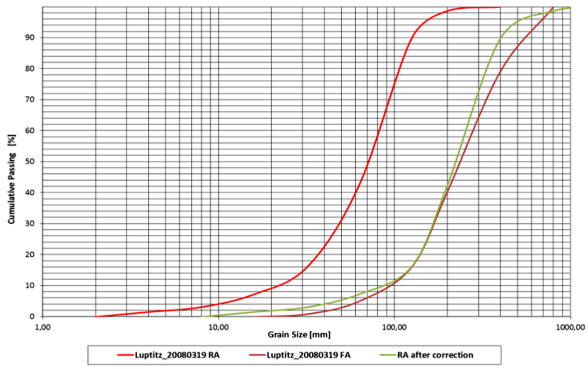

Fig. 17. Rhyolite

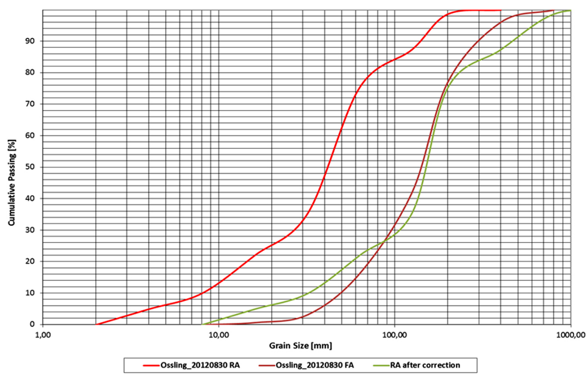

Fig. 18. Greywacke

In the context of the measurements in the quarry, it was demonstrated that the reflectivity has limits as described in equations (3.3) and (3.4). Blastings were also evaluated in a speed-time-reflectivity system too. Figure 19 illustrates this dependence. With these results, it was possible to add to the evaluation of the blast itself, not only the determination of the grain size but also the evaluation of the outbreak velocity. In this way we were able to describe the overall blasting kinetics (as an example Fig. 20), which have a significant impact on the environment and is one of the main inputs to optimizing the overall blasting operations without reducing the required production.

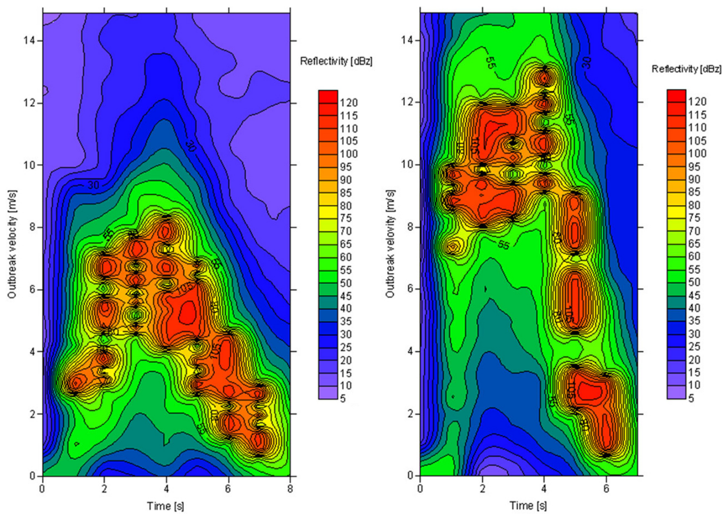

Fig. 19. Blasting in greywacke material with maximal outbreak velocity is 7.9 m/s and limestone with maximal outbreak velocity is 11.0 m/s

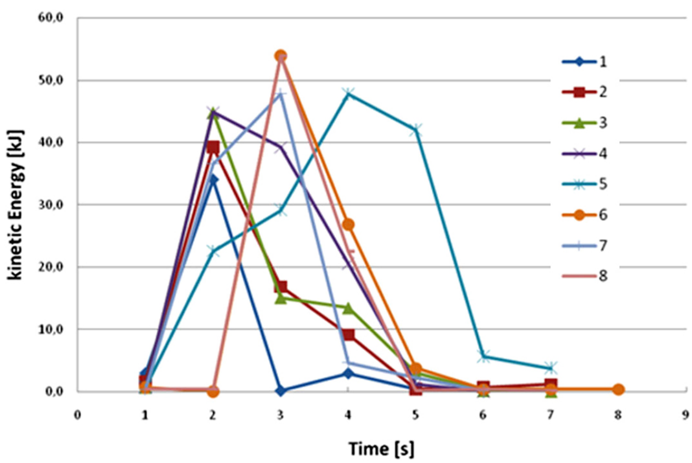

Fig. 20. Changes of kinetic Energy during the blasts per second for the Leukersdorf quarry

5. Change of the blasting wall in time

The pulse period of Doppler radar is in all cases, 1 s. This means that the grain size distribution can be determined every second of the initiation of blasting and thus track the change of structure of the blast wall.

The variability of the setting of the detected reflectivity for a selected time interval gives the radar method of determining the size of flying fragments a strong argument for further use. This advantage, compared to static image analysis, makes it possible to study the blasting wall in real time. As an example, we present a grain-size analysis that was carried out in the Seifersdorf quarry (basalt). For better visualization, the blasting was also recorded with a high-speed camera (Fig. 21).

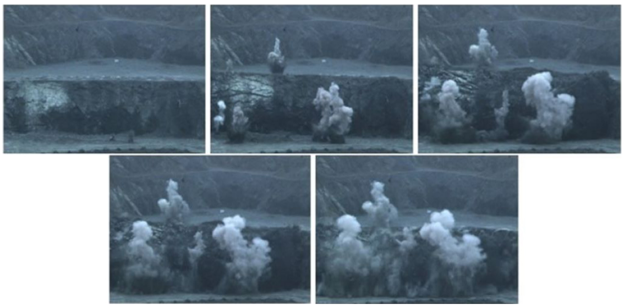

Fig. 21. The progress of the blasting captured by a high-speed camera (the blast duration is 5 seconds)

The following Figure 22 shows the grain size distribution analysis recorded in real time, in this case one-second time interval. The advantage is that the intensity of the record can be increased according to the requirement or necessity, which is dependent on the blasting speed.

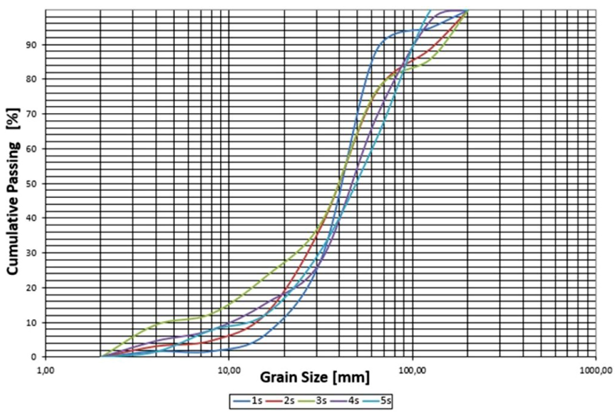

Fig. 22. Grain size distribution recorded in real time

6. Conclusions

This paper discussed the estimation of the grain size in the muck-pile that is produced by blasting mining. Generally, the determination of fragmentation can be divided into two problematic levels. The first problem is the digital image analysis itself and the limitations that come with it. And secondly, to efficiently design and back-correlate blasting schemes to achieve the most efficient production with the lowest impact on the environment.

Doppler radar has been used to detect objects for more than a century. The modification of the meteorological radar to a volcanic radar helped its adaptation to record the outbreak velocity during the blasting and from it determine the global kinetics of blasting. Within this research it was possible to describe the spectral echo, recorded by the radar and to attribute this to the size of the flying fragments. As a result, a detection algorithm and deployed as one of the options for determining the grain size of muck-pile, which was also tested and compared with the classical digital method. This comparison has confirmed that the use of radar has great prospects for the future.

Based on the positive results from in-situ measurements, it is possible to use radar to:

1. described the kinetic of blasting,
2. development of an adaptive technique for the completion of algorithm for Doppler radar grain size distribution model,
3. development of the new grain size distribution method,
4. development of the method as a timestamped record for monitoring of blasting wall,
   integration of the Doppler radar grain size distribution method into a method for the primary analysis of the muck-pile.

Flexibility and simple representation of the grain size distribution time are just a few of the advantages of measuring with Doppler radar. But the biggest advantage is saving time because this method gives the possibility of accelerating the main analysis of the fragmentation of the muck-pile from a few hours (Photo analysis) for a few minutes (Radar analysis), which is presented in Figure 23.

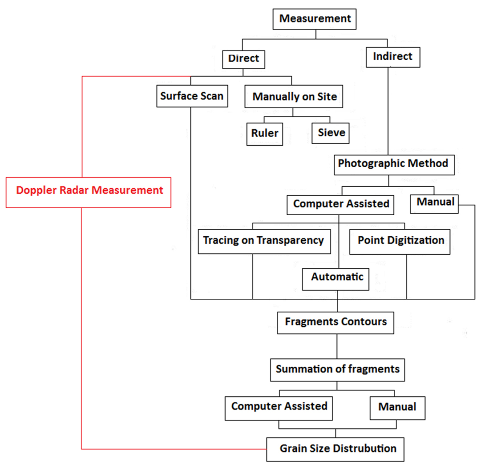

Fig. 23. Schematic diagram of commonly (black colour) used methods and Doppler radar measurement (red colour) for Grain Size Distribution [modified by Ortuta]

Other advantages of radar analysis are especially its adaptability to any material. This is mainly since the recorded reflectivity is independent of the blasting material itself and therefore the main variable is just the fragment area. Thanks to the radar modification, its deployment is possible even in difficult natural conditions and measurements can be made over long distances. Which, given the ratio of speed of evaluation and purchase price, will help small and medium-sized quarries to optimize processes that will have a large impact on the environment.

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