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Less fines in aggregate and industrial minerals production - results of a European research project

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ABSTRACT: The average annual consumption of raw minerals in Europe is around 10 ton per person. About 50% is produced by blasting. For a population of 450 million this makes 2.25 billion tons of blasted rock, 80 % being building industry aggregates and industrial minerals. In aggregate quarries 10-15 % of the rock blasted can't be sold, as the material is too fine, i.e. smaller than 4 mm. This 'fines problem' is worse in the quarries of limestone and cement producers where up to 30% of the material is useless. Thus about 450 million tons of useless rock fines are produced and put on waste dumps every year, i.e. 1 ton/person. This problem was addressed by the research project LESS FINES ("Less Fines production in aggregate and industrial minerals industry"), which was funded by the European Union, under the project contract G1RD-CT-2000-00438. The project consortium consisted of nine partners from 5 EU countries. Coordinator was the Department of Mining & Tunnelling at the University of Leoben, Austria.

1 INTRODUCTION

The objective of the LESS FINES project was to reduce the amount of fines created during rock blasting down to the inherently unavoidable, rock type dependent, minimum percentage. For that purpose the following work has been carried out:

- Investigations into the blast breakage behaviour of rock. These firstly comprised of the determination of the natural breakage characteristic (NBC) of the rock, which is considered to be a material parameter. Secondly, the actual blast fragmentation in the quarries was monitored over a period of two years. This allowed one to see how far away the actual blast fragmentation results in the quarries are from the NBC curve of the rock mass, the fragmentation curve with maximum uniformity.
- Analysis of the influence of the type of explosives and the timing of a blast upon the production of fine material in the muck pile. This analysis was done based on a series of around 100 full scale production blasts closely monitored in three quarries in Austria, Spain and Sweden.
- Development of a blast design concept and a charging technology to adjust the explosives energy input into the rock mass during blasting to the actual rock volume to be broken. One major strategy of this development work was, in a first step, "to keep the powder factor constant", that is to say, to strictly adapt the explosives energy input into the rock mass to the actual rock volume to be broken and, in a second step, to reduce the energy input in the column charge as much as possible to achieve a fragmentation result as coarse as possible, while guaranteeing a satisfying toe breakage.

Table 1 shows the LESS FINES consortium involved in the project work. The work for the LESS FINES project was started in March 2001 and finished in June 2004. All together 602 personmonths were spent, which corresponds to around 17 fulltime working persons over a period of three years.

The preparation of this summary report was done by the author on behalf of the whole project consortium and is aimed to contribute to a further dissemination of the project results as part of the LESS FINES objectives.

Table 1. Overview over the LESS FINES project consortium.

Partner	Activity	Country
Departments of Mining Engineering & Mineral Processing, University of Leoben	Research organization	Austria
Dyno Nobel Europe	Explosives manufacturer	Norway
Unión Espanola de Explosivos S.A.	Explosives manufacturer	Spain
Partek Nordkalk Storugns AB	Limestone producer	Sweden
Cementos Portland S.A.	Cement manufacturer	Spain
Bitustein Strassenbaustoffe GmbH	Aggregate producer	Austria
Armines/ École Nationale Supérieure des Mines de Paris	Research organization	France
Stiftelsen Svensk Bergteknisk Forskning	Research organization	Sweden
Universidad Politecnica de Madrid	Research organization	Spain

2 MAJOR RESULTS ACHIEVED

2.1 The natural breakage characteristic (NBC) of the rock

The feasibility of the application of the concept of the "Natural Breakage Characteristic of rock" for actual rock blasting could be shown. A methodology was developed, based on the combination of the results from the lab scale blasting tests and from the in-situ block size distribution analysis, for the determination of the maximum uniform fragmentation distribution in a certain type of rock mass at best achievable during blasting. These results allow:

- the characterisation of the disintegration behaviour of a rock with respect to the production of fines,
- the forecast of the amount of fines for a full blast result, depending on the maximum particle size and
- the evaluation of a blast fragmentation result.

With respect to the NBC approach the following conclusions can be drawn:

- The characteristics of the fragment size distribution curves, obtained in the lab scale blasting tests, from the extreme fines up to a fragment size of around 20mm - 50mm are estimated to reflect the breakage properties of the rock, that is to say the NBC. A variation of the specific energy input (J/t) in fragmentation experiments results in a shift of the fragmentation curve along the vertical passing axis (Fig. 1). The characteristics of the distribution curves remain unchanged (Fig. 2).
- The type of the fragmentation process has little influence on the distribution characteristics in the fines range. There is a strong similarity between the size distribution curves from mechanical fragmentation and blasting tests. A strong similarity has also been found for the fragment size distribution curves of blast samples of the same rock type but of different size. The material dependent characteristic change of the slope of the fragment size distribution curves has been found to be constant over the whole size range of samples blasted. A comparison between lab scale blasting and full scale blasting showed that, even for the fine material coming from full scale blasting, a comparable characteristic exists.
- From the lab scale blast experiments the NBC of the rock can be derived up to a particle size of 20 to 50 mm. The NBC of the rock mass for larger fragment size classes can at the current moment only be estimated on the basis of the in-situ blockometry measurements and calculations. The in-situ blockometry curves are estimated to reflect the steepest possible size distribution of blocks in the coarse spectrum of a fragment size distribution. The in-situ blockometry existing before blasting cannot be made coarser through blasting.

The material specific breakage behaviour can also be taken from the surface – energy relation. But with respect to the blast characterization it has to be taken into consideration that the blast energy register curve only reflects the characteristic of the fragment size distribution curves up to 1 mm, as around 80% of the surface is related to the particles smaller than 1 mm. Based on the mechanical fragmentation and the lab scale blast tests, the theoretical minimum energy necessary in order to achieve a certain fragmentation status, e.g. characterised by the mass specific surface in [cm²/g] units, can be derived.

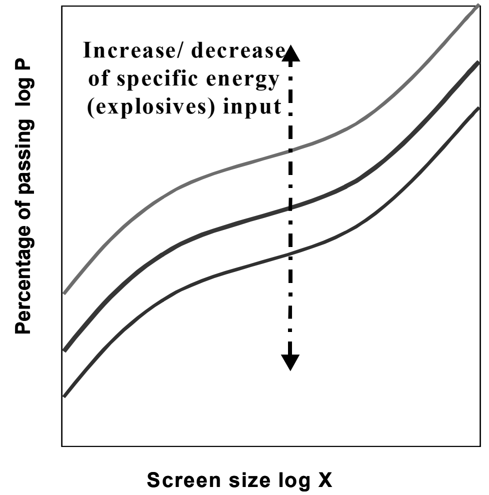

Figure 1. Shift of fragmentation curves with varying energy input.

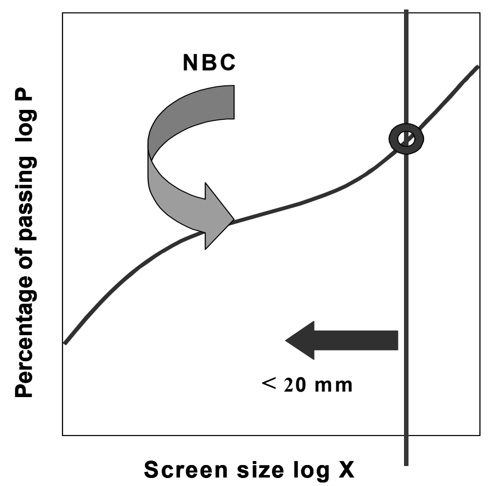

Figure 2. The NBC as the characteristic curvature of the particle size distribution curve in the fines range.

2.2 Energy controlled blasting

On the basis of both full scale and lab scale blasting results it could be shown that the specific explosives energy input (specific charge) during blasting is the controlling parameter for the fragmentation result and thus also for the amount of fines (Figure 3). Based upon this result a generally applicable blast design methodology for the reduction of fines, called the "Energy Controlled Blasting", was developed and successfully implemented in the Eibenstein quarry of Bitustein.

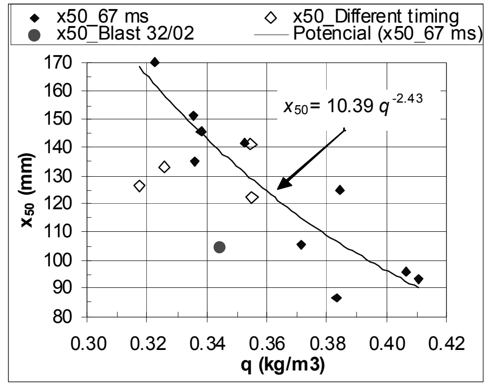

Figure 3. Relation between the specific charge and x_{50} for the test blasts at CP.

The concept of "Energy Controlled Blasting" is the precise adaptation of the explosives energy input into the rock mass with respect to the actual volume/mass to be blasted on a hole per hole basis over the total bench height.

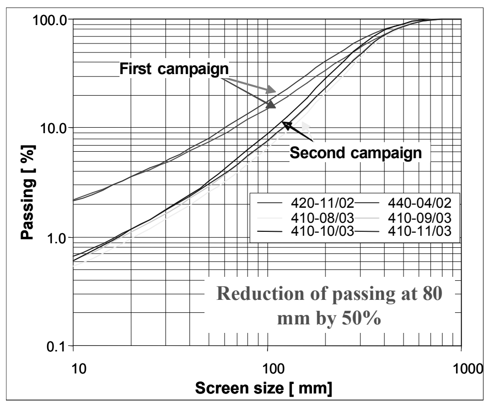

Figure 4. Fragmentation results at Hengl for the "Energy controlled blasts".

With the help of this concept the passing at 80 mm (Fines!) in the Eibenstein quarry of Bitustein could be reduced by 50% (Figure 4). At the same time the total drilling and blasting costs were reduced by around 20%.

2.3 Differentiated gassing of explosives

One of the most important results and technical breakthroughs in the frame of the LESS FINES project was the success in developing the differentiated gassing technology for pumped emulsions to full industrial application.

This differentiation of the density of the explosives and thus also of the energy input in the hole is achieved both by the explosives mixing technology used and also by a careful charging technology comprising a certain charging hose guidance and a wetting of the holes with water before charging in order to smooth out the friction effects of the borehole wall. It is now possible to bring the in-situ charge density to the desired value with a precision of 10-20 cm along the charge column. The new technology enables for the first time to really adapt the density and thus the energy of the explosives to the necessary fragmentation energy. The differentiated gassing technology is the basis for the realisation of the "Energy Controlled Blasting" when using emulsion explosives. This new technology is in regular use in the Klinthagen quarry of Nordkalk since November 2003 and has thus already found its way into the industry.

2.4 The Swebrec particle size distribution function

Based on the analysis of the characteristics of hundreds of fragmentation curves from inside and outside of the LESS FINES project, comprising fragmentation curves from virtually any fragmentation process (blasting, comminution, etc.) a new function that describes the distribution of the particles of blasted material better than the RRS function, which is the current standard for describing the particle size distribution of blasted material, has been found. It is called the Swebrec© function (Equations 1& 2).

$$P(x) = \frac{1}{1 + f(x)} \tag{1}$$

$$f(x) = [\ln(x_{max}/x) / \ln(x_{max}/x_{50})]^b \tag{2}$$

where x_{50} is the particle size [mm] at 50% passing, x_{max} is the maximum particle size [mm] and b is a function parameter. The shortcomings with the currently widely used RRS function mainly lie in the fines range of the curve, where the deviation between the model and the actual distribution usually are too high to be able to derive any meaningful conclusions. The new Swebrec function describes the whole fragmentation curve extremely well down to a particle size of 0.5 mm (Figure 5). The new function works well both for material coming from blasting, crushing and sometimes grinding. The development of the Swebrec function can be considered as a real advance in the engineering description of fragmentation curves and it is estimated that this new function will become a new standard for the engineering analysis of fragmentation curves in the future.

2.5 Characterisation of explosives

A new testing procedure, the cylinder expansion test, for the determination of the energy of civil explosives was developed (Fig. 6).

The tests are made in copper tubes, where the expansion time history of the outer tube wall during the explosion is measured. From that the Gurney energy for the explosives is derived. A comparison of the cylinder expansion test data with energy balance measurements for blasting in rock has shown that the cylinder test is a reasonable analogue to the energy transfer in rock blasting. It transfers roughly the same percentage of the explosive's energy. It stops doing useful work at roughly the same expansion ratio as in rock blasting. It partitions the energy between shock wave and other kinetic energy roughly the same way. The traditional underwater test was found to be a much less suitable measure of the transfer of energy in rock blasting.

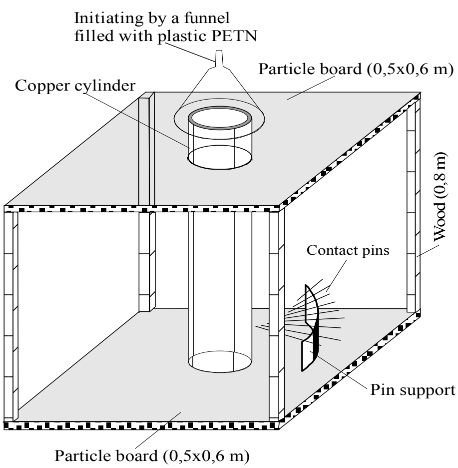

Figure 6. Set up of the cylinder expansion test.

3 FURTHER PROJECT RESULTS

Further project results comprise:

the development of a numerical blast fragmentation simulation approach as a basis for the future development of a blast fragmentation simulation software.

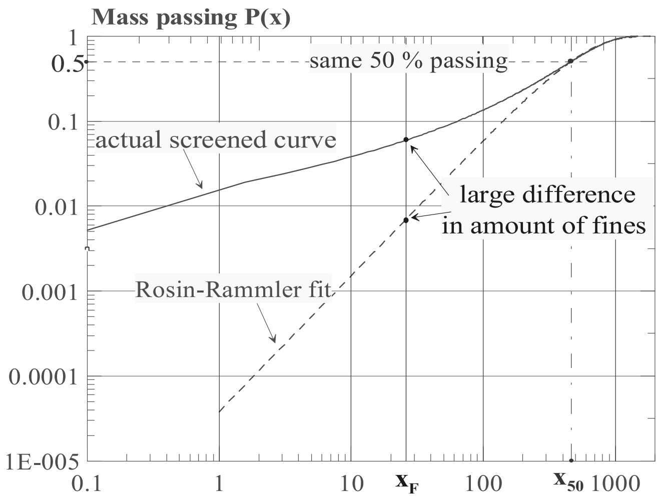

Figure 5a. RRS fit for a particle size distribution of blasted Amphibolite.

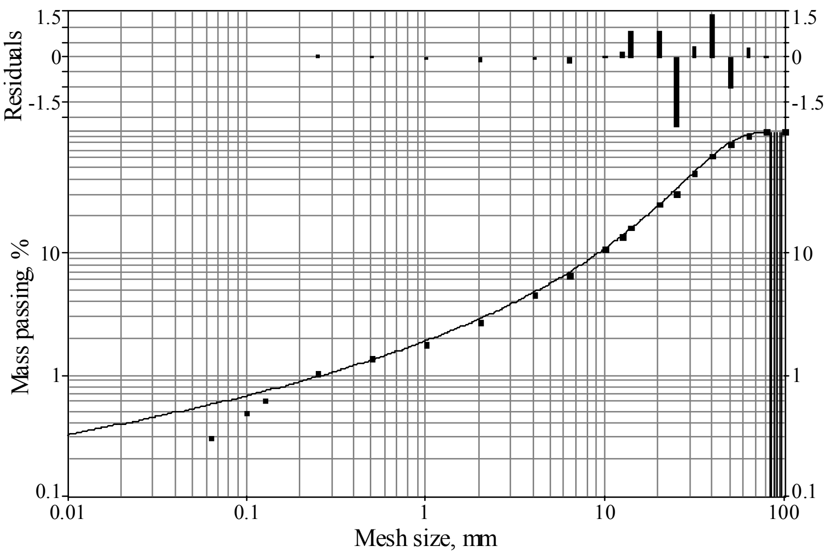

Figure 5 b. Swebrec function fit for a particle size distribution of blasted Amphibolite.

- the development of an algorithm for the fines correction of optical fragmentation measurement systems,
- the development of a standard procedure for the determination of the micro fracturing (damage) of rock blocks from the muck pile after blasting,
- the development of a procedure for the determination of the relation between the micro fracture status of the rock and its fine creation behaviour,
- the implementation of a procedure for a better characterisation of the rock mass (definition of zones with similar rock mass conditions within a quarry),

– the development of a standard procedure for the monitoring of full scale blasts,

– the establishment of an energy balance for field blast operations, and the preparation of a pilot study on the blast fragmentation-primary crusher interaction as the basis for future work.

All the detailed results of the project work are described in 97 technical reports, prepared in the frame of the project. Till the end of the project two theses were prepared and 20 scientific papers about the project results were published in conference proceedings and international scientific journals (a list is given in the references).

Further papers have been submitted to conferences and journals for publication after the project end. For a continuous dissemination of the project results in the future, all the results of the project work have been compiled in the form of a "Knowledge book about blast fragmentation".

In summary it can be concluded that the results of the LESS FINES project have already found their way into industrial application and that they have triggered an increased awareness of fragmentation control in rock blasting.

4 SUMMARY

The objective of the LESS FINES project was to reduce the amount of fine material created during blasting. For that purpose the following major project work was carried out:

– investigation into the blast breakage behaviour of rock and rock masses;

– analysis of the influence of explosives and delay upon the production of fines;

– development of a blasting design concept and charging technology to adjust the explosives energy input into the rock mass to the actual rock volume to be broken.

The major results achieved during the project work are as follows:

– The feasibility of the application of the concept of the "Natural Breakage Characteristic of Rock" for actual rock blasting could be shown. A methodology was developed, based on the combination of the results from the lab scale blasting tests and from the in-situ block size distribution analysis, for the determination of the maximum uniform fragmentation distribution in a certain type of rock mass achievable at best during blasting. These results allow the characterisation of the disintegration behaviour of a rock (with respect to the production of fines), the forecast of the amount of fines for a full blast result (depending on the maximum particle size) and the evaluation of a blast fragmentation result.

– A general applicable blast design methodology, "Energy Controlled Blasting", for the reduction of fines was developed and successfully implemented in a quarry. The concept of "Energy Controlled Blasting" is the precise adaptation of the energy input with respect to the volume/mass to be blasted hole per hole over the total bench height. With the help of this concept the amount of fines in a quarry could be reduced by 50%.

– A technology for the differentiated gassing of explosives in a blast hole has been developed. This enables to reliably adapt the density and thus the energy of the explosives with respect to the necessary fragmentation energy. The differentiated gassing technology is the basis for the realisation of the "Energy Controlled Blasting" when using emulsion explosives. This new technology is already in regular use in a quarry and has found its way into industrial application.

– A new particle size distribution function – the Swebrec function – was developed. The new function overcomes the shortcoming of the traditional RRS distribution function in the fines range and provides a new tool for the modelling of fragmentation curves both from blasting and comminution.

– A new testing procedure, the cylinder expansion test, for the determination of the explosives energy was developed.

– Further project results comprise (i) a numerical blast fragmentation simulation approach as a basis for the future development of a blast fragmentation simulation software, (ii) a standard procedure for the monitoring of full scale blasts, (iii) an algorithm for the fines correction of optical fragmentation measurement systems, (iv) a procedure for the determination of the relation between the micro status of the rock and its fines creation behaviour, (v) a better characterisation of the rock mass and (vi) the establishment of an energy balance for field blasting operations.

All the detailed results of the project work have been compiled in the form of a "Knowledge book about blast fragmentation".

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