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Waterless Fines Removal

Technical feasibility of using air classification to separate fines from sand and gravel

Economic Minerals Programme

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Technical feasibility of using air classification to separate fines from sand and gravel

D Wagner & CJ Mitchell

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Laboratory air classification trials using a Hosokawa Alpine 1-40 MZM zig-zag air classifier.

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British Geological Survey offices

Keyworth, Nottingham NG12 5GG

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Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

This report is a deliverable of the 'Waterless Fines Removal' project; it details a study carried out to determine the technical feasibility of using air classification to produce clean, fine aggregate. The continued use of abstracted water in sand and gravel quarries will require more concerted efforts by operators to demonstrate the use of water efficient practices; this will affect the renewal of abstraction licenses. The use of waterless fines removal equipment, such as air classification, is one means that companies can use to comply with these new regulatory requirements. Laboratory and pilot scale trials using air classifiers were carried out on samples from four sand and gravel operations. The findings of this study will be of interest to quarry operators, especially those working in areas where water resources are under increasing pressure.

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Washing plants are commonly used by sand and gravel operations to produce clean aggregate; they are effective in removing fines (silt and clay) but use a large volume of water. New regulations controlling the abstraction of water require quarry operators to demonstrate 'water efficient' practice as part of the abstraction license renewal process. The use of waterless technologies for removing fines would go a long way to satisfying this requirement; air classification is one such technology. This report details the findings of air classification trials carried out to determine the technical feasibility of using a waterless method for producing clean aggregate. This work forms part of the 'Waterless Fines Removal' project funded by the Aggregate Levy Sustainability Fund (ALSF).

Four samples of sand were collected from sand and gravel operations (these will remain anonymous) for laboratory and pilot-scale air classification trials. The laboratory-scale trials were carried out using a Hosokawa Alpine zig-zag air classifier and the pilot-scale trials using a Bradley Pulverizer Windsifter.

The proportion of fines removed by air classification from two of the sites was poor, ranging from 12% to 29% (average of 18%); the main factor causing the lower fines removal figures was insufficient disaggregation of fines during the separation. This highlights one of the advantages of using wet processes; the fines are fully dispersed before separation and they are easier to remove. The other two sites had fines removals ranging from 33% to 84% (average of 58%); this is comparable with the fines removal achieved by air classifiers used in other parts of the world. There are apparently no recorded cases of quarries in the UK using air classifiers as part of the fine aggregate production process. There are a few quarries across the world, mainly in dry parts of the USA, where air classifiers are used to produce manufactured sand; in these cases fines removal is typically 50 to 65%.

In the future, it is possible that crushed rock quarries may adopt air classification to process quarry fines (material finer than 4mm); this would be especially attractive to limestone operations for production of a saleable fine aggregate and a fine-grained by-product (which could find use as agricultural lime or as mineral filler). It seems unlikely that air classification will be adopted by UK sand and gravel operations in the near future; however given the pressure on water resources and technological improvements it may be adopted in the longer term.

1 Introduction

Sand and gravel quarries use washing plants to produce clean aggregate for use in construction; the use of water is a cost effective and efficient means of removing silt and clay. Production of sand and gravel involves washing and scrubbing to remove clay, separation of the sand fraction by screening, grading of the gravel, sand classification and dewatering, and crushing of any oversize gravel to produce a saleable product. Washing removes silt and clay (material finer than 0.063mm), which is present either as surface coatings or as clay bound agglomerates that need to be broken down. The silt and clay is removed using cyclones and settled out in lagoons, from which process water is recovered. Washing plants are being built at some hard rock quarries to upgrade the quality of the scalpings and fines.

The consumption of water by quarrying operations will become more restricted due to changes in the abstraction licensing conditions introduced by the Water Act 2003 (www.opsi.gov.uk/acts/acts2003/20030037.htm). This law aims to ensure the sustainable use of water resources, strengthen the voice of consumers, allow a measured increase in competition, and promote water conservation. The Environment Agency is responsible for implementation of the new water abstraction licensing system. The approval of water abstraction licenses will be through the CAMS (Catchment Abstraction Management strategy) process; this introduces local consultation to help make water resource allocation public, and help balance the needs of abstractors and the aquatic environment (www.environment-agency.gov.uk/subjects/waterres/). One of the key changes is the introduction of time-limited abstraction licences; CAMS will work on a 6-year cycle, with the normal licence period being 12 years. Longer licences, up to 24 years will be considered in exceptional cases; shorter licences will apply where there is pressure on water resources. The impact of the new system could be significant as in certain areas licences may be refused particularly in highly sensitive hydrogeological, hydrological or ecological settings (Lenton & Morgan, 2004). Renewal of licences will depend on environmental sustainability, continued justification of need and efficient use of water. The quarrying industry will need to adopt 'water efficient' processing methods to continue abstracting water.

The use of waterless, and reduced water technologies for removal of fines would not only minimise water use (thus reducing the environmental impact of mineral extraction) but also remove the need for settling ponds and lagoons and enable easier handling of fines (potentially encouraging their use in other applications).

Air classification is a waterless, or ´dry` method that is used in other parts of the minerals industry for the separation of fine and coarse-grained material. This report details the findings of air classification trials carried out on raw material from four sand and gravel quarries; the aim was to determine the technical feasibility of using a waterless method for producing clean aggregate.

This work was carried out as part of the 'Waterless Fines Removal' research project; this was funded by the Mineral Industry Sustainable Technologies (MIST) programme as administered by the Mineral Industry Research Organisation (MIRO). This forms part of the Aggregate Levy Sustainability Fund (ALSF) of the UK Government's Department for Environment, Food and Rural Affairs (Defra).

2 Methods

The air classification trials were carried out using laboratory-scale and pilot–scale equipment. The feed material for these processing trials was collected from four sand and gravel quarries; the name and location of these will remain anonymous (for commercial confidentiality reasons). The moisture content (in-situ and after drying) and the particle-size distribution of each sample was determined (before and after processing). The particle-size data for the feed material and processing products were plotted to determine the degree to which silt and clay had been removed.

2.1 SAMPLE COLLECTION & IN-SITU MOISTURE TESTING

Samples were collected for the laboratory-scale trials (5kg) and for the pilot-scale trials (1000kg); details for each sample are given in Table 1. The samples were taken from stockpiled sand at each site.

Table 1. Samples for air classification trials

Quarry	Operation	Sample description
1	Standard washing plant to produce building and concrete sand	2mm wet-screened sand; Ochre in colour, with small pieces of wood
2	Standard washing plant to produce concrete sand and dry screening to produce building sand	4mm dry-screened sand; Brown-orange in colour
3		6mm dry-screened sand; Red-brown in colour due to Fe-content
4	Standard washing plant to produce building and concrete sand	4mm wet-screened sand Greyish-brown in colour

The ‘in situ’ moisture content of the sand samples was determined using a ‘Speedy Moisture Tester D2’ (Photo 1). The tester consists of a sealable container into which the sample is placed with a small amount of calcium carbide (CaC_2); the moisture contained in the samples reacts with the calcium carbide to form acetylene gas (C_2H_2). The pressure created within the container by the generation of the acetylene gas is proportional to the moisture content; this is read off a pressure gauge attached to the end of the container.

Particle-size analysis was carried out by wet screening a representative sub-sample through a standard sieve series (2mm to 0.063mm). The material retained on each sieve was calculated as a percentage of the whole sub-sample; this was used to determine the proportion of material finer than 0.063mm and also to plot the cumulative frequency particle-size distribution on log-normal graphs.

The moisture content and particle-size data are shown in Appendix 1 (Table 1) and Appendix 2 (Diagrams 1 to 4).

2.2 LABORATORY-SCALE AIR CLASSIFICATION TRIALS

Laboratory-scale air classification trials were carried out using oven-dried sub-samples of sand; all remaining moisture in the sand was removed prior to processing by drying overnight at 80°C.

The processing trials were carried out using a Hosowaka Alpine 1-40 MZM laboratory zig-zag air classifier (Photos 2 & 3); this is a static or gravitational air classifier (www.hosokawa.co.uk/zigzaglab.php). The classifier consists of a vertical zig-zag shaped column within which there is an upward moving current of air. Sample material is introduced into the column one-third from its top using a vibratory feeder. Coarser-grained material is separated from finer-grained material depending on the airflow velocity, and particle-size, shape and specific gravity. Coarser-grained material falls down through the column into a container; whereas finer-grained material passes upwards and is recovered by a cyclone into another container. The velocity of the airflow can be altered to change the 'cut point' of the separation i.e. the particle-size above which particles report to the coarse-grained product and below which they report to the finer-grained product. During the processing trials the optimal airflow rate was determined by repeated separations.

The yield of each product was determined i.e. the weight proportion that it represents of the feed material. The particle-size distribution of the products was determined as for the feed material.

The moisture content and particle-size data are shown in Appendix 1 (Table 1) and Appendix 2 (Diagrams 1 to 4).

2.3 PILOT-SCALE AIR CLASSIFICATION TRIALS

Pilot-scale air classification trials were carried out using air-dried bulk samples of sand; the moisture content was reduced to less than 0.5% in each case. The moisture content was determined by weighing the bulk samples before and after drying.

The processing trials were carried out using a Bradley Pulverizer MS20 'Windsifter' classifier; this is a dynamic or centrifugal air classifier (www.bradleypulverizer.co.uk/winsifter.html). The trials were based at the pilot-scale processing facility of Bradley Pulverizer Company in Crayford, Kent (Photo 4). The classifier consists of an inverted cone with a mechanical rotor wheel and an external fan; the combined effect, of the rotor and the air introduced by the fan, creates cyclonic airflow conditions within the classifier. Coarser-grained particles are flung to the inside wall of the classifier (under the influence of centrifugal force), fall down through the classifier outlet and into the coarser-grained product. Finer grained particles are swept upwards and out of the classifier with the airflow and are recovered by a separate cyclone into the finer-grained product.

Air classification tests were carried out using two different rotor wheel speeds (200 and 300 pm) to determine the optimal fines separation. The air fan was set at 3400rpm. Between 23 and 36kg of 'feed' material were used in each trial; each run taking less than 2minutes. Feed throughput ranged from 885 to 1152 kg/hr.

The yield of each product was determined i.e. the weight proportion that it represents of the feed material. The particle-size distribution of the products was determined as for the feed material.

The moisture content and particle-size data are shown in Appendix 1 (Table 2) and Appendix 2 (Diagrams 1 to 4).

Photo 1. Speedy moisture test 'in situ'

Photo 2. BGS laboratory test work

Photo 3. Hosokawa Alpine 1-40 MZM laboratory-scale zig-zag air classifier

Photo 4. Bradley Pulverizer 'Windsifter' pilot-scale air classifier

3 Results

The data tables in Appendix A show the moisture content and fines content (material finer than 0.063mm) of the feed material. They also show the yield (the amount recovered from the feed material into the product) and fines content of the coarser-grained air classification products, as well as the percentage fines removal.

The moisture content of the *in situ* sand ranges from 3 to 12%; the sand samples dried in the laboratory have no remaining moisture, whereas the bulk samples dried for the pilot-scale trials have up to 0.4% moisture.

The results of the air classification trials are summarised for each sample as follows:

<u>Sand & gravel quarry 1</u>

The air classification products have a narrower particle-size distribution than the feed material (Diagram 1); they have lower fines contents (0.9 to 1.5%) and a higher proportion of coarse-grained particles. The laboratory-scale trial product yield is 91% and fines removal is 44%; for the pilot-scale trial the yield is 88% and fines removal is 72%.

<u>Sand & gravel quarry 2</u>

The air classification products have a narrower particle-size distribution than the feed material (Diagram 2); they have lower fines contents (5.2 to 5.3%) and a higher proportion of coarse-grained particles. The laboratory-scale trial product yield is 96% and fines removal is 12%; for the pilot-scale trial the yield is 93% and fines removal is 29%.

<u>Sand & gravel quarry 3</u>

The feed material and air classification products display very similar particle-size distributions (Diagram 3). The products have lower fines contents (7.4 to 9.0%) and they have the same or a lower proportion of coarser-grained particles than the feed material. The laboratory-scale trial product yield is 94% and fines removal is 20%; for the pilot-scale trial the yield is 99% and fines removal is 12%.

<u>Sand & gravel quarry 4</u>

The feed material and air classification products display very similar particle-size distributions (Diagram 4). The products have lower fines contents (0.4 to 0.5%) and they have a lower proportion of coarser-grained particles than the feed material. The laboratory-scale trial product yield is 98% and fines removal is 33%; for the pilot-scale trial the yield is 89% and fines removal is 84%.

4 Discussion & conclusions

Overall, the air classification trials have had mixed success in removing fine material from the sand samples. The proportion of fine material removed from sites 2 and 3 ranged from 12% to 29%; the average fines removal was 18%. This is a poor result. The main factor causing the lower removal rates is insufficient disaggregation of material finer than 0.063mm; this highlights one of the advantages of using wet processing as material is fully dispersed before size separation takes place. Also, a small amount of moisture present in the apparently dry feed material will cause fines to adhere to coarser particles or form aggregated particles.

The proportion of fine material removed from sites 1 and 4 ranged from 33% to 84%; the average fines removal was 58%. This is a good result and is comparable with that achieved by air classifiers used in other parts of the world (50 to 65%, see below). Air classification products from the trials of material from quarry 4 have a lower proportion of coarse-particles than the feed. At first this appears to be counter intuitive; it is likely that some of the coarser-grained particles present in the feed were aggregated fines, which broke apart during air classification and were removed.

The use of waterless methods for removing fines from quarry materials has yet to be taken up in the UK. An example of the use of an air classifier, outside of the UK, is at Hanson Aggregates Tyrone quarry in Lawrenceburg, Kentucky, USA. This quarry produces manufactured sand for use in asphalt using a Vertical Shaft Impact (VSI) crusher; the crusher product contains 16% ‘fines’ (in this case material finer than 0.075mm). A portable air classifier is used to remove the fines and produce a sand product with 7% finer than 0.075mm (Contantino, 2004); the air classifier used is a dynamic centrifugal separator (www.fisherind.com/Air_Separator.htm). Another example is Sunrock Group’s Butner quarry in North Carolina, USA that adopted the same dry processing technology. This is a basalt quarry that produces manufactured sand for use in asphalt and concrete using impact crushers; the crusher product contains 15% ‘fines’. Two air classifiers are used to remove the fines and produce sand products containing 5 to 6% finer than 0.075mm (Kuhar, 2005).

Other examples of the use of air classifiers to remove fines from crushed quarry material include:

- Bowling Green North quarry (Cemex), Kentucky, USA: a Sturtevant Whirlwind air classifier is used to remove material finer than 75 microns from crushed limestone to produce material for Superpave and aglime as a by-product (Carter, 2002).
- Pompton Lakes quarry (Tilcon New York), New Jersey, USA: a Buell gravitational inertial classifier is used to produce a manufactured sand from granite gneiss quarry fines (Constantino, 2005).
- Thorold quarry (Walker Industries), Ontario, Canada: a Buell gravitational inertial classifier is use to remove material finer than 0.075mm from crushed dolomitic limestone to produce manufactured sand (Bateman, 2006).
- PGI quarry (Hanson), Johor, Malaysia: an air classifier is used to remove the material finer than 0.075mm present in the quarry fines and produce a manufactured concrete sand (Hanson, 2005).
- Plesovice quarry (Kamen a Pisek spol. Sro) South Bohemia, Czech republic: a cascade air separator is used to remove material finer than 63 microns from granulite quarry fines to produce a manufactured sand (0/4mm) product (European Aggregates Association, 2005).

In these cases the main motivation for using air classifiers include the following:

- The lack of available water; many of these quarries are located in dry areas where water use is restricted or has to be transported by truck into the quarry sites
- The desire to avoid the environmental issues that accompany the use of settling ponds
- The need to reduce the amount of fines sent to the settling ponds by the washing plant; in one case, before the use of air classifiers, the settling ponds had to be emptied once a week which was proving to be expensive and required excessive handling of fines stockpiles.

Potential limitations to the use of a waterless approach may include the quality of the final product, and an inability to completely eliminate the use of water. Equally, the environmental and social issues associated with potential increases in dust generation within the plant, and subsequent releases to the external environment (unless mitigated) may to some extent offset the benefits arising from reduced water use and consumption.

The trials described in this report were carried out on material from a limited number of sand and gravel quarries. It is possible that air classification would be more successful at other sand and gravel sites. However, many sand and gravel operations rely on ‘wet’ technology and the material is often naturally wet as extracted. Therefore, for air classification to be effective the feed material would have to be dried; the cost of drying may make air classification economically unfeasible for sand and gravel operations. It seems unlikely that air classification will be adopted by UK sand and gravel operations in the near future; however given the pressure on water resources and technological improvements it may be adopted in the longer term.

A more successful application of air classification in the UK may be in crushed rock quarries, particularly in the processing of ‘quarry fines’ (material finer than 4mm) to produce saleable manufactured sand products. Crushed rock quarries typically use ‘dry’ technology and it may be easier to integrate waterless fines recovery technology into their existing process plants.

It is possible that air classification would provide an efficient means of reducing current stocks of quarry fines, especially at many limestone quarries, producing a sand product and a saleable agricultural lime or mineral filler by-product. Whereas, air classification may be useful at sandstone and other hard rock quarries for producing manufactured sand, the silica-rich, fine-grained by-product currently has no sales outlet and would likely remain a waste material.

Appendix 1 Air classifications trials

Table 1. BGS laboratory air classification trials

Quarry site	Feed material			Air classification product[1]		
	Moisture content[2] (wt %)		Fines content (% <63µm)	Yield[3] Wt %	Fines content[4] (% <63µm)	Fines removal[5] Wt %
	In situ	After drying				
1	6	0.0	2.7	91	1.5	44.4
2	7	0.0	5.9	96	5.2	11.9
3	8	0.0	9.3	94	7.4	20.4
4	3	0.0	0.6	98	0.4	33.3

Table 2. Bradley Pulveriser pilot scale air classification trials

Quarry site	Feed material			Air-classification product[1]		
	Moisture content[2] (Wt %)		Fines content (% <63µm)	Yield[3] Wt %	Fines content[4] % <63µm	Fines removal[5] Wt %
	In situ	After drying				
1	7	0.0	3.2	88	0.9	71.8
2	11	0.3	7.5	93	5.3	29.3
3	12	0.4	10.2	99	9.0	11.8
4	7	0.3	3.2	89	0.5	84.4

1. ‘Air classification product’, this is the coarser-grained product from the air classification trials.

2. Moisture content was determined by Speedy Moisture tester for pilot-scale air classification samples and by oven drying for laboratory-scale air classification samples.

3. ‘Yield’ is the amount recovered from the feed material into the product, e.g. for quarry 1 the laboratory air classification product represents 91% of the feed material.

4. ‘Fines’ refers to particles finer than 0.063mm (i.e. silt and clay grade material)

5. The ‘Fines removal’ is the percentage reduction in fines content relative to the feed material.

Appendix 2 Air classification product size distribution

Diagram 1. Cumulative frequency particle-size distribution of the feed material and air classification coarser-grained products, Quarry 1.

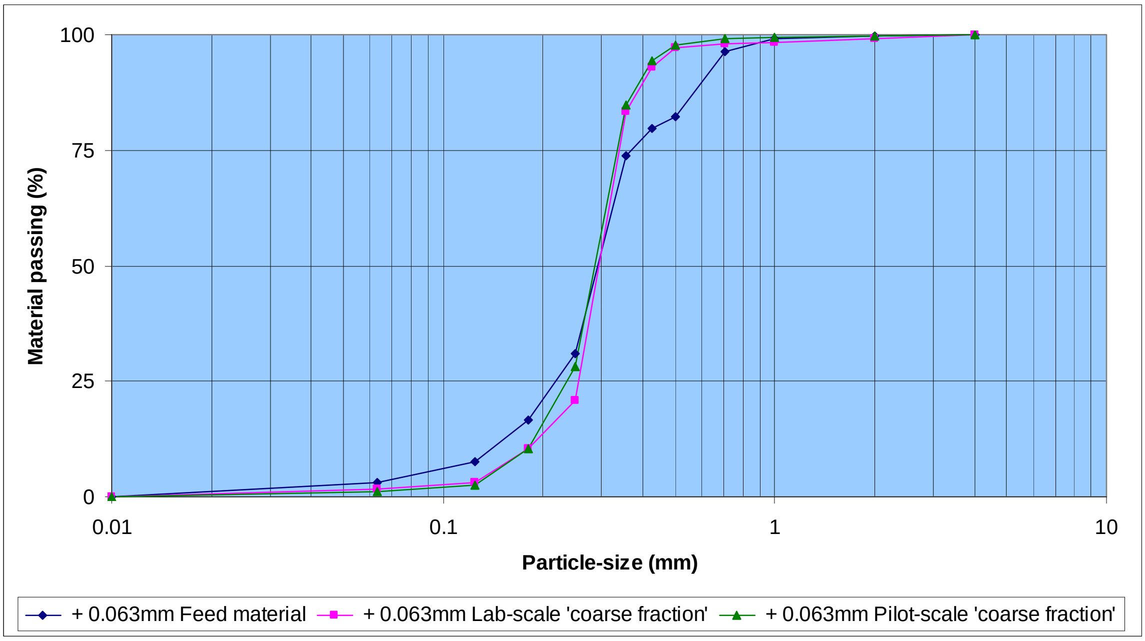


Diagram 2. Cumulative frequency particle-size distribution of the feed material and air classification products, Quarry 2.

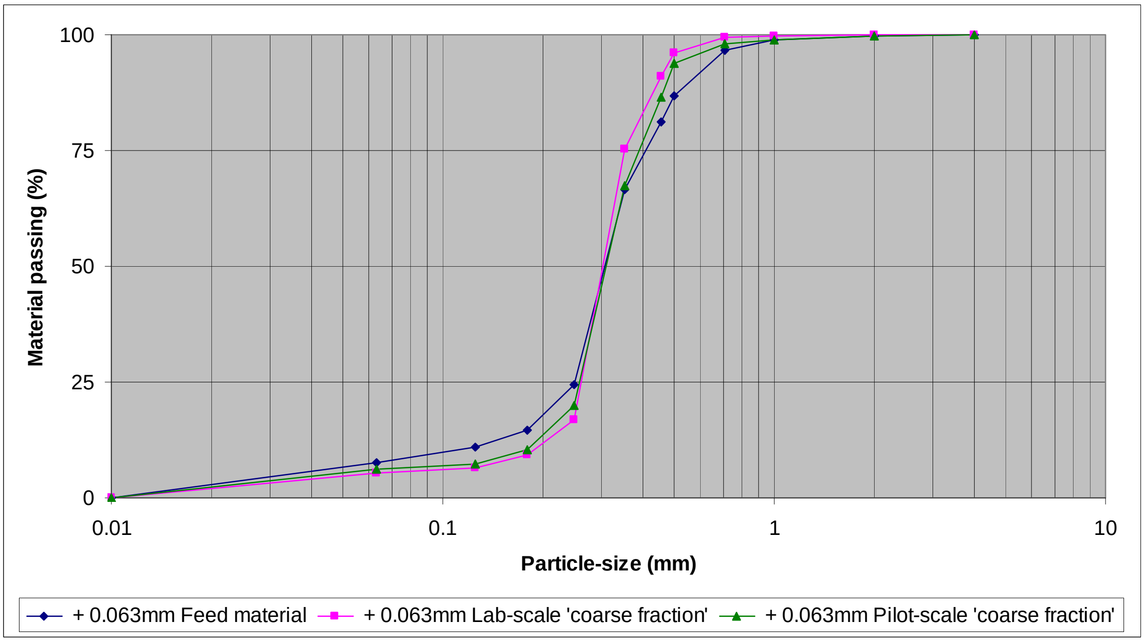


Diagram 3. Cumulative frequency particle-size distribution of the feed material and air classification products, Quarry 3.

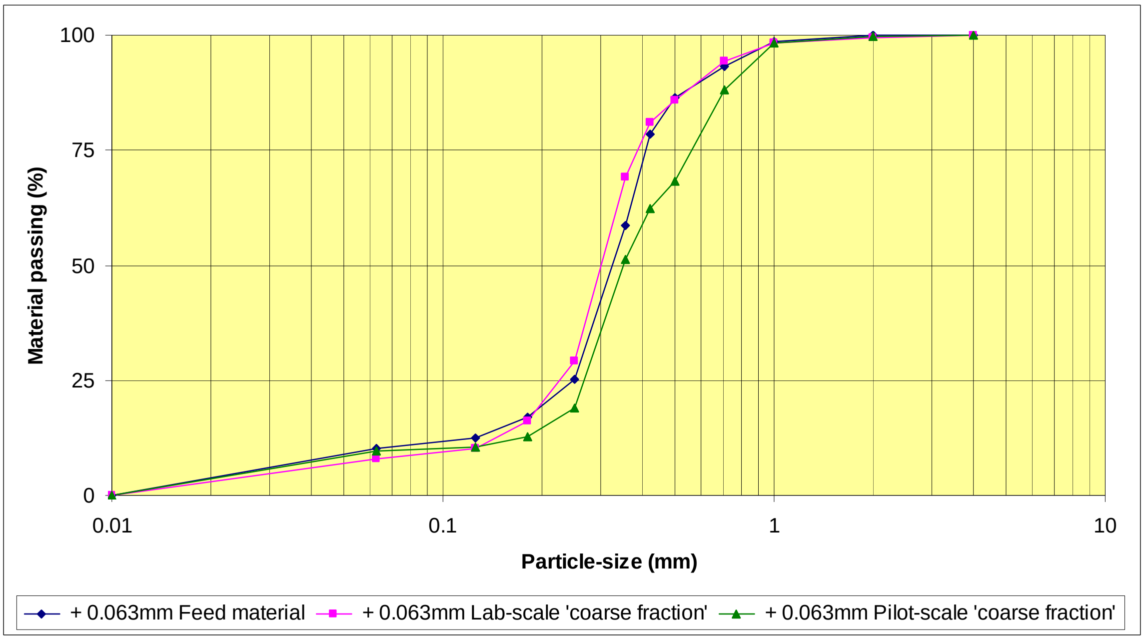
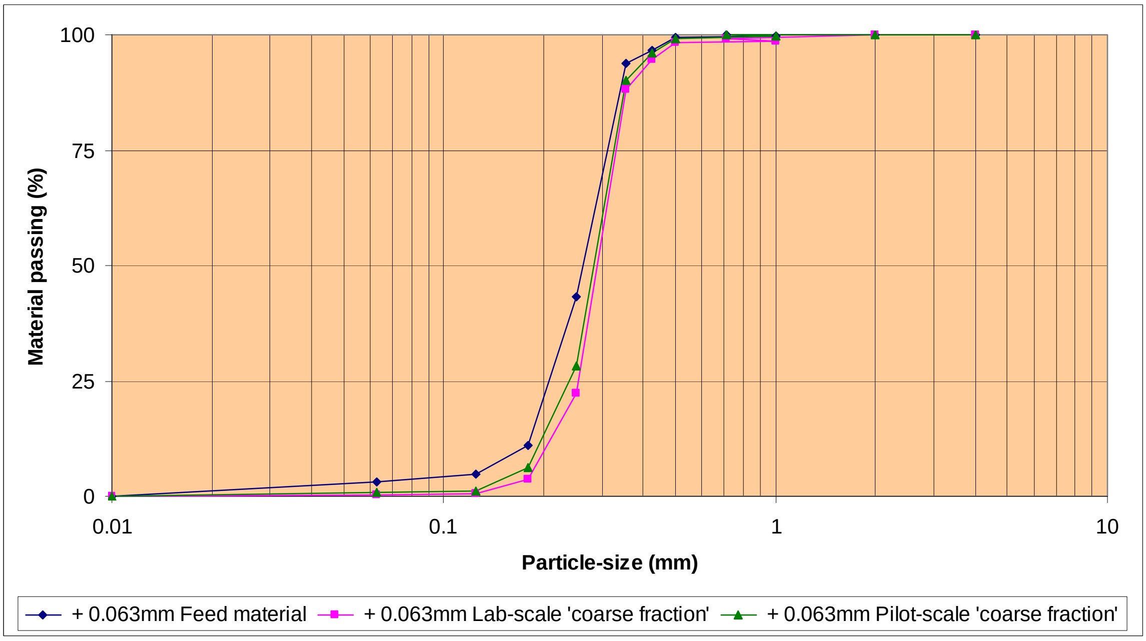


Diagram 4. Cumulative frequency particle-size distribution of the feed material and air classification products, Quarry 4.



References

BATEMAN, A (2006) Air classifier a first for a Canadian quarry www.rocktoroad.com/06on.html

CARTER, RA (2002) Turning dust into dollars. Rockproducts.com/mag/rock_turning_dust_dollars

CONSTANTINO, D (2004) Just (don't) add water. Pit & Quarry, June 2004. www.pitandquarry.com/pitandquarry/article/articleDetail.jsp?id=97684

CONSTANTINO, D (2005) High and dry. www.pitandquarry.com/pitandquarry/article/articleDetail.jsp?id=149440

EUROPEAN AGGREGATES ASSOCIATION (2005) Aggregates Industry and the Philosopher's Stone

www.nesmi.net/downloads/Vanbelle_Aggregates_Industry_and_the_Philosophers_Stone.pdf

HANSON (2005) Making sand in Malaysia

www.hanson.biz/files/pdf/magazine/2005/2005Q2_op.pdf

KUHAR, MS (2005) Less water, less waste. Pit & Quarry, November 2005. www.pitandquarry.com/pitandquarry/article/articleDetail.jsp?id=188913&searchString=quarry%20fines

LENTON, S. and MORGAN, D. 2004. The Water Act 2003. *Quarry Management*, December 2004, 19-20.