COIN

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Review report on dry and wet classification of filler materials for concrete

State-of-the-art

COIN Project report 52 – 2014

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Preface

This study has been carried out within COIN - Concrete Innovation Centre - one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, work on presently eight projects in three focus areas:

- • Environmentally friendly concrete
- • Economically competitive construction
- • Aesthetic and technical performance

COIN has presently a budget of NOK 200 mill over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %).

For more information, see www.coinweb.no

Tor Arne Hammer
Centre Manager

Summary

Due to depletion of natural sand resources in many central locations, it is an increased production and utilisation of crushed sand for concrete purposes. This crushed and processed sand is referred to as; *Manufactured sand*.

Due to high and often variable content of fines (i.e. material less than 125 μm), in crushed sand, it is a necessity to be able to reduce and enable control of the amount of fines. This could be done either by wet- or dry processing of the sand.

This report reviews some of the most common processes for both wet- and dry classification applied for manufactured sand. Some cases of experience in use are reported.

Eventually in the report, a set of factors are discussed when selecting the most appropriate system and equipment for classifying manufactured sand. It is the anticipation that this report will assist aggregate producers in selecting appropriate equipment in order to produce high quality manufactured sand at a reasonable cost.

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1   Introduction

The problems with lack of suitable fluvial and glaciofluvial (natural sand) resources in Norway and Sweden, and many other countries, have become more pronounced during the last two decades. As described in the State-of-the-art report by Wigum and Danielsen (2009), there is an increasing discrepancy between the growing need for aggregates in the society and the available geological sources traditionally used for concrete. As a result, a lot of effort has lately been put into research and development of the crushed sand technology (manufactured sand) - both in the aggregate processing and concrete technology parts.

When producing manufactured sand the excess amounts of fines[1] is the main challenge, and extensive work has been done to find methods to separate and classify the fines from the coarser parts. By use of classification the fines can be separated into higher quality products with known and desired Particle Size Distribution (PSD) curve.

Classification is a method of separating mineral grains by size, form or weight. The grains are separated by the velocity with which they fall through usually air or water. The cut size, d_{50}, characterizes the classification, which is the border between separated fractions (Shapiro and Galperin, 2005).

1.1   Objective

The main objective of this report is to present some different methods for classification of fines as aggregates for concrete purposes. An aim is to give recommendations/guidelines to new producers of manufactured sand with focus on advantages and quality output of the different methods and equipment.

1.2   Background

Traditionally in Norway, most sand aggregates for concrete have been supplied from glaciofluvial sand/gravel deposits. The particle size classification has been limited to dry sieving of the gravel part (+4, +8 or +10 mm, depending on the moisture content). Sand sizes (0/4 or 0/8 mm) have most commonly been used as provided by the nature, as dry sieving of moist sand has proven to be difficult.

Exceptions has been in connection with dry, fine sand production, where heating was applied for drying – often combined with long mesh sieves. Beside this, the concept was mostly to accept the sand grading as it was by nature, and to adjust the concrete mix accordingly. This concept was more or less feasible due to the fact that the grading curve of glaciofluvial sand was mostly relatively well suited for concrete purpose. This origin of Norwegian sands also ensured a fairly clean product with limited need for washing of clay size fractions.

However, there were regional differences depending on geology; bedrock as well as de-glaciation history caused some sand deposits to be too high in fines – while others were too low. As long as the supply of aggregates was sufficient, one could simply afford to let these resources remain un-used.

In Norway a new era in aggregate production came with the construction of the concrete platforms for the North Sea. Significantly higher demands for concrete quality (workability and strength) called for higher requirements of the aggregates. And it became obvious that with high requirements, regional quality differences became important. It became necessary

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[1] The definition of particle size of fines is diverse. According to the EN-product standard EN 12620[i] for concrete aggregates, fines are all material less than 63 μm. ASTM standards have a similar limit of 75 μm. For practical concrete purposes in Norway it is quite common that all material less than or 125 μm are referred to as fines.

to avoid grading variations, and also to start developing tailor made aggregates – grading engineering.

Materials technology, concrete recipes and specifications depend very much on the local geological conditions. In many other European countries methods for engineering the grading curve had been used for many years due to un-suited natural grading and excessive fines/clay. First of all this was wet processing being used especially in connection with river sands and in areas with ample access to recipients. Even though such processing was used with some success in the main aggregate plant for platform construction, it never came into general use – much due to our climatic conditions and environmental regulations.

Also – heating/drying was expensive, which together with long mesh sieve unsuitability with sharp angular materials made dry sieving for sand grading control not very feasible. The real need for sand classifying came with the introduction of crushed/manufactured sand aggregates. If a suitable particle shape should be achieved through many-steps crushing (especially when applying VSI's) the aggregates ended up with very high fines content.

With most hard rock quarries being located at some distance from rivers/seaside, sometimes also in vulnerable areas, wet processing proved problematic from a pollution point of view. This encouraged the development and introduction of alternative dry technologies which could offer grading control of fine grained, dry materials, without getting into conflict with climatic and environmental limitations.

In this report the main focus is on dry processes for classification of filler, but also includes a summarized overview of available wet technology for classification of filler.

Metso has been an important contributor to this report with their technical expertise. Metso is at the moment the supplier with the highest market share of equipment for classification in Norway.

2   Wet processes

2.1   Principles of washing

Washing of sand is a simple physical separation process of high capacity, and is often used in e.g. sand and gravel deposits with clay. The material is disintegrated by agitation with water to disperse the clay/fines. The coarser, denser and rounded particles are directed to the underflow, and the finer, less dense and flaky particles follows the overflow (Smith and Collis, 1993). Typical washers are presented in this chapter. However, it must be commented, that a washer usually is a part of a plant, and never stand alone, see Figure 1. The detailed descriptions of the different equipment are mainly based on contribution from Metso.
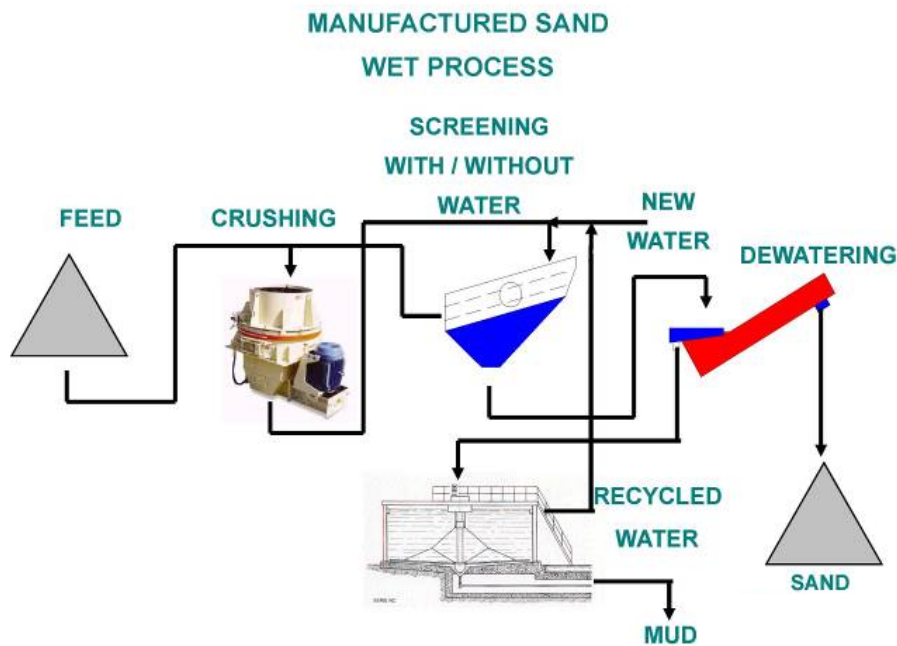

Figure 1. An example of a flow sheet of the wet process in a manufactured plan.

2.1.1 Scrubbers/barrel washers

Scrubbers can be used to wash fine sand, clay and silt from the coarser material. Scrubbers are often a rotating cylindrical barrel with a weak slope. The rotating movement makes the material cascade and conglomerates breaks separating the coarse and fine material. The output can be adjusted with different factors: Lifters and slower speed can make the washing less aggressive, speed of rotation, the direction of the water flow and the volume of the water flow. Scrubbers can give a cut size of 150-180 μm, with a capacity of 80-200 t/h dependent of the size of the devise.

2.1.2 Log washers

Log washers are often used for cleaning and clay removal. The principle of the log washers are two rotating axes in an inclined trough supplied with paddles, strides or sticks. Water and material is fed in the lower part of the trough and is mixed and transported to the upper part of the trough. The fine material is dissolved and leaves the trough with the water. Wet screening after the washing is required because the product will still contain fine particles (clay). The feed size of log washers can be from 2/50 mm and dependent on the size of the device a log washer can wash form 50-300 t/h.
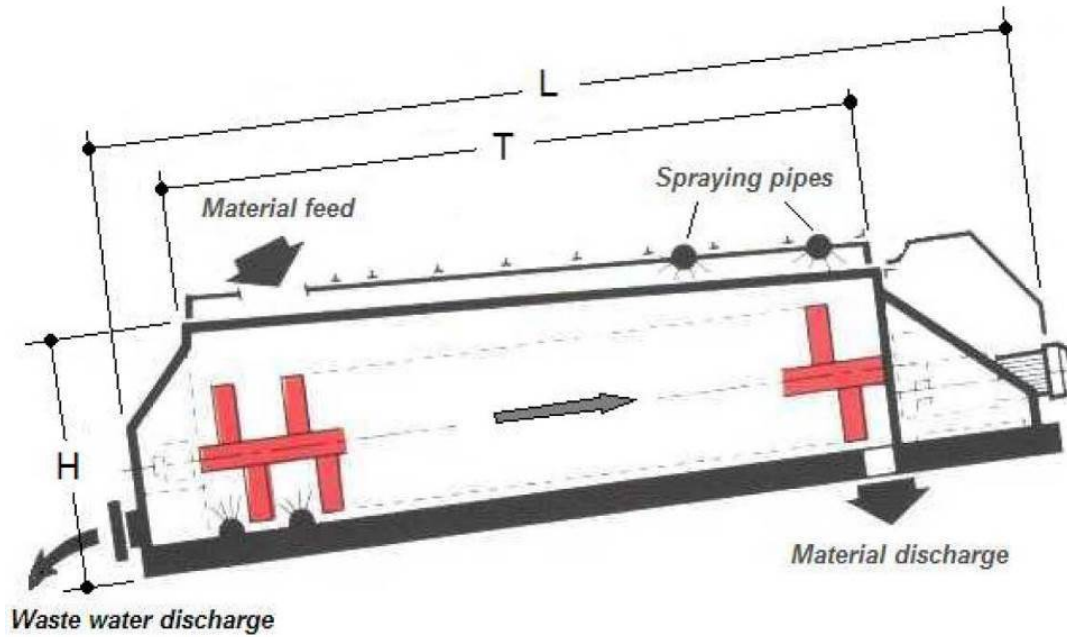
Figure 2. Log washer. Figure from Metso.

2.1.3 Aquamators

Aquamators is another kind of washer where material with different density is separated. The aquamator has an inclined vibrating conveyor and several nozzles for flushing with water. The vibration forces the material with less density to follow the water while the denser material is transported up with the conveyor. Different factors can adjust the output: the speed and amout of water, the speed of the conveyor and the frequenze and magnitude of the vibration.

2.1.4 Sand traps/spiral classifiers

Sand traps are machines that can be used for recovery of sand from the discharge water from dewatering screens and cyclone underflows. Sand traps require low drive power and are distinguished by operation with a minimum of maintenance and wear. In the sand trap, the principle of decantation is used. The slurry is fed into the trap and a continuously revolving spiral moves the sand up a slope. The material enters the trough in a non-turbulent section on the dewatering wheel. The sand then settles on the bottom of the trough. A slow moving spiral transports the material to the dewatering wheel. The waste water flows over a weir at the opposite end of the machine. The dewatering wheel discharges the product into a dewatering screen.

The output can be adjusted with the following factors: speed of the screw, the amount of water and the inclination of the trap. The cut size of the sand trap is normally 100-150 μm, with a capacity of 50-180 t/h.
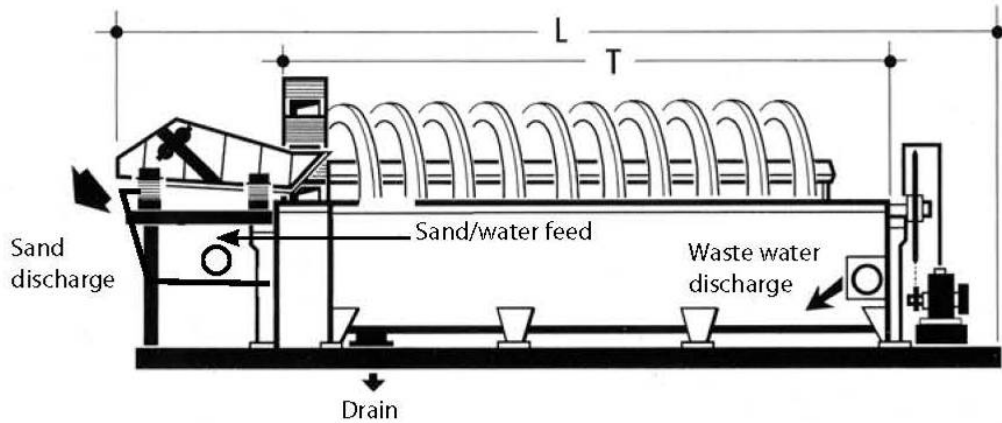
Figure 3. The principle of as sand trap. Figure from Metso.

2.1.5 Dewatering
There are several methods to separate water from fines, and dewatering wheels and screens can be used for this purpose.

The lamella principle uses several parallel inclined plates to maximize the available settling area for any available floor area. In this way, the size and cost of the gravity settler can be minimized by matching the clarifying and thickening requirements more closely. Furthermore sedimentation ponds can be used to separate fines to permit discharge of clean water or for recycling and reuse within the plant. The sediment or silt is usually a waste product, but can also be used in the restoration of the quarry. Filter presses are used for filtering of sludge with low clay content. All these dewatering methods can be used in plants for manufactured sand.

Table 1. Available equipment for washing.

Equipment	Suppliers
Scrubbers/washing barrels	Mc Lanahan Corporation: http://www.mclanahan.com/ The Jet Pump: http://www.jet-pumps.co.uk/ Zhengzhou E.P Machinery: http://www.epmining.com/ Metso: http://www.metso.com/
Log washers	Mc Lanahan Corporation: http://www.mclanahan.com/ Trio: http://www.trioproducts.com/ Grey Stone Inc: http://www.greystoneinc.com/ Gator Machinery Company: http://www.gatormachinery.com/ CDE Global: http://www.cdeglobal.com/ Comec: http://www.comec.it/ Metso: http://www.metso.com/
Aquamators:	Metso: http://www.metso.com/ Rohr Dredge NA, LLC: http://www.rohrdredge.com/
Sand traps	Metso: http://www.metso.com/ Comec: http://www.comec.it/
Inclined plate settlers	Metso: http://www.metso.com/
Filterpresses	CDE Global: http://www.cdeglobal.com/ Comec: http://www.comec.it/ Metso: http://www.metso.com/

2.2 Wet classification

Wet classification is a principle where an external force (e.g gravity) acts upon a mineral particle suspended in a fluid and the particle begins to accelerate in the direction of the applied force. Stokes law is used where the terminal velocity is proportional to the particles size. Particles with the same shape and size but higher density will follow larger particles and particles with the same size but more flaky will behave as finer particles.

Wet classifiers in aggregate production can be devided into gravitational hydraulic classifiers and centrifugal hydraulic classifiers (Hydrocyclones) (Smith and Collis, 1993).

2.2.1 Gravitational hydraulic classifiers
The principle of the gravitational hydraulic classifiers is that a vertical rising current of water is used to classify particles by gravity. A vertical current is established by an incoming feed of sand and water and the finer particles follow the overflow. The size cut point can be adjusted by the feed rate, water injection rate, the height of the overflow and the solid/water ratio. The cut size of such devices can be from 100-1000μm. Dependent of the size of machine and cut size, the capacity can vary from 100-1000 μm.

The sediment/sand is continuously removed from the classifiers, often mechanically with drag links or spiral rakes (Smith and Collis, 1993).
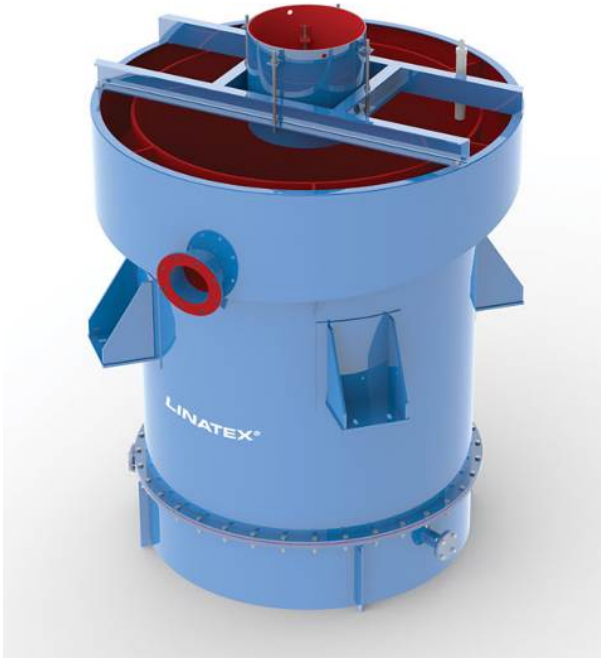
Figure 4. Example of a gravitational hydraulic classifier, here from Linatex.

2.2.2 Hydrocyclones

Hydrocyclones uses the centrifugal force to classify the fines and is a continuously classifying device (Wills and Napier-Munn, 2006).

The principle is that slurry is fed at the top and tangential to the cyclone, and is rotated. The centrifugal forces accelerate the particles to the outer wall of the cyclone and downward into a conical section. In the conical section the fines and the water forced to the middle of the cyclone together with the water, up and out. The coarser particles remain in their downward path along the walls and out through the apex.

There are many factors that are important for the output: dimension of the cyclone, area of the inlet nozzle, vacuum, difference between the pressure at the inlet and outlet, amount of particles vs water, size and shape of the particles and several cyclones can be used together.
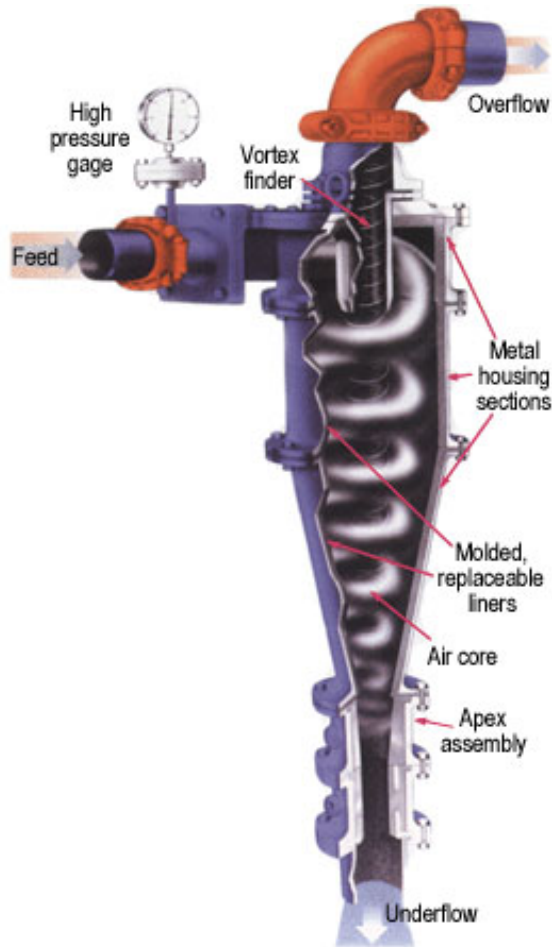
Figure 5. The principle of a hydrocyclone. Figure from Krebs.

Table 2. Available equipment for wet classification.

Equipment	Suppliers
Hydrocyclones	Mc Lanahan: http://www.mclanahan.com/ CDE global: http://www.cdeglobal.com FLSmith/Krebs: http://www.flsmidth.com/ Weir/Cavex: http://www.weirminerals.com/
Gravitational hydraulic classifiers	Linatex (Weir): http://www.weirminerals.com

3 Dry processes

3.1 Air classification theory and practice

Air classification uses air to classify a product by size and form. By accelerating air inside a chamber and adding materials such as fly ash, sand or other minerals into this chamber, one can use the counteracting forces of gravitational and/or centrifugal forces versus the dragging force of the air to create a separation of particles by their combined shape, weight and density.

Coarse particle   **Fine particle**   **Near size particle**

F_d = Air drag force
F_g = Gravitational force particle mass x g
F_i = Inertial drag force provided by the secondary air
F_c = Centrifugal force or the reactional force counteracting the air drag force
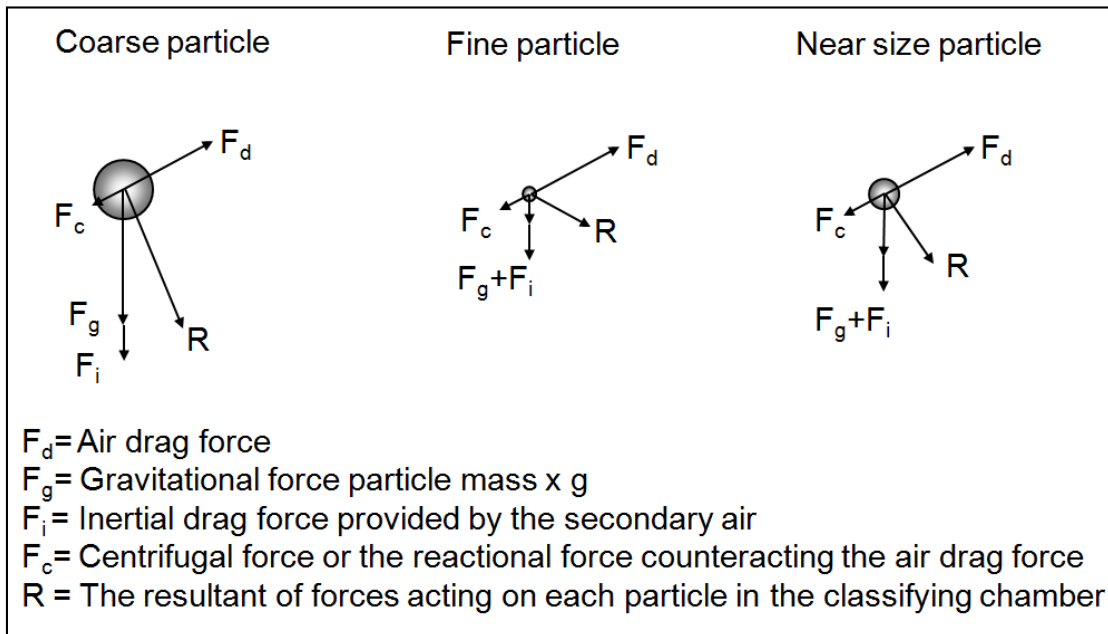R = The resultant of forces acting on each particle in the classifying chamber

Figure 6. Schematic diagram showing forces acting on particles of different sizes in the Classifying chamber of a Gravitational Inertial Air Classifier. The resultant of the coarse particle is pointing downwards and will therefore most probably drop down through the chamber. The fine particle force resultant is pointing more sideways/upwards towards the fines exit opening.

Air classification is a process of approximate sizing of dry mixtures of different particle sizes into groups or grades at cut points ranging from 2 mm to micron sizes. Air classifiers complement screens in applications requiring cut points below commercial screen sizes and supplement sieves and screens for coarser cuts where the special advantages of air classification warrant it. Air sizing is the counterpart of water classification.

Common application parameters
There has been a number of air classifiers developed and used over recent decades. Today the two most commercially successful are the dynamic rotor type and the static types. They are both used in fines removal applications in manufactured sand for asphalt and concrete. They differ in operating principles but they share the same two main parameters for being successfully applied in this type of application:

- Feed material moisture content.
- Material feed rate to total air flow ratio.

The moisture content of the feed material should be considered to be the most important parameter. Most air classifiers perform optimally at feed moisture levels under 1.5-2% (for potentially sticky rock types like limestone the limit is closer to 1-1.5%) Above these levels the fine material that one wishes to remove with the air stream will agglomerate as heavier

particles and the drag force will not be sufficient for separation. A secondary negative effect is that material buildup may occur in feed and discharge openings and cause blockages or disturbing the aerodynamics inside the classifiers. Hence only a short period of operating with high feed moisture content may greatly disturb the continuity and stability of product size gradation. For this reason, mobile systems with its more variable and weather dependent nature have so far proven to be less successful than fixed plants in producing continuous high quality manufactured sand.

The feed rate to air flow ratio is the way the operator can adjust the cut point of the air classifier. Each type of classifier has a typical required air flow per ton for a specified separation. By increasing the total air flow (or lowering the feed rate), a cleaner and coarser sand product is achieved. But because of the approximate nature of sizing, more of the sellable sand product will end up in the fines fraction if this is done. Controlling the feed rate by means of a feed hopper and adjustable (belt) feeder is therefore important if high yield and consistent gradation is required.

3.2   Air classifiers types

3.2.1 Dynamic classifiers
Dynamic classifiers, in which the rotary type is the dominating solution for the aggregate industry, all have in common mechanical, rotating or moving parts in the air stream.

The main advantage with the dynamic rotor type air classifiers is that it has no need for a separate fan and filter assembly. This lowers the investment cost and reduces the machine assembly footprint and makes the system easier to transport in a mobile configuration

The main disadvantage is increased wear cost because the fan blades are moving inside the dust laden air stream inside the classifying chamber. The fan blades will be exposed to relatively high abrasion and wear during operation. In non-abrasive rock types like limestone this is normally not critical but with abrasive rock types like granite or gneiss the wear very often becomes much more significant. The wear on the fan blades will also lead to changes in the aerodynamics inside the classifier and as a result the cut point will change. With this the properties of the manufactured sand will also change and consequently the properties of concrete or asphalt made with this sand.

3.2.2 Static air classifiers
The word static refers to the fact that there are no moving parts in the air stream. The classifying air stream is generated by a separate fan and the fines/filler are collected in a bag filter assembly. This makes it more expensive and complex than the dynamic rotary type classifiers. In return, the accuracy, yield and operational economics are improved, especially in abrasive rock types like granite or gneiss.

3.3   Operating principles

3.3.1 Dynamic air classifiers, Rotary type
A dynamic air classifier is based on a centrifugal-crossflow separation zone with an internal aerodynamic cycle (Johanson, 2011). Usually an air vortex in the centre of a chamber separates the coarser and finer particles. The centrifugal force drags the coarsest particles out to the chamber walls and down while the finer particles are forced to the middle of the chamber and up together with the air, see Figure 7. For aggregate purposes the classifiers should have ceramic liners to reduce the wear. Still there is a challenge that e.g. granitic rocks easily wear the inner walls of the machine.
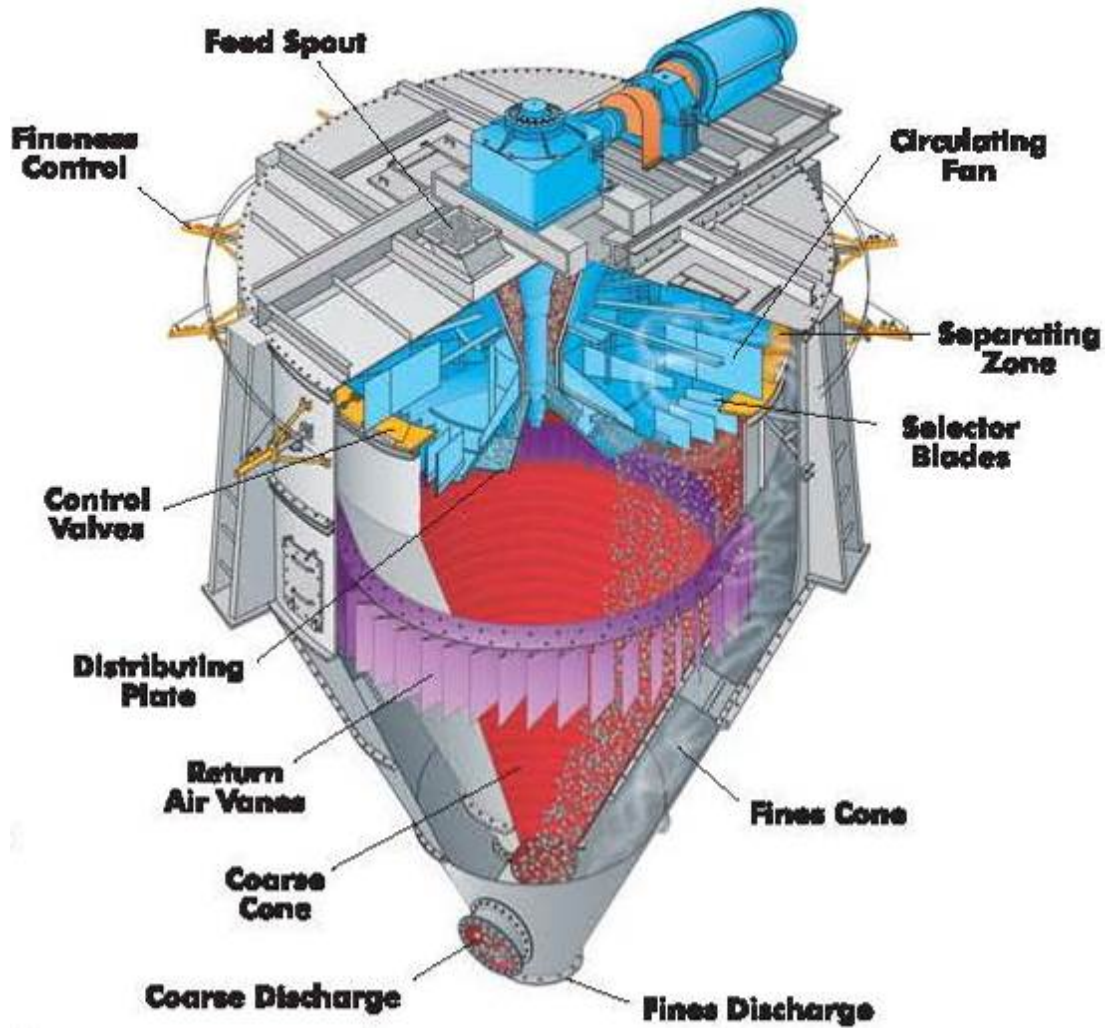
Figure 7. The principle of a dynamic rotary air classifier. Figure from CDE Global.

3.3.2 Static air classifiers

The Buell air classifiers were originally developed in the early 1960's for classifying potash. First unit developed was the G (Gravitational) which was followed by the GI (Gravitational Inertial) and then finally the C (Centrifugal) The operating principles of these main types are described below.

Historically, the majority of units sold in the U.S. have been for asphalt sand. In the U.S., the ASTM asphalt specification sets a target envelope for the amount of minus 75 microns between 5 and 8%.

In 2010 Metso Minerals purchased the air classifier product from Buell and is now the leading supplier of Static air classifiers on a global scale.

3.3.2.1   Gravitational Classifier

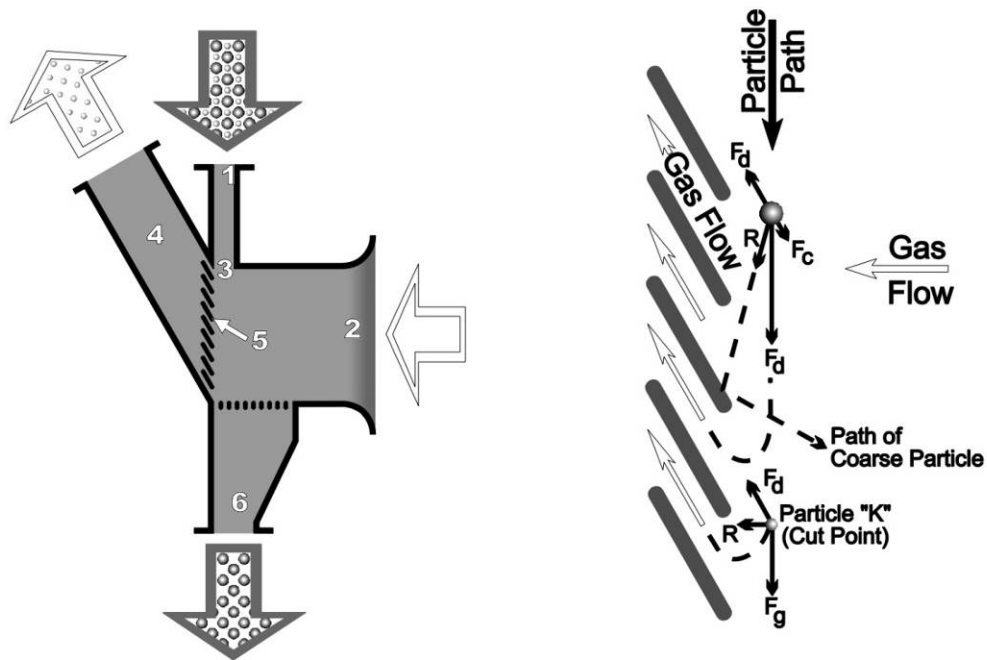The operating principles of the gravitational classifier are demonstrated in Figure 8.

Figure 8. Operating principles for gravitational classifier.

Feed material is dropped in a continuous feed curtain and enters the classifier at the top of the unit (1). Low velocity air enters the classifier at inlet (2) and is forced through the feed curtain (3) which is dropping in front of the air outlet (4) provided with widely spaced vanes (5). The air stream enters the feed curtain perpendicularly, but is changed to an almost parallel, but reverse, direction to the feed curtain as it passes through the vane.

Each particle entering the classifier has a gravitational force (FG) proportional to its mass, which in turn is proportional to the cube of its diameter. The particle is also subjected to a drag force (FD) proportional to the square of its diameter, created by the air flow through the feed curtain. As the particle is influenced by the drag force (FD) and changes direction, it is subjected to a small, centrifugal force (Fc) proportional to its mass, directly opposing drag force (FD). Under set conditions, the resultant force (R), acting on a particular particle diameter (K) referred to as the cut point, will be of a magnitude and direction such that the particle will either be swept through the vanes by the air stream or impinge on the vanes, throwing it back into the feed curtain. The resultant force (r) on particles larger than (K) is in a direction at small variance with the gravitational force (FG). These particles will either impinge on the vanes and be knocked out or will fall directly into the coarse discharge outlet. (6) Smaller particles will have a resultant force (R) almost parallel to the drag force (FD), permitting them to be swept through the vanes and collected by a filter.

Metso gravitational classifiers separate particles at any predetermined cut point between 2 mm to 150 micron (10 to 100 mesh). The cut point is controlled by the air velocity through the vanes, which determines the magnitude of drag force (FD).

Power requirements are extremely low; most energy lost is due to the change of direction of the air stream as it is exhausted through the vanes.

3.3.2.2 *Gravitational-Inertial Classifier*

Gravitational-Inertial classifiers utilize patented classifying principles combining gravitational, inertial, centrifugal and aerodynamic forces. Figure 9 graphically illustrate the operating principles.
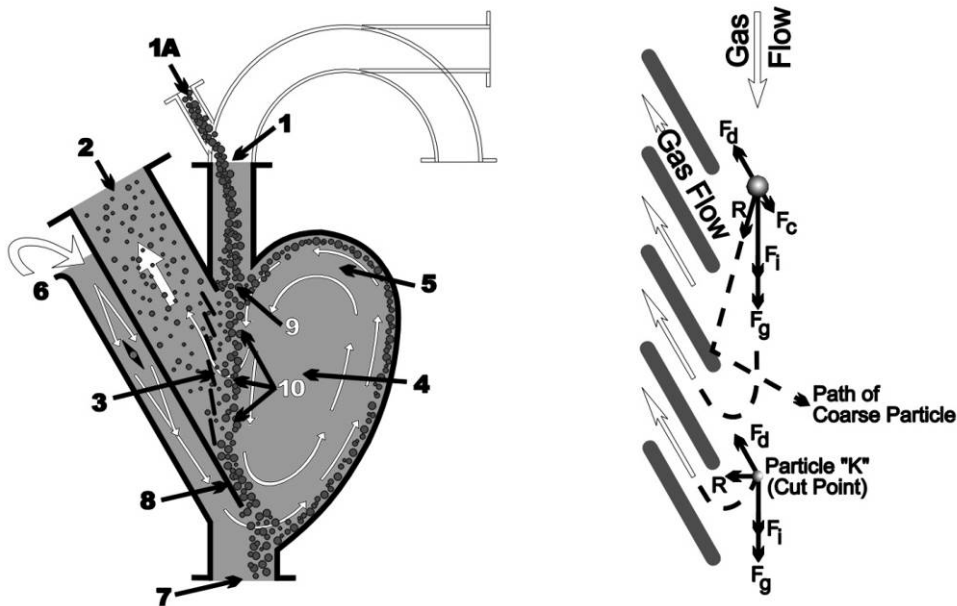

Figure 9. Operating principles for gravitational-inertial classifier.

Air or gas-entrained feed material enters the classifier primary air inlet (1). Mechanically fed material is introduced at point (1A).

The curtain of feed material drops in front of the air outlet (2) which is provided with widely-spaced vanes (3) almost reversing the air flow introduced through the primary air inlet (1). Prior to passing through the vanes, the friction of the relatively high velocity causes the particles to flow in a counterclockwise current (eddy) (5) in the chamber (4).The eddy is reinforced by air entering through the secondary air inlet (6) located just above the coarse discharge outlet (7).

Each particle entering the classifier has a gravitational force (FG) proportional to its mass, which is in turn proportional to the cube of its diameter. As the particle is introduced into the classifier primary air stream, it is further subjected to an inertial force (Fi) also proportional to its mass.

Because the air stream flows in a downward direction, the inertial and gravitational forces (Fi) and (FG) complement each other. As it passes through the vanes, the air stream changes direction, exerting a drag force (Fd) proportional to the diameter of the particle and approximately opposite in direction to the gravitational and inertial forces. As the particle is influenced by the drag force (FD) and changes direction, it is subjected to a centrifugal force (Fc) proportional to its mass, which directly opposes the drag force (FD).

Under design condition, the resultant force (R) acting on a particular particle diameter (K) (cut point) is of a magnitude and direction to cause the particle to either be swept through the vanes or be thrown back into the feed curtain. The resultant force (R) on particles larger than (K) is in a direction at small variance with the gravitational-inertial forces. The

particles will either impinge on the vanes and be knocked out or fall directly into the coarse discharge (7).

The eddy current (5) flowing downward, parallel to the place formed by the vanes, provides a moving wall containing the curtain of feed material in the classifying zone without the detrimental frictional drag effects of a solid wall.

The particles not swept through the vanes fall onto an inclined baffle plate (8) located at the bottom of the air outlet (2) directly beneath the primary air inlet (1). The coarse product is scrubbed by the secondary air as it slides off into the coarse discharge outlet. Secondary air flow dislodges any fines adhering to coarser particles. They join the stray fine particles entrained by the eddy current and are returned to the classifier inlet point (9) and reintroduced into the classifying zone (10).

Metso Gravitational-Inertial classifiers separate particles at any desired cut point from 300 to 63 micron (50 to 230 mesh).The cut point is controlled by the air velocity through the vanes, which determines the magnitude of drag force (FD) and the primary air inlet velocity which determines inertial force (Fi). Varying cut point requirements are met by regulating the inlet velocity while keeping the total air volume, i.e., vane velocity, constant.

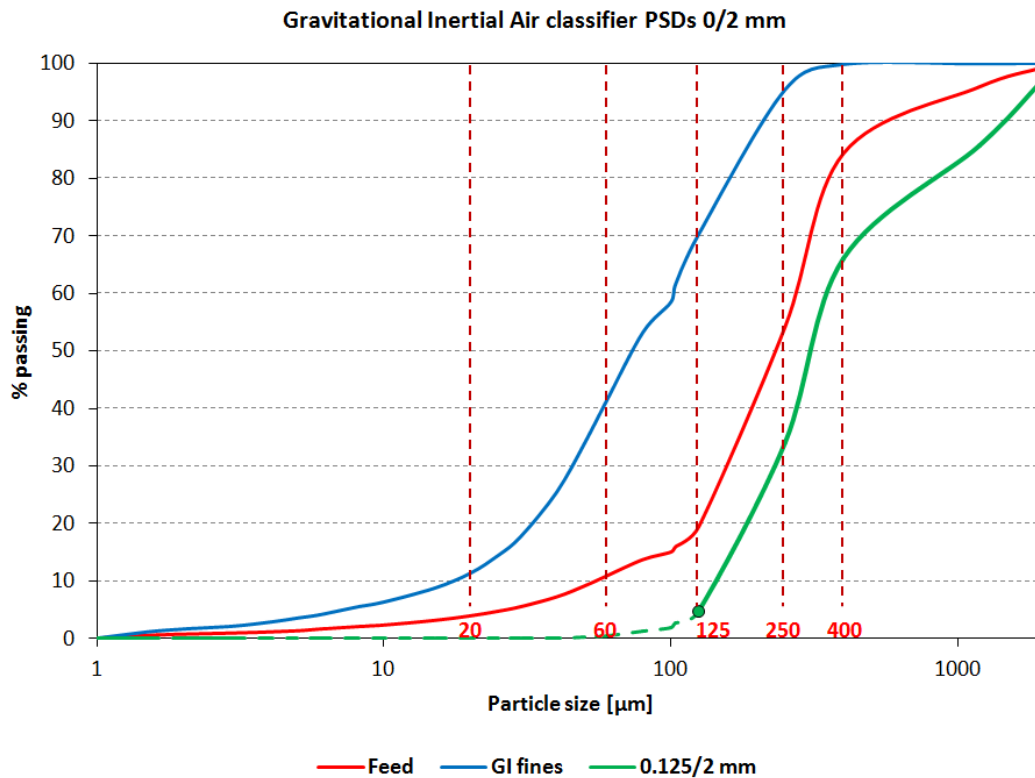**Figure 10. Typical gradation of feed and products of gravitational-inertial classifier.**
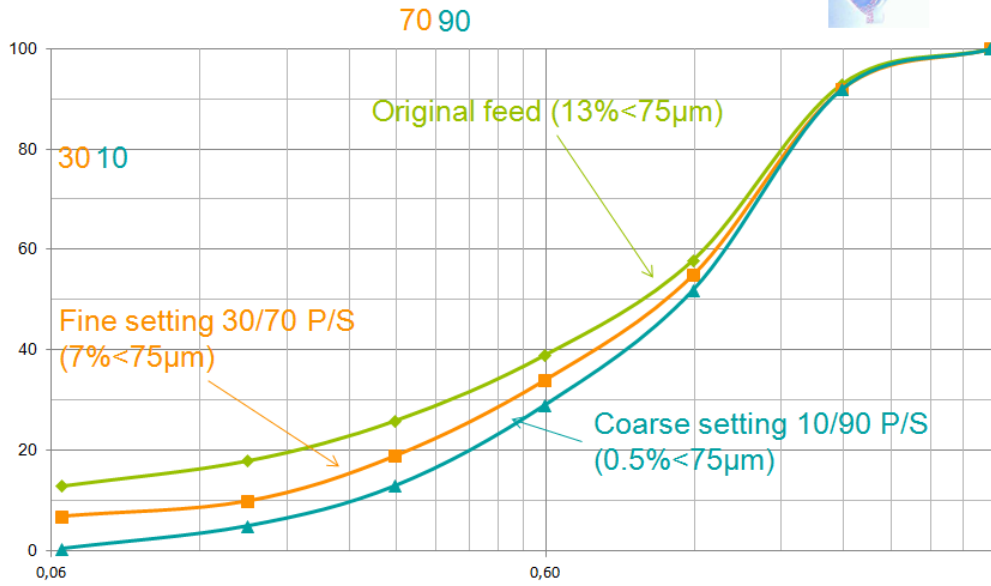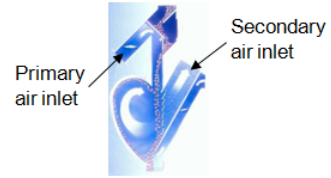
Figure 11. **Typical range of product size distribution by using different ratios of primary and secondary air in Gravitational Inertial Air Classifiers.**

3.3.2.3   Centrifugal Classifiers

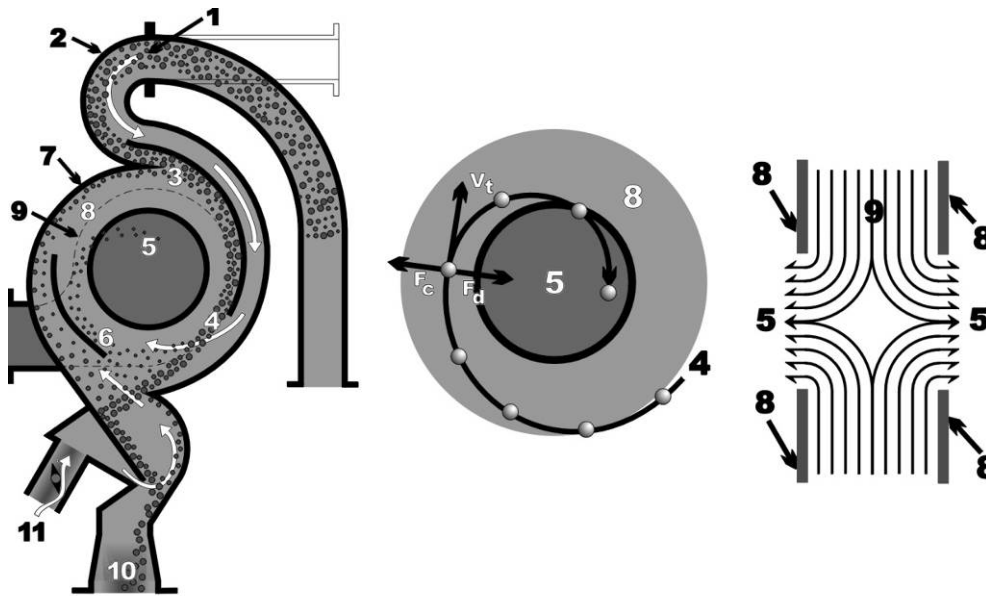The operating functions of the Centrifugal Classifier are detailed in Figures 8, 9 and 12.

Figure 12. Operating principles of centrifugal classifiers.

Feed material and gas (usually air) enter the classifier inlet (1). The connecting duct for pneumatically conveyed material can be positioned from a vertical to a horizontal position to suit layout requirements (see dashed outline Figure 12). Air inlet velocity is approximately 20 metres per second, dependent upon feed material physical characteristics and cut point. Conveying velocity may be higher for pneumatically fed, open air systems, the classifier inlet is flared and the feed dropped directly into the air stream.

The sharp bend (2) behind the inlet separates feed material from the air stream by centrifugal action. The resultant "clean" air stream passes behind a baffle plate (3) against which the feed material is sliding.   The air stream then crosses the curtain of feed material (4) producing an intense scrubbing action which separates fine particles from the tailings, breaks up agglomerates and subjects all particles to an equal drag force.

Gravitational force immediately precipitates any very large particles to the bottom of the classifier. Intermediate and finer particles flow with the air stream in a spiral path around the exhaust orifice (5) and are classified. The baffle plates (3, 6), the classifier outer casing (7), and side plates (8) form a flat, cylindrical classifying chamber (9) through which the air stream spirals inwardly in a two-dimensional flow.

Each particle is subjected to centrifugal force (Fc) proportional to the cube of its diameter, causing the particle to move towards the periphery of the chamber. Concurrently, the air stream is exerting a drag force (FD) directly proportional to the diameter of the particle. Under design conditions, the centrifugal force (Fc) equals the drag force (FD) of a particular particle diameter (K) (cut point). These two opposing forces which are in equilibrium only at cut point separate feed particles into two groups. Centrifugal force (Fc) causes particles larger than cut point (greater mass) to be propelled outwardly, impinging on the peripheral walls; their velocity is slowed; gravity causes them to settle to the bottom of the classifier.

Drag force (FD) causes particles smaller than cut point (lower mass) to be swept inwardly and discharged with the air stream through the orifice (5) where they are collected by a cyclone.

To obtain sharp separation, forces acting on cut point particle (K) must be in equilibrium through the classifying chamber assuring that every introduced particle is subjected to the same separation influence. The centrifugal classifier uniquely meets this requirement with its patented method of introducing feed material and air flow into the classifying chamber to form a controlled vortex with a constant velocity profile. Appropriate classifying chamber proportions and specialized orifice design eliminate detrimental frictional drag effect from the chamber side walls (8) without moving parts.

Centrifugal classifiers separate at any desired cut point from 15 to 100 microns. The cut point is controlled by the vortex flow path steepness, the tangential velocity (VT) and the absolute dimensions of the classifying chamber. The flow path is controlled by the ratio of exhaust orifice diameter to the classifying chamber diameter and the amount of secondary air introduced at the bottom of the unit (11). Customers' varying cut point requirements are met by regulating secondary air flow.
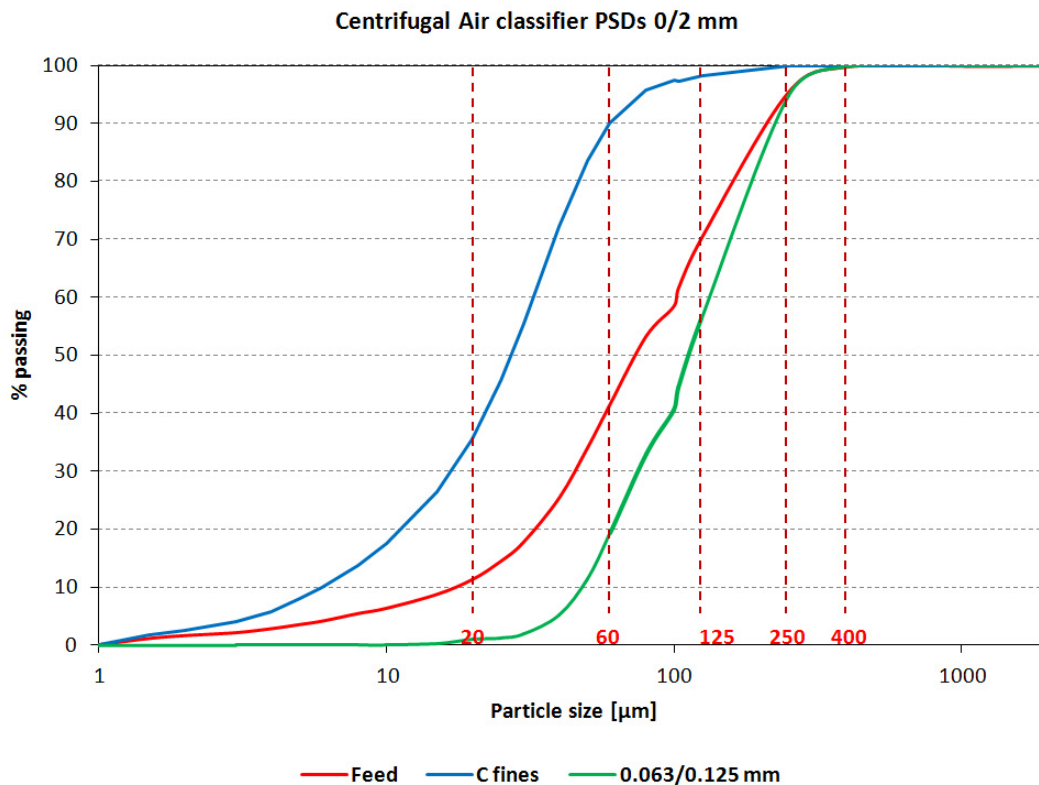

Figure 13. A typical gradation of feed and products from a centrifugal air classifier.

3.3.3 Air screens

Vibrating air screens can be used for separation of fine material. There is also air screen technology using a combination of air and multi deck vibrating screens to separate sand particles available see Figure 14.

The sand-size particles, travelling varying distances according to their size, impinge upon a vibrating screen which sets the top size for the sand. The upper of the two decks acts as a relieving deck to provide increased efficiency and wear life for the lower deck. The airflow is used to regulate the performance of the screen together with a damper, which allows some of the coarser product-size particles to be diverted back to the crusher for further reduction.

This type of air screen has to be used in combination with a specially developed VSI producing partices with grainsize, 150µm – 1 mm particles as the basis of a complete sand-making system. The capacity of such a system could be up to 250 tons/h (Pettingell,2008).
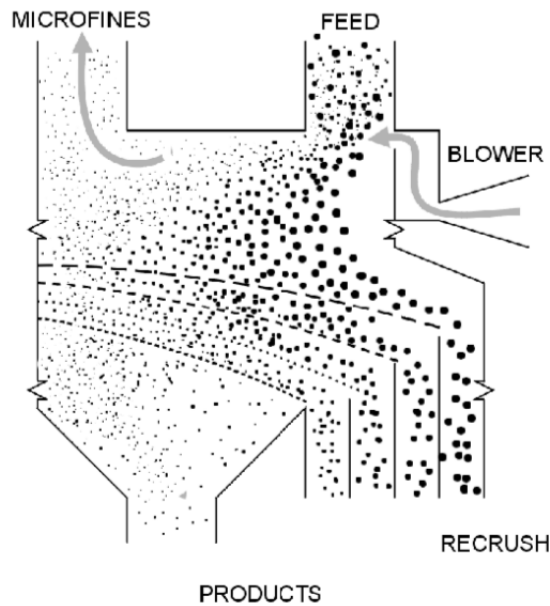
Figure 14. The principle of a multi deck air screen. Figure from Hugo Pettingell/Kemco.

Table 3. Equipment for air classifying.

Equipment	Suppliers
Dynamic rotary air classifiers	Metso Gyrator: www.metso.com Fisher Air separator: http://www.fisherind.com/ CDE Global Sirocco:
Static Air classifiers	Metso Gravitational Crossflow Classifier, Metso Gravitational Intertial Classifier and Metso Gravitational Centrifugal Classifiers: www.metso.com
Air screens	Kemko V7 Dry Sand Making System: http://www.kemco.co.jp/eng/

4   Experience in use

Some selected cases are described and discussed to illustrate the use of different processes and equipment, and to present lessons learned from some quarries where the conditions and requirements as well as user philosophies differ.

4.1   Wet processes

Wet processes are predominant in sand production from alluvial and glaciofluvial deposits. Voluminous records could be produced showing the use of advanced wet processing equipment on barges in the large rivers and in major sand/gravel deposits on land, partly for fines removal, partly for classification to improve the grading curve. In Norway the pioneering plants with wet classification of large volumes of natural sand where the quarries supplying the off-shore platform and export markets – respectively Tøtlandsvik and Årdal in Rogaland. These plants probably also served as examples for the later development of processing plants in hard rock quarries.

However, the present report is dedicated to hard rock quarries and the processing of crushed aggregates. So processing of natural sand/gravel will not be further discussed.

To our knowledge wet processing for classification/grading design of crushed sand is very rarely applied in Scandinavian quarries. Maybe the process for fines reduction in the large Jelsa quarry could be as close as we come to large volume grading design of crushed sand by wet methods (4.1.1), while an effort of small scale classification (4.1.2) at Blentarpstäkten should also be mentioned.

4.1.1 Norsk Stein, Jelsa -washing

Norsk Stein at Jelsa in Norway has a yearly production of 10 mill tons of crushed aggregates. The material is screened in a dry process down to 2 mm, see Figure 15. The < 2 mm material is handled in a Metso sand trap, where the finest particles follow the water discharge and the coarsest particles are transported to a dewatering screen. The capacity of the sand trap is 200 t/h.

The amount of water in the sand trap defines the cut size. The cut size for the filler classification is 0.06mm. The classification is inaccurate but the filler content can be adjusted from 18% down to 7% or 4 %. After the screen the 0.06/2 mm is dewatered in stock piles.

The filler content is adjusted at shipping according to the request from the customers. The discharged water is pumped into a sedimentation pond. The overflow from the sedimentation pond is recycled into the sand trap.

In general there is a challenge to sell the 0/2 mm material, especially the unwashed 0/2 mm materials with up to 15-20% filler. The washed 0.06/2 mm material with approx. 4-8 % fines has a larger market. But still the plant at Jelsa deposits 150.000 tons/year of 0/2 material.

The company has not at the moment any plans to invest in equipment to process the 0/2 material, since there is no demand for such material. An increase in the market for manufactured sand would however justify such an investment. For Jelsa a wet processing plant would be the most probable solution.
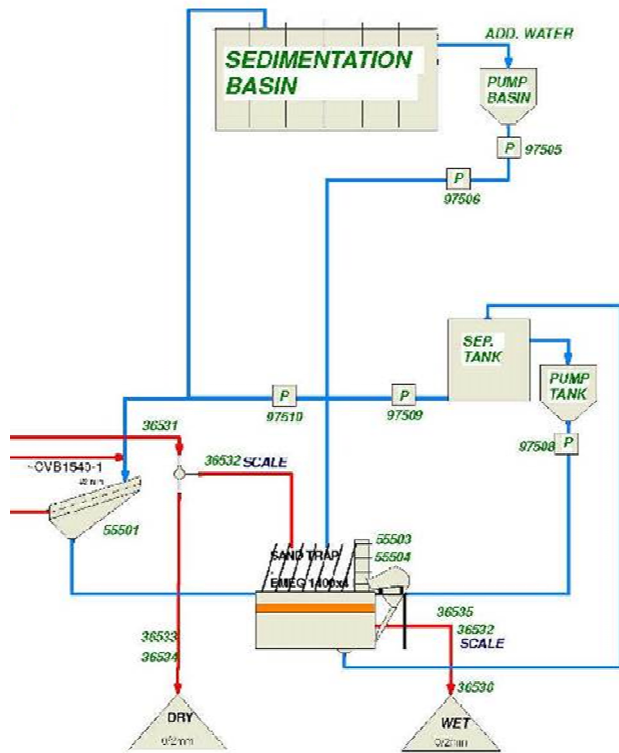
Figure 15. A flowsheet showing the tertiary plant including the washing plant at Norsk Stein, Jelsa.

4.1.2 Blentarpstäkten, Swerock, Sweden – wet classification

Swerock's plant in Blentarpstäkten in Sweden is a small plant with a production of 60.000 tons/year of crushed rock. ¼ of this is fine grained material. In 2005 the company installed two Comec hydro cyclones.

The crushed 0/4 mm is transported to the two hydro cyclones, placed in series, where the material is separated into different sizes by use of centrifugal force.

The most important ruling factor is to keep the feeding as constant as possible to get a precise separation. Other important factors are the speed in the hydro cyclone and the size of the nozzle.

The fines from the hydro cyclone are then transported to a thickener, where the sludge is worked into a concentrate. The centrifugal force presses the material to the walls of the tank and the material is then scraped down to the bottom of the tank. The sludge is pumped to a filter press. In the filter press the water is pressed trough a filter and the material is concentrated. The water is reused as process water. Remaining fines are deposited at the plant.

At the moment the concrete industry does not buy any material from Blentarpstäkten, but for other applications the market is good. Swerock is optimistic on the future prospect for wet classifying of crushed sand.

4.2 Dry processes

Dry processing of crushed aggregates has become more and more developed and used during the later years. Important reasons are climate (to avoid winter problems with water) and the fact that many quarries are located in a way that makes access to recipients and handling of excess water and sludge difficult. Besides, the novel processing equipment has proved very efficient in controlling fines content as well as designing sand grading curves. Four cases will be presented, which in each individual way constitute state-of-the-art in the aggregate business.

4.2.1 Velde Pukk, Sandnes, Norway   - air classification

Background

In 2008, Velde started the operation of a new industrial sand and aggregate plant that had been added to the existing conventional crushing plant. The purpose was to serve both an asphalt and ready mix concrete plant as well as potential external customers with manufactured sand and aggregates. By using a Vertical Shaft Impact crusher (VSI) the particle shape of 0/22mm aggregate is further improved from the preceding four stages of conventional jaw- and cone crushers. As a result of the particle shaping, the 0/2mm sand contains too much fine particles to work optimally in conventional asphalt and concrete. Therefore, an Air Classifier system has been incorporated at the end of the screen line to process the 0/2mm sand. The sand is classified in two steps into sand (0.25/2mm) and two filler[1] fractions: 0.063/0.5mm and the finest 0/0.063mm. All fractions are stored in silos of 600 tons each, and two separate dosage lines provide any given mix to either asphalt, concrete or industrial sand and aggregates for external customers.

Figure 16. The centrally located silo system for storing of the 8 fractions for asphalt, concrete and industrial sand for external customers.
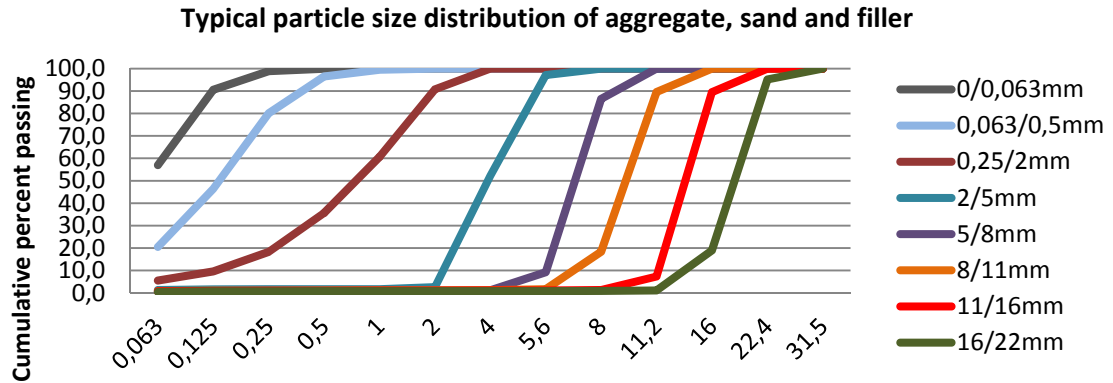
Typical particle size distribution of aggregate, sand and filler

Figure 17. Summary of the particle size distribution of the eight fractions of sand and aggregate end products.

Air classification system description
The air classification process used at Velde Pukk is a combination of the Metso static air classifiers as described in chapter 3.3.2 arranged in series.

As can be seen in figure 18, the air classification system uses a fan to generate an air flow which is regulated by a main valve and adjusted by inlet valves to classify sand. By gravitational and centrifugal forces heavy particles are drawn downwards and finer particles are carried upwards by the air stream. Three products are made and the cut point and gradations are affected by the following parameters: 1) The feed rate of the ingoing material. 2) The product size distribution of the feed material 3) The moisture content of the feed material. 4) The setting of the air inlet valves and finally 5) the total airflow adjusted at the main fan valve. After two years of operating this type of system some experiences has been made on how to achieve a good continuity of the gradation of the different products. After an initial setup and trial period the internal air inlet settings were fixed and are never changed during operation. The gradation of the feed shows very little variation over time. Parameter no. 3, moisture content of the feed, has shown to be the most important parameter to the end result of the classification and a lot of focus is put on this in the daily operation. The target operating range is from 0.5% to 1% moisture, with an absolute maximum of 1.5% There are two ways to adjust for changes in the moisture content: Increasing or decreasing either the total air flow or the feed rate. Experience so far shows that changing the feed rate, is the most practical way. Installation of a moisture sensor and belt scale on the feed material conveyor enables good control of the process. Heating of the inlet air can also have a positive effect on the stability of the process.
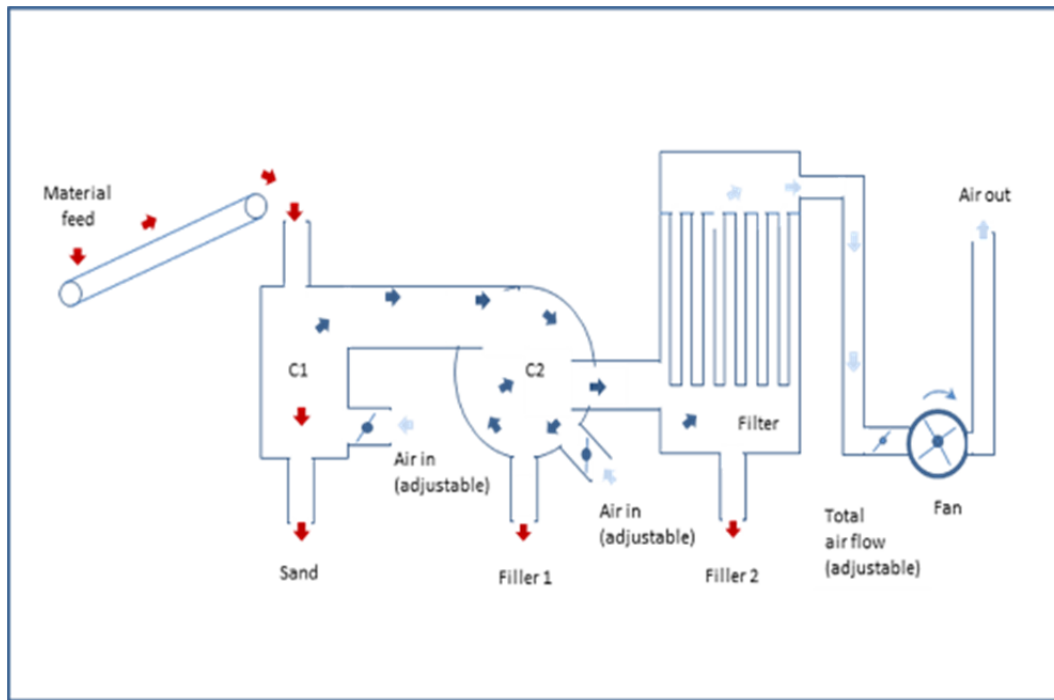
Figure 16. Schematic diagram of the air classifier system. Detailed description of the operating principles of C1 (gravitational inertial classifier) and C2 (centrifugal classifier) can be found in chapter 3.3.2.

Advantages

The main advantage with this process is the flexibility it offers for optimization of asphalt and concrete mix design. The dry system provides products which can be easily mixed and batched since they are dry. Especially for the two finest filler products, dry end products are a major advantage as they have a big impact on the rheological properties of asphalt and concrete. The two stage classifying process ensures waste fines are kept to a minimum. The finest fraction has only 2-5% of particles bigger than 250 microns. This means the particle range 250-1000 microns stays in the sand and coarse filler. This is important in concrete and mix design, especially for manufactured sands which may have a lower concentration in this particle range compared to natural sand.

Another advantage is the continuity of the products in terms of moisture content and particle size distribution. Once the system has been tuned in and the feed moisture content is kept within a range of 0.5-1.5% the static air classifier system will provide continuous gradations of the end products. This is because it has an external fan generating the classifying air stream and no fan blades moving inside the highly turbulent and abrasive environment inside the classifier. As fan blades wear, the air stream they generate will change, and so will the product grading.

Challenges

The first and most obvious challenge for anyone considering this process is the investment. The system is more complex than non-static air classifier as it contains two separate classifier bodies which are lined with ceramic tiles to give a long service life. In addition to the classifier a fan and bag house filter system is needed to generate the air stream and collect the filler fraction. This gives a considerably higher investment.

Secondly the number of adjustment possibilities of operating parameters may provide a challenge to anyone who are not prepared to make a thorough tuning at the startup of the plant and study the properties of the sand and filler in the concrete and asphalt end product.

Finally, if the moisture content or feed rate changes during operation, the end product gradation will fluctuate. The main motivating factor to set up a system like this is most probably the ambition to make a high class manufactured sand for concrete. With this come high demands on continuity from the end user. This cannot be achieved if care is not taken in the design and operation of the preceding stages of the crushing and screening plant. It is important to not allow the 0-2mm sand to be too wet (or too dry!) The working range of 0,5 to 1.5% moisture content may give dust problems at the rest of the plant. Instead of using water to suppress the dust, one will have to think about covering and encapsulating crushing and screening equipment. This adds to the total investment.

4.2.2 NCC Stenungsund – Air classification

The NCC plant at Stenungsund at the south west coast of Sweden had a big challenge with increasing amounts of useless 0/2 sand that was deposited in the quarry. To solve this, the company decided to invest in a classification system for the 0/2 material in 2007, despite the fact that they did not have any customer demands on new products. A 75 ton per hour Metso Buell air classification system was installed.

A Gravitational Inertial classifier is used to classify the 0.5/2 mm. The -0.5 mm is then transported to a C Classifier (centrifugal) for separation of the 0.063/0.5 mm and -0.063 mm, see figure 19. The capacity of the station is: 50-75 tons/h and it requires maximum moisture content of 1.5-2 %.
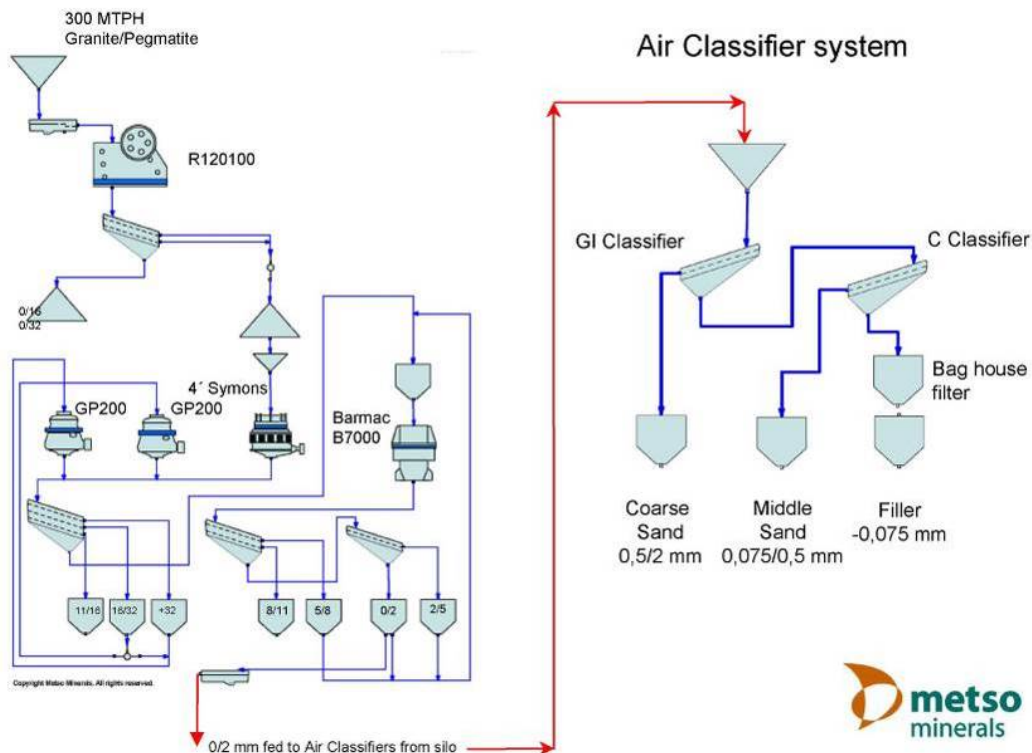

Figure 19. The flowsheet of the NCC Stenungsund plant where an air classifier system is installed.

Figure 20. The Metso Buell GI Classifier.

Figure 21. The Metso Buell C-classifier.
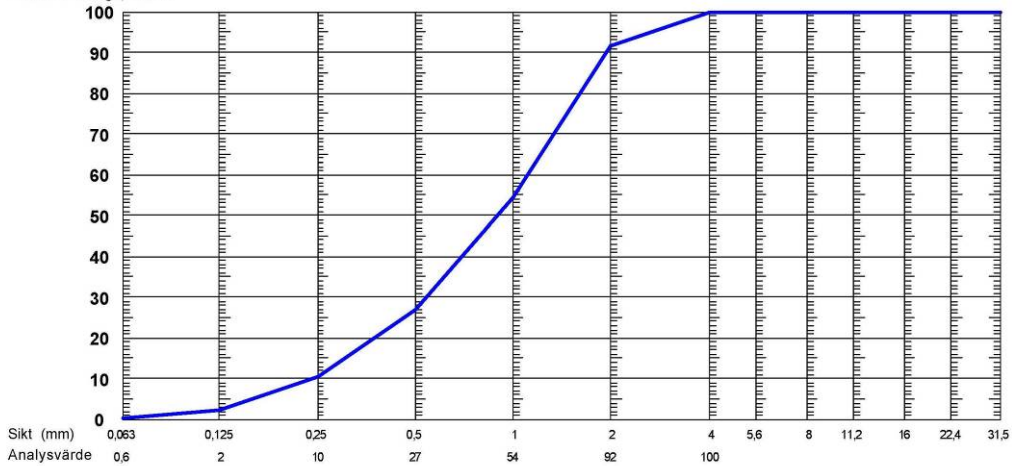
Figure 22. The grain size distribution of the output from the GI classifier, 0,5-2 mm .
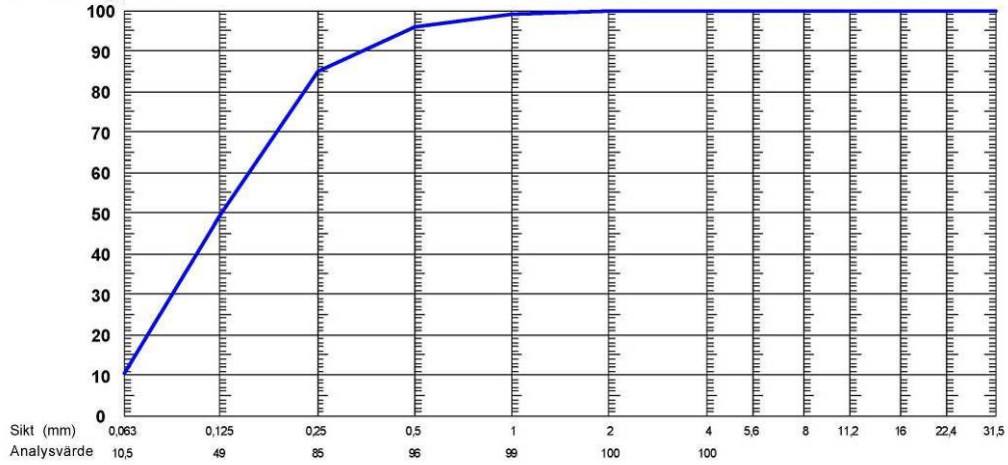
Figure 23. The grain size distribution of the output from the C-classifier, 0,063-0,5 mm.
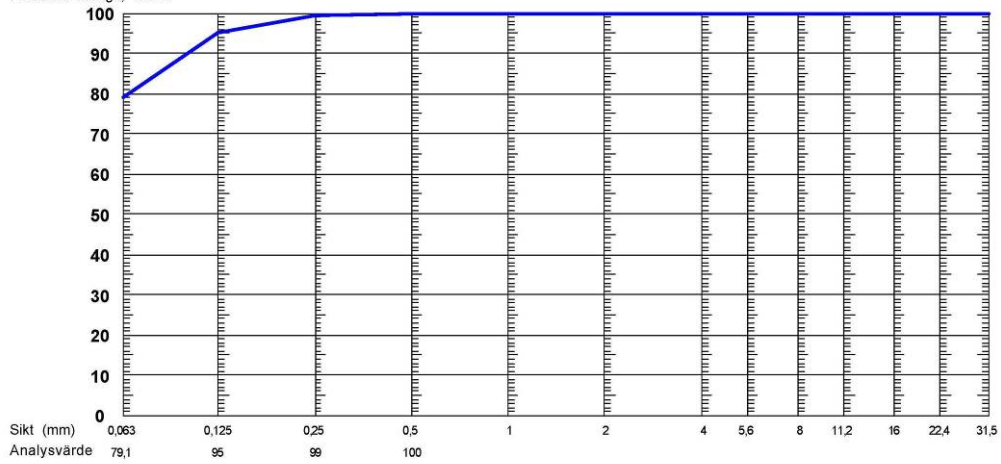

Figure 24. The grain size distribution of the filler (-0,063 mm) output from the C-classifier.

In the beginning NCC Stenungsund had large challenges to overcome the skepticism for a new, unknown product and it was not until 2012 that a ready mix concrete company started to use their filler products. The air classification system now produces 0-2 mm sand to a nearby ready mix concrete factory, who have replaced almost all filler with the products from NCC Stenungsund. Now the plant does not only have local customers, but also producers of pavement stones more than 100 km away.

The plant has now started to see if it could be possible to produce even tighter curves with the installed Air Classification system, and to see if this product can be introduced in new markets.

4.2.3 LuckStone – air classification

Luck Stone Corporation is one of the largest family-owned and operated aggregates companies in the US with seventeen locations in Virginia (VA) and North Carolina (NC). The company has a long time experience with producing manufactured sand for asphalt purposes by utilizing Metso's (previously Buell) static Gravitational Inertial (GI) air-classifiers for fines below 75 μm (#200 mesh) removal. The first 90" unit for manufactured asphalt sand production was installed in 1993 at their northern Virginia Leesburg Plant and as the asphalt sand market grew the second GI was added. In 2007 the two 90" units were replaced with 108" units to increase capacity. Today 7 out of their 17 quarry locations are equipped with Metso's static air-classifiers.

In 2005 Luck Stone came up with a solution where the GI air-classifiers are adopted also for high quality crushed sand production which has been introduced to the market as the ADVANTA® Engineered Concrete Sand. The production began at their Goose Creek plant and the concept included improving the particle shape by VSI crushing, followed by fines removal with two parallel AC22.5GI air-classifiers from Metso. In 2013 the ADVANTA® sand production by utilizing the same principles was introduced also in Luck Stone's Leesburg plant (VA) by adding a VSI shaping crusher to the existing air-classification circuits. Figure 25 shows the dual AC22.5GI units at the Goose Creek plant while on Figure 26 a view of the inside of the classifier chamber (also called the "half-heart") of one of them is visible. As it can be seen from Figure 26, all inside of the chamber is covered with ceramic linings. The rock type in the Goose Creek deposit is diabase– a dense, igneous rock with a greenish-black to bluish-black colour. Diabase is composed mainly of pyroxene, a dark mineral containing iron, and plagioclase, a lighter mineral in weight and colour. Other minerals lending it its green-black colour are epidote (green) and hornblende (black). Two things are of matter to this respect. First the diabase rock is hard and abrasive (in contrast to limestone for example) with a LA value of 14%, however, after 8 years of operation (since 2005) there has not been a need to replace the ceramic linings. It was though noted by the Luck Stone engineers at the Goose Creek plant that some other parts of the classifier feeding system might be worn out due to lack of/ not properly placed linings. So care must be taken when designing the whole classifier installation. Also in Luck Stone's very first GI installation (1993) in the Leesburg Plant, operating with the same type diabase rock, even after 20 years of operation most of the ceramic lining tiles are still original. Another important note with regard to the rock type at Goose Creek plant is the lack of mica minerals that are normally abundantly present in most rock types used for aggregate production in Scandinavia. Free mica particles in the finest sand fractions are not only harmful for the fresh and hardened concrete properties but can also have special behaviour with respect to the air-classification due to their physical characteristics, i.e. the very flaky particle shape.

Figure 25. The dual Metso's AC22.5GI air-classifier units at Luck Stone's Goose Creek plant

Figure 26. Ceramic linings and vanes inside one of the GI classifier units in Figure 2, after 8 years of operation the wear of the linings is still negligible

Figure 27 shows a picture of the ADVANTA® Engineered Concrete Sand of size 0/4.74 mm (up to #4 mesh). Nominally the aim of air-classification is to reduce the amount of fines (below 75 µm or #200 mesh) generated by the rock crushing process (including shaping in the VSI) from the typically initial 12% to approximately 5% which is the maximum amount allowed by the ASTM C33 "*Standard Specification for Concrete Aggregates*" for manufactured fine aggregate that is to be used in concrete not subjected to abrasion. This is, however, not the optimal amount, which according to Luck Stone's experience would be around 8 or 9% passing the 75 µm sieve (#200 mesh) to assure the best performance in

concrete in case of the ADVANTA® sand. When using the GI air-classification units for manufactured asphalt sand production the target of minus 75 µm (#200 mesh) is usually also set to 5%. Some typical gradings of the crushed concrete sand before and after the air-classification are presented in Figure 28. Thus Figure 28 shows a typical feed coming from a VSI as being further fed to the dual AC22.5GI units to produce a typical grading of the product, i.e. the ADVANTA® Engineered Concrete Sand.

The capacity of the dual air-classifiers is up to 100 tph sand, producing both ADVANTA® Engineered Concrete Sand as well as mineral filler (the minus 75 µm or #200 mesh material). The sand plant fines (i.e. the minus 75µm or #200 mesh) that has been removed by the classifiers and is separated from the air by a dust collector are then stored in a 350 ton silo. Draft for both the dust collector and the dual AC22.5GI classifiers is provided by a 75 kW (100 HP) system fan. The system operates under negative pressure so fugitive dust is not a problem. According to Luck Stone the generated ultrafines can then either be blended back into a base product without any detrimental effects or sold to the asphalt producers. Asphalt producers would use the fines in hot mix asphalt and in particular Stone Mastic Asphalt (SMA) also known as Stone-Matrix Asphalt. The use of the ultrafine mineral filler helps to adsorb the high asphalt cement (bitumen) content and provide a stiffer mastic to limit draindown.

As already mentioned, the feed to the GI air-classifiers for the ADVANTA® sand production is coming from the VSI crushers (Barmac B9100 in the Goose creek plant and a Merlin RP series VSI in the Leesburg plant), the utilised conveyor belts are covered, however, according to Luck Stone the market situation does not allow for costly preheating (drying) of the material. In a study before installation of the crushers that was conducted over a six month period Luck Stone had found an average moisture level of 1.5% in the product. Keeping the moisture level below 1.5% allows the air-classifiers to operate in the most efficient manner. Excessive water for dust control can be one of the factors that influence the proper operation of the classifiers. According to Luck Stone's experience 4% of moisture is a really critical level and when it is reached for example during heavy rain, the production of the ADVANTA® sand is simply stopped. Moisture content at this level would not only lead to fluctuations of the product quality (the fines content) but also block the vanes located in front of the air outlet (see Figure 26). The cleaning of the vanes in case of wet material blockage, once detected, is not difficult to correct, according to Luck Stone or some installations have vibrating vane racks installed which help keep them clean.

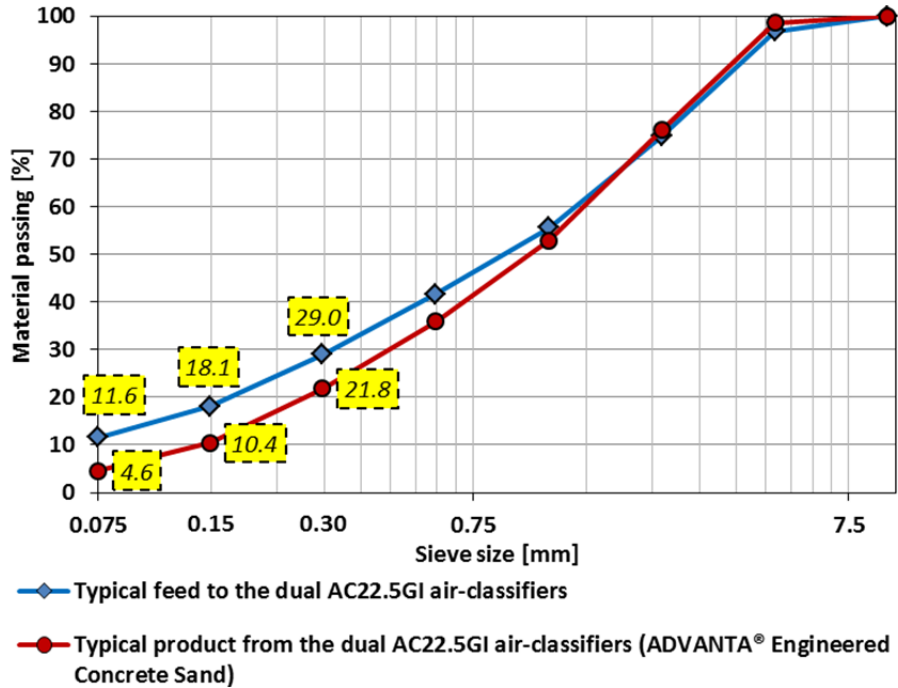**Figure 27. ADVANTA® concrete sand from LuckStone's Goose Creek plant**

Figure 28. Typical feed to and product from the dual AC22.5GI air-classifiers at LuckStone's Goose Creek plant

On a daily basis the parameters of the GI air-classification, i.e. the air-flow which is regulated by the main air inlet valve and adjusted by the secondary air inlet valve (i.e. the primary and secondary air ratio) are normally kept fixed after the initial adjustments (see Figure 5). The sophisticated quality management system at LuckStone (called Aggregate Intelligence) has proven that by running in this way the results of the classification can still provide acceptable consistency with respect to the fines content. For example, statistical analysis of grading of the ADVANTA® Engineered Concrete Sand for time period of 1.5 months (01.04.2013-16.05.2013) including 40 samples at the Goose Creek plant indicates an average minus 75 µm (#200 mesh) content of 4.6% from a target of 5%. The standard deviation for this data set is 1.23%.

Figure 29. Primary and Secondary air inlet valve adjustment system for one of the AC22.5GI air-classifiers at LuckStone's Goose Creek plant

4.2.4 Bro VSI Plant – air classification

Jehander's plant at Bro in Sweden is built up as a trial plant for Jehander customer Benders (pavers maker) situated in Bålsta. The customer wanted to reduce the filler amount to less than 4% in the 0/4 mm product, in addition to requirements also for the 4/6 mm material. In the beginning 0/2 mm and a 2/6 mm products were delivered. This was later changed to 0/4 mm to increase the capacity of the plant.

To keep the moisture content as low as possible, the feed material for the VSI crusher is 8/16 mm from the tertiary crusher. Trials have been made with other feeds but without any great results in end product.
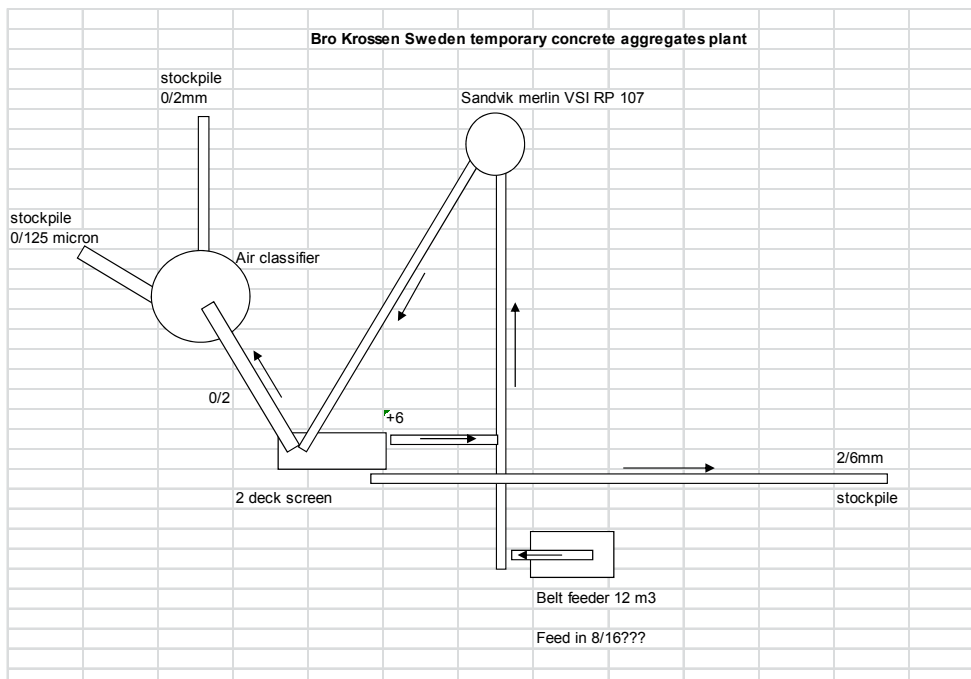

Figure 30. Feed materials.

Figure 31. Flow sheet of the Bro plant with the Fisher Industry air classifier.

A Sandvik RP107 VSI is installed, with a capacity of around 150 t/h in the rotor. Due to lack of screening capacity in the screen (VF 42/18) the plant is not able to get the VSI working properly, however, the production improved when producing 0/4 mm instead of 0/2 mm.

Figure 32. The Sandvik RP107 VSI crusher.

The screen is a 3 deck Svedala VF 42/18, which is too small for the amount of material that the RP107 could handle. The screen mesh in the screen is: Bottom deck 4 mm, second deck 7 mm, top deck 11 mm. The VSI operates in closed circuit from the top deck. All mesh that is installed is steel.

Figure 33. The screen station.

The air separator installed is a Fisher industry dynamic rotary air classifier. The capacity of the separator is 150t/h. There are challenges to obtain an accurate cut in this machine. resulting in a lot of saleable product in the filler. Both engineers and the manufacturer of the machine have been at the site in order to try to adjust the machine, however this has not been any great success.
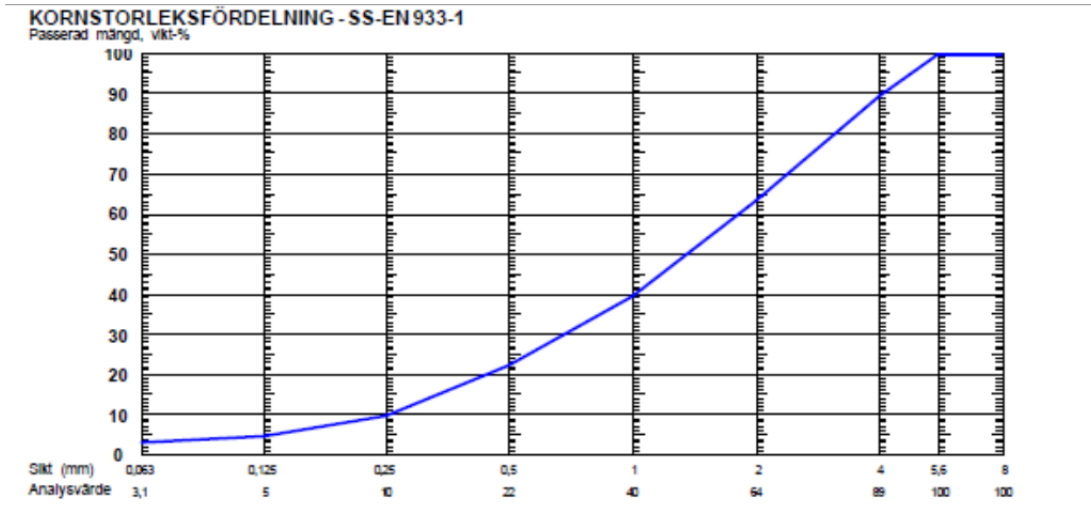

Figure 34. Sieve analyses from the Air separator. 0/4 Product, 25ton/h

4.3 Summary experience in use

Table 4 – Overview of cases recorded, and some lessons learned.

User	Equipment	Product	Lessons learned
Washing			
Norsk Stein, Jelsa	Metso sand trap	0,06-2 mm	Filler content can be adjusted from 18 to 7 or 4 %. Still they need to deposit 150' tons per year due to lack of market.
Wet classification			
Swerock, Bletarpstäkten	Comec hydro cyclones, thickener, filterpress	0-4 mm with reduced fines content	Reduction of fines and adjusted grading. The sand still has no market for concrete, but sells for asphalt
Air classification			
Velde Pukk, Sandnes NCC, Stenungsund	Metso Buell air classifiers (GI and C)	0-0,063 mm 0,063-0,5 mm 0,25 (0,5)-2 mm For asphalt and concrete	Vital parameters: 1) Feed rate, 2) grading of feed, 3) moisture content of feed, 4) setting of air inlet valves, 5) total airflow. Total sand grading can be designed to purpose and kept stable. Competitive properties for both asphalt and concrete. Products kept dry and handlable.
LuckStone, several quarries in USA		Asphalt and concrete aggregate – "Engineered Concrete Sand – ADVANTA sand. 0-4,74 mm with controlled content of fines (< 0,075 mm)	Cheramic linings of air-classifier units have proven very durable – wear still negible after several years of operation.
Heidelberg, Bro	Fisher Industry dynamic rotary air classifier	0-4 mm with filler kept at max 4 %	Feed for the VSI to be from 8/16 to keep moisture down. Challenges to obtain an accurate cut.

5   Recommendations

A set of factors will be decisive when selecting the most appropriate system and equipment for classifying aggregates, especially manufactured (crushed) aggregate. Some of these are:

- Requirements for the end product – accuracy, customer expectations. Interaction between user requirements for final material and the need for/ requirement to aggregate processing
- The total quarry layout – interaction between crushing, sorting, logistics
- Dependency on local setting (availability of water and locations for sludge deposits)
- Climate conditions, recipients
- Price/running cost
- Volume and product requirements will decide the ambitions for plants; when are the advanced plants needed and when can we do with more simple solutions?
- Local quarry concept – the total cost (economy and environment) comparing local investments/conflicts with the costs of long transport

The below table intends to summarize some of these issues, relating levels of wet and dry processing respectively to the relevant situation regarding crushing process, environmental issues and market situation.

Table 5 – Recommendations for choice of equipment

	Wet processing		Dry processing	
	Simple washing	Hydro cyclones for classifying	Simple air screening	Advanced air classifying
Crushing status				
Simple crushing, few steps	Wet processing in this case is seldom appropriate, unless some size fractions are heavily contaminated		In case normal dry sieving is not sufficient for fines removal, simple air screening should be appropriate	The user needs and market for these materials will seldom justify big investments in classifying
Advanced crushing, with cubicising	A too simple solution, after heavy crushing investment, more advanced classifying will normally be relevant	Can be a relevant solution depending on environmental conditions	Can be used to simply reduce fines content, depending on which qualities are requested in the market	Probably the main case where such investments are justified, but depending on moisture content
Combination sand / crushed aggregates	Due to moisture in the sand, classifying would need to be the wet way. But normally in these cases grading is being designed/adjusted just by blending the crushed and natural sand curves		Could be relevant for reducing fines content before blending	Hardly the case for an advanced air classifying, neither from economic nor technical point of view
Surface contamination after crushing	Could be a cheap and useful treatment in this case	Can be relevant if combined with grading adjustment	Not relevant in this case	
Environmental issues				
Availability of water and recipient	Availability of water supply and a recipient / opportunity for mud/sedimentation pond will be a must		The absence of water supply and of opportunity for sedimentation is a key argument for choosing dry processes	
Winter conditions	In general, wet processing should be avoided during winter conditions. Also out-door storage of wet-processed aggregates can give frozen stocks for a long time after winter		Winter conditions normally is one of the best arguments for using dry processing	
Logistics, distance to market	Two basically contradictory considerations, depending on specific case; 1) High cost/high value materials will be justified with long transport distance to high quality markets, since the relative weight of production cost decreases with long transport distances, 2) Use of advanced processing can be justified if it enables the use of local raw materials instead of long transport of remote resources.			
Market situation				
Production / sales volume	Relevant for small to medium volumes	Big investments will need a high sales volume	Mostly for medium volumes and stable production	Big investments will need a high sales volume
User requirements, quality ambitions	Mostly relevant for more local markets without big focus on quality properties.	Quality requirements, a need to keep stable products with respect to grading and cleanness	Quality requirements, but without a need to be able to vary the composition depending on customer requests	Quality requirements and a need to be able to adjust properties to meet different customers' requests will justify expensive plants
Mostly concrete market	Suitability depending on the composition of origin materials and specific requirements, but moisture content will need to be controlled	System has proved effective in achieving and keeping a wanted grading. But water content in the product must be kept under control	Will probably not contribute to a designed grading for crushed sand, mostly to remove fines from the coarser sizes	Probably the technologically best alternative for both these types of aggregate
Mostly asphalt market				
Road base and general market		Too advanced and expensive to be justified only for such purpose	Could be a good alternative if the crushed materials have high fines content	Too advanced and expensive to be justified only for such purpose

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