



Case Study

## **Sand from the Rocks - New Type of Crushed Sand to replace Natural Sand in Concrete Production**

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The availability of natural sand for concrete production is facing challenges, while the so-called waste stockpiles at aggregate crushing areas are causing problems for producers. This means that the industry has a huge need to solve this challenge by finding suitable technology for usable crushed sand production.



Fig. 1: Early attempts to use this co-generated material as fine aggregate were mainly unsuccessful. However, today the important differences between natural sand and surplus quarry fines are well known and there are examples of the producer successfully overcoming the challenges. (Picture: © Rolands Cepuritis)

Issues related to aggregates prices, sales and technical issues of the production are usually among the topics of concern to coarse aggregate quarry managers. Another issue is the mass balance of production because, as part of a normal production process of crushed aggregates, up to 30 percent (rock dependant) of the material acquired from the bedrock is reduced to sizes smaller than 4 mm and thus cannot be used as coarse aggregates.

This co-generated material has long been the most unfavorable fraction in terms of assuring a profitable mass balance, since it can be hard to sell or even to get rid of at any price. As a result, in many places there are huge stockpiles of this “waste” that not only affects the profitability of the aggregate operation, but also causes environmental issues.

In the past few decades, the availability of suitable natural sand for concrete production near the point of consumption has been exhausted around many populated regions in the world. This has led to a search for a replacement material; the aforementioned surplus fines from crushing operations are expected to be the next best alternative – due to both great availability and suitable physical properties.

## **Natural Sand and surplus Quarry Fines - Differences**

Early attempts to use this co-generated material as fine aggregate were mainly unsuccessful. However, today the important differences between natural sand and surplus quarry fines are well known by aggregate producers, and there are examples of the producer successfully overcoming the challenges after working in close cooperation with with the quarrying machinery supplier, e.g. Metso Minerals.

With respect to particle shape, this includes optimizing the crushing process along with vertical shaft impact (VSI) crusher, rock-on-rock shaping at the end. This can result in a particle shape that closely resembles that of natural sand.

The issue of the high fines content can be resolved with either wet or dry processing, i.e. different washing techniques or air classification. Finally, if the sand particles are sieved and classified into reasonably narrow particle sizes of a good shape, they can be successfully used as high-quality manufactured sand already today.

## **The challenging Task of crushed Sand**

Developing new approaches in the field of crushed sand production and then increasing its markets share is not a simple task, one of the reasons being that it involves many parties. This can be described as a sort of “chain”, starting with rock blasting in a hard rock quarry, advancing to rock crushing and screening, then continuing to a ready-mix producer, and finally ending up at the construction site, where the crushed sand concrete is to be evaluated by the end user, i.e. the contractor.

In order to bring all the involved parties together to solve the challenges, COIN, Concrete Innovation Centre ([www.coinweb.no](http://www.coinweb.no)), was founded in 2006. Since 2009, Metso Minerals has been an active and key participant in the COIN project “High-quality manufactured sand for concrete”. This focus area has served as a source of funding and a hub for facilitating the crucial networking between professionals from the different industries involved and universities and research institutions. The purpose has been to create a better crushed sand solution for the future.

## **A new Trend in crushed Sand Production**



Fig. 2: Different types of fine aggregates: (1) High-quality, 0/8 mm natural glaciofluvial sand from Norway; (2) Low-quality, 0/8 mm co-generated material of coarse crushed aggregate production (should not be called crushed or manufactured sand); (3) High-quality, 0/8 mm crushed sand, produced using an optimized crushing circuit and VSI shaping. (Picture: © Rolands Cepuritis)

There are two scenarios for a new approach to crushed sand production. One includes choosing the best available geological resources and then trying to copy “mother nature” by putting extreme effort into shaping of the aggregates and the design of grading curves.

Another approach involves finding ways to make crushed sand perform as well or better than natural sand by utilizing its intrinsic properties. This also includes developing a new concrete mix design philosophy that is adapted to crushed sands with specially engineered properties that are different from those of natural sands. The latter is what has been chosen as the philosophy of the new approach of crushed sand production currently under development within the COIN project.

It is also worth mentioning here that crushed fine aggregates normally outperform natural sand when the most essential hardened concrete properties, such as compressive and tensile strength, are compared. At the same time, the problems of achieving economical mixes with suitable workability (fresh state properties of concrete) are normally reported as the main problem that can render the use of crushed sand non-favorable in many cases.

## Performance of crushed Sand - Recent Findings

The current trend in the concrete construction industry is an attempt to increase the market share of self-compacting concrete. This is a special type of very flowable concrete that was developed two decades ago in Japan and is special due to its ability to compact and level itself into a mold without any external vibration.

In the previous work carried out by the author within the COIN project, it was recognized that crushed sand with its naturally high fines content is perfectly suited for this type of concrete. This is because of the high flowability and the fact that self-compacting concrete needs a much higher content of very fine particles ( $\leq 0.125$  mm or 120 mesh) to assure good cohesion between the water and particles in the mix to avoid segregation and also to prevent interlocking of the coarse aggregate grains.

Research carried out elsewhere has also proved that increased fine particle content can in many cases be desirable compared to natural sand concrete. This is because a high fines content in natural sand usually indicates increased silt, clay or shale concentration, which is detrimental to both fresh and hardened concrete properties.

In crushed sand, the presence of these contaminants is rare (at least in Scandinavia) and some level of fines would normally increase the content of filler-modified cement paste, thus helping with lubrication between the coarser aggregates particles ( $\geq 0.125$  mm or 120 mesh). When the optimum level of fines content is exceeded, they start reducing the flowability of the cement paste itself and thus the effect of lubrication with respect to coarse particles can then be overruled.

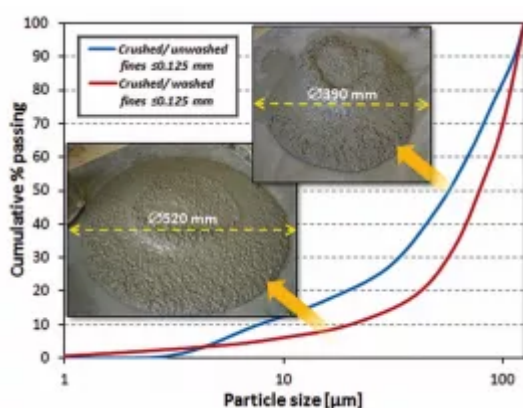


Fig. 3: Influence of fines grading in crushed sand on the fresh state properties of flowable concrete. Fines in this case constituted only 3.3% (57 kg/m<sup>3</sup>) of the total volume of 0/16 mm aggregates; changes in their grading, on the other hand, affected the slump-flow value by 130 mm. (Picture: © Rolands Cepuritis)

Further trials within the COIN project also proved that the type of the fines mattered as well. This means that not only is the total percentage of fine particles below the sieves 0.250 (60 mesh), 0.125 (120 mesh) or 0.063 (230 mesh) mm important, as normally interpreted in the past, but so are the characteristics they possess; these characteristics can vary widely for different crushed fine aggregates. The most important properties of the fines are believed to be their particle size distribution (specific surface), mineralogical composition, particle shape and surface texture.

For example, if the grading of two crushed fines ( $\leq 0.125$  mm) coming from the same deposit is altered by classification (washing, in this case) and this is the only variable between two concrete mixes (i.e. the total fines content is kept constant), this can have a tremendous effect on the concrete slump-flow value (see Fig. 3).

From a concrete technology point of view, those findings can be explained by the adsorption of the free water on a larger total surface area of a finer grading, thus leaving less water available for the lubrication of the cement paste itself. The recent findings have also indicated that varying the properties (flakiness) of coarser crushed sand fractions (0.125/2 mm and 2/4 mm) has much less relative impact on fresh concrete properties, and that the other fine particle ( $\leq 0.125$  mm) characteristics, such as shape, surface texture and mineralogy, could have a similar effect as grading (specific surface).

## **Further Improvement in Concrete Properties**

The current state-of-the-art for crushed sand production is VSI shaping and wet or dry classification to reduce the total fines content. However, it is our belief – and our findings indicate – that further important improvement in concrete properties can be achieved if the properties of the very fine part of the crushed sand ( $\leq 0.125$  mm) are modified (engineered).

Two tasks then have to be solved, in order to see if our hypothesis is valid also when applied to industrial scale production. The first task includes the concrete technology side, which would require a complete understanding of how and which

fine particle properties affect fresh concrete properties. The second task involves finding an industrial solution that would render a controlled modification and optimization of the filler part properties possible also at aggregates quarries.



Fig. 4: Ceramic linings and vanes inside one of the G1 classifier units to the left; after 8 years of operation, the wear of the linings is still negligible. (Picture: © Metso Minerals)

Otherwise, our findings would be only of scientific importance with limited practical relevance. What seemed to be a difficult task at the beginning turned out to be possible with the equipment readily offered by Metso Minerals. This is because if the fine ( $\leq 0.125$  mm) part of the crushed sand is separated into different fractions by Metso's static air-classifiers and stored into silos, we just need to find the best way of combining them afterwards.

Moreover, two-stage dry air-classification is a concept that is already used today, providing in total four dry filler fractions to be mixed back either before or during the concrete production. The static air-classifiers are perfectly suited for aggregate operations, since they do not have any moving parts; the inside of their chambers is lined with ceramic lining, assuring very low wear costs even with highly abrasive feeds.

At the same time, they can be designed to accommodate the throughput necessary for most aggregate operations. In addition, they do not have the problems usually associated with the wet classification process (washing), i.e. space and environmental issues from de-watering ponds and operation problems in places where negative temperatures are reached in the winter time.

## **Developing a future Sand Solution**

In order to proceed with the experiments to further elaborate the proposed hypothesis, great effort and care were taken in the preparation of a set of model materials (crushed fillers) that represent the complete range of local geological



variety in Scandinavia. This involved collecting 4/22 mm crushed rock samples from 10 different quarries. Further processing included another step of Barmac VSI crushing to generate fines and screening of 0/4 mm crushed sand. Special care was taken to ensure that all the fines were generated only in this strictly controlled way.

Previous research findings within the COIN project and elsewhere had proved that the geometrical properties (such as shape) of the fine particles  $\leq 0.125$  mm can be affected by the crushing procedures applied. For example, an increase in VSI tip speed demonstrated an improvement in the properties of particles all the way down to and including the filler ( $\leq 0.125$  mm or 120 mesh) sizes; moreover, those improvements proved the introduction of measurable changes in the fresh concrete properties.

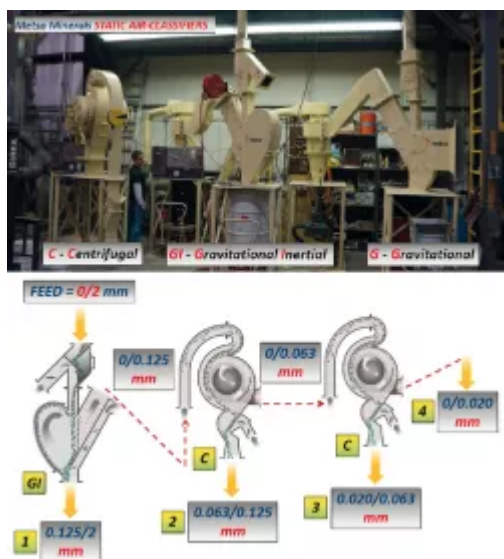


Fig. 5: Metso Minerals air-classification lab in Lebanon, PA, USA (above) and flow sheet of the experiments carried out. Metso Minerals static air-classifiers, C - Centrifugal, GI - Gravitational Inertial, G - Gravitational. (Picture: © Rolands Cepuritis)

After VSI crushing, the 0/4 mm crushed sand material was further split in two fractions – 2/4 mm and 0/2 mm. Almost 9 tons of the 0/2 mm fractions were then sent to Metso’s air-classification laboratory in Lebanon, Pennsylvania, USA, for controlled removal of filler and alteration of filler grading. This means that as much material below 0.125 mm as possible was removed and further split into fractions 0.063/0.125, 0.020/0.063 and 0/0.020 mm.

Industrially, this could be achieved by connecting a gravitational-inertial (GI) air-classifier in a row with two centrifugal (C) classifiers. This is illustrated in the flow chart in Fig. 5. As mentioned, already today there are aggregate operations that

have two Metso static air-classifiers (GI and C) connected in a row to produce multiple different fine filler fractions.

The air-classification experiments with the 10 different materials are now finished. The results demonstrated that the classification process of the equipment can be successfully adapted to a narrow desired result by adjusting the classification process parameters, i.e. the air-flow, which is regulated by the main air inlet valve and adjusted by the secondary air inlet valve (primary and secondary air ratio).

The success of the experiments can be illustrated (see Figs. 6 - 8) by the initial gradings of filler from all 10 crushed sands after the first stage of classification, an example of classification results (when the filler part is distributed into separate fractions), and the possibilities of recombining those fractions if one of the initial gradings is chosen as the reference.



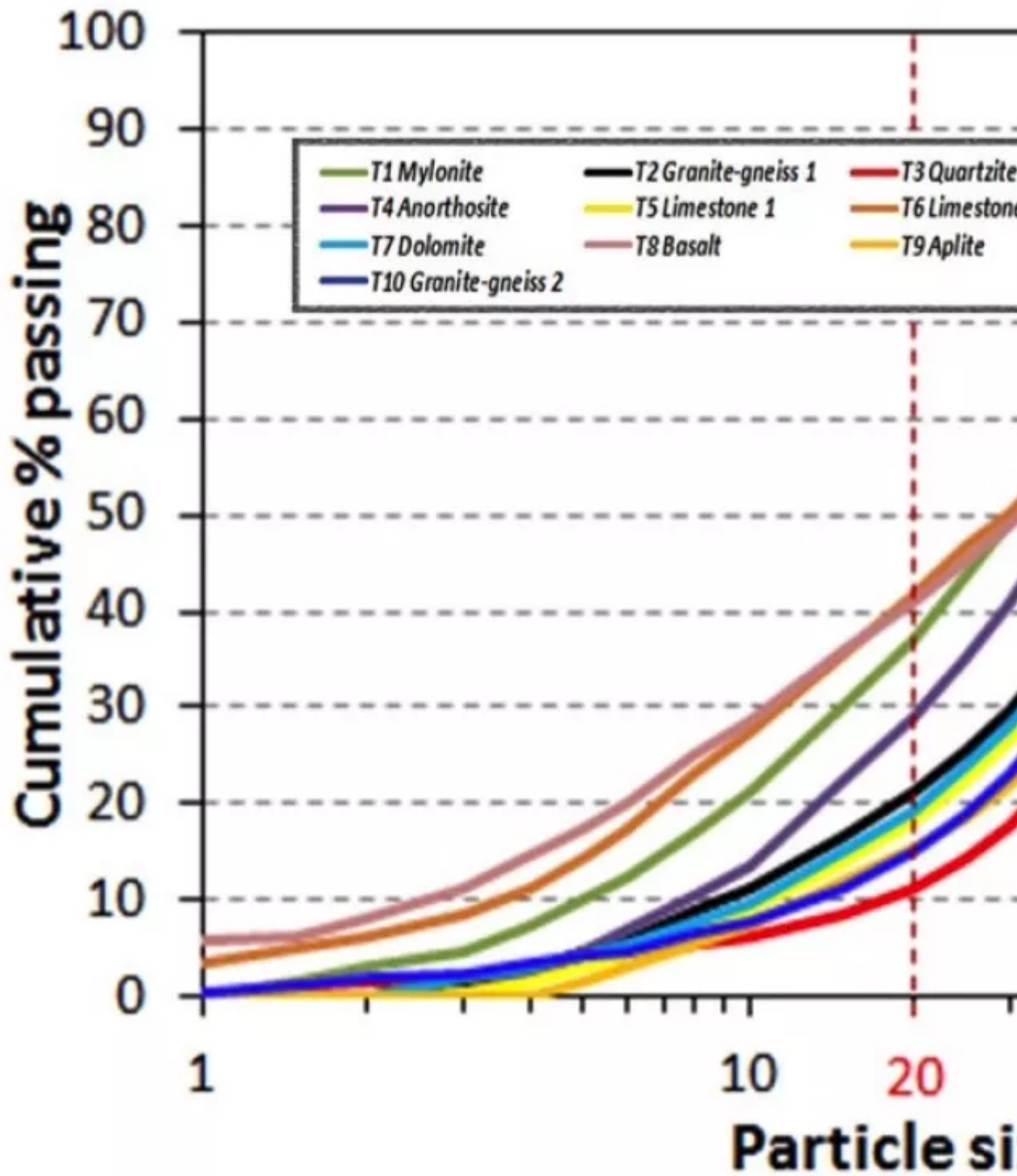


Fig. 6: The intrinsic gradings of fillers from all 10 crushed sands after the first stage of the curves at 100 µm is an artefact of the PSD measurement method used. (Picture: ©

The acquired filler fractions have now been delivered to the Norwegian University of Science and Technology where work within the COIN project will continue with the further elaboration of the knowledge on how the different filler characteristics

affect the properties of fresh concrete.

## Crushed Sand Application on the Aggregates Market

As described above, already today a technology for producing high quality manufactured sand that would be acceptably similar to that of the natural origin or at least “good enough” is available. Even though it is not always straight forward and not all the rocks can be classified as equally suitable for that, the questions for the future still are- can we make the manufactured sand even better than the natural, how, and, last but not least, why? An attempt to answer the first two parts of the question was given above in the article. If continuing with the last part of the question: aggregates constitute up to 75% of the total volume in concrete, while their price is second from the bottom, normally only water being less expensive. The aggregate prices in many places do not even keep up with the inflation, the only exception being natural sand, in some cases.

There can be two reasons for the sometimes high natural sand price, when compared to crushed aggregate. First, a good quality sand can make a huge impact on the cement consumption (the highest share of concrete self-price) to produce concrete with desired properties and second, because availability of good natural resources is almost exhausted in many parts of the world. This enlightens the two possible approaches in the crushed aggregate business (that can in fact be applied to any industry).

The first way is perhaps the most common, which is producing coarse aggregates that are virtually the same as from the other suppliers and trying to compete on the market with the price. This usually involves having only a marginal profit from every sold ton and an avoidable need to produce and sell huge volumes in order to render the operation profitable. For many huge aggregate quarries this has turned out to be especially difficult after the last financial crisis and, as a result, a lot of the so called “mammoth” quarries, operating on the first principle, have turned out to have overcapacities. Increasing the price at times, when everyone else has overcapacity as well and is selling virtually the same product, is of course a difficult task. Another type of approach would then be selling high added value (profit part of the price) crushed aggregate products at volumes that the market today can readily consume. In special market situations this is of course a normal occurrence, like for example in the mentioned case of lack of natural sand.

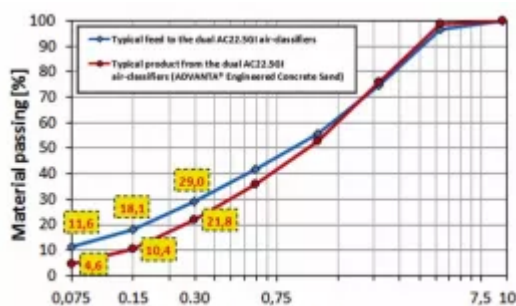


Fig. 9: Typical feed to and product from the dual AC22.5GI air-classifiers at Luck Stone's Goose Creek plant. (Picture: © Rolands Cepuritis)

The basic commercial idea under future solutions for crushed sand from the aggregate producer's point of view then lies in developing a technology to have a different kind of aggregate production approach. This involves not only trying to compete with the price but in fact producing high added value product that can even be brand named on the market to emphasize that it is unique, which has normally not been typical for natural sand or aggregates in general.

This interesting trend has already recently began and producers who have invested into considerably improving the quality of their crushed sand want to emphasize that it is different from the material that is co-generated in the coarse aggregate production process.

The two brand-named crushed sands to the author's knowledge currently are the Advanta engineer concrete sand produced by LuckStone ([www.luckstone.com](http://www.luckstone.com)) in Virginia, United States and the RoboSand produced by Robo Silicon ([www.robo.co.in](http://www.robo.co.in)) in India. The Advanta crushed sand is in fact being produced by the aid of Metso's static air-classification solutions.

## Choosing the best Sand Production Process



Fig. 10: Metso's Dual AC22.5GI static air-classifier units at Luck Stone's Goose Creek plant, operating at maximum throughput of up to 100 tph. (Picture: © Metso Minerals)

It must, however, also be noted, that the new concepts described here is not a claim of inventing a "new type of bicycle" or a "miracle one button technology". Is rather a concept that shows the unexplored possibilities of the technology that

is available out from “Metso Minerals shelf” already today. The author will at all circumstances admit that the task of proving that a crushed sand product is worth a higher price (even if this is true) will not be a simple and easy task. The main reasons for that are the aforementioned first historically unsuccessful attempts of using co-generated crushed fine material in concrete and second of all also because of legislative requirements that in many parts of the world can be discriminating towards the use of crushed sand, if it is tailor made for special performance in concrete and not a mime of an “ideal” natural sand. Then the aggregate producer can end up not only proving his clients that his product is worth the price, but in fact also proving to the authorities that it is allowed to be used for the projects that have to comply with the local standards.

Still every coarse aggregate production company has a wide range of choices of what to do with their surplus fines- dumping it in huge stock piles, trying to get rid of it at a very low or no price or try to make business out of it. If going for the last option, the next choice would then be choosing among the options of how sophisticated their crushed sand production should be. In some cases, the surplus fines can readily be of a quality that is suitable to be used in concrete in a blend with natural sand. However, this can also readily introduce some practical problems that need attention.

Such as that many concrete producers might not have an extra silo for the crushed sand available in their concrete plants and that if the fines content in the sand is extremely high, it would simply get stuck in the concrete producer’s aggregate silos at higher moisture content. The next step up the “ladder of crushed sand production” is probably installing a VSI, such as one of the Barmac’s. That would allow considerably improving shape in the particle range down to and including the filler fractions. This would normally also have to be accompanied with a technique to reduce the fines content to an acceptable amount, such as a static air-classifier. Then if even higher quality of the sand is desired, the approach, described in this article, can be implemented, i.e. installing more than one air classifier and splitting the finest part of the sand in separate fractions.

Which is the best choice in each case, to the author’s opinion, will be rendered by the local market situation, however, to the same extent also by the fact, how much efforts in the long run the producer is willing to put forward in developing his product, not only on the technical side, but also actively working with technical support, sales and promotion. Or put it another way, crushed sand cannot be sold in the same way as for example 8/16 mm coarse aggregate, i.e. by sending a price offer and a declaration of determined physical/ alkali reactivity

properties to a possible customer.

To the author's perception, crushed sand needs much more technical kind of marketing and sales, in order to make it a success story. Those understanding the ready-mix concrete production business can compare this to selling concrete admixtures. Thus the author would advise one to be sure to have not only a skilled and professional team to deal with questions related aggregate but also concrete technology, and only then pursue the goal of developing a "different" aggregate production operation. This, is however, also true when analysing the market in which the producer operates. Thus not only such crucial factors as the availability of good natural sand or the overall price level of the aggregates should be considered.

Another important factor is in fact the technological level of the possible concrete clients. For example, Scandinavia in this case can be mentioned as a good example, since in general the largest concrete producers have experienced and most importantly highly academically educated concrete technology people. This means that there will be someone able to understand the possible benefits of the use of specially designed crushed fine aggregates. This also suggests, that companies having aggregate-concrete vertical integration have a larger potential of making money of high added value crushed sand production. This is since they can avoid the hard and time consuming work of getting the product into the market and also because they have the knowledge of concrete production technology readily available within the company.

The final remark would be that even though today crushed sand is still a developing business line among the minority of aggregate producers, one should keep in mind that without the risk and hard work it is doubtful possible coming to a great success, which in this case is a successful, more sustainable and profitable aggregate production in a long run.