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COIN Project report 32 – 2011

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FA 2 Competitive constructions

SP 2.3 High quality manufactured sand for concrete

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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

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1 Introduction

1.1 Background

Recently there has been a renewed and increased focus on the production of manufactured sand (aggregate grain size <4mm) for use in concrete, as the natural sand resources, which previously were taken for granted, now are depleted in many central areas in Norway.

It has been proven that manufactured sand can perform at least as good as natural sand in concrete, when produced under controlled circumstances e.g. the right skills and machinery. Using manufactured sand has the advantage that a specific type of bedrock can be selected in order to obtain finished sand with specific properties. Additionally, the use and production of manufactured sand gives rise to environmental benefits such as proximity to market, and integrated production. Despite the good experiences with the use of manufactured sand in concrete, this "new" product also provides new challenges which need to be met. When designing concrete, one can not directly transfer the knowledge based on experiences with natural sand. The manufactured sand will differ from natural sand regarding grading, particle shape, surface texture and will have a higher content of fines (< 63µm).

In the "State-of-the-art" Report regarding "Production and Utilisation of Manufactured Sand" published as part of the COIN Project at SINTEF (Wigum & Danielsen, 2009)[1] several of these issues are discussed. These include; environmental issues, mineralogical properties, production processes, specifications and the application in concrete.

Several researchers, e.g. Hudson (2000)[2], have pointed out that one of the problems in dealing with manufactured sands is the lack of a set of tests that fully characterize the three main properties of the individual particles, i.e.; particle shape, particle size and particle surface texture. It is not only a necessity to know these individual properties of the aggregates, it is also important to understand how these properties influence the concrete in both hardened and fresh state. Additionally, it is desirable to understand how the properties of each of the aggregate sizes, or material types, affect the entire aggregate blend.

1.2 Projects background, aims and description

As part of the Concrete Innovation Centre (COIN) at SINTEF, the focus area 2.3 deals with the production and use of manufactured sand as concrete aggregate. In addition to the work carried out in the focus area 2.3, there was a need to carry out an additional specific study regarding classification of particle properties of fine aggregates (< 63µm), applied as concrete aggregate. This report is an individual work; however, results from this work will be presented to the COIN project. Funds from the Norwegian Concrete Association enabled the accomplishment of this project. The work was carried out at the Department of Geology and Mineral Resources Engineering at the Norwegian University of Science and Technology (NTNU).

The main task of this project was limited to carry out both simple and more advanced particle characterisation of fine aggregates (< 63µm), intended for the use as concrete aggregates. In a report by Stewart et al. (2006)[3], simple tests were defined as tests that can be done on the fines with relatively simple equipment. Characterization tests were classified as tests done on the fines that need to be done in specialized facilities or with highly specialized equipment. They are useful in research for determining exact characteristics of the fine aggregates, but are not able to be done in the field, in a quarry lab, or similar setting. It is assumed that the different test methods do not necessarily characterise the properties of the fines in the same way.

It is the ultimate aim to find which tests, simple or more advanced, that mirror in a best way the effects of the properties of fines as concrete aggregate. This includes both the fresh and hardening state of concrete, and strength and durability issues during the service life of the concrete. Within the frame of this project it was not carried out experimental work with concrete or mortars, but this project will add an important basis for a possible follow-up project to look into these issues.

The various materials tested are both of natural and/or crushed aggregates origin. Methods of characterisation were selected based on available methods at the Particle Characterisation Laboratory at the Department of Geology and Mineral Resources Engineering, NTNU. The Particle Laboratory is specialized in this type of characterization, i.e. analysis of particles using a variety of different measurement principles and equipment. The most common assays are the measurement of particle size, surface, grain shape, weight and porosity.

2 Materials

2.1 Samples

A total of 7 different samples of fine aggregates (< 63µm) were received from 6 different quarries. Four of the samples are produced from crushed rocks (manufactured sand), while three of the samples are produced originally from natural deposits.

2.1.1 Jelsa 1 & 2

The production process at the company Norsk Stein, Jelsa, applied for production of the material "Jelsa 1" and "Jelsa 2" can be described in this way:

There are totally 5 crushing steps:

- Primary: Jaw crusher 160x120. Metso C160
- Secondary: Gyratory (Cone) Crusher Metso GP550S
- Step 3,4 and 5: Cone crusher Metso GP 550

All fine material (< 16 mm) from blasting, primary and secondary crushing steps is screened out after the secondary crushing step. The feed size for step 3 is approximately 16/80 mm.

In the fine crushing plant, all the three crushers run in closed circle and the flows are carefully controlled to secure that the crushers are run with a completely filled crushing chamber and with a controlled and stabile feed of material i.e. a fixed amount of material less than the closed side setting of the crusher. The cavity in each crusher is selected to obtain the requested pressure in the crushing chamber.

The smallest product grading is 0/2 mm, obtained by dry screening. The plant is equipped with a simple wet processing unit that can reduce the filler (<0.060 mm) content in the 0/2 grading from some 12 % to 8 % or 3 %. In that way, three different classes of 0/2 mm material can be produced. The sample "Jelsa 1" in this study is the material with approx. 8% filler, while sample "Jelsa 2" is the material with approx. 3% filler

2.1.2 Årdal - NSBR

The fine aggregate (< 63µm) from the quarry of NorStone in Årdal is sieved out of sand aggregate (called NSBR) with the size fraction of 0/8 mm. The sand consists of approximately 60% washed natural sand. Due to the fact that this sand contains a high amount of fines, it is washed by using a simple washing wheel without any dewatering screen and lamella sedimentation. That means that it is not possible to govern the amount of fines in the sand, and some aggregate particles up to 0.25 mm will be washed away with the water. The remaining 40% of the sand is washed natural/crushed materials from the main washing process. In this process only particles <0.030mm will be washed away. The fed into the main washing process is 50/50 natural and crushed/manufactured materials. The manufactured sand is cubical 0/8 mm. It is believed that the percentage of filler (<0,125mm) in the crushed material is approx. 15-20%.

2.1.3 Tau

The fine aggregate (< 63µm) from the quarry of NorStone at Tau originates from washed manufactured sand with the size fraction 0/2 mm. The sand is produced by 3 steps of gyratory crushing, followed by VSI crushing. The sand is then washed using a segregation cone, followed by a dewatering screen.

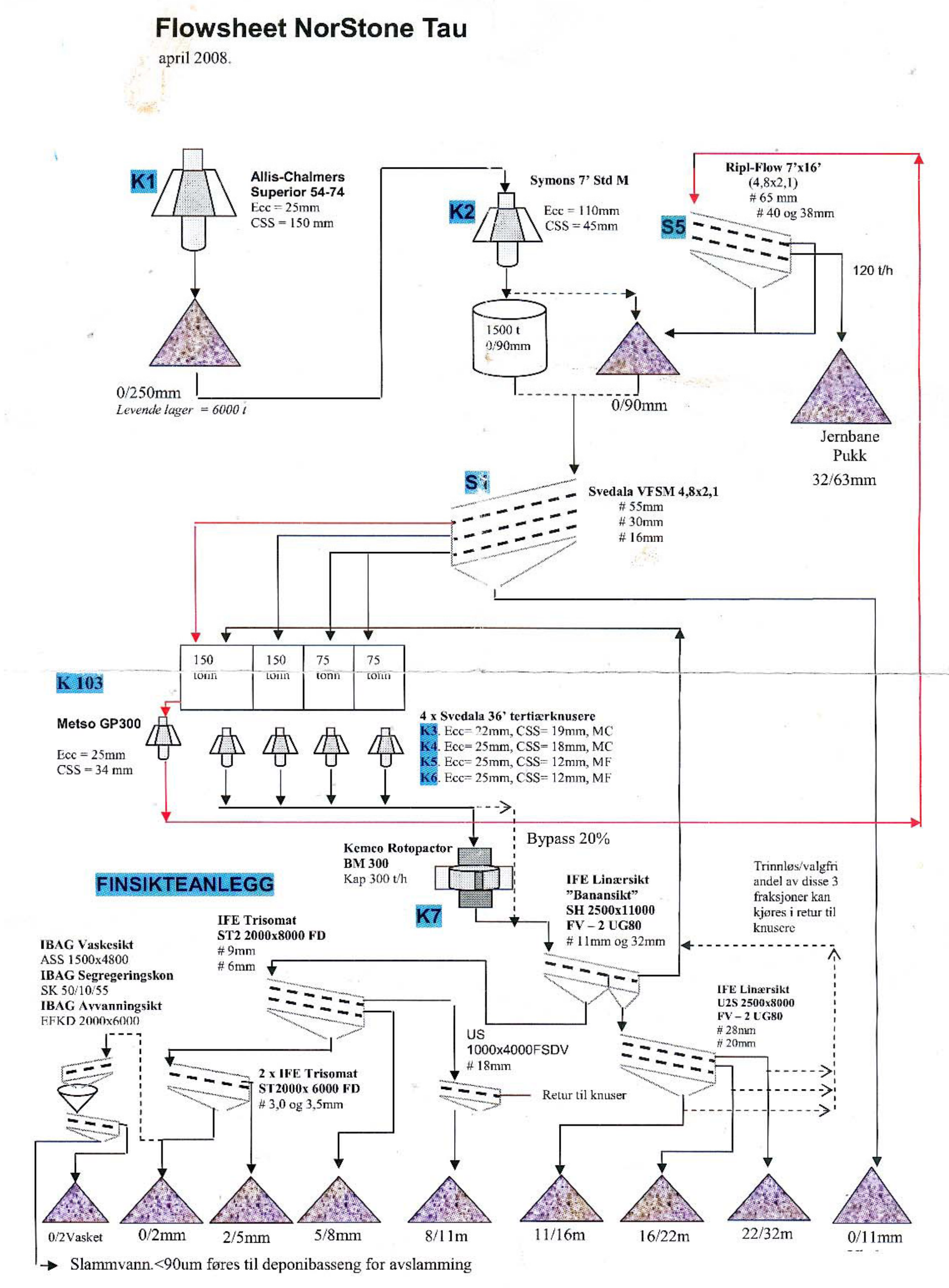

Figure 1. The flowsheet of the production at Tau Quarry.

2.1.4 Hokksund

The fine aggregate (<63µm) from the quarry of Veidekke at Hokksund is originally from unwashed manufactured sand in the size fraction 0/4 mm. The 0/4 mm manufactured sand is produced in the third and final crusher unit of the plant, as shown in Figure 2. Two cone crushers stand in parallel, with stroke 22 mm and feed opening 15 mm. The 0/4 mm manufactured sand is then finally screened at a screen with mesh size of 4 mm.

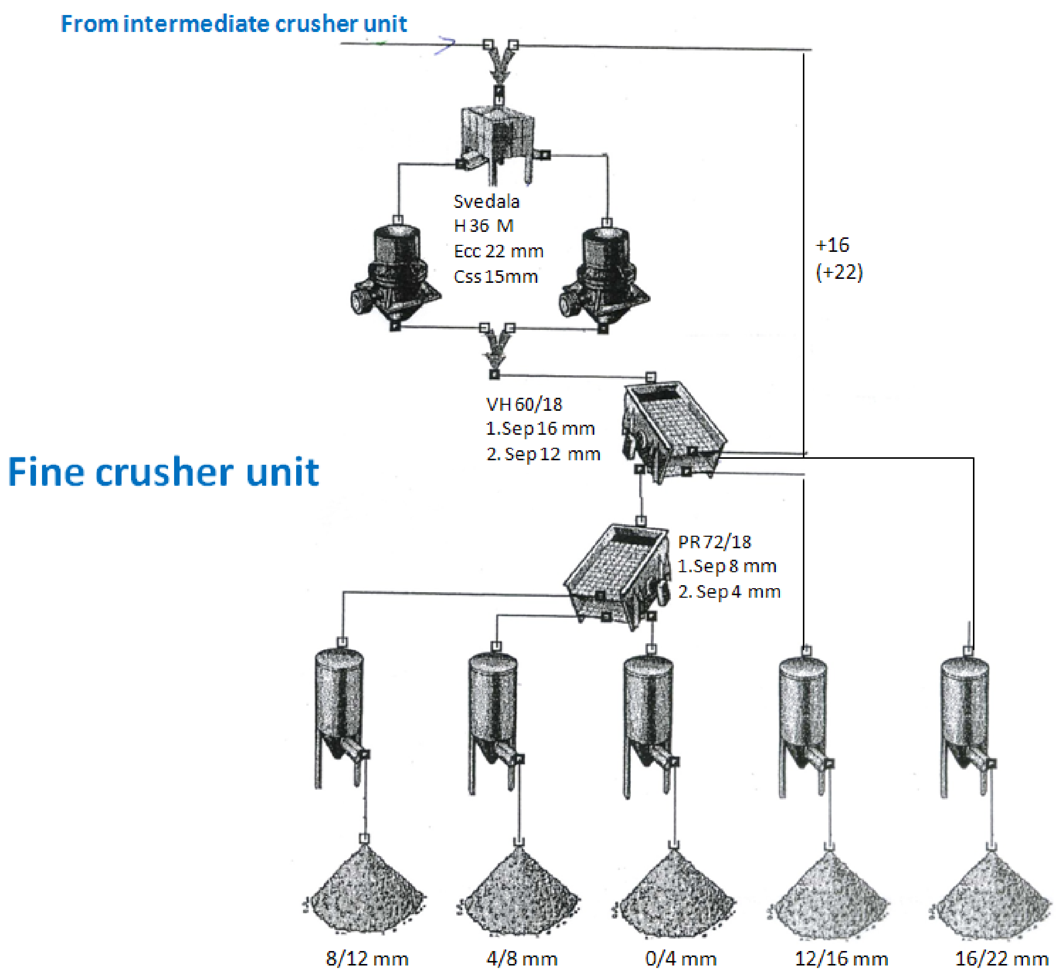

Figure 2. The third and final crusher unit at Hokksund Quarry.

2.1.5 Norwegian Aggregates

In the quarry of Norwegian Aggregates in Verrabotn, the aggregate materials on the final screen are flushed. The water, together with the 0/2 mm size fraction, is subsequently transported to the Power Screen Fine Master washing equipment. In this equipment the 0/2 mm size fraction goes into a tank with water. The material is then lifted out of the water by a wheel and brought on a dewatering screen. On the dewatering screen the material is separated at approximately 0.3 mm. This material plus the surplus water from the wash tank, then go through 2 cyclones where aggregate particles > 63µm are removed and returned back to the 0/2 mm size fraction. Aggregate particles < 63µm go along with the water to a sedimentation basin for clearance. The "pure" water after clearance is returned as process water and reused.

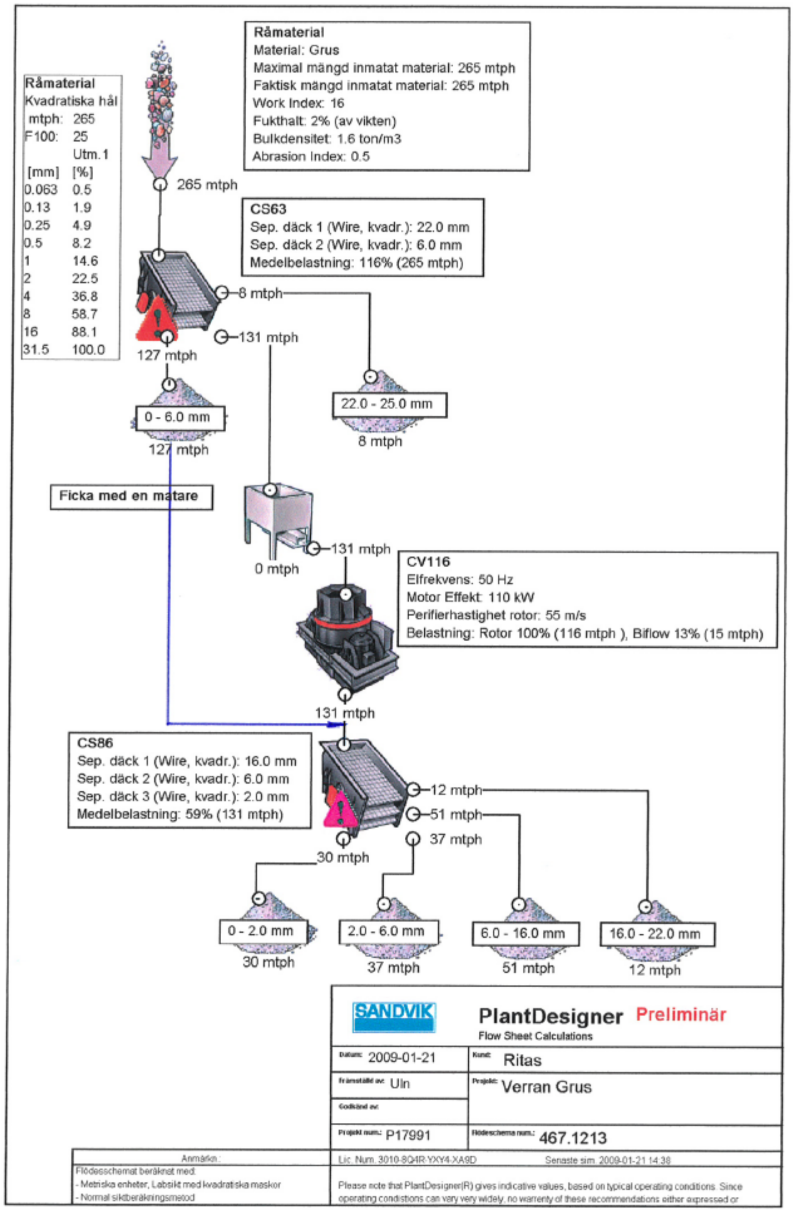

Figure 3. The flowsheet of the production at Norwegian aggregates at Verran grus.

2.1.6 Svelviksand

The aggregate is from the production plant at Hurum, and consists of deposited glacifluvial materials. The aggregate contains a great variation of rock types, including; granites, gneisses, porphyry rocks, sandstone, siltstone, conglomerate, basalt, hornfels, quartzite.

The aggregate is screened and coarser boulders are crushed, both by a cone crusher and a VSI crusher. The fines will consequently be a combination of both fines from natural materials, and fines from the crushers. The aggregate is not washed.

3 Methods

3.1 The New Zealand, NZ Flow Cone test

In order to compare the more advanced measurement with a more simple method the NZ Flow Cone test was applied (1986)4. This is a method to evaluate sand or a blend of sand, and is used to measure flow and void properties (Goldsworthy)5. The method is widely used in New Zealand and has also been adopted in other countries for characterisation of sand aggregates, e.g. at SINTEF in Norway. Moreover, a version of the test has been introduced as an ASTM standard6. The test involves passing a determined mass of sand through a cone into a receiver. The time necessary for the sand to pass is recorded. In addition, the loose density of the sand after passing through the cone is measured. The flow time of sand is a function of grading, particle shape and texture. According to Goldsworthy5, experience has shown that this test provides a very good starting point for determining the performance of fine aggregate for use in concrete.

Figure 4. New Zealand Flow Cone – From Goldsworthy5

In the 1980's the New Zealand Ministry of Works tested a variety of sands and measured their influence on the properties of fresh concrete. It was concluded that sand that lies within the prescribed envelope consistently produces good results. Figure 5 illustrates these correlations. Coarse, poorly shaped, sands have high flow times and high void contents. The application of these sands has led to poor performance in concrete and some negative feeling about the use of manufactured sand in concrete. Fine sand, while having good flow properties, has high void contents. These sands have high water demands when applied in concrete. For sand or a resultant blend of sands to be fit for use, they must comply with the flow limits shown in Figure 5. If not, further blending or processing may be required. The flow time of sand is a function of grading, particle shape and texture. For a given flow time, the evaluation process will determine the properties that lead to such a result. For example, if the sand has a high flow time one would find that either the grading is coarse and/or the particle shape is poor. The void content is a function of the water demand of sand. High water demand will come from poor grading and from poor particle shape.

This test has been used extensively to measure the performance of sand or to estimate the properties of a blend of two or more sands. In blending two or more sands, each sand is first tested individually. Blends of the two sands at various percentages are mixed and tested. The results, when plotted, will produce a curve that reflects the changing properties of the blend.

Figure 6 shows such a test. The top end of the curve is 100% manufactured sand. Even though it has a good void content this material has poor flowability. Inspection of the sand shows it to be coarse, while particle shape and texture are of a good quality. The addition of 20% fine sand improves the flowability, while slightly reducing the percentage of voids. After the addition of 40% fine sand the properties of the blended sand start to deteriorate. For this blended sand the addition of 40% fine sand would produce the best properties of the sand.

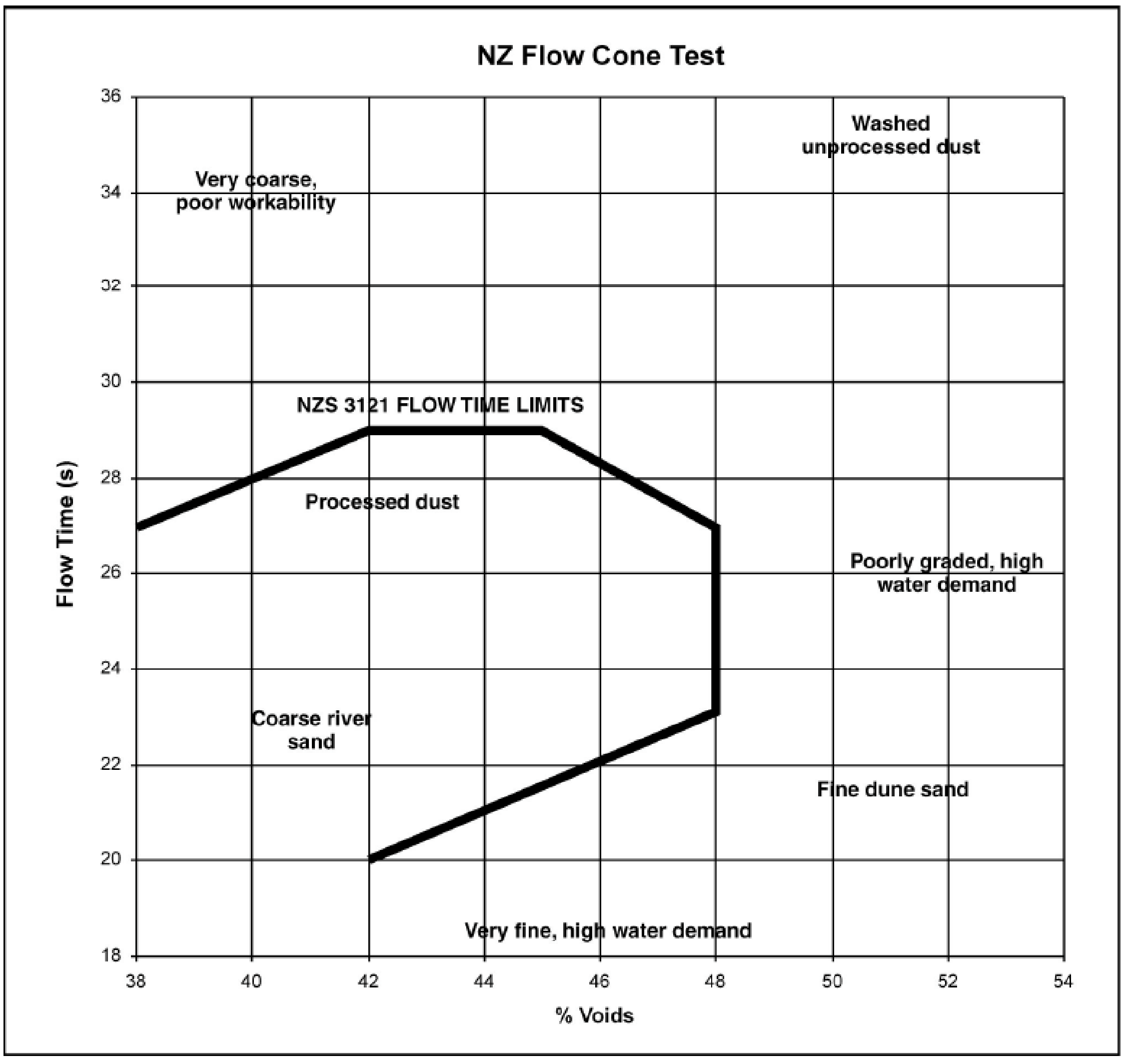

Figure 5. NZ Flow Cone correlations – From Goldsworthy5

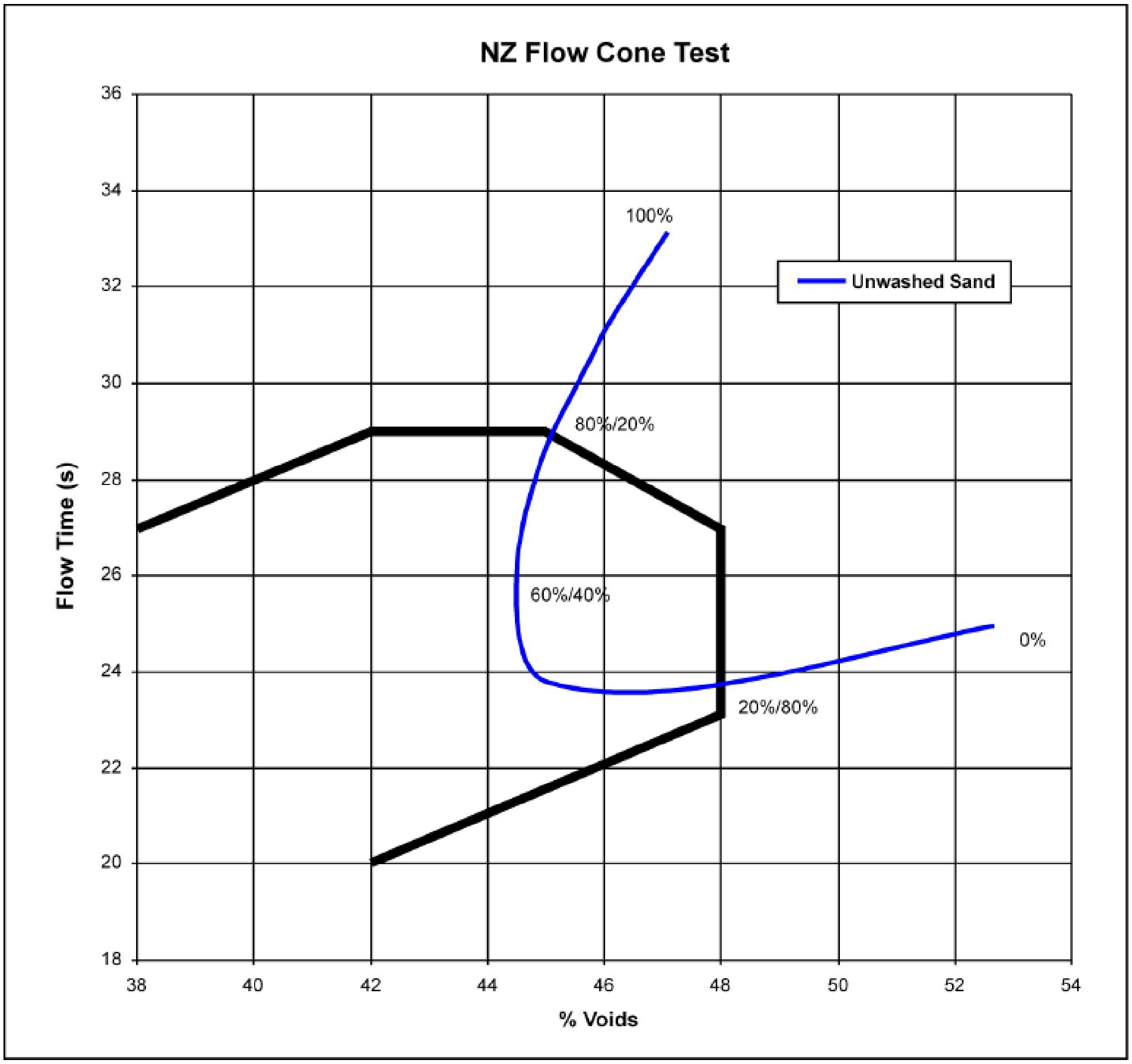

Figure 6. Sand blending using the NZ Flow Cone – From Goldsworthy5

3.2 Coulter LS 230 Laser diffraction – grain size analysis

The Coulter LS 230 measures particle sizes from 40 nm to 2,000 µm (0.04 – 2000 µm) by laser diffraction. It is based on the principle that particles scatter and diffract light at certain angles based on their size, shape, and optical properties. A 750 nm diode laser is used for analysis in the size range from 400 nm to 2 mm. The beam passes through filters as well as projection and Fourier lenses and is spatially recorded onto 126 photodiode detectors. The particle size, shape, and optical properties of the particles control the spatial variation of the diffracted beam. The calculations assume the scattering pattern is due to single scattering events by spherical particles. The advantages of this technique include ease of operation, large range of detectable particle sizes, and accuracy in the micron and submicron range. The Polarization Intensity Differential Scattering (PIDS) assembly sizes particles from 40 nm to 400 nm and improves resolution in the 400 nm to 800 nm range. PIDS uses a tungsten-halogen lamp and three sets of vertically and horizontally polarized colour filters at 450, 600, and 900 nm as the light source. PIDS is based on the principle that at high scattering angles

(~90 degrees) the difference in scattering intensity of the two polarizations is a sensitive function of the ratio of particle size to wavelength.

3.3 SediGraph – grain size analysis

The SediGraph particle size analyzer measures the sedimentation rates of particles in suspension and automatically presents these data as a cumulative mass percent distribution in terms of the Stokesian or equivalent spherical diameter in micrometers (μm). The instrument determines, by means of a finely collimated beam of X-rays, the concentration of particles remaining at decreasing sedimentation depth as a function of time. The instrument typically yields a particle diameter distribution over the range 50 to 0.18 μm.

3.4 Pharmavision 830 – Image analyses, shape

3.4.1 The procedure

The following description of the procedure of operation of the Pharmavision 830 is compiled from the brochure: "*PharmaVision Automated Microscopy System*"[1] provided by the manufacturer; Malvern Instruments Ltd

The PharmaVision 830 is an automated vision system for the size and shape analysis of dry powders and the analysis of foreign particles on filter membranes. The image analysis procedure follows a simple 4-step process:

Camera scanning

A computer-controlled actuator moves the camera across the sample in the x and y directions. For each movement a new image (a frame containing a number of particles) is acquired. A zoom lens allows the user to analyze particles in the range 25μm – 2000μm. An optional high magnification unit enables particles in the range 0.7μm – 100μm to be analyzed. Small apertures are used to increase the depth of field whilst maintaining the required resolution. The coordinates of each particle are logged, preventing particles from being counted twice. Importantly, scanned fields overlap. Conventional image analyzers ignore particles which touch the edge of a field which biases the results towards smaller sizes. By collecting overlapping images, PharmaVision 830 removes this bias.

Thresholding

The particles in the raw image are separated from the background by a process known as thresholding. The threshold value is defined as the lightest grey scale value that should be considered a particle. Any pixels at this critical value or darker are automatically defined as a particle. Any pixels lighter than this critical value are automatically defined as background. Because transparent particles may have a dark perimeter surrounding a lighter interior, an algorithm automatically fills such voids to ensure that complete particles with varying intensity are not detected as a number of smaller particles.

Segmentation

Where particles are touching a segmentation algorithm is applied. This technique is used to determine the number and size of component particles in a cluster and is carried out in two stages. The first stage is known as marker-setting and involves dividing an image into regions containing pixels with similar intensities. The greyscale of an image can then be thought of as a three-dimensional topographic representation with the darkest pixels being minima. Regional minima are then identified and referred to as 'markers' and defined as a

[1] www.malvern.de/common/downloads/MRK516-01_LR.pdf

point where all neighbours have higher values. If only one marker is found i.e. the particle is not a cluster, the segmentation algorithm will stop and not continue with the second stage – the watershed algorithm. The watershed technique regards the minima in the three-dimensional greyscale landscape as basins and determines where watersheds must divide the basins to ensure that if an imaginary drop of water were to fall towards the basins it would travel to one of the minima along the steepest slope i.e. the largest greyscale gradient. These watershed lines are used to define boundaries between individual particles in a cluster.

Statistical results generation
The images of each individual particle are extracted and the software calculates pre-defined morphological parameters including: diameter, width, length, area, volume, roundness and convexity. The values are displayed as real-time histograms as either number or volume distributions. The PharmaVision 830 typically analyzes between 20,000 and 500,000 particles depending on particle size and dispersion density. Images of all particles can be stored and recalled for further analysis.

3.4.2 Morphological parameters

Mean diameter
The radius from the centre of mass to the edge of the particle is measured at every pixel on the circumference of the particle. The diameter is calculated from the mean value of these measurements.

Circle equivalent diameter
The diameter of a circle with the same area as the particle.

Max distance
The maximum distance found within the particle.

Volume
An estimate of the particle volume using the area and mean diameter.

Width
All possible lines from one point of the perimeter to another point on the perimeter are projected on the minor axis. The maximum length of these projections is the width of the object.

Area
The visual projected surface area of the particle.

Length
All possible lines from one point of the perimeter to another point on the perimeter are projected on the major axis. The maximum length of these projections is the length of the object.

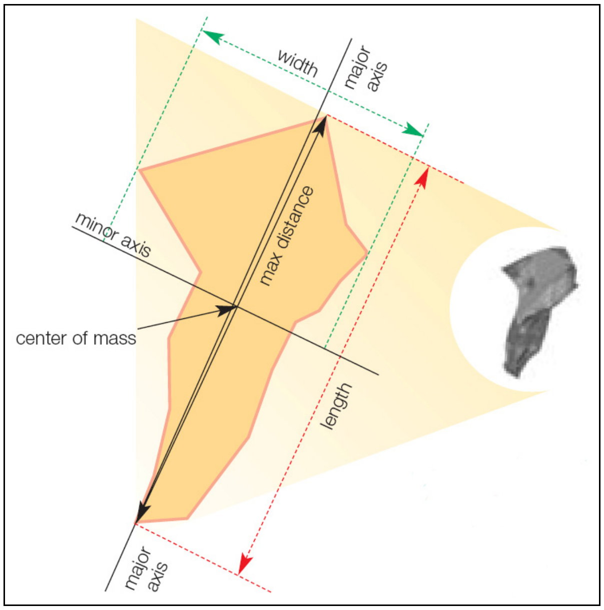

Figure 7. Definition of Length – from[1]

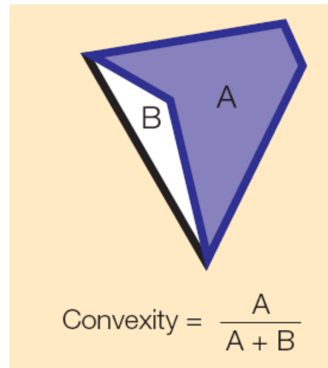

Figure 8. Definition of Convexity– from[1]

Convexity

Convexity is the object area divided by the area enclosed by an imaginary "rubber band" wrapped around the object. The convexity has values in the range 0 to 1. A convex shape has convexity 1.0, while a concave shape has a lower value, close to 0.

Roundness

Roundness is a measurement of the length/width relationship, with values in the range 0 to 1. A perfect circle has roundness 1.0 (a), while a needle shaped object has roundness close to 0 (b). Intuitively the roundness is a comparison between the "strength" of the major axis and the "strength" of the minor axis.

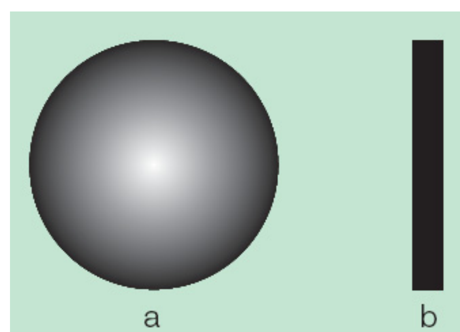

Figure 9 Definition of Roundness – from[1]

Roundness	1.00	0.07	0.00	0.76
Convexity	1.00	0.94	0.97	0.76

Figure 10 Comparison of Roundness and Convexity – from[1]

3.5 Blaine and Flowsorb II 2300 Nitrogen absorption by BET-method - Surface area

When determining surface area of fines, e.g. in the cement industry, the usual method is the so-called **Blaine method**. This simple method measures the time for a specific volume of air to flow through a known volume of compacted powder and together with the density of the substance, this is used to calculate the specific surface area of the sample. The main advantages of this technique are that it is simple and rapid. However, it is not very accurate and suffers from a number of weaknesses, e.g. it does not take into account variable particle shape and it becomes extremely unreliable at surface areas greater than 500 m^2/kg (Potgieter and Strydom, 1996)7.

In situations where accurate measurements are required, one of the most common methods to measure surface area is the **BET method** (Brunauer, Emmett and Teller). This method relies on a mathematical formula that describes the adsorption of a particular gas on the finely divided material. The amount of adsorbed gas at a specific partial pressures is determined. From this value the surface area of the sample can be calculated, including both the internal and the external surface area of a material.

In this study the surface area of the samples examined was tested both by the Blaine method and by the BET method, where the Flowsorb II 2300 Nitrogen absorption device was used.

3.6 AccuPyc pyknometer - Density and volume

The AccuPyc 1330 Pycnometer determines the volume and the density (by dividing by the mass) of a sample by measuring the amount of gas (helium) displaced by the sample. The pressure difference observed upon filling the sample chamber and then discharging it into a second empty chamber allows the computation of the amount of displaced gas, and thereby the sample's solid phase volume. Gas molecules rapidly fill the tiniest pores of the sample; only the truly solid phase of the sample displaces the gas.

4 Results & discussions

Data from Metso Minerals; Sand Flow data collected 2003-2008 are presented in Figure 11 (Mähönen, 2008)8. In addition materials tested in this study are plotted at the graph.

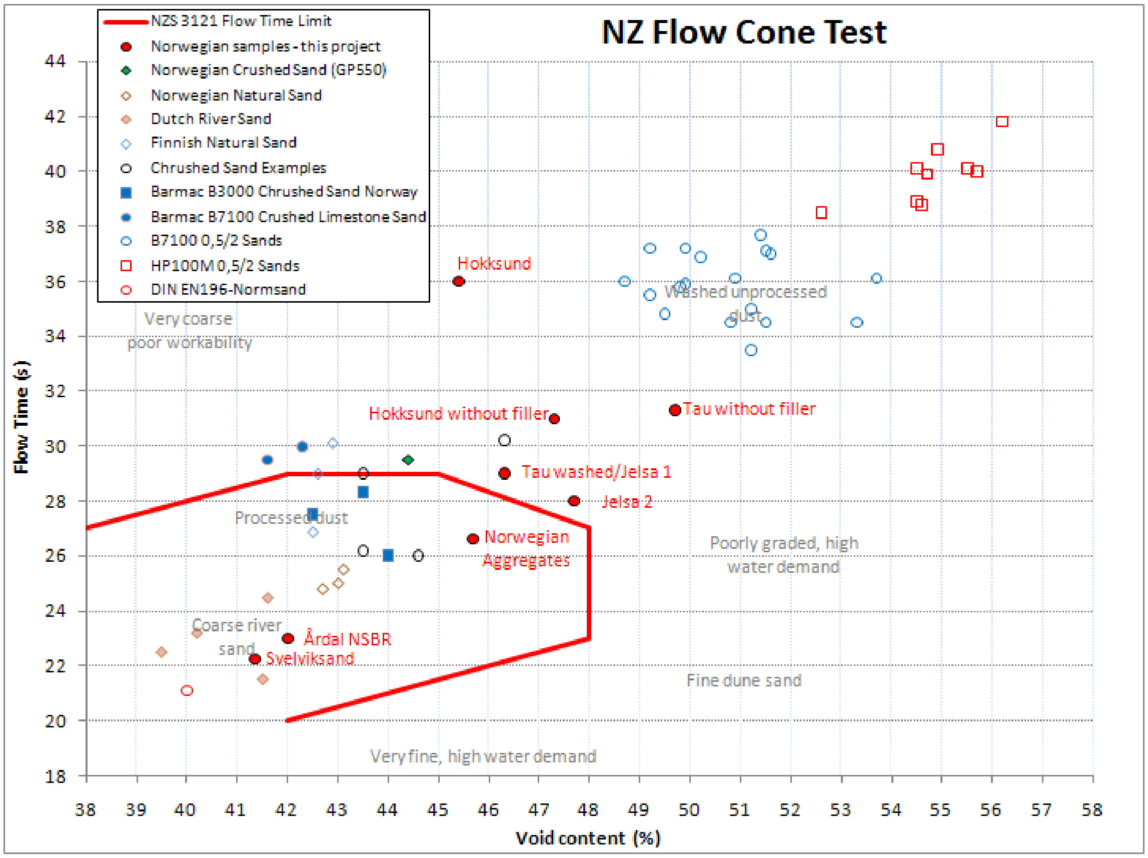

Figure 11. NZ Flow Cone Test results – From8 and this study.

It is evident that all three of the natural and natural/crushed materials (Svelviksand, Årdal NSBR and Norwegian Aggregates) are within the prescribed envelope, and should hence produce good results in concrete. All the 100% crushed materials are outside the envelope, whereof the samples; Tau without filler and Hokksund appear to have the worst properties.

4.1 Grain size analysis by Coulter LS 230 Laser diffraction & Sedigraph

The particle grain size distributions of the 7 different samples were measured by Coulter laser diffraction (Coulter LS 230) and sedigraphy. The results are presented in **Error! Reference source not found.** Figure 13 respectively.

Even though the relative particle size distributions are similar in the two graphs, it is evident that the results from the Coulter present coarser grading than the results from the sedigraph. For instance, the amount of particles of the most coarse material (NSBR) passing the 10µm size, determined by the Coulter is approx. 18%, while the corresponding result obtained by the Sedigraph is approx. 22%. The difference between both techniques is even more significant for the finest materials (Jelsa 1 & 2).

In a study by Stewart et al. (2006)3, it was found that the independent variables quantifying the particle size distributions found with the laser analysis and the hydrometer were strongly correlated. It was suggested that a simple test, the hydrometer settling test, can give nearly as accurate an analysis of particle size distribution as the much more specialized and expensive laser diffraction test. Further, these data show no indication that the hydrometer analysis becomes inaccurate for particles smaller than 30 µm, a limitation that Ahn (2000)9 believed existed.

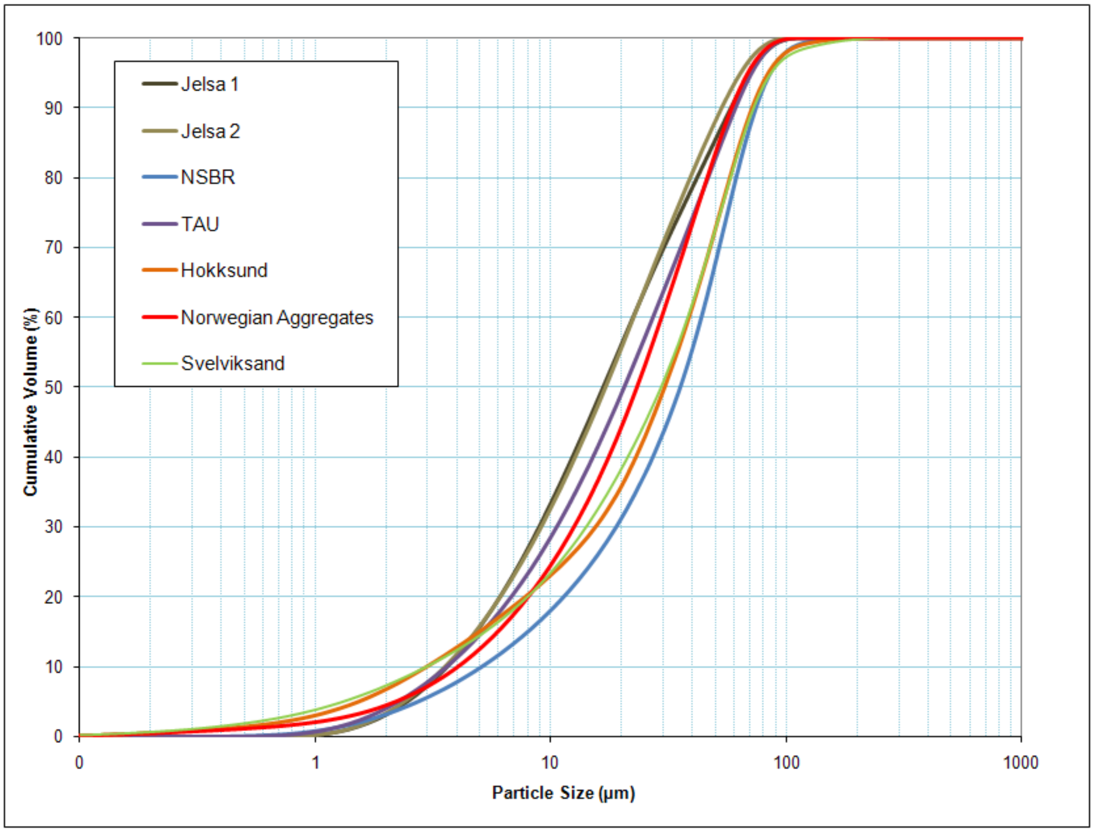

Figure 12. Coulter LS 230 Laser diffraction – Grain size analyses

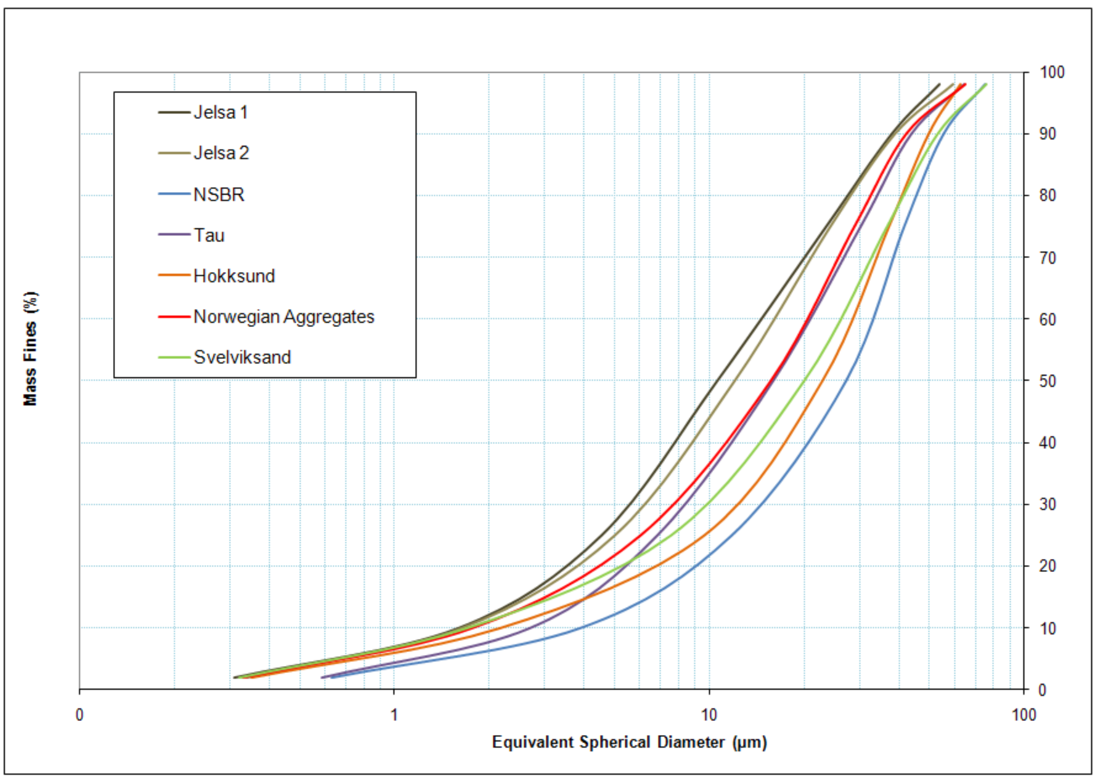

Figure 13. Sedigraph – Grain size analyses

4.2 Pharmavision 830 – Image analyses, shape

The software of the Pharmavision 830, image analyses device creates analysis statistics in tables for the various parameters measured as shown in an example in Table 1. The results are all presented as average values for all the particle sizes measured. According to information from the Particle Laboratory at NTNU, it is not possible to extract particular results from specific particle sizes.

Table 1 Example of analysis statistics created by Pharmavision 830 in a table format for the parameter; Roundness

No. of objects	10000	STD[1]	0.200	D[n,0.1][2]	0.355	D[v,0.1][5]	0.346
Parameter	Roundness	RSD	32.232%	Median[3]	0.616	D[v,0.5][6]	0.644
Mean:	0.620	D[4,3]:	0.776	D[n,0.9][4]	0.880	D[v,0.9][7]	0.868
Min,max:	[0.000000, 1.000]	D[3,2]:	0.735	Confidence N:	100.00%	Confidence Vol:	0.00%

Explanations:
[1]STD = Standard Deviation
[2] <10% of the particles are measured with Roundness; 0.355, wheras;
[3] the median for those particles are; 0.616
[4] <90% of the particles are measured with Roundness; 0.880
[5] 10% of the volume of particles are measured with Roundness under 0.346
[6] 50% of the volume of particles are measured with Roundness under 0.644
[7] 90% of the volume of particles are measured with Roundness under 0.868

An overview of some selected parameters are presented in Table 2, and in Figure 14 to Figure 18.

Table 2 Overview of some selected parameters.

	Roundness			Width (µm)			Length (µm)			Area^3 (µm)		
	D[n,0.1]*	Median	D[n,0.9]**	D[n,0.1]*	Median	D[n,0.9]**	D[n,0.1]*	Median	D[n,0.9]**	D[n,0.1]*	Median	D[n,0.9]**
Jelsa 1	0,326	0,601	0,861	2,546	4,493	9,841	3,244	6,491	14,949	4,860	17,830	93,180
Jelsa 2	0,315	0,592	0,844	3,041	6,222	16,586	4,023	9,392	25,066	8,100	37,240	259,900
NSBR	0,330	0,605	0,857	2,929	6,376	18,888	3,914	9,540	28,531	8,090	38,820	342,940
TAU	0,369	0,629	0,862	2,698	5,326	13,919	3,597	7,705	20,744	6,470	26,690	192,490
Norwegian Aggregates	0,355	0,616	0,880	2,543	4,198	9,460	3,179	5,980	13,940	4,850	15,360	83,280
Hokksund	0,349	0,624	0,864	2,727	5,272	13,822	3,636	7,745	21,052	5,780	26,440	193,310
Svelviksand	0,367	0,636	0,862	2,726	6,448	18,369	3,851	9,071	25,533	7,430	37,970	323,550

	Mean Diameter (µm)			Contour/Area (1/µm)			Volume (µm^3)			Convexity		
	D[n,0.1]*	Median	D[n,0.9]**	D[n,0.1]*	Median	D[n,0.9]**	D[n,0.1]*	Median	D[n,0.9]**	D[n,0.1]*	Median	D[n,0.9]**
Jelsa 1	3,049	5,305	11,520	0,399	0,796	1,156	9,88	65,18	710,16	0,967	1,000	1,000
Jelsa 2	3,674	7,423	19,144	0,253	0,595	1,035	19,70	185,90	3318,47	0,937	1,000	1,000
NSBR	3,568	7,544	22,091	0,222	0,580	1,047	19,24	194,66	5073,22	0,945	1,000	1,000
TAU	3,267	6,321	16,266	0,281	0,665	1,112	14,09	113,10	2066,37	0,978	1,000	1,000
Norwegian Aggregates	2,832	4,944	10,907	0,413	0,833	1,178	9,16	52,76	607,01	0,983	1,000	1,000
Hokksund	3,165	6,308	16,360	0,279	0,669	1,100	12,20	110,82	2109,12	0,988	1,000	1,000
Svelviksand	3,497	7,458	20,948	0,218	0,576	1,063	16,66	188,91	4537,65	0,980	1,000	1,000

In Figure 14 the mean values for the parameter; _Roundness_ are presented. It is evident that materials from Svelviksand, Tau, Hokksund and Norwegian Aggregates exhibit the highest mean values for Roundness. The material from NSBR, Jelsa 1 and Jelsa 2, exhibit the lowest mean values for Roundness.

In Figure 15 the mean values for the parameter; *Mean Diameter* are presented. The samples; Jelsa 1 and Norwegain Aggregates exhibite the smallest Mean Diameter, while Årdal NSBR exhibit the highest mean Diameter. These results correspond well with the results obtained by the Sedigraph as presented in Figure 13. For the other samples it is difficult so see any clear correlation with the results from the Sedigraph.

In Figure 16 the mean values for the parameter; *Contour/Area* are presented. The lowest values are observed for Svelviksand, Årdal NSBR and Jelsa 2. Jelsa 1 and Norwegian Aggregates are showing the highest values. It is evident that results of the Contour/Area are in many ways reverse of the results obtained for the Mean Diameter.

In Figure 17 the mean values for the parameter; *Volume* are presented. It is evident that the samples are divideded into three groups; Norwegian Aggregates and Jelsa 1 are exhibiting the lowest Volume, samples Tau and Hokksund exhibit medium values, while Jelsa 2, Årdal NSBR and Svelviksand are showing the highest values.

In Figure 18 the mean values for the parameter; *Convexity* are presented. As the median values all were 1.000, it appears difficult to use thess results. However, by looking at the D[n,0.1][5], it can be observed that Jelsa 2 and Årdal NSBR are showing the lowest values.

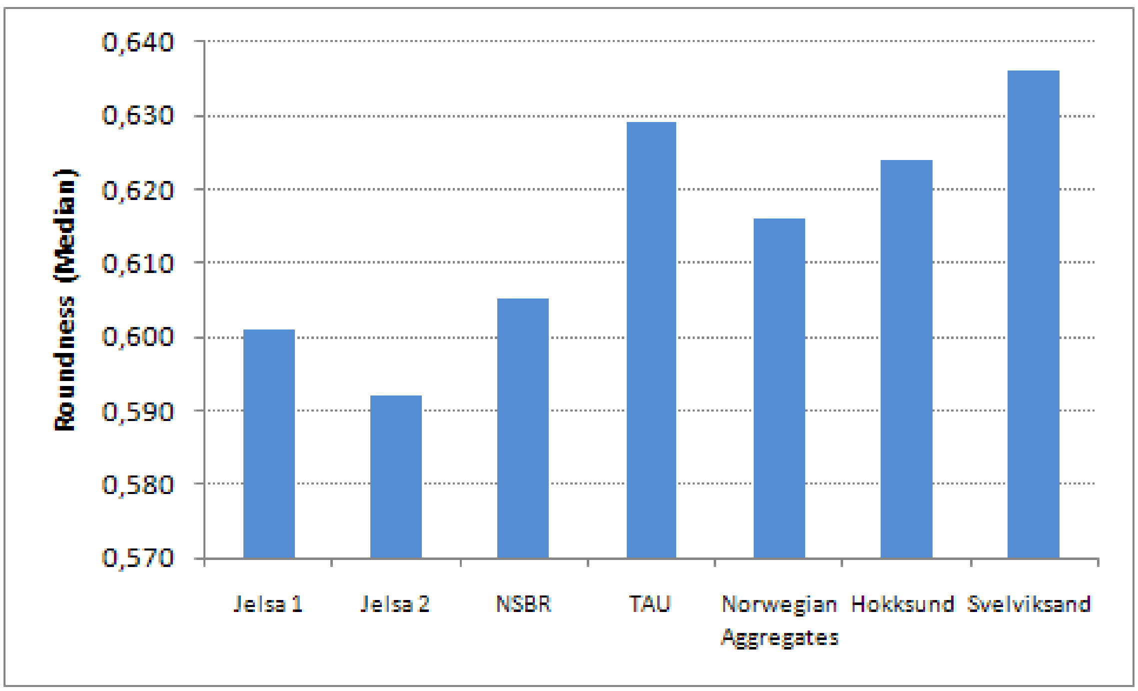

Figure 14. Roundness – Median values.

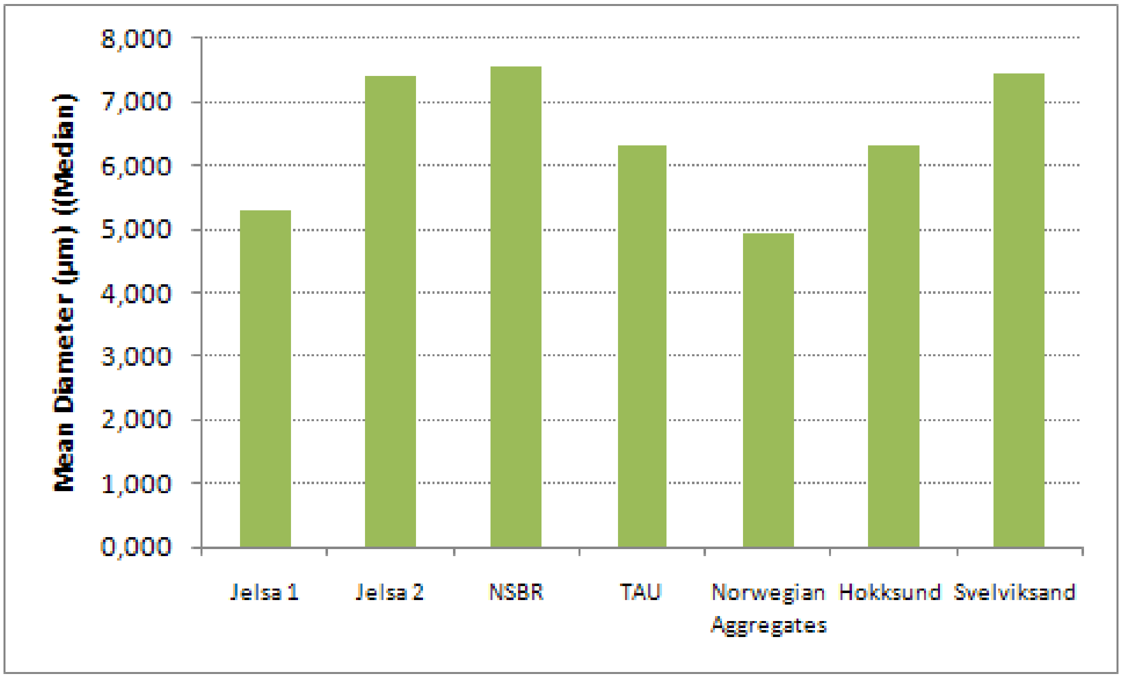

Figure 15. Mean Diameter – Median values.

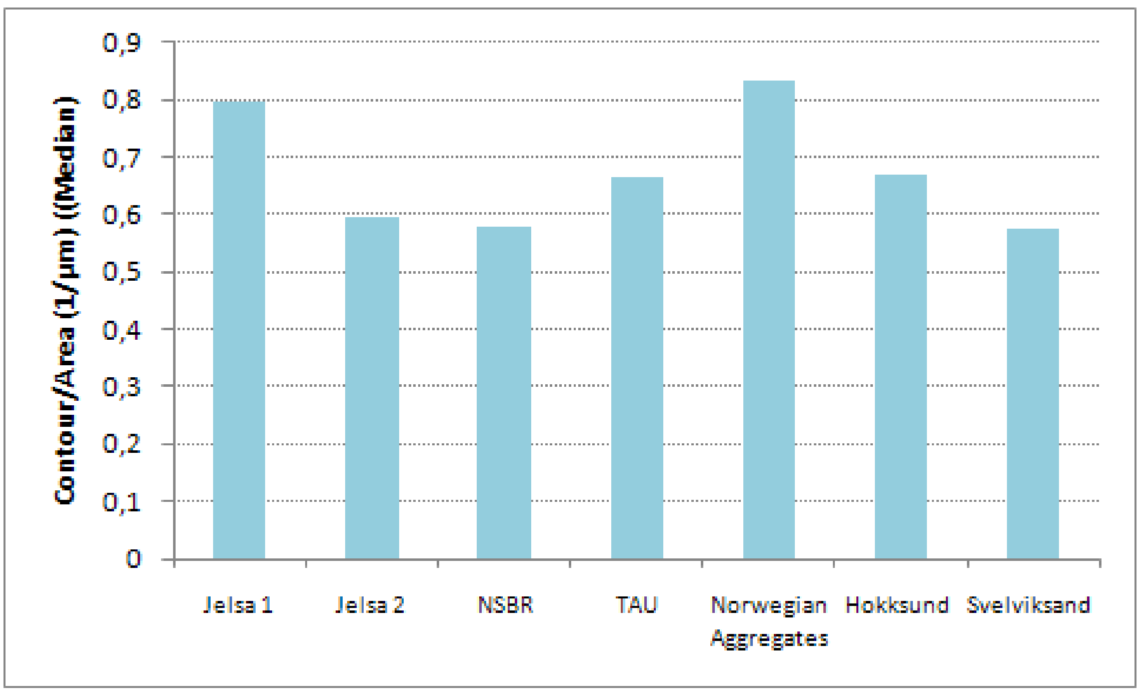

Figure 16. Contour/Area – Median values.

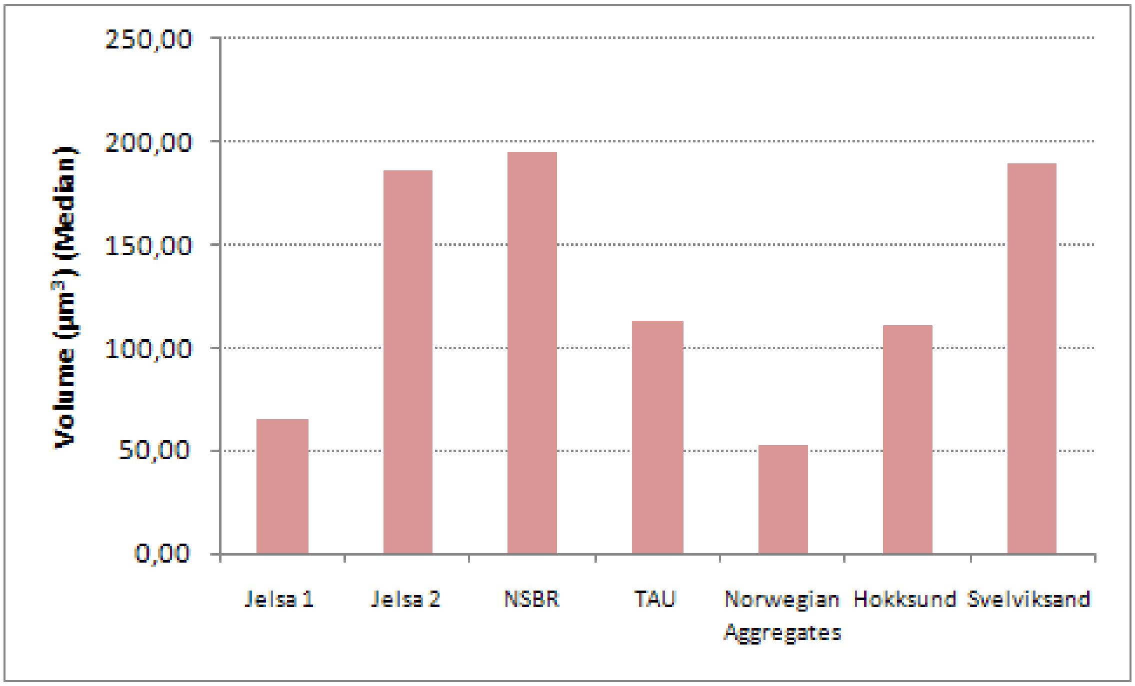

Figure 17. Volume – Median values.

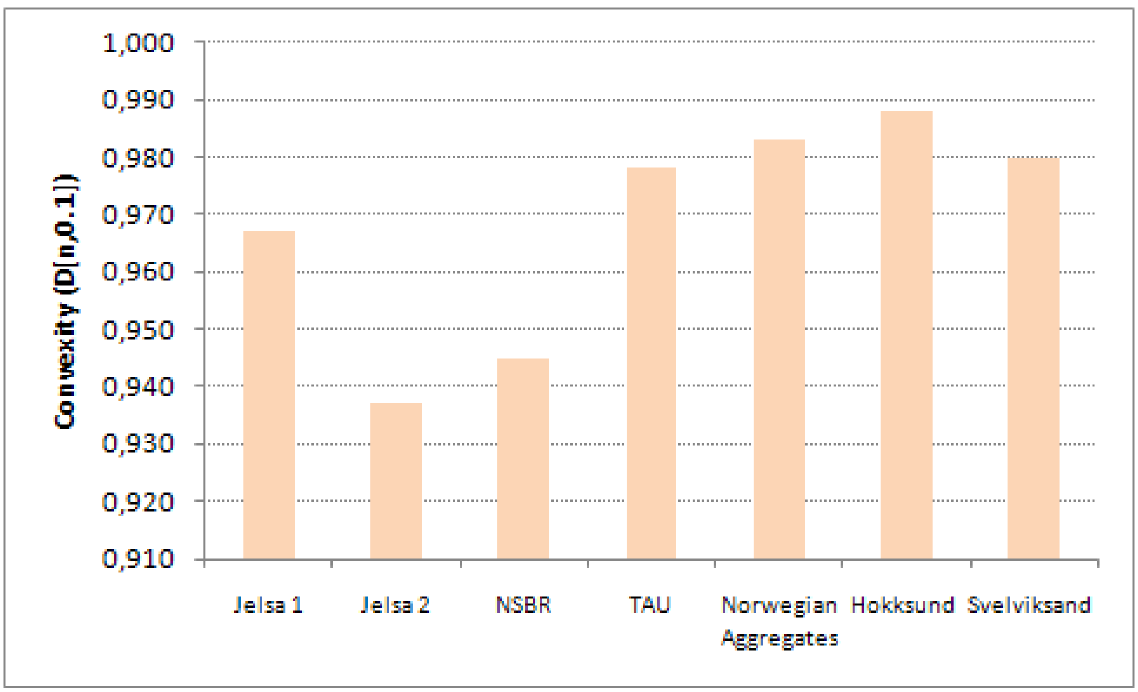

Figure 18. Convexity – D[n,0.1][5] values.

4.3 Blaine and Flowsorb II 2300 Nitrogen absorption by BET-method - Surface area - Absolute density by Accupyc 1330

Specific surface is the relationship between surface area of a particle and its volume. The higher the surface area to volume ratio, the greater is the specific surface. The specific surface would directly influence the cement and water demand for the fines when used as aggregates in mortar or concrete, when considering that in a concrete mix every surface of every particle has to be coated by the cement paste in order to be "glued" together.

The specific surface results (m^2/g), obtained by both the Blaine and the Flowsorb II 2300 Nitrogen absorption by BET-method, are presented in Table 3. The materials from Jelsa (1&2), NSBR, Tau and Hokksund, appeared to exhibit similar values in the BET measurements, with Jelsa 2 exhibiting the lowest value of 2.06 m^2/g. It is difficult to explain the high specific surface values for Norwegian Aggregates and Svelviksand, however, if not attributed to errors in measurements, this could be due to mineralogical properties of the fines, e.g. high mica, chlorite or clay content in these samples. A poor relation was found between the results obtained by the BET vs. the Blaine method. It was noted by Stewart et al (2006)3 that the results from the Blaine fineness test turned out to be questionable for approximately half of the aggregates they tested. It was stated that because the Blaine fineness test is so unreliable when used with fillers, any correlations with these test results are most likely insignificant.

In a previous Norwegian project (NORMIN, 1995)10 it was pointed out that various properties of the fines may influence the value of the specific surface, obtained by the BET method. These are properties such as amount of particles < 10 µm in the tested material, mineralogy, and surface texture. In this previous project, fine aggregates (< 63µm) from Tau and Årdal were tested. For comparison to this study the previous values are shown in Table 4.

Table 3. Results of Absolute density and Specific surface.

Sample	Absolute density (Accupyc 1330)	Specific surface		
	Specific weight (g/cm^3)	BET (m^2/g)	Blaine (cm^2/cm^3)	Blaine (m^2/g)
Jelsa 1	2.8600	2.36	11498.20	0.402
Jelsa 2	2.8200	2.06	8292.50	0.294
NSBR	2.7414	2.75	6365.33	0.232
TAU	2.8004	2.24	9345.09	0.333
Hokksund	2.9200	2.20	6053.48	0.207
Norwegian Aggregate	2.8000	4.44	9260.73	0.330
Svelviksand	2.7300	8.10	6343.70	0.232

Table 4. Results from previous Norwegian project10.

Sample	Specific weight (g/cm^3)	Specific surface Blaine (m^2/g)	Specific surface BET (m^2/g)
Tau	2.81	0.28	2.02
Årdal	2.73	0.10	2.03

5 Conclusions – Final remarks

A summary of the results of this study is presented in Table 5. The ranking of the results of the NZ Flow Cone Test is a qualitative subjective assessment in this project based upon the judgment provided by the method4.

For the particle size distribution, it is evident that the measurement by the Sedigraph is exhibiting a coarser grading than measured by the Coulter. Looking at the approximate amount of material passing the 10µm size, the Sedigraph exhibits results with a factor of 1.2 to 1.5 larger when compared to the results by Coulter.

The Pharmavision 830 Image analysis results are presented as average results for all particle sizes tested, i.e. 0-63µm. As a consequence it is not possible to make any conclusions if particular particle grain sizes are exhibiting particular properties that may affect the utilisation in concrete. Data from the image analyser device; AnaTec, carried out by Norsk Stein (Odd Hotvedt, pers. med. 2010) showed that the grain shape (length/width) was significantly worse (for several samples) for particle sizes of 200µm and 30µm, compare to other particle sizes. This needs to be investigated further.

As no mortar- or concrete tests have been carried out within this project with these particular filler materials, it is difficult to assess how these materials, and which particular properties that may affect the mortar and concrete qualities.

Further research is needed on the characterization of selected properties of fillers, and subsequent mortar- and concrete testing with the same filler materials.

Table 5. Summary of results.

Sample / Test-methods	NZ Flow Cone Test*	Coulter LS 230 – approx.material (%)passing10 μm	Sedigraph – approx. material (%) passing10 μm	Sedigraph vs. Coulder (ratio material (%) passing10 μm	Pharmavision 830 – Image analyses: Roundness (Median)	Contour/Area (1/μm)	Volume (Median)(μm^3)	Convexity D[n,0.1]	BET (m^2/g)	Blaine (m^2/g)
Jelsa 1	Medium	33	48	1.5	0.601	0.796	65.18	0.967	2.36	0.402
Jelsa 2	Medium	32	44	1.4	0.592	0.595	185.90	0.937	2.06	0.294
Årdal/NSBR	Good	18	22	1.2	0.605	0.580	194.66	0.945	2.75	0.232
TAU	Medium**	28	35	1.3	0.629	0.665	113.10	0.978	2.24	0.333
Hokksund	Bad***	22	26	1.2	0.624	0.669	110.82	0.988	2.20	0.207
Norwegian Aggregates	Good/ medium	24	36	1.5	0.616	0.833	52.76	0.983	4.44	0.330
Svelviksand	Good	22	30	1.4	0.636	0.576	188.91	0.980	8.10	0.232

** The classification into; "Good", "Medium", "Bad" is a subjective classification used in this project, based on "Flow time limits" presented in the NZ Flow Cone Test4.*
*** Tau washed*
**** Hokksund with filler*

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