CRUSHED SAND AS A COMPLEMENTARY AGGREGATE

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ABSTRACT

In the autumn of 1992 a project was started with the objective of investigating the possibility of using a blend of crushed and natural sand in concrete. Several methods have been used to characterize the crushed sand. The effect of filler content and the filler grading have been analyzed both in paste, mortar and concrete.

Laboratory results with blended sand in the concrete, but primarily the experiences from ready mix concrete plants clearly demonstrated the potential of crushed sand as a complementary aggregate. Depending on both the type of natural and crushed sand, it has been possible to use up to 60% crushed sand in the blend in concrete of strength grades C25 and C35. Stability, pumpability as well as finished surfaces of the concrete structures have been improved. This paper summarises the concrete results using Vassfjell crushed sand blended with different natural sands

At the end of the first year of the project eight ready mix plants have found it beneficial to use crushed sand in addition to the natural sand.

Key words: concrete, crushed sand, blended sand, waste material

1 INTRODUCTION AND BACKGROUND

Generally there is no shortage of natural sand of good quality in Norway. Regardless of this, a number of readymix plants have recently found it beneficial to use crushed sand in a blend with natural sand in their concrete production. The benefit have been partly of economical and partly of technical nature. The use of mixed natural- and crushed sand was motivated from two main reasons:

- to use the surplus from the production of crushed coarse aggregate
- the availability of sound natural sand without alkali reactive rock types with short transport distance has decreased

The main objective has been to maintain the workability of concrete without increasing the cement or water content.

The project was initiated by Franzefoss Bruk A/S and is supported by The Research Council of Norway. The other participants in the project are Aker Betong as, Partek Norspenn, Partek Østspenn, Hønefoss ferdigbetong, Norwegian Road Research Laboratory, Norsk Stein as and SINTEF Structures and Concrete. In addition diploma students at the Norwegian Institute of Technology, NTH, Department of Structural Engineering has been involved in central parts of the laboratory investigations.

The project was started late 1992 and will continue to the end of 1995. This paper reports some of the aggregate investigations as well as results obtained for concrete made with Vassfjell crushed sand in combination with different natural sands.

A literature review revealed that much work has been done with respect to use the crushed fine aggregate in concrete. Several regions in Germany, USA and Japan have to use crushed aggregates only, but the review concentrated on Scandinavian experiences, since these results most likely would be directly applicable in Norway.

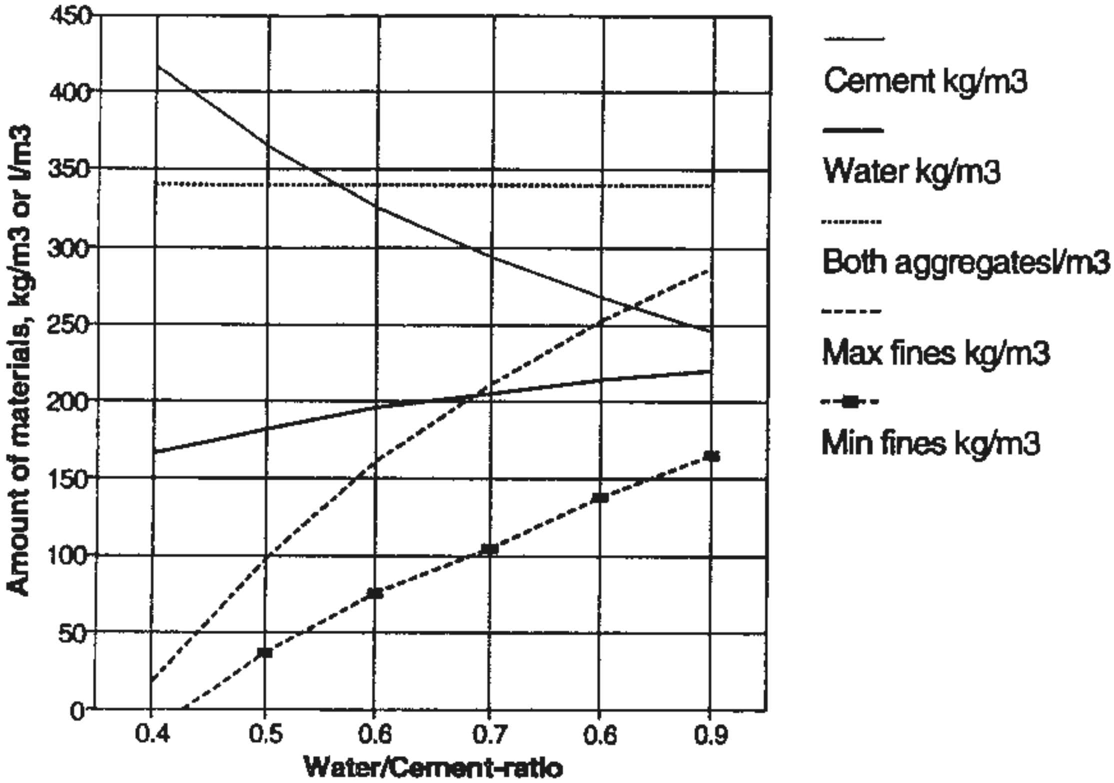

Fig 1 Composition of concrete with 300 l/m^3 paste depending on w/c-ratio

Filler particles less than 0.125 mm have been investigated by Poijärvi /1/ and reported in 1967. He found that crushed fillers in certain amounts had positive effect upon workability, stability and strength; independent of type of crushed filler. Based on Poijärvi's work, Fig 1 shows a plot of the cement and water content (kg/m^3), fine and coarse aggregate (l/m^3), ending up with two filler contents (kg/m^3) as a function of water/cement-ratio. The maximum content of fines is recommended to achieve the best workable concrete, /1/ and the minimum content of fines to avoid bleeding is recommended, /2/. The everyday concrete in Norway often only contains filler in the amount of 40 to 80 kg/m^3. The effect of high contents of fines, has been one of the main topics to be investigated, and within the project a Ph Dr thesis is going on to study the effects of fillers. To measure the viscosity of the pastes including the filler particles a modified Mars Cone test has been used, /3/ and /4/.

Very different properties have been reported for the concrete when using 100% crushed sand /5/, and /6/, and some results were reported with blended sand /7/, but the potential of blended sands has not yet been fully utilized in industrial production of concrete.

2 AGGREGATE TESTING

2.1 Introduction

The crushed sand used here has been improved by increasing the cubisity of the material. It is recommended to avoid larger particles than 3- 4 mm in crushed sand, /8/. From literature studies a comparison between quarry waste and crushed sand with respect to properties is shown in Table 1.

Table 1 Comparison between quarry waste and crushed sand with respect to properties and proposed requirements, /9/:

Properties	Quarry waste	Crushed Sand
1 Particle shape	Cubicity* in the fraction 1-2 and 2-4 mm < 50%	Cubicity in the fraction 1-2 and 2-4 mm > 50%
2 Resistance to alkali aggregate reactions	No demands	Less than 20% reactive/ possible reactive minerals
3 Grading curve	No demands	Grain size < 4 mm Convex grading curve
4 Filler	No demands	< 20% less than 0,125 mm
5 Mica content	No demands	< 20% of counted particles in the fraction 0,125 - 0,25 mm
6 Friable particles	No demands	No friable particles
7 Surface coating	No demands	No demands

*Cubical particles had the following ratio between thickness (t), width (w) and length (l): l/t < 2.5 and w/t < 1.45, determined by evaluation, measuring and counting of particles.

2.2 Particle - matrix model

The fundamental impact of the crushed sand on workability of concrete has been analyzed using a "particle-matrix model" /10/. The model supposes the properties of concrete to be under the influence of three main parametres;

1. the properties of the aggregate
2. the properties of the matrix
3. the volume of the matrix

The model defines the matrix phase to consist of cement, water and aggregate fines (< 0.125 mm). The particle phase consists of the remaining aggregate (> 0.125 mm).

2.3 Testing methods

The main properties of crushed sand in respect to concrete properties is the grading, the shape of the aggregate particles and the amount and grading of the aggregate fines. To determine these properties, tests have been made with different types of aggregates, both crushed and natural;

Crushed sand; Vassfjell 0-4 mm
Feiring 0-4 mm
Hole 0-4 mm
Steinskogen 0-4 mm

Natural sand; Årdal 0-3 mm

Several methods have been used to determine the mentioned properties of the crushed sand. Grading, shape and the effect of aggregate fines are described by testing the sliding angle and also the void content by loose packing. The best results are obtained by using the "Intensive Compaction Tester" (ICT) and a "Modified Marsh Cone test". All tests are executed on different blends of crushed and natural aggregate.

ICT compacts the material by using revolvement under compression, which all together gives a kneading movement. The compaction rate is mesured continousely.

The viscosity of the matrix phase (containing all aggregate fines) has been characterized by the use of a modified "Marsh Cone Test". The matrix is passed through a funnel while the time is measured. The matrix contains cement and water, condensed silica fume, admixtures and aggregate fines in the same ratio as in a given concrete.

2.4 Test results

Crushed sand will normally have a grading closer to the Füller-grading than a natural Norwegian sand. The particle distribution of the crushed sand is therefore characterized by a "hanging" grading and high content of fines. This gives a lower void ratio, which will require a lower volume of matrix. Tests on crushed sand vs natural sand confirm the advantageous packing of crushed sand. Fig. 2 shows compaction grade of two types of crushed sand and one type of natural sand. The difference between the crushed sands is the shape of the aggregate particles; the material from Hole has a less favourable particle shape than Vassfjell, cubicity in the fraction 1-2 mm was 0,40 respectively 0,70, which gives far more internal friction and less compaction. The figure clarely demonstrates the necessity of an optimal particle shape and grading.

The effect of aggregate fines on the viscosity of the matrix is tested using a "modified Marsh Cone test". Large amounts of aggregate fines will give a considerable increase of aggregate surface area. This will affect the viscosity of the matrix and thereby the viscosity of the concrete. The next figures include four different types of crushed sand and one natural gravel. The grading of the fines is shown in Fig 3, while the viscosity properties of paste including fines is shown in Fig 4.

The results clearly demonstrate the effect of the grading of the aggregate fines upon the total surface area and the matrix's viscosity properties. The finest aggregate fines (Vassfjell) gives an increase in time of more than 400 % compared to the fines from the natural gravel (Årdal).

From the aggregate aspect, the use of crushed sand will be a balance between the positive effect of the favourable compacting properties and the stability of the matrix versus the negative effect of internal friction and increased viscosity. The optimum content of crushed sand in a blend with natural gravel depends on the local aggregate and the purpose of the concrete production. The cement paste demand could be reduced by blending most natural gravels with some crushed aggregates.

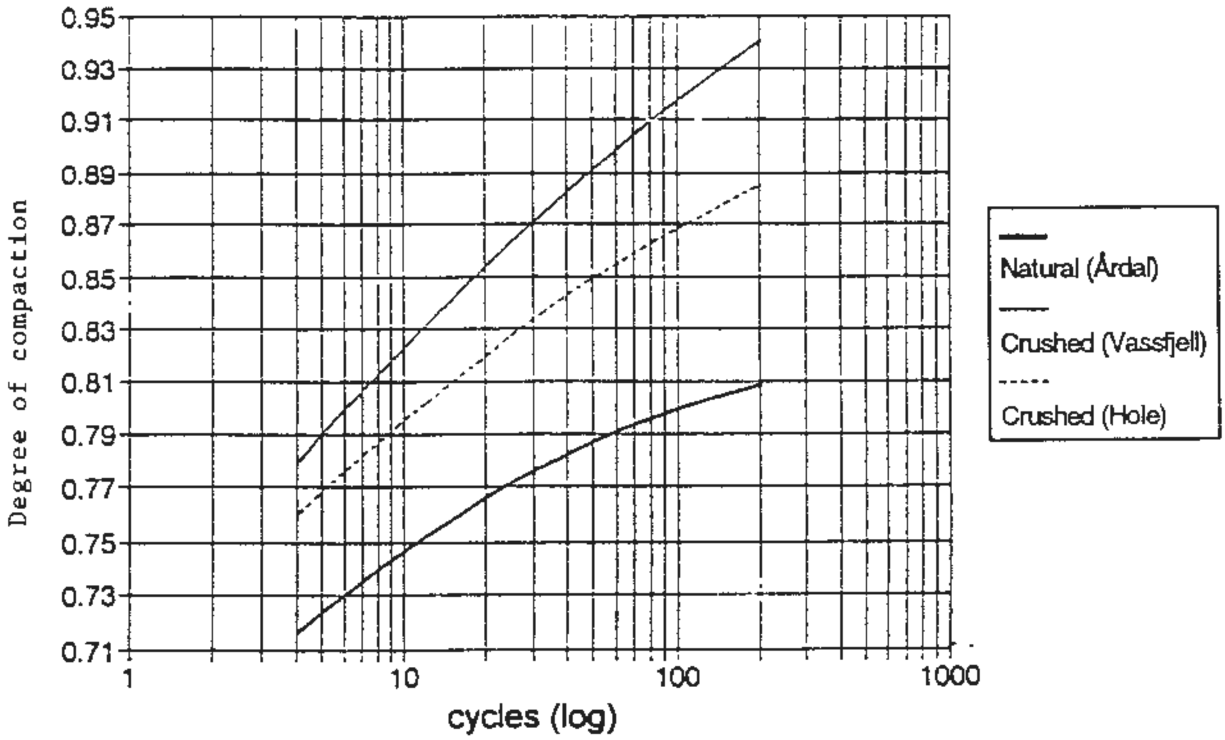

Fig 2 Compaction of two crushed sands and one natural sand tested in the ICT

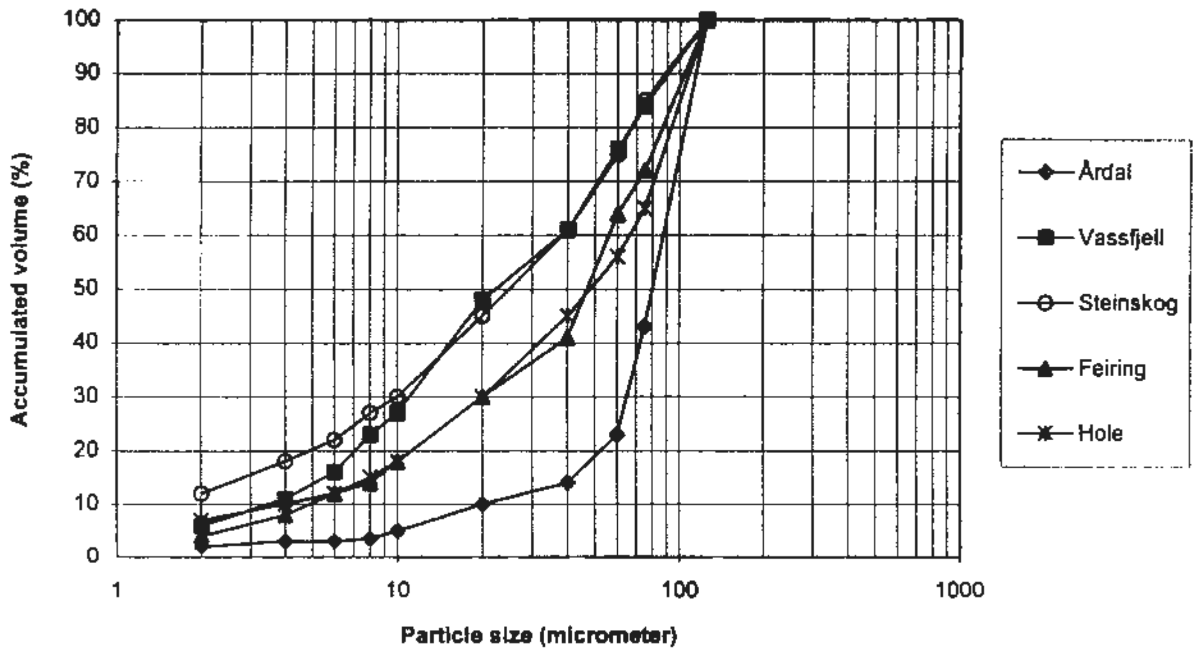

Fig 3 Grading curve of fines

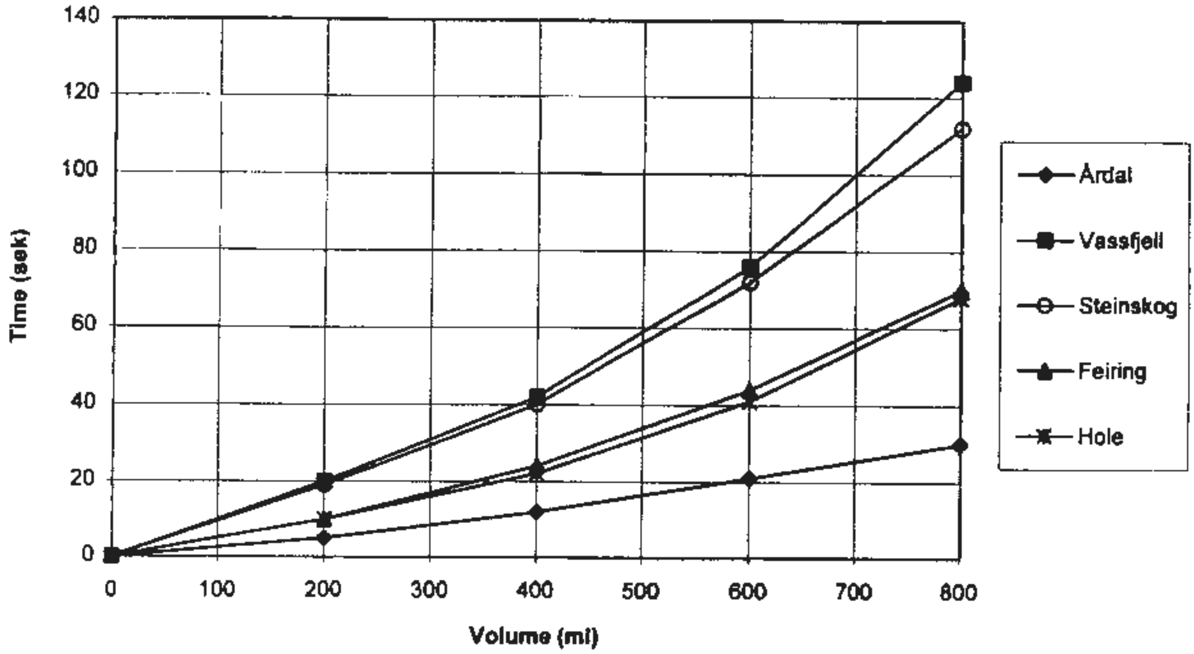

Fig 4 Viscosity of different matrixes, tested in Marshcone

3 CONCRETE TESTING

3.1 Introduction

The sand tests clearly demonstrated the potential of crushed sand as a complementary aggregate in concrete. In the planning of concrete tests the main objective was to find out whether it was possible to utilize the positive effects of crushed sand in full scale concrete production.

Both laboratory and in situ testing of different concrete grades have been performed.

3.2 Materials

-	Cement:	OPC: NORCEM P30
-	CSF	condensed silica fume from Ila/Lilleby
-	Water:	Ordinary deionized potable water
-	Natural sands:	Ekle 0-10 mm, Gimse 0-8 mm, Årdal 0-8 mm and 0-3 mm, all with density 2.67. Ekle was dominated by clay/siltstone, granite/gneiss, mafic rock/greenstone and phyllite. Gimse is dominated by gneiss/granite, mylonite/cataclastic and rhyolite while Årdal is dominated by granite.
-	Crushed sand:	Cubicised Vassfjell 0-3 mm with density 3.05 (Gabbro)
-	Coarse aggregate:	Vassfjell 8-11 and 11-16 with density 3.05 or Årdal 8-11 and 11-16 mm with density 2.68
-	Lignosulfonate plasticizer:	SCANCEM P (with 40% dry material)

The sieve curves for the fine aggregates are given in Fig 5.

3.3 Test set up

The variables mentioned below have been isolated in the following way:

- using the same paste content (cement, water and plasticizer is constant)
- start testing with todays recipe
- testing concrete with blended sand using crushed sand amounts of 15, 30, 60 and 100 volume percent of the total sand
- control the workability using slump or fall table tests
- keep the mortar content constant, some mixes with decreased mortar content have been made
- measuring other properties than workability on fresh concrete, such as bleeding, plastic shrinkage and setting.
- measuring hardened concrete properties
- producing the best fitted concretes in full scale.

The density is higher for the Vassfjell crushed sand than for the natural sands, and the concrete had to be designed on a volume basis to ensure compatibility of the results. The composition as volume parts of concrete grade C25 and C35 for different natural sands is given in Table 2.

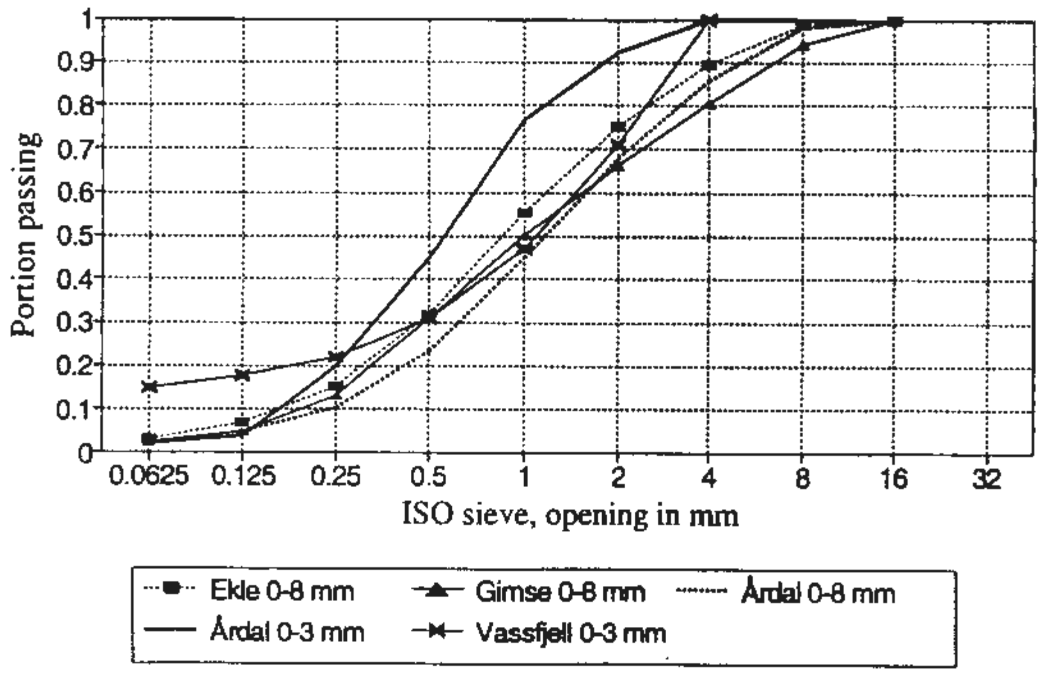

Fig 5 Sieve curves for the crushed sand and the natural fine aggregates

Crushed sand was gradually introduced into these basic mixes on a volume replacement basis, 15, 30, 60 and 100% of sand aggregate. The new recipes had the same paste content and composition and the same mortar content. Due to the high filler content of the crushed sand, the filler content increased with increasing amount of crushed sand.

Table 2 Volume composition of the five basic concretes with different natural sand.

Concrete grade	C25	C35	C35	C35	C35
Natural sand	Ekle	Ekle	Gimse	Årdal 0-8	Årdal 0-3
Cement l/m^3	78.6	95.4	92	98.7	99.1
Silica Fume l/m^3	4.7	5.7	5.5	5.9	
Total water l/m^3	206.4	187.7	181.3	194.4	187
Plasticizer l/m^3	2.5	3.0	2.9	3.1	2.2
Natural gravel l/m^3	432	374	393	374	
Natural sand l/m^3	(384)	(342)	(325)	(355)	277.6
Coarse Aggregate l/m^3	247	306	300	305	416
Air in average l/m^3	30	30	30	20	20
Paste ex air l/m^3	290	290	300	300	290
Mortar content l/m^3	674	664	625	655	563
W/(C+SF)	0.80	0.60	0.60	0.60	0.60

( ) The parentheses give the material < 4 mm of the aggregate

3.4 Measured factors

Workability was determined by ordinary site methods like slump, fall table measure and Thaulow strokes. The stability of the masses have been tested by measuring the bleeding. Strength was assessed using the compressive strength and to some extent flexural and tensile strength.

3.5 Results and discussion of concrete workability

Slump for concrete made of different natural sands blended with 0, 15, 30, 60 and 100% of crushed Vassfjell 0-3 mm is shown in Fig 6. It is clearly demonstrated that for these natural sands it is positive to increase the replacement of natural sand by crushed sand from 15 to 30%, and for Ekle sand even more than 60% without loosing slump.

Highest potential for crushed sand replacements, the Ekle 0-10 mm was tested with different mortar contents. Due to the high content of fines, the concrete was cohesive with the lower mortar content, without bleeding tendency. Results are found in Fig 7.

The fall table measure gave basically the same tendencies as the slump measure.

The Thaulow fall table measure indicated the work to compact the concrete. Although the slump decreased 40 to 50 mm, the number of Thaulow blows did not change.

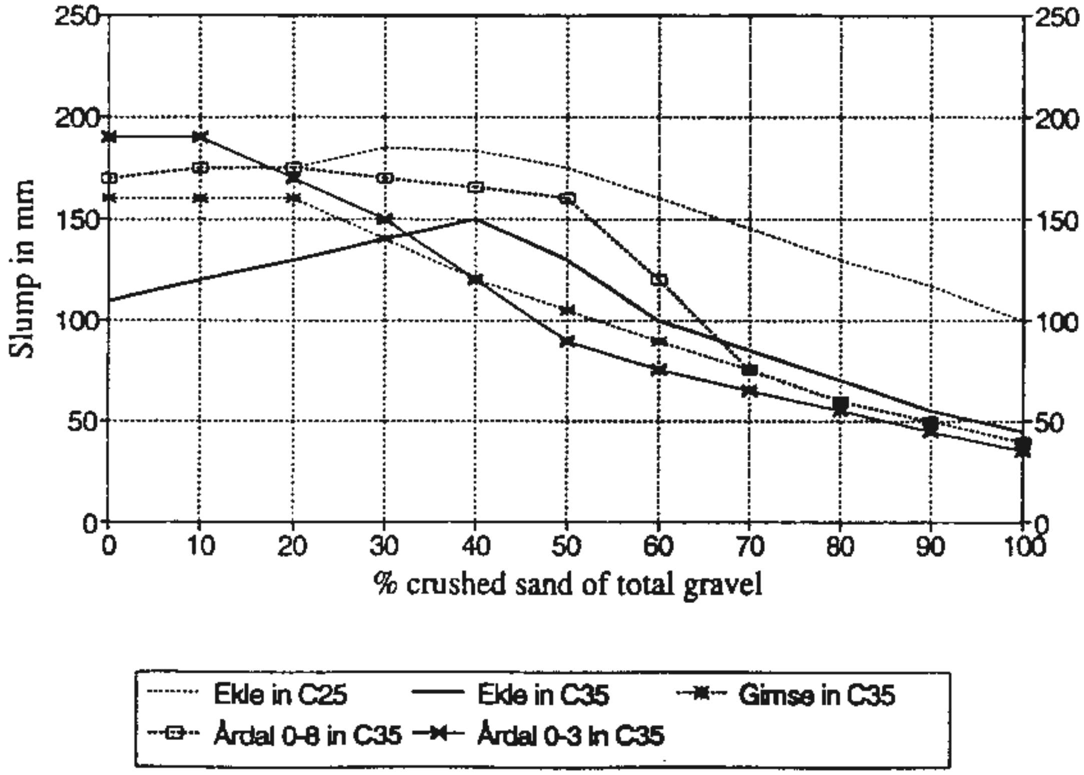

Fig 6 Slump development with increasing amounts of crushed sand

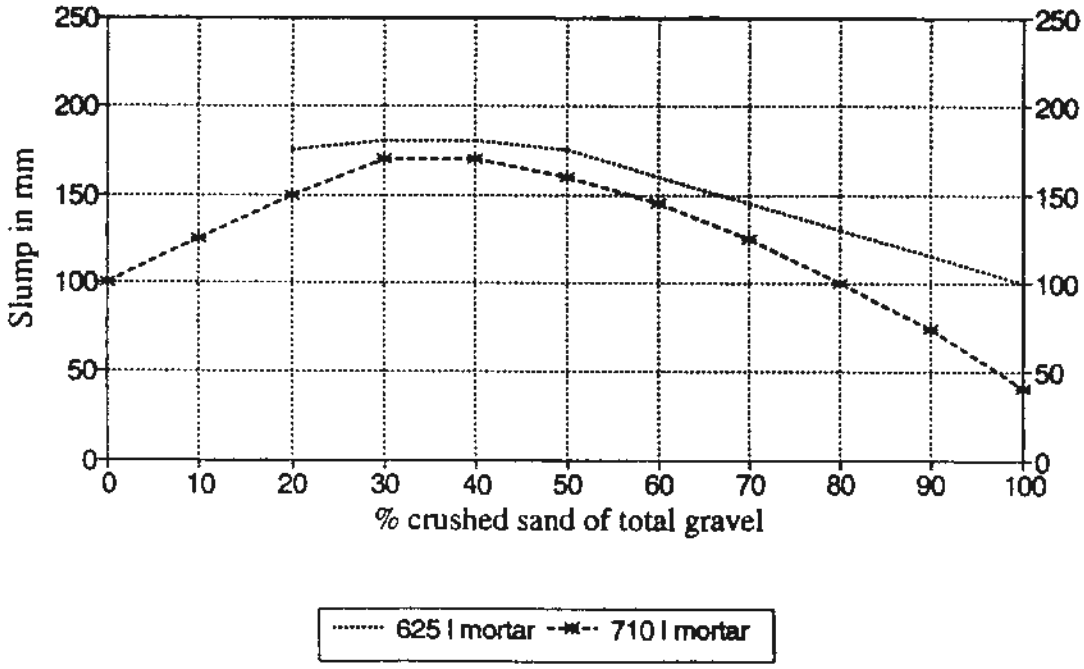

Fig 7 Slump development with two different mortar contents and Ekle sand

The conclusion is that the often used slump measure is not a good measure of workability for concrete with high content of fines.

The bleeding was decreased when increasing amounts of crushed sand was used.

When using crushed sand the workability changes depend on three factors:

1 The increase in fines gave increased surface area and a more sticky paste (including fines), but also better pumpability, less permeability and good surface finish.
2 Crushed sand has a lower voids ratio, which caused less demand for paste included fines.
3 Increased shear resistance, especially in the fractions greater than 2 mm. This made it necessary to use crushed sand 0-2 , 0-3 or 0-4 mm rather than 0-8 mm.

The total workability is balanced by these three factors. In most cases a preferable blend with respect to workability may be found. There may also be other technical reasons for using crushed sand, like better stability, decreased permeability and of course increased strength. Crushed sand is a manufactured sand with even properties making the standard deviation in the concrete production less, thereby increasing the characteristic strength, (or reducing the cement content).

3.6 Compressive strength results

A slight strength increase when using crushed sand was measured. An example of compressive strength is shown in Fig 8.

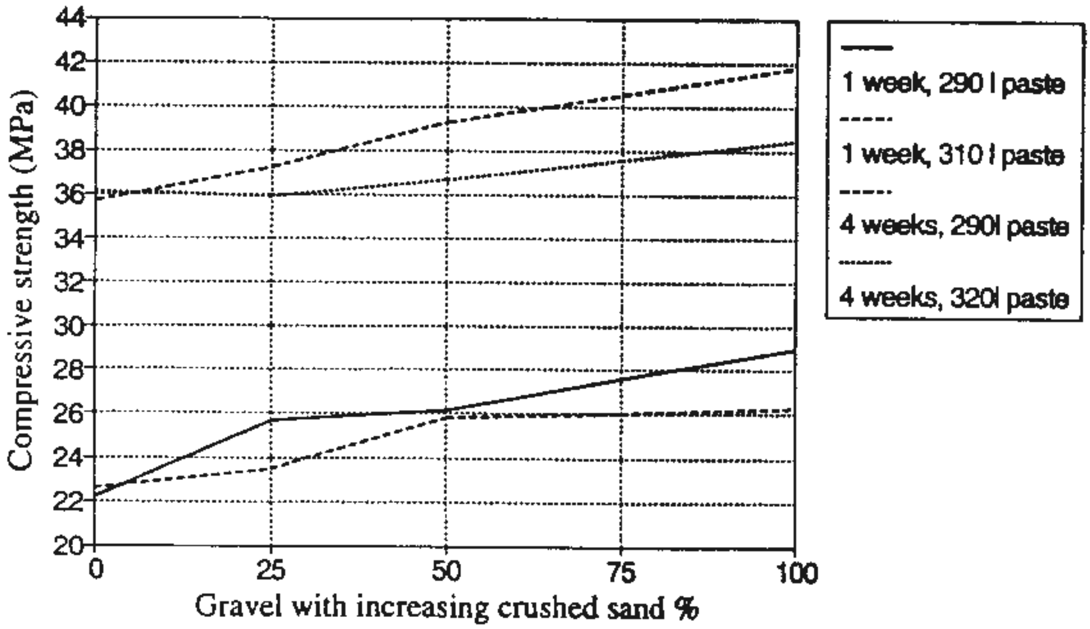

Fig 8 Compressive strength for C25 with increasing crushed sand amounts

4 CONCLUSIONS

Crushed sand in a blend with natural sand can profitably be used in concrete when crushed sand fulfill theese requirements:

- The cubicity of the fractions 1-2 and 2-4 is greater than 50%
- Grain size is less than 4 mm, (or preferably 3 mm)
- The content of fines (<0.125 mm) is 10-20% of the crushed sand
- A dence sieve curve (Fuller sieve curve)

The optimum amount of crushed sand in concrete depends on the properties of the natural sand. Here optimum replacement was determined to be between 15 and 60 % of the total sand content.

So far the project has shown that cubicised Vassfjell crushed sand might be a supplementary fine aggregate, and it may improve qualities like:

- stability
- workability
- pumpability
- surface finish
- less permeability
- increased characteristic strength

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