CONCRETE RHEOLOGY AND COMPACTION

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ABSTRACT

Today availability of good natural aggregates meet economical problems as we have to find places where crushing and/or washing of aggregates is most economical.
Also higher quality requirements of high-strength concrete set more and more demands on aggregate quality. It's traditionally known that humus and slurry have negative influence on concrete quality.
Also influence of gap-graded curves has been investigated and positive features have been found in the use of them. Thus it's possible to take use of aggregates with poorer quality, too.
One field of this research consisted of investigating the influence of natural and crushed aggregates on concrete workability.
When using crushed aggregate, the particle shape was the most important factor affecting concrete workability. This property was emphasized when using coarse aggregates.
Crushed aggregate can be used as the natural aggregate can be used. However, the grading curve of fines and quantity of coarse aggregate are decisive for the usability of concrete.
Usually when choosing crushed aggregate over crushed aggregate the content of water and cement becomes higher.
By developing a crushing technique so that the particle shape is as round as possible workability can be almost as good as for natural aggregate, and concrete strength even better.
The quantity of coarse aggregate has to be proportioned to the quantity of cement and fines. The percent fines must not be too low in order to achieve good workability.

1. Introduction

The characteristics of the aggregate affect significantly the characteristics of concrete. More than half of the concrete volume consists of aggregate. Therefore the quality of the aggregate is a very important factor. Especially the purity, shape, surface and mineralogy of particles affect workability of concrete and strength of cured concrete. Particularly in southern Finland the quantity of natural aggregates has decreased, and crushed aggregate is already used in many products.

At the beginning of 1991 a research project was started at Lohja Betonila Oy with the objective to improve fresh concrete rheology. By better mastering concrete rheology the shrinkable particles of concrete (cement and water) can be reduced, but nevertheless sufficient workability of concrete can be maintained. By using just the right vibrating frequence and amplitude even harsh-consistency concrete can be efficiently compacted. Thus durable concrete with first-class surface is achieved with little shrinkage.

At the same time a project was going on at Lohja Parma Engineering LPE Oy at Tammer Elementti Oy's factory, to develop a casting technique for facade units. In this project, by using new method of thinking, concrete is fed into the mould in accurate batches depending on the final shape of the unit. Simultaneously time suitably adjusted and well mastered vibration is used in order to achieve right energy density and right compaction time. Vibration mechanics is carried out in such a way that no disturbing noise will be caused to the surroundings. Patents have been applied for this method.

The biggest variables in practical use were charted at the beginning of the project. For concrete rheology the most essential factors are: aggregate particle shape, grading curve and additives. For casting technique concrete compaction is affected by vibration technique casting method.

The research was divided in two fields: The first consisted of laboratory-scale tests at Lohja Oy Ab's concrete laboratory on rheological characteristics of various concrete types. The second stage consisted of full-scale test castings carried out at element factories. At the new facade unit production line of Tammer Elementti Oy it was possible to test both casting and vibrating technique.

For the laboratory-scale tests aggregates with clearly different properties were looked for. The used recipes were then tested with various measuring devices: IC-tester, Tattersall device, flow and slump cone.

2. Test program

2.1 Aggregates

For aggregates fraction grading curves, percent crushed aggregates, particle shape, schistosity and elongated form was defined. In addition the fines (slurry) of the stone was pictured by a microscope. Comparison of aggregate effects was performed with concrete tests. The concrete used was a typical K40 element concrete. The aggregate effect on concrete properties was tested by slump, define sVB value and Tattersall readings. For hardened concrete the 28 day strength was used.

Poorly, crushed fractions were improved by adding natural pebbles and good-quality crushed stones. It was thought that round particle shape would improve workability of slaty crushed stone. Effects on workability of K40 concrete and on properties of hardened concrete were defined as above.

2.2 Grading curves

Effect of grading curve on concrete properties was also carried out by concrete tests. With laboratory pure aggregates three different grading curves were made, one of which was continuous and the two others were discontinuous. The gap-grading of discontinuous curves were 4-8 mm and 2-8 mm.

2.3 Compaction

The effect of vibrating methods and its influence on concrete casting was obtained at the Tammer Elementti factory where concrete compaction was tested with high-frequency equipment placed on the casting machine. The frequence and amplitude of this high-frequency equipment was steplessly adjustable. Frequency band 100 - 200 Hz (6000 - 120000 l/min) was tested. In the same connection shock station was tested where travel and frequence were steplessly adjustable. Stroke lengths of 1-6 mm with approx. 1 mm intervals were tested. Stroke frequences were tested in the band of 1 - 7 Hz (60 - 420 l/min). The basic recipe used in the tests was as follows (units kg/m^3, concrete quality K 40-2):

Rapid cement	340
Sikament FF40	3,75
Filler	190
Sand # 0-4	850
Sand # 4-8	275
Crushed stone # 6-12	282
Shingle # 8-16	180
W/c ratio	0,609

3. Theoretical survey and test results

3.1 Assessment of sand properties

Properties of filler and sand are especially important for concrete quality. They affect both water requirement and workability of the concrete mix. Filler properties can be rated with several characteristics:

- particle shape
- surface design
- surface porosity
- particle mineralogy

Especially when using crushed aggregates it's important to define the particle properties. Also the grading curve affects concrete properties. The grading curve used should be in accordance with the materials available.

When comparing grading curves of various sand qualities values for the water-requirement coefficient ranged from 2.8 to 5.1, according to literature. The differences in the water requirement coefficients are clear.

By screening various samples to same grading, the very properties of the particle (sand) were achieved. The water-requirement coefficient achieved this way describes in the best way the sand properties. The coefficient varied from 2.9 to 3.9 for various sand qualities. For crushed sand the water requirement coefficient varied from 3.3 to 4.6. The difference compared to natural sand was clear. The results show that for good natural sand the coefficient does not exceed 3. For normal natural sand the coefficient falls in the range of 3.0 to 3.5. For good crushed sand the coefficient falls in the range of 3.5 to 4.0, but in practice it often exceeds 4.0.

Grading of fines of 0 - 0.15 mm can vary a lot in the fraction. By measuring the fraction fineness a picture of the filler properties is achieved. However, the results don't show connection with water-reguirement. Although the Blaine value of sand is high, no differences in water-requirement coefficients can be found.

The particle shape of natural and crushed aggregate clearly deviate from each other which can be seen in water requirement. This depends on surface texture, too.

It has been stated that aggregate quality has great significance with respect to concrete water requirement. Especially mica and muscovite are harmful. This depends on particle shape and surface texture, which again are the result of differencies in mineralogy. The water-requirement coefficient shows clear differences here, too.

Also for crushed sand the same phenomenon can be seen. In addition to grading also anorthosite may cause considerably high water requirement (4.6), while dolomite requires only little water (3.3).

Properties of sand and filler can be defined by measuring particle size distribution. By measuring the fineness of fractions and grading is found out. The methods used are nitroge adsorption and laser granulometer. However, the results vary a lot. The most reliable one should be nitrogen adsorption.

A good picture of properties of fines can be achieved by dividing result of nitrogen absorp tion with result of laser granulometer. The achieved quotient describes the properties of fines. The less the quotient the better the fines.

This opinion is based on measuring error by laser granulometer. The laser granulometer assumes that the particles are round. The rounder the particles the more accurate the result. As the result of nitrogen absorption is accurate the quotient remains low for round particles. If again the particle is very angular, the laser granulometer gives too low a result for the specific area and the quotient becomes too high. For sand filler with good compaction and small water requirement, the particles are round and thus the quotient is low.

3.2 Crushed aggregate

The properties of crushed aggregate mainly depend on particle surface texture and grading. Of these factors the first one is affected by aggregate composition and the latter one mainly by crushing process.

According to referenced literature good grading is mainly given by gneiss and poor grading by diabase. Diabase requires effective crushing. Densities of aggregates crushed in various fractions are nearly equal. Volume of empty space in crushed aggregate does not depend on aggregate used. Crushing method or phase did not affect volume of empty space either. There was, however, a distinct difference in empty space between crushed and natural aggregate.

Share of empty space is affected by changes in grading of crushed fines. Amount of fines has to exceed certain level so that influence of grading would become less with fractions of fines. The same affect shows for both crushed and natural aggregates. Volume of empty space is considerably affected by grading, so the comparison has to be made with equal fractions.

When using crushed aggregate amount or grade of fines should be increased. The fineness modulus should lie between 1.6 and 2.6. Total quantity of cement and filler should be 400 kg/cu.m. The amount of fines should thus be added with low-cement concrete mixes. With large cement quantities gap-grading of 2-4 mm is to be recommended. Use of plasticizer is also recommended.

The more elongated particles the more empty space. By surveying fractions of 0.25-0.5 and 2.0-4.0 a sufficient picture of the fines is achieved. For different aggregate fractions the particle coarseness grows to 0.5-1.0 mm and starts then to become less. The smaller the particle size the higher the coarseness.

There is a clear difference in coarseness of crushed and natural aggregate. The difference is small between various aggregate minerals (quarz, diabase and gabbro). Further crushing makes particles more elongated and the grading worse.

For crushed aggregate the workability is not so good as that of natural aggregate. Therefore water has to be added. Crushed aggregate affects concrete strength mainly through workability and water content. For crushed aggregate the shrinkage can be more than normal. This also depends on higher water content.

With higher water-cement ratios the frost resistance is not so good for crushed aggregate, due to higher water content. With small water-cement ratios the frost resistance is as good as that for natural aggregates.

Crushed aggregate does not cause quicker stiffening of concrete. Grading of crushed aggregates affects concrete workability and water content. However, still more important is the form of the grading curve.

Table 1

Measured properties of various aggregates

Code	Crushed %	Bulk density (kg/m^3)	Schistosity b/a	Elongated form c/a
Pebbles (S):				
Porvoo	10	1432	1.27	1.67
Suomies	3	1554	1.42	1.90
Crushed aggregates (M):				
Pasila	100	1420	1.35	1.79
Mustio	100	1331	1.53	2.25
Haavisto	80	1414	1.56	2.15
Suomies	72	1331	1.89	2.76

a = thickness   b = width   c = length

Table 2

Workability results of concrete mixes made of coarse aggregates

Code	Flow mm	Slump mm	sVP s	Tattersall g	Tattersall h
Pebbles (S):					
Porvoo	410	54	2.19	4.24	1.79
Suomies	410	52	2.09	2.97	1.98
Crushed aggregates (M):					
Pasila	400	50	2.19	2.79	2.26
Mustio	380	48	2.11	3.67	2.13
Haavisto	400	42	2.14	4.72	1.75
Suomies	390	30	2.45	6.27	2.12

3.3 Influence of aggregates

The slump tests proved that crushed aggregate with normal cement content required more water. Natural aggregate mortar with high cement content requires more water. When the particle size increases or when the cement content decreases the difference becomes smaller. With high cement content natural aggregate mortar was rubbery. Crushed aggregate again gived normal mortar.

In flow tests natural aggregate requires less water than crushed aggregate. Although the fineness modulus was made bigger water requirement hardly increased. The differences in slump and flow tests depended on the fact that the methods measure different things.

Although good workability could be achieved by a certain grading curve handling can be difficult. E.g. with too much aggregates concrete becomes granular (> 50 %). Best workability of harsh-consistency concrete mixes was achieved by concrete mixes with finer grading, the percentage of fines being 20 % and aggregate optimum being 60 %.

With fine grading curves influence of grading on the water requirement is 10-20 l/cu.m. Coarser grading curves influence more on water requirement, 30-40 l/cu.m. (15-20 %). However, differences are small.

Natural aggregate requires least water. For crushed aggregate the water requirement varied. Quarzy sandstone had nearly the same water requirement as natural aggregate. Also crushed quarz had low water requirement. Crushed gabbro and diabase had higher water requirement than the others.

Grading, empty space and water content do not have any clear relation when crushed aggregate is used. But with natural aggregate the relation can be clearly seen. Uncrushed aggregate has lower coarseness which may affect water requirement.

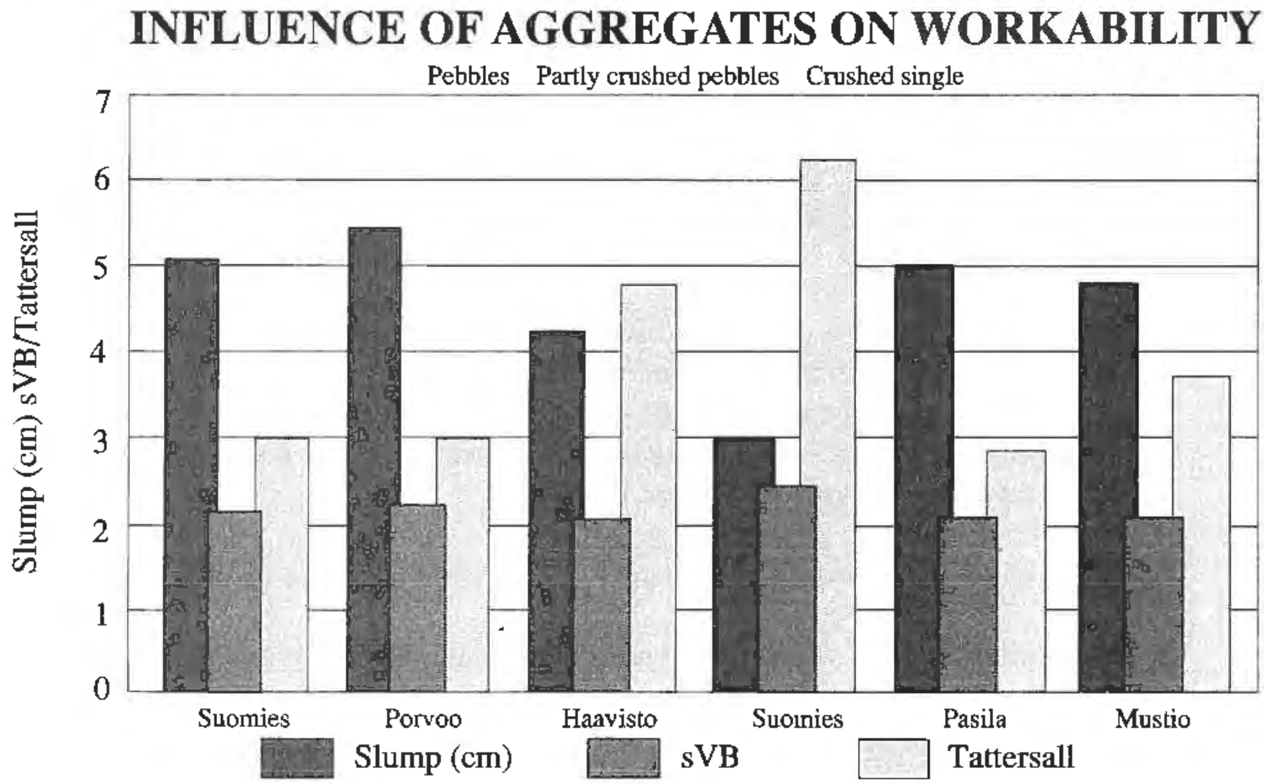
Increase in fines brings only little rise in water requirement. Increase in coarse aggregates causes a quick rise in water requirement. For natural aggregate increase in fines hardly affects water requirement.

When a third of slate was replaced by pebbles, concrete compaction became worse. The same thing happened when slate was replaced by cubical pieces of aggregate.

Continuous and gap-graded curve gave nearly the same results. With continuous grading curve workability was slightly better than that of gap-graded. The strength level was the same for the both.

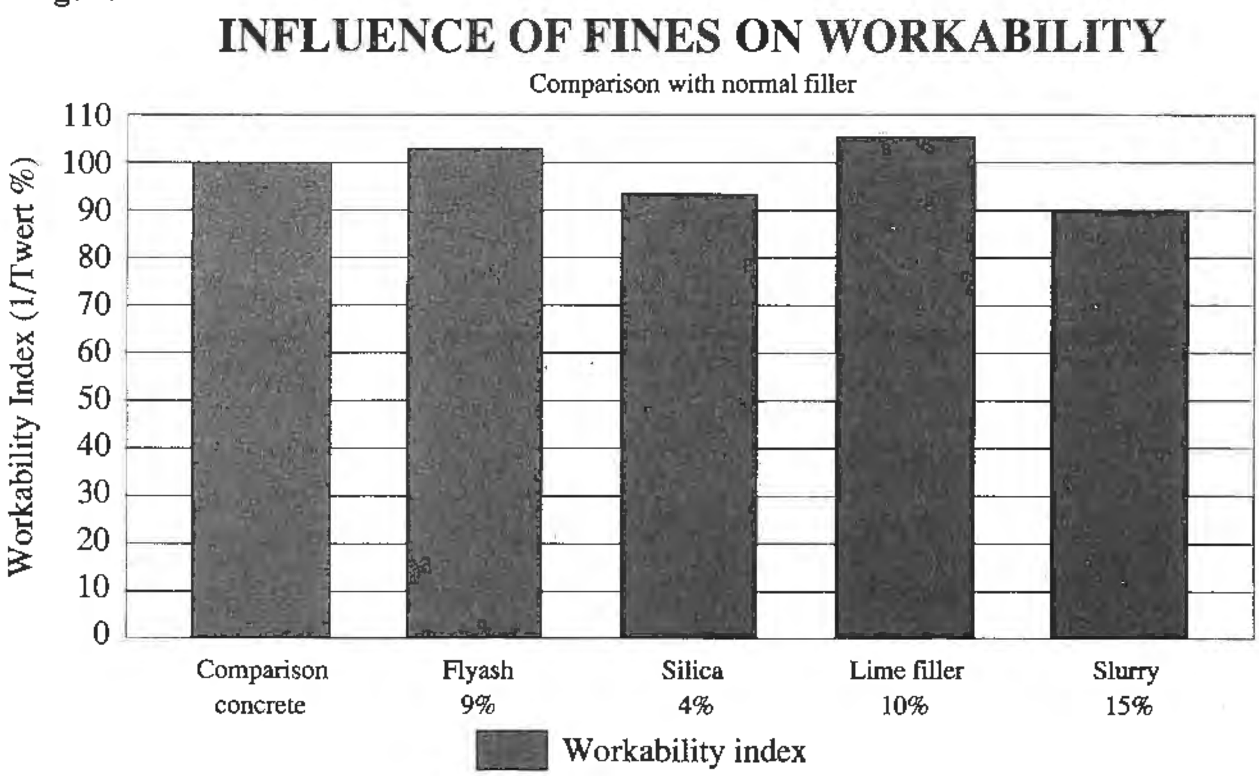
In full-scale concrete casting the workability of concrete greatly affects needs for vibration. Too high vibrating effect and time cause separation. For adjusting of vibrating effect in high-frequency vibration adjustement of frequence is suited. In shock vibration better result than traditional 5 mm fall height was achieved by a little shorter fall of approx. 3 mm with simultaneous increase of impact frequence.

Figure 1



For the coarse aggregate shape of crushed stone strongly affects workability.

Figure 2



For the fines good-quality flyash and lime filler improve workability whereas silica and slurry make it much worse.

3.4 Adjustment of concrete properties

By gap-grading concrete properties can be affected. Gap-grading at 2-4 mm makes a finer grading curve and thus requires more water than corresponding continuous curve. On the other hand coarse aggregate of finer gap-graded curve can be added to achieve the same water requirement as for continuous curve.

For concrete with harsher consistency gap-grading at 4-8 mm gives optimum influence on workability.

Air-entraining agent raises air-content and decreases water requirement but improves workability. Due to air-entraining agent common water and air content increases. This leads to lower strength level and increases the requirement for cement. As workability is improved by adding air, amount of coarse stones can be added and thus drop water content. However, this does not replace decrease in strength.

By means of superplasticizer water content can be considerably decreased.

Additives often improve workability, but may add water requirement.

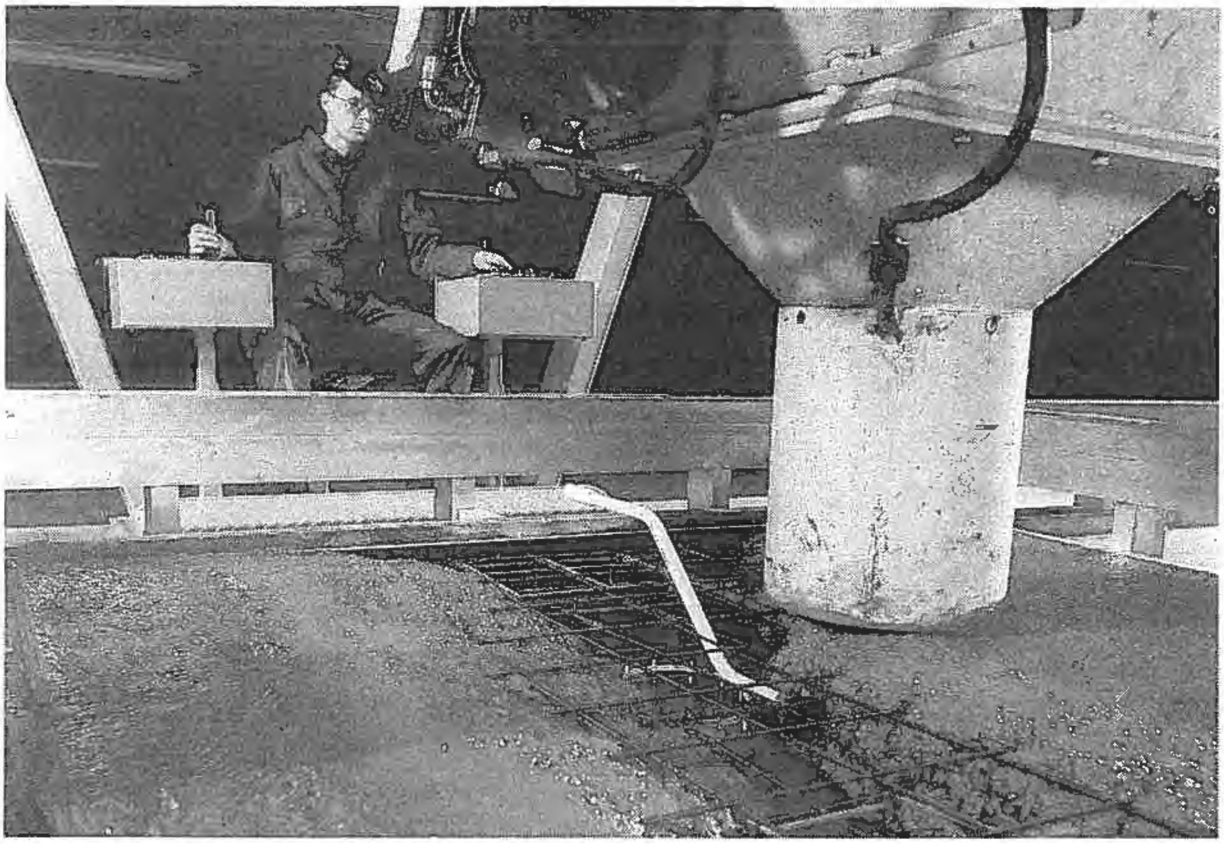


Figure 3
A drop chute manufactured at Tammer Elementti Oy's factory.
With this drop chute concrete batching and compaction can be stepplessly adjusted.

4. Conclusions

Various aggregates have considerable influence on concrete properties. With natural pebbles best workability properties were achieved. Fully crushed aggregates were the second best. The worst workability properties were achieved by aggregates with part of pebbles and part of slate. Washed and pure aggregates also influenced on the workability by clearly improving it.

By improving rheological properties of concrete it is possible to achieve, with only little vibrating energy (vibrating effect and vibrating time), a high-class and compact concrete unit.

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