# The Optimization of the Self-Compacting Concrete (SCC) Production Scheduling–Specially the Effect of the Fine Aggregate

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***Abstract*—Nowadays the demand for concrete with high quality is permanent. The claim to build aesthetic reinforced concrete structures is increasing. In the last decade the development of the new concreting procedures became faster, therefore the concrete was further developed to be economical and multi-faceted. The self-compacting concrete has widespread use in the prefabricated concrete industry. Pretensioned prestressed concrete specimens are finished in the factories, where the high early strength is the most important requirement. The production became profitable and quicker with this new technology. Hence it follows that, the optimization of the production scheduling is very important.**

***Index Terms*—Optimization, self compacting concrete, prestressed concrete, production scheduling**

## I. Introduction

Nowadays, the optimization is a very important task for engineers and mathematicians of a company, which aims to produce maximum profit while using minimum resources and spending least money.

Combinatorial Optimization is a widely applied area of Mathematical Optimization. There are famous, widely known problems, and algorithms in this area, as well. Lots of real-life problems need such method, for example one or bigger dimensional bin packing or allocation problems, scheduling of machines (or processors), distribution problems, routing problems, and so on. [1]

These problems are usually very difficult to solve. In the last few decades, many well-working algorithms have been proposed by lots of researchers in these fields. However, many new problems arise that have not been solved yet and do not have any known algorithm. [2]

One of our goals is, to model a virtual factory [3], where self-compacting concrete can be made. We would like to optimize the production of scheduling of SCC in this factory. However, the first step is to optimize the amount of the fine aggregate in the SCC.

Self compacting concrete was first developed in 1988, although the necessity of this type of concrete was proposed by Okamura in 1986. Since then, various investigations have been carried out. This type of concrete has been used in practical structures in Japan. [4], [5]

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"Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete." [6]

Increasing attention is directed to the durability of concrete structures. During design durability requirements need to be fulfilled in addition to the static requirements. One of the most important factors is the amount of the fine aggregate. [7]

The using of self-compacting concrete is popular nowadays. The self-compacting concrete is used in the prefabricated concrete industry, because in these factories it is possible to measure the aggregate enough precisely. Therefore our goal was with this research to answer the following question: How the mechanical and other properties of the self-compacting concrete is affected by the fine aggregate?

## II. Method

The aim of present paper was to study the effect of fine aggregate, and to evaluate and compare the results, especially the compressive strength, the frost-resistance and the water tightness. Therefore, 12 different and reference concrete recipes were studied. In the special recipes the amount of fine aggregate was different with increasing fine aggregate content. The fine aggregates were: limestone and metakaolin. It was important to change the water-cement ratio during the designing of the recipes as well. Table I indicates the relationship between these variables.

***Constant parameters:***

- *amount of water:* 180 l/m$^3$
- *same grading curve/same particle size distribution*
- *cement:* CEM II A-S 42,5 N

***Variable parameters:***

- *quantity of cement:*
  - 320 kg/m$^3$; 360 kg/m$^3$; 400 kg/m$^3$
- *amount of limestone:*
  - 100 kg/m$^3$- 300 kg/m$^3$ (40 kg/m$^3$ gradually)
- *amount of metakaolin:*
  - 0 kg/m$^3$, 40 kg/m$^3$

TABLE I: AMOUNT OF FINE AGGREGATE

| | | Amount of limestone [kg/m³] | | | | | Amount of limestone and metakaolin [kg/m³] | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 140 | 180 | 220 | 260 | 300 | 100+40 | 140+40 | 180+40 |
| Quantity of cement [kg/m³] | 320 | | | 540[9] | 580[3] | 620[6] | | | |
| | 360 | | 540[8] | 580[1] | 620[5] | | | | |
| | 400 | 540[7] | 580[2] | 620[4] | | | 540[12] | 580[11] | 620[10] |

The upper index shows the number of the different concrete recipes.

144 concrete cubes were made, for the different kinds of laboratory tests. The size of these cubes was 150×150×150 mm. First the strength test, then the water tightness and the frost-resistance were carried out.

The strength test was carried out with the machine: FORM+TEST ALPHA-3-3000 S. The load capacity was: 3000 kN, the load speed was: 11.20 kN/s.

The water tightness was carried out with the machine: WE 6 MM, with 5 bar water pressure for 3 days (3×24 hours).

The frost-resistance was made (f50) in 50 freezing-thawing cycles (-20 °C freezing in air and + 20 °C thawing under water).

During the process of making SCC, the most important dates were: 2, 7, and 28 days. At the age of 2 days, the forw-works of SCC members can be striked. This process is economical for the whole implementation, because the form-works can be used immediately for other SCC members. The test specimens were stored in water for 7 days after the concrete mixing. The strength tests were carried out on 2, 7 and 28 days old specimens. 3-3 pieces of specimens were used for every strength test. It is easy to show the effect of the variables (additional additive, cement content, water-cement ratio, and fine aggregate content) for the strength with the laboratory experimental results.

The specimens were 28 days old when the frost-resistance and water tightness tests were carried out. Therefore, the results can be compared with reasonable accuracy.

This paper is focused on the laboratory experimental results and on the evaluation and comparison of the results. [8]

## III. COMPRESSIVE STRENGTH

### A. Compressive Strength

If 40 kg/m³ limestone was applied, then ca. 2-10% increase was expected in the compressive strength. This positive increase was shown at the age of 2 days. The monitored range was: 100 kg/m³ – 300 kg/m³. The trend was the same in the case of: 320 kg/m³, 360 kg/m³ and 400 kg/m³ cement amount. If 40 kg/m³ metakaolin was applied with 400 kg/m³ cement, then the rise of the compressive strength was also clearly seen. The metakaolin caused a change in strength, as Fig. 1 shows.

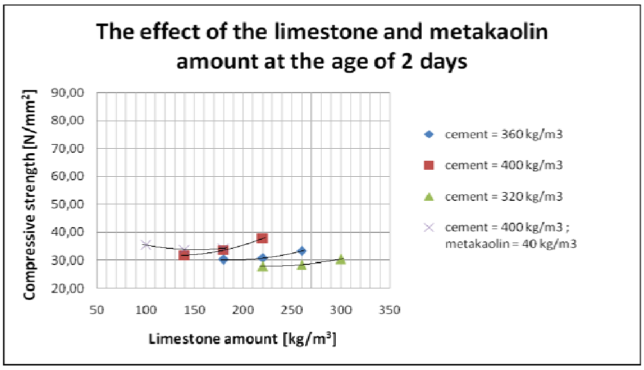


Fig. 1. The compressive strength at the age of 2 days.

If the limestone amount was excessive, then the compressive strength decreased, at the age of 28 days. If 40 kg/m3 limestone was applied, then ca. 3-5 % decrease was expected, as Fig. 2 shows. This trend has not been shown if 40 kg/m3 have been used as well.

It can be set forth, that the early compressive strength can be increased by using limestone as fine aggregate. The value of the compressive strength can be increased by using metakaolin as well. Therefore the time of the striking can be reduced, and the form-works can be used earlier. With this short time the companies can produce maximum profit while using minimum resources and spending least money.

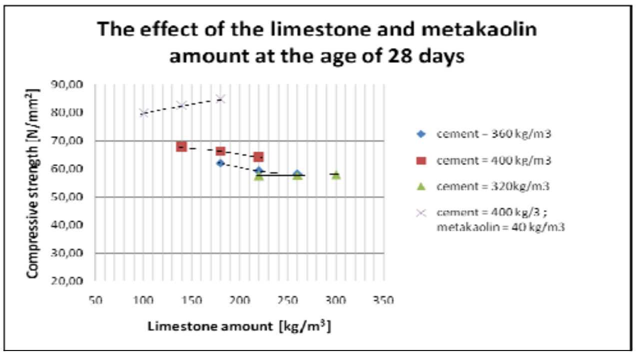


Fig. 2. The compressive strength at the age of 28 days.

### B. Water Tightness

The water tightness was carried out with the machine: WE 6 MM, with 5 bar water pressure for 3 days (3×24 hours). The cubes were slitted after the tests, and the depth of the water penetration was measured. Table II contains the values in millimeters. 3-3 cubes were used for each water tightness test, so the results were sufficiently accurate.

TABLE II: WATER TIGHTNESS TEST RESULTS WITH THE RECIPES

| Recipes | Cement | Fine agg. | Fine agg. | Amount of fine aggregate | Water | Depth of water penetration |
|---|---|---|---|---|---|---|
| | CEM II A-S 42,5 N | Limestone | Metakaolin | | | |
| | [kg/m3] | [kg/m3] | [kg/m3] | [kg/m3] | [kg/m3] | [mm] |
| 1 | 360 | 220 | - | 580 | 180 | 6,66 |
| 2 | 400 | 180 | - | 580 | 180 | 7,36 |
| 3 | 320 | 260 | - | 580 | 180 | 6,05 |
| 4 | 400 | 220 | - | 620 | 180 | 5,61 |
| 5 | 360 | 260 | - | 620 | 180 | 6,47 |
| 6 | 320 | 300 | - | 620 | 180 | 7,08 |
| 7 | 400 | 140 | - | 540 | 180 | 7,59 |
| 8 | 360 | 180 | - | 540 | 180 | 5,77 |
| 9 | 320 | 220 | - | 540 | 180 | 7,05 |
| 10 | 400 | 180 | 40 | 620 | 180 | 5,04 |
| 11 | 400 | 140 | 40 | 580 | 180 | 4,69 |
| 12 | 400 | 100 | 40 | 540 | 180 | 4,08 |

### C. *Frost Resistance*

The cubes after the drying were tested in compression, with the machine: FORM+TEST ALPHA-3-3000 S. We calculated the decrease in strength. The results and the measurements showed that ca. 3-16 % decrease is expected due to freezing.

## IV. FUTURE PLANS

In the future we would like to extend our research. We would like to use other material as fine aggregate as well. Furthermore we plan to make laboratory tests with these new materials, and we would like to create high and ultra high strength self-compacting concrete.

The authors would like to optimize the relationship between the production scheduling and the delivery of the self-compacting concrete prefabricated specimens using ALVI software. [3], [9].

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