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# Optimization of heavy weight concrete composition and process of prefabrication for prefabricated shielding cladding tiles

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**Abstract.** The aim of experimental research was to verify the possibility of the prefabrication of the thin shielding cladding tiles from heavy weight concrete with fine. The minimal required density of the concrete was 3800 kg/m<sup>3</sup> and the maximal particle size was 2 mm. Because of the though over technology of the complicated locks in the touch of tiles was necessary to achieve consistency around 210 mm flow with the Chryso cone test (modified slum flow test). To obtain this consistency without danger of the heavy weight aggregate segregation the superplasticizer was used. In first step was determined optimal amount of mixing water, in the second step we tested different frequency of vibration to achieve maximal consolidation and as a last step to define composition of mixture we tested 3 types of accelerators of concrete hardening to shorten time of hardening and to facilitate more effective production. As the optimal frequency of vibration for compacting process was determined 75 Hz. The best accelerator of concrete hardening for optimized mixture was MasterSert XS100 from BASF producer.

## 1. Introduction

Heavy weight concrete is concrete with the density above 2600 kg/m<sup>3</sup> in the dry state [1]. High density is achieved by the using heavy weight aggregate (with density higher than 3000 kg/m<sup>3</sup>) or in the special cases by the using barium sulphate cement [2-4]. Heavy weight concrete is used as the shielding concrete for the protection again the radiation in the nuclear powerplants, the hospitals and in the research centres. Another way of using is to load the construction for example in the case of the machines subjected by the dynamic forces. As a heavy aggregate are used the steel bullets, the artificial corundum or the natural aggregate barite or the ironstones such as the magnetite and the hematite. The heavy aggregate complicates mixing of the fresh concrete - the lower volume of fresh concrete in the mixing machine because of the high weight, worse homogenisation and the tendency to the segregation.

To produce the thin shielding cladding tiles there had to be designed the heavy weight concrete with the fine aggregate - heavy weight mortar. Requests for mixture were following:

- Water/binder ratio as low as possible but with the requested consistency. High water/binder ratio can lead to the segregation and lower density.
- Using of the superplasticizers with the best coworking with the accelerator of hardening.
- Higher content of the cement because of the higher specific surface of the fine aggregate.



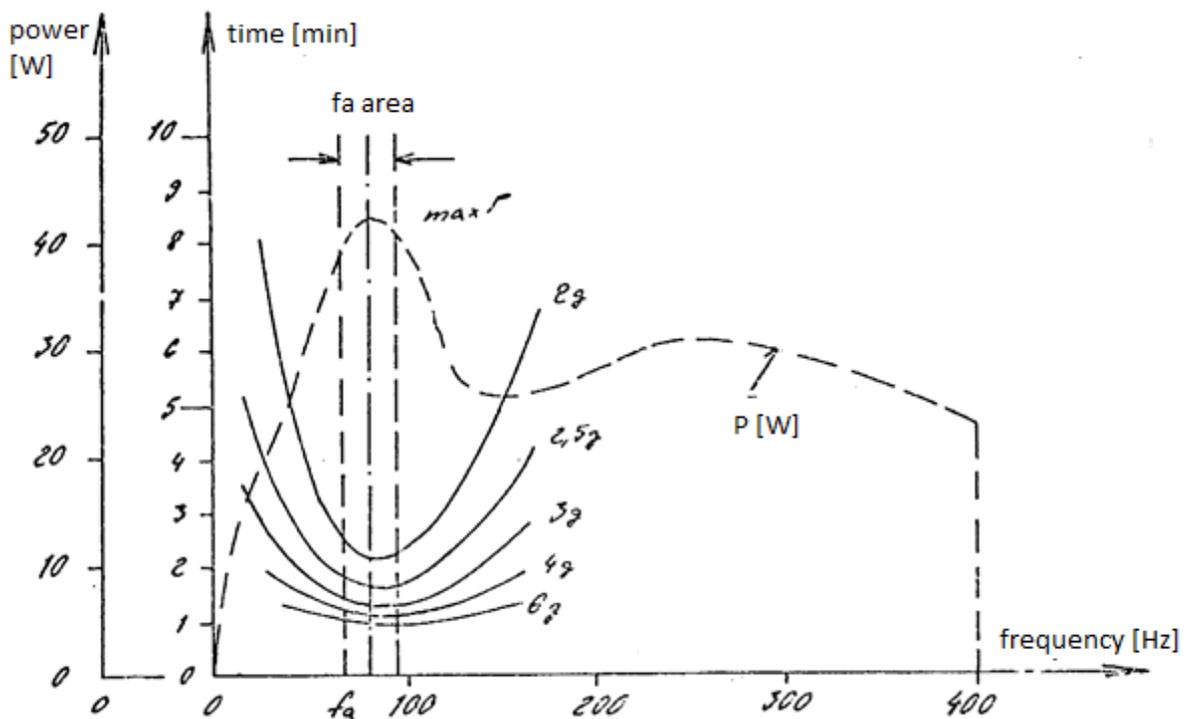
- Minimalization of the air content.
- As effective compaction of the concrete as possible.

The compaction of the concrete is technological process which aim is to achieve maximal compactness and minimal porosity. Balance between inner and outer forces is destroyed during the compaction. Inner forces are capillary forces, surface tension, aggregate friction and physically-chemical bonds. Outer forces are gravitational force and loads affected concrete. Quality of concrete (mortar) can be influenced in the compaction process by:

- Separation of fresh concrete.
- Segregation - separation of mixture components according to their density.
- Bleeding.

In more than 90 % of the compaction processes is used vibration. By vibration are particle moved and inner forces are changed. With higher speed of vibration, the speed gradient of particles is higher too. The viscosity of cement paste is lower and mixture is compacted.

On Figure 1 we can see influence of frequency on time of compaction.



**Figure 1.** Influence of frequency on time of compaction [5].

The time of compaction is increasing till the  $f_a$  (absorption frequency) and then is decreasing. By the tests was found that each concrete mixture has different absorption frequency.

The aim of the experimental research was to verify the possibility of the prefabrication heavy weight concrete with the fine aggregate for the manufacturing thin shielding cladding tiles. Required density of the concrete was  $3800 \text{ kg/m}^3$  and the maximal particle size was 2 mm. Because of the though over the technology of the complicated locks in the touch of the tiles was necessary to achieve the consistency around 210 mm by slump test. To obtain this consistency without danger of the heavy weight aggregate segregation different types of the superplasticizers was tested. Accelerators of the hardening was tested to shorten time of hardening and to facilitate more effective production. Optimal frequency of vibration was determined to achieve maximal density.

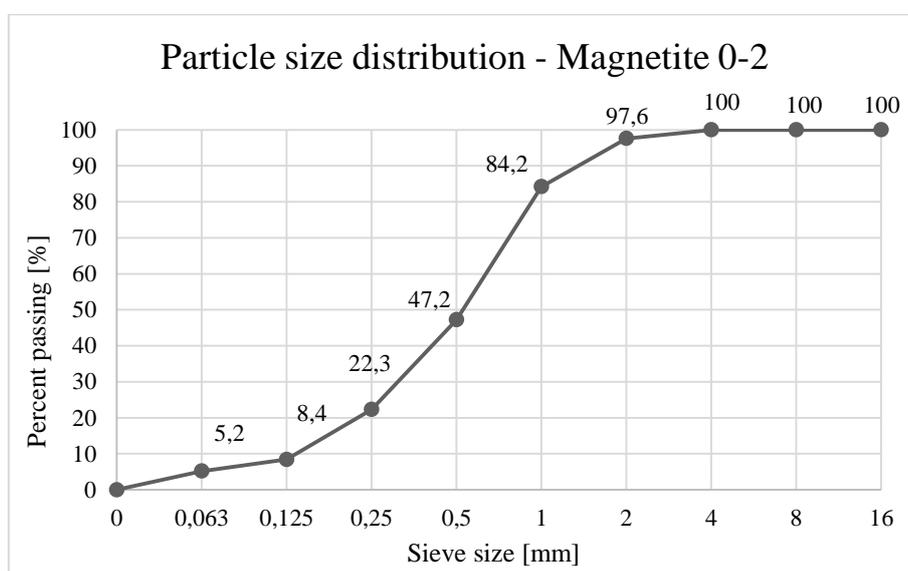
## 2. Materials and Methods

For design of reference concrete mixture were used cement CEM I 52.5 R, as aggregate was used magnetite in fraction 0-2 mm imported from Sweden, silica fume, stone filler, superplasticizer Glenium 430 from BASF producer and accelerator of hardening Master set SX 100 from BASF producer.

In first step was looking for optimal amount of water to achieve maximal density, in second step we found optimal frequency of vibration to get best compaction and as a last step we tested another two types of accelerator of concrete hardening.

### 2.1. Magnetite

Magnetite imported from Sweden in fraction 0-2 mm was used. Density of aggregate is  $5120 \text{ kg/m}^3$  in natural state and  $5060 \text{ kg/m}^3$  in dry state. Particle size distribution is shown on Figure 2.



**Figure 2.** Particle size distribution - magnetite 0-2.

### 2.2. Amount of water

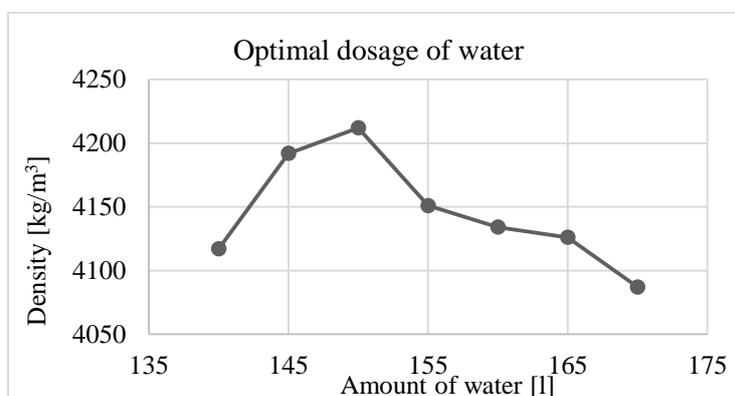
As assumed before, we looked for optimal dosage of water to achieve maximal density. In reference mixture 7 dosages of water was tested. Composition of reference mixture is shown in Table 1. Tested amount of water and corresponded density is shown in Table 2.

**Table 1.** Composition of reference mixture.

Component	amount for $1 \text{ m}^3$ of concrete
Cement CEM I 52,5 R from Cement Hranice producer	490 kg
Fine aggregate 0-2 mm - sweden magnetite	3240 kg
Silica fume	20 kg
Stone filler - Želešice	50 kg
Superplasticizer BASF Glenium 430	10 kg
Accelerator of concrete hardening BASF master set XS 100	21.2 kg

**Table 2.** Tested amount of water and correspondent density of concrete.

amount of water for 1 m <sup>3</sup> of concrete [l]	140	145	150	155	160	165	170
density of fresh concrete [kg·m <sup>-3</sup> ]	4117	4192	4212	4151	4134	4126	4087



**Figure 3.** Influence of amount of water to density of fresh concrete.

As optimal dosage of water was determined amount of 150 l per 1 m<sup>3</sup> of concrete.

### 2.3. Frequency of vibration

The second step was determination of optimal frequency of vibration. To reference mixture from table 1 was added 150 l of water. To achieve smoother surface of concrete 40 kg of stone filler Želešice per 1 m<sup>3</sup> of concrete was added to reference mixture. This mixture was vibrated on vibrating table with possibility of changing frequency from Wacker-Werke producer. 4 frequencies were tested. Frequency, speed of motor rotation and density of fresh concrete are shown in Table 3.

**Table 3.** Optimization of compaction process.

speed of motor rotation [min <sup>-1</sup> ]	frequency of vibration [Hz]	density of fresh concrete [kg·m <sup>-3</sup> ]
4000	66.7	4069
4300	71.7	4079
4500	75.0	4197
4700	78.3	4114

As optimal frequency for compaction process was determined frequency 75 Hz.

### 2.4. Accelerators of concrete hardening

Three types of accelerators of concrete hardening were tested. MasterSet XS 100 from BASF producer, Betodur A5 from STACHEMA producer and Fast Kick 111 from MC Bauchemie producer. The accelerators of hardening did not influence consistency of fresh concrete.

**2.4.1. Betodur A5.** Betodur A5 is chloride free admixture accelerating hardening of concrete. Density is 1450 kg/m<sup>3</sup>.

**2.4.2. MasterSet XS 100.** MasterSet XS 100 is ready to use liquid accelerating admixture for use in concrete and portland cement. MasterSet XS 100 admixture brings down setting times in general and specially under cold weather, leading to early high and ultimate increased strengths. In addition, it reduces bleed and segregation while improves workability. MasterSet AC 100 does not contain any added chloride ions ensuring that the product does not contribute to the corrosion of reinforcing steel.

In fact, studies indicate MasterSet XS 100 helps in reduction of chloride attack on concrete. Density is 1260 kg/m<sup>3</sup>.

2.4.3. *Fast Kick 111 - MC Bauchemie*. With MC-FastKick, MC has developed a new functional group of accelerators as a further development of the BASF-patented concept of stabilising CS phases with polycarboxylate ethers. MC-FastKick not only kick-starts the hardening of the concrete but also results in significant plasticisation, providing the mix with very good processing, flow and application properties, including high early strength values. These accelerators thus greatly reduce cycle times in precast operations and will also facilitate shorter hardening times during wintertime construction. MC-FastKick has a positive influence on crystal growth in the calcium-silicate-hydrate phases within the concrete. This results in a significant increase in the crystallisation rate and thus substantially higher early strength values – but without negatively influencing the other concrete properties.

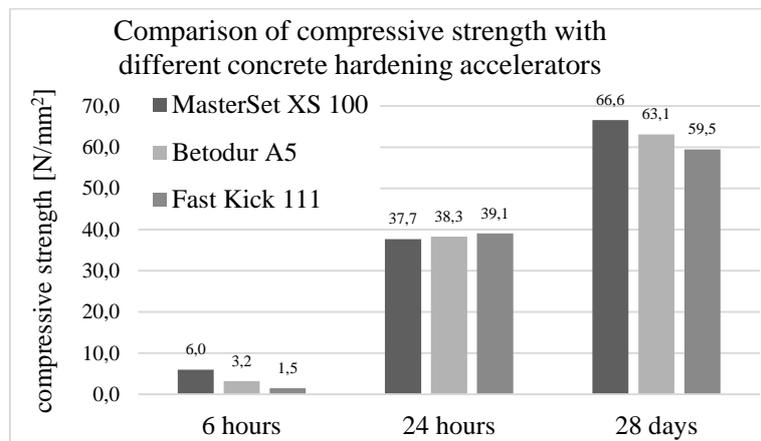
Composition of compared mixtures is shown in Table 4. Dosage of accelerators were according to producers recommendation. Compressive strength was determined in age 6 hours, 24 hours and 28 days.

**Table 4.** Composition of mixtures with different types of concrete hardening accelerator.

Component	Note	Amount for 1 m <sup>3</sup> of concrete
Cement CEM I 52,5 R from Cement Hranice producer		490 kg
Fine aggregate 0-2 mm - sweden magnetite		3240 kg
Silica fume		20 kg
Stone filler - Želešice		90 kg
Superplasticizer BASF Glenium 430		10 kg
Mixture A Accelerator of concrete hardening	BASF MasterSet XS 100 0.4 % m <sub>c</sub>	19.6 kg
Mixture B	Stachema CZ Betodur A5 0.3 % m <sub>c</sub>	14.7 kg
Mixture C	MC Bauchemie Fast Kick 111 0.2 % m <sub>c</sub>	9.8 kg

**Table 5.** Time evolution of compressive strength of concretes with different accelerator of concrete hardening from different producers.

Mixture	Accelerator of concrete hardening	Compressive strength [N/mm <sup>2</sup> ]		
		6 hours	24 hours	28 days
A	MasterSet XS 100	6.0	37.7	66.6
B	Betodur A5	3.2	38.3	63.1
C	Fast Kick 111	1.5	39.1	59.5



**Figure 4.** Comparison of compressive strength.

Average density of fresh concretes was  $4100 \text{ kg/m}^3$  and in age of 28 days and in natural humidity  $4040 \text{ kg/m}^3$ .

### 3. Conclusion

Optimal composition of the heavy weight concrete for prefabrication thin shielding cladding tiles was determined. With 490 kg of cement, 3240 kg of magnetite, 20 kg of silica fume, 90 kg of stone filler, 10 kg of superplasticizer Glenium 430 and 19.6 kg of accelerator of concrete hardening MasterSet XS 100 we achieved concrete with the density over  $4000 \text{ kg/m}^3$ , compressive strength in 6 hours age  $6 \text{ N/mm}^2$ , in 24 hours  $37.7 \text{ N/mm}^2$  and in age of 28 days  $66.6 \text{ N/mm}^2$ . Consistency of the mixture fulfil requested 220 mm flow by Chryso cone test. Due to the low water cement ratio we achieved smooth surface of the concrete without the pores. For the process of the compaction the optimal frequency of vibration was determined as 75 Hz. Due to used accelerator of the concrete hardening we got compressive strength in 24 hours around  $38.0 \text{ N/mm}^2$  which means rapid reusing moulds during manufacturing.

### Acknowledgment

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