Effect of different mix compositions and curing regimes on ultra high performance concrete compressive strength

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Abstract. Influence of different mix compositions and curing regimes on ultra high performance concrete (UHPC) compressive strength are analysed in this paper. All produced mixes have self compacting consistency. For test purposes cubes 100x100x100 mm were produced and cured in different regimes: at 20°C; 90°C and 220°C. Test results indicate that compressive strength of UHPC increased significantly after curing at 220°C comparing to the standart curing at 20°C. Obtained results varied from 133–218 MPa.

Keywords:.UHPC, silica fume, W/C ratio, superplasticizer, curing regimes

Introduction

Ultra high performance concrete (UHPC), namely concrete with compressive strength starting from 150 MPa, is a relatively new construction material and therefore its potential is not yet fully discovered. (Mehta *et al.* 2005) Although there are some projects in USA, Germany and Japan where UHPC has been applied successfully, in Latvia research on this material has begun only recently. To encourage further research on qualities and application of concrete, Latvian Concrete Association organizes competition on concrete samples since 2002. The target of participants is to prepare a sample achieving maximum concrete cube compressive strength. As it can be seen from figure 1, concrete, which can be described as ultra high performance concrete (compressive strength >150 MPa), was first obtained in Latvia in 2006.

Some preconditions have to be considered in order to reach such strength: 1) lower water/cement ratio that for conventional concrete; 2) use of high quantity of cement; 3) dense packing of particles. (Mačiulaitis *et al.* 2009) have confirmed that physical and mechanical properties of the hardened concrete depend on the size of utilized coarse aggregate. Very fine particles are used to achieve dense packing, In this study silica fume was used as fine particles. However silica fume in concrete matrix is not only filling voids between larger particles, but also takes part in chemical reactions. It takes part in pozzolanic reaction, where $Ca(OH)_2$ is consumed and stronger calcium hydrosilicates are produced (Grutzeck *et al.* 1982). Ultra high performance concrete has numerous advantages compared to conventional concrete. Due to

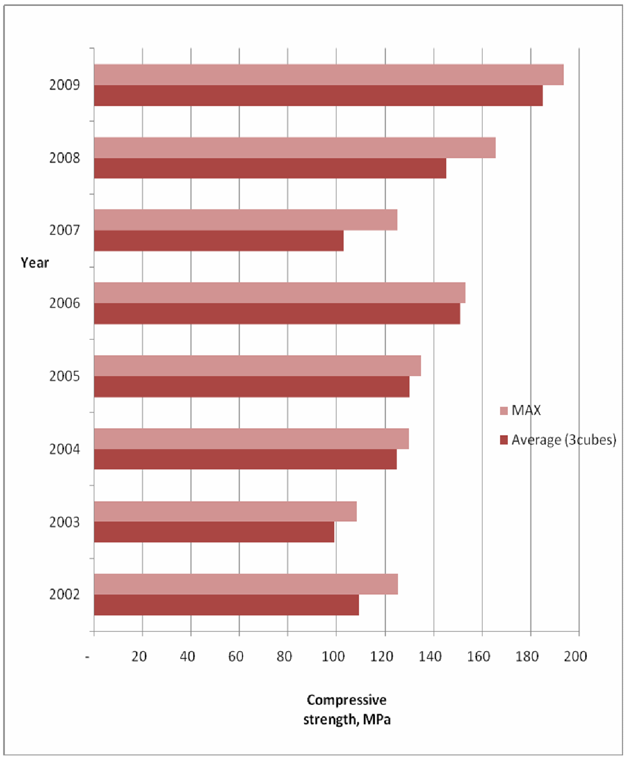

Fig 1. Results of Latvian Concrete Association concrete competition

excellent mechanical properties, dimensions of structural members can be decreased thus allowing to reduce construction dead weight significantly. It helps to improve concrete durability by producing more dense matrix (Aitcin 2003). Silica fume also improves chemical resistance of concrete (Yamato *et al.* 1989). Higher compressive strength can be reached by curing concrete under elevated temperatures (Urs Muller *et al.* 2008). Elevated temperature accelerates pozzolanic reaction. As (Ingo Scachinger *et al.* 2008) long term study shows, the strength development after heat treatment is not ceasing.

1. Materials

1.1. Cementitious materials

Portland cement CEM I 52.5R and silica fume were used as cementitious materials. Chemical composition of Portland cement and silica fume are shown on Table 1.

Table 1. Chemical properties of portlandcement and silica fume (SF)

Chemical composition (%)		
Chemical element	CEM I 52.5R	Silica fume
SiO_2	25	97.5
Al_2O_3	2.1	0.4
Fe_2O_3	3	0.1
CaO	69	0.2
SO_3	2.3	0.1
MgO	0.7	0.1
Na_2O	0.2	0.1

Physcial properties of portlandcement and silica fume are shown on Table 2.

Table 2. Physical properties of portlandcement and silica fume (SF)

	Material	
	CEM I 52.5R	SF
Specific surface (m^2/kg)	389	20000
Bulk density (kg/m^3)	1100	400
Compressive strength (MPa)		
1 day	21	
7 days	62	
28 days	75	

1.2. Aggregate

Four types of aggregate were used:
1. Diabaz 2–5 mm
2. Diabaz 0–5 mm
3. Sand 0.3–2.5 mm
4. Sand 0–0.5 mm

Granulometric curves for aggregate were determined by percentage of particles passing through the different size sieves. Obtained curves are shown in figure 2.

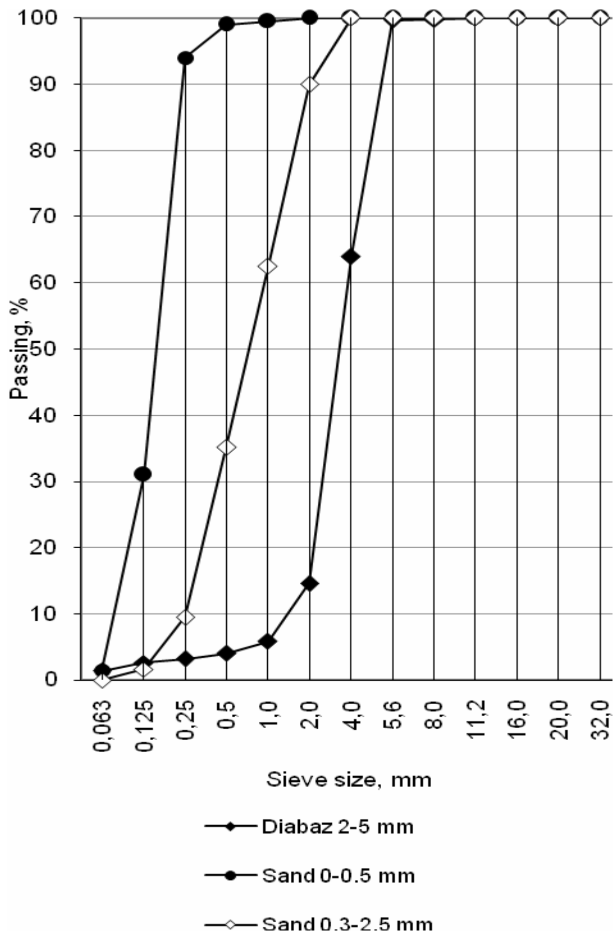

Fig. 2. Agregate granulometric curves

1.3. Fibers

Steel fibers brass coated with length 6 mm and diameter 0.16 mm were used

1.4. Superplasticizer

Polycarboxylate based superplasticizer was used.

2. Mix proportions

To identify effect of mix composition on concrete compressive strength four mixes were tested. First two mixes were with identical amount of cement, silica fume and constant water/cement ratio, but different aggregate particle packing. In first mix all sizes of particles were represented but in the second mix particles with diameters 0.5-2 mm were absent. Computer program was used for determining particle packing curve. The computer program was based on formula:

$$CPFT=(d/D)^{q}*100 \quad (1)$$

CPFT – Cumulative (Volume) Percent Finer Than
d – particle size
D – maximum particle size
q – distribution coefficient

Third and fourth mixes were with high cement content - 1300 kg/m^3 and 1500 kg/m^3 respectively. Water/cement ratio was identical for both. Mix proportions are shown on Table 3.

Table 3. Mix proportions (kg/m^3)

	M-1	M-2	M-3	M-4
CEM I 52.5R	800	800	1300	1500
Diabaz 2-5mm	320	860		
Diabaz 0-5mm	320			
Sand .,3-2,5mm	320			
Sand 0-0.5mm	320	420	700	375
Silica fume	120	120	400	400
Water	207	207	247	280
Superplasticizer	13	13	30	30
Fibers 6mm	60	60	60	60
W/C	0.26	0.26	0.19	0.19

3. Test specimens preparation

At first portlandcement, aggregates and silica fume were dry-mixed for 5 minutes. Then water and superplasticizer were added. Due to the low water/cement ratio some difficulties in mixing process were experienced. It was not possible to mix this extra dry composition in conventional mixer. To be able obtain a homogenous substance, delivery of high energy to the mix was necessary to force particles mutually interact. After 15 minutes of mixing, composition started to show self-compacting properties. Steel fibers were added gradually and, to evenly distribute them, mixing process was continued for another 3 minutes. Then self-compacting mix was cast into the steel moulds with dimensions 100x100x100 mm. After 24 hours specimens were demoulded.

4. Curing regimes

Three different types of specimen curing were considered:

1. Standard curing at 20^{o}C in water.
2. Curing at 90^{o}C in water for 40 hours.
3. Curing at 220^{o}C in air for 24 hours.

5. Results and discussion

Before compressive strength test all specimens were measured and weighted. Density of specimens was calculated from obtained data. Average test cube densities for different mixes are displayed on figure 3.

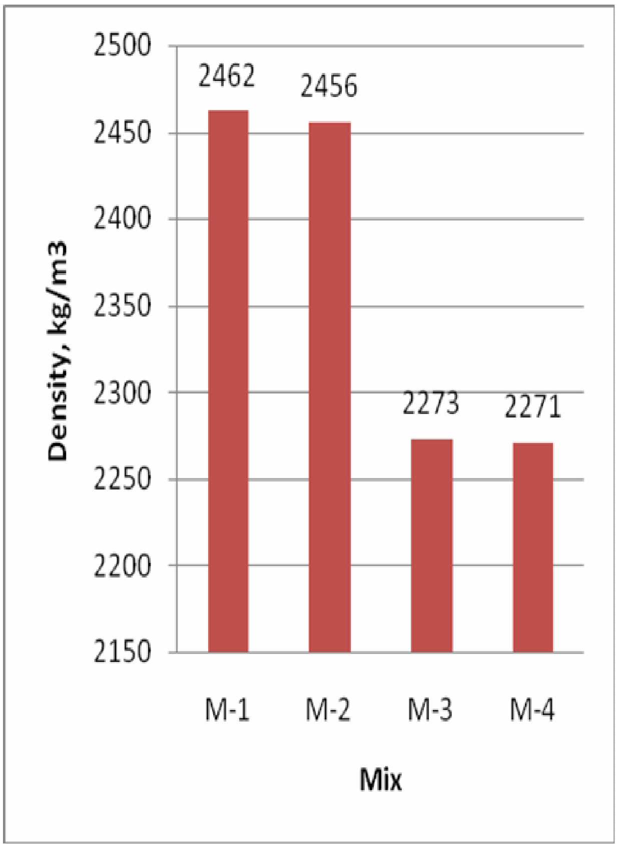

Figure 3. Average density of different mixes.

Analysing the results, mix M-1 has the highest density. According to the design of researcher, mix M-1 has slightly better particle grading than mix M-2. Apparently due to better packing of particles mix M-1 has higher density. Mixes M-3 and M-4 have lower density than first two mixes because higher amounts of cement are used and no diabaz agregate is used. Mixes M-3 and M-4 have almost the same density despite the fact that M-4 has 200 kg/m^3 more cement. This could be explained with deviations in compacting level when moulds were filled.
Cube compressive strength was tested using loading rate of 0.75 KN/s. Specimens were tested 3, 7 and 28 days after production. Test results for mix M-1 are shown in

figure 4. Test results show that after 28 days specimens, which were cured in temperature 90°C, show 22.3% higher compressive strength compared to those cured at 20 °C, and specimens which were cured at 220 °C show 35.8% higher compressive strength than those cured at 20 °C.

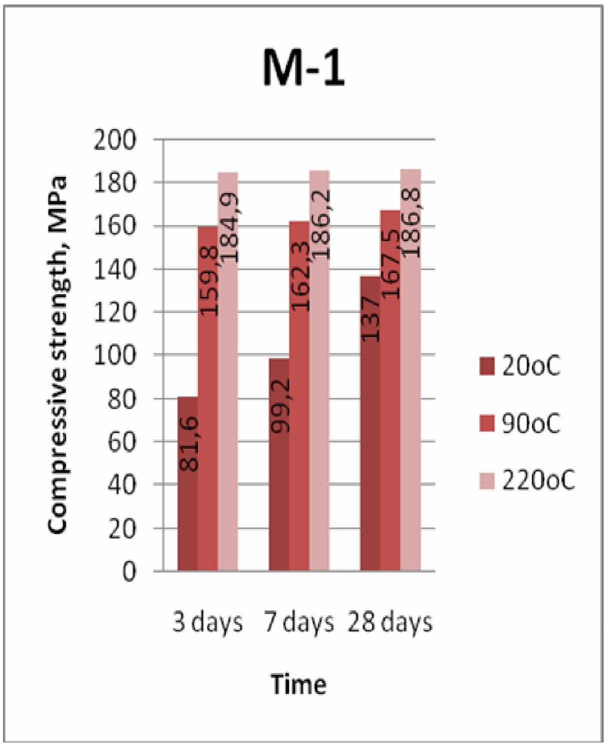

Figure 4. Compressive strength results for mix M-1.

Test results for mix M-2 are displayed in figure 5.

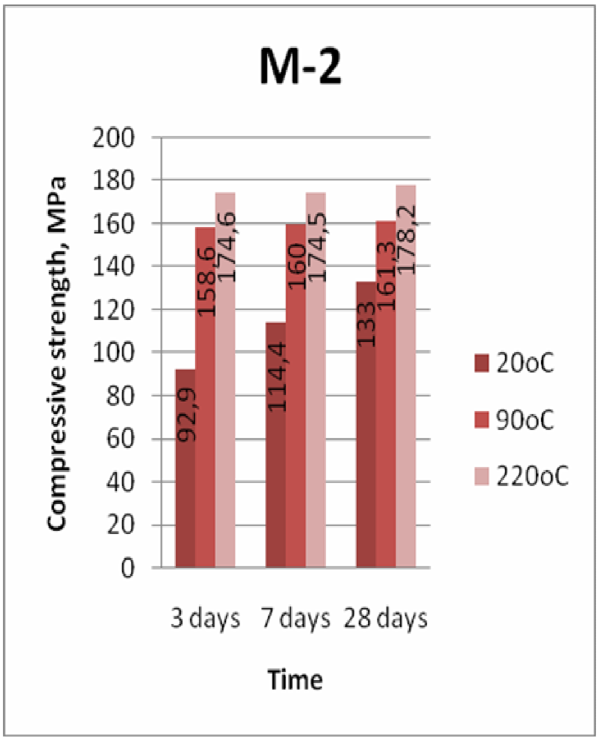

Figure 5. Compressive strength results for mix M-2.

After 28 days specimens which were cured at 90 °C show 21.3% higher compressive strength than those which were cured at 20 °C. Comparing specimens which were cured at 220 °C with those cured at 20 °C the latter show 33.9% lower compressive strength.

28 day compressive strength for mix M-2 is lower than for M-1. This coherence is valid for all 3 types of curing. It proves that particle grading is important and influences not only matrix density, but also compressive strength of the concrete. For samples cured at 20 °C difference is 3% and for samples cured at 90 °C and 220°C – 3.8% and 4.8% respectively.

Compressive strength test results for mix M-3 are included in figure 6. After 28 days specimens which were cured at 90°C show 14.4% higher compressive strength than those which were cured at 20°C, and specimens which were cured at 220°C show 39.3% higher compressive strength than those cured at 20°C. In this study mix M-3 has shown highest compressive strength: 218.5 MPa. However, mixes M-3 and M-4 were also the most sensitive to the high temperature curing. One sample from each mix was damaged during high temperature curing. Temperature provoked internal stresses were so high that specimens were broken. Although all other high temperature cured specimens have shown good compressive strength results, microcracs were observed on the surface of test samples. Attention should be paid to th fact that concrete cured at high temperature could have lower durability because of formation of microcracs.

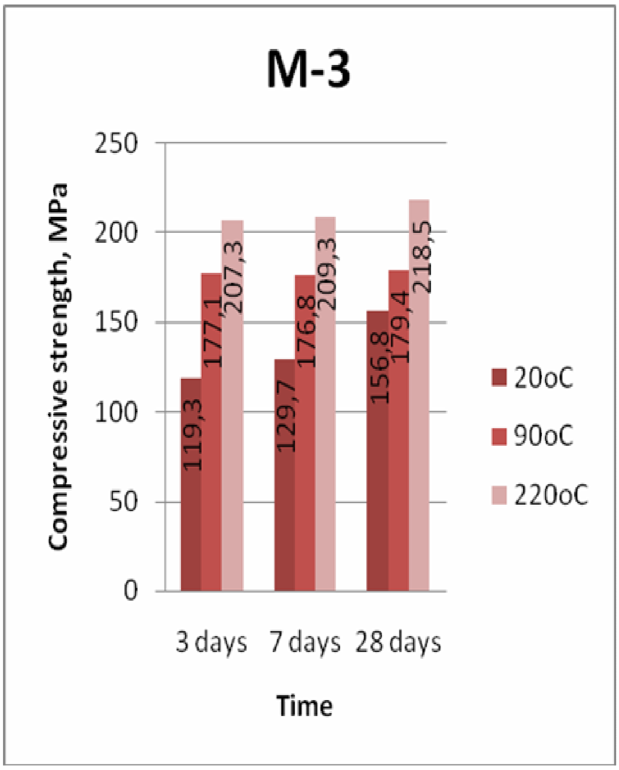

Figure 6. Compressive strength results for mix M-3.

Compressive strength test results for mix M-4 are shown in figure 7

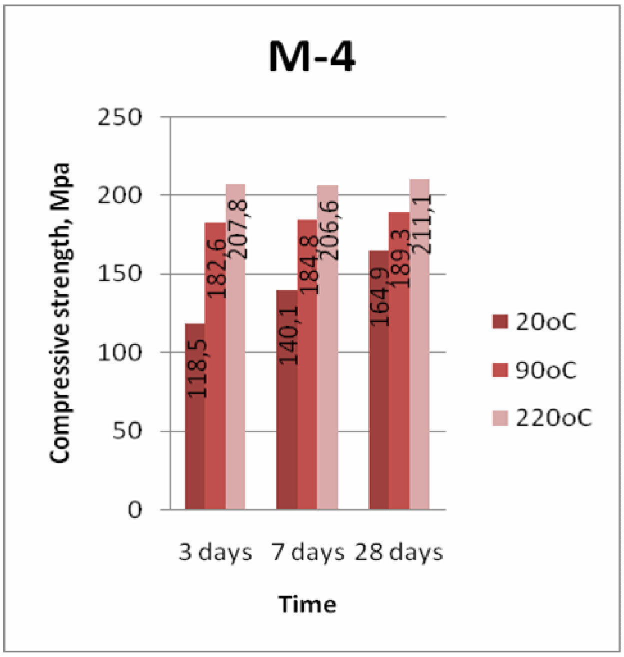

Figure 7. Compressive strength results for mix M-4.

After 28 days specimens which were cured at 90°C display 14.8% higher compressive strength than those which were cured at 20°C, and specimens which were cured at 220°C show 28.0% higher compressive strength than those curedat 20°C.

6. Conclusions

Results of this research show that granulometry of mix particles is important. In case where particles with diameter 0.5 – 2 mm were removed, compressive strength of concrete decreased from 3% (for specimens cured at 20°C) to 4.8% (for specimens cured at 220°C). It can be concluded from the results that significant compressive strength increase can be obtained by reducing aggregate size, increasing amount of cement and curing at 220°C. According to test results, compressive strength of specimens increases 14.4 – 22.3% by curing at 90°C and 28.0 – 39.3% by curing at 220°C in comparison to standard curing. Although compressive strength for specimens cured at 220°C increase significantly, microcrack formation can influence durability of concrete. There is impression that pozzolanic reaction does not stop after heat curing, because from test results it can be seen that compressive strength of heated specimens after 28 days is higher than after 3 or 7 days.

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