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Influence of the Concrete Mixture Compaction Time on Density and Compressive Strength of Hardened Concrete Samples

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Paper discusses the influence of the concrete mixture compaction time on density and compressive strength of hardened concrete samples. Concrete specimens, of diameter about 106 mm (*D*) and height about 1000 mm (*H*), were formed during the experiment. The ratio of height and diameter *H/D* was 9.4. Concrete mixture, placed in forms, was compacted by poker vibrator, when vibrating element was placed to the top part of the form. Different time was used for compacting mixture in forms: 0, 3, 6, 9 and 12 s. The study results show the changes in density and compressive strength of samples (radius about 106 mm and height about 100 mm) depending on the location of the sample in specimen (1000 mm height). It was found, that samples taken from different height of the specimen had different density and compressive strength.

KEYWORDS: compaction time, compressive strength, concrete mixture, density, hardened concrete.

Introduction

Density is defined as the measure of how much particles of an element or material is squeezed into a given space. The more closely packed the particles, the higher the density of the material. Higher levels therefore, indicate a corresponding degree of compaction. From compaction degree depended density, compressive strength, water permeability, durability and other properties of hardened concrete.

Depending on the physical state, concrete mixture is in intermediate place between solids and viscous fluids. During the quiescence phase, fresh concrete is like solid body, and at the phase then it's mixed, pumped or vibrated – it looks like viscous fluid. Liquefaction of concrete mixture due to mechanical effects and thickening of the mixture after stopping them is called thixotropy. (Gurskis 2008). Rheological characteristics of the concrete mixtures depend on mechanical impact. Thixot-

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ropy usually becomes apparent during vibration when shear stress and viscosity go down (Khayat *et al.* 2002, Roussel 2006, Mewis and Wagner 2009).

Because concrete itself is a porous composite material, the pores in concrete structure are classified as compaction pores, air pores and capillary pores (which affect durability) and gel pores. The change in the compaction pores may significantly affect the carbonation rate and the sorptivity coefficient, and compacting of the fresh concrete is the more important in terms of the durability (Gonen and Yazicioglu 2007).

To assess adequate level of vibration, consideration should be given to match the amplitude of vibration and concrete viscosity. High amplitude means greater vibratory forces. The viscosity of the mix should be strong enough to bear these forces while keeping the suspensions of coarse aggregates. Thus, the amplitude of vibration should match the viscosity of mix when applying vibration (Safawi *et al.* 2005).

According to authors (Arslan *et al.* 2005) in normal construction practice, concrete is placed in 1 m layer and compacted by using poker type vibrators, which are immersed into only the top 1 m of the concrete. If concrete is placed to a depth of 1 m, the vibrator is immersed 1 m into the concrete. The concrete is completely fluidised and the lateral pressure is hydrostatic. If concrete is placed to a depth of 2 m, the effect of the vibrator will extend below the vibrator and the 2 m depth of concrete will be fluidised, giving hydrostatic pressure. If concrete is placed to a depth of 3 m, the lower concretes develop significant shear strength, settling vertically under load and developing friction between the concrete and the formwork surface.

According to authors (Banfill *et al.* 2011) in the inner liquefied zone around the vibrator the flow is due to shear whereas in the outer unsheared zone propagation is due to compressive waves. The research results gives a method of predicting the radial position at which the flow changes, which coincides with the radius of action of the vibrator. Experiment agree that the peak velocity of the vibration governs its efficacy, with radius of action increasing with increasing velocity. The work offers the potential to optimise the design and use of vibrators.

Teranishi et al. (1993) investigated theoretically the mean deformation resistance of fresh concrete under vibration by simplifying the vibration as a repeated static shear stress and using the Bingham model to express the deformation behaviors of fresh concrete under static stress. As a result, when the vibration acceleration is greater than a certain value, the shear rate – shear stress relationship in the lower shear rate – range becomes a curve without a yield value, rather than a straight line as in the Bingham model.

Gong *et al.* (2015) developed a UWB-based tracking method for real-time 3D tracking and visualization of concrete vibration effort during concrete placement. The research results indicate that the developed occupancy grid-based vibration effort visualization method can identify defective vibration practices. The research outcome will contribute to the improvement of concrete consolidation quality assurance methods.

Concrete-filled steel tubular columns have better structural performance than that of bare steel or reinforced concrete. For reinforced concrete columns, concrete compaction only affects the mechanical properties of concrete. But for concrete-filled steel tubes, it is well known that the interaction between steel tube and concrete is the key issue to understand the behaviour of this kind of column. The concrete compaction not only affects the properties of the core concrete itself, but also may influence the interaction between the steel tube and its concrete core, and thus influences the behaviour of the composite columns (Han and Yao 2003).

Scientists Grabiec and Piasata (2004) say that the big influence on the concrete's resistance to freezing – thawing cycles is being made by the density and the compressive strength of the concrete.

The outcome of this article was to find how different compaction time influences the density and compressive strength of hardened concrete.

Methods

Portland cement CEM II/A-LL 42.5 R (MA) (A) (JSC Akmenės cementas production) was used for the test. Physical, mechanical properties and chemical composition of Portland cement are given at the **table 1**.

Sand with the fraction of 0/4, bulk density of 1680 kg/m^3 and fineness module of 3.2 was used as fine aggregate. Crushed gravel with the fraction of 4/16 and bulk density of 1450 kg/m^3 was used as the coarse aggregate. Granulometric composition of aggregates is conducted according to LST EN 12620:2013 and presented in **Table 2**.

Plasticizing admixture based on policarboxile polymers Glenium SKY 628 (BASF Construction Chemicals Italia Spa) was used with density of solution 1.06 g/ml. The total dosage of admixture was 0.5 % of cement.

The concrete mixtures were prepared in 3 minutes by two stages in laboratory forced type concrete mixer Zyklos Rotating Pan Mixer ZZ 75 HE. During the first stage cement, aggregates and 2/3 of water were poured into the moistened mixer and mixed for 2 minutes. While during the second phase, the remaining amount of water was poured with concrete admixture and concrete mixture was mixed for 1 minute. During the research, dry aggregates were used for concrete mixtures. Cement and aggregates were dosed by weight while water and chemical admixture were dosed by volume. When preparing the concrete mixture, 90 % of water was instantly poured to the mix. Super-plasticizing admixture was mixed with 10 % of water and poured into the mixer.

The concrete specimens, columns of diameter about 106 mm and height about 1000 mm dimensions size, were formed in plastic angular tube and compacted by using poker vibrator ENAR DINGO (frequency: 50÷60 Hz, vibrations: 18.000 r.p.m.). Concrete mixture was compacted by poker vibrator, when vibrating element was placed to the top part of the form. Different time was used for compacting mix-

Table 1

Physical, mechanical properties and chemical composition of Portland cement CEM II/A-LL 42.5 R (MA) (A)

Specific surface area, m^2/kg	410
Particle density, kg/m^3	3110
Dry bulk density, kg /m^3	1220
Water demand for normal consistency (by Vicat), %	26.5
Volume stability, mm	0.8
Initial setting time, min.	195
Compressive strength after 2 days / after 28 days, MPa	27.1/54.0
Loss on ignition, %	5.05
Insoluble materials, %	-
SO_3, %	2.48
Cl^-, %	0.015
Alkalis, calculated by Na_2O equivalent, %	<0.72

Table 2

Granulometric composition of aggregates

Radius of the sieve's mesh, mm	The amount of poured out material, %	
	Sand fraction 0/4	Crushed gravel fraction 4/16
32.0	-	100.0
16.0	-	94.8
8.0	100.0	37.8
4.0	94.8	4.9
2.0	78.7	1.2
1.0	55.7	0.8
0.5	37.9	0.7
0.25	14.9	0.7
0.125	2.7	0.7
0	0.4	0.5

ture in forms: 0, 3, 6, 9 and 12 s. The concrete mixture was compacted immediately after placing in the forms in such a way as to produce full compaction of the concrete with neither excessive segregation nor laitance. The specimens were kept for 28 days in forms at the temperature about 16° C. When specimens were removed from the forms, they were cut by100 mm. After cutting the specimens, we got 10 samples, cylinders of diameter about 106 mm and height about 100 mm dimensions size. The cut surfaces of samples were polished by abrasive stone. If surface was extremely rough, it was smoothed by cement mortar.

The consistency of fresh concrete mixture was determined according to standard LST EN 12350-2:2009, density – according to standard LST EN 12350-5:2009. The density of hardened concrete was determined according to standard LST EN 12390-7:2009, the compressive strength – according to standard LST EN 12390-3:32009.

Microsoft Excel program was used for identifying the best dependence of the dispersion of the density and comprehensive strength values of samples and equation's empirical coefficients values.

Results

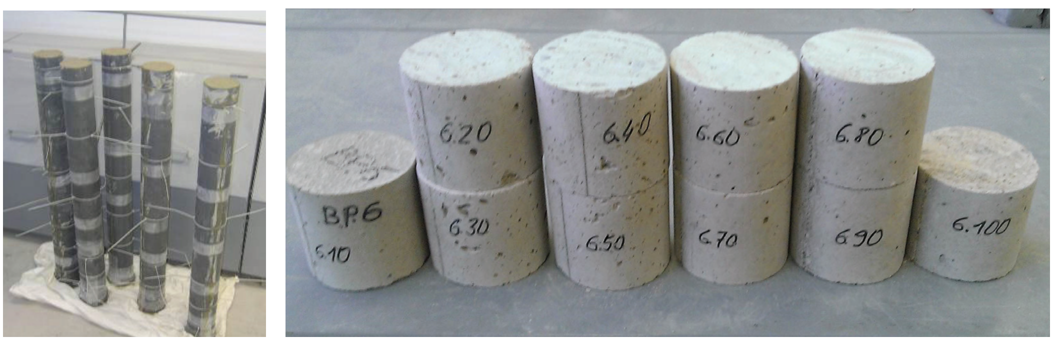
The concrete mix was designed for compressive cube strength at 28 days of approximately 30 MPa. The mix proportions presented at Table 3.

Table 3

Composition of concrete mixture

Materials	Unit	Materials per 1m^3 concrete mixture
CEM II/A-LL 42,5 R (MA) (A)	kg	333
Water	l	180
Crushed gravel fraction 4/16	kg	868
Sand fraction 0/4	kg	1058
Glenium SKY 628 (0.5 %)	l	1.6
Water and cement ratio	-	0.54

Technological properties of the concrete mixture were determined. Mixture fulfilled class S3 (S3=(100–150)±30 mm) according to cone abatement. Determined density of the mixture was 2230 kg/m^3. From the prepared concrete mixture 5 specimens were formed in the shape of column with dimensions: diameter 106 mm, the height 1000 mm (Fig. 1).



a b

Fig. 1

The formed concrete mixture specimens, columns of diameter about 106 mm and height about 1000 mm dimensions size (a), the concrete samples of diameter about 106 mm and height about 100 mm dimensions size (b)

The dependence of the concrete samples' (106 mm diameter and 100 mm height – H/D=0.94) density on the duration of compacting is presented in **Fig. 2.** From the presented graphic it could be observed, that the average values of the concrete samples' density is in the range of 2130÷2190 kg/ m^3. The highest average value of the density of the concrete samples (2190 kg/m^3) was obtained when mixture was compacted for 3 seconds during the formation (H/D=9.4). As it was expected, the lowest average value of concrete sample's density (2130 kg/m^3) was obtained when mixture was not compacted during the formation (H/D=9.4).

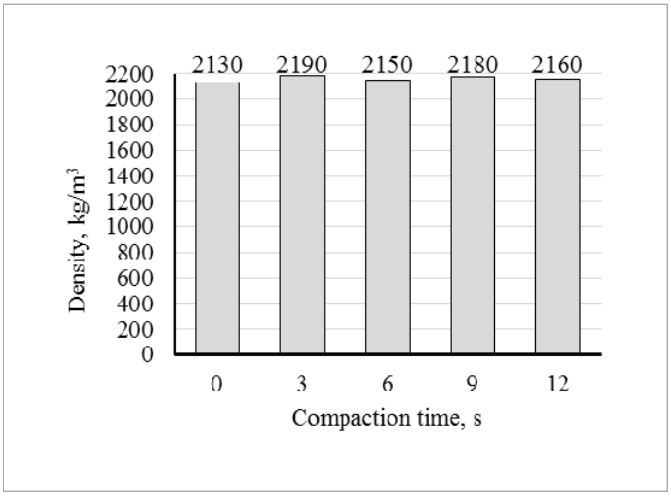


Fig. 2

The change of density of concrete samples depending on the compacting time

The dependence of concrete sample's (H/D=0.94) compressive strength on the duration of the compacting is presented in **Fig. 3.** The average values of compressive strength of the concrete samples were in a small range 30.3÷32.6 MPa. The tendencies of changes of the concrete samples' compressive strength, when the duration of the compacting is different while forming the specimens H/D=9.4, corresponded to the tendencies of changes of the concrete samples' density. While compacting concrete mixture with poker vibrator for 3, 6, 9 and 12 s, it had no significant difference for concrete samples' compressive strength.

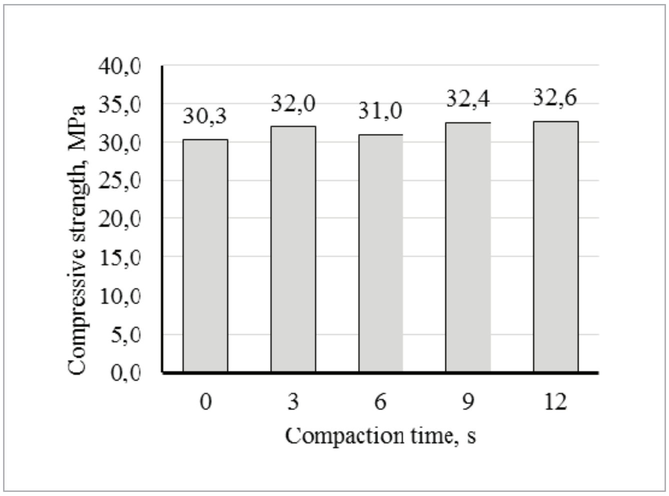


Fig. 3

The change of compressive strength of concrete samples depending on the compacting time

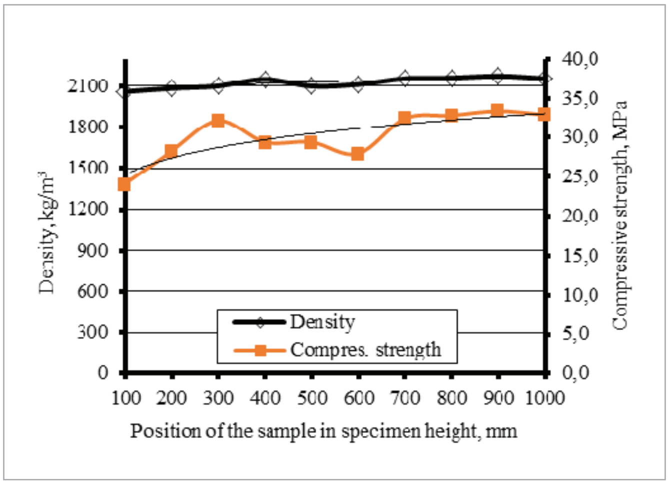
It was not effective to compact concrete mixture with poker vibrator in plastic form, when vibrating element was placed to the top part of the form. The average values of density of concrete samples, depending on the time of compacting, were 1,01÷1,03 times higher compared with average values of the control samples.

Distribution of density and compressive strength of the concrete samples (H/D=0.94) depending on the location of the sample in specimen's (H/D=9.4) height, when the duration of compacting is different is presented in **Fig. 4.**

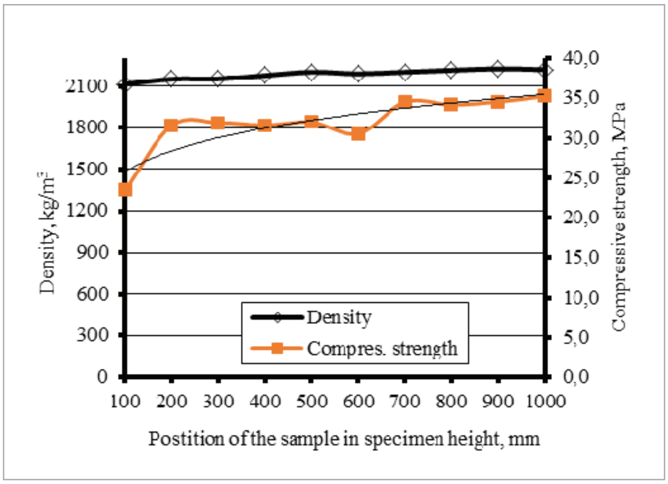
Results show, that the tendencies of distribution of concrete samples (H/D=0.94) density and compressive strength depending on the location of the sample in specimens (H/D=9.4) height are similar. At higher sample's location, density and compressive strength were increasing. Also it was noticed, that regardless the duration of the compacting of the specimens (H/D=9.4), values of density and compressive strength at 500-600 mm height were close to values of specimens

Fig. 4

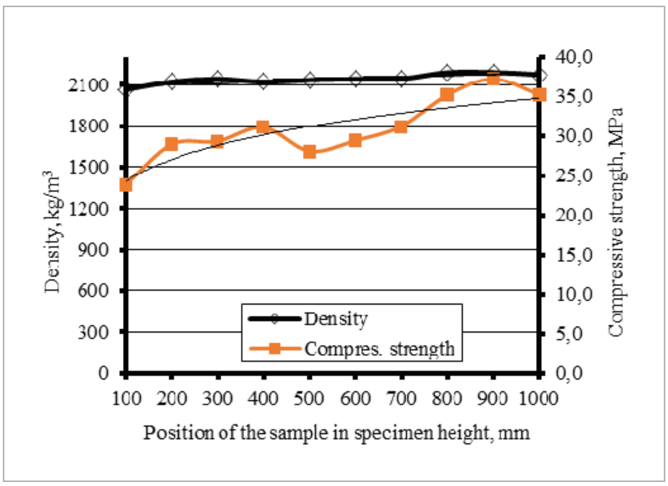
Distribution of density and compressive strength of concrete depending on location of sample in the specimen's height, when the duration of compaction time is different



a) Compaction time, 0 s



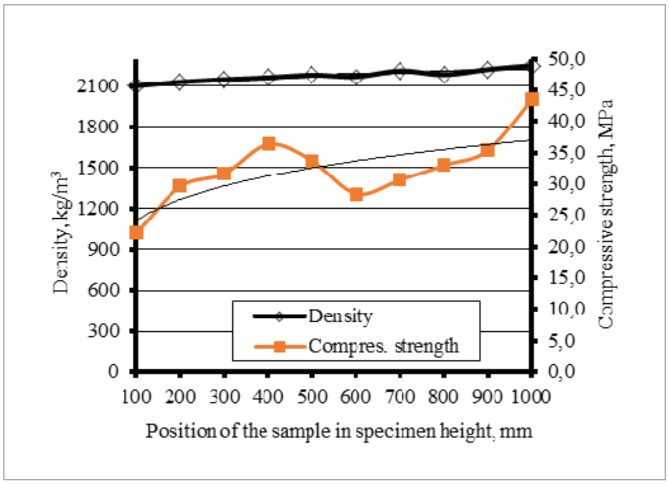
b) Compaction time, 3 s



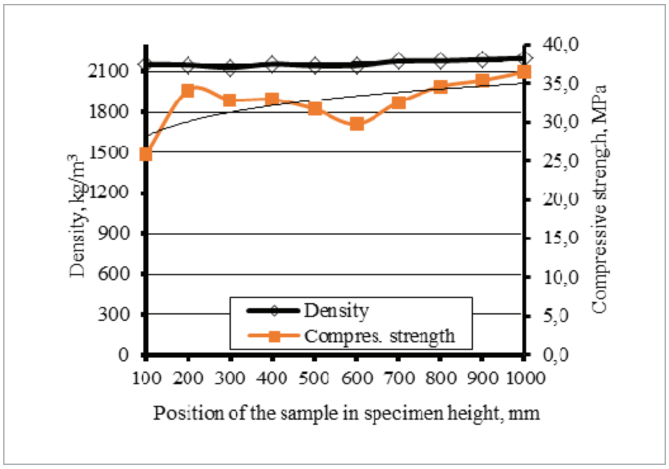
c) Compaction time, 6 s

taken at 100 mm height. That could be influenced by filling the forms with concrete mixture during the formation of the specimens: forms of 1000 mm height were filled with mixture in two steps and only after the mixture was compacted in forms. Filing forms with several layers and instantly compacting separate layers could have more significant influence on density and compressive strength of hardened concrete.

The best dependence of dispersion of values of concrete samples' (H/D=0.94) density and compressive strength is presented in Fig. 4. Equations of dispersion of the results, empirical and correlation coefficients values are presented in Table 4. Correlation coefficient (Pirson), which is evaluating the strength of linear relationship, and presented in the Table 4, was calculated according to coefficient of empirical equation. The closer correlation coefficient is to 0, the better representation of the dispersion of values in the curve. According to the obtained correlation coefficient, it was determined which equation describes the best distribution of statistical data. From Table 4 we can see, that values of dispersion of dependence of concrete samples density on the duration of the compaction time can be described by gradual, linear and parabolic dependencies. The values of correlation coefficient were in the range from 0.88 till 0.98. The relationship between the variables will be stronger



d) Compaction time, 9 s



e) Compaction time, 12 s

when the correlation coefficient values is close to 1. it means, that variables are statistically dependent and based on the values of the correlation coefficient, there is a strong connection between variables.

The dispersion of values of dependence of concrete samples compressive strength on the compaction time could be described by a gradual and linear dependencies. The calculated values of correlation coefficients are in the range of 0.70 to 0.88. It shows, that variables are statistically dependent and based on values of correlation coefficients – the relationship between variables is strong. Compared with the influence of time of compacting the concrete mixture with poker vibrator on the density and compressive strength it can be noticed, that values of correlation coefficients' showing dispersion of concrete samples' density are higher then values of correlation coefficients' showing dispersion of

Table 4

The dependence of dispersion of data

Compaction time, s	Properties of hardened concrete	Equation	Coefficients value of equation				R-squared value	Correlation coefficient *r*
			a	*b*	*c*	*d*		
0	Density	$y = a{\cdot}x^d$	1953.9	-	-	0.0221	0.776	0.88
	Compres. strength	$y = a{\cdot}x^d$	19.282	-	-	0.1171	0.682	0.83
3	Density	$y = a{\cdot}x^d$	2007.7	-	-	0.0221	0.956	0.98
	Compres. strength	$y = a{\cdot}x^d$	18.776	-	-	0.1381	0.746	0.86
6	Density	$y = a{\cdot}x^d$	1970.2	-	-	0.0218	0.817	0.90
	Compres. strength	$y = a{\cdot}x + b$	0.1166	24.548	-	-	0.775	0.88
9	Density	$y = a{\cdot}x + b$	1.3944	2099.6	-	-	0.905	0.95
	Compres. strength	$y = ax^d$	15.907	-	-	0.1833	0.581	0.76
12	Density	$y = a{\cdot}x^2+b{\cdot}x+c$	0.0126	0.7789	2155.3	-	0.842	0.92
	Compres. strength	$y = a{\cdot}x^d$	22.657	-	-	0.0946	0.491	0.70

concrete samples' compressive strength. Having longer duration of compaction time, correlation coefficients' showing dispersion of concrete samples' compressive strength are getting smaller when the duration of compacting is 6 s. When the duration of compaction time is getting longer, the density dispersion dependence values are changing from gradual, linear to parabolic. The duration of the compaction time, during the formation of the mixture (H/D=9.4), from 3 to 6 s can be considered as optimal variant.

Conclusions

1 The average values of density of the concrete samples, depending on the compaction time, were 1,01÷1,03 times higher compared with control sample.

2 The duration of the compacting of specimens (H/D=9.4), during formation of the mixture, had more significant influence on the density of the specimens (H/D=0.94) but not on the compressive strength.

3 Regardless the duration of the compacting of the specimens (H/D=9.4) during the formation of the mixture, values of density and compressive strength of samples taken at 500-600 mm height were close to the values of samples taken at 100 mm height.

4 Density correlation coefficients were higher than compressive strength's correlation coefficients.

5 Having longer duration of compaction time, correlation coefficients' showing dispersion of concrete samples' compressive strength are getting smaller when the duration of compacting is 6 s. The duration of the compaction time, during the formation of the mixture (H/D=9.4), from 3 to 6 s can be considered as optimal variant.

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