An In-Situ Study on The Specimen Size Effects on Compressive Strength for Different Strength Concretes

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Abstract

The compressive strength of concrete is the most basic and considerable material property while reinforced concrete structures are designed. It has become a problem to use this value, however, because the control specimen sizes and shapes from country to country may be dissimilar. The study presents the results of an experiment that examined the effect of specimen size on the different classes of compressive strengths of concrete. The study included casting specimens, cubes, and six different classes of the concrete mixture. Compression tests were conducted at the age of 3, 7, and 28 days on 150 mm & 100 mm cube samples. The fresh properties of concrete were measured by slump and unit weights tests. Moreover, the specimen size of concrete has an important role both on the compressive strength and capacity of a curing cabinet. Correlations between compressive strengths and sizes of specimens are compatible for classes of structural concretes. Therefore, it can be used in curing cabinet varying sizes of concretes like 150 mm & 100 mm cube samples. Although almost 220 concrete specimens sized of 150 mm cube can be poured in curing tank, roughly 585 concrete specimens can be poured with using 100 mm cube concrete specimens. The most convenient size resulted from this study is suggested as 100 mm sized cubic specimen that it promote to change the law for concrete both curing and compressive strength test.

1. Introduction

The compressive strength test result is the most important event related to concrete. It is most essential to obtain accurate values for concrete strength to ensure the safety of executed designs [1,2]. Frequently, two geometric types of specimens are used for compressive strength tests of concrete worldwide – cylinders and cubes [3]. Specimens of differing shapes and sizes are preferred in such countries. Cubic formed concrete specimens sized 150x150x150 mm is standard in several countries such as UK, Germany, Turkey, and many other European countries. Cylindric shaped concrete specimen in 150/300 mm dimensions are commonly used in the United States, South Korea, France, Canada, and Australia. The compressive strength standard in Norway is conducted with both 150/300 mm sized cylinder, and 150 mm sized cubic forms [4].

It is well-known that as the sizes of a concrete specimen changes, compressive strength values change. These variations of the specimen's strengths are not stable because of their different geometries. Further, it was found to be more apparent in high-strength concrete [5]. Gonnerman [6] studied the size effect on cylinders, prisms, and cubes with diverse dimensions for normal-strength concrete. He found that as the sizes of concrete specimens in cylindrical shapes with the same slenderness ratio decrease, compressive strengths increased. This has resulted from an increment of microstructural defects of high dimensioned specimens [7]. Various tests and large-scale analyses have been conducted concerning the size effect [8–11]. The source of the size effect is debated through the literature [5,12–14]. The main outcome of various theoretical models and experiments is the same derived from the literature. Experimental results indicate the presence of an asymptotic strength as the size approaches infinity, and this is very important for further analyzing the various size effect models [5]. The moving debate is about the nature of this size effect. Many empirical models were created from the analysis, and the most important model

has been created by Neville (1966) [15]. The model is depending on the strength and some of the specimen properties such as volume (V), lateral dimension (d), height to lateral dimension (h/d) ratio. By using this model, effect of size and shape on conventional concrete strengths can be calculated from experimental results. The correlations of a correction factor for 150 mm and 100 mm sized cubic specimens are between 0.89 to 1.29 for conventional concretes [16]. In another study, the compressive strength for different sized and ages concrete specimens were investigated. The test outcomes showed that compressive strength of the 100 mm cubic specimen was higher approximately 5 - 6% than that of 150 mm cubic specimen [17].

Thanks to the concrete technology, gradation and maximum size of aggregate used in concrete have get smaller recently because of good workability requirements of concrete to pour within pipe. Formerly, the maximum size of aggregate was accepted at least 31.5 mm. Because there is no need for any pipe on the construction site. However, nowadays, there is a requirement to use ready-mixed concrete in construction sites. Recently, since both high-rise buildings and high strength concrete are needed in the construction sector, the maximum aggregate size is decided to smaller from 31.5 to <25 mm in structural concretes [18]. Therefore, compressive strengths of concretes can be determined by smaller molds, mostly by 100 mm cubes, because of reduced the maximum aggregate sized in the design of concrete. There are several reasons to choose cubic shape concrete specimens. Firstly, the top and bottom sides of cylinder shape concrete specimens need surface preparation. Secondly, smaller specimens are also favorable because of the easier handling of the samples and lower material source consumption. The most important reason wherefore smaller cubes are preferred is the effort to decrease testing machine capacity requirements. According to the author's experience, the capacity of common testing machines usually does not exceed 3000 kN, which means that the maximum probable strength of a 150 mm cube can be obtained at most 130 MPa. If 100 mm cubic specimen are used, the necessary force is theoretically 2.25

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times lower. This enables compressive strength testing of concretes as high as 250 MPa using the same machine [19]. In addition, the smaller molds are lesser demanding to deal with; they are lesser inclined to damage, the molds are lesser expensive, the machine needs less testing limits, the lesser substance of concrete is used, which means smaller lab capacity and smaller space, and the extra smaller amount of preparation [20]. According to (150 mm) cubes, the (100 mm) cubes are simpler to deal with and will bring about sparing materials, stockpiling, relieving space, and work as well [4].

In this experimental study, the effects of sample sizes were investigated to determine compressive strength. For this purpose, compressive strength tests were carried out on both 150 mm and 100 mm sized cubic specimens with different strength classes of concretes. The study aims to define the correlation of different sized cubic specimens with other dimensions and geometries.

2. Material and Methods

2.1. Material

In this experimental study, six different concretes such as C14/16, C20/25, C25/30, C30/37, C35/45, and C40/50 were produced. The components of all concretes were used the same. CEM II AM/PL 42,5R type cement and ground blast furnace slag (GBFS) was used as binder. Crushed limestone was used as aggregates. Domestic water from Ankara province was used for mixture and curing water. "Fluid GT-X" brand superplasticizer (SP) and Chryso "Optima 283" brand hyper plasticizer (HP) were used as chemical additives. The physical and chemical properties of the cement and mineral additive are given in Table 1. Physical properties of the aggregates are given in Table 2.

Table 1. Chemical and physical properties of cement

Oxides (%)	CEM	GBFS	Properties	CEM	GBFS
Fe ₂ O ₃	3,43	0,87	Specific gravity (gr/cm ³)	3,03	3,00
Al ₂ O ₃	5,20	9,17	Specific surface (cm ² /gr)	3700	4078
SiO ₂	20,39	38,13	Standard consistency	0,30	-
CaO	64,14	36,93	Initial setting time (min)	160	180
MgO	2,12	8,24	Final setting time (min)	210	200
SO ₃	3,13	1,83	Volume expansion (mm)	1,0	0
K ₂ O	0,79	0,91	Compressive	2 days	30,9
Na ₂ O	0,39	-	Strength	7 days	43,3
LOI*	3,71	0,19	(N/mm ²)	28 days	53,9
					38,1

*LOI: Loss on ignition

Table 2. Physical properties of aggregates

Aggregate type	Crushing sand 0 – 4 mm	Crushed stone 8 – 16 mm	Crushed stone 16 – 22,4 mm
Dry BHA (kg/dm ³)	1.50	1.82	1.76
Fine material rate %	13.2	1.20	0.50
Specific weight	2.60	2.67	2.67
Water absorption (%)	2.63	0.67	0.66

Pozzolanic activity test of GBFS were performed according to ASTM C311 [21], and test results showed that the compressive strengths were obtained at the rate of 52% for 7th day and 72% for 28th day by reference specimen. Aggregate gradation used in concretes is given in Figure 1 as current aggregate curve. According to the Figure 1, gradation of current aggregate is like the fuller curve. Small different can be observed between 2 mm and 10 mm sieve sizes. Between these sieves, the material amount is little high. Therefore, more workable concretes can be produced with this aggregate gradation.

Figure 1. Aggregate gradation curves

2.2. Methods

The mixing design is given in Table 3 for producing concretes. In fresh concrete preparation, aggregates are placed in a laboratory type vertical axis concrete mixer from coarse to fine. Then, water requirement of aggregates was added and waited for 15 min, until saturated surface of aggregate was observed. After that, GBFS and cement were added. After the solid mixture was mixed about 1 min, the mixing water was added by visually inspecting whether the cement is bound to all aggregates. Chemical admixtures were dissolved in mixing water, 1.3% SP in C14/16, C20/25, C25/30, C30/37 type concretes and 1.4% HP in C35/45 and C40/50 type concretes were added. After totally 3 minutes of mixing, slump test was performed. afterwards, the concrete mortars were poured in 100x100x100 mm and 150x150x150 mm cubic plastic molds according to TS EN 12390-2 [22]. Compacting fresh mortars in the molds was carried out in two stages for 60 s with a table-type vibration mechanism. Concrete specimens were kept in a curing tank filled with lime saturated water at 22 ± 2 °C. Compressive strength tests were performed at 3rd, 7th, and 28th days according to TS EN 12390-3 [22]. To balance the hydration heat, 10% GBFS was used instead of cement in C35 and C40 concretes. Moreover, Schmidt hammer tests were performed before compressive strength tests on concrete specimens within the hydraulic press.

3. Results and Discussion

Compressive strength test results obtained from the experimental study are given in Figure 2 as an average strength values of at least 10 specimens for each period, and the correlation between strength and sample size is given in Figure 3. According to the results, 100 mm cubic concretes in C20/25 - C30/37 are higher at 3 – 6% ratios than 150 mm cubic concretes. It has been determined that there are not many differences in compressive strength due to size changes.

Figure 2. Compressive strengths of cubic specimens A) 3rd day, B) 7th day, and C) 28th day

Table 3. Mixing proportions and fresh state properties of concrete classes

Codes	Cement (kg/m ³)	W/C	Unit weight (kg/m ³)	Slump (cm)	GBFS (%)	0-4 (kg/m ³)	8-16 (kg/m ³)	16-22,4 (kg/m ³)	SP (kg)	HP (kg)
C14/16	185	0.95	2355	13.0	-	1136	371	492	2.41	-
C20/25	250	0.75	2366	14.2	-	1048	380	499	3.25	-
C25/30	280	0.65	2365	13.3	-	1010	387	502	3.64	-
C30/37	320	0.55	2363	14.1	-	944	394	511	4.48	-
C35/45	300	0.55	2379	19.0	80	868	396	532	-	5.32
C40/50	330	0.55	2380	21.3	100	855	394	520	-	6.02

According to the compressive strength results, when reference strength value is accepted as 28th day at 100% development of strength, 3rd day strength developments of all concretes are obtained between 63 – 73% except C14/16 concretes. This strength development for early age is derived from the cement substances because of its higher C₃S ratio, although w/c ratios are determined between 0.55 – 0.65. GBFS was used in C35 and C40 designs approximately 30% by cement weight. In these concretes, 7th day strength developments are higher than the rest of concretes. So, pozzolanic and binding reactions occurred at higher ratios in these concretes. Although the concrete designs were made of for C35/45 and C40/55, compressive strength values are observed quite high in these batches. Compressive strength from C40/55 class 150 mm and 100 mm cubic concretes were obtained average 63 MPa and 67 MPa at 28th day, respectively. Hence, these batches can be described as high strength concrete.

The results derived from Figure 2 show that compressive strengths of concrete specimens decrease with the increase of size, regardless of the strength class of the concrete sample. This expected behavior is similar to the most of researches [23–25]. There are common weaknesses such as micro cracks and voids in the concrete samples produced. The best explanation for this situation is that as the volume increases, the defects and weaknesses in concrete are more and more distinct. As sample sizes increase the number of micro-cracks or other defective parts that may be present in the sample statistically are also increase. Therefore, higher compressive strength values are obtained on smaller sized samples [20,26]. In addition, the smaller cubes had lower stress concentration at the corners; thus, this initiated later cracks making the compression test measured to be higher [27].

Figure 3. Correlation of 10x10x10 cm and 15x15x15 cm edge samples

In the Figure 3, totally 59 compressive strength results of different sized cubic specimens are correlated. In Figure 3, a correlation has been established between 100 mm and 150 mm cubic concrete specimens by using data obtained from the experimental study and performing linear regression modeling. According to this relation, a strong relationship can be seen with the coefficient $R^2 = 0.993$. Hence, the compressive strength values of 100 mm cubic specimens can be acceptable in 5% deviation.

The full savings can be imported in financial terms. However, engineers are averse to use 100 mm cubes for determining the compressive strength, wherefore the perceived greater instability in their compressive strength over that of the 150 mm cubes. Also, there is a without adherence criteria for the 100 mm cubes as the General Specification provides acceptance criteria based on 150 mm cube strengths only.

Figure 4. Schmidt hammer rebound test values and compressive strength correlation

In the Figure 4, the results from Schmidt hammer rebound test obtained during the compression tests from different sized specimens are correlated to the totally 40 compressive strengths and rebounds. It is found with the performing linear regression modeling that it is quite similar R^2 values between 100 mm and 150 mm cubic sized rebounds. According to this relation, there is approximately 30% deviation in compressive strength and rebound values with different sized of specimens.

4. Conclusion

In the literature, the effect of samples of different sizes and geometries on compressive strength has been investigated, generally without considering concrete classes. In this study, the effect of specimens with the same geometry but different sizes on compressive strength was investigated, considering the commonly used concrete classes. The results obtained are as follows:

1. The compressive strengths of 100 mm cubic specimens are quite similar to the compressive strengths of 150 mm cubic formed specimens. Thus, 100 mm cubic formed specimens can be used in industrial applications regardless of classification of concretes.
2. As expected in experimental studies, as the sample size increases in concretes with the same geometry, it has been observed that the compressive strength decreases as the error rate in the sample increases. The reason for this is that the error rate increases because the concrete, which is a mixture, cannot be distributed 100% homogeneously and does not show the same feature everywhere.

3. It has been determined that there is a linear relationship with a high correlation coefficient between the compressive strength values measured on samples of different sizes. It has been observed that the compressive strength of concrete increases as the sample size gets smaller, in accordance with the literature. The lower concrete compressive strength of large-sized specimens compared to small-sized specimens is an expected result, considering previous studies in the literature and the increased probability of defects in the specimen.
4. Using 100 mm sized cube specimens in the quality inspection are good, both in terms of low-capacity pressure testing machine in the construction sites, ease of sample transportation with reduced weight, and reduced amount of concrete lost.
5. 100 mm cubic specimens are approximately 2.25 times effective for curing tank capacity usage.
6. Regarding the compressive strength values 3-, 7- and 28-days long period, there is not much difference between 100 mm and 150 mm cubic specimen sizes.

Considering the above results, a 100 mm cubic specimen can be useful and effective for standard compressive strength tests in small-sized aggregates such as a maximum of 25 mm. Moreover, (TS13515-T1 and TS13515-T2) [18], when the necessary precision is provided in the measurements, it will be beneficial to become widespread in practice.

Declaration of Conflict of Interests

The authors of this paper declared that there is no conflict of interest in this research paper.

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