Research Journal of Applied Sciences, Engineering and Technology 7(20): 4251-4257, 2014
DOI:10.19026/rjaset.7.796
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: December 13, 2013 Accepted: January 02, 2014 Published: May 20, 2014

Research Article

Compressive Strength Conversion Factors of Concrete as Affected by Specimen Shape and Size

[1]N. Zabihi and [2]Ö. Eren
[1]Department of Civil Engineering, Istanbul Technical University, Istanbul, Turkey
[2]Department of Civil Engineering, Eastern Mediterranean University, Gazimağusa, Mersin 10, Turkey

Abstract: In this study, concrete specimens, having different shapes and sizes have been studied for two different strength levels cured in air and in water. Compressive strength test was performed on cubic and cylindrical samples, having various sizes. The analyses of this investigation were focused on conversion factors for compressive strengths of different samples. Conversion factors of different specimens against cross sectional area of the same specimens were also plotted and regression analyses were done. It was found that according to the results of analyses, the best fit curves, tend to have different trends at different curing conditions.

Keywords: Compressive strength, concrete, curing, mechanical properties, modeling

INTRODUCTION

Compressive strength test is probably the most widespread experiment, which is performed on concrete samples.

Two of the most important factors, which can influence the results of compressive strength test, are shape and size of the specimens.

Shape and size effect of the specimens can be defined as the alteration of the nominal strength of concrete samples, by changing the shape and size of the specimens (Bažant and Planas, 1998).

According to different testing standards, for compressive and splitting tensile strengths, there are two main shapes for testing specimens; cubes and cylinders. While cylindrical specimens (150×300 mm) are used mostly in Australia, Canada, France, New Zealand and the United States, cubic specimens (150 and 100 mm) are used generally in European region (Elwet and Fu, 1995).

Having two main shapes and various sizes, testing specimens can easily result in different and scattered results even if they are from the same batch and tested at the same testing condition.

The effect of shape and size of specimens have been widely studied previously. Various relations and conversion factors have been proposed to understand the effect of shape and size of concrete samples on their compressive strength.

One of the first studies in this field was conducted by Gonnerman (1925). In his research, cubes of 150 and 200 mm and different sizes of cylinders were tested. Conversion factors of 0.85 to 0.88 were obtained for converting compressive strength of cylinders to compressive strength of cubes.

The effect of different curing conditions on conversion factors of specimens was studied by Plowman *et al*. (1974).

Size and shape effect and the factors influencing them were also studied by Tokyay and Ozdemir (1997). They also specifically focused on the phenomenon of wall effect, according to which, in a concrete specimen there is more mortar between wall of the mould and aggregates of the specimen, than the amount of mortar between the aggregates (Neville, 2002). This fact also influences the results of compressive strength, as well as the conversion factors of different specimens to each other. There have been also researchers, studying specifically the wall effect, in which a three dimensional model to describe the change of density of aggregates inside of concrete specimens (Zheng and Li, 2002).

Size effect was specifically studied by Bažant and Planas (1998), proposing an equation, which indicates that by increasing the size of the specimen, compressive strength tends to decrease.

In recent years, research studies about shape and size effect of specimens are mostly concentrated on concrete of higher strengths. A research has been done on investigation of effect of different shape and size on compressive strengths of higher strength concrete samples, focusing on different fracture pattern and stress strain behavior (Del Viso *et al*., 2008). Malaikah (2009) also investigated the effect of size and shape of specimens, focusing on conversion factors of cylinders to cubes.

Corresponding Author: N. Zabihi, Department of Civil Engineering, Istanbul Technical University, Istanbul, Turkey, Tel.: +905319599601

Table 1: Mix design of strength level I and II

C (kg/m^3)	W (kg/m^3)	W/C	Fine (kg/m^3)	D10 (kg/m^3)	D14 (kg/m^3)	D20 (kg/m^3)	level	Range[a]
402	225	0.56	815	167	251	501	I	30-54
486	170	0.35	628	212	318	630	II[b]	50-73

[a]: Regardless of curing method; [b]: Super plasticizer (glenium, 0.6% by weight of cement) is used for this concrete strength levels

In this study, the behavior of effect of different shape and size of concrete specimens have been investigated, by mainly focusing on the conversion factors of specimens as affected by changing the curing conditions and also by changing the strength level of concrete specimens.

Two strength levels of concrete have been investigated in this research. In order to provide the strength levels, concrete samples of two different mixtures have been casted and cured at two different curing conditions.

Experimental program: The experimental part of this research was planned in order to study the effect of size and shape of the specimens on strength for different strength levels and curing conditions. In another words, the goal of this investigation is to find out variations of strength by changing the shape and size of concrete samples having different curing conditions and different strength levels.

During the experimental program, two different concrete mix designs were carried out. These mix designs were aimed to have two different compressive strength levels as, Level I and Level II. Level I consist of compressive strength results less than 54 MPa and Level II consist of compressive strength results less than 73 MPa.

Before starting the main experimental program, in order to ensure the target strength levels, trial mixes were made and tested. In Table 1, different mix design results have been shown for strength level I and II. It should be explained that in these tables, D10, D14 and D20 stand for the aggregates with maximum nominal size of 10, 14 and 20 mm, respectively. Also, range in the table, shows the strength range of each of the levels. Two different curing conditions, namely water curing and air curing, were applied for concrete specimens until the specified testing ages.

For casting the concrete samples, totally five different moulds were utilized, which were three different sizes of cubes and two different sizes of cylinders. The cubic moulds were 100, 150 and 200 mm. The cylindrical moulds were 150×300 and 100×200 mm. It should be explained that in this research, cross sectional area of concrete samples were highlighted to find out a relationship between size and shape effect on compressive strength of concrete samples.

MATERIAL PROPERTIES

As explained before, two different mixes were designed for this experimental program. Crushed limestone aggregates from Beşparmak Mountains of Cyprus (both fine and coarse), potable water and super plasticizer (Glenium) was used only for strength level II of concrete samples.

Table 2: Specimen shape and size

Specimen shape	Specimen size (mm)
Cylinder	100×200 (diameter×length)
Cylinder	150×300 (diameter×length)
Cube	100
Cube	150
Cube	200

For casting all the specimens, locally produced GGBS (Ground Granulated Blast furnace Slag) cement with the class of 42.5 was used.

As it is shown in Table 1, strength level I has the higher ratio of water to cement (0.56) and strength level II has a water to cement ratio of 0.35. This variation in water to cement ratios and also difference in aggregate fraction makes the concretes give different compressive strength levels.

The process of designing the mixes was according to Building Research Establishment (Teychenné, 1997); also constructing the concrete samples was according to British standard of BS 1881: Part 125, British Standards Institution (1986).

Concrete was poured in cubic and cylindrical samples in three layers and compacted by using vibrating tables. After this process, the filled molds were taken to the curing room and cured for 24 h at a humidity of more than 90% and air temperature of around 21°C. After 24 h the specimens were taken to water tankor air room, regarding their pre specified curing conditions and kept in their places until their testing age.

In Table 2, the utilized moulds and their sizes have named.

Testing procedure: Compressive strength test was performed on both cubes and cylinders. For cubic samples, the test was performed according to BS EN 12390-3:2009 (2009) and compressive strength of cylindrical samples was performed according to ASTM C39/C39M (2011).

Before sampling, workability test was performed for each mix according to BS EN 12350-2:2009 (2009).

Hardened density of the concrete samples was also determined according to British Standards Institution (1983), by measuring the weight of hardened concrete samples before performing compressive strength test. The results of this test and also slump test are shown in Table 3.

In order to perform the compressive strength test on cylindrical samples in the direction of casting, sulfur capping was made.

Table 3: Results of hardened density and slump

Strength level	Hardened density (kg/m^3)	Slump (mm)
I	2385	65
II	2477	20

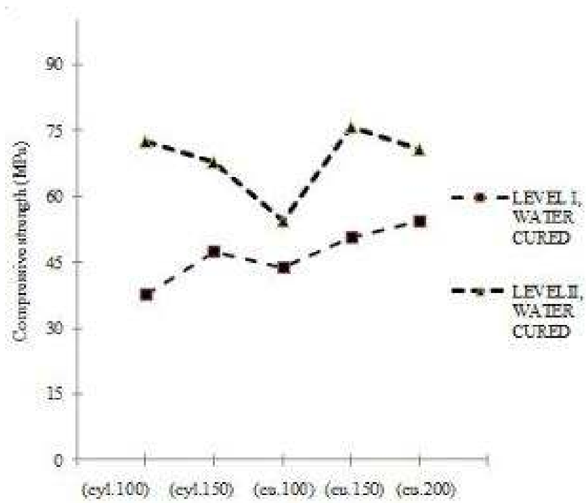

Fig. 1: Compressive strength test results for specimens cured in water, tested at 28 days, strength level I, II

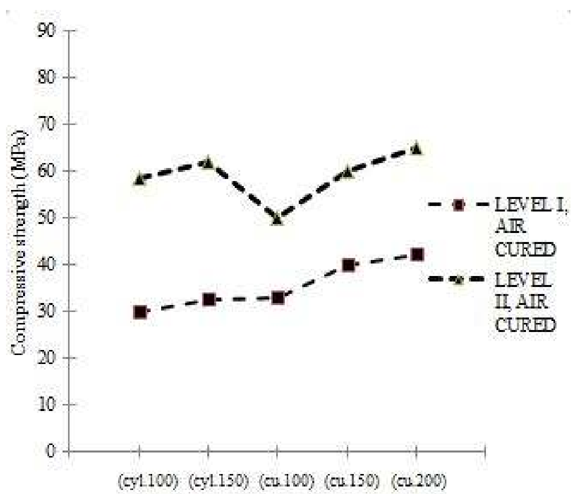

Fig. 2: Compressive strength results for specimens cured in air, tested at 28 days, strength level I, II

To minimize the errors in results of the experiments, all of the processes of casting concrete, vibrating and conditions of curing were controlled precisely according to the relevant standards. In addition, for each testing condition, three samples were casted and the results used in analyses are the average of the obtained results.

After calculating the average values of the results, conversion factors were calculated. Finally, trend lines of conversion factors against cross sectional area of different concrete specimens were plotted.

Table 4: Cross-sectional area of specimens

Specimen shape and size (mm)	Cross-sectional area (mm^2)
Cylinder 100×200	7854
Cylinder 150×300	17671
100^3	10000
150^3	22500
200^3	40000

RESULTS OF EXPERIMENTS

In this part, the results of compressive strength test and the relevant analyses which were carried out on the results have been shown. Compressive strength results of all specimens for water and air curing conditions are given in Fig. 1 and 2, respectively.

To plot the graphs of conversion factors against cross sectional area, firstly the cross sectional area of each of the samples were calculated. The results are shown in Table 4. Regression analyses have also been done, using Data Fit version 9.0, to obtain a relation between conversion factors and cross-sectional area of the samples.

Results of strength level I concrete samples: In Table 5, the results of conversion factors, for samples of strength level I have been revealed.

The graphs of conversion factors against cross sectional area for samples of strength level I at two different curing conditions have been shown in Fig. 3 and 4.

The best fitted curves and their respective equations are shown in Table 6.

According to Table 6, all the specimens follow third order polynomial model order for air cured samples and water cured ones follow third order inverse polynomial model.

Table 5: Conversion factors for strength level I

Water cured	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Cylinder 100×200	1.00	1.18	1.16	1.35	1.38
Cylinder 150×300	0.84	1.00	0.98	1.14	1.17
100^3	0.86	1.02	1.00	1.16	1.19
150^3	0.74	0.88	0.86	1.00	1.02
200^3	0.72	0.86	0.84	0.98	1.00
Air cured	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Cylinder 100×200	1.00	1.09	1.10	1.33	1.41
Cylinder 150×300	0.92	1.00	1.01	1.22	1.30
100^3	0.91	0.99	1.00	1.21	1.28
150^3	0.75	0.82	0.83	1.00	1.06
200^3	0.71	0.77	0.78	0.94	1.00

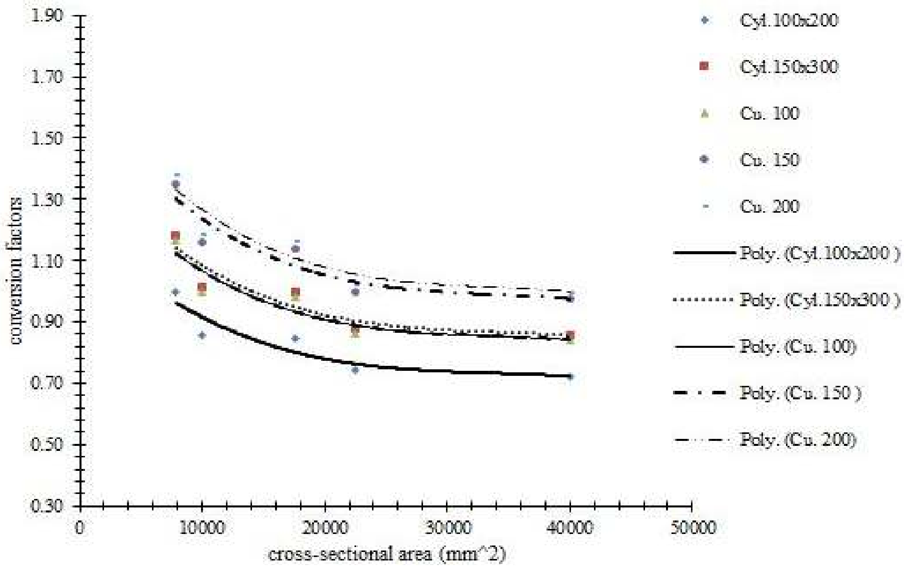

Fig. 3: Conversion factors against cross-sectional area for water cured specimens at strength level I

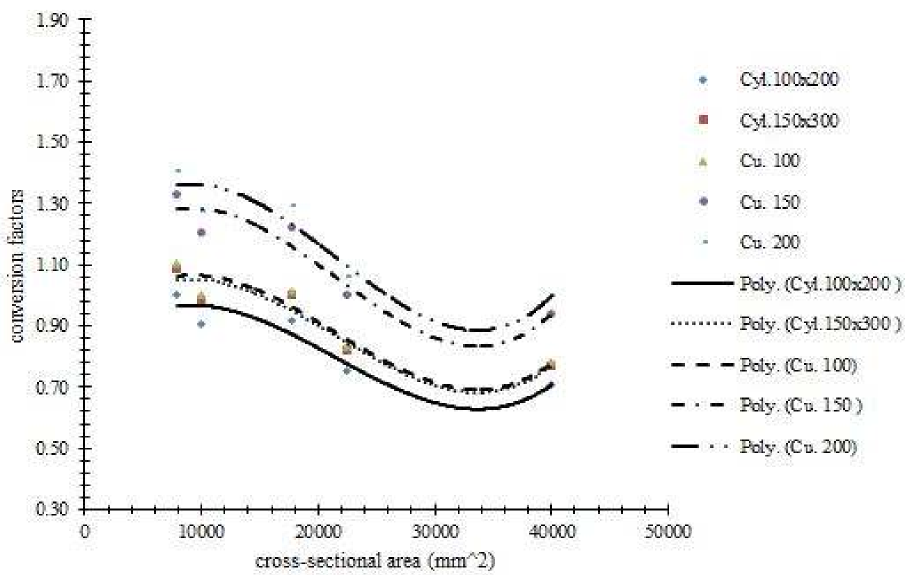

Fig. 4: Conversion factors against cross-sectional area for air cured specimens at strength level I

Table 6: Coefficients of best fitting curves of conversion factors-strength level I

	Water cured				
	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Y = a + b/x + c/x^2 + d/x^3					
a	5.23E-01	6.34E-01	6.14E-01	7.18E-01	7.29E-01
b	1.04E+04	1.19E+04	1.19E+04	1.39E+04	1.42E+04
c	-1.32E+08	-1.51E+08	-1.51E+08	-1.77E+08	-1.79E+08
d	6.23E+11	7.10E+11	7.10E+11	8.43E+11	8.39E+11
R^2	0.94	0.93	0.93	0.93	0.92
	Air cured				
	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Y = ax^3 + bx^2 + cx + d					
a	5.03E-14	5.04E-14	5.04E-14	6.26E-14	6.97E-14
b	-3.25E-09	-3.25E-09	-3.25E-09	-4.03E-09	-4.51E-09
c	4.82E-05	4.69E-05	4.69E-05	5.86E-05	6.70E-05
d	7.61E-01	8.58E-01	8.68E-01	1.04E+00	1.08E+00
R^2	0.88	0.88	0.88	0.88	0.87

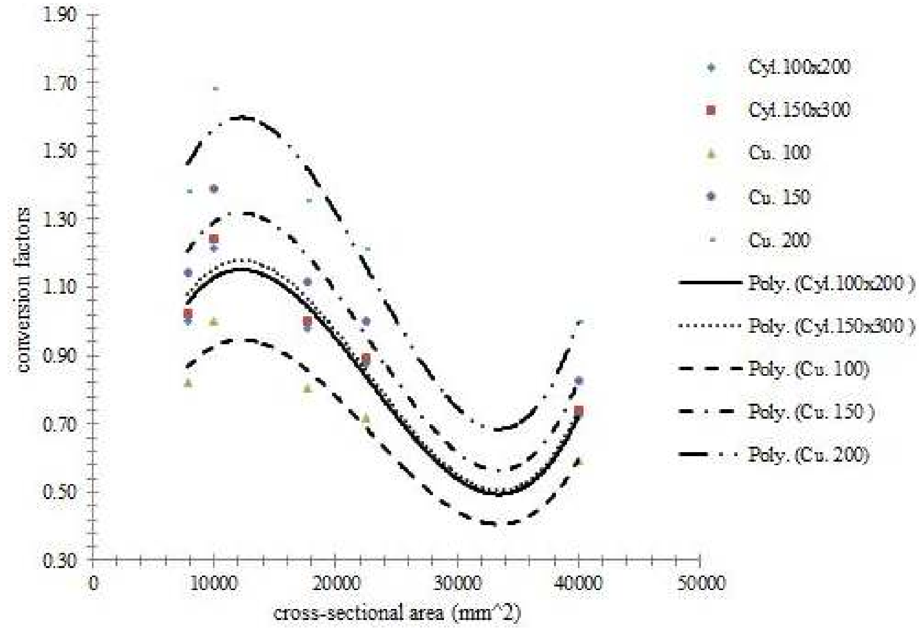

Fig. 5: Conversion factors against cross-sectional area for water cured specimens at strength level II

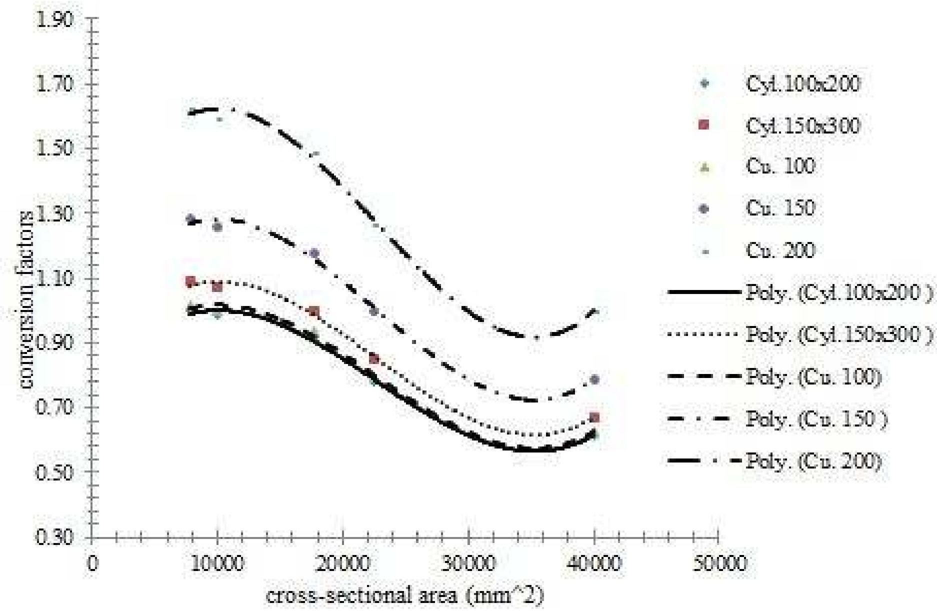

Fig. 6: Conversion factors against cross-sectional area for air cured samples at strength level II

Table 7: Conversion factors for strength level II

Water cured	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Cylinder 100×200	1.00	1.02	0.82	1.14	1.39
Cylinder 150×300	0.98	1.00	0.80	1.12	1.36
100^3	1.22	1.24	1.00	1.39	1.69
150^3	0.87	0.89	0.72	1.00	1.21
200^3	0.72	0.74	0.59	0.82	1.00
Air cured	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Cylinder 100×200	1.00	1.09	1.02	1.28	1.62
Cylinder 150×300	0.92	1.00	0.93	1.18	1.49
100^3	0.98	1.07	1.00	1.26	1.60
150^3	0.78	0.85	0.79	1.00	1.27
200^3	0.62	0.67	0.63	0.79	1.00

Table 8: Coefficients of best fitting curves of conversion factors-strength level II

	Water cured				
	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Y = a + b/x + c/x^2 + d/x^3					
a	6.77E-01	6.97E-01	5.50E-01	7.50E-01	9.31E-01
b	-3.29E+03	-3.29E+03	-2.35E+03	-2.50E+03	-3.98E+03
c	2.39E+08	2.39E+08	1.90E+08	2.54E+08	3.21E+08
d	-1.52E+12	-1.52E+12	-1.22E+12	-1.65E+12	-2.05E+12
R^2	0.99	0.99	0.99	0.99	0.99
	Air cured				
	Cylinder 100×200	Cylinder 150×300	100^3	150^3	200^3
Y = ax^3 + bx^2 + cx + d					
a	5.45E-14	5.82E-14	5.40E-14	7.24E-14	8.90E-14
b	-3.71E-09	-3.96E-09	-3.64E-09	-4.94E-09	-6.07E-09
c	5.83E-05	6.18E-05	5.59E-05	7.84E-05	9.56E-05
d	7.33E-01	8.09E-01	7.69E-01	9.20E-01	1.19E+00
R^2	0.99	0.99	0.99	0.99	0.99

In addition, the value of R^2, for all water cured and air cured samples are above 0.87, which is an acceptable value for the fitted curves.

Results of strength level II concretes: Conversion factors of strength level II concretes are shown in Table 7.

Figure 5 and 6 show the conversion factors of different specimens against the cross sectional area of these specimens.

Regression analyses have been performed on the outcomes of strength level II specimens and results are shown in Table 8.

Samples of strength level II are also following third order inverse polynomial curves and third order polynomial for water and air curing, respectively.

The value of R^2 for all the samples of strength level II, for both curing conditions, is about 0.99, which is absolutely acceptable.

DISCUSSION

In this section, obtained results will be discussed. As the results of analyses of this research, some curves and their corresponding formulas were obtained. It is known that the influence of curing condition on concrete specimens is mainly viewed as its effect on strength gain rate of concrete; in a way that air cured samples have a lower strength gain rate than water cured samples (Plowman *et al*., 1974). According to the analyses, this fact seems to have influence on the conversion factors of cylindrical and cubic samples as well. In other words, changing the curing condition influences the strength gain of cylinders and cubes in different manners and rates, especially if the effect of extra hydration of water cured samples is considered. Consequently, conversion factor analyses can result in different trends.

These achieved formulas and curves indicate the trends of changing the conversion factors by changing the cross sectional area of test samples. For each specimen and each curing condition, there is a specific formula. To convert compressive strength of the specimen to the strength of other specimens (with different cross sectional area), the specimen's compressive strength should be multiplied by the values which were obtained from the curves.

One of the significant outcomes of these analyses can be the fact that there are two different trends for water cured and air cured samples.

Another point that can be observed from the results is that the types of the formulas are regardless of shape and size of the specimens. In other words, all the water cured samples and air cured samples seem to be following third order inverse and third order polynomials, respectively.

Generally, it can be said that any factors which can influence compressive strength of the samples in different ways, can also influence conversion factors as well.

CONCLUSION

As the conclusions of this experimental investigation, the following points could be mentioned:

- In the strength levels for each curing type, fitted curves follow a specific model, which was found to be third order inverse polynomial and third order polynomial for water and air cured samples, respectively.
- According to the test results, behavior of conversion factors against the cross sectional areas of concrete samples alter by changing the curing conditions.
- The reason of different trends of curves for water cured and air cured samples could be the different influences of curing conditions on strength gain of different shaped specimens.
- The mentioned reason may be more notable, if the lateral surfaces of cubic and cylindrical samples are considered.

- It can be said that any factor, which influences the strength level of concrete specimens, in a deviated manner, can have influence on conversion factors of samples.

REFERENCES

ASTM C39/C39M, 2011. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Retrieved from: http://www.rangson.com/ pdf/astm%20concrete/CON020_C39.pdf.

Bažant, Z.P. and J. Planas, 1998. Fracture and Size Effect in Concrete and Other Quasibrittle Materials. CRC Press, Boca Raton and London, Vol. 16.

British Standards Institution, 1983. Testing Concrete. Methods for Determination of Density of Hardened Concrete. BS 1881: Part 114, BSI, London.

British Standards Institution, 1986. Methods for Mixing and Sampling Fresh Concrete in the Laboratory. BS 1881: Part 125:1986, BSI, London.

BS EN 12350-2:2009, 2009. Testing Fresh Concrete. Slump-test. Retrieved from: http:// shop.bsigroup.com/ProductDetail/?pid=000000000030164882.

BS EN 12390-3:2009, 2009. Compressive Strength of Test Specimens. British Standards Institution, London.

Del Viso, J., J. Carmona and G. Ruiz, 2008. Shape and size effects on the compressive strength of high-strength concrete. Cement Concrete Res., 38(3): 386-395.

Elwet, D.J. and G. Fu, 1995. Compression Testing of Concrete: Cylinders vs. Cubes. Transportation Research and Development Bureau, New York State Department of Transportation, Albany.

Gonnerman, H.F., 1925. Effect of size and shape of test specimen on compressive strength of concrete. Proc. ASTM, 25: 237-250.

Malaikah, A.S., 2009. Effect of specimen size and shape on the compressive strength of high strength concrete. Pertanika J. Sci. Technol., 13(1): 87-96.

Neville, A.M., 2002. Properties of Concrete 4/E. John Wiley and Sons, NY.

Plowman, J., W. Smith and T. Sheriff, 1974. Cores, cubes and the specific strength of concrete. Struct. Eng., 52(11): 421-426.

Teychenné, F.E., 1997. Design of Normal Concrete Mixes. Construction Research Communications Ltd., Garston, Watford.

Tokyay, M. and M. Ozdemir, 1997. Specimen shape and size effect on the compressive strength of higher strength concrete. Cement Concrete Res., 27(8): 1281-1288.

Zheng, J.J. and C.Q. Li, 2002. Three-dimensional aggregate density in concrete with wall effect. ACI Mater. J., 99(6): 568-575.