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Size and Shape effects of testing specimens on the compressive Strength of SCC

Dillshad K. H. Amen[1], Mohammad A. Ihsan [1], Sinan A. yaseen [1],

1- Civil Department , College of Engineering, Salahaddin University, Erbil, Kurdistan Region, Iraq.

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***Corresponding Author:**
Dillshad K. H. Amen
Dillshad.bzeni.@su.edu.krd

ABSTRACT

To control the quality of concrete during concreting works, there are various moulds that are used for casting concrete samples according to different standards at different countries. And these differences in the shapes and sizes of concrete samples can cause variations in the results of measured compressive strength. Self-compacting concrete (SCC) have a structural strength and high flowability. This material used in modern concrete technology and extensively in the construction applications of high-rise buildings and long-span concrete structures.This research concentrated on the effect of specimen sizes and shapes on compressive strength of High strength SCC, Specimens were normally cured in the Lab. and tested at age of 28 days. Results were plotted, and indicated that for all testing specimens, there was a significant Influence of size and shape of the specimens on the measured compressive strength. Common sizes that have used for testing compressive strength of concrete were investigated; (100 X100 X100), (150X150X150) mm for cubes and (100 X 200), (150 X300) for cylinders. To determine the best conversion factors, linear relationship added as a trend line between compressive strength measured based on testing cylinders to that measured based on testing cubes, on the other hand relationships was conducted to relate compressive strength tested on cubes and cylinders of different sizes.

1. INTRODUCTION

To control the quality of concrete, there are lots of experiments, each one designated to specify different properties of concrete. Among these experiments, compressive strength is the most important and useful property of concrete. There are many factors that effect on the compressive strength test results, such as environmental condition, loading rate and size and shape of the testing specimens.

The cylinder specimen of concrete (150 diameters and 300 heights) is a standard specimen to test the compressive strength in United States (ASTM C39-2003). While in Britain and Europe, the standard specimen for testing the compressive strength is a cube specimen of concrete by size 150 X 150 X150 mm (BS EN 12390-3,2009, A.M. Neville, J.J. Brooks,2010) The cubes are smaller compared with the cylinder specimen of concrete, and the advantages of cylinders do not depend on the quality and condition of the moulds and that their density can be more readily and accurately established by weighing and measuring(Day, K.W, 2006). The main difference between cylinder and cube specimens is that the cylinder specimens need capping before loading because the top surface of the cylinder finished by the trowel causes no plane for testing. Two methods are used to obtain the plane surface of the cylinder. (i) Capping method: using sulphur mortar, high strength gypsum plaster and cement paste in order to have plain loading surfaces, the thickness of the capping should be 1.5–3 mm and have the same strength of the concrete. (ii) Grinding method: is satisfactory but expensive

Cubes do not require capping as they are turned over on their sides, when being loaded. The height / diameter ratio equal to 2, the compressive strength of cylinder specimens with varying diameter, the larger the diameter, the lower will be the strength (Day, K.W, 2013, A.M. Neville, J.J. Brooks, 2010, Jin.-keum. Kim, Y. Seong-Tae,2002). The cylinders are cast and tested in the same position, but the cubes are cast in one direction and tested at right angles to the position cast and thus no need of capping or grinding. In actual structures in the field, the casting and loading are similar to those of the cylinder and not like the cube (Neville A.M, 2012). The comparison between the compressive strength of cube and compressive strength of cylinder, a factor of 0.8 to the cube strength is often applied for normal strength concrete (E.I. Al-Sahawneh 2013). Fig. 1 shows the influence of the height to diameter ratio on the compressive strength of concrete. If a cylinder with an aspect ratio h/d = 1, then it will be able to resist higher loads than a cylinder with an aspect ratio of 2 (E.I. Al-Sahawneh, 2013, A.M. Neville, J.J. Brooks, 2010, Jin.-keum. Kim, Y. Seong-Tae,2002). The usual fracture of cylinder specimens is columnar and there are other types such as cone, cone and split, cone and shear and shear (ASTM C39-2003). And typical failure modes of cubes are non-explosive, semi-explosive and explosive (BS EN 12390-3,2009). It's found that the restraining effect of the platens of the testing machine extends over the entire height of a cube but leaves unaffected a part of a test cylinder. It is, therefore, to be expected that the strengths of cubes and cylinders made from the same concrete differ from one another (Neville A.M, 2000).

Because European Standard (ENV 206:1990) recognizes the use of both cylinders and cubes it includes a table of equivalence of strengths of the two types of compression specimens up to 50Mpa (measured on cylinders). The values of the cylinder/cube strength ratio are all around (0.8). These tables should be used for purposes of conversion of a measured strength of one type of specimen to the strength of the type. For any one construction project, a single type of compressive strength test specimen should be used.

It is difficult to say which type of specimen, cylinder or cube, is better but even in countries where cubes are the standard specimen, there seems to be a tendency, at least for research purposes, to use cylinders rather than cubes, and this has been recommended by RILEM -an international organization of testing laboratories. Cylinders are believed to give a greater uniformity of results for nominally similar specimens because their failure is less affected by the end restraint of the specimen, their strength is less influenced by the properties of the coarse aggregate used in the mix, and the stress distribution on horizontal planes in a cylinder is more uniform than on a specimen of square cross section (Neville A.M, 2000, Al-Hayderi H.S, 2003, Carino N.J., Guthrie W.F. and Lagergren E.S, 1994).

It may be recalled that cylinders are cast and tested in the same position, whereas in a cube the line of action of the loads at right angles to the axis of the cube as-cast. In a structural compression members, the situation is similar to that existing in a test cylinder, and it has been suggested that, for this reason, tests on cylinders are more realistic, the relation between the directions as-cast and as-tested has, however, been shown not to affect appreciably the strength of cubes made with unsegregated and homogenous concrete (Aitcin P.C. 1998). The size of test specimens for strength testing is prescribed in the relevant standards, but occasionally more than one size is permitted. Moreover, from time to time arguments in favor of use smaller specimens are advanced. These point out their advantages, smaller specimens are easier to handle and are less likely to be accidentally damaged, the moulds are cheaper, a lower capacity testing machine is needed, and less concrete is used, which in the laboratory means less storage and curing space, and also smaller quantity of aggregate to be processed(Aitcin P.C, 1994).

This paper was conducted to study the size and shape effect on the high strength SCC. The shapes used were the cubes and cylinders. The size of cubes were 150 X150 X150 mm and 100 X100X100m against the size of cylinders which were 150 X 300 mm and 100 X 200 mm. These sizes were chosen because it represented the sizes that are most commonly used locally and universally in concrete construction.

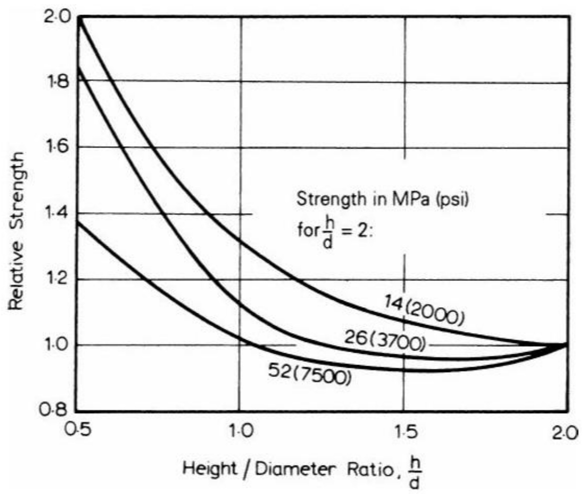


Figure 1. Influence of the height/diameter ratio on the apparent strength of a cylinder for Different strength level [5].

1.1 Research significance

The use of SCC is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. Three mixes of high strength SCC were considered starting approximately from 60 to greater than 100 MPa . It must be remembered that the same concrete will not give the same compressive strength when tested as cubes and cylinders. The compressive strength measured on cubes is always higher than that obtained on cylinders. The importance of this investigation is to determine the conversion factors for compressive strength tested by specimens having different shapes and size. Specifically in Kurdistan region, different design methods have been followed for the design of concrete structures. This consequently needs more accurate conversion factors among cubes and cylinders to satisfy strength of concrete for the quality control. From the literature it is shown that there are several previous works and standards on this topic. No standard or research works have been done to determine these conversion factors in specific for self-compacting concrete.

2. MATERIALS AND METHODS

2.1. Materials

The following Materials are used for the preparation of self-compacting concrete specimens

Cement: - Ordinary Portland cement of 42.5 grade , manufactured by Mass cement factory-Iraq, and its chemical composition confirmed the requirements of ASTM type I grade having a specific gravity of 3.15.

Silica Fume: Type SikaFume-HR was used to increase the stability and flowability of SCC mixtures with replacement rate approximately 9% by weight of total cementitious material. Size of particles extremely was 0.1 μ and specific gravity of 2.24.

Fine Aggregate: Natural river sand from Erbil city quarries, with 95 % passing sieve of 5 mm was used. Percentage passing conformed the requirements of ASTM C-33 ,with the apparent specific gravity 2.67 and fineness modulus of 2.85.

Coarse Aggregate: Natural river gravel, un-crashed type, with a maximum size of 12.5 mm was used and their gradation in accordance to ASTM C-33. Specific of gravity was (2.71).

Filler: - Limestone Powder obtained by grinding limestone rocks , particles passing sieve 150 µ were used as inert filler to enhance the particle size distribution of Portland cement.

Admixture: A polycarboxylates based polymer superplasticizer type Sika Visco Crete-PC 15 having a specific gravity of 1.09 used in all the mixtures to obtain the required flowability.

Water: - Tap water was used for mixing and curing.

Table-1 Quantities of materials selected for 1 m^3 of SCC mixtures.

Mix. No.	C	A_c	A_f	SF	P	SP %	W_f
SCC-1	384	859	910	3	5	1.33	**157**
SCC-2	437	794	893	4	6	2.13	**164**
SCC-3	**494**	**926**	**741**	**4**	**7**	**2.13**	**143**

2.2. Mix design

The procedure adopted by (ACI committee 237-2007) was followed to select three mixtures of SCC with different powder contents; SCC-I, SCC-2- and SCC-3. Their w/cm ratios were 0.265, 0.345, and 0.375, respectively. Cementitious material contents ranged from 422 kg/m3to 543 kg/m3. Several trial mixes were conducted to obtain the proper mixture proportions. The quantities of materials selected for 1 cubic meter are shown in Table-1.

2.3. Laboratory Tests

The following tests were conducted on fresh SCC mixtures: the slump flow and T50, according to ASTM C 1611, V funnel test, and L-Box test according to BS EN 12350- 2010. Test results indicated that the selected mixtures of SCC had a good filling and passing abilities. Rheological properties of fresh SCC are shown in table-2. SCC specimens were cast without any compaction. Fresh concrete samples moulded into cubes and cylinders with two different sizes which are most commonly used in concrete works. Cubes of size 150 mm and 100 mm and cylinders of size (150 X 300) and (100 X 200) mm were produced. The specimens were de-moulded after one day of casting and immersed in water until testing age was 28 days.

In this research, as concrete specimens were chosen from different sizes and shapes, for executing compressive strength test, different standards were followed. For measurement of

compressive strength of cubes, BS EN 12390-3:2009 was followed. Compressive strength test of cylindrical specimens were carried out according to ASTM C39/C39M-2011. Testing cylinders in compressive strength has an additional stage of capping.

Table-2 rheological properties of SCC mixtures.

Mix No.	Slump Flow (mm)	T_{500} (Sec)	V-Funnel time (Sec)	L-Box ratio H2/H1
SCC-1	645	4.45	9.65	0.88
SCC-2	675	3.12	8.4	0.91
SCC-3	565	5.85	12.32	0.8

3. RESULTS AND DISCUSSION

Totally three different factors were investigated to find out their influence on concrete compressive strength test results. The factors are two different shapes of moulds, two different size of moulds and three different concrete mix proportions. The employed moulds were 2 different cubes (100 and 150 mm) and two different cylinders (100×200 mm and150×300 mm). Twelve specimens of concrete were cast for each case of testing and analyses. Totally 144 concrete specimens with different sizes and shapes were prepared and tested

3.1. Effect of Size

The compressive strength test results for different size cubes and different size cylinders are plotted as shown in figure-3. The best fit linear equations without intercept (started from zero) are added as a trend lines for the current results. Equations that relate compressive strength of concrete cubes of size 150 mm to cubes of size 100 mm are presented in figure 3-a. and equations that relate compressive strength of cylinders of size (150 X 300) mm to cylinders of size (100 X 200) mm are presented in figure 3-b, for three mixture proportions. It can be seen that strength of cubes or cylinders of smaller sizes were higher than compressive strength of bigger sizes of the corresponding shape and for the same mixture proportion. Moreover the conversion factor depended upon the strength grade of concrete, which is represented by type of the mix. The slope of the trended lines represents the average value of the ratio of compressive strength measured on big specimens to that strength measured on small specimens. Therefore the slope is always less than 1. The value of slopes determined from the plots are listed in Table-3

Table-3 correction factors taking the effect of size of specimens

Mixes	**for cubes**	**for cylinders**
	$\frac{f_{cub(150)}}{f_{cub(100)}}$	$\frac{f_{c(150X300)}}{f_{c(100X200)}}$
SCC-1	0.88	0.86
SCC-2	0.91	0.89
SCC-3	0.92	0.91

3.2 Effect of shapes

The compressive strength test results for different shape of moulds cubes and cylinders are plotted as shown in figure-4. The best fit linear equations without intercept (started from zero) are added as a trend lines for the current results. Equations relate compressive strength of concrete measured on cubes to that measured on cylinders for three mixture proportions. It can be seen that strength of cylinders were lower than strength of cubes of the same corresponding size and for the same mixture proportion. Moreover the conversion factor also depended upon the strength grade of concrete, which is represented by type of the mix. The slope of the trended lines represents the average value of the ratio of compressive strength measured on cylindrical specimens to that strength measured on cubes. Therefore the slope is always less than 1 and called as conversion factors, thus to convert from cubes to cylinders , the following values as listed in table-4 were determined to be multiplied by strength on cubes.

Table-4 correction factors taking the effect of shape of specimens

Mixes	for small specimens $\frac{f_{cyl(100\,X\,200)}}{f_{cub(100)}}$	for big specimens $\frac{f_{cyl(150X300)mm}}{f_{cub(150)mm}}$
SCC-1	0.83	0.81
SCC-2	0.89	0.87
SCC-3	0.91	0.90

3.3. Discussion

It has been reported [5] that within the range of sizes of specimens normally used, the effect of size on strength is not large, but it is significant and should not be ignored in work of high accuracy or in research. Analysis of numerous test data applied for normal type concrete has suggested a general relation to determine conversion factor as a function to the shape and size of the specimen in terms of ($\frac{V}{hd} + hd$), where V = volume of specimen, h = its height, and d = its least lateral dimension. Conversion factor is defined as the ratio of strength of concrete cylinder f_c of any size to the strength of cubes f_{cub} of 150 mm size. The relation has been confirmed also for high strength concrete.

$$\varphi = \frac{f_c}{f_{cub(152)}} = 0.56 * \frac{0.697}{\left(\frac{V}{152\,hd} + \frac{h}{d}\right)}$$

To make the comparison between the equation suggested and the analysis of current results, it can be obtained that conversion factor suggested by the equation equal to 0.84 to convert from cylinders of size (100 X200) mm to cube of size 150 mm, and equal to 0.81 to convert from cylinder of size (150X300) mm to cube of size 150 mm.

Analysis of current results proposes the following conversion factors:

1. From cylinder (150X300) to cube of size 150 mm, for SCC and high strength SCC.

when the cylinder strength was 80MPa. It has been reported that there is no simple relation between the strength of the specimens of the two shapes. The ratio of the strength of the cylinder to the cube increase strongly with an increase in strength (4) and is approximately equal to (1) at strengths of more than (100MPa.).

In the current results the average ratio of the compressive strength of the cubes (f_{cube}) in size 150 × 150 × 150 mm to the cubes of size 100 × 100 × 100 mm was 0.90 and the average ratio of the compressive strength of the cylinders (f_{cyl}) in size of 100 × 200 mm to the cylinder of size 150 × 300 mm determined was 0.88. These results very close to the results obtained by Hamad , who studied the effects of size and shape of specimens on the compressive strength of high performance lightweight foamed concrete ,their ratios determined and averaged were 0.909 for cubes and 0.87 for cylindrical specimens.

50 Mpa. The cylinder/cube strength ratio rises progressively, and was reaching (0.89).

$\varphi 3$ = 0.90 for strength grade-3 or SCC-3

From cylinder (100X200) to cube of size 150 mm, for SCC and high strength SCC. $\varphi 1$= 0.95 for strength grade-1 or SCC-1

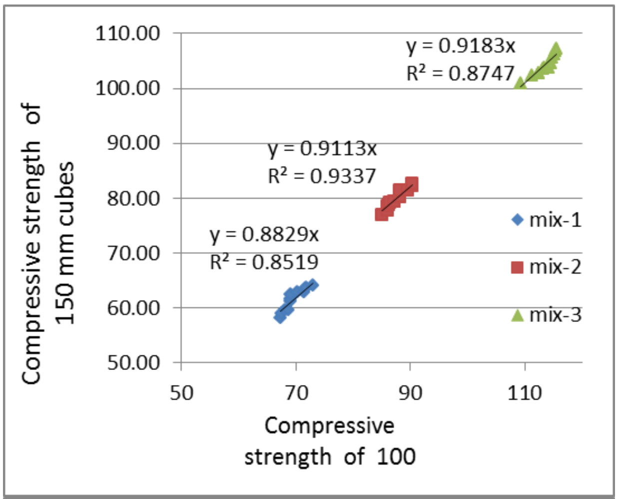
$\varphi 2$ = 0.98 for strength grade-2 or SCC-2

$\varphi 1$= 0.81 for strength of grade-1 or SCC-1

$\varphi 2$ = 0.87 for strength grade-2 or SCC-2

$\varphi 2$ = 0.99 for strength grade-2 or SCC-2

The (CEB-FIP Design Code)[15] gives a similar table of equivalence strength, but above



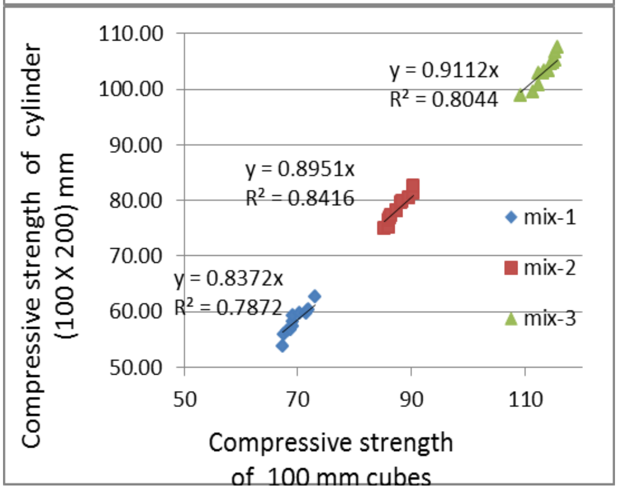
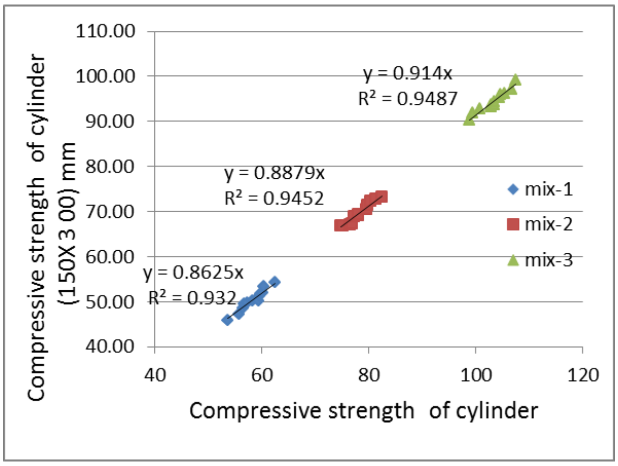


Figure-2 Relation between the compressive strength of SCC for different shapes and sizes of testing specimens; (A) tested by 150 mm cubes versus by 100 mm cubes; (B) tested by cylinders (100 X 200) mm versus to that tested by 100 mm cubes.



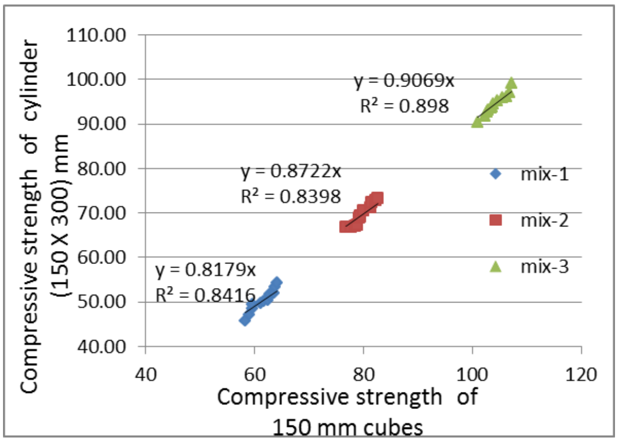


Figure-3 Relation between the compressive strength of SCC for different shapes and sizes of testing specimens; (A) tested by 150 X 300 mm cylinders versus to the strength tested by 100X 200 mm cylinders; (B) tested by cylinders (150 X 300) mm versus to that tested by 150 mm cube.

4. CONCLUSIONS

Based on the results of this study the following conclusions can be drawn.

1. On average the ratio of compressive strength of Self compacted concrete of 150 X 300 mm cylinders to 150 mm cubes was 0.86
2. On average the ratio of compressive strength of self-compacted concrete of 100 X 200 mm cylinders to 150 mm cubes was 0.97
3. On average the ratio of compressive strength of self-compacted concrete of 100 mm to 150 mm cubes was 1.10
4. On average the ratio of compressive strength of self-compacted concrete of 100 X 200 mm to 150 X300 mm cylinders was 1.13
5. The obtained results indicated that increasing strength of concret
6. increased strength ratios of cylinders to cubes regardless of size and increased strength ratios of big specimens to that of small specimens regardless of shape of specimens.

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