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Comparative Analysis of Using Small Cylindrical Specimens for Compressive Strength of Portland Cement Concrete

تحليل مقارن لإستخدام العينات الإسطوانية الصغيرة في فحص القوة المحوري للباطون البورتلندي

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Abstract

Cast compressive strength tests performed on Portland cement concrete varies from one standard to another and from one country to another. In many situations, it may be necessary to compare compressive strength values tested using different specimen sizes specially in areas were no specific specimen size requirement is adapted. It is considered that the restraining effect of the platens of the testing machines extends over the entire height of the cube but leaves a part of a test cylinder unaffected. For that reason, many codes prefer to use cylinder of 300 ×150 mm rather than cubes, but this leaves the problem of preparation and handling of relatively large sample (300×150 mm), which creates a difficulty during construction. The proposed cylindrical specimen of 150x75 mm considered in this research will enable a practical and easy handling, at the same time it keeps the effect of machine plates at minimum. For the purpose of this research, specimens were prepared and tested having 100 mm and 150 mm for cubes, and 150x75 mm and 300x150 mm for cylinders. Ten mixes were used in preparation of specimen above having variable water-Cement ratio varying from 0.30 to 0.83. A compressive strength results shows that a relationship exists between the different specimens sizes especially the proposed 150x75 mm cylinder and the standard 300x150 mm cylinder. Based on the outcome of this research it is recommended to use the proposed 150x75 mm cylinder specimen and the correlation developed between the proposed specimen size and the standard cylindrical specimen.

Keywords: compressive strength, cylindrical specimen, Portland Cement concrete, comparative analysis, age factor.

ملخص

المواصفات المتبعة في الفحص المحوري للباطون البورتلندي تختلف من دولة لأخرى في إجراءات الفحوص خاصة بما يتعلق بشكل وحجم العينة. في معظم الأحيان تكون هناك حاجة لمقارنة النتائج من هذه العينات المختلفة خاصة في الأماكن التي لا تتبع مواصفة محددة. من الحقائق المسلم بها في مجال فحص عينات

الباطون أن تأثير الربط للعينة الناتج من صفائح الحديد المستخدمة في تثبيت وفحص العينة تؤثر على كامل ارتفاع العينة المكعبة وليس كذلك بالنسبة للعينة الأسطوانية، لهذا السبب يفضل كثير من المواصفات استخدام العينة الأسطوانية ذات الأبعاد ٣٠٠ × ١٥٠مم ولكنها تواجه مشكلة تحضير ونقل عينة ذات حجم كبير نسبياً خلال فترة البناء. من هذا المنطلق تم اقتراح العينة ذات الحجم ١٥٠ × ٧٥مم والتي تمكن استخدام عينة صغيرة نسبياً والتي تمكنها من أن تخفف من ظاهرة الربط أعلاه وأن تكون عملية النقل أسهل وكلفتة أقل أثناء عملية البناء. ولفحص جدوى استخدام هذه العينة فقد تم تحضير وفحص عينات من أحجام مختلفة من بينها المكعبة (١٠٠ و١٥٠مم) وكذلك الأسطوانية (٣٠٠ × ١٥٠مم و ١٥٠ × ٧٥مم). أيضاً فقد تم تحضير عدة خلطات بنسب ماء للأسمنت تراوحت بين ٠.٣ و٠.٨٣. النتائج الخاصة بالفحص للعينات المستخدمة خاصة بما يتعلق بالعينة الأسطوانية المقترحة (١٥٠ × ٧٥مم) والعينة الأسطوانية ٣٠٠ × ١٥٠مم. بناءً على نتائج هذا البحث فقد تمت التوصية باستخدام العينة الأسطوانية المقترحة ١٥٠ × ٧٥مم وكذلك العلاقة التي تم استنتاجها بين العينة الأسطوانية التقليدية والعينة الأسطوانية المقترحة.

Introduction

Compressive strength of Portland Cement concrete is considered as the fundamental property in the design and construction of civil engineering structures. In general, compressive strength tests are performed for quality control purposes using two basic types of specimen shapes, cubes and cylinders. Each of those shapes is used in several sizes mainly 150x150 mm, 120x120 mm and 100x100 mm, for cubes, while cylinders are used in the size of 300 × 150 mm. Concrete compressive strength is in general dependant upon the constituents of the matrix formed of cement and water. But variables such as specimen geometry, specimen preparation, moisture content, temperature, loading rate, type of testing machine and loading fixture (fixture with machine platens) will all affect the observed mechanical behavior.

It is expected that the strength of cubes and cylinders made from the same concrete differ from one another, because the restraining effect of the platens of the testing machine extends over the entire height of the cube but leaves a part of the test cylinders unaffected. In addition, the strength of different sizes of cubes traditionally used in practice different from one another.

According to B.S 1881: 1970 the strength of cylinder is equal to 4/5 of the strength of cubes, but experiments have shown that there is no unique relation between the strength of the specimens of the two shapes. The ratio of cylinder-strength to cube-strength increases as the strength of concrete strength increases, the same is reported for the ratio of cubes of 100 mm to 150 mm in which the ratio decreases as the compressive strength decreases [(1)]. With regard to the use of cubes and cylinders, some secondary factors affecting strength may influence the strength of the two specimens to a certain degree, for instance, the coarser the aggregate grading the lower the ratio cylinder–strength to cube –strength [(2)]. The reason for this is not clear, but the observation illustrates the fact that the relation between the cube and cylinder strength is not a simple function of strength alone. The moisture condition of the specimen at the time of testing has been found to affect the ratio of strength of the two types of specimen is better. But 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 [(2)]. The standard field molded cylinder size is 150 mm in diameter with a length-to-diameter ratio of two. However, smaller sizes are acceptable under current standards, and there are increasing interests in their use. Smaller specimens require less material to make and are much easier to handle: a standard concrete cylinder weight 13.6 kg, compared to 4 kg for 100x200 mm cylinder and 1.7 kg for 150x75 mm cylinder. The dimension of the concrete member and the coarse aggregate size often determines the size of drilled core. In addition to these factors, the use of concrete having increasingly higher strengths in construction requires that testing machines having higher load capacity; smaller diameter specimens fail at lower ultimate loads. In cases of mass concrete placements, such as dams, the use of very large aggregates requires the use of larger diameter specimens in order to maintain a minimum diameter-to-aggregate ratio of 3 to 1, or wet sieving to remove larger sizes. Although the testing of smaller specimens is more convenient, precision of strength determination should not be sacrificed. Equal precision can be obtained with smaller specimens if the number of specimens tested is increased. Correlation between specimens of diameters other than 150 mm and the standard cylinders can be made [(3)].

This research is aimed towards the exploration of the effect of specimen shape and sizes on the measured compressive strength. More specifically, it aims to study the feasibility of using cylindrical specimen having a size of 150 × 75 mm in comparison with both traditional cylindrical specimen of 300×150 mm, and cubes of 100×100 mm and 150x150 mm. In addition, this research is aimed at establishing a correlation between the proposed cylinder size ,and those specimens of standard cylinder and cubes of 100x100 mm and 150x150 mm. The analysis of the effect of specimen size with respect to different compressive strength values is considered in the range of 200 to 550 kg/cm^2 for maturity of 7 and 28 days.

Literature review

Cylinders are nominally similar specimens as their failure is less affected by the properties of the coarse aggregate used in the mix [(2)], and the stress distribution on horizontal plans in a cylinder is more uniform than on specimen of square cross-section.

It may be recalled that cylinders are cast and tested in the same position, that in cubes the line of action of the load is at right angles to the axis of the cube as cast. In structural compression members the situation is similar to that testing in a test cylinder, and it has been suggested that for this reason tests on cylinders are more realistic.

Ahmed E. Ahmed [(4)] tested the effect of Portland cement concrete core size on the strength of concrete in the existing structures. Cores of different sizes 150 ×200 mm, 100×200, and 75x150 mm were drilled from slabs, columns, and beams. The results showed that the size of core has significant effect on the tested strength of core. The larger the size of core, the higher the compressive strength. In addition, core tests used for the acceptance of the quality of concrete in the structures may be based on the 100×200 mm core or the 75 ×150 mm core. In case of 75x 100 mm cores, concrete quality may be considered satisfactory if the average strength of cores is 50 percent of the 150 mm lab-cured cylinder or 60 percent of the 150 mm field–cured cylinder.

Qingbin Li and Farhad Ansari [(5)] tested very high strength concrete in triaxial compression with very high confining pressures and comparison with available data for different sizes of cylindrical specimens. The experimental data pertain to failure strength and stress-strain curves of high strength concrete (HSC) in triaxial compression with very high confining pressures by 3 ×6 in. (76 ×152 mm) cylinders. The proposed model for predicting failure strength of HSC 3 × 6 inch, cylindrical specimens in triaxial compression is in agreement with the experimental data.

N. J. Carino [(6)] investigated the effect of end preparation, cylinder size (100 versus 150 mm diameter), type of testing machine, and nominal stress rate. Statistical analysis indicated that all the factors had significant effects on the measured compressive strength. On average, the 100 mm cylinder resulted in about 1.3 percent greater strength, over the 150 mm cylinder. Analysis of dispersion indicated that the 100 mm cylinder had higher within test variability, but the differences were not statistically significant.

R. L. Day and M. N. Haque [7] studied the correlation between strength of small and standard concrete cylinders using fly ash concrete (Air entrained concrete). Results indicated that the compressive strength of 75 mm cylinder is statistically identical to that of 150 mm cylinder. Analysis suggested that this one-to-one relationship between strength of 75 and 150 mm cylinder might be valid for concretes up to 50 MPa (510 kg/ cm^2).

Robert L. Day [8] investigated measurement of concrete using different cylinder sizes of 150 mm diameter, and smaller 100m and 75 mm diameter cylinders. Results showed that of the overall strength ranges, the coefficients of variation (CV) for the 100 and 150 mm cylinder are equivalent. While for strength of 75 mm cylinder within strengths in the 20-60 MPa range (204-612 kg /cm^2), the mean CV of 3.0 percent for both 100 and 150 mm cylinders.

K. W. Nasser and J. C. Kenyon [9] investigated the suitability of using 3x 6 inch (7 x 152 mm) cylinders to determine the potential compressive strength of concrete. The conclusion was that 3x6 in (76 × 152 mm) cylinders may be successfully used in concrete compression tests were the maximum size of the aggregate does not exceed 1.0 in (25 mm). No correlation was established within that of the standard 300x150 mm cylinder nor other shapes and sizes.

Pierre-Clavde Aitcin [10] tested the effect of size and curing on cylinder compressive strength of normal and high strength concrete. The curing condition includes air-cured, sealed, and water-cured for the 100, 150, and 200 mm diameter cylinders. The beneficial effects of preventing moisture loss and water curing are directly observed in the test results. The increased apparent strength with decreasing cylinder size is also presented.

K. W. Nasser and A. A. Al-Manaseer [11] compared the compressive strength of 3x6 inch (75x150 mm) cylinder with that of 6 x12 in (150 x300 mm). The conclusion from this study is that 3x6 in (75x150 mm) roded 10 times in two equal layers is satisfactory specimen to determine the potential strength of concrete. No correlations between the two sizes were presented.

M. Imam, L. Vandewalle, and Mortelmans [12] tested the effect of size and shape of the test specimen, as well as the mold material on high strength concrete. The comparative results indicated that for each 50 mm increase in cube size, there is a five-percent drop in compressive strength. It was also found that the concrete strength of 150x300 cylinder was, on average, 94.5 percent of the 150 mm cube strength.

Bartlett F. M. and Macgregor J. G. [13] tested the effect of core strength. Analysis of the 2-in diameter core is 94 percent of the predicted average strength of a 4-in diameter core and 92 percent of that of a 6-in. diameter core. The data also indicated that the effect of the core length to diameter on the compressive strength is more significant for 2-in diameter cores than for 4-in. diameter cores.

Methodology

The effect of sample size, shape and age on the compressive strength of Portland cement concrete was investigated. This is to establish a relationship between size, age and compressive strength for cylindrical specimens of 300× 150 mm, and the proposed 150 ×75 cylindrical specimens as well as cubes of 150 mm and 100 mm. For that purpose, ten mixes were prepared with different compressive strength (different w/c), in which samples of each size mentioned above is prepared. Coarse aggregate used consists of crushed limestone having three group sizes; P1, P2, and P3 with maximum aggregate size of 19, 12.5, and 9.5 respectively. Fine aggregate used consists of two group sizes; aggregate from limestone passing No. 4 sieve and natural sand passing No. 16 sieve. Table 1 describes some properties of coarse and fine aggregates. Ordinary Portland Cement PC 250 was used in concrete mixes having not more than 10% fly ash. Table 2 gives the percentage and proportions of each material used in the mix.

Table (1): Properties of fine and coarse aggregates used in the concrete mix.

Aggregate Type	Property	Size groups and percentages (Size mm, %)		
		P1 (19 mm,15%)	P2 (12.5 mm,18%)	P3 (9.5 mm,15%)
Coarse Aggregate	Bulk specific gravity	2.66	2.62	2.60
	Bulk specific gravity (SSD)	2.82	2.78	2.88
	Apparent specific gravity	2.76	2.77	2.81
	Absorption (%)	1.93	1.62	2.88
	Unit weight (kg/m^3)	1552.6	1516.44	1511.28
	Void content (%)	41.56	41.96	42.0
	Los Angeles test (%loss)	26.8		
		P3 (4.75mm,9%)	**P4 (Sand,43%)**	
Fine Aggregate	Unit weight (kg/m^3)	2.5	1668	
	Bulk specific gravity	2.88	2.64	
	Void content (%)	42.0	36.7	

Table (2): Percentage and proportions of materials used.

Mix Number		Materials				W/C
		Water	Cement	Coarse Aggregate	Fine Aggregate	
M1	%	7.67	25.55	45.82	20.96	0.3
	kg/m^3	178	593	1063.8	486.6	
M2	%	7.75	19.35	46.28	26.61	0.4
	kg/m^3	178	444.8	1063.8	611.7	
M3	%	7.78	17.27	46.43	28.52	0.45
	kg/m^3	178	395.4	1063.8	653.5	
M4	%	7.8	15.58	46.56	30.06	0.5
	kg/m^3	178	355.8	1063.8	686.9	
M5	%	7.81	14.17	46.67	31.35	0.55
	kg/m^3	178	323.5	1063.8	714.3	
M6	%	7.82	13.03	46.75	32.39	0.6
	kg/m^3	178	296.5	1063.8	737	
M7	%	7.8	11.2	46.9	34.1	0.7
	kg/m^3	178	254.2	1063.8	772.9	
M8	%	7.82	14.73	46.61	30.84	0.53
	kg/m^3	178	335.8	1063.8	703.3	
M9	%	7.84	12.05	46.85	33.25	0.65
	kg/m^3	178	273.8	1063.8	755	
M10	%	9.16	11.04	46.21	33.59	0.83
	kg/m^3	211	254.2	1063.8	772.9	

Concrete constituents were prepared using an electric mixer. Samples of cylinders and cubes were cast in molds of 300×150 mm and 150x75 mm for cylinders, and 150 mm and 100 mm for cubes with six samples for each size and shape. Preparation and casting of the cylinders with 300 mm height and 150 mm diameter specimen were carried out in accordance with ASTM C39 while preparation and casting of cubes of 150mm and 100mm were carried out in accordance with ASTM C192. Casting of cylinders of 150×75 mm were carried out in accordance with ASTM C39 with the exception of using two layers of 56 blows for each instead three layers of 56 blows for each due to the limited specimen height.

Samples were cured in a standard curing conditions in accordance with ASTM C192. Samples were tested in compression using a digital compression machine, one set of samples was tested at seven-day curing and the second set of samples was tested at twenty-eight days curing. Several parameters were considered as presented in equations 1-4.

$$\text{Shape Factor } (SAF_1) = \frac{\text{Compressive Strength of } 300\text{x}150 \text{ mm cylinder}}{\text{Compressive strength of } 150 \text{ mm cube}} \text{ …………equation 1}$$

$$\text{Shape Factor } (SAF_2) = \frac{\text{Compressive Strength of } 300\text{x}150 \text{ mm cylinder}}{\text{Compressive strength of } 100 \text{ mm cube}} \text{ …………equation 2}$$

$$\text{Size Factor } (SF_1) = \frac{\text{Compressive Strength of } 300\text{x}150 \text{ mm cylinder}}{\text{Compressive strength of } 150\text{x}75 \text{ mm cylinder}} \text{ …………equation 3}$$

$$\text{Age Factor (AF)} = \frac{\text{Compressive Strength at seven days}}{\text{Compressive strength at twenty eight days}} \text{ …………equation 4}$$

Age factor was taken for each size and shape of the specimens considered.

Analysis of Results

Based on the results obtained in the laboratory, Figure 1 shows the relationship between compressive strength at twenty-eight days versus shape and size factor designated as SAF_1, SAF_2, and SF_1 as defined in equations 1-3. Each curve was indicated by an equation that reflects the relation between the variables as well as the degree of fitting of the curve equation, which is an indication of regression fitting. This relation shows an increase in the shape and size factor as compressive strength increases, this is general for all cases tested. This is explained by the behavior indicated earlier in which the failure plan and angle in cylindrical specimens have separate cones of failure, since the specimen is long enough to allow a clear angle of failure, while for short cylindrical specimens an angle of overlap exists between the cones of failure. As the compressive strength of Portland Cement concrete increases the range of overlap increases, which creates further decrease in the rate of compressive strength in both small cylindrical specimens and cubical specimens. The effect on the 300x150 mm specimens is expressed as minimal effect on the rate compressive strength increase as compressive strength of Portland cement concrete increases.

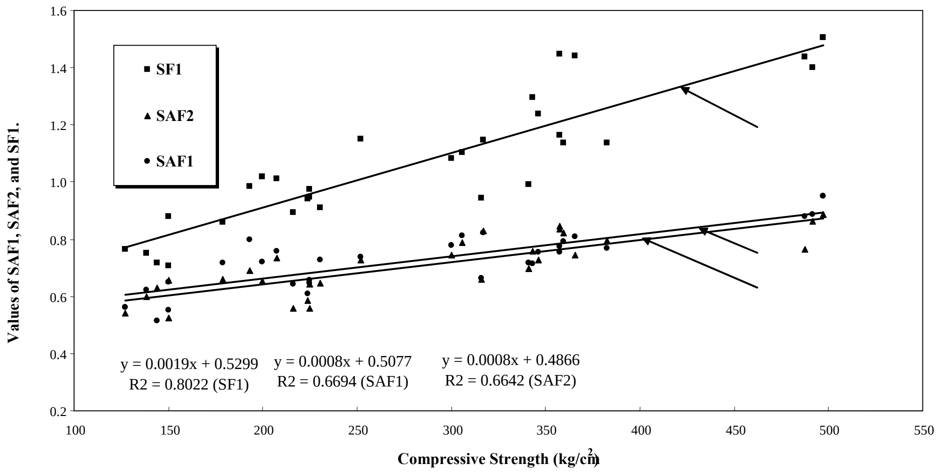

Figure (1): Compressive Strength of Portland Cement Concrete Versus Shape and Size Factors SAF1, SAF2, SAF3, and SF1.

In the analysis of the behavior of the proposed 150x75 mm cylinders relative to the 300×150 mm cylinders, Figure 1 shows that the proposed cylinder have values of compressive strength higher than those of the standard 300×150 cylindrical specimens for low strength concrete (up to 250 kg/cm^2). While compressive strength of 300×150 mm cylinder specimens gets higher and increases drastically for moderate and higher strength PCC. This behavior is considered normal since the shorter specimens provide higher resistance to applied load compared with that of the longer specimen. The average size factor in this case for the range tested (150 to 550 kg/cm^2) is approximately 1.2, this indicates that the compressive strength of the 300x150 mm standard cylinder specimen is approximately 83% of the proposed 150x75 mm specimen. In case different specimens sizes are used or a comparison of compressive strength is needed, it is recommended to use the proper conversion factor for each value of compressive strength of the standard 300×150 mm specimens or the proposed 150× 75 mm specimens.

In the analysis of the cubical specimens of 150 mm and those of the standard cylindrical specimens of 300×150 mm as shown in Figure 1, the compressive strength of the cubical specimens are higher than the standard 300x150 mm cylinder specimens for all ranges of compressive strength tested. The shape factor SAF_1 ranges between 0.6-0.9 indicating lower shape factor for low strength concrete and higher values for higher strength concrete in which it approaches unity for very high strength concrete. The average shape factor for the range tested in this research is approximately 0.75 which indicates that the compressive strength of the standard cylindrical specimens of 300×150 mm is 75% of that of the 150 mm cubical specimens.

In the analysis of the cubical specimens of 100 mm and those of the standard cylindrical specimens of 300×150 mm as shown in Figure 1. The compressive strength of the cubical specimens of 100 mm is higher than those of cylindrical specimens of 300×150 mm for all ranges of compressive strength tested. The shape factor SAF_2 ranges between 0.59-0.88 indicating lower size factor for low strength concrete compared to that of moderate and high strength concrete. The average size factor for the range tested is approximately 0.74 indicating that the compressive strength of standard specimens of 300×150 mm is 74% of that of the 100 mm cubical specimens.

In the analysis of the proposed 150x75 mm cylindrical specimens of Portland Cement concrete and the two cubical specimens of 100 mm and 150 mm relative to the standard 300x150 mm cylinder specimens. It can be seen that the slope of SF_1 is greater than SAF_1 and SAF_2 indicating higher sensitivity to change in compressive strength compared to cubical specimens. This can be explained by the effect of width-length ratio (one for cubical specimen and one half for cylindrical specimen), it is clear for compressive strength of the two cubical specimens in which identical behavior is noticed. It is evident that the use of the proposed cylindrical specimen of 150x75 mm resembles more to that of the standard cylinders of 300x150 mm specimens, also it keeps the effect of machine plates at minimum and have the advantage of that of cubical specimens of practical and easy handling. Equation 5 can be used to convert values of compressive strength of Portland Cement concrete specimens taken into consideration the constraints of this research.

$$SF_1 = 0.0019X + 0.5299 \quad \text{……equation 5}$$

where,

X = Compressive strength of 300x150 mm specimen.

For example; if the SF_1 value for a compressive strength of 350 kg/cm^2 of a 300x150 mm Portland Cement concrete specimen equals 1.195, this means that the compressive strength of the same concrete mix molded in a 150x75 mm will be 418 kg/cm^2.

In the analysis of the relation between the compressive strength of Portland Cement concrete and age factor for cylinders of 300x150 mm and 150x75 mm as shown in Figure 2. Age factor for the 300x150 mm are constant for the range of compressive strength tested at a value of 0.68, this behavior agrees with the conclusions of O. A. Abaza and A. Salameh (14). Age factor curve for the proposed cylinder of 150x75 mm shows a decrease in age factor with increase in compressive strength; age factor in this case ranges between 0.62-0.70 with an average of 0.66. Average age factor for 100 mm and 150 mm cubical specimens are 0.71 and 0.73 respectively. It is evident here too that the proposed 150x75 mm resembles that of the standard 300x150 mm cylinders.

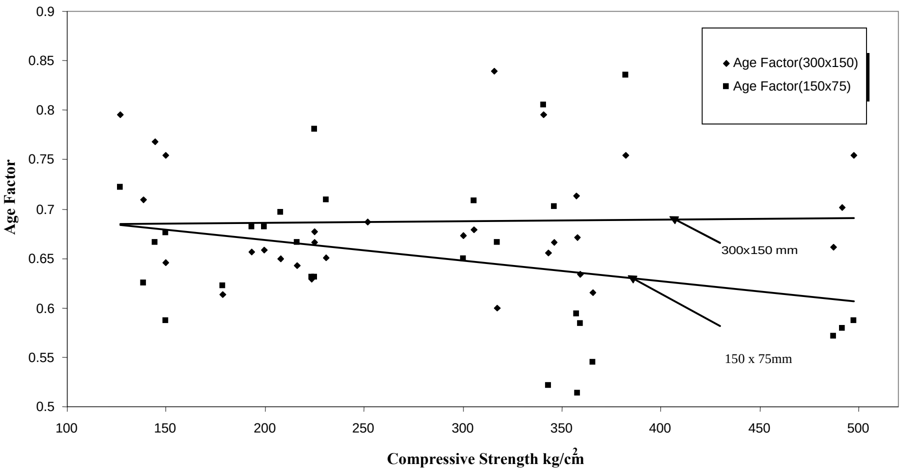

Figure (2): Compressive strength at Twenty Eight days versus Age Factor for Cylinders of 300x150 and 150x75 mm.

In general and within the constraints of this research, the proposed 150x75 mm cylinders are considered satisfactory for the purposes of compressive strength testing of Portland Cement concrete considering the limitation of maximum aggregate size of 25 mm. In addition, it is considered satisfactory to use the correlation developed as a part of this research to be used to convert values of compressive strength for cylindrical specimens of 300x150 mm and 150x75 mm specimens interchangeably.

Summary and Conclusions

Based on the obtained results, the following are considered valid:

1. There exists a relation between the different compressive strength specimens of cylinders and cubes relative to that of the proposed 150x75mm cylinders.
2. There is no fixed constant conversion factor for compressive strength values between the proposed 150x75 mm cylinder and the standard 300x150 mm cylinder and it is mainly dependent on compressive strength range tested.
3. The behavior of both cubical compressive strength specimens is the same relative to the standard 300x150 mm specimens.
4. The behavior of the proposed 150x75 mm compressive strength cylindrical specimens resembles that of the standard 300x150 mm specimens.
5. Strength gain behavior expressed in terms of age factor is relatively the same for both types of cylinders considered in this research.
6. It is considered satisfactory to use the 150x75 mm cylindrical specimens for the purposes of compressive strength testing of Portland Cement concrete within the limitation of maximum aggregate size up to 25 mm.
7. It is considered satisfactory to use the relation developed between the compressive strength of the proposed 150x75 mm and the standard 300x150 mm cylinders interchangeably for the purposes of comparative analysis.

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