Effect of Height to Diameter Ratio on the Behaviour of High Performance Concrete Specimen with Different Shapes under Compression Load

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ABSTRACT

The strength of concrete is considered as the most basic and important material property in the design of reinforced concrete structures. The two standard methods (ASTMC39-03 and BS1881-part 116) for determining the compressive strength of concrete are the testing to failure of cylinder and cube specimens respectively. It has become a problem to use this value as the control specimen sizes and shapes are different from country to another.

This study is made to comparison between propose hexagonal specimens with the standard cylindrical one in behaviour of specimens with different sizes under compression load. The new hexagonal specimen has a cross sectional area 4% greater than the cylindrical cross section. The volume of the hexagonal specimen is approximately equal to the cylindrical ones to give a greater uniformity of results. This proposed shape has height to average diameter ratio (H/D) = 1.95.

The hexagonal mould has the ease of making a control specimen while avoiding the capping process which is necessary in cylinders and reducing the cost and time it takes to prepare. When the hexagonal specimen cast in horizontal plane so no need for end preparation because the top and bottom surface of the specimen who will be in contact with platen of testing machine, are 100 % levelled and orthogonal to the height of the specimen. Results show that the mean ratio of compressive strength for hexagonal to cylindrical specimen is 0.95.The results of testing specimens show that the compressive strength of the specimen obviously increases with decreasing the ratio of H/D. This behaviour is proving that the hexagonal specimen acts like the standard cylindrical in stress distribution.

The using of hexagonal specimen to find the strength of concrete give better factor of safety in structural design that because strength determined from hexagonal specimens will be slightly smaller when compared with results determined from cylindrical and the behaviour of the hexagonal shape is similar to cylindrical one.

تاثير نسبة الارتفاع للقطرباختلاف الشكل للنموذج على سلوك الخرسانه عالية الاداء تحت احمال الانضغاط

الخلاصة

تعتبر مقاومة التحمل للخرسانه من اهم الخواص التي تعتمد في تصميم المنشاءات الخرسانية المسلحة. وهناك عدة طرق قياسية لتحديد مقاومة التحمل والتي تتفق بطريقة الفحص وهي تحميل النموذج حتى حدوث الفشل النهائي ولكنها تختلف في اعتماد شكل وابعاد العينات المستخدمة في الفحص. فبعضها يختبر عينات مكعبة (مثل المواصفة البريطانية 1881-part 116BS) والاخر يفضل اختبار عينات اسطوانية (مثل المواصفة الامريكيةC39-03ASTM).

تهدف هذه الدراسة للمقارنه بين النموذج المقترح ذو الشكل السداسي مع النموذج القياسي ذو الشكل الاسطواني في السلوك عند التعرض لاحمال الانضغاط مع تغير نسبة الارتفاع الى قطر النموذج. تم اختيار ابعاد العينات السداسية المقطع لتكون مقاربة الى درجة كبيرة لحجم ومساحة مقاطع النماذج الاسطوانة القياسية ليسهل مقارنة النتائج وبيان مدى اعتمادها. ان الشكل السداسي للنموذج المقترح يمتلك 1.95 كنسبة معدل القطر لارتفاع النموذج. تمتاز هذه القوالب الجديدة بخاصية سهولة تصنيع العينات والتي ولاتحتاج الى الجهد والوقت المبذولين في تهيئة النهايات.

عند صب النموذج بشكل افقي لن تكون هنالك حاجة الى تهيئة النهايات للفحص وذلك بسبب كون السطح العلوي والسطح السفلي للنموذج واللذين سيكونان بتماس مع صفائح التحميل في جهاز الفحص مستويان بنسبة 100% ومتعامدان مع ارتفاعه. اظهرت نتائج الفحوصات المختبرية ان معدل نسبة مقاومة الانضغاط للنماذج هي 0.95 عند مقارنتها مع النماذج الاسطوانية. ومن الواضح في النتائج ان مقاومة الانضغاط تزداد مع نقصان نسبة الارتفاع للقطر. وهذا السلوك يتشابه مع النماذج الاسطوانية القياسية والذي يثبت كون النموذج السداسي المقترح يعمل بشكل مشابه من ناحية توزيع الاجهادات داخل النموذج مع النموذج القياسي (الاسطواني).

ان استعمال الشكل السداسي في ايجاد مقاومة الخرسانه يعطي المصمم الانشائي مقدارا اكبر من معامل الامان وذلك كون النتائج المستحصلة من فحص النماذج السداسية هي اقل بمقدار قليل من نتائج المستحصلة من فحص النماذج الاسطوانية.

INTRODUCTION

The compressive strength is used as the most important property of concrete, both for its implications for design purposes, and for the structural integrity assessment of any concrete-based structural element. Moreover, it has to be remarked that most of the other mechanical parameters of concrete can be more or less directly related to its compressive strength. As a consequence, the accurate evaluation of this mechanical parameter represents a key issue from the engineering point of view. However, in this respect, it has to be noticed that this mechanical parameter can be affected by a large variability, even though the tested specimens are coming from the same concrete mix **[1]**.

Focusing one's attention on the problem of evaluating the concrete compressive strength according to laboratory tests, it has to be pointed out that several variables can affect the obtained results. Among them, one mentions shape and dimensions of the specimen, *w/c* ratio, age, curing conditions, type of the testing machine, planarity of the surfaces in contact with the plates, loading application rate, as well as specimen slenderness **[1]**.

As a consequence, this study is made to comparison between proposed hexagonal specimens with the standard cylindrical one in behaviour of specimens with effect of size.

The new hexagonal specimen which is proposed has a cross sectional area 4% greater than the cylindrical cross section. The volume of the hexagonal specimen is approximately equal with the cylindrical one to give a greater uniformity of results.

This hexagonal shape has Height to average Diameter ratio(H/D) = 1.95 which according to ASTM C42-03[2] no correction factor is required.

Literature Review

High performance concrete (HPC) is that concrete which meets special performance and uniformity requirements that cannot always be achieved by conventional materials, normal mixing, placing and curing practices[3].

Size effect is the dependence of material properties (not necessarily at failure) on the characteristic dimensions of the structural element. It can be characterized in terms of the nominal stress at failure, the concrete modulus of elasticity, or the strain at maximum stress. It can be understood through a comparison of geometrically similar structures of different sizes**[4]**.

Most investigations into the size effect have been performed for tensile loading, and only few test series have been carried out on compressive strengths. The test series on size effects under compression with concentric loading have been carried out for ordinary and high strength concrete specimens in the size range of 1:4 with side lengths up to 500 mm [5].

The effect of size on concrete compressive strength has been proved through many studies and for different types of specimens with variable dimensions and ratios (as long as geometric similarity is maintained). Studies, such as those performed by Harris et al. [6], Baalbaki et al [7], Lessard et al. [8], Aiticin et al. [9], and Sener[10], examined the variation of concrete compressive strength with age and volume for concrete cylinders of different sizes. The results showed that small specimens exhibited higher compressive strength values than the larger ones.

Neville [11] proved the existence of size effects on compressive strength of concrete cubes of different volumes. Marti [12] reported the existence of size effect in double-punch compression failure of cylinders.

Malaikah[13], made a comparison of the compressive strength between 150 mm cubes, 150 x 300 mm and 100 x 200 mm cylinders. These sizes were chosen because they represent the sizes that are most commonly used locally in the construction industry and research.

Benjamin and Marshall [14]conducted an experimental program to determine whether alternate specimen types can be reliably used to determine the compressive strength of an Ultra-High-Performance Fibre-Reinforced Concrete (UHPFRC) in the strength range from 80 to 200MPa (11.6 to 29ksi).

That was because accurate determination of the compressive strength of very high strength concrete is currently a difficult proposition due to large testing machine capacity requirements and the need for cylinder end preparation.

Nasser and Kenyon [15]investigated the suitability of using 76*152 mm cylinders to determine the compressive strength of concrete. The 76*152 mm cylinder has the same length-to-diameter ratio of 2.0 as the 152*305 mmcylinder but weighs approximately 1.7 kg ascompared to about 13.4 kg for the 152*305 mm cylinder, which is 8 times less.

Taghaddos et al.[16]described the results of a comparative concrete testing program conducted by 15 laboratories in Edmonton, AB, Canada, over the past 10 years. They attempted to develop within-laboratory (repeatability) and between-laboratory (reproducibility) precision indexes for small and conventional concrete specimens by analysing more than 2700 compressive strength concrete testing data within a compressive strength range of 17 to 57MPa .

From the work of RILEM TC 148SSC [17], it was found that the specimen strength increases with decreasing slenderness when using rigid steel loading platens. In contrast, when friction-reducing measures are taken, the specimen strength becomes independent of the slenderness ratio. This specimen-machine interaction is illustrated in **Figure (1)**.

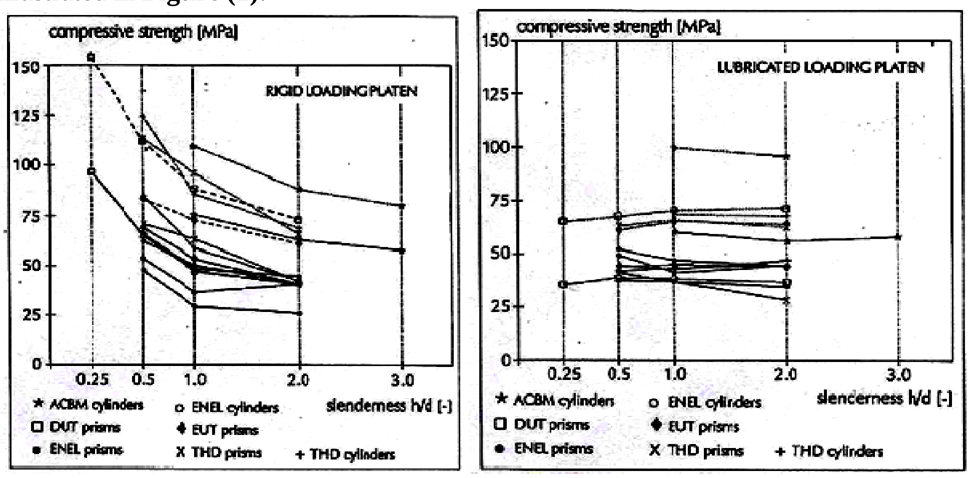


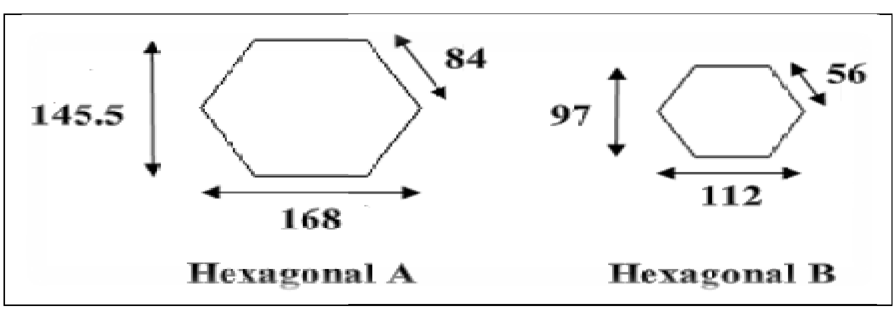
Figure (1): Compressive strength using rigid and lubricated loading platen, respectively [18]

Krishna et al.[19]investigated the effect of shape and size of plain and glass fibre reinforced concrete (GFRC). They used different sizes of specimens having circular and square base of 100,150 mm. with slenderness ratio (H/D) ranging from 1 to 5. The results were obtained from 192 specimens cast and tested for compressive strength between 14 and 35 MPa.

Experimental Work

- **Casting Moulds Preparation**

The new test specimens used in this investigation were cast in steel moulds to obtain a specimen having hexagonal cross section of two sizes (A and B) as shown in Figure (2) and a length of 300, 200 mm (12, 8 in) respectively. Each one of these steel moulds consists of five parts joined together by 12 bolts φ10 mm as shown in Plate 1.



*All dimensions are in millimetre

Figure (2): Dimensions of the hexagonal specimens

Plate 1:Mould assembly of the hexagonal specimens

As shown in Figure (3), there are two dimensions nominated di ,d1: is the distance between two parallel faces and d2: is the distance between two parallel faced corners in the specimen.

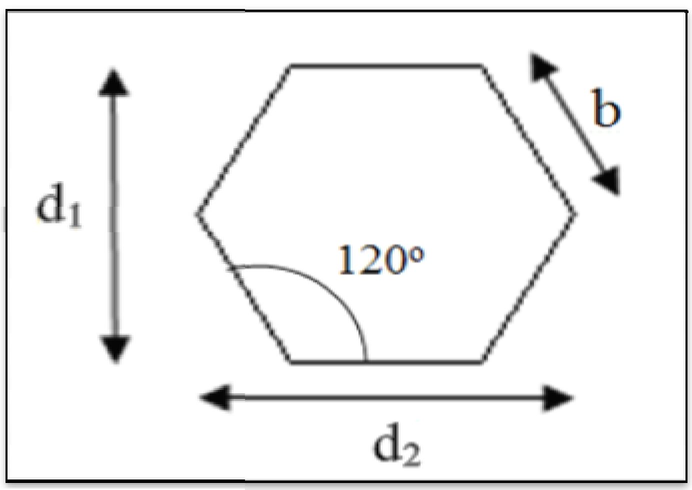


Figure (3): Details of the hexagonal specimens

The area of the hexagonal cross section of the specimen could be measured by:

Area of hexagonal = **1.5 * 30.5 * b2** …..(1)

Where b = is the least lateral dimension.

The hexagonal cross sectional area has six corners of 120o. It was intended to make the hexagonal cross sectional area of both size (A, and B) to be as equal as to the cylindrical shape specimens having diameter of 150 mm and 100mm respectively as shown in Table (1).

Table (1): Area of the hexagonal specimen convergence to cylindrical one

Type of mould	Size (mm)			Area (mm2)	A hex. /A cyl.
	d1	d2	h		
Hexagonal A	145.5	168	300	18332.026	1.03738
Cylinder A	150	-	300	17671.459	
Hexagonal B	97	112	200	8147.567	1.03738
Cylinder B	100	-	200	7853.982	

Mix Proportioning

Mix design was performed in accordance with a method called (proposed method) as cited by Aïtcin [20]. It is very simple method and follows the same approach as ACI 211–1 standard practice for selecting proportions for normal, heavy weight, and mass concrete. It is a combination of empirical results and mathematical calculations based on the absolute volume method. The dominant mix for all work is 1:1.3:2.13:0.1 (cement: sand: coarse aggregate: silica fume) by weight of cement. The dosage of super plasticiser was 1.2% every 100 kg of cementations material with liquid / binder ratio 0.27 and the targeted maximum compressive strength for capped cylinder 100*200 was 77 MPa at 28 days of curing.

Height to Diameter ratio (H/D) Test

Cylindrical and hexagonal specimens with (H/D) ratios of 0.5, 1, 1.5, and 2 were tested in compression. The goal of the testing was to compare the effect of the variable H/D on the strength. In order to make that various specimens, Polymers filler were used at different thickness *50* and *75* mm (2 and 3 in) to shorten the specimens, as required. Plates 2and *3*show the polymers filler and the specimens with various heights.

Plate 2: Polymer filler in the hexagonal mould to produce specimens with H/D= 0.5, 1, and1.5

Plate 3: Hexagonal and cylindrical specimens of various sizes

Results and Discussion

The compressive strength values for different H/D ratio are summarized in Table 2at 28 days of curing. The symbols used in this part are presented in Table (1).

Table (2):Compressive strength having different H/D ratio at 28 days of curing

Type of specimen	H / D	Measured strength (MPa)			Mean. Strength (MPa)
Cylinder A	2.00	74.23	73.49	73.83	73.85
	1.50	77.96	77.68	78.13	77.92
	1.00	85.49	84.64	84.81	84.98
	0.50	107.12	107.23	107.01	107.12
Cylinder B	2.00	77.71	76.18	77.45	77.11
	1.50	82.93	82.17	81.78	82.29
	1.00	89.68	88.92	89.30	89.30
	0.50	120.38	119.49	120.76	120.21
Hexagonal A	1.95	69.50	69.17	69.33	69.33
	1.46	73.97	74.13	74.46	74.19
	0.97	79.64	80.02	79.75	79.81
	0.49	103.59	104.19	104.52	104.10
Hexagonal B	1.94	72.78	73.40	72.91	73.03
	1.46	80.02	79.16	79.41	79.53
	0.97	83.83	83.58	83.22	83.54
	0.49	113.53	114.76	113.29	113.86

Results demonstrate that the compressive strength continuously increased with decreasing height as shown in Figure (4). The higher compressive strength for specimens which have $H/D < 2$ are attributed to the overlapped restrained zone in the specimen tested under uniaxial compression on the other hand, when the $H/D = 2$ the specimen has an unrestrained zone away from the ends which causes an increase in lateral strain leading to a drop in ultimate strength.

Figures (5) is showing the influence of the H/D ratio on the apparent compressive strength for cylindrical and hexagonal specimens relative to compressive strength of H/D ratio of 2.

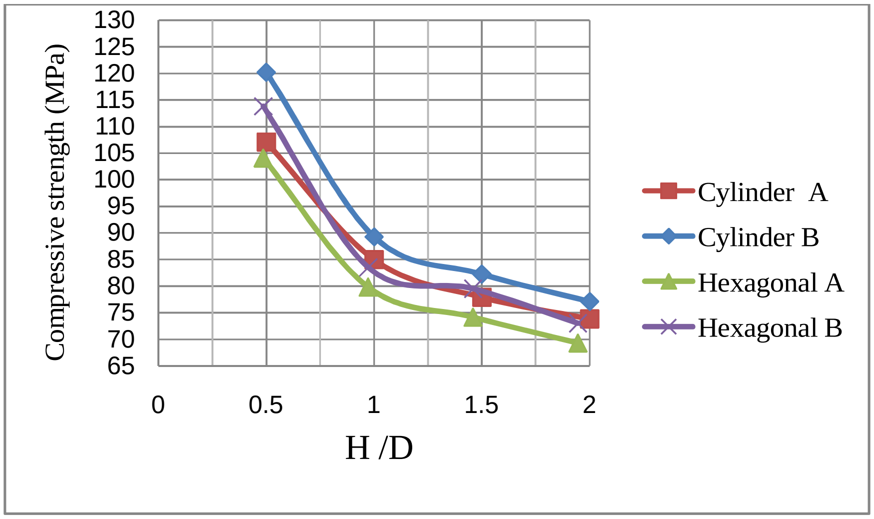


Figure (4):Compressive strength with different H/D ratio

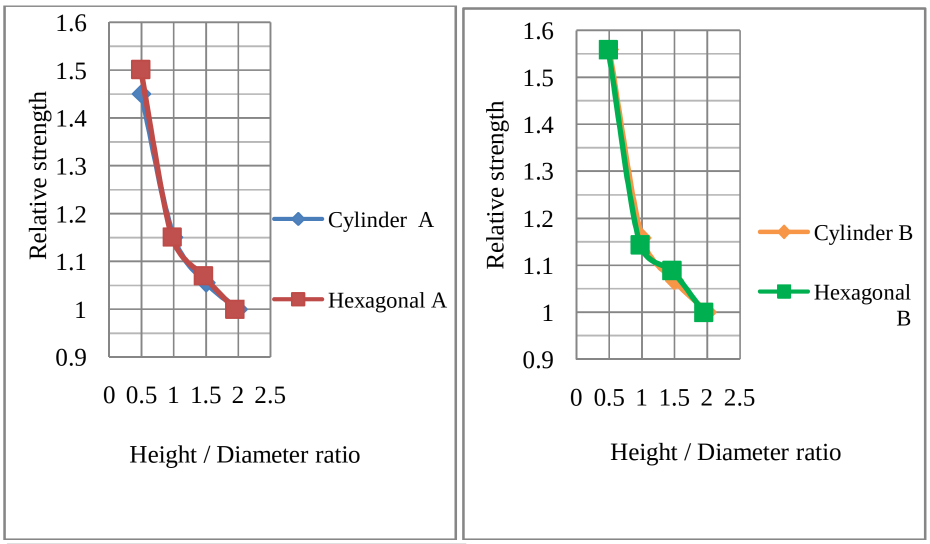


Figure (5): Influence of the height/diameter ratio on the apparent compressive strength for cylindrical and hexagonal specimens

Plate 4:Fracture failure for a) cylindrical specimens and b) hexagonal specimens with different H/D ratios; where H/D being 2, 1.5, 1, and 0.5.

Failure patterns of hexagonal and cylinder specimens conforms well to Type A and C fracture according to ASTM-C39-03. These are well shaped cones which are formed on one end or both ends of the specimens.

Conclusions and Recommendations

1.The hexagonal specimen has the advantages of easily making and preparation the control specimen while avoiding the capping process and reducing the cost and time it takes to prepare.

2.The ratio of compressive strength for hexagonal to cylindrical specimen, 0.94 for size A and 0.95 for size B at 28 days.

3.The differences in compressive strength between cylindrical and hexagonal specimen may bedue to many factors including testing at 90o from the casting direction, influence of necessary end preparation for the cylinder per ASTM C 617-03, and the effect of specimen shape on crack formation.

4.The study of the size effect in uniaxial compression for hexagonal specimen shows that the compressive strength of the specimen obviously increases with decreasing the ratio of H/D. This behaviour is similar to the cylindrical one and it is proving that the hexagonal specimen acts like the standard cylindrical in stress distribution.

5.The failure pattern of hexagonal conforms well to Type A and C fracture according to ASTM C39-03 .These are well shaped cones were formed on one end or both e n d s of the specimen.

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