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EFFECT OF SPECIMEN SIZE AND SHAPE ON COMPRESSIVE STRENGTH OF SELF-COMPACTING CONCRETE

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ABSTRACT: This study aims to show the effect of specimen size and shape on compressive strength of self-compacting concrete (SCC). The work is divided into two parts, the first was to designed Normal Concrete (NC), High Strength Concrete (HSC) and Self Compacting Concrete (SCC) of strength between (25-70) MPa. from locally available materials. The values percent of cylinder to cube strength were between (0.86-0.9), (0.94-0.96), (0.96-0.99) of NC, HSC and SCC respectively.

The second is to investigate the effect of specimen size on compressive strength, the values of correction factor of cube specimens (150*150*150)mm and (100*100*100)mm is (0.89-1.29), (0.98-1.26) and (0.98-1.22) of NC,HSC and SCC respectively. The values of correction factor of cylinder specimens of (150*300) mm and (100*200) mm is (0.88-1.08), (0.93-1.07) and (0.95-1.04) of NC, HSC and SCC respectively.

Keywords: Self-compacting concrete, Specimen, Correction factor.

INTRODUCTION

The standard specimen for testing the compressive strength of concrete is a (150*300) mm cylinder. While maintaining the height/diameter ratio equal to (2), if a concrete mixture is tested in compression with cylindrical specimen of varying diameter, when the diameter is increased beyond 18in (457.2mm), a much smaller reduction in strength is observed. Such variation in strength with variation of the specimen size is to be expected due to the increasing degree statistical homogeneity in large specimens. In general, the greater the specimen geometry can affect the laboratory test data on concrete strength. The strength of cylinder specimens with a slenderness ratio (L/D) above (2) or a diameter above 12in (304.8mm) are not much influenced by the size effects (1).

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 [2].

According to the expressions converting the strength of cores into the strength of equivalent cubes in (BS 1881: Part 120) [3], the strength of cylinder is equal to (0.8) of the strength of cube but, in reality, 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 nearly (1) at strengths of more than (100MPa.). Some other factors, for example, moisture condition of the specimen at the time of testing have also been found to affect the ratio of strengths of the two types of specimens.

Because European Standard (ENV 206:1990) [5] 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). The (CEB-FIP Design Code) [6] gives a similar table of equivalence but, above 50 Mpa. the cylinder/cube strength ratio rises progressively, reaching (0.89) when the cylinder strength is 80MPa. Neither of these tables should be used for purposes of conversion of a measured strength of one type of specimen to the strength of the another 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 (Reunion International des Laboratoires d Essais et de Recherches sur les Materiaux et les Constructions)-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 [2] [7] [8].

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 [4].

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 [9].

It is not intention here to renew the controversy on the pros and cons of testing concrete either as cubes or as cylinders. When testing high-performance concrete in the form of cubs, it seems that the parallelism of the two faces on which the two platens of the testing machine apply the load is critical. A lack of parallelism can result in an increase number of shear failures, which tend to lower the compressive strength value [10]. So to restore the parallelism of the two of the cube, it is necessary either to use a capping compound or to grind them, the use of cube specimens does not solve the end preparation problem, In addition, those who work with both cubes and cylinders know well the inconvenience of using cube mould, they are heavy take a long time to clean, need careful maintenance and are costly when compared with the present reusable plastic cylindrical moulds [11].

It must also 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 issue is to know exactly what a (100Mpa.) compressive strength value obtained on a (150*300) mm specimen. Such a correlation is well documented for usual concrete [12] [13] [14].

For example, Carrasquillo [15] found that (150*300) mm specimens gave around (7%) higher compressive strength than (100*200) mm specimens for 48 to 80MPa. concretes. Moreno [14] found on the contrary, a (1%) increase in the compressive strength when it was measured on (100*200) mm specimens rather than that on (150*300) mm specimens. Cook [16] indicated that for a 70Mpa. mix design, (100*200)mm specimens had a compressive strength approximately (5%) higher than (150*300)mm specimens.

The use of SCC is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. Two basic categories of concrete are considered a housing category (normal concrete) and civil engineering category (high strength) with characteristic cube strengths of 35Mpa. and 75Mpa. respectively [17].

EXPERIMENTAL WORK

Involves the following statements:-

1- Materials used :-

- Cement: - Ordinary Portland cement (Kufa) of 42.5 grades available in local market is used. And Tables (1) and (2) show the physical and chemical properties of cement according to Iraqi Standard Specifications No.5/1984 [18].
- Fine Aggregate :- Karbala quarries sand was used as fine aggregate its specific gravity of (2.63) and fineness modulus of (2.778) and the ratio of sulphate content was (0.11)% .The grading of the sand is compatible with zone (2) of fine aggregate grading according to the(IQS No.45/1984) [19] and Table (3) illustrates its gradiation .
- Coarse Aggregate: - Al-Nibaee crushed aggregate is used with a maximum aggregate size (20mm). Its specific of gravity was (2.65) and sulphate content was (0.02) %. Table (4) shows its gradiation which conforms to (IQS No.45/1984) [19].
- Filler: - Additions are commonly used in SCC due to the need for substantial contents of fine particles .All additions conforming to the EN Standards are suitable. Limestone dust filler is used. The filler is measured according to (BS 7979) and Table (5) shows the chemical properties of limestone powder.
- Admixture:-Superplasticizer (SP 905) is a super plasticing concrete admixture based on synthetic polymer. It has advantage of producing high early strength, higher workability concrete and Table (6) shows technical properties of superplasticizer According to (ASTM C494 Type G) [20].
- Water: - Tab water was used for mixing and curing.

2-Mix Design :- Four mixes were designed, two mixes Normal and High Strength Concrete (NC and HSC) according to (ACI code 318-2005) [21] and two types of SCC called housing (Normal (HSCC)) and civil engineering (High Strength(CSCC)) with strength between (35-75) MPa. respectively. Admixture and concrete addition such as limestone powder contribute to both increases in workability and segregation resistance. The proportion of the SCC mixes is shown in Table (7).

3- Mixing of Concrete: - Four mixes were prepared, the first normal concreter mix (NC), the second high strength concrete (HSC), third and fourth mixes are housing and civil engineering self-compacting concrete (HSCC and CSCC).

The concrete was mixed according to Swedish Cement and Concrete Research Institute [22]. Table (8) shows the contents of the four mixes.

4-Laboratory Tests:-

- Workability: - The fresh concrete of (NC and HSC) was assessed by the slump test according to (BS 1881 Part 102:1983) [23]. The workability of the mixes (NC , HSC) was designed according to (BS 5328 Part 2, 1992) [24] to be within (90-110) mm slump while for the mixes of SCC of fresh concrete is related entirely to the mobility of the concrete. The SCC is required to change shape under its own weight and mould itself to the formwork in place. Measurement of the fresh concrete can be achieved by slumpflow test utilizes a British Standard slump cone which is filled in one layer without compaction. The mean spread value in millimeters recorded. Typical values lie between 650 and 800 mm. A further evaluation can be carried out at the same time. This is the t_{50cm} value, which measures the time taken to reach a spread of 500 mm. L-Box test is used to measure the fillingability and passing of SCC, as the acceptable value of blocking ratio (H_2/H_1) is normally (0.8-1), and V-funnel test is used to determine the segregation of concrete, the time of flow through the V-funnel for SCC mixes is (6 and 12) seconds.
- Compressive Strength :- In order to evaluate usual concrete compressive strength (150*150*150) mm, (100*100*100) mm cubes and (150*300) mm, (100*200) mm cylinder specimens are used . After (28) days of standard curing in saturated water at (23ºC + 3 ºC) , specimens is then placed between the two platens of a testing machine and the load is applied at a defined rate until failure

RESULTS AND DISCUSSION

It is clear from the results that the (NC) and (HSC) are less slump than (HSCC) and (CSCC) as shown Table (9), the values of slump of (NC) and (HSC) are between (90-105)mm for all mixes, while the values of slump flow of (HSCC) and (CSCC) are between (695-705)mm, t_{50cm} lies between (2-3) seconds, the values of V-funnel test lie between (7-9) seconds, and the values of L-box test lie between (0.93-0.95) for all mixes of SCC. This agreement with (Johan and Ban) [25].

The concrete is considered as Bingham fluid and its behavior is a low shear yield stress and limited plastic viscosity value, this can be achieved by the use of superplasticizer and incorporating a high volume of fines in the mix [25].

It can be observed from the results of compressive strength shown in Table (10) for age 28 days, the strength of cylinder to cube ratio, that the effect of specimen shape in an increase in the cubes strength than cylinder strength, with decrease of strength cylinder to cube ratio of SCC. The main factor due to the friction force generated between the surface of specimen with surface loading.

When normal concrete is vibrated, water will tend to migrate to the surface of coarse particles causing porous and weak interfacial zones to develop. If SCC has been well designed and produced it will be homogeneous, mobile and resistant to segregation. This will encourage minimal interfacial zones to develop between the coarse aggregate and the mortar phase. Thus the microstructure of SCC can be expected to be improved promoting strength [(1)].

On the other hand, the results of the compressive strength of different size of cubes and cylinders of the mixes investigated are summarized in Table (11), (12), (13) and (14), and Figure (1), (2), (3) and (4), for age 28 days, the compressive strength correlation to standard cube and cylinder has indicated that the reduction in compressive strength with increase in column height is less pronounced, showing good homogeneity, indicating that factors such as mix proportion, superplasticizer and limestone with decrease in water to binder ratio, this can be first attributed to the better dispersion of the cementations particles throughout the concrete mix, and second to lower volume of voids have been effect on strength concrete [(26)], this agree with Griffith Theory , which indicated that the failure of specimen would be at the zone of cracking. Growth of cracks, therefore, decrease of section area of specimen and stresses would increase with increasing the size of specimen [(4)].

CONCLUSIONS AND RECOMMENDATIONS

1) The effect of specimen shape was decrease when the compressive strength increasing.
2) The compressive strength of cylinder or cube with dimensions smaller than standard is higher strength of the larger specimen.
3) Correction factor of SCC for cylinder and cube specimen reaches to one.
4) Recommended of using any shape or size of concrete specimen when SCC produce with a good characteristic on state of fresh and hardened.

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Table (1): Physical properties of cement.

Test	Result	Limits of (IQS No. 5/1984)
Initial Setting Time (min.)	125	>=45min.
Final Setting Time (hrs.)	6.10	<=10hrs.
Compressive Strength at (3days)	17.2	>=15Mpa.
Compressive Strength at (7days)	26.5	>=23Mpa.

Table (2): Chemical properties of cement.

Oxide	Result	Limits of (IQS No. 5/1984)
(SiO_2) %	21.4	
(CaO) %	60.3	
(Al_2O_3) %	3.88	
(Fe_2O_3) %	4.91	
(MgO) %	2.34	<=4%
(SO_3) %	2.14	<=2.5% if C_3A <5% <=2.8% if C_3A >5%
Loss on Ignition (L.O.I)	1.2	<=4%
Insoluble Residue (I.R)	0.92	<=1.5%
L.S.F	0.87	0.66-1.02

Free Lime	0.72	
(C_3S) %	43.58	
(C_2S) %	28.55	
(C_3A) %	1.98	
(C_4AF) %	14.92	

Table (3): Gradiation of fine aggregate.

Sieve Size (mm)	Passing (%)	Limits of (IQS No.45/1984) (%)
10	100	100
5	100	90-100
2.36	89.4	75-100
1.18	67.2	55-90
0.6	45.4	35-59
0.3	27.5	8-30
0.15	2.7	0-10

Table (4): Gradiation of coarse aggregate.

Sieve Size (mm)	Passing (%)	Limits of (IQS No.45/1984) (%)
50	100	-
37.5	100	100
20	97.2	95-100
10	46.5	30-60
5	3.2	0-10

Table (5): Chemical properties of Limestone Powder.

Oxide	Test Result (%)
CaO	50.2
SiO_2	2.7
Al_2O_3	0.83
Fe_2O_3	0.36
MgO	0.24
SO_3	3.36
L.O.I	41.1

Table (6): The technical properties of the superplasticizer.

Main Action	Concrete Superplasticizer
Subsidiary Effect	Hardening retarder and flowable concrete mixes
Fire	Non-flammable
Color	Brown liquid
Freezing point	-2 ºC
Specific gravity	1.175±0.01 at 25 ºC
Chloride content	Nil
Air entrainment	Typically less than 2%

Table (7): The proportion of the Self-Compacting Concrete mixes.

Property	Comments
Water Content Admixtures	Typically range (160-180)Kg/m^3 superplasticizer used
Binder	Typically range (450-550)Kg/m^3
Water/binder ratio	0.3-0.36
Aggregate	Both gravel and crushed rock used up to (20)mm nominal size is common

Table (8): The contents of the mixes.

Water/Cement Ratio	Superplastisizer %	Limestone Content Kg/m^3	Gravel Content Kg/m^3	Sand Content Kg/m^3	Cement Content Kg/m^3	Mixing Ratio
0.4	0	0	1100	760	400	2.75:1.9:1
0.4	1	0	1000	790	450	2.22:1.75:1
0.4	4	100	830	750	400	2:1.75:1
0.4	4	100	830	750	400	2:1.75:1

Table (9): The results of workability of mixes.

Type of mixes	Slump (mm)	Slumpflow (mm)	T_{50cm} Sec.	V-funnel Sec.	L-Box H_2/H_1
NC	105				
HSC	90				
HSCC		705	3	7	0.95
CSCC		695	2	9	0.93

Table (10): The results of Compressive strength of mixes.

Self-Compacting Concrete (SCC) MPa.						High Strength Concrete (HSC) MPa.			Normal Concrete (NC) MPa.		
CSCCs/ CSCCc	CSCCs	CSCCc	HSCCs/ HSCCc	HSCCs	HSCCc	HSCs/ HSCc	HSCs	HSCc	NCs/ NCc	NCs	NCc
0.98	61.7	60.8	0.96	34.3	35.8	0.94	40.9	43.5	0.86	22.1	25.7
0.99	68.3	67.6	0.97	40.3	41.6	0.94	45.8	48.3	0.88	24.9	28.3
0.99	72	71.4	0.97	45.8	47.3	0.96	53	54.8	0.9	28.3	31.5

Table (11): The Correction Factors for strength of (150*150*150) mm cube with different ratios of (L/W).

Strength Correction Factor				Compressive Strength (Average of six specimens) MPa.				L/W ratio	Cube dimensions mm
CSCC	HSCC	HSC	NC	CSCC	HSCC	HSC	NC		
1	1	1	1	54.7	43.6	44.7	26.2	1	150*150
0.99	0.98	0.98	0.89	55.3	44.5	45.3	29.4	0.83	150*125
0.95	0.95	0.95	0.87	57.5	45.8	47	30.7	0.66	150*100
1.15	1.16	1.18	1.2	52.2	40.5	39.2	23.5	0.5	150*75

Table (12): The Correction Factors for strength of (100*100*100) mm cube with different ratios of (L/W).

Strength Correction Factor				Compressive Strength (Average of six specimens) MPa.				L/W ratio	Cube dimensions mm
CSCC	HSCC	HSC	NC	CSCC	HSCC	HSC	NC		
1	1	1	1	60.3	47.3	46.3	28	1	100*100
1.01	1.03	1.05	1.06	54.2	42.3	42.5	24.6	0.75	100*75
1.22	1.23	1.26	1.29	49.4	38.4	36.7	18.2	0.5	100* 50

Table (13): The Correction Factors for strength of (150*300) mm cylinder with different ratios of (H/D).

Strength Correction Factor				Compressive Strength (Average of six specimens) MPa.				H/D ratio	Cylinder dimensions mm
CSCC	HSCC	HSC	NC	CSCC	HSCC	HSC	NC		
1	1	1	1	44.3	36.5	35.4	20.6	2	150*300
0.97	0.95	0.93	0.88	45.7	38.4	38.1	23.2	1.66	150*250
0.95	0.93	0.91	0.84	46.5	39.2	38.8	24.5	1.33	150*200

Table (14): The Correction Factors for strength of (100*200) mm cylinder with different ratios of (H/D).

Strength Correction Factor				Compressive Strength (Average of six specimens) MPa.				H/D ratio	Cylinder dimensions mm
CSCC	HSCC	HSC	NC	CSCC	HSCC	HSC	NC		
1	1	1	1	47.6	38.6	37.2	23.1	2	100*200
0.98	0.97	0.97	0.97	48.3	39.5	38.4	23.7	1.5	100*150
1.02	1.04	1.07	1.08	46.6	37.1	34.5	21.3	1.25	100*125

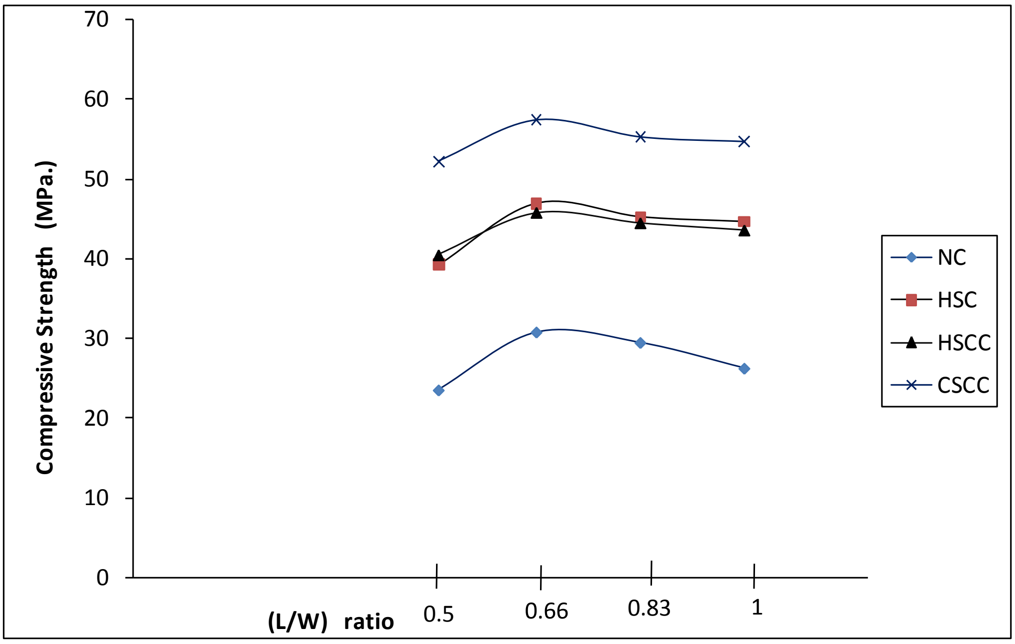

Figure (1): Relation between (L/W) ratio and compressive strength of (150*150*150) mm cubes.

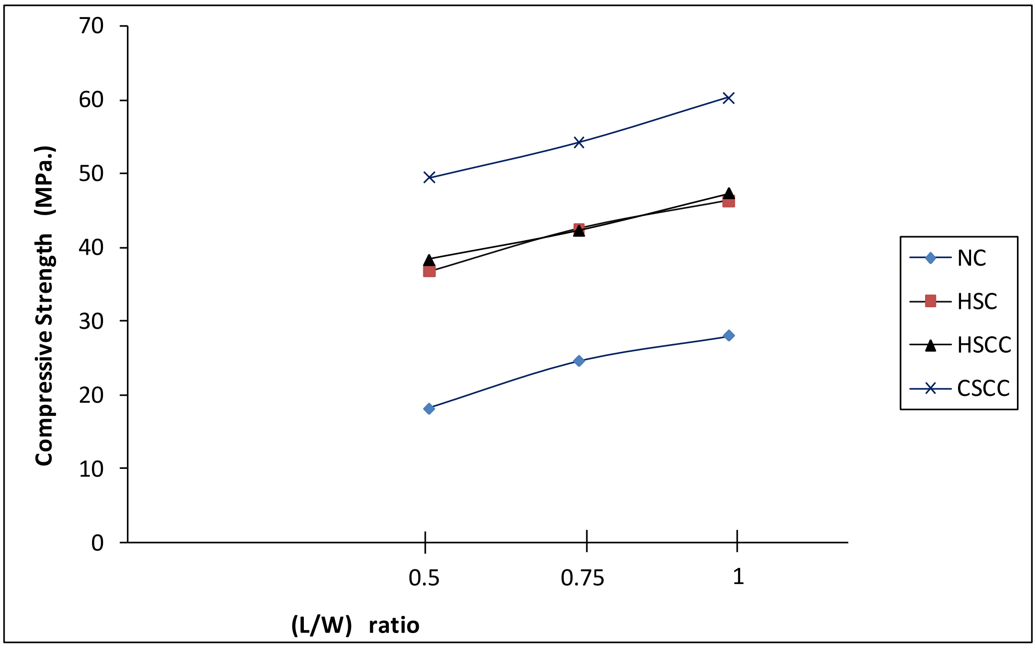

Figure (2): Relation between (L/W) ratio and compressive strength of (100*100*100) mm cubes.

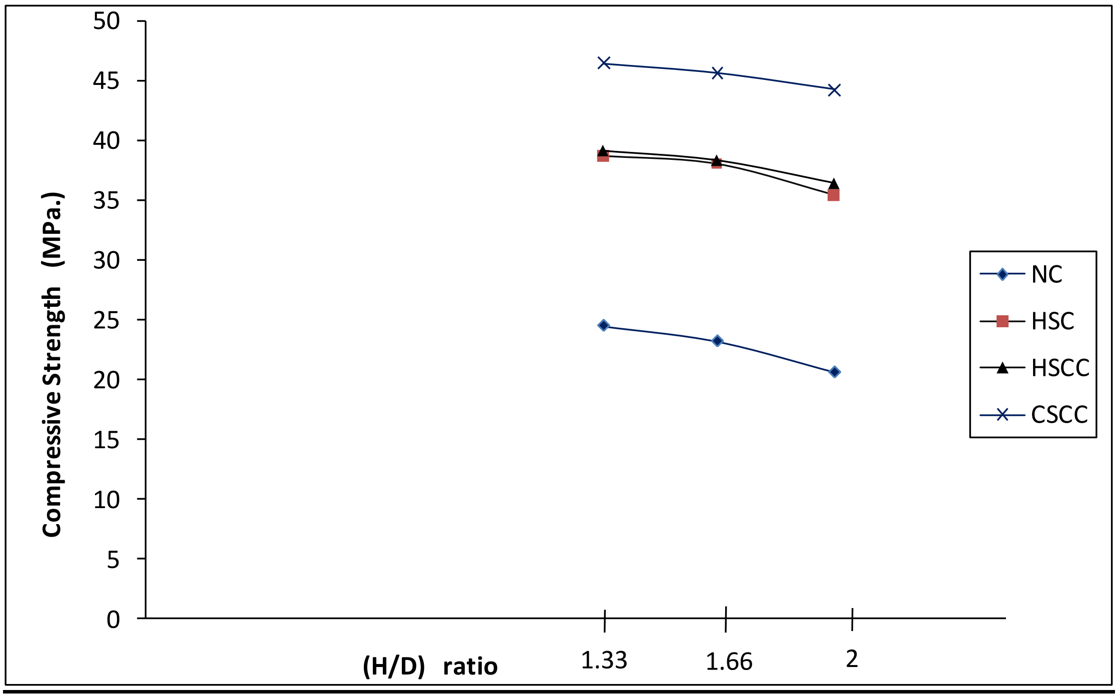

Figure (3): Relation between (H/D) ratio and compressive strength of (150*300) mm cylinders.

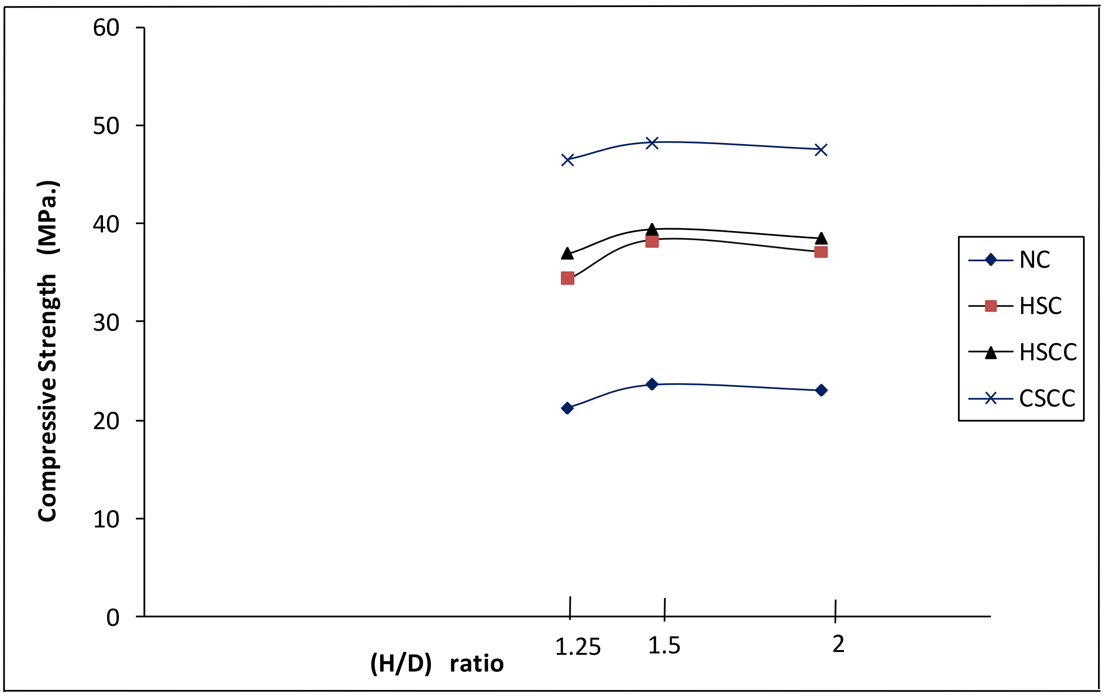

Figure (4): Relation between (H/D) ratio and compressive strength of (100*200)mm cylinders.

تأثير شكل و حجم النموذج على مقاومة الانضغاط للخرسانة ذاتية الرص

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الخلاصة

تهدف هذه الدراسة إلى تقييم تأثير شكل وحجم النموذج الخرساني على مقاومة الانضغاط للخرسانة ذاتية الرص. انقسم العمل في هذا البحث إلى جزئين، الأول هو تصميم خرسانة اعتيادية وعالية المقاومة وخرسانة ذاتية الرص ذات مقاومة انضغاط تتراوح بين (25–70) نيوتن/ملم^2 ودراسة خاصية مقاومة الانضغاط للخرسانة للنموذج الاسطواني والمكعب وكانت قيم نسبة مقاومة الاسطوانة إلى مقاومة المكعب تتراوح بين (0.84–0.9)، (0.94–0.96) و(0.96–0.99) للخرسانة الاعتيادية والعالية المقاومة والذاتية الرص على التوالي.

أما الجزء الثاني فشمل دراسة تأثير حجم النموذج على مقاومة الانضغاط وكانت قيم معامل التصحيح للنموذج المكعب بأبعاد (150*150*150) ملم و(100*100*100) ملم هي (0.89–1.29)، (0.98–1.26) و(0.98–1.22) للخرسانة الاعتيادية والعالية المقاومة والذاتية الرص على التوالي. وقيم معامل التصحيح للنموذج الاسطواني بأبعاد (150*300) ملم و(100*200) ملم هي (0.88–1.08)، (0.93–1.07) و(0.95–1.04) للخرسانة الاعتيادية والعالية المقاومة والذاتية الرص على التوالي.

الكلمات الدالة: الخرسانة الذاتية الرص، النموذج، معامل التصحيح.