Relationship between cube and cylinder compressive strengths of mortar used for ferrocement

Azad A. Mohammed,[a] Serwan K. Rafiq[b], Taghreed M. A. Khalifa[c]
[a] Civil Engineering Dept., Faculty of Engineering, University of Sulaimani, Sulaimani, Kurdistan Region, Iraq, e-mail: azadkadr@yahoo.com
[b] Civil Engineering Dept., Faculty of Engineering, University of Sulaimani, Sulaimani, Kurdistan Region, Iraq, e-mail: serwanzh@yahoo.com
[c] Architectural Engineering Dept., Faculty of Engineering, Koya University, Koya, Kurdistan Region, Iraq, e-mail: taghreed.khaleefa@koyauniversity.org

Abstract. In this paper the relationship between cylinder and cube compressive strengths of ferrocement and the influence of wire mesh on such relationship was fairly studied. Different mortar mixes having different compressive strengths were attempted, and for this purpose a total of 108 specimens were tested in the laboratory. The influence of wire mesh on mortar compressive strength was found to be not important, except in cubes reinforced with wire mesh perpendicular to direction of loading. Strength enhancement was due to the difference in mode of failure of specimens. The size of specimen seem to have an influence on compressive strength of mortar contain wire mesh. In general, the ratio of cylinder to cube mortar specimen is close to 0.94, this ratio can be used for the design of thin ferrocement sections. For thick sections, it is better to take the effect of any wire mesh perpendicular to the direction of loading. This paper gives an equation for calculating cylinder compressive strength for this case.

Keywords: Compressive strength, Cube specimen, Cylinder specimen, Ferrocement, Mortar.

1 INTRODUCTION

Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small- size wire mesh. The mesh may be made of metallic or other suitable materials (ACI 549R-97 1997). In general, ferrocement is designed to resist tensile force and rarely subjected to compression. If there were cases of ferrocement section been designed for compression, the contribution of wire mesh is neglected, except when the maximum stress calculated without considering wire mesh exceeds the permissible stress (Shah and Balaguru 1985). Different thin ferrocement structures were designed based on compressive strength of mortar and the influence of wire mesh on such strength was neglected. Balaguru et al (1977) were measured compressive strength of plain mortar of 3in x 6in (76 x 150 mm) cylinders. Namman and Homrich (1986) were measured the strength on cylinders (the result represented as f_c') without pointing to the specimen dimension. The study of Walraven and Spierenburg (1985) was based on cube compressive strength of mortar (represented by f_{cu}) without pointing to the specimen dimensions.

Other tests by Johnston and Matter (1976) indicated that there is an increase in compressive strength of small columns (102x102x292mm), as a results of ferrocement wire mesh addition. For both longitudinal and transverse wire meshes there was compressive strength enhancement, and the efficiency of square welded wire mesh was better than that of expanded metal mesh. However the case is different from the usual compression specimen, because failure was concentrated in the central zone of tested prismatic specimen and the specimen can be considered as small column.

With regard the shape of specimens, measuring compressive strength of concrete is made on a cube specimen according to the specifications followed in Europe, China and Middle East countries. The standard size of cube specimen is 150x150x150mm according to BS 1881, Part 108: 1993 and 100x100x100mm cube can also be used. In North America and Australia the test is made on cylinders and according to ASTM C470-81 the size of cylinders is 150x300mm, and the ratio of height to diameter was kept to be 2.

According to BS 1881: Part 120: 1983 expressions the strength of cylinder is equal to 0.8 of the strength of a cube, but the ratio of strengths increases with an increase in strength. For concrete of compressive strength more than 100 MPa the ratio is 1 (Neville (1995)). Graybeal and Davis (2008) concluded that to convert the compressive strength of 70.7 mm cube to an equivalent 76 mm diameter cylinder the factor of 0.96 should be used.

In general, measuring compressive strength of ferrocement is made on small mortar cube or cylinder specimens and the influence of wire mesh on such strength is neglected. The present study aims to throw a light on the compressive strength of mortar used for ferrocement as affected by changing mix proportions and wire mesh arrangement. The study also searches the relationship between the cylinder and cube compressive strength of mortar as affected by the mentioned variables.

2 EXPERIMENTAL WORK

2.1 Materials

To cast ferrocement cube and cylinder specimens cement mortar and ferrocement wire mesh were used. Materials for cement mortar were cement, water, fine aggregate, and high range water reducer (superplasicizer). Ordinary Portland cement (Type I) locally available was used. Dry sand passed by 100% on 2.36 mm sieve was used as fine aggregate. Potable water was used for mixing and curing specimens. The type of high range water reducer (superplasticized) used in some mixes was Proplust PC260 hyperplust. Ferrocement wire mesh was welded steel wire mesh of 0.6 mm diameter and 12.7 mm square spacing. The yield stress of wire mesh was found to be 450 MPa.

1.2 Casting specimens

All specimens were cast in plastic molds. The dimensions of cube specimens were 70 x 70 x 70 mm and those of cylinders were 70 mm diameter and 140 mm height (height/diameter = 2). Wire mesh was cut according to the arrangement attempted for each group of specimens. Table 1 shows the details of mix proportions and wire mesh arrangement. Fig. 1 shows details of wire mesh arrangement. Wire mesh was provided to study the role of wire mesh on compressive strength of mortar used for making ferrocement members, either in the direction of loading (vertical wire mesh) or perpendicular to it (horizontal wire mesh). To represent the case of vertical wire mesh in cylindrical specimens wire mesh was arranged in a spiral form as shown in the arrangement of specimen (6) and (10). Water/cement ratio and superplasticizer used were selected to make mortar mix with high flow ability, because some specimens contain high ratio of wire mesh (specimen (7),(8),(9) and (10)). After 24 hrs from casting, all specimens were put in water tank and curing was continued for 28 days. All specimens were left in laboratory for air drying for another 7 days before testing. With regard the specimens code the symbol CU used for cube and CY for cylinder, a number was used which is the fine aggregate/cement ratio, the symbol H beside the number is used for high strength mix contains superplasticizer. Furthermore, the symbol M is for medium wire mesh content and H for high wire mesh content, the last symbol H is for horizontal mesh and V for vertical mesh. For example the specimen having the symbol CY1-HV is the cylinder specimen made from a mix of sand/cement ratio of 1 reinforced with high ratio of vertical wire mesh.

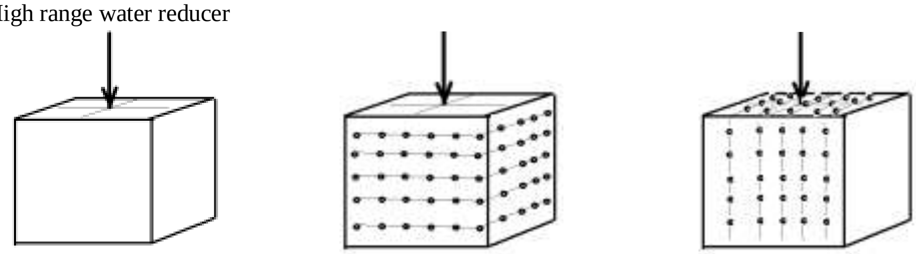
1.3 Testing specimens

For some of cube specimens and all cylinders capping was necessary, because in such specimens loading was applied to the casting surface which is in general not smooth. For this purpose high strength cement paste with average thickness of 2 mm was used. All specimens were tested for ultimate load capacity with a loading rate of 0.3 MPa/sec till failure. Photographs were taken for some specimens to show the mode of failure. The measured compressive strength was taken as the average of three specimens. Accordingly, a total of 54 cubes and 54 cylinders were cast and tested.

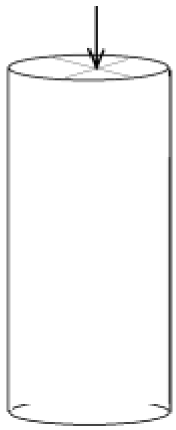
Table 1 Mix proportion, ferrocement arrangement and results of compressive strength

Code	Mix Proportion	w/c ratio	HRWR*	Ferrocement mesh Arrangement	Compressive strength (MPa)	Cylinder/Cube compressive strength
CU3	1:3	0.7	-	Specimen (1)	27.21	-
CU3-MH	1:3	0.7	-	Specimen (2)	33.54	-
CU3-MV	1:3	0.7	-	Specimen (3)	26.81	-
CY3	1:3	0.7	-	Specimen (4)	26.39	0.97
CY3-MH	1:3	0.7	-	Specimen (5)	28.51	0.85
CY3-MV	1:3	0.7	-	Specimen (6)	27.08	1.01
CU2	1:2	0.6	-	Specimen (1)	36.05	-
CU2-MH	1:2	0.6	-	Specimen (2)	45.78	-
CU2-MV	1:2	0.6	-	Specimen (3)	36.37	-
CY2	1:2	0.6	-	Specimen (4)	34.51	0.96
CY2-MH	1:2	0.6	-	Specimen (5)	37.24	0.81
CY2-MV	1:2	0.6	-	Specimen (6)	34.71	0.95
CU1	1:1	0.5	-	Specimen (1)	42.46	-
CU1-MH	1:1	0.5	-	Specimen (2)	46.26	-
CU1-MV	1:1	0.5	-	Specimen (3)	42.82	-
CY1	1:1	0.5	-	Specimen (4)	41.37	0.97
CY1-MH	1:1	0.5	-	Specimen (5)	47.24	1.02
CY1-MV	1:1	0.5	-	Specimen (6)	42.44	0.99
CU1	1:1	0.5	-	Specimen (1)	36.73	-
CU1-HH	1:1	0.5	-	Specimen (7)	49.86	-
CU1-HV	1:1	0.5	-	Specimen (8)	36.55	-
CY1	1:1	0.5	-	Specimen (4)	34.90	0.95
CY1-HH	1:1	0.5	-	Specimen (9)	36.77	0.74
CY1-HV	1:1	0.5	-	Specimen (10)	35.10	0.96
CU1H	1:1	0.3	1%	Specimen (1)	62.04	-
CU1H-MH	1:1	0.3	1%	Specimen (2)	67.59	-
CU1H-MV	1:1	0.3	1%	Specimen (3)	62.46	-
CY1H	1:1	0.3	1%	Specimen (4)	60.12	0.97
CY1H-MH	1:1	0.3	1%	Specimen (5)	62.66	0.93
CY1H-MV	1:1	0.3	1%	Specimen (6)	61.46	0.98
CU1H	1:1	0.3	1%	Specimen (1)	61.91	-
CU1H-HH	1:1	0.3	1%	Specimen (7)	76.16	-
CU1H-HV	1:1	0.3	1%	Specimen (8)	62.90	-
CY1H	1:1	0.3	1%	Specimen (1)	59.39	0.96
CY1H-HH	1:1	0.3	1%	Specimen (9)	64.18	0.84
CY1H-HV	1:1	0.3	1%	Specimen(10)	61.42	0.98

* High range water reducer

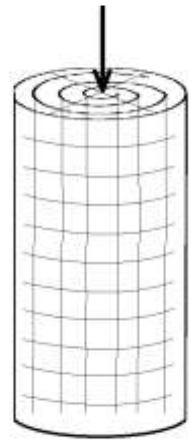


Specimen (1) No ferrocement wire Specimen (2) Five horizontal layers Specimen (3) Five vertical layers

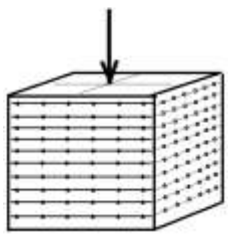


Specimen (4) No ferrocement wire

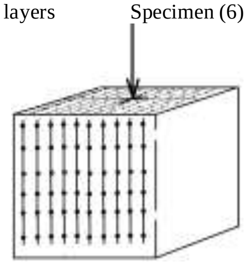
Specimen (5) Ten horizontal layers



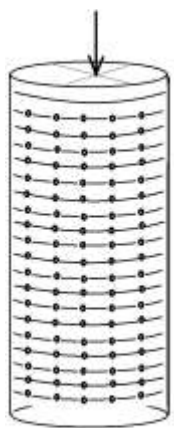
Specimen (6) Five vertical layers



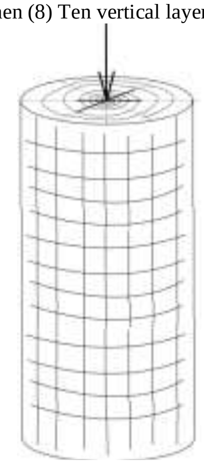
Specimen (7) Ten horizontal layers



Specimen (8) Ten vertical layers



Specimen (9) Twenty horizontal layers



Specimen (10) Ten vertical layers

Fig.1 Wire mesh arrangement in mortar cube and cylindrical specimens

3 RESULTS AND DICUSSION

3.1 Effect of wire mesh on compressive strength

Results of compressive strength of tested specimens are shown in Table 1. From the obtained results the influence of parameters of mix proportion and wire mesh arrangement on the strength can be studied. It is well observed that the combined effect of increasing cement content and reducing w/c ratio has an important influence on the compressive strength of cube and cylinder specimens. The strength can be enhanced if lower w/c ratio combining with superplasticizer are used, as shown from the results of the last twelve specimens given in Table 1. Higher mortar compressive strength equal to 76.16 MPa as a results of using low w/c ratio and 1% superplasticizer was obtained (for specimen CU1H-HH).

As the compressive strength of specimens contain wire mesh is compared with that of plain mortar specimens one can find that there a positive effect horizontal wire mesh (perpendicular to loading) on mortar strength for cube specimens. The strength enhancement may be due to some control of lateral pieces of mortar separated from the produced undamaged end pyramids near failure. If the failure is shear failure which is observed in some specimens the influence of horizontal wire mesh disappear, like in the case of cylinders. In cube specimens, the wire mesh tend to provide some arrest against the separation of specimens into pieces near failure. This behavior is not active if wire mesh arranged in the direction of loading. It is followed that in the case of horizontal wire mesh the size of specimen may have an influence on the enhancement in compressive strength, because failure of small mortar specimens may be different from that of large specimens, and the positive effect of horizontal wire mesh is expected to be more active in large cube specimens.

The ratio of cylinder to cube strengths is shown in the last column of Table 1. Fig. 2 shows cylinder and cube compressive strength relationship considering all specimens, with and without wire mesh. Fig. 3 shows cylinder and cube compressive strength of plain mortar. Cylinder and cube compressive strength relationship of mortar reinforced with vertical wire mesh is shown in Fig. 4 and that of specimens reinforced with horizontal wire mesh is shown in Fig. 5.

Based on statistical regression analysis applied on the test data, cylinder compressive strength can be related to cube compressive strength as follows.

For all specimens

$$f_c' = 0.89\, f_{cu} + 2 \qquad (1)$$

For plain mortar

$$f_c' = 0.97\, f_{cu} - 0.14 \qquad (2)$$

For mortar reinforced with vertical wire mesh

$$f_c' = 0.979\, f_{cu} \qquad (3)$$

For mortar reinforced with horizontal wire mesh

$$f_c' = 0.8811\, f_{cu} - 0.77 \qquad (4)$$

The correlation coefficient for each relationship is shown in the corresponding figure.

The average ratio of cylinder to cube compressive strength of plain mortar is 0.96, for mortar reinforced with vertical wire mesh is 0.98, and for mortar reinforced with horizontal wire mesh is 0.88. The average ratio for all specimens is 0.94. The low ratio of cylinder to cube compressive strength of specimens reinforced with horizontal wire mesh is due to the positive effect of wire mesh on compressive strength of cube specimen. It should be noted that maximum wire mesh ratio used in this study is not more than 0.35%. This ratio is not high as compared with that provided for ferrocement elements using advanced techniques. It is expected that if high ratio of horizontal wire mesh is used the strength enhancement will be higher. Therefore there is a safety related to using the proposed equations for the cylinder/cube compressive strength ratio in the case of providing horizontal wire meth.

3.2 Mode of failure

Failure pattern for cube specimens was different from that of cylinders. Since coarse aggregate not exists in the mortar used for casting specimens, the role of such component on failure mode is not available. Tested mortar specimens were of a high homogeneity and the failure was similar to that of high strength concrete. Coarse aggregate if exist in normal concrete usually influences the mode of failure, because many shear cracks will exist in the vicinity of coarse aggregate particle, that can join together and at high stresses lead to steady failure. The case in the tested mortar was different because cracks joined and extended rapidly near the peak stress lead to a sudden failure. In most of cylinder specimens failure occurred suddenly accompanied with explosion of specimen into pieces. The source of failure was vertical cracks in the direction of loading that joined together and extended suddenly near peak compressive stress. Fig. 6 shows two cube specimens after failure, it is observed that the specimen near failure have been subjected to high lateral movement lead to the separation of many portions from the specimen. Making a comparison between mode of failure of cubes and that of cylinders the role of horizontal wire mesh is positive to produce a steady type of failure. Such phenomenon is not exist in cylinders, because most of cylinders were failed in shear and the role of wire mesh on such type of failure is not important. Fig. 7 shows samples of cylinders after testing. Shear type of failure is clearly shown in most of the cylinder specimens. Failure of cylinders was more violent, and explosive manner was observed for most cylinders in contrast with cubes. In the case of specimens reinforced with vertical wire mesh, the behavior is not different from plain mortar specimens, because layers of mortar with wire mesh can easily separate from each other, as a result of crack extension between them.

4 CONCLUSIONS

From the research study presented here the following conclusions can be drawn.

1- There is an enhancement in compressive strength of cube mortar if the horizontal wire mesh is used (perpendicular to the direction of loading). In other cases of wire mesh arrangement in cube specimen and in cylinder specimens the role of wire mesh on compressive strength is low.

2- There is In general, the ratio of cylinder to cube compressive strength of mortar is equal to 0.96. If cement mortar reinforced with wire mesh layer perpendicular to the direction of loading, the strength ratio is reduced to 0.88.

3- The size of specimen is responsible to the mode of failure and the positive effect of horizontal wire mesh. If small specimens are used the positive influence of wire mesh is reduced.

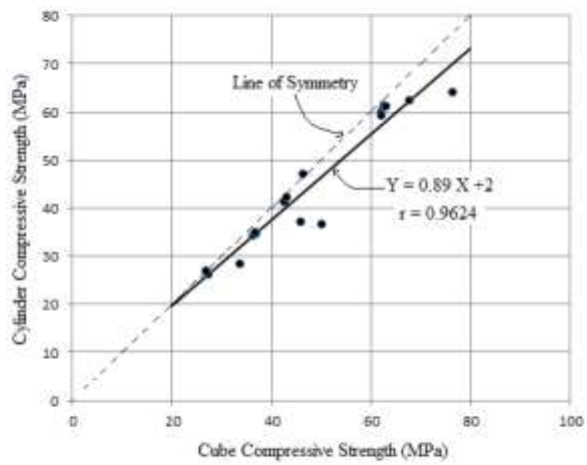


Fig. 2 Cylinder versus cube compressive strength (all specimens)

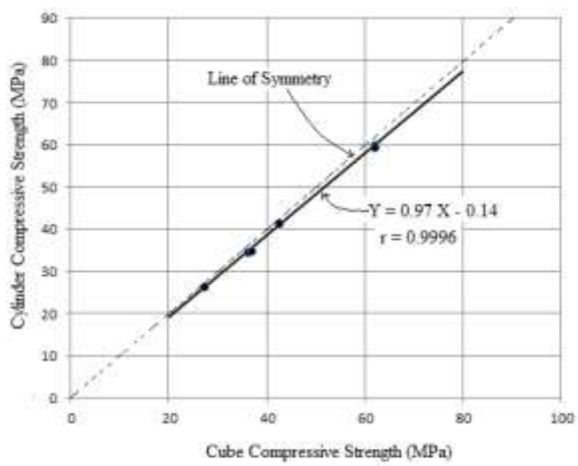


Fig. 3 Cylinder versus cube compressive strength (Plain mortar)

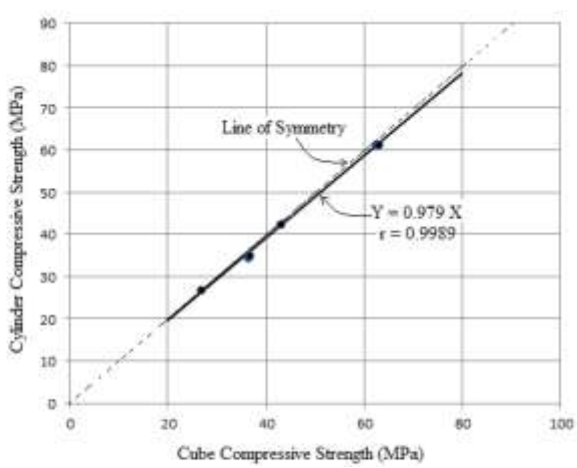


Fig. 4 Cylinder versus cube compressive strength (specimens contain vertical wire mesh)

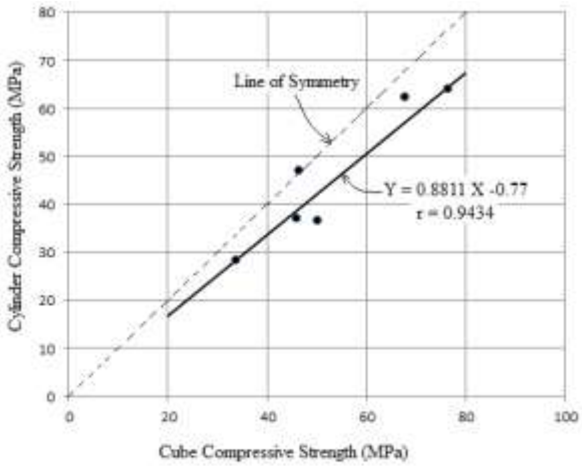


Fig. 5 Cylinder versus cube compressive strength (specimens contain horizontal wire mesh)

Fig. 6 Sample of cube specimens after failure

Fig. 7 Sample of cylinder specimens after failure

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