# Relationship between Cubical and Cylindrical Compressive Strength of Recycled Aggregate Concrete

**[1]Abdul Hafeez Buller , [2]Mahboob Oad, [3]Bashir Ahmed Memon**

[1]Postgraduate Student, [2]Assistant Professor, [3]Professor
[1]Civil Engineering Department,
[1]Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah Sindh Pakistan

***Abstract*: This research work presents relationship between cylindrical compressive strength and cubical compressive strength of concrete made with 50% replacement of natural coarse aggregates with recyclable concrete aggregates from old demolished concrete. 200 samples of each cube and cylinder of standard size made using 1:2:4 mix with 0.54 water cement ratio are tested. Based on the obtained results the conversion factor of 0.7 is obtained to convert compressive strength of cube to cylinder. Also, the regression analysis is performed to develop numerical relationship between two strengths. The obtained equation meets statistical norms and successfully predict the compressive strength of cylinders from the compressive strength of cubes.**

***Index Terms*: Cube compressive strength, Cylindrical compressive strength, Old concrete, Recyclable coarse aggregates, Fire resistance, Compressive strength, Green concrete.**

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## I. INTRODUCTION

Concrete is being used worldwide in construction industry. To ensure the quality of material being used in construction testing is done. To ensure the quality of concrete one of the parameters which is generally evaluated is its strength. To this end specimens from running batch of concrete are cast, cured for required time and tested. Different shape specimen from cube to prism are used in different parts of world. Not only this but different are sizes also used for the purpose. This change in shape and size have significant effect on the compressive strength of concrete.

Another issue with concrete since past few decades is its mass use in construction due to infrastructure development and to meet the growing demand of the living and associated space particularly in city centers of the world. It has forced the industry to demolish old or short height structures to construct new high-rise structures. This not only generates huge quantum of demolished waste including old concrete but also required lot of natural coarse aggregates to be used in new construction. On other hand lack of dumping space increases the cost of projects as waste need to be transported to far distances. One of the possible methods of properly dealing with this waste is making its use in new construction. Various materials of the waste have been attempted to be used in new concrete as partial or full replacement of one or more ingredients of concrete by different scholars. Use of old demolished concrete as coarse aggregate in new concrete as partial and full replacement of natural aggregates has also been studied and successfully used by scholars and construction industry personals in different parts of the world. This not only deals to some extent the waste handling problem but also creates environmental friendly green concrete.

Therefore, this research work is conducted to study the relationship between the cube compressive strength and cylindrical compressive strength of concrete made with recyclable old concrete as coarse aggregate.

As mentioned earlier the use of old concrete in new concrete is not new. Several scholars around the globe have conducted research to study its various properties. The Recent developments on use of demolished concrete as partial or full replacement of natural coarse aggregates in new concrete has been reviewed by Memon [1]. In another similar approach Li [2] reviewed use of the recyclable concrete aggregates in China with reference to environmental preservation and effective utilization. The author also presented the achievements regarding mechanical behavior and successful use of the material along with description of standards available in Chinese technical code for use of recyclable material. Oad and Memon [3] while studying the compressive strength of concrete made with demolished concrete as coarse aggregates as partial replacement of natural coarse aggregates concluded that the 50% replacement of natural coarse aggregates with demolished recyclable concrete is the optimum dosage without comprising much on the compressive strength of the material.

Bhutto and Memon [4] in their research work studied effect of cube size on compressive strength at different curing ages. The authors used 50% old concrete as coarse aggregates and cured concrete samples at 7, 14, 28, 56 and 190 days. Based on the obtained results the authors coined out different correction factors to correct the strength with standard size and curing. In another study to check effect of specimen size on compressive strength Hamad [5] used high performance light weight foamed concrete reinforced with glass fiber. The author used glass fiber in dosage of 0%, 0.06%, 0.2%, 0.4% and 0.6% by total volume of concrete. The author used three sizes of cube specimen and two sizes of cylinder specimen. Based on the test results of the specimen the author concluded correction factors in the range of 0.8 to 1.11. The author also observed that the compressive strength of concrete with glass fiber increased in all sizes of specimen. The smaller size specimen gave higher strength than other sizes. The author concluded that the disparity in compressive strength can be reduced with increase in dosage of glass fiber. Yuliarti et al [9] used ultra-high-performance concrete and ultra-high-performance fiber reinforced concrete to check the relationship between compressive strength of cube and compressive strength of cylinders. Based on the obtained results the author concluded that the correction factors for concrete used in the research are different than conventional concrete.

High strength concrete was also investigated by Del Viso et al [10] to study the effect of shape and size of the specimen on its compressive strength under stable stress-strain tests. The authors used different sizes of cube and cylinder specimens to test the concrete at single strain rate. Based on the test results authors studied relationship between two sizes of specimen and concluded that in post-peak region the behavior of cubes and cracking pattern were milder than cylinders. Further observation revealed that micro-cracking in beams were denser than in cylinders.

Graybeal and Marshall [12] also studied ultra-high-performance fiber reinforced concrete to check the possibility of using alternate size specimen than standard size specimen. It is due to machine capacity required to test very high strength concrete. The authors used several sizes of test specimen. Based on the analysis of the results they concluded that in case if machine capacity is problem to test the standard size then 70.7 mm size specimen can effectively be used for the purpose.

Al-Sahawneh [6] also conducted research to check the size effect on compressive strength of normal weight concrete specimen under uniaxial compression. The author used cylinder specimen of same cross-section but different depths and used shear model to study the effect on compressive strength. Based on the obtained results the author proposed general equation to predict the correction factors.

Kumavat and Patel [7] in their research paper studied relationship between strength of cube and strength of cylinder due to different size aggregates. The authors used standard size cube and cylinder specimen to cast the concrete specimen. After 7 and 28 day curing all specimens were tested. From the test results authors observed that ratio of cube to cylinder strength in case of 10 mm aggregates increasing than 20 mm aggregates. However, the authors concluded that there is no unique relationship between strength of cube and strength of cylinder due to different size of coarse aggregates used.

Bisher [8] while studying compressive strength relationship between cylinders and cores used four different w/c ratios, two types of cements, and two types of aggregates. From comparison of test results of cylinders and cored specimen, the authors observed linear relationship between two specimens independent of mix parameters.

Saurav et al [11] also studied relationship between compressive strength of cubes and cylinders by using ultra-fine slag as partial replacement of cement. From the comparison of the results with normal concrete, the authors observed that hardened properties of ultra-fine slag concrete are improved. The optimum dosage of proposed concrete is 13%. The authors also observed that cylindrical strength of ultra-fine concrete increases but is always lesser than cubical strength.

Gul [13] in his research work used 100 mm and 150 mm cube specimen to check the size effect on compressive strength. The author after 7- and 14-day curing tested the samples in compression testing machine. Based on the obtained results the author observed that smaller size specimen shows higher strength.

Zabihi and Eren [14] studied the effect of curing conditions and size effect on the compressive strength of concrete. For the purpose the authors used air and water curing for cube and cylinder specimen of various sizes. From the obtained results the authors plotted conversion factors vs cross-sectional area of same specimen. Regression analysis of the results showed that conversion factors have different trends for different curing conditions.

Yi et al [15] conducted research work to check the effect of size, shape and placement direction on compressive strength using fracture mechanics. The authors used cube, cylinder and prism specimen and plotted the obtained results using least square method to obtain new parameters for size effect. The authors observed dominant effect of size and shape on compressive strength of concrete.

The above discussion shows that although good quantum of work has been done to check the size effect on compressive strength and relationship between compressive strength of cube and cylinder under different conditions. But less work is done using recyclable concrete aggregates / old demolished concrete as partial or full replacement of coarse aggregates in normal concrete. Therefore, this research work presents experimental study on relationship of compressive strength of cube and cylinder using 50% replacement of natural coarse aggregates with recyclable concrete aggregates. Selection of 50% is made based on the conclusion of Oad and Memon [3].

Large blocks of old demolished concrete were collected and reduced to required size. These aggregates along with natural coarse aggregates in 50% proportion are then used in 1:2:4 mix with 0.54 water cement ratio to cast 200 each cubes and cylinders. All the specimens are cured for 28-days before testing for compressive strength in universal load testing machine.

The obtained results are analyzed and accordingly conversion factor for compressive strength of cylinder from compressive strength of cube for concrete with recyclable concrete as coarse aggregates is obtained. Also, the regression analysis of the obtained results is performed to obtain the numerical equation for prediction of cylindrical strength of RAC form cubical compressive strength of the same. For 1:2:4 mix with 0.54 water cement ratio both correction factor and numerical equation are in good agreement with the experimental results.

## II. Material and Testing

Large pieces of old concrete were collected from the slab of a demolished reinforced concrete building about 60 years age. Using manual hammering these blocks were broken to smaller pieces. Manual sorting of these aggregates was performed for cracked particles followed by sieve analysis with maximum size equal to 25 mm in standard fashion. Accordingly, the natural coarse aggregates were also sieved to same size. Figure 1 shows both aggregates and in figure 2 sieve analysis of both types of aggregates is shown and compared.

Using 50% of each of recycled old concrete and natural coarse aggregates in 1:2:4 mix with 0.54 water cement ratio 200 cylinders and 200 cubes are casted in standard fashion. Standard size of both specimen 150mmx300mm and 150mmx150mmx150mm is used for the cylinder and cube respectively. Curing of the specimen is done for 28-days by immersing fully in water. After curing specimens are allowed to air dry in laboratory for 24-hours. Finally, all the samples are tested for compressive strength in universal load testing machine following the standard procedure of testing. Table 1 shows the compressive strength results of concrete cubes whereas table 2 gives details of load and compressive strength for concrete cylinders.

Figure 1: RCA

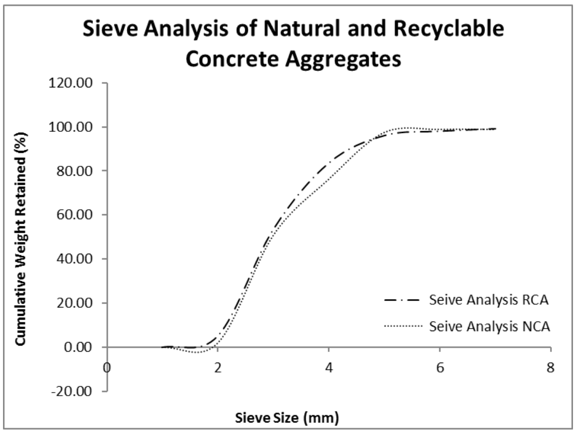


Figure 2: Sieve Analysis of NCA and RCA

**Table 1: Compressive strength of concrete cubes**

| # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 673.30 | 29.92 | 41 | 665.22 | 29.57 | 81 | 695.08 | 30.89 | 121 | 715.22 | 31.79 | 161 | 692.69 | 30.79 |
| 2 | 676.20 | 30.05 | 42 | 656.36 | 29.17 | 82 | 696.98 | 30.98 | 122 | 745.15 | 33.12 | 162 | 692.55 | 30.78 |
| 3 | 687.65 | 30.56 | 43 | 696.31 | 30.95 | 83 | 692.36 | 30.77 | 123 | 696.36 | 30.95 | 163 | 698.77 | 31.06 |
| 4 | 680.65 | 30.25 | 44 | 695.11 | 30.89 | 84 | 697.25 | 30.99 | 124 | 694.25 | 30.86 | 164 | 693.55 | 30.82 |
| 5 | 657.78 | 29.23 | 45 | 695.47 | 30.91 | 85 | 699.26 | 31.08 | 125 | 690.12 | 30.67 | 165 | 689.69 | 30.65 |
| 6 | 695.87 | 30.93 | 46 | 698.23 | 31.03 | 86 | 697.33 | 30.99 | 126 | 690.52 | 30.69 | 166 | 688.56 | 30.60 |
| 7 | 690.25 | 30.68 | 47 | 692.21 | 30.76 | 87 | 680.56 | 30.25 | 127 | 688.36 | 30.59 | 167 | 678.02 | 30.13 |
| 8 | 695.64 | 30.92 | 48 | 690.56 | 30.69 | 88 | 682.36 | 30.33 | 128 | 668.25 | 29.70 | 168 | 672.45 | 29.89 |
| 9 | 685.96 | 30.49 | 49 | 699.63 | 31.09 | 89 | 690.78 | 30.70 | 129 | 665.36 | 29.57 | 169 | 677.31 | 30.10 |
| 10 | 698.74 | 31.06 | 50 | 699.47 | 31.09 | 90 | 692.06 | 30.76 | 130 | 660.45 | 29.35 | 170 | 701.05 | 31.16 |
| 11 | 690.58 | 30.69 | 51 | 692.36 | 30.77 | 91 | 693.07 | 30.80 | 131 | 662.58 | 29.45 | 171 | 722.36 | 32.10 |
| 12 | 691.25 | 30.72 | 52 | 694.23 | 30.85 | 92 | 692.88 | 30.79 | 132 | 644.38 | 28.64 | 172 | 692.56 | 30.78 |
| 13 | 691.68 | 30.74 | 53 | 692.45 | 30.78 | 93 | 693.56 | 30.82 | 133 | 652.69 | 29.01 | 173 | 672.22 | 29.88 |
| 14 | 692.53 | 30.78 | 54 | 695.69 | 30.92 | 94 | 691.58 | 30.74 | 134 | 690.25 | 30.68 | 174 | 678.69 | 30.16 |
| 15 | 690.48 | 30.69 | 55 | 695.87 | 30.93 | 95 | 692.03 | 30.76 | 135 | 697.36 | 30.99 | 175 | 690.26 | 30.68 |
| 16 | 690.48 | 30.69 | 56 | 694.99 | 30.89 | 96 | 705.12 | 31.34 | 136 | 688.22 | 30.59 | 176 | 682.59 | 30.34 |
| 17 | 698.35 | 31.04 | 57 | 697.44 | 31.00 | 97 | 708.63 | 31.49 | 137 | 692.63 | 30.78 | 177 | 673.69 | 29.94 |
| 18 | 681.25 | 30.28 | 58 | 697.22 | 30.99 | 98 | 712.52 | 31.67 | 138 | 698.78 | 31.06 | 178 | 690.54 | 30.69 |
| 19 | 691.69 | 30.74 | 59 | 698.26 | 31.03 | 99 | 665.69 | 29.59 | 139 | 661.36 | 29.39 | 179 | 680.56 | 30.25 |
| 20 | 673.56 | 29.94 | 60 | 662.36 | 29.44 | 100 | 666.47 | 29.62 | 140 | 650.55 | 28.91 | 180 | 680.99 | 30.27 |
| 21 | 668.58 | 29.71 | 61 | 665.36 | 29.57 | 101 | 666.32 | 29.61 | 141 | 656.42 | 29.17 | 181 | 680.01 | 30.22 |
| 22 | 685.87 | 30.48 | 62 | 665.99 | 29.60 | 102 | 661.58 | 29.40 | 142 | 650.24 | 28.90 | 182 | 670.25 | 29.79 |
| 23 | 671.25 | 29.83 | 63 | 678.07 | 30.14 | 103 | 660.23 | 29.34 | 143 | 642.56 | 28.56 | 183 | 671.23 | 29.83 |
| 24 | 697.56 | 31.00 | 64 | 670.22 | 29.79 | 104 | 652.48 | 29.00 | 144 | 689.37 | 30.64 | 184 | 670.25 | 29.79 |
| 25 | 735.26 | 32.68 | 65 | 640.36 | 28.46 | 105 | 670.98 | 29.82 | 145 | 680.56 | 30.25 | 185 | 690.54 | 30.69 |
| 26 | 754.25 | 33.52 | 66 | 642.56 | 28.56 | 106 | 652.69 | 29.01 | 146 | 682.65 | 30.34 | 186 | 692.89 | 30.80 |
| 27 | 752.66 | 33.45 | 67 | 681.23 | 30.28 | 107 | 645.23 | 28.68 | 147 | 686.89 | 30.53 | 187 | 666.23 | 29.61 |
| 28 | 753.25 | 33.48 | 68 | 697.68 | 31.01 | 108 | 644.01 | 28.62 | 148 | 695.45 | 30.91 | 188 | 653.45 | 29.04 |
| 29 | 715.79 | 31.81 | 69 | 698.69 | 31.05 | 109 | 672.59 | 29.89 | 149 | 694.65 | 30.87 | 189 | 654.22 | 29.08 |
| 30 | 682.36 | 30.33 | 70 | 698.05 | 31.02 | 110 | 690.89 | 30.71 | 150 | 696.58 | 30.96 | 190 | 683.11 | 30.36 |
| 31 | 695.67 | 30.92 | 71 | 725.58 | 32.25 | 111 | 692.09 | 30.76 | 151 | 690.25 | 30.68 | 191 | 636.55 | 28.29 |
| 32 | 698.87 | 31.06 | 72 | 626.36 | 27.84 | 112 | 691.55 | 30.74 | 152 | 691.65 | 30.74 | 192 | 682.56 | 30.34 |
| 33 | 699.89 | 31.11 | 73 | 630.88 | 28.04 | 113 | 691.69 | 30.74 | 153 | 691.87 | 30.75 | 193 | 698.25 | 31.03 |
| 34 | 660.33 | 29.35 | 74 | 633.09 | 28.14 | 114 | 693.58 | 30.83 | 154 | 699.58 | 31.09 | 194 | 691.26 | 30.72 |
| 35 | 682.55 | 30.34 | 75 | 621.69 | 27.63 | 115 | 725.36 | 32.24 | 155 | 692.56 | 30.78 | 195 | 694.36 | 30.86 |
| 36 | 666.36 | 29.62 | 76 | 622.56 | 27.67 | 116 | 731.69 | 32.52 | 156 | 693.87 | 30.84 | 196 | 694.55 | 30.87 |
| 37 | 672.58 | 29.89 | 77 | 655.36 | 29.13 | 117 | 726.69 | 32.30 | 157 | 694.56 | 30.87 | 197 | 694.69 | 30.88 |
| 38 | 673.25 | 29.92 | 78 | 640.36 | 28.46 | 118 | 717.88 | 31.91 | 158 | 695.69 | 30.92 | 198 | 681.33 | 30.28 |
| 39 | 674.25 | 29.97 | 79 | 685.88 | 30.48 | 119 | 765.19 | 34.01 | 159 | 696.87 | 30.97 | 199 | 690.36 | 30.68 |
| 40 | 670.23 | 29.79 | 80 | 699.04 | 31.07 | 120 | 762.81 | 33.90 | 160 | 692.47 | 30.78 | 200 | 681.44 | 30.29 |

**Table 2: Compressive strength of concrete cylinders**

| # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) | # | Load (KN) | Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 385.80 | 21.84 | 41 | 386.25 | 21.87 | 81 | 362.54 | 20.53 | 121 | 395.10 | 22.37 | 161 | 392.44 | 22.22 |
| 2 | 381.30 | 32.89 | 42 | 365.10 | 20.67 | 82 | 353.90 | 20.04 | 122 | 393.60 | 22.28 | 162 | 390.12 | 22.09 |
| 3 | 378.90 | 21.45 | 43 | 550.66 | 31.18 | 83 | 340.11 | 19.26 | 123 | 398.65 | 22.57 | 163 | 382.25 | 21.64 |
| 4 | 365.70 | 20.70 | 44 | 340.22 | 19.26 | 84 | 342.33 | 19.38 | 124 | 388.77 | 22.01 | 164 | 380.14 | 21.52 |
| 5 | 345.70 | 19.57 | 45 | 361.64 | 20.48 | 85 | 350.01 | 19.82 | 125 | 392.61 | 22.23 | 165 | 370.26 | 20.96 |
| 6 | 378.97 | 21.46 | 46 | 372.66 | 21.10 | 86 | 388.63 | 22.00 | 126 | 380.98 | 21.57 | 166 | 390.58 | 22.11 |
| 7 | 320.60 | 18.15 | 47 | 341.22 | 19.32 | 87 | 388.92 | 22.02 | 127 | 399.56 | 22.62 | 167 | 390.69 | 22.12 |
| 8 | 322.80 | 18.28 | 48 | 350.44 | 19.84 | 88 | 382.11 | 21.63 | 128 | 398.71 | 22.57 | 168 | 390.66 | 22.12 |
| 9 | 325.12 | 18.41 | 49 | 392.88 | 22.24 | 89 | 380.23 | 21.53 | 129 | 398.20 | 22.54 | 169 | 380.14 | 21.52 |
| 10 | 324.25 | 18.36 | 50 | 375.01 | 21.23 | 90 | 390.66 | 22.12 | 130 | 398.33 | 22.55 | 170 | 380.15 | 21.52 |
| 11 | 392.36 | 22.21 | 51 | 320.11 | 18.12 | 91 | 392.66 | 22.23 | 131 | 398.20 | 22.54 | 171 | 388.74 | 22.01 |
| 12 | 391.66 | 22.17 | 52 | 372.33 | 21.08 | 92 | 310.23 | 17.56 | 132 | 398.12 | 22.54 | 172 | 378.36 | 21.42 |
| 13 | 390.33 | 22.10 | 53 | 378.55 | 21.43 | 93 | 311.22 | 17.62 | 133 | 398.11 | 22.54 | 173 | 377.06 | 21.35 |
| 14 | 350.25 | 19.83 | 54 | 399.56 | 22.62 | 94 | 312.55 | 17.70 | 134 | 374.87 | 21.22 | 174 | 388.94 | 22.02 |
| 15 | 350.40 | 19.84 | 55 | 398.77 | 22.58 | 95 | 396.66 | 22.46 | 135 | 374.99 | 21.23 | 175 | 382.55 | 21.66 |
| 16 | 352.81 | 19.98 | 56 | 397.88 | 22.53 | 96 | 368.78 | 20.88 | 136 | 374.87 | 21.22 | 176 | 385.66 | 21.83 |
| 17 | 352.83 | 19.98 | 57 | 399.70 | 22.63 | 97 | 395.33 | 22.38 | 137 | 375.60 | 21.27 | 177 | 385.92 | 21.85 |
| 18 | 360.36 | 20.40 | 58 | 360.66 | 20.42 | 98 | 392.10 | 22.20 | 138 | 380.38 | 21.54 | 178 | 392.54 | 22.22 |
| 19 | 388.99 | 22.02 | 59 | 352.50 | 19.96 | 99 | 395.50 | 22.39 | 139 | 390.23 | 22.09 | 179 | 393.56 | 22.28 |
| 20 | 387.69 | 21.95 | 60 | 378.91 | 21.45 | 100 | 392.30 | 22.21 | 140 | 360.98 | 20.44 | 180 | 393.58 | 22.28 |
| 21 | 392.36 | 22.21 | 61 | 391.03 | 22.14 | 101 | 393.60 | 22.28 | 141 | 362.67 | 20.53 | 181 | 393.69 | 22.29 |
| 22 | 381.31 | 21.59 | 62 | 398.02 | 22.53 | 102 | 390.55 | 22.11 | 142 | 372.98 | 21.12 | 182 | 392.01 | 22.19 |
| 23 | 372.20 | 21.07 | 63 | 399.61 | 22.62 | 103 | 380.78 | 21.56 | 143 | 382.99 | 21.68 | 183 | 382.69 | 21.67 |
| 24 | 378.77 | 21.44 | 64 | 360.63 | 20.42 | 104 | 382.65 | 21.66 | 144 | 350.20 | 19.83 | 184 | 382.65 | 21.66 |
| 25 | 378.99 | 21.46 | 65 | 350.22 | 19.83 | 105 | 383.56 | 21.72 | 145 | 360.14 | 20.39 | 185 | 383.88 | 21.73 |
| 26 | 372.36 | 21.08 | 66 | 340.69 | 19.29 | 106 | 382.55 | 21.66 | 146 | 370.65 | 20.99 | 186 | 388.77 | 22.01 |
| 27 | 362.69 | 20.53 | 67 | 340.15 | 19.26 | 107 | 382.91 | 21.68 | 147 | 388.55 | 22.00 | 187 | 382.51 | 21.66 |
| 28 | 363.44 | 20.58 | 68 | 342.65 | 19.40 | 108 | 392.10 | 22.20 | 148 | 380.25 | 21.53 | 188 | 386.97 | 21.91 |
| 29 | 365.66 | 20.70 | 69 | 360.78 | 20.43 | 109 | 393.20 | 22.26 | 149 | 387.36 | 21.93 | 189 | 370.23 | 20.96 |
| 30 | 388.99 | 22.02 | 70 | 362.89 | 20.55 | 110 | 392.50 | 22.22 | 150 | 388.96 | 22.02 | 190 | 372.45 | 21.09 |
| 31 | 390.61 | 22.12 | 71 | 363.99 | 20.61 | 111 | 392.84 | 22.24 | 151 | 387.56 | 21.94 | 191 | 392.69 | 22.23 |
| 32 | 392.56 | 22.23 | 72 | 362.81 | 20.54 | 112 | 393.58 | 22.28 | 152 | 382.59 | 21.66 | 192 | 352.19 | 19.94 |
| 33 | 351.69 | 19.91 | 73 | 360.54 | 20.41 | 113 | 493.61 | 27.95 | 153 | 383.21 | 21.70 | 193 | 362.03 | 20.50 |
| 34 | 351.77 | 19.92 | 74 | 361.26 | 20.45 | 114 | 393.51 | 22.28 | 154 | 382.14 | 21.64 | 194 | 375.44 | 21.26 |
| 35 | 372.36 | 21.08 | 75 | 366.36 | 20.74 | 115 | 390.58 | 20.11 | 155 | 382.36 | 21.65 | 195 | 360.36 | 20.40 |
| 36 | 360.65 | 20.42 | 76 | 395.66 | 22.40 | 116 | 395.57 | 22.40 | 156 | 391.58 | 22.17 | 196 | 390.68 | 22.12 |
| 37 | 375.80 | 21.28 | 77 | 396.55 | 22.45 | 117 | 490.88 | 27.79 | 157 | 396.58 | 22.45 | 197 | 391.71 | 22.18 |
| 38 | 372.91 | 21.11 | 78 | 395.88 | 22.41 | 118 | 370.22 | 20.96 | 158 | 391.25 | 22.15 | 198 | 382.82 | 21.67 |
| 39 | 395.52 | 22.39 | 79 | 397.88 | 22.53 | 119 | 371.68 | 21.04 | 159 | 396.41 | 22.44 | 199 | 393.57 | 22.28 |
| 40 | 345.11 | 19.54 | 80 | 366.11 | 20.73 | 120 | 371.20 | 21.02 | 160 | 391.25 | 22.15 | 200 | 392.81 | 22.24 |

## III. Discussion of Results

Compressive strength of RAC cubes is plotted in figure 1. Figure 2 shows similar parameter for RAC cylinders. To compare of both RAC cubes and cylinders, compressive strength of both specimen is plotted on same axis. From this figure it may be observed that there is not much difference in the results of individual specimen in comparison to each other. Statistical analysis of the results given in table 1 and table 2 is done and the basic parameters are given in table 3. It is observed that minimum and maximum values of compressive strength of 200 specimens are 27.63 MPa and 34.01 MPa with average compressive strength equal to 30.46 MPa. The deviation of both minimum and maximum values from mean value is equal to 7.9% and 10.4%. The same for RAC cylinders in comparison to its mean strength is recorded as 17.9% and 23.5%. Standard deviation is the statistical measure showing the spread of the individual results from mean value. For cubes and cylinders the standard deviation obtained are 1.04 and 1.29, both values are small showing minor scatter from the average compressive strength. Further analysis of the data reveals confidence interval of 0.14 for 95% confidence level for cubes and 0.18 for cylinders. Therefore at 5% significant level compressive strength may be written as 30.46±0.14 for cubes and for cylinders the same becomes 21.66±0.18.

Based on the average values of all samples the relationship between compressive strength of cube and cylinder is obtained as 0.7. This means compressive strength of RAC cylinder is 0.7 times the compressive strength of RAC cube. Therefore, if compressive strength of cube is available then compressive strength of cylinder will be obtained by multiplying it with 0.7 and incase of reverse situation the value in hand will be multiplied by 1.4286.

The compressive strength results obtained from laboratory testing are also analyzed using regression analysis to develop relationship between compressive strength of cylinders and compressive strength of cubes. Cube compressive strength is treated as independent variable whereas, the compressive strength of cylinder is treated as dependent variable. Based on the analysis following equation is obtained

$$y = 17.796 + 0.125x$$

Where, y is the compressive strength of cylinder and x represents compressive strength of cube. The equation successfully predicts the compressive strength of RAC cylinders from the compressive strength of RAC cubes.

From the above analysis of the results the conversion coefficient of cube compressive strength to cylindrical compressive strength of recycled aggregates concrete with 1:2:4 mix and 0.54 water cement ratio is 12.34% to 18.34% less than the correction factor reported by Hassoun[16] for the strength range (20.0 – 24.5 MPa). Indeed, it may be because of the old concrete aggregates used. Both the correction factor and the numerical equation are found in good agreement with the experimental results presented in this research.

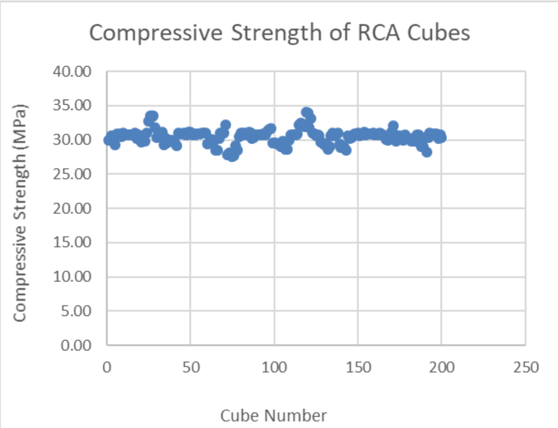


Figure 1: Compressive strength of RCA cubes

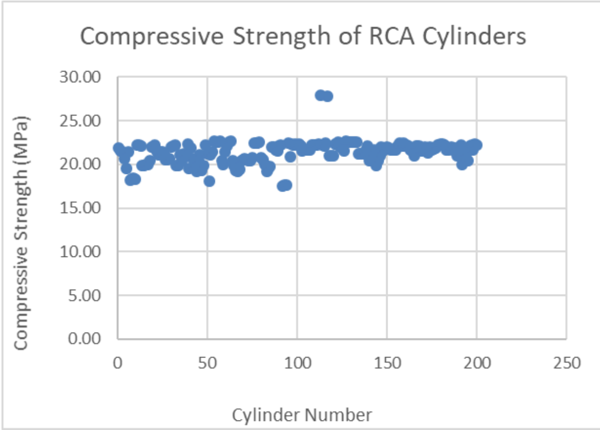


Figure 2: Compressive strength of RCA cylinders

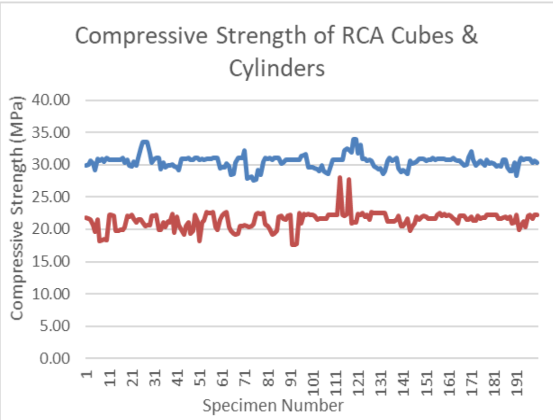


Figure 3: Compressive strength of cubes & cylinders

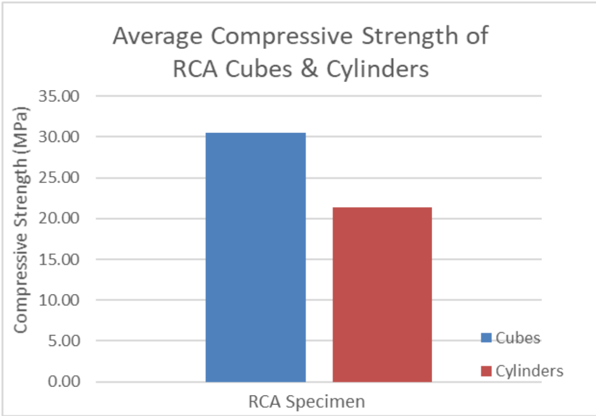


Figure 4: Average compressive strength

**Table 3: Statistical values of compressive strength of cubes and cylinders**

| Measure | Cubes | Cylinders |
|---|---|---|
| Specimen Count | 200 | 200 |
| Minimum Compressive Strength (MPa) | 27.63 | 17.56 |
| Maximum Compressive Strength (MPa) | 34.01 | 27.95 |
| Average Compressive Strength (MPa) | 30.46 | 21.39 |
| Mode | 30.68 | 22.21 |
| Median | 30.69 | 21.66 |
| Standard Deviation | 1.04 | 1.29 |
| Confidence Level (95.0%) | 0.14 | 0.18 |

## IV. Conclusion and Suggestion

In this research paper relationship between compressive strength of cubes and cylinders of RAC is presented. RAC is made by using 50% replacement of natural coarse aggregates with recyclable coarse aggregates from old demolished concrete. 200 samples of each cube and cylinder are prepared using 1:2:4 mix with 0.54 water cement ratio. After 28-days curing samples are tested for compressive strength. Based on the obtained results conversion factor of compressive strength from cube to cylinder is obtained equal to 0.7. Also, numerical equation using regression analysis is presented to give relationship between compressive strength of cylinder and cube. Both conversion factor and numerical equation predict the cylindrical strength from cube crushing strength successfully.

## REFERENCES

[1] Memon B A, "Recent Development on Use of Demolished Concrete as Coarse Aggregates". International Journal of Emerging Technology and Innovative Engineering, Vol. 2, No. 1, 2016.

[2] Li X P, "Recycling and reuse of waste concrete in China Part I. Material Behavior of Recycled Aggregate Concrete", Resources, Conservation and Recycling, Vol. 53, 2008.

[3] Oad M and Memon B A, "Compressive Strength of Concrete Cylinders using Coarse Aggregates from Old Concrete". 1st National Conference on Civil Engineering (NCCE 2013-14) - (Modern Trends and Advancements), April 28th – 29th, 2014.

[4] Bhutto A H and Memon B A, "Effect of Cube Size on Crushing Strength at Different Curing Ages", 1st National Conference on Civil Engineering (NCCE 2013-14) - (Modern Trends and Advancements), April 28th – 29th, 2014.

[5] Hamad A J, "Size and Shape Effect of Specimen on the Compressive Strength of HPLWFC Reinforced with Glass Fibers", Journal of King Saud University – Engineering Sciences, Vol. 29, No. 4, 2017.

[6] Al-Sahawneh A L, "Size Effect and Strength Correction Factors for Normal Weight Concrete Specimens under Uniaxial Compression Stress", Contemporary Engineering Sciences, Vol. 6, No. 2, 2013.

[7] Kumavat H R and Patel V J, "Factors Influencing the Strength Relationship of Concrete Cubes and Standard Cylinders", International Journal of Innovative Technology and Exploring Engineering, Vol. 3, No. 8, 2014.

[8] Bisher H, "Relationship between Cylinder and Core Compressive Strength", Journal of Science and Technology, Vol. 15, No. 1, 2010.

[9] Yuliarti K, Ekkehard F and Mohammed I, "UHPC Compressive Strength Test Specimens: Cylinder or Cube?" The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF – 5), Procedia Engineering, 125, 2015.

[10] Del Viso, J R, Carmona J R and Ruiz G, "Experimental Study on the Influence of the Shape and the Size of the Specimen on Compression Behavior of High Strength Concrete", Experimental Analysis of Nano and Engineering Materials and Structures: Proceedings of the 13th International Conference on Experimental Mechanics, Alexandroupolis Greece, 2007.

[11] Saurav and Gupta A K, "Experimental study of strength relationship of concrete cube and concrete cylinder using ultrafine slag Alccofine", International Journal of Scientific & Engineering Research, Vol. 5, No. 5, 2014.

[12] Graybeal B and Davis M, "Cylinder or Cube: Strength Testing of 80 to 200 MPa (11.6 to 29 ksi) Ultra-High-Performance Fiber-Reinforced Concrete", ACI Material Journal, November 2008.

[13] Gul M, "Effect of Cube Size on the Compressive Strength of Concrete", International Journal of Engineering Development and Research, Vol. 4, No. 4, 2016.

[14] Zabihi N and Eren Ö., "Compressive Strength Conversion Factors of Concrete as Affected by Specimen Shape and Size", Research Journal of Applied Sciences, Engineering and Technology, Vol. 7, No. 20, 2014.

[15] Yi S T, Yang E I and Choi J C, "Effect of Specimen Sizes, Specimen Shapes and Placement Direction on Compressive Strength of Concrete", Nuclear Engineering and Design, 236, 2006.

[16] Hassoun M N, "Design of Reinforced Concrete Structures", PWS Publishers, 1985.