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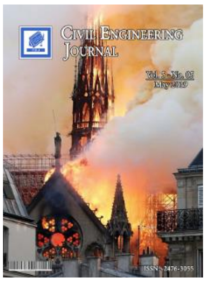

Effect of Mould Size on Compressive Strength of Green Concrete Cubes

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Abstract

This paper is aimed to evaluate the effect of mould size on compressive strength of concrete cubes made with recyclable concrete aggregates. Natural coarse aggregates were replaced with 50% recycled aggregates from old demolished concrete. Five different mould sizes were used to cast 420 concrete cubes using 1:2:4 mix and 0.55 water/cement ratio. In each size equal number of cubes was cured for 3, 7, 14 and 28-day. After curing, weight of cubes was determined followed by testing for compressive strength in universal load testing machine with gradually increasing load. From the obtained results the strength correction coefficients were computed keeping 28-day cured standard size cubes as control specimens. Also, numerical expression based on regression analysis was developed to predict the compressive strength using weight of cube, area of mould and curing age as input parameter. The numerical equation predicts the compressive strength very well with maximum of 10.86% error with respect to experimental results.

Keywords: Cube Size; Compressive Strength; Green Concrete; Old Concrete; Coarse Aggregate.

1. Introduction

Pace of construction of high-rise buildings around the globe is increasing day by day. It is mainly due to lack of space particularly around the city centers where need of space for accommodation and associated facilities is more in comparison to other parts of the country. To meet the need of construction of high-rise buildings in place of old and short height structures is unavoidable. Construction of new high-rise buildings not only consumes large quantities of natural aggregates but on other hand demolishing of old or short height structures generates huge quantum of demolishing waste. Proper disposal of this waste is another serious issue around the globe due to less available space for dumping.

One way of dealing this issue is by reusing it in new construction. This aspect remained active area of research among the researchers since couple of decades. Various components of demolishing waste have been successfully used in new construction. Coarse aggregates are the major component of concrete and occupy more space than other ingredients. Replacement of natural coarse aggregates in to or in percentage not only preserves the natural coarse aggregates but also reduces the waste disposal problem to some extent. Therefore, the use of old concrete as coarse aggregate in new concrete has got the insight of the researchers. Memon (2016) in his research article presented recent developments on

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use of old demolished concrete as course aggregates in new concrete [1-3]. Quality assurance of new construction is ensured by material testing. Quality of concrete is mainly ensured by testing its compressive strength. To ensure this, specimens from running batch of concrete were prepared and cured for required time. ASTM defines procedure for making and curing concrete test specimens [4]. But different countries use different test specimen cube, cylinder or prism for compressive strength evaluation. Also depending on the loading capacity of testing machine available, different sizes of same specimens are in practice. Variation in strength results due to different shapes and sizes of specimens are evident from literature. Graybeal and Davis in their experimental work argued that strength testing of ultra-high-performance concrete is difficult due to machine capacity and cylinder end preparation [5]. Therefore, the authors used three different sizes of cylinders (2", 3" and 4") and cubes (2", 2.78" and 4") as an alternative specimen to test ultra-high-performance concrete in the strength range of 80-200 MPa. The authors used 51 samples of each cylinder and cube. From the experimental finding, authors observed that 3"cylinder and 2.78" and 4" cubes were acceptable as an alternative to standard cylinder specimen.

Although self-compacting concrete can be compacted under its own weight, yet any modification in mix design may affect the mechanical properties of the concrete. To this end Aslani in his research work studied the effect of mould size and shape on the compressive and tensile strength of self-compacting concrete with and without fibers. The authors in his experimental work used 100 mm and 150 mm cubes and 100×200 mm and 150×300 mm cylinders to test the compressive and tensile strength of plain SCC, steel- polypropylene and hybrid-fiber reinforced SCC concrete after 3-, 7-, 14-, 28- and 56-day curing. Based on the obtained results the author observed that effect of size on cube is more than cylinder. The author also developed numerical relationship based on fracture mechanics for size effect for cube and for cylinder [6]. Muhammad and Zuhair also conducted research work to check the effect of specimen size on strength of normal, high strength and self-compacting concretes. The authors conducted research in two phases. In first phase they cast cube and cylinder specimens of various sizes using locally available material. In second phase they analyzed the results and observed that variation of shape and size of specimen affects the strength of concrete. The authors concluded that correction factor for 150 mm to 100 mm cube for normal strength, high strength and self-compacting concrete are in the range of 0.89-1.29, 0.98-1.26 and 0.98-1.22 respectively. Similar values for standard cylinder to 100 × 200 mm cylinder were reported in the range of 0.88-1.08, 0.93-1.07 and 0.95-1.04 for normal, high strength and self-compacting concretes respectively [17]. Hemraj and Vikram conducted research work to explore the factors influencing the relationship between the cube and cylinder. The authors used standard sizes of cubes and cylinders to prepare the concrete specimens and cured them at 7 and 28 days. Based on the finding the authors concluded that there is no unique relationship between strength of cube and strength of cylinder [7].

Misba studied effect of size of cube mould on the compressive strength of concrete. Author used 4" and 6" cubes to cast the specimens. Based on compression tests results of specimen cured at 7, 14 and 28 days the author concluded that the 4" cube specimen gave more strength than 6" size specimen [8]. Matulic et al. for their research paper conducted experimental analysis of effect of size of test specimen on mechanical properties of shotcrete. The authors studied compressive strength and dynamic modulus of elasticity. The authors observed that the small size specimen results in higher compressive strength than large size specimen. Using the test results of dynamic modulus of elasticity, the authors also developed numerical expression to determine compressive strength of shotcrete [9].

In another study to check the effect of mould size and shape Alaa presented his research work using 260 specimens of different sizes from 30 high strength concrete mixes. Based on the experimental findings the author concluded that ratio of compressive strength of 150×300 mm cylinder to 150 mm cube is 0.8. For 100×200 mm cylinder to 150 mm cube the compressive strength ratio is 0.93. Finally, the author also pointed out that the compressive strength ratio of 150×300 mm cylinder to 100×200 mm cylinder is 0.86 [10]. Issa et al. in their research conducted to evaluate the size effect of cylinders on compressive strength of concrete, used 150×300 mm, 100×200 mm, 75×150 mm, and 50×100 mm size plastic moulds to cast 600 cylinders [11]. Experimental evaluation of compressive strength and modulus of elasticity revealed that co-efficient of variation of compressive strength increased as size of cylinder decreased.

Mansur and Islam conducted research to evaluate concrete strength for non-standard specimens. In their work the authors used five different sized of specimen and eleven batches of concrete to cast 210 cylinders and cubes. All the specimens were cured for same age and condition followed by testing them for the compressive strength. From the obtained results and their comparison with similar results available in literature the authors observed that strength ratio using standard cube to other specimen decreased with increase in concrete strength. Also decrease in strength was observed with decrease in size or aspect ratio of the specimen. The authors also developed numerical relationship for concrete strength, specimen size and specimen aspect ratio [12]. In another similar study by Ejiogu et al., for evaluation of effect of dimensions of sample on compressive strength of concrete samples, the authors used 170 concrete samples. They used 100, 150 and 200 mm size cubes, 100×150 mm cylinders and prism [13]. Based on the test results the authors concluded similar conclusion as given by Mansur and Islam [12]. Niloufaralso conducted research to check effect of size and shape of specimen on concrete strength at early and late age by PUNDIT (Non-destructive testing technique). Based on test results the author concluded that not only the shape but size of specimen also affects the strength of concrete. The author further observed that testing with non-standard size of specimen but at late age can diverge the results [14]. Therefore, should be treated accordingly. Yi et al. conducted research to check the effect of mould size, shape and placement direction on compressive strength of concrete based on fracture mechanics. The authors used cube, cylinder and prism to test compressive strength of concrete. Observation from the test results shows that the effect of shape, size and placement direction is presented on compressive strength of concrete [15]. In another study by Krishna et al. conducted to study the effect of size and shape of specimen on compressive strength of glass fiber reinforced concrete, authors used standard cylinder, standard cube and 100×200 mm cylinder for the purpose [16]. Based on the obtained results the authors concluded almost similar conclusion as by Yi et al. [15].

Hasan et al. in their research work performed finite element modeling to check the effect of specimen size, slenderness ratio and rate of loading on compressive strength of high-performance concrete using prismatic specimen with 0.5 to 3.5 slenderness ratio. From the results of variation of stress-strain, the authors observed maximum stress with slenderness ratio equal to one. Whereas, decrease in stress concentration, was recorded with increase in slenderness ratio. The authors also performed regression analysis to develop equations for dynamic strength dependency on strain rate and length to depth ratio. The authors also verified their developed equation with results from the literature [18]. Josef and Peter has also performed similar sort of research but used high strength fiber reinforced concrete to study the effect of specimen size [19].

This motivated for the research presented in this research article. In this research work effect of cube size on compressive strength of green concrete cubes is presented. The cubes were made with 50% replacement of natural coarse aggregates with coarse aggregates from demolished old concrete. The selection of 50% replacement was made based on the recommendations of Oad and Memon [2]. The details of material and testing is given in relevant section. From the obtained results correction coefficients due to mould size other than standard size (6"×6"×6") were developed. These coefficients can be used to correct the strength equivalent to strength of standard size cube. Also, numerical equation to predict the strength of cube based on mould area and weight of cube was developed using regression analysis. The predicted strength results using developed equation were in good agreement with experimental results.

2. Materials and Testing

Large blocks of demolished old concrete (Figure 1) were collected from balcony slab of a reinforced concrete school building about 50-year old situated in Nawabshah city. These blocks were manually hammered down to maximum size of 20 mm followed by screening of the material for cracked and damaged particles. After discarding cracked and damaged particles sieve analysis of the material was carried out following the standard procedure of sieving with maximum sieve size of 20 mm. Natural coarse aggregates (crushed) were also sieved using the same sieve sizes as used for recycled concrete aggregates. The result of sieving is plotted and compared in Figure 2.

Along with recyclable concrete aggregates from old concrete, crushed natural coarse aggregates, hill sand and ordinary Portland cement were used in preparation of concrete cubes using 1:2:4 mix and 0.55 water cement ratio. The concrete ingredients were batched using weight batching process. Five different sizes 2" ×2" ×2", 3" ×3" ×3", 4" ×4"×4”, 6" ×6" ×6" and 9" ×9" ×9" of cube moulds were used to cast the cubes. As explained earlier both natural coarse aggregates and recyclable concrete aggregates from old concrete were used in 50% proportion. For each size of mould 84 cubes were cast, thus total of 420 concrete cubes were used in this research work. In each size of the mould equal number of cubes (21) was cured for 3, 7, 14 and 28 days by immersing in water.

After curing, cubes were allowed to air dry in laboratory for 24-hour, followed by determination of weight of each cube. For accurate determination of the results digital weight balance was used for the purpose. Finally, all the cubes were tested in universal load testing machine for compressive strength. The universal load testing machine is digital with display of applied load. The load was applied at the constant rate of 0.25 MPa per second till failure of the specimen. At failure the machine displays the peak load. The recorded failure load was then divided by the area of specimen to obtain the compressive strength of the specimen. The average values of weight and compressive strength of the cubes are given in Tables 1 and 2.

Figure 1. Old demolished concrete

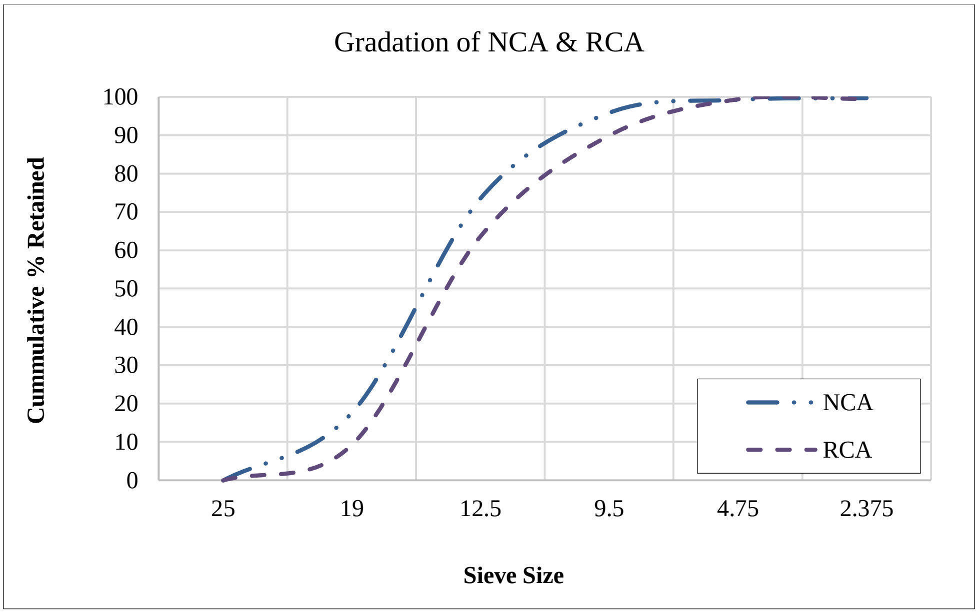


Figure 2. Sieve analysis of NCA and RCA

Table 1. Average weight (kg) of concrete cubes at different curing ages

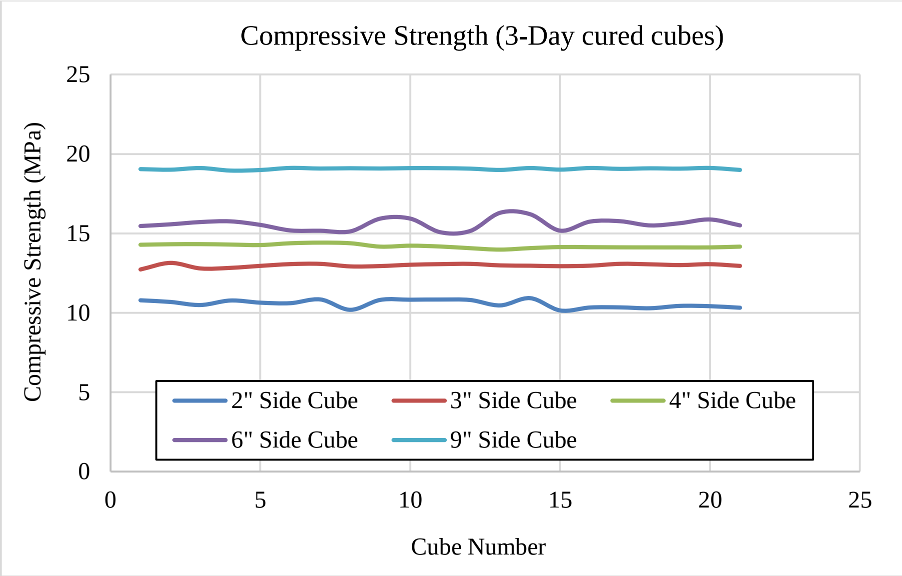
#	Size	Curing Age (Days)			
		3	7	14	28
1	2"×2"×2"	0.31	0.32	0.35	0.41
2	3"×3"×3"	1.11	1.18	1.23	1.32
3	4"×4"×4"	2.58	2.60	2.63	2.82
4	6"×6"×6"	8.52	8.43	8.42	8.62
5	9"×9"×9"	28.51	28.45	28.29	28.83

Table 2. Average compressive strength (MPa) of concrete cubes at different curing ages

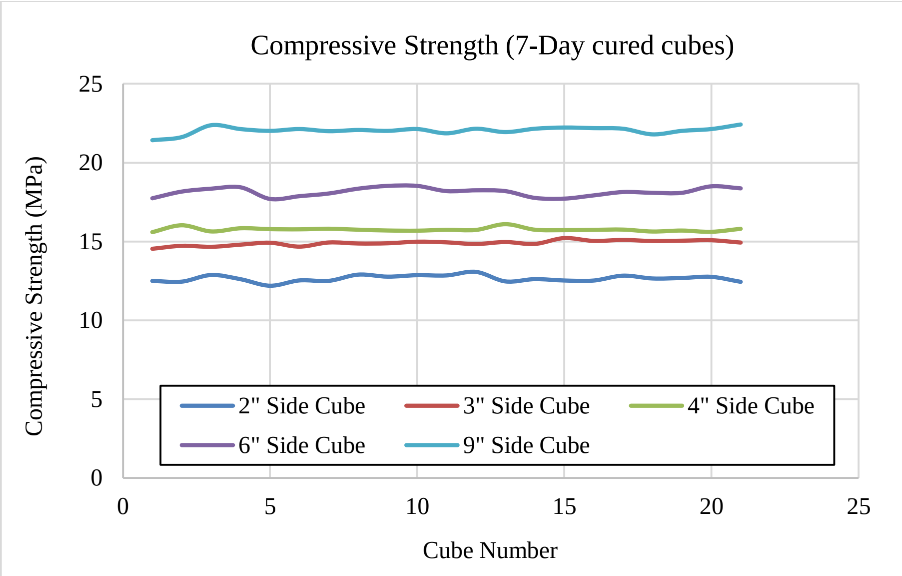
#	Size	Curing Age (Days)			
		3	7	14	28
1	2"×2"×2"	10.56	12.65	14.21	18.40
2	3"×3"×3"	12.98	14.90	15.76	20.21
3	4"×4"×4"	14.20	15.75	17.59	22.70
4	6"×6"×6"	15.59	18.14	20.25	25.45
5	9"×9"×9"	19.07	22.04	24.74	30.07

3. Results and Discussion

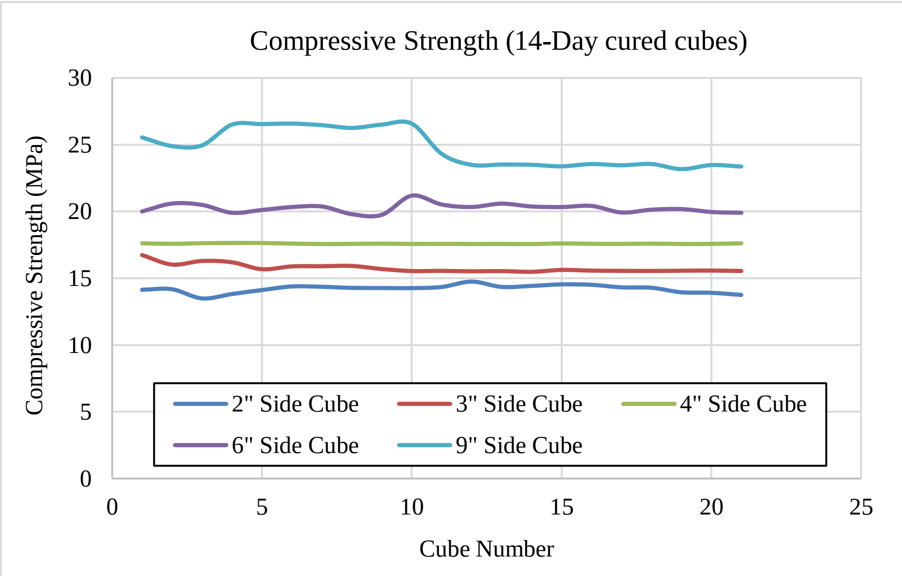
The compressive strength results obtained by using failure load and area of specimen in numerical expression of stress were analyzed. It is observed that the percentage difference between individual readings of stress within the group of specimens is less than 15% which shows compatibility of the results and proper casting of the specimens. Similar observation was also made for the weight of the cubes, the percentage difference between the weight of specimens remained within acceptable limits. Compressive strength vs cube numbers are plotted in Figure 3 for all curing ages considered in this research work. Sub plot (a) of this figure shows compressive strength trend all cubes for 3-day curing. Similarly, subplot (b) to subplot (d) shows the same for 7-, 14- and 28-day curing. From this figure it may be observed that the trend of compressive strength gain is similar in all cases.



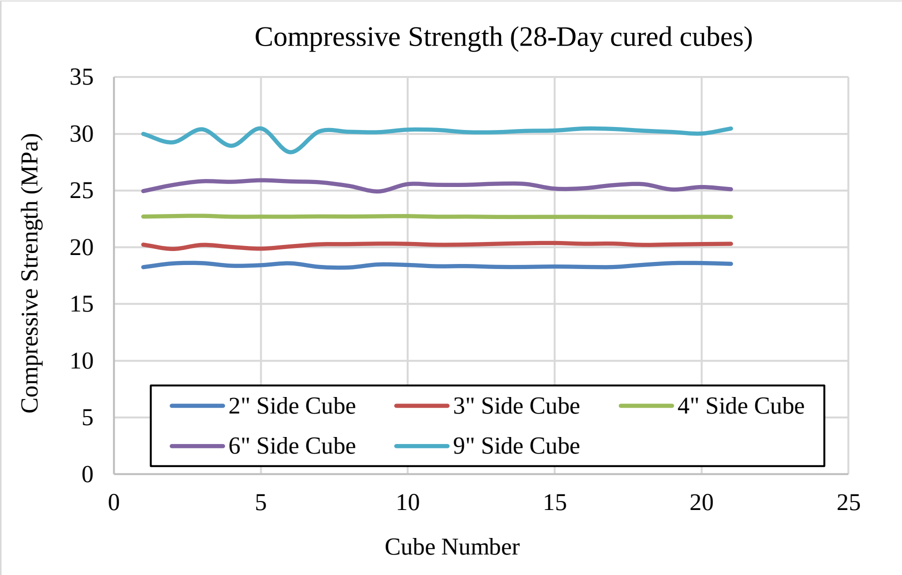
(a) 3-day curing



(b) 7-day curing



(c) 14-day curing



(d) 28-day curing

Figure 3. Compressive strength of all cubes

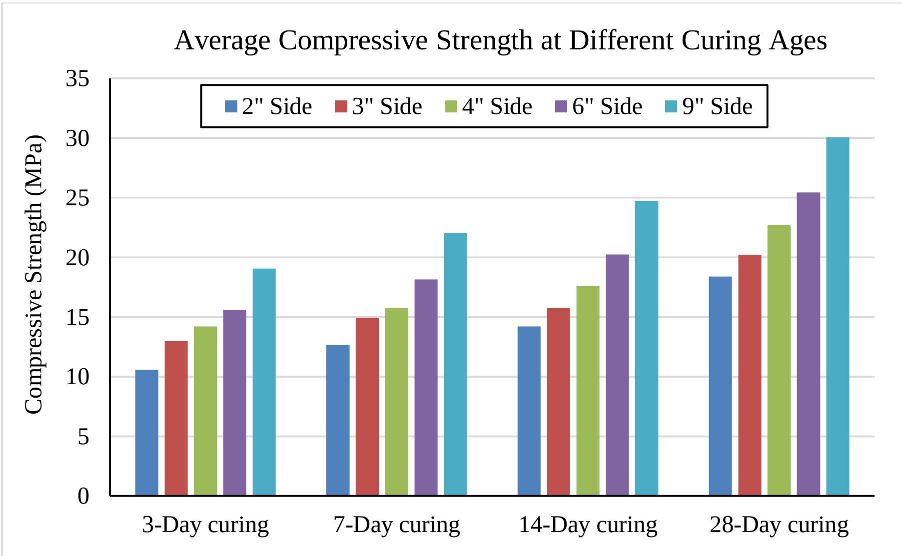


Figure 4. Compressive strength of cubes at all curing ages.

Figure 4 shows the average values of compressive strength at all curing ages for purpose of visualization and comparison. It may be observed that increase in compressive strength is recorded with increase in specimen size. Therefore, if any project site uses larger cube size in preparation of samples for strength testing will definitely results in higher strength values. These values may mislead the observer if size of the specimen is not declared. Therefore, strength correction should be applied. As the standard size of cube specimen is 6" x 6" x 6", and standard curing is 28 days, therefore compressive strength relevant to above two parameters was taken as standard. Accordingly, the correction coefficients due to difference of mould size were evaluated and are given in Table 3. From this table it may be observed that as size of specimen reduces the correction co-efficient becomes smaller and with increase in size of specimen than standard size coefficient becomes larger showing that the strength reported is more compared to the strength of standard size specimen. These coefficients may be used to equate the compressive strength of non-standard size cube to compressive strength of standard size cube cured at 28 days. The strength of non-standard size cube is divided with the coefficient given in table to obtain the strength equivalent to standard size cube.

In addition to above regression analysis was made to predict numerically the compressive strength based on weight of cube, curing age and area of mould. The predicted equation is given as under

$$y = 8.9393 + 0.000479 \times A + 0.3467 \times C - 0.5102 \times W \quad (1)$$

In above equation dependent variable y represents target strength, A is area of mould, C denotes curing age (3, 7, 14 or 28) in days and W represents weight of the cube. In regression analysis significant F is the check variable which shows the reliability of the results and should be less than 0.5. In the current regression analysis both F and P values obtained are less than 0.5. Also, the R-square value is equal to 96.9%. This shows the obtained equation is reliable in predicting the strength values. Using this equation compressive strength of all cubes tested for this research work was computed. It was observed that the equation predicted the compressive strength very well with minimum and maximum error equal to -10.72% and 10.86% respectively. Figure 5 shows the comparison of experimental observation of 4"×4"×4" cubes cured for 28 days vs the strength results obtained from numerical equation given in (1). It may be observed that the numerical equation produces strength results with similar trend to the experimental observation. However, for the particular comparison the predicted strength is about 4% less than experimental results.

During the testing process, the specimens were carefully observed for cracking and failure. Under gradually increasing load the crack started from top layer of the cube and propagated towards center and then towards bottom layer. With further loading first corners of the cube at top layer started reputing followed by rupture of the sides of cubes. At this point front and back faces of the cube were all cracked. Finally, the cube ruptured completely. Although old concrete as coarse aggregates is used in 50% dosage for preparation of the cubes, yet the failure mechanism of the cubes follows same pattern as of all-natural aggregate cubes. This shows viability of the old concrete as coarse aggregates in new concrete.

Table 3. Correction coefficients

#	Size	Curing Age (Days)			
		3	7	14	28
1	2"×2"×2"	0.42	0.50	0.56	0.72
2	3"×3"×3"	0.51	0.59	0.62	0.79
3	4"×4"×4"	0.56	0.62	0.69	0.89
4	6"×6"×6"	0.61	0.71	0.80	1.00
5	9"×9"×9"	0.75	0.87	0.97	1.18

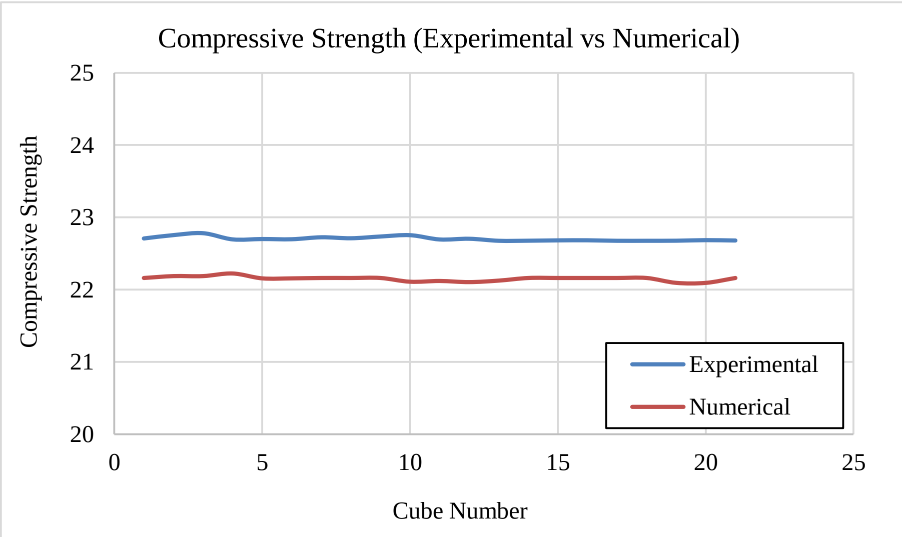


Figure 5. Comparison of experimental and numerical strength results of 4" side cube (28-day curing)

4. Conclusion

For this research work total of 420 concrete cubes with 50% recyclable old demolished concrete as coarse aggregate were cast using five different mould sizes to check the impact of mould size on compressive strength. After desired curing time, weight and compressive strength of all beams were determined. From the obtained results correction coefficients for compressive strength were determined by taking 150mm each size cube cured at 28-day as standard. These coefficients may be used to find compressive strength of non-standard size cubes equivalent to standard size cube cured at 28-day. Also, regression analysis was done to develop numerical equation to predict the compressive strength. Weight, area of cube and curing age were used as input parameters. The developed equation predicts the compressive strength in good agreement with experimental observations.

5. Conflicts of Interest

The authors declare no conflict of interest.

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