Identifying the Impact of Concrete Specimens Size and Shape on Compressive Strength

A Case Study of Mud Concrete

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Abstract—**Mud is a versatile material with a prodigious interest for traditional wall construction such as wattle and daub or rammed earth, with and without reinforcements. Mud concrete has been identified as a unique modern material, though more research is required for generalization. Compressive strength, a measure of concrete quality usually depends on the specimen's size and shape. Specimen's size and shape for mud concrete is yet to be identified and established. Addressing this knowledge gap, this research aims at investigating the effect of specimen's size and shape on the compressive strength of mud concrete. At first, the compressive strength's variation was estimated by varying water content. Then, the water content was kept constant and the variations of compressive strength were estimated by varying specimen size and shape. Both experiments were conducted for different mixtures and percentages of cement. The initial results suggest that the compressive strength of mud concrete decreases with the increase of water content. The decrease indicated linear behavior with a constant gradient. Less influence on compressive strength was observed by considering specimen size, while the shape showed more contribution. The effect of specimen size and shape was increased with the increase of compressive strength.**

Keywords-mud concrete; compressive strength; specimen size and shape

I. Introduction

Mud concrete is a modern composite material made out of soil consisting of gravel (sieve size: 4.75mm≤gravel≤20mm), sand (0.425mm≤sand≤4.75mm) and fine particle (≤0.425mm) in different compositions, which is composed of elements that have various strengths for different applications such as walling material, paving blocks etc., with various cement percentages and types [1, 2]. Only a small number of researches have been conducted and fewer standards have been set to evaluate the strength characteristics of mud as a construction material. To determine the compressive strength of concrete, usually 150mm×150mm×150mm standard cubes are used for compressive strength test [2]. Previous studies can be found on the effect of size and shape for conventional cement concrete and cement concrete with several other constituents such as glass fiber, admixtures, etc. Literature testifies that hardening mechanical properties of mud concrete in different proportions are dissimilar to cement concrete, different size and shape effects can be expected. Therefore the effects of specimen's shape and size on the compressive strength of mud concrete are, to the best of our knowledge, not yet studied.

Cross sectional shape of the specimen and mix proportions were considered mainly as the two effective factors for compressive strength of concrete. Further, there are advantages of using smaller specimens, which affect the test results such as ease of handling, likelihood of accidental damage, cheaper moulds, lower capacity testing machine and type of machines used [3, 4]. According to authors in [5], the compressive strength of materials such as concrete, stone, etc. is a function of the test specimen's dimension [5]. The size of the test specimens is prescribed in different standards, but occasionally more than one sizes are permitted. In the case of cement concrete, the compressive strength test specimens vary from one country to another. Table I summarizes the standard specimens used in different countries. Table II summarizes some of the studies regarding the effect of shape and size of the specimens on the compressive strength of cement concrete. Many researches concentrated on the size and shape effect of the specimens and most of them found that the strength decreases with increase of the specimen size [7-12]. Authors in [10] established that the ratio of cube to cylinder compressive strengths decreases with an increase in the level of concrete strength [10].

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TABLE I. STANDARD SPECIMENS USED.

Specimen	Country	Source
150mm×300mm cylinders	USA, France, Australia, America, S. Korea, Canada, Norway	[6-9]
150mm cubes	UK, Europe	[6, 7, 9]
Cylinders and cubes	Turkey	[6]
200mm cube, 150mm×300mm cylinder	Old Turkish standard	
300mm cubes, 150mm×300mm cylinder	New Turkish standard	
150mm×150mm×600mm Prismatic specimen	Russia	[8]

TABLE II. RELATIONSHIP OF COMPRESSIVE STRENGTH OF SPECIMEN WITH STANDARD

	Relationship	Relationship between	Source
(1)	$\frac{P}{P6} = 0.56 + \frac{0.697}{\frac{v}{6hd} + \frac{h}{d}}$	Strength of cylindrical, cubical or prismatic specimen to strength of 150mm cube	[11]
(2)	$\frac{fcy}{fc'} = 0.8 + \frac{0.4}{\sqrt{1 + \frac{h-d}{50}}}$	Strength of cylindrical specimen to strength of standard cylinder	[12]
(3)	$fcy = \frac{0.49fc'}{\sqrt{1 + \frac{d}{2.6}}} + 0.81fc'$	Strength of cylindrical specimen to strength of standard cylinder	[9]
(4)	$fcu = \frac{1.17fc'}{\sqrt{1 + \frac{d}{2.6}}} + 0.62fc'$	Strength of cube specimen to strength of standard cylinder	[9]
(5)	$fpr = \frac{1.02fc'}{\sqrt{1 + \frac{d}{2.6}}} + 0.52fc'$	Strength of prisms specimen to strength of standard cylinder	[9]
(6)	$\frac{fc}{fcu15} = 1.317 - \frac{0.1694}{\frac{v}{b15hd} + \frac{h}{d}}$	Strength of cylindrical, cubical, or prismatic specimen to strength of 150mm cube	[13]

NOMENCLATURE

P	Compressive strength of cylindrical, cubical, or prismatic specimen
P6, fcu15	Compressive strength of a 150mm cube
fc'	Compressive strength of standard cylinder
fcy	Compressive strength of general cylinder
fcu	Compressive strength of general cube
fpr	Compressive strength of general prism
b	Length of cubic specimen
v	Volume of specimen
h	Height
b15	Length of 150mm cube
d	Lateral dimension

In [20], the ASTM C39/C39M-03 is intended, cylindrical concrete specimens as the standard test specimen to determine the compressive strength. Authors in [11] proposed (1) to show the relationship of compressive strength of a concrete specimen and its size and shape. Authors in [12] suggested (2) to convert the compressive strength [12]. Both considered the conversion factor as a function of the specimen's volume (*v*), aspect ratio (*d/h*), height (*h*), maximum lateral dimension (*d*), which were considered the main parameters for compressive strength. The effect of the specimen's size is stronger for low strength concrete and it was more notable for specimens with less slenderness ratio. The effect of the specimen's size for cubes and prisms is stronger than for cylinders [6, 17]. Equations (3)-(5) were suggested by authors in [9], to obtain compressive strength relationship of general cubes with standard cubes, compressive strength of prisms with standard cubes and of general cylinder to standard cylinder respectively [9]. Authors in [13] developed (6) to relate the compressive strength of general cylinder with the standard cylinder's [13]. According to authors in [17], the effect of the shape is unimportant and the effect of the size is noticeable in static compressive strength, but it is insignificant in dynamic tests. Further, they reported that the effect of the specimen's size and shape on concrete static test is independent of concrete's grade [17]. Moreover, the variation of compressive strength of 100mm cubes and 150mm standard cubes were in the range of 5-6% and the strength of smaller cubes was higher than that of larger cubes [5, 6].

Based on the above, experiments were carried out for mud concrete to identify the relationship between compressive strength on specimen's size and shape.

II. MATERIALS AND METHODS

A. Materials Used

The soil for mud concrete mixture was extracted and sieve analysis was performed for randomly selected samples to identify particle size distribution. Three sieve analyses were done and the average was used. In these experiments, the extracted soil samples were developed by adding gravel and sand to make soil to be 35%, gravel (sieve size 4.75mm≤gravel ≤20mm), 60% sand (0.425mm≤sand<4.75mm), and 5% fine particles (<0.425mm). The maximum gravel size used in all mixes was 20mm which was identified as the best proportion for mud concrete [1]. The samples were cast in different cement percentages varying from 10% up to 20% and type 1 ordinary Portland cement was used in all mixtures. The mud concrete mix proportions used are provided in Table III. Figure1 shows the materials used to prepare the mud concrete.

B. Casting procedure: Mud Concrete Mixing and Specimen Preparation

1) Step 1: Identifying the Compressive Strength Variation with Moisture Content

When creating the mixture, the moisture percentage of dry mix can have slight differences, although the added water quantity during mixing is the same. Therefore, before addressing the main objective, finding out the effect of specimen's size and shape on compressive strength, the variation of strength of mud concrete with moisture content was investigated. In this step, five different water contents were added for each mix (M1-M5). Water content increased by 250ml gradually, starting from 2000ml up to 3000ml, which is identified as the workable range for mud concrete [1, 2]. 150mm×150mm×150mm cubes were prepared using steel moulds for the test. Three cubes (X_1, X_2, X_3) were cast from each mix which was mixed with different amounts of water (W_j for i=1,…,5). The preparation plan of these mud concrete specimens is indicated in Figure 2. After 24h from casting, the specimens were taken out from the moulds and all were subjected to moist-curing under equal conditions until the time of test. A total of 75 cubes were cast. After 28 days of curing, all cubes were tested for dry compressive strength. In addition, three samples from each mix were oven dried at constant temperature (105°C) for 24hrs to calculate the moisture content.

TABLE I. MUD CONCRETE MIX PROPORTIONS

Mixture code	Cement %	Gravel %	Sand %	Fines %
M_1	10	35	60	5
M_2	14	35	60	5
M_3	16	35	60	5
M_4	18	35	60	5
M_5	20	35	60	5

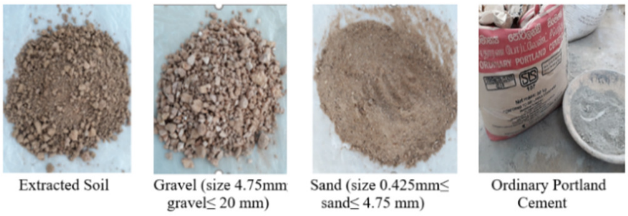

Fig. 1. Material used to prepare mud concrete

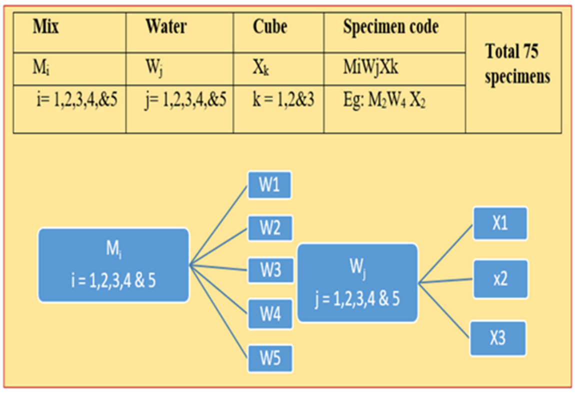

Fig. 2. The preparation plan of mud concrete specimens

2) Step 2: Finding the Effect of Specimen's Size and Shape on Compressive Strength

Five different mud concrete mixes were made while keeping water content constant to investigate the relationship of compressive strength variation with the specimen's size and shape. The dimension and the shape of the selected specimens are shown in Table IV and Figure 3.

Fig. 3. Steel moulds used for casting

All specimens (cubes, cylinders) were cast in three layers in steel moulds inside the laboratory and with no vibrations during compacting. After 24h from the casting, the specimens were taken out from the moulds and were subjected to moist-curing under equal conditions until the time of test. A total of 135 specimens (Table V) were cast. After curing, the cubes were tested for dry compressive strength. In addition, three samples from each mix were oven dried at constant temperature (105°C) for 24h to calculate moisture content. The process of mixing and casting in the moulds is shown in Figure 4. Figure 5 shows the prepared cylindrical and cubical specimens.

TABLE II. SHAPE AND SIZE OF SPECIMENS

Type	Shape	Dimension (mm)	Aspect ratio (*h*/*d*)	Lateral dimension *d* (mm)
Cube	Square	100×100×100	1	100
Cube	Square	150×150×150	1	150
Cylinder	Circle	150×300	2	150

Fig. 4. Mud concrete mixing and casting to different mould sizes and shapes

TABLE III. SPECIMEN PREPARATION DETAILS

Mix (M_i=1,2,3,4,5)			
Age of test (days)	No. of specimens		
	150mm cube	100mm cube	150mm×300mm cylinder
7	3	3	3
14	3	3	3
28	3	3	3
	9	9	9
Total	27		
Total no of specimens × five mixes=27×5=135			

Fig. 5. Prepared specimens for testing

C. Procedure of the Compressive Strength Test

To determine the compressive strength in both above mentioned steps, axial compressive strength tests were carried out. An axial compressive load was applied using a universal compressive strength testing machine with a capacity of 2000kN under a constant rate of 6.8kN/s until the failure of the specimen. The tests were performed in accordance with the [18]. Figure 6 shows a few photos of specimens' testing. In Step 1, the samples were tested for 28days, while in Step 2 the samples were tested for 7, 14, and 28 days. The top surface of the cylinder was finished with a trowel, which was not really plane according to [14]. Therefore, prior to the testing, the cylindrical specimens were ground to level the surface.

Fig. 6. Testing for compressive strength

III. RESULTS AND DISCUSSION

A. Step 1: Identifying Compressive Strength Variation with Moisture Content

Figure 7 shows the behavior of mud concrete against the compressive strength test, with different moisture contents. The results indicate that the increase in water content causes a linear decrease in compressive strength at a constant rate. According to the results, gradient (*m*) of each graph gives equal values with negligible difference. Thus, (7) can be derived to determine the compressive strength for any mix, with any water content value.

$$y = mx + c \quad (7)$$

where, *y*=compressive strength, *x*=water % from the dry mix,

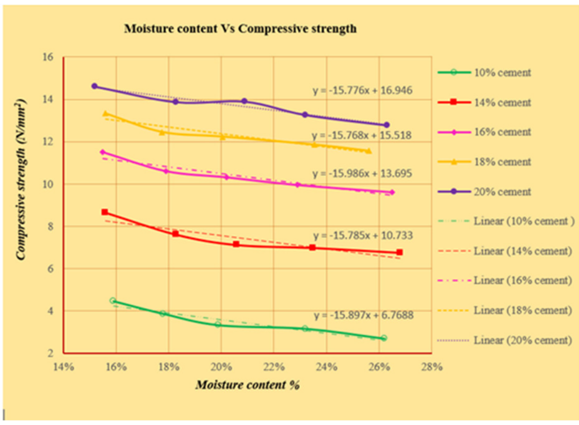

Fig. 7. Compressive strength behavior of the mud concrete with different moisture content

B. Step 2: Finding the Effect of Specimen's Size and Shape on Compressive Strength

Although the added water was content kept constant, the moisture percentages of dry mixes showed slight variations (Table IV). Since the compressive strength results obtained in this step included these slight moisture content variations, it was decided to take the compressive strength values of all the mixes to a common moisture content value, which is 19%.

TABLE IV. CALCULATED MOISTURE CONTENT

Mixture code	Moisture %
M_1	19.7
M_2	19.2
M_3	18.9
M_4	18.3
M_5	19.1

The compressive strength test results were recalculated to a common moisture content value, as the compressive strength shows a drastically change with the moisture content with the results obtained in Step 1. Compressive strength variations with age to different shapes and sizes for the selected mixes are shown in Figure 8. The results show that the compressive strength increased with age, exhibiting a large increment for the first 7 days, and showing a slow increment with time.

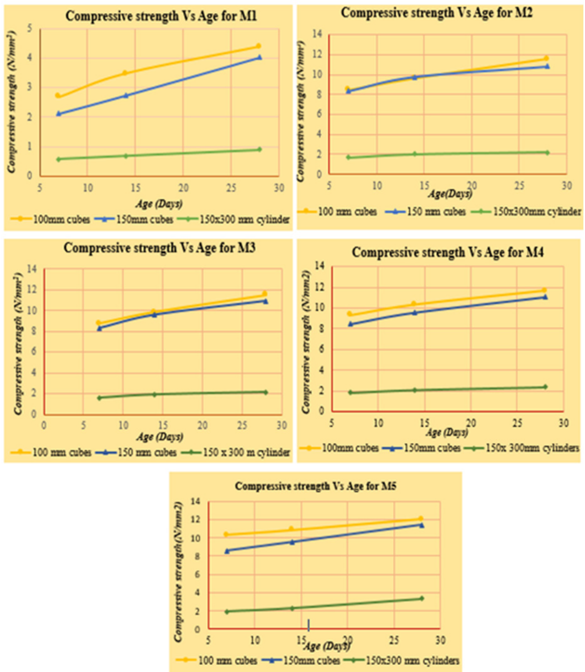

Fig. 8. Compressive strength variation with age for different mixtures.

The variations of compressive strength with cement percentage regarding different shapes and sizes for the selected mixes are graphically represented in Figure 9. These results indicate that the compressive strength is increased with the increment of cement percentage. However, the rate of this increment was higher for lower cement percentages (10% to 14%) and lower for higher cement percentages (14% to 20%). It can be concluded that the pattern of the compressive strength variation is uniform for all the tested specimen shapes and sizes. The cylinder specimens showed lower strength than the cubes in all mixes. Moreover, the difference in compressive strength at 28 days for both 100mm and 150mm cubes was found negligible, regardless to the cement content. This fact is in accordance with the findings for cement concrete in [6].

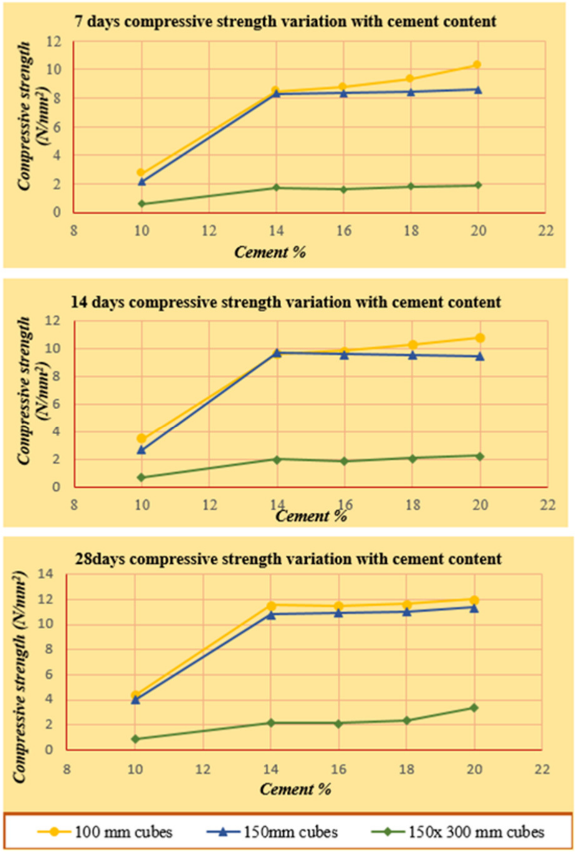

Fig. 9. Compressive strength variation with cement percentage

C. Relationship of Compressive Strength with Different Sizes and Shapes of the Specimens

The 150mm cubical specimen's compressive strength was taken as the standard to compare the relationship of compressive strength with different sizes and shapes of the specimens. In the analysis of the results, the ratio of 28 days compressive strength of cubes with size of 100mm×100mm×100mm to the cubes with size of 150mm×150mm×150mm was between 1.05 and 1.09, and the average of this ratio was 1.06. For 7 days and 14 days, the same ratio was found to be 1.13 and 1.10 respectively. These results indicate that the effect of specimens' size for the above two cube sizes decreased with age. The ratio of 28 days compressive strength of 150mm×300mm cylinders to 150mm×150mm×150mm cubes was between 0.17 and 0.21, with an average of 0.2. For 7 days and 14 days specimens, the same ratio was 0.22 in average. These results indicate that the effect of specimen's shape also decreased with age.

Figure 10 illustrates how the compressive strength of 100mm×100mm×100mm cubes and the compressive strength of 150mm×300mm cylinders behaved against the 150mm×150mm×150mm cube's compressive strength. The solid and dashed lines of the graph in Figure 10 indicate the best-fit lines obtained from the linear regression analysis and the lines of equality *y=x* respectively. The equations showed in Figure10 are obtained from linear regression analysis of the test data points. In [3], the cube's compressive strength of cement concrete is found as 1.25 times the compressive strength of the cylinder, but the actual strength relationship of the two shapes (cube and cylinder) depends on the strength level and the moisture content of the concrete during testing. In [10], the factor to convert the cylindrical specimen's strength to cube's strength in normal cement concrete was 1.2. However, the correction factor depends on the level of the concrete strength, while the high strength concrete is less affected than the low strength concrete [19].

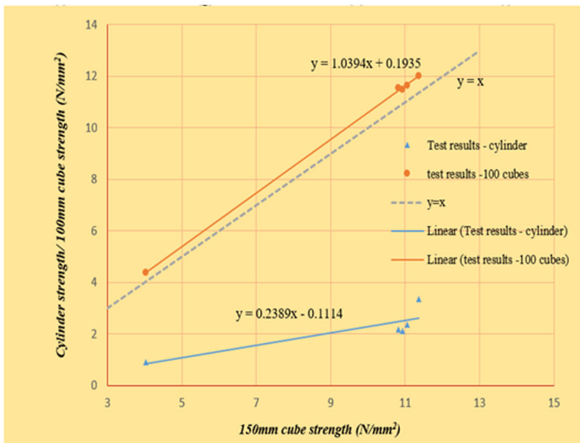

Fig. 10. Compressive strength variation for 150mm×300mm cylinder and 100mm×100mm×100mm cubes versus 150mm×150mm×150mm cubes

D. Crack Propagation and Failure Zone

During the initial stage of loading, cracks were developed longitudinally, and when the applied load increased, the initial cracks were sharply propagated from top to bottom until the failure of the specimen (Figure 11). When the load on the cubical specimens increased, the cracks were slowly propagated and decreased (due to the effect of shear) toward the center of the cube. The center core was relatively undamaged, following the 'non explosive' failure pattern [11, 15]. According to authors in [11], failure pattern of this cylindrical specimens can be defined as cone and split failure [11, 20] and not as shear or splitting and shear [3, 11], or explosive [3, 21].

IV. CONCLUSIONS

The findings of this research can be concluded as:

- The 150mm mud concrete cube's compressive strength is 0.94 times the compressive strength of the 100mm cubes. The 150 cube's compressive strength of mud concrete is 5 times the compressive strength of the cylinder. Therefore, a relationship between the size and shape of specimens with mud concrete's compressive strength is identified, as it was found for cement concrete in literature.
- The increase in water percentage exhibited a decrease in the compressive strength linearly at a constant rate with negligible difference. This finding can be used to determine the compressive strength for any mix, with any water content value.

- The pattern of the compressive strength variation was uniform for all the mud concrete specimen shapes and sizes which were tested, and the cylindrical shaped specimens showed lower strength than the cubes in all mixes.

(a) (b)

Fig. 11. Observed failure patterns of the specimens: (a) Observed crack similar to cone and split crack, (b) observed crack similar to non explosive

V. LIMITATIONS AND FUTURE WORK

This experimental study was done for a limited range of cement content of mud concrete mixes (cement content 10%-20%). The research was also limited to one moisture content value (19%) due to time and financial limitations for casting. Moreover, the range of sizes and shapes which were tested during the research were limited to the selected number of types (100mm and150mm cubes, 150mm×300mm cylinders) due to resources limitations. The findings of this research can be taken as a basis for further research directions with improvement regarding more specimens' sizes, shapes, cement, and water content percentages. Thereby, further directions are open to develop a quantitative relationship between the size and shape of specimens with mud concrete's compressive strength, as found for cement concrete in literature.

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