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Effect of Specimen Size on Compressive, Modulus of Rupture and Splitting Strength of Cement Mortar

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Abstract: It is well known that the strength of any tested matrix materials like concrete or mortar is affected by the specimen size; therefore it is important to consider the effect of specimen size when estimating the ultimate strength of such materials. This study presents the effect of specimen size on the mechanical properties of cement mortar. These include the compressive, splitting strength and modulus of rupture. For the compressive strength three different sizes of cylinder and three sizes of cubes are used and the same sample sizes are used for testing the splitting strength. Also three different sizes of specimen are used for modulus of rupture. Preparation, casting and testing procedures are carried out according to ASTM specifications using constant mix proportion of cement/sand and water cement ratio. The obtained results show that the three mechanical properties of mortar affected by the specimen size specially the compressive strength and splitting strength of cylinders. Some best fit relationships that relate these properties are presented in this study although it cannot be generalized due to the fact that the presented results are based on limited number of tested specimens with constant mix proportion.

Key words: Cement mortar, compressive strength, modulus of rupture, size effect, splitting strength

INTRODUCTION

It is well known that the nominal strength of specimens made of quasi-brittle materials such as mortar, concrete, rock, ice, ceramic and composite materials are affected by the specimen size (Bazant, 1984; Bazant *et al*., 1991), more specifically, the nominal strength of laboratory size specimens differ from that of structural members used in construction sites of real structure. The difference in the nominal strength is a direct consequence of energy release into a finite-size fracture process zone (damaged localized zone). Gonnerman (1925) has experimentally showed that for concrete the ratio of the compressive failure stress to the compressive strength decreases as the specimen size increases. This phenomenon of reduction in strength due to specimen size increase is called the reduction phenomenon and this is due to the fracture mechanics-based derivation of size effect law (Gonnerman, 1925). Earlier researches have focused on pure tension and shear loading conditions rather than compressive, splitting and flexural loading conditions. Recent studies, based on size effect on the compressive strength, became a focus of interest among researchers (Cotterell, 1972; Bazant and Xiang, 1994; Jen and Shah, 1991; Bazant *et al*., 1997). Most design codes for structures do not consider the effect of size which is an important phenomenon. Since, quasi-brittle materials fail by formation of cracks and initiation of these cracks in materials like mortar and concrete are affected by micro-cracks which depends upon so many factors, in which coarse aggregate size is one of them. Therefore; for such materials, size effect has to be considered in estimating their strength characteristics. In this field there is a lack of work for cement mortar, therefore, in the present study the effect of specimen size on the compressive, splitting strength and modulus of rupture of cement mortar are investigated. The importance of knowing and estimating mechanical properties of mortar is based on the facts that mortar at present is widely used in restoration and rehabilitation of defected concrete and masonry structures and its application in ferrocement structures as well, therefore it is necessary to precisely estimate its strength.

MATERIALS AND METHODS

Materials for cement mortar: Essentially, cement mortar is composed of cement, sand and water. In the present study only a single mix proportion of cement: sand ratio equal to 1:2 by weight is used with a water cement ratio equal to 0.45. The properties of each material used in this study are presented below:

- **Cement:** Normal portland cement (I) produced locally that comply the Iraqi Specification (IQS, No.5, 1984) was used for all the mixes of mortar

Table 1: Details of tested samples

Type of sample mold	Type of test	No. of samples	Size (mm)		
Cube	Compressive strength	3×3	50×50×50	100×100×100	150×150×150
	Splitting strength	3×3			
Cylinder	Compressive strength	3×3	50×100	100×200	150×300
	Splitting strength	3×3			
Prism	Modulus of rupture	3×3	25×25×300	50×50×300	100×100×500

- **Sand:** Graded river sand at Mosul city was used for preparing the test specimens and passing from sieve No. 20 (850 μm) and retaining on sieve No. 30 (600 μm), complying the requirements of (ASTM C-33, 1978)
- **Mixing water:** drinking tap water was used for both mixing and curing. The temperature of the used water throughout the experimental period ranged between (20-27°C)

Cement, sand and water are all measured by weight according to the required proportion and the specified water cement ratio in all the mixes.

Test program: To study the effects of specimen size on the compressive, modulus of rupture and splitting strength of cement mortar, it was proposed to prepare (45) mortar specimens having different sizes and with cement/sand ratio equal to 1:2 and water cement ratio equal to (0.45) as explained below:

- Six samples of cement mortar are casted in a cube molds for each of the sizes (150, 100, 50 mm). For each size three samples are tested for compressive strength and the other three samples for splitting strength (Table 1). The procedure of casting and testing is carried out for size (50×50×50 mm) cube as per the (ASTM C-109-02, 2002) for compressive strength. Similar procedures are followed for the other cube sizes
- Three samples of cement mortar are casted in prism molds of sizes (100×100×500, 50×50×300 and 25×25×300 mm) with three samples for each size (Table 1). The (ASTM C-78 2002, specification) for modulus of rupture strength of mortar has specified a sample size (40×40×160 mm) and to be tested under central Point loads. In the present study all the specimen sizes are different from that specification and tested under two point loads to maintain a zone of pure moment
- Six samples of cement mortar are cast in cylindrical molds for each of the sizes (150×300, 100×200 and 50×100 mm). For each size three samples are tested for compressive strength and the other three samples for splitting strength (Table 1). The procedure of casting are carried out for size (150×300 mm) as per the ASTM C-39-01 (2001)specification for compressive strength of concrete and ASTM C 496 (1996) specification for splitting strength of concrete. Similar procedure is used for preparing and testing the other specimen sizes

The casting are took place under laboratory conditions at a temperature of (20-27°C) and a relative humidity ranged between (50-60%).

Procedure for preparing and testing specimens: To prepare the specimens, the required amount of cement is weighted and the corresponding quantity of saturated surface dry sand according to the mix proportion of cement/sand ratio and also the require weight of water for mixing is weighted according to the water cement ratio stated before. The mixing is carried out using mechanical mixing powel.

The rate of loading for all the tests was applied according to the ASTM specifications (ASTM C-109-02, 2002) by either maintaining the specified rate of loading or the specified applied stress throughout the loading period. All specimens were tested at the age of 28 days using (ELE) compression machine. All the samples are tested immediately after being removed from the curing water tank.

Figure 1a-f show some of the tested cement mortar samples with different sizes used for compression, splitting and flexural tests.

Curing: Specimens were covered with wetted cloths and kept in the mold for 24 h after casting, thereafter, the specimens were removed from the mold and immersed in the water tank for 28 days at a temperature of 20-27°C.

RESULTS AND DISCUSSION

The test results presented in terms of compressive strength, modulus of rupture and splitting strength are listed in Table 2. Each value is the average of three specimens.

The variation of compressive strength of mortar with the specimen's size of both cubes and cylinders is shown in Fig. 2. In this Fig. 2 and the subsequent figures, the size of cylinder refers to its diameter. The Fig. 2 shows a similar trend in compressive strength reduction with the

Fig. 1: (a-f) Samples of tested mortar having different specimen's sizes

Table 2: Test results of compressive, flexural and splitting strength

Type of sample mold	Size (mm)	Compressive strength	Modulus of rupture	Splitting strength
		----------------------(Mpa)----------------------		
Cube	50×50×50	50.83	-	4.80
	100×100×100	47.16	-	4.73
	150×150×150	32.33	-	4.62
Cylinder	50×100	36.00	-	4.82
	100×200	29.83	-	4.10
	150×300	21.50	-	3.51
Prism	25×25×300	-	7.05	-
	50×50×300	-	6.40	-
	100×100×500	-	6.30	-

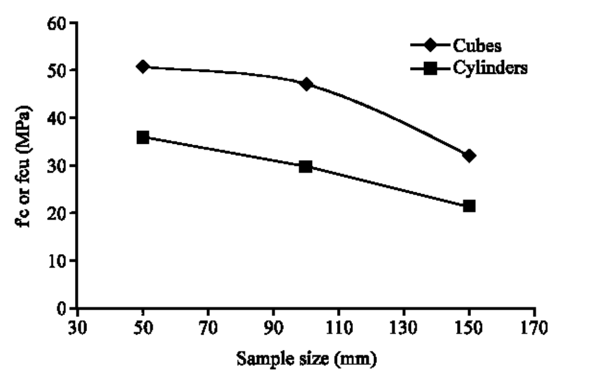

Fig. 2: Variation of mortar compressive strength with specimen's size

increase in the specimen's size of both cubes and cylinders. The average ratio of cylinder compression strength to the cube strength (having cube side equal to cylinder diameter) is equal to 0.67.

The variation of mortar splitting strength with the specimen's size of both cubes and cylinders is shown in Fig. 3. It is worth to mention that the width of the indenter that is used for testing the splitting strength of each cube size is equal to 10% of the cube side, while for cylinder splitting test the ASTM C 496 (1996) are applied. Figure 3

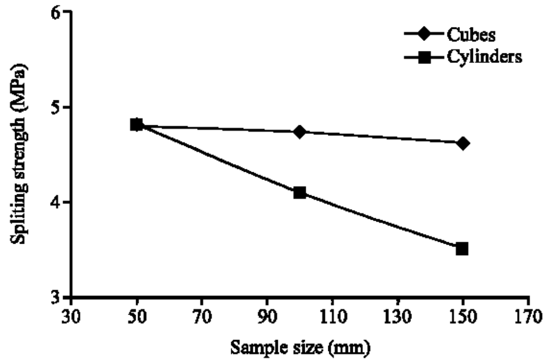

Fig. 3: Variation of mortar splitting strength with specimen's size

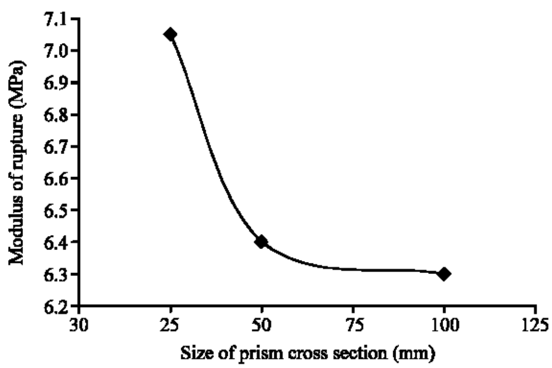

Fig. 4: Variation of modulus of rupture with the prism's size

shows that for cubes the variation of splitting strength with specimen's size is only marginal compared with that of the cylinders. The splitting strength of cube 50×50×50 mm is almost equal to that of cylinder 50×100 mm, while the reduction in splitting strength in cylinder 100×200 mm compared with that of cube 100×100×100 mm is 13% and for cylinder 150×300 mm the reduction in splitting strength compared with cube 150×150×150 mm is about 24%. This indicates that increasing the cylinder specimen's size cause to increase the reduction in the splitting strength of cylinders compared with that of cube specimens.

The variation of the modulus of rupture with the dimensions of prism's cross section is shown in Fig. 4. It can be noticed that the modulus of rupture is drastically reduced from 7.05 MPa for prism cross section 25×25 mm to 6.4 for prism with cross section 50×50 mm and it is almost came to a stationary value (6.3 MPa for the present mix proportion) when the cross section of the prism is greater than 50×50 mm.

Figure 5 depicts the variation of splitting strength with the counterpart compressive strength of the same

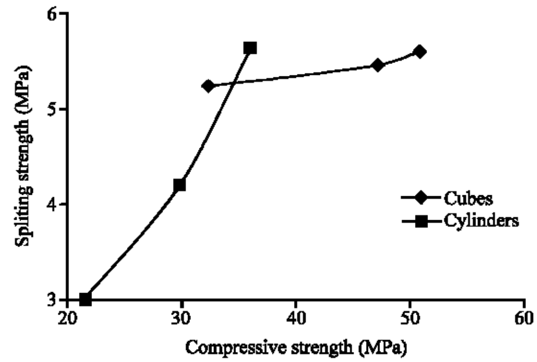

Fig. 5: Variation of splitting strength with the compressive strength of cubes and cylinders specimens

specimen size for both cubes and cylinders. It can be notice that the splitting strength for cubes is almost linearly increased with the compressive strength (with the reduction in sample size) and are related by the best fit equation:

$$f_{tcub} = 4.3+0.01fcu \quad (1)$$

With R^2 = 0.96, where, f_{tcub} is splitting strength of cube specimen and fcu copmressive strength of mortar using cube specimen in MPa.

While, for cylinder specimens the best fit to relate splitting and compressive strength can be expressed by the power relation as:

$$f_{tcyl} = 0.54(f'c)^{0.17} \quad (2)$$

With R^2 = 0.97, where f_{tcyl} is splitting strength of cylinder specimen and f'c is copmressive strength of mortar using cylinder specimen in MPa.

Figure 6 shows the relation between splitting strength of mortar using cubes and that using cylinder spacimens, the sizes of the specimens are shown in the same figure. The relation is nonlinear and the best fit that relate splitting strength of cylinder with that of cube can be expressed as:

$$f_{tcyl} = 10^{-5}(f_{tcub})^8 \quad (3)$$

With R^2 = 0.97.

The relation between copmressive strength of cylinderecal mortar specimens with that of cube specimens is shown in Fig. 7. The corresponding specimen sizes are shown in the same figure. These relation can be expressed with best fit by a linear equation as:

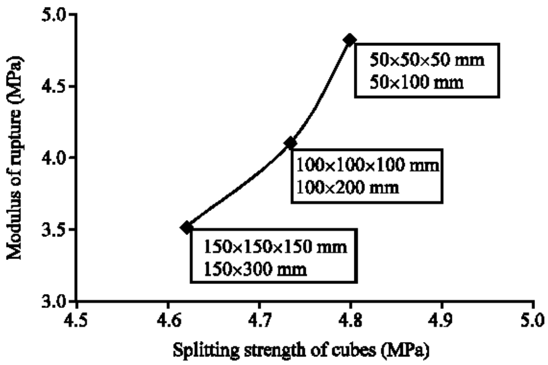

Fig. 6: Variation of splitting strength of cylinders with that of cubes

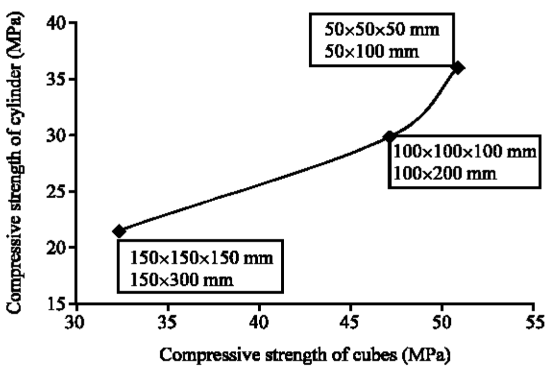

Fig. 7: Variation of compressive strength of cylinders with that of cubes

$$f'c = 0.72fcu-2.2 \quad (4)$$

With $R^2 = 0.94$.

CONCLUSIONS

From the test results and discusion of the obtained mechanical properties of cement mortar using different specimen sizes, the following may be stated:

- Generally the compressive, modulus of rupture and splitting strength of the mortar is increased by reducing the size of the specimen
- The compressive strength of mortar using either cubes or cylinders specimens is drastically affected by the specimen's size
- For cubes the variation of splitting strength with specimen's size is only marginal compared with that of the cylinders
- Some best fit relationships that relate mechanical properties of mortar are presented in this study. Although, it cannot be generalized due to the fact that the presented results are based on limited number of tested specimens, nevertheless; it can gives an amble ideas about the variation of these properties with each other

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