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Proposing Relation with Fracture Strength of Masonry to Cement Percentage and Compressive Strength of Mortar

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Abstract - In this study, relation between fracture strength of masonry with cement percentage and compressive strength of mortar have been tried to propose. Seven weight based mix ratios- 1:1-1:7 were taken into consideration. For the determination of compressive strength 50 mm cube samples and for the identification of shear strength masonry samples made by clay bricks were prepared. All tests were conducted after 28 days of casting. Finally, different relations, have been proposed; i) between cement percentage and compressive strength of mortar, ii) between cement percentage of mortar and fracture strength of masonry, iii) between compressive of mortar and fracture strength of masonry. Finally an overall relation is proposed where fracture strength of masonry is considered as a function of cement percentage and compressive strength of mortar.

Keywords - Cement, Compression, Fracture, Mortar, Relation, Shear, Strength.

I. Introduction

Masonry is a combination of brick and mortar. Mortar is the compound product of cement, sand and water. Quality of masonry work largely depends on the property of mortar. Compressive strength and shear strength, both are two very important physical properties of mortar. It is obvious that the more the cement content in mortar the higher the strength will be. Often, confusion arises between the shear strength of mortar and the bond strength between mortar and masonry. Failure of masonry wall may be due to the failure of any one of the two, stated above. Shear strength of any material is a fundamental mechanical property, which depends on the compressive strength. On the other hand, Bond Strength between two materials mainly depends on the surface property. Sometimes, even having high compressive and shear strength, two adjoining materials can fail due to lack of surface roughness, in other words due to low bond strength. On the other hand, even having good surface roughness the adjoining materials can fail due to low shear strength.

That's why; the cause of the failure of a masonry wall may be any one; either low bond strength between mortar and masonry or low shear strength of mortar. In real field, it is really very confusing and tough to identify which might be the actual cause of the failure of a masonry unit. To overcome this situation, in this study, a new name ‘failure strength’ of masonry is going to be used. In this case, ‘failure strength’ can be defined as the ultimate strength parallel to the surface of mortar that causes fracture in masonry. Further, it can cause the separation of brick either from mortar or also can cause the shear crack in the center line of mortar. To quantify this ‘failure strength’, relation is going to be established with compressive strength of mortar and percentage of cement in mortar. Both experimental and theoretical approaches are used in the study.

II. A SHORT DISCUSSION ON THE EXISTING STUDIES

Evaluation of the shear strength in masonry is such a field of research where many researchers are seen to make useful contribution. Studies have been conducted both in theoretical and experimental basis. Even different experimental setup is suggested by different codes, standards as well as by different researchers. Yet the exact nature of strength in masonry is not fully understood.

For example, many years back, it was tried to make a review of the available literature on the shear strength of mortar — masonry joints is presented in this paper. Some of the parameters which affect the shear strength of clay brick — mortar joints and concrete block — mortar joints are highlighted. A few experimentally determined shear strength values are compared with those obtained from the proposed empirical equations, and it is shown that the two do not show good agreement [1]. Similarly, attention was given to determine the accurate values of the coefficient of friction developed between brick masonry and its supports by experimental investigation. Friction forces developed between clay brick and supports of steel and concrete, with and without common flashing, were evaluated. Both in—plane and out—of—plane load was applied [2]. Also effort was given to find out the effect of mortar properties on strength of masonry [3].

In modern times, discussion was seen on several test set-up for the evaluation of the shear strength in masonry. It was revealed that some test rigs are simple but the distribution of stresses is not desirable, while the other arrangements provide nearly uniform shear deformation but require rather complex test devices. A simple test procedure was introduced where the application of external forces into the mortar layers leads to almost pure shear stress and in the presence of pre-compression create a uniform normal stress [4].

Researcher like Vermeltfoort [5] showed that even for industrially made mortars the mortar compressive strength varied considerably. However, no clear relationship between mortar compressive and masonry shear strength could be established. Therefore a series of tests (like Figure 1) was performed to investigate the relationship between mortar compressive and masonry shear strength by varying the mortar properties under laboratory conditions. More experiments conducted by the same researcher showed no clear relationship between mortar compressive and masonry shear strength [6,7].

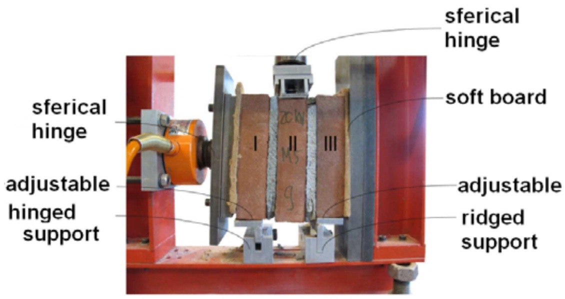

Figure 1: Shear test set up by Vermeltfoort (2012)

Meanwhile, another study concluded that, when assessing different shear test setups, due to the non-negligible bending moment caused by the mortar joint thickness, the stresses should be directly evaluated at the interfaces between mortar and unit instead of at the center line of the mortar joint. Also, the initiation of damage at the extremity of the interface does not significantly influence the maximum shear resistance [8].

Jukes and Riddington [9] used a finite element program, designed to predict the ultimate shear strength of block masonry triplets. The program is iterative and allows for progressive crack propagation at the brick-mortar interface. The FE program was validated by comparing predicted ultimate strength values with experimental test results obtained from nine sets of triplets formed with different block and mortar combinations. The results demonstrate that the FE program is generally capable of predicting the shear strength of block triplets with reasonable accuracy for pre-compression stress levels up to approximately 2 N/mm^2.

The influence of bond strength on masonry compressive strength has been examined through an experimental program. The results clearly indicate that an increase in bond strength, while keeping the mortar strength constant, leads to an increase in the compressive strength of masonry [10].

Based on the triplet shear test, the presence of fly ash had a strong influence on the brick-mortar joint. The bond strength of unreinforced clay brick masonry in the ratio of 1:6 cement mortar with 20% replacement of fine aggregate with fly ash was 1.45 times more than the unreinforced clay brick masonry in the ratio of 1:6 cement mortar. The bond strength of reinforced clay brick masonry in the ratio of 1:6 cement mortar with 20% replacement of fine aggregate with fly ash was 1.5 times more than the unreinforced clay brick masonry. The bond strength of reinforced fly ash brick masonry in the ratio of 1:6 cement mortar with 10% replacement of fine aggregate with fly ash was twice than the unreinforced fly ash brick masonry. The bond strength was seen to vary from 0.064- 1.244 MPa at different condition [11].

It was also found that, bond strength does not develop in the same manner to compressive strength and that bond strength may decline post 28-days. Samples up to 2-years in age can demonstrate up to 40% loss of bond due to the effects of sustained drying shrinkage. It is presented that initial bond strength is developed by volumetric plastic shrinkage of the mortar bed, induced by rapid removal of the excess mix water by brick background suction, which generates a mechanical lateral gripping action to the undulations of the brick bed-face [12].

Even the increment of temperature can affect the strength of mortar. At 200ºC the modulus of elasticity is reduced from 70% to 80%, at 400ºC values of 40% to 50% were reached [13]. The masonry wallettes experienced a reduction in the compressive strength, which was approximately 9%, 19%, 60%, and 83% at 400ºC, 600ºC, 700ºC and 800ºC [14].

Therefore, from the above discussion, it can be said different researchers contributed on different aspects on Masonry (Table 1). Yet, there is very little comprehensive way to predict the failure of the masonry units, as found form the previous summery. Also the confusion between the dominance of shear strength of mortar and bond strength between mortar and brick has made the decision tougher to take. Therefore in this study, as stated earlier, leaving this fact out of consideration, a comparatively new attempt is going to be taken to relate 'fracture strength' of masonry unit with the cement percentage in mortar and compressive strength of mortar.

Table 1: Major contributions of different researchers on Masonry

Source	**Research done on**				
	a	b	c	d	e
[1]	√				
[2]			√		
[3]	√	√			
[4]	√				
[5,6,7]	√	√			
[8]	√				
[9]	√				
[10]		√		√	
[11]				√	
[12]				√	
[13]					√
[14]					√

Note: *a- Shear strength of Mortar, b- Compressive strength of mortar, c- Coefficient of friction, d- Bond strength, e- Effect of temperature on masonry*

III. EXPERIMENTAL SETUP:

During concrete mortar preparation, Ordinary Portland Cement (OPC) of CEM I, 52.5 N (ASTM C-150, Type-1) was used as binder materials. Constant Water to cement ratio was also maintained (0.4±0.02). As fine aggregate, Sylhet Sand having a Fineness Modulus of 2.67±0.01 was used. Seven mortar mix ratios were used in this study (1:1, 1:2, 1:3, 1:4, 1:5, 1:6 and 1:7 by weight). Three 50mm cube samples (Figure 2) were prepared for each mix ratio to know the corresponding compressive strength. Therefore, the total of number of cube samples was: 21 (=7 concrete mix ratios×3 three samples per mix ratio). For fracture strength test, masonry units made of three standard size burnt clay bricks (230mm×115mm×63mm) were used. Three samples were prepared for each mix ratio to know the corresponding fracture strength. Therefore, the total of number of cube samples was: 21 (=7 concrete mix ratios×3 three samples per mix ratio). After 28 day curing, all samples were tested in UTM (model UTE 60, SR. No. 2/2008-3849) under triplet loading arrangement as shown in Figure 4.

Figure 2: Mortar cubes in mould

Figure 3: Mortar cubes in compression machine

Figure 4: Triplet loading arrangement

IV. Result and Discussion:

The compressive strength of mortar cube samples varies from 72.49 MPa (for 50% cement, mix ratio-1:1) to 3.81 MPa (for 12.50% cement, mix ratio-1:7). The Standard deviation and Standard Error of the data of compressive strength is presented in Table 2. The result of compression strength test of mortar is presented in Figure 5. The shape of the curve is not perfectly linear. In Table 3 a list of proposed equations (1-5) is presented, relating compressive strength (σ) and percentage of cement (C_p). It is seen that, the Linear, Logarithmic and Polynomial relations have $R^2 > 0.95$, that indicates a good match with the experimental values. It is to be noted that, the Polynomial relation has the highest $R^2 (= 0.987)$.

Table 2: The Standard deviation (SD) and Standard error (SE) of the experimental data of compression and fracture strength (MPa) of mortar of different mix ratio

Mix ratio	**Cement %**	**Compressive strength (MPa)**		**Fracture strength (MPa)**	
		SD	SE	SD	SE
1:1	50.00	4.929	2.846	0.317	0.183
1:2	33.33	5.959	3.441	0.215	0.124
1:3	25.00	1.914	1.105	0.128	0.074
1:4	20.00	0.723	0.418	0.059	0.034
1:5	16.67	2.368	1.367	0.046	0.027
1:6	14.29	0.273	0.158	0.058	0.033
1:7	12.50	0.273	0.158	0.042	0.024

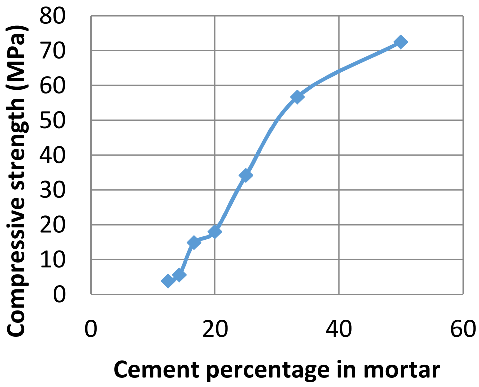

Figure 5: Compressive strength (σ)at different cement percentage (C_p) in mortar

Table 3: List of proposed equations relating compressive strength, MPa (σ) and percentage of cement (C_p)

Equation type	**Proposed equation**	R^2	**Equation No**
Exponential	$\sigma = 3.056e^{0.073C_p}$	0.769	1

Linear	$\sigma = 1.944C_p - 18.34$	0.955	2
Logarithmic	$\sigma = 53.05 \ln C_p - 134.5$	0.977	3
Polynomial	$\sigma = -0.033{C_p}^2 + 3.993C_p - 43.76$	0.987	4
Power	$\sigma = 0.023{C_p}^{2.158}$	0.905	5

The fracture strength of masonry samples varies from 1.47 MPa (for 50% cement, mix ratio-1:1) to 0.42 MPa (for 12.50% cement, mix ratio-1:7). The Standard deviation and Standard Error of the data of fracture strength is also presented in Table 2. Out of 21, 9 masonry samples were seen to have both side fractured. Six of the above nine was of the mix ratio 1:5, 1:6 and 1:7. The rest samples (12) were seen to have one side fractured. Typical example of one and both side fracture is shown in Figure 6 and 7 respectively. The result of fracture strength test of masonry samples is presented in Figure 8. The shape of the curve also is not perfectly linear. In Table 4 a list of proposed equations (6-10) is presented, relating fracture strength (ϑ) and percentage of cement (C_p). It is seen that, the Logarithmic and Polynomial relations have $R^2 > 0.95$. It indicates a good match with the experimental values. It is to be noted that, the Polynomial relation has the highest $R^2 (= 0.997)$.

Figure 6: Fracture in one side

Figure 7: Fracture in both sides

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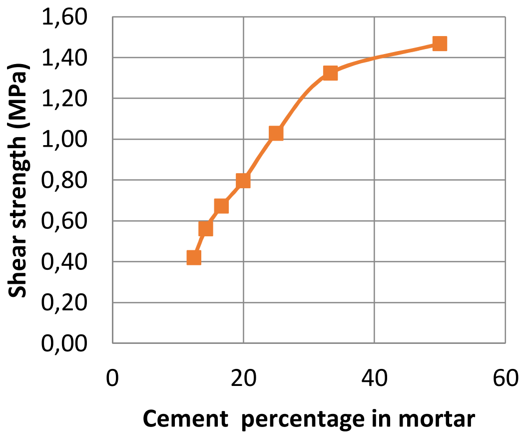

Figure 8**:** Fracture strength (ϑ) at different cement percentage (C_p) in mortar

Table 4: List of proposed equations relating fracture strength, MPa (ϑ) and percentage of cement (C_p).

Equation type	**Proposed equation**	**R^2**	**Equation No**
Exponential	$\vartheta = 0.384e^{0.031C_p}$	0.811	6
Linear	$\vartheta = 0.028C_p - 0.206$	0.903	7
Logarithmic	$\vartheta = 0.789 \ln C_p - 1.544$	0.980	8
Polynomial	$\vartheta = -0.0003{C_p}^2 + 0.08C_p - 0.441$	0.997	9
Power	$\vartheta = 0.051{C_p}^{0.897}$	0.936	10

Figure 9 shows relation between the compression strength of mortar and fracture strength of masonry. The shape of the curve is not perfectly linear. In Table 5, a list of proposed equations (11- 15) is presented, relating fracture strength of masonry (ϑ) and compressive strength (σ) of mortar. It is seen that, the Linear, Polynomial and Power relations have $R^2 > 0.95$, that indicates a good match with the experimental values. It is to be noted that, the Polynomial relation has the highest $R^2 (= 0.992)$.

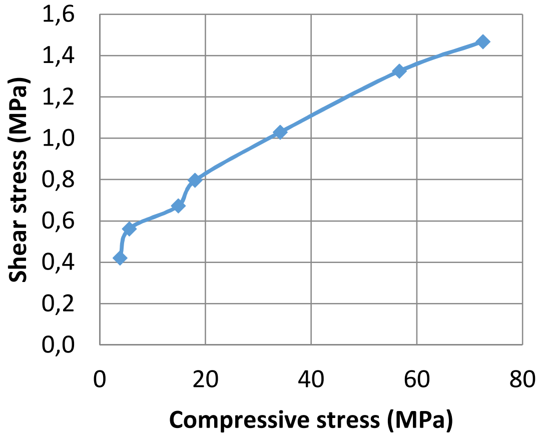

Figure 9**:** Fracture strength of masonry (ϑ) at different compressive strength (σ) of mortar

Table 5: List of proposed equations relating fracture strength of masonry (ϑ) and compressive strength (σ) of mortar

Equation type	**Proposed equation**	**R^2**	**Equation No**
Exponential	$\vartheta = 0.507e^{0.016\sigma}$	0.898	11
Linear	$\vartheta = 0.014\sigma + 0.464$	0.974	12
Logarithmic	$\vartheta = 0.34 \ln \sigma - 0.1$	0.936	13
Polynomial	$\vartheta = -0.0002\sigma^2 + 0.023\sigma + 0.383$	0.992	14
Power	$\vartheta = 0.251\sigma^{0.404}$	0.978	15

Moreover, using the software, SPSS-17, a linear relation (Equation-16**,** having $R^2 = 0.979$) is going to be proposed considering fracture strength of masonry as a function of percentage of cement and compressive strength of mortar, (i.e. $\vartheta = \int(C_p, \sigma)$). In Figure 10, the comparison between experimental fracture strength and fracture strength from modal (Equation-16) is presented, which shows a good match between the both as well.

$$\vartheta = 0.555 - 0.009C_p + 0.019\sigma \ldots 16$$

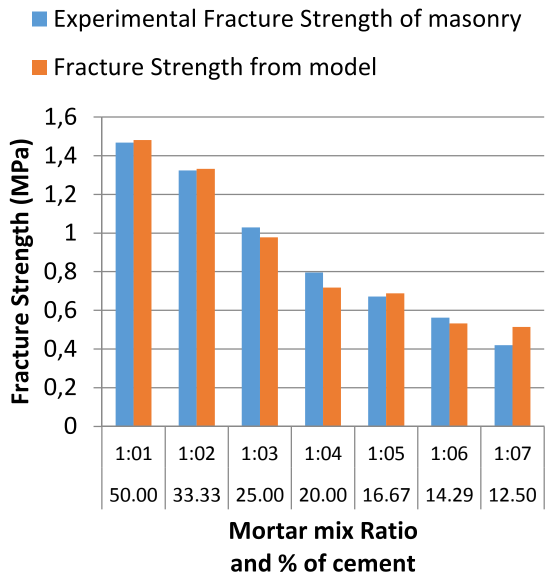

Figure 10: Comparison between experimental fracture of masonry and fracture strength from modal.

V. Conclusion

In the present study a number of approaches have been taken to drag the fracture strength of masonry into some proposed mathematical models keeping it as a function of cement percentage in mortar and compressive strength of mortar. Few of the proposed models have good match with the experimental values. Thought in most of the cases, polynomial equations hold the maximum value of R^2, yet in terms of simplicity linear equations (2, 7, 12 and 16) may be convenient to use. There may be limitation of the research, but the result and discussion obtained from the experimental work can help to take further decision in future.

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