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Experimental evaluation of the effect of mix design ratios on compressive strength of cement mortars containing cement strength class 42.5 and 52.5 MPa

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Abstract

Cement mortar is one of the major cement-based construction materials and its mechanical properties perform an important role in the strength of structures. The effect of different mortar mix design parameters on its compressive strength has always been of great significance. Specifically, this research investigates the simultaneous effect of cement strength class and sand-cement (S/C) and water-cement ratios (W/C) on the compressive strength of mortars containing with cement strength class 42.5 and 52.5 MPa. For this purpose, an extensive experimental plan with 540 cubic 50 mm specimens made with 36 different mix designs. The results showed that the compressive strength of specimens increased with age and was strongly influenced by cement strength class, S/C and W/C ratio. The optimal mix design in terms of compressive strength is the with S/C ratio of 2.75, W/C ratio of 0.3, and cement strength class of 52.5 MPa.

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Keywords: Cement mortar; Compressive strength; Cement strength class; Water-Cement ratio; Sand-Cement ratio.

1. Introduction

The evaluation of concrete structures from different aspects of the laboratory, optimization, and modeling has attracted the attention of researchers [1-4]. Hence, cement mortar is an important heterogeneous composite used in

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construction. Cement mortar is tasked with provision of uniform stress distribution and thermal deformation, and plays an important role in conjunction resistance properties of structure [5-7]. The significant variables that affect the behavior of fresh and hardened mortar include the water-cement ratio (W/C), the sand-cement ratio (S/C) and cement strength class.

The role of W/C and cement type on the various properties of cementitious materials such as concrete and cement mortar has been extensively studied [8-10]. For example, the effect of changes in water and temperature on deformation of cement and concrete pastes [11], cement content and W/C ratio on the early hydration process [12] and cement type and additives materials on the properties of cement materials [13, 14] have been researched. In another research, Body and Mindess [15] performed an experimental study on the effect of two W/C (0.45 and 0.65) and two types of cement (ordinary and sulphate resistant) on strength and sulphate resistance of concrete at different ages. The results showed that W/C has a greater effect on the sulfate resistance than the type of cement has, and that compressive strength test is more sensitive than tensile test in detecting internal damages, especially at an early age. Also, Kim et al. [16] found that increasing the W/C from 0.45 to 0.6 increases the porosity of cement mortar by 150% and decreases its compressive strength by 75.6%.

Typically, water-cement ratio is the most important mix design parameter for cementitious materials such as cement mortar. Studies on concrete have shown that compressive strength is inversely proportional to the W/C. It should however be remembered that mortar and concrete are more precisely different materials with different structure and composition. Few studies, the effect of mix design factors such as W/C and S/C on the properties of cement mortar have attracted. One of the studies on the effect different materials and mix designs on mechanical properties of mortars have reported that Abram's law applies on mix designs with W/C ratios of higher than 0.4 [17]. Researchers have also expressed the effect of W/C ratio on the compressive strength of cement mortar with a relationship similar to the Abram's law. It has been found applying more parameters to this law will allow it to be used for cement mortars [18].

Research has shown that aggregates have a significant effect on rheology and mechanical properties of cement mortar [19]. So the impact of gradation and sand type on properties of cement mortar has been the subject of many studies [20, 21]. Schutter and Poppe [22] have shown that the type of sand has a significant effect on the properties of cement mortar, as gradation-based geometric parameters of aggregate such as fineness modulus are associated with water demand of the aggregate and dry density of mortar. In a study by Haach et al [23] on the effect of aggregate and W/C on workability and compressive strength of cement mortars, the results show that an increase in W/C weakens the mechanical properties and improves the workability of cement mortar. Reddy and Gupta [24] have studied the effect of sand gradation on tensile strength. The results show the strength is reduced with the change in fineness modulus of sand from 3.21 to 1.72. They have also reported that to make a mortar with a given consistency with fine sand, 25 to 30% more water need to be added to the mix design. There are only a few studies on the combined effects of cement strength class, and S/C and W/C ratios, and their interaction on the mechanical properties of cement mortar. In one of these studies by the same authors, the effects of various cement categories have been investigated by the neural network method. The results showed that cement type is one of the important parameters in predicting the compressive strength of cement mortar [25].

The aim of this research was to determine a wide range of mix design parameters that are required to achieve balanced mechanical properties in the cement mortar. To achieve this purpose, the simultaneous effect of mix design factors such as type of cement strength class, W/C and S/C was investigated through an experimental program. Mixture design was conducted on 540 cubic specimens made with 36 cement mortar mix designs composed of six different W/C, three different S/C and two different types of cement strength classes (42.5 and 52.5 MPa). Compressive strength test was performed to determine the combined effect of factors, and the mix designs with the best mechanical properties were determined.

2. Experimental study

A typical cement mortar is the mixture of sand that acts as the filler material, cement that acts as the binder and water that triggers the hydration process. The basic composition and characteristics of each of these components affect the ultimate compressive strength of the resulting cement mortar.

2.1. Specifications of materials and mix designs

In this study were performed using two types of Portland cement (the product of Bojnoord cement factory, Iran) with strength classes of 42.5 and 52.5 MPa. Information regarding the chemical composition and physical properties of the used Portland cements is provided in Table 1. Mix designs were prepared for fine-grained aggregates (sand) with maximum diameter of 4.75 mm, density of 2.6 kg/cm^3, fineness modulus of 2.48, and standard gradation according to ASTM C33 [26]. Specimens were made with polycarboxylate superplasticizer to ensure self-consolidation of the cement mortar after bring cast into the mold. This superplasticizer improves both workability and ultimate strength of the cement mortar [27, 28].

Table 1 Physical and chemical properties of the Portland cement.

	Chemical Analysis (%)												Physical Analysis		
CSC (MPa)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI	F.CaO	C_3A	C_3S	Specific Gravity(ton/m^3)	Sieve residue on 90 mm (%)	Blaine Test (cm^2/gr)
42.5	20.2	4.6	3.5	64	1.94	2.4	0.35	0.7	2.7	1.3	6.27	64.27	3.13	0.8	3050
52.5	21	4.7	3.52	64.18	1.93	2.53	0.32	0.65	1.2	1.2	6.5	57.85	3.15	0.1	3600

An experimental program was set up to assess the effect of cement strength classes, W/C and S/C on the properties of cement mortar. In this experiment, 36 cement mortar mix designs were prepared based on S/C of 2.5, 2.75 and 3, W/C of 0.25, 0.30, 0.35, 0.40, 0.45 and 0.50. For each specimen, superplasticizer was introduced to the mixture until obtaining a flow of 110 ± 5 in 25 drops of the flow table [29]. The specifications of mix designs are provided in Table 2.

Table 2 Mixture design of cement mortar for cement strength classes of 42.5 and 52.5 MPa.

Exp. No	C (kg)	S/C	W/C	HRWR (ml)	
				CEM- 42.5 (MPa)	CEM- 52.5 (MPa)
1	2.85	2.5	0.25	40	40
2	2.67	2.75	0.25	100	90
3	2.5	3	0.25	85	50
4	2.85	2.5	0.3	30	30
5	2.67	2.75	0.3	35	45
6	2.5	3	0.3	35	35
7	2.85	2.5	0.35	17	12
8	2.67	2.75	0.35	17	22
9	2.5	3	0.35	17	30
10	2.85	2.5	0.4	5	5
11	2.67	2.75	0.4	7	10
12	2.5	3	0.4	10	12
13	2.85	2.5	0.45	3	3
14	2.67	2.75	0.45	3	3
15	2.5	3	0.45	3	3
16	2.85	2.5	0.5	2	2
17	2.67	2.75	0.5	2	2
18	2.5	3	0.5	2	2

2.2. Preparation of specimens and experimental procedure

The specimens used in this study were 50 × 50 × 50 mm cubic mortar, which were subjected to compressive strength test in accordance with ASTM C109 [30]. To prepare specimens, a mixer was used to mix the materials in proportions specified by the mix design in accordance with ASTM C305 [31]. Mixing was continued until archiving a uniform consistency, and the resulting cement mortar was then cast into the molds. The open surfaces of specimens were perfectly smoothed to ensure uniform force distribution under the loading and thus the lowest error in the strength measurement. After 24 hours, specimens were removed from their molds and were put into a water tank with a temperature of 22 ± 2 °C until the time of test. Test of compressive strength was performed using a compression testing machine with a capacity of 20 tons. Mortar specimens were tested along the direction that they were cast into the molds. For each mix design, three specimens at ages of 3, 7, 14, 21 and 28 days (a total of 15 specimens for each mix design) were tested and the mean values of their results were obtained.

3. Results and Discussion

The quantity of superplasticizer used for specimens with different W/C, S/C and cement strength classes are presented in Fig. 1. As Fig. 1a-c shows, in W/C of 0.4 and higher, the quantity of superplasticizer used for both cement strength class and all three S/C are almost the same. This is maybe due to presence of enough water for mortar mixtures in W/C ratios of that range. In low W/C ratios however, superplasticizer consumption of mix designs undergoes a change. Fig. 1a shows that as W/C decreases from 0.4 to 0.25, consumption of superplasticizer increases more sharply and even more so in cement strength class of 42.5 MPa. Superplasticizer consumption also increases with the increase of S/C from 2.5 to 2.75, and this increase is sharper in W/C of 0.35 and 0.3 with cement strength class of 52.5 MPa (Fig. 1b). In all three curves of Fig. 1a-c, the sharpest increase in superplasticizer consumption can be seen when W/C ratio decreases from 0.3 to 0.25, and this is probably due to the severe deficiency of water which results in increased need for superplasticizer to achieve the desired fluidity. The greatest quantity of superplasticizer consumed in a specimen (100 milliliters) was used in the one made with cement strength class 42.5 MPa, W/C of 0.25 and S/C of 2.75. Figs. 2 and 3 show the changes in S/C versus compressive strength (Fc) of cement mortars made with cement strength class 42.5 and 52.5 MPa. In Fig. 2, the results of the compressive strength of cement mortar are illustrated for W/C ratios ranging from 0.25 to 0.50. For each S/C, compressive strength of cube specimens at ages of 3, 7, 14, 21 and 28 days are presented. As can be seen, compressive strength of specimens increases with age. This strength growth is more rapid in ages of 3 to 7 days and ages of 21 to 28 days. For example, in the mix design with W/C = 0.5 and S/C = 3, strength growth from the of age 3 to 7 days is from 8.5 to 26 MPa (i.e. 67%); and strength growths from the age of 7 to 21 days and from the age of 21 to 28 days are respectively 20% and 16%. The changes in the compressive strength as the result of increase in S/C ratio depend slightly on the W/C. When W/C is low, the peak strength occurs at S/C = 2.5, but as W/C increases, this peak moves toward S/C = 3. For example, when W/C = 0.25, the 28-day compressive strength of specimens with S/C ratios of 2.5, 2.75 and 3, are respectively 42, 28 and 22 MPa; but when W/C = 0.4, these compressive strength are respectively 45, 51 and 56 MPa. The W/C is an important factor in fluidity and stability of fresh and hardened self-consolidating mortars [32].

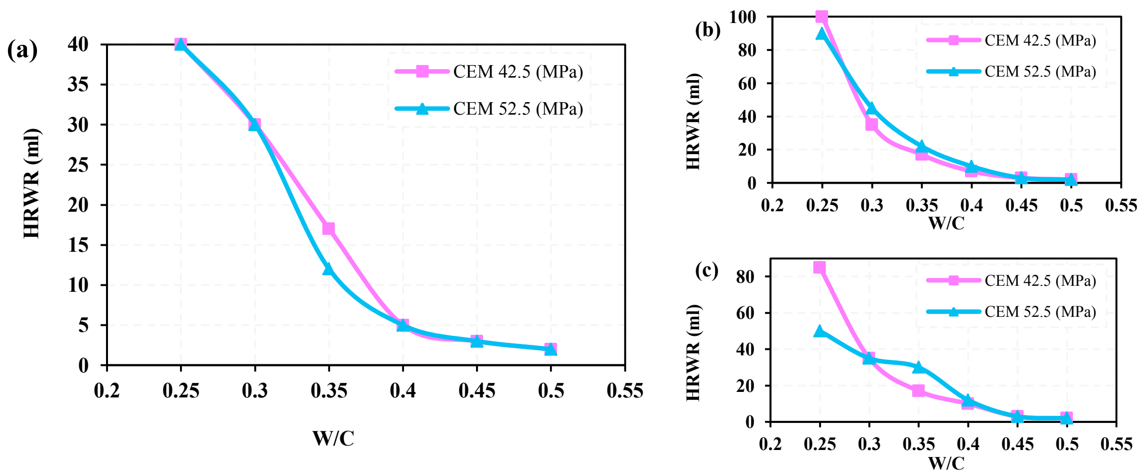

Fig. 1. Superplasticizer consumption versus W/C of mix design for (a) S/C=2.5, (b) S/C=2.75 and (c) S/C=3.

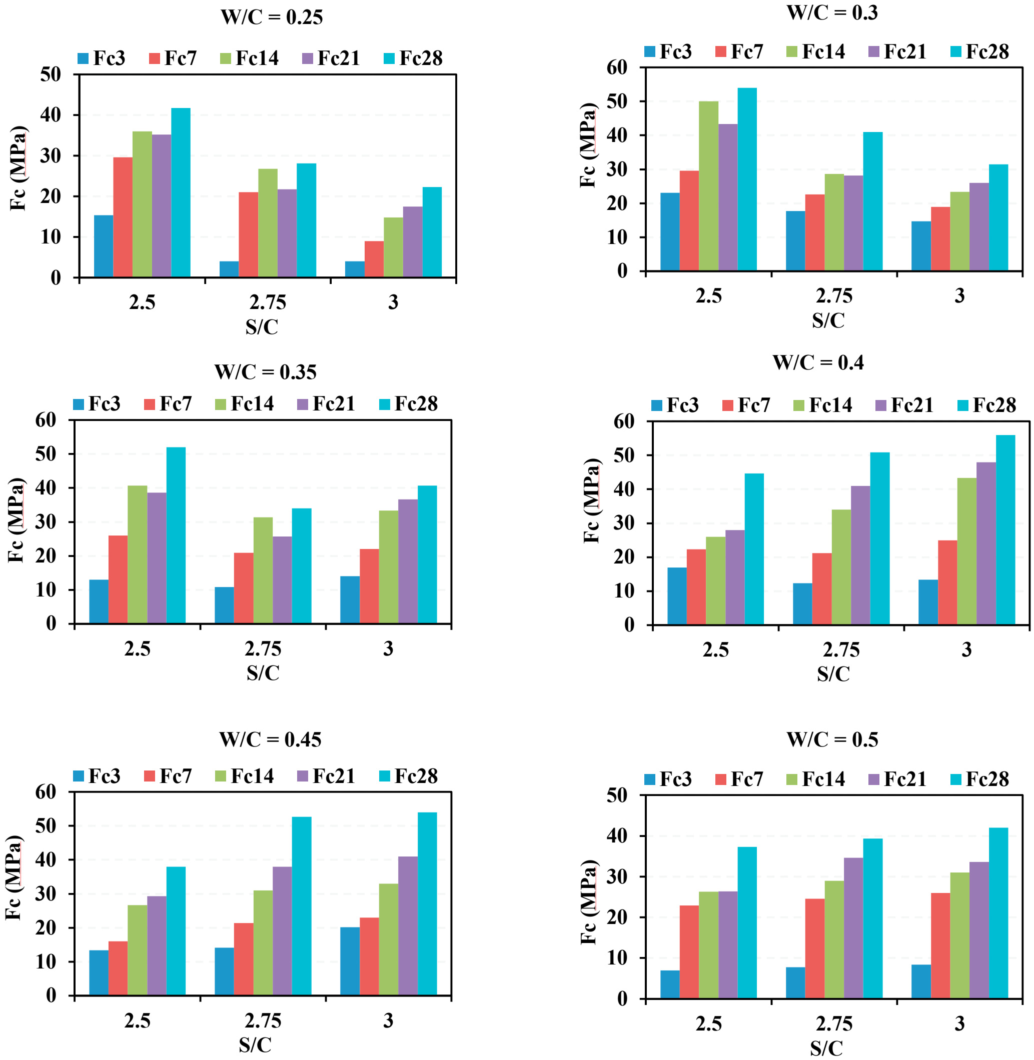

Fig. 2. S/C ratio of mix design versus compressive strength for specimens made with 42.5 MPa cement.

So in this study, experiment was conducted with six levels of W/C ratio. The results show that the specimens with highest 28-day compressive strength are those made with cement strength class 42.5 MPa, W/C of 0.4 and S/C of 3. Fig. 3 shows the effect of changes in S/C and W/C ratios on the compressive strength of mortar made with cement strength class 52.5 MPa. Like in Fig. 2, compressive strength increases with age, except for a few cases, which can be attributed to experimental error. Examining the variation of S/C in each W/C range shows that the greatest compressive strengths mostly belong to the specimens made with S/C of 2.75. It can also be seen that, as W/C ratio increases, compressive strength of the specimens decreases. Meanwhile the highest compressive strength belong to the mix design with W/C = 0.3 and S/C = 2.5. According to the results of compressive strength test for specimens of different ages (Fig. 3), mix designs containing cement strength class 52.5 MPa have a better strength than the mix designs containing cement strength class 42.5 MPa.

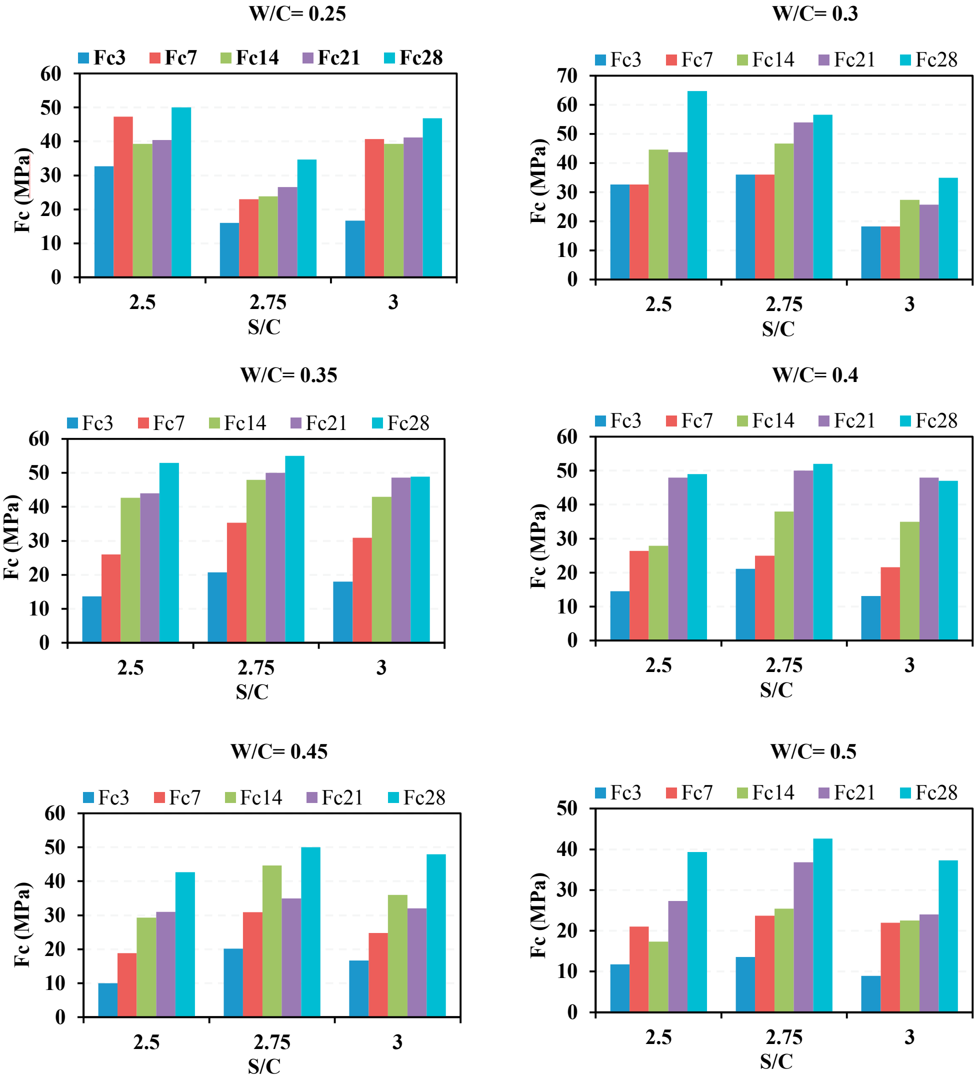

Fig. 3. S/C ratio of mix design versus compressive strength for specimens made with 52.5 MPa cement.

4. Conclusion

This study evaluated the effect of sand-cement ratio, water-cement ratio, age of specimen and cement strength class on the compressive strength of specimens made with different cement mortar mix designs. The results obtained in this study can be summarized as follows:

1. When used in combination with other mix design components, each particular cement strength class yield unique properties, which reflect the wide range of mix design variables that need to be considered to achieve the desired cement mortar.
2. In low water-cement ratios, the trend of changes in superplasticizer consumption is more in cement strength class 42.5 MPa than in 52.5 MPa.
3. The greatest rate of strength growth in specimens was observed from 3rd day to 7th day and from 21st day to 28th day.
4. Mix design containing sand-cement ratio of 2.75 and water-cement ratio of 0.3, with cement strength class of 52.5 MPa was identified as the optimum mix strength design.

References

[1] Korouzhdeh, T., H. Eskandari-Naddaf, and M. Gharouni-Nik, An Improved Ant Colony Model for Cost Optimization of Composite Beams. Applied Artificial Intelligence, (2017). 31(1): p. 44-63.
[2] Eskandari, H. and T. Korouzhdeh, Cost optimization and sensitivity analysis of composite beams. Civil Engineering Journal, (2016). 2(2): p. 52-62.
[3] Eskandari, H., Designing, Proposing and Comparing the Methods Predicting the Compressive Strength of the Ferro cement Mortar. Concrete Research Letters, (2015). 6(1): p. 1-10.
[4] Madadi, A., H. Eskandari-Naddaf, and M. Gharouni-Nik, Lightweight Ferrocement Matrix Compressive Behavior: Experiments Versus Finite Element Analysis. Arabian Journal for Science and Engineering, (2017): p. 1-13.
[5] Edgell, G. and B.A. Haseltine. Building Mortar for Low Rise Housing: Recommendations, Problems and Solutions. (Year) of Conference.: British Masonry Society.
[6] Roberti, G.M., L. Binda, and G. Cardani. Numerical modeling of shear bond tests on small brick-masonry assemblages. in Computer Methods in Structural Masonry-4: Fourth International Symposium. (Year) of Conference.: CRC Press.
[7] Binda, L., C. Tiraboschi, and S. Abbaneo, Experimental research to characterise masonry materials. Masonry International, (1997). 10(3): p. 92-101.
[8] Nunes, S., et al., Interaction diagrams to assess SCC mortars for different cement types. Construction and Building Materials, (2009). 23(3): p. 1401-1412.
[9] Eskandari-Naddaf, H. and M. Azimi-Pour, Performance evaluation of dry-pressed concrete curbs with variable cement grades by using Taguchi method. Ain Shams Engineering Journal, (2016).
[10] Eskandari, H. and M. Tayyebinia, Effect of 32.5 and 42.5 cement grades on ann prediction of fibrocement compressive strength. Procedia Engineering, (2016). 150: p. 2193-2201.
[11] Cagnon, H., et al., Effects of water and temperature variations on deformation of limestone aggregates, cement paste, mortar and High Performance Concrete (HPC). Cement and Concrete Composites, (2016). 71: p. 131-143.
[12] Hu, J., Z. Ge, and K. Wang, Influence of cement fineness and water-to-cement ratio on mortar early-age heat of hydration and set times. Construction and Building Materials, (2014). 50: p. 657-663.
[13] Chandra, S. and J. Björnström, Influence of cement and superplasticizers type and dosage on the fluidity of cement mortars—Part I. Cement and Concrete Research, (2002). 32(10): p. 1605-1611.
[14] Eskandari, H., A.M. Nic, and A. Ghanei, Effect of Air Entraining Admixture on Corrosion of Reinforced Concrete. Procedia Engineering, (2016). 150: p. 2178-2184.
[15] Boyd, A.J. and S. Mindess, The use of tension testing to investigate the effect of W/C ratio and cement type on the resistance of concrete to sulfate attack. Cement and concrete research, (2004). 34(3): p. 373-377.
[16] Kim, Y.-Y., et al., Effect of W/C ratio on durability and porosity in cement mortar with constant cement amount. Advances in Materials Science and Engineering, (2014). 2014.
[17] Rao, G.A., Generalization of Abrams' law for cement mortars. Cement and Concrete Research, (2001). 31(3): p. 495-502.
[18] Singh, S., P. Munjal, and N. Thammishetti, Role of water/cement ratio on strength development of cement mortar. Journal of Building Engineering, (2015). 4: p. 94-100.
[19] Neville, A.M., Properties of concrete. (1995).
[20] Westerholm, M., et al., Influence of fine aggregate characteristics on the rheological properties of mortars. Cement and Concrete Composites, (2008). 30(4): p. 274-282.
[21] Ganaw, A.I. and A.F. Ashour, Rheological properties of mortars prepared with different sands. (2014).
[22] De Schutter, G. and A.-M. Poppe, Quantification of the water demand of sand in mortar. Construction and Building Materials, (2004). 18(7): p. 517-521.
[23] Haach, V.G., G. Vasconcelos, and P.B. Lourenço, Influence of aggregates grading and water/cement ratio in workability and hardened properties of mortars. Construction and building materials, (2011). 25(6): p. 2980-2987.
[24] Reddy, B.V. and A. Gupta, Influence of sand grading on the characteristics of mortars and soil–cement block masonry. Construction and Building Materials, (2008). 22(8): p. 1614-1623.
[25] Eskandari-Naddaf, H. and R. Kazemi, ANN prediction of cement mortar compressive strength, influence of cement strength class. Construction and Building Materials, (2017). 138: p. 1-11.
[26] Commitee, A., C09. ASTM C33-03, Standard Spesification for Concrete Agregates, (2003), ASTM International.
[27] Shah, A., et al., Effect of high range water reducers (HRWR) on the properties and strength development characteristics of fresh and hardened concrete. Iranian Journal of Science and Technology. Transactions of Civil Engineering, (2013). 37(C): p. 513.
[28] Plank, J., et al., Effectiveness of polycarboxylate superplasticizers in ultra-high strength concrete: the importance of PCE compatibility with silica fume. Journal of Advanced Concrete Technology, (2009). 7(1): p. 5-12.
[29] ASTM, C., 230/C 230M (2008) Standard specification for flow table for use in tests of hydraulic cement. ASTM International, West Conshohocken, (2008).
[30] Standard, A., C109/C109M. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens), ASTM International, West Conshohocken PA, (2008).
[31] Standard, A., C305. Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency, (2012), West Conshohocken, PA: ASTM International.
[32] Libre, N.A., R. Khoshnazar, and M. Shekarchi, Relationship between fluidity and stability of self-consolidating mortar incorporating chemical and mineral admixtures. Construction and Building Materials, (2010). 24(7): p. 1262-1271.