Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 3, No. 10, October, 2017

Effect of Main Factors on Fracture Mode of Mortar, A Graphical Study

Sahar Mahdinia [a], Hamid Eskandari-Naddaf [b*], Rasoul Shadnia [c]

[a] MSc student, Department of Civil Engineering, Hakim Sabzevari University, Sabzevar, Iran.

[b] Associate professor Department of Civil Engineering, Hakim Sabzevari University, Sabzevar, Iran.

[c] Assistant professor ,Department of Civil Engineering, Hakim Sabzevari University, Sabzevar, Iran.

Received 22 August 2017; Accepted 15 October 2017

Abstract

One of the most effective ways to identify the concrete properties is to understand further about the cement mortar, which is a mixture of cement paste and fine aggregate. In order to identify the behavior of cement mortar, all required materials including cement, fine aggregate, water as well as the different ratios of each material should beinvestigated. The main objective of this research is to study the effectiveness of main parameters of mortar on the fracture mode and related factors. Specifically 26 mixing designs of flexural mortar with three cement strength classes (32.5, 42.5 and 52.5 MPa), three water to cement (W/C) ratios (0.25, 0.3 and 0.35) and three sand to cement (S/C) ratios (2.5, 2.75 and 3) were first prepared. The prepared samples were then tested using a stress-strain apparatus. Some pictures were finally taken from the fracture surfaces to investigate the mode and angle of fractures. The results indicated that any change in the main parameters of mortar changes the fracture mode and the fracture angle.

Keywords: Cement Mortar; Water to Cement Ratio; Sand to Cement Ratio; Fracture.

1. Introduction

Nowadays, obtaining information about the concrete and cement materials seems to be necessary due to several reasons such as the increase of construction [1] and the wide applications of concrete in different structures like buildings [2] dams [3] , nuclear power plant [4] and bridges [5]. According to different standards, physical and mechanical properties of mortar have a direct effect on concrete properties. On the other hand, due to the fact that the concrete is widely used in daily life [6-9], studying the parameters of mortar does essentially help the concrete to be applied in structures. In their experiments, different scholars have figured out the concrete to be an integrated homogenous material [10] which is consists of cement mortar and coarse aggregates. To obtain the information about cement mortar, the properties of the constituents of mortar including fine aggregates, cement and water should be studied [11] .

One of the most important properties of mortar is the compressive strength [12, 13] taken into account in all constructions projects. Many scholars have conducted several research works on the effects of different parameters including water to cement (W/C) ratio, sand to cement (S/C) ratio and aggregate type S/Con the compressive strength and related factors such as porosity, workability and durability of mortar [14-20]. As instance, Singah et al. studied the effect of W/C ratio on mechanical properties of cement mortar such as compressive and tensile strengths [14]. The effect of different types of aggregates on the compressive strength of mortar was studied by Bumanis et al [16]. Snuck et al. investigated the effect of W/C ratio and aggregate grade on the workability and hardened properties of mortar [20].

* Corresponding author: hamidiisc@yahoo.com

http://dx.doi.org/10.28991/cej-030923

Burguba studied the effect of the type of aggregates on the mortar durability [17]. The effect of porosity on cement mortar was also studied by Anglin et al [19]. Another principal subject related to cement mortar is the fracture type which has been widely investigated so far. The fracture type could become more highlighted in large structures under heavy loads or in earthquake-prone areas where the structures are threatened by cracks. Many scholars have studied the fracture of mortar [21, 22]. One of the conducted studies by Reis and Menezes investigates the effect of additives on the behavior of mortar fracture [21]. They used barley residue as aggregate substitute to synthesize the mortar specimens. The results indicated that the fracture properties of mortar specimens promoted until 5% barley residue were incorporated. Moreira et al. investigated the effect of fiber on the mortar fracture and showed that glass fiber reinforcement is able to improve the resistance of fracture to the propagation of crack [22].

To the knowledge of the authors, however, no research work has studied the effect of main constituents on fracture mode of mortar. A graphical study has been performed in this research work to investigate the effect of main factors such as W/C, S/C ratios and cement strength class on the fracture mode of mortar by considering 26 mixtures of flexural samples prepared by standard metal molds of $4 \times 4 \times 16\ cm$ according to ASTM [23] with three cement strength classes of 32.5, 42.5 and 52.5 MPa, three W/C ratios of 0.25, 0.3 and 0.35 and three S/C ratios of 2.5, 2.75 and 3.

1.1. Materials and Methods

Three cements with the strength classes of 32.5 MPa, produced in Sabzevar Cement Factory, 42.5 and 52.5 MPa, produced in Bojnurd Cement Factory were used in this study. The chemical and physical properties of cements are shown in Table 1. Cement paste was prepared by mixing the mentioned cements with drinking water of Sabzevar at 20±2oC temperature. In order to prepare the cement mortar, the cement paste and fine aggregates available in Sabzevar were mixed. The specific gravity and fineness modulus of sand are respectively 2.6 and 2.48. A different admixture from the conventional super plasticizer called High range water reducing (HRWR) which is based on poly carboxylic technology (Structuro 100) was also used. HRWR content used in this study for different mixtures is sufficient to reach to the flow of 110 ± 5 in 25 drops according to the flow table.

Table 1. Properties of cement

Cement strength class	Chemical Analysis (%)												Physical Analysis		
	CaO	C3S	SiO2	C3A	Al2O3	Fe2O3	SO3	LOI	MgO	F.CaO	K2O	Na2O	Gravity(ton/m^3)	Sieve residue on 90 mm (%)	Blaine Test (cm^2/gr)
325	64.12	63.94	20.4	6.33	4.56	3.4	2.3	2.2	1.93	1.3	0.7	0.32	3.13	0.9	3000
425	64	64.27	20.2	6.27	4.6	3.5	2.4	2.7	1.94	1.3	0.7	0.35	3.13	0.8	3050
525	64.18	57.85	21	6.5	4.7	3.52	2.53	1.2	1.93	1.2	0.65	0.32	3.15	0.1	3600

All materials required to prepare the cement mortar were first mixed by the laboratory mixer and then poured in standard molds. The specimens were compacted in two layers by tamping for each mixture. After 24 hours, the samples were taken out from the molds and moved into a water tank with the temperature of 20°C for 28 days according to ASTM C348 [28]. They were finally tested in a closed-loop servo-controlled universal testing machine under the compressive loads. Table 2 presents the details of mixtures used in this research where CSC and C are respectively the Cement Strength Class and cement.

Table 2. Mix Properties

No.	CSC (MPa)	C (kg)	S/C	W/C	HRWR (ml)
1	32.5	2.85	2.5	0.25	90
2	32.5	2.85	2.5	0.3	40
3	32.5	2.85	2.5	0.35	17
4	32.5	2.67	2.75	0.25	90
5	32.5	2.67	2.75	0.3	45
6	32.5	2.67	2.75	0.35	22
7	32.5	2.5	3	0.25	95
8	32.5	2.5	3	0.3	90
9	32.5	2.5	3	0.35	22

10	42.5	2.85	2.5	0.25	40
11	42.5	2.85	2.5	0.3	30
12	42.5	2.85	2.5	0.35	17
13	42.5	2.67	2.75	0.25	95
14	42.5	2.67	2.75	0.3	35
15	42.5	2.67	2.75	0.35	17
16	42.5	2.5	3	0.25	85
17	42.5	2.5	3	0.3	35
18	42.5	2.5	3	0.35	17
19	52.5	2.85	2.5	0.25	40
20	52.5	2.85	2.5	0.3	30
21	52.5	2.85	2.5	0.35	12
22	52.5	2.67	2.75	0.25	90
23	52.5	2.67	2.75	0.35	17
24	52.5	2.5	3	0.25	50
25	52.5	2.5	3	0.3	35
26	52.5	2.5	3	0.35	30

2. Experimental Results and Discussion

Figure 1. shows the pictures captured from the failed flexural samples prepared by cement with the strength class of 32.5 MPa. As can be observed, the samples are categorized into three groups: A, B and C. Each group of samples is made of one S/C ratio which is constant and three different W/C ratios. In group A, the S/Cratio is 2.5 and the W/C ratios are respectively 0.25, 0.3 and 0.35. Group B consists of the samples with the S/C ratio of 2.75 and three W/C ratios of respectively 0.25, 0.3 and 0.35; and in group C, the S/C ratio is 3 and the W/C ratios are respectively 0.25, 0.3 and 0.35.

Investigating these flexural samples indicates that in the cement with the strength class of 32.5 MPa and constant W/C ratio, any change in S/C ratio changes the fracture angle. This may be due to the fact that there is an optimum S/C ratio which led to the highest compressive strength [24]. As the previous research work of one of the authors of the current study shows [24], the optimum S/C ratio for the corresponding samples is 2.75. At this ratio, hydration is well accomplished and the adhesion between paste and fine aggregates is also at the best possible form. Therefore, the highest strength is achieved, the fracture surface is tended to get closer to the vertical surface and thus the fracture mode is tended to get closer to mode I. For the other S/C ratios, the fracture surface is more inclined toward the combination of mode I and II (tensile and shear modes) and is no longer in mode I. The relationship between the S/C ratio and the W/C ratio is not a predefined relationship. On the other hand this relationship varies when the W/C ratios vary. For instance, considering the W/C ratios of 0.25 and 0.35, it is seen that the strength of mortar made by S/C ratio of 3 is higher than that for S/C ratio of 2.5 while for the W/C ratio of 0.3, the strength corresponded with S/C ratio of 2.5 is higher than that for S/C ratio of 3 [24].

The fracture mode in the mentioned samples is also indicative of the fact that in higher strengths, the fracture mode is tended to get closer to mode I. For instance, as shown in Figure 1, in the case of W/C ratio of 0.25, when the S/C ratio changes as respectively 2.75, 3 and 2.5, the brittle fracture is getting less. On the other hand, for the S/C ratio of 2.75, the fracture mode is mode I, while for the S/C ratio of 2.5 and 3, the fracture mode does gradually shift from mode I toward the mixed modes. Moreover, in a constant S/C ratio, as the W/C ratio increases, the brittle fracture occurs less occasionally and consequently the fracture mode is shifted toward the mixed modes due to the reduction in the strength of samples.

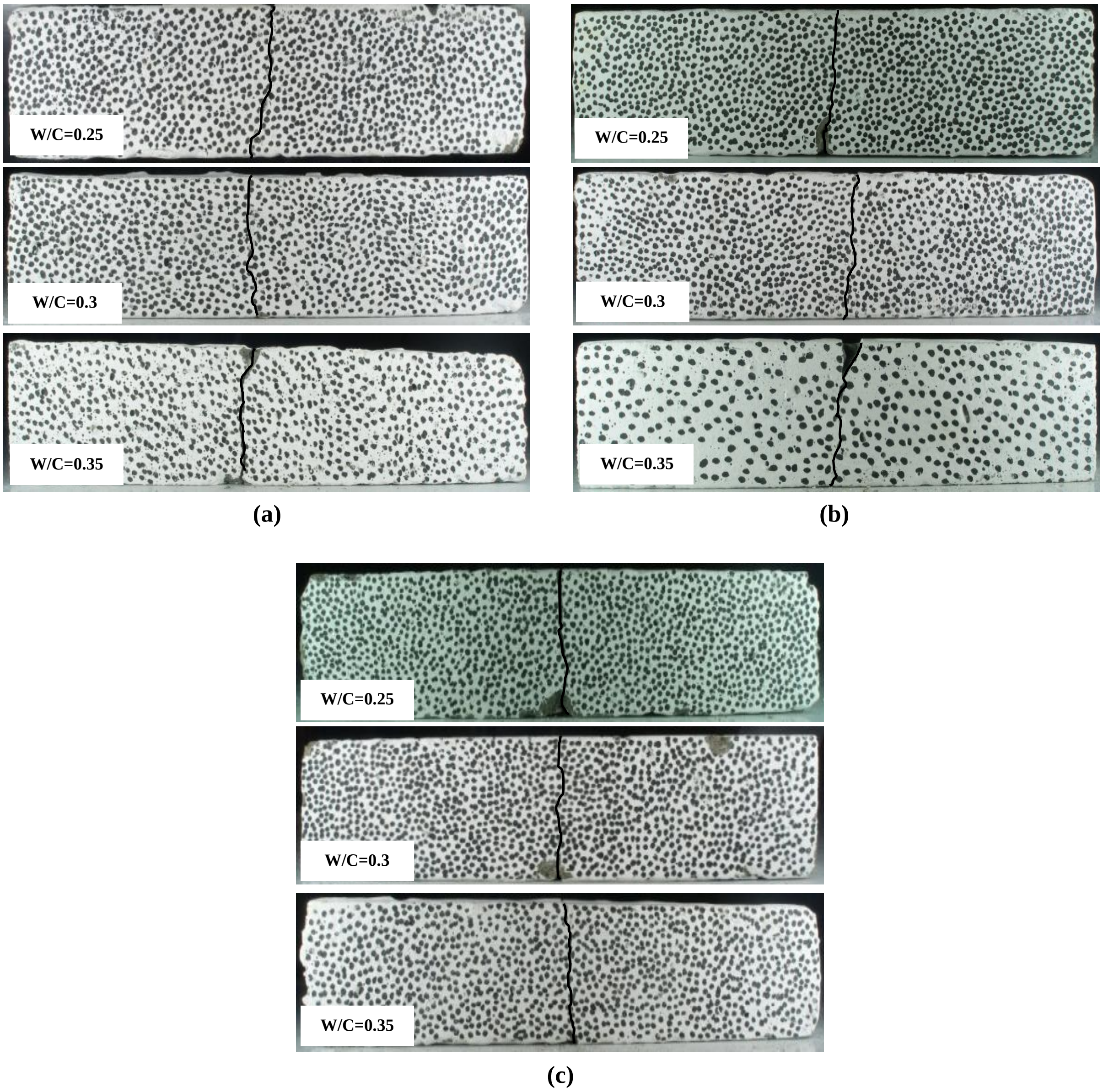

Figure 1. The pictures captured from the failed flexural samples made by cement with the strength class of 32.5 MPa and the S/C ratios of (a):2.5 (b):2.75 (c):3

Figure 2. shows the pictures captured from the failed flexural samples prepared by cement with the strength class of 42.5 MPa. The samples shown in this figure are categorized into three different groups of A, B and C. In group A, the samples were synthesized with the S/C ratio of 2.5 and the W/C ratios of respectively 0.25, 0.3 and 0.35. Group B includes the samples with S/C ratio of 2.75 and W/C ratios of respectively 0.25, 0.3 and 0.35. Group C shows the samples with S/C ratio of 3 and W/C ratios of respectively 0.25, 0.3 and 0.35. It has been found that for all W/C ratios, the samples with the S/C ratio of 2.5 have the most vertical surface of fracture, so the brittle fracture occurs in mode I. By looking at different W/C ratios, one can find out that the samples with different W/C ratios have different fracture angles. For instance, for the samples synthesized with the S/C ratio of 3 and the W/C ratios of 0.25 and 0.3, fracture is no longer brittle and so the fracture mode tends toward mixed modes. On the other hand, for the samples made by the W/C ratio of 0.35 and S/C ratio of 2.75, the deviation of fracture surface from the vertical surface is higher than that for the other two S/C ratios due to the alteration in the strength of samples.

As the results of Eskandari and Kazemi [24] showed, the trend of strength reduction for the samples made by different W/C ratios and various S/C ratios at each strength class of cement is totally unique. For instance, in the cases of W/C ratios of 0.25 and 0.3, as the S/C ratio changes from 2.5 to 2.75 and 3, the strength is reduced. For the W/C ratio of 0.35, however, the strength decreases as the S/C ratio changes respectively from 2.5 to 3 and then 2.75.

According to Figure 2, it can be observed that the fracture mode exactly corresponds to the trend of strength changes in the samples. On the other hand due to the negative effect of water on the strength, as the W/C ratio (at a constant S/C ratio) increases, the fracture mode of the sample is further inclined toward the mixed modes.

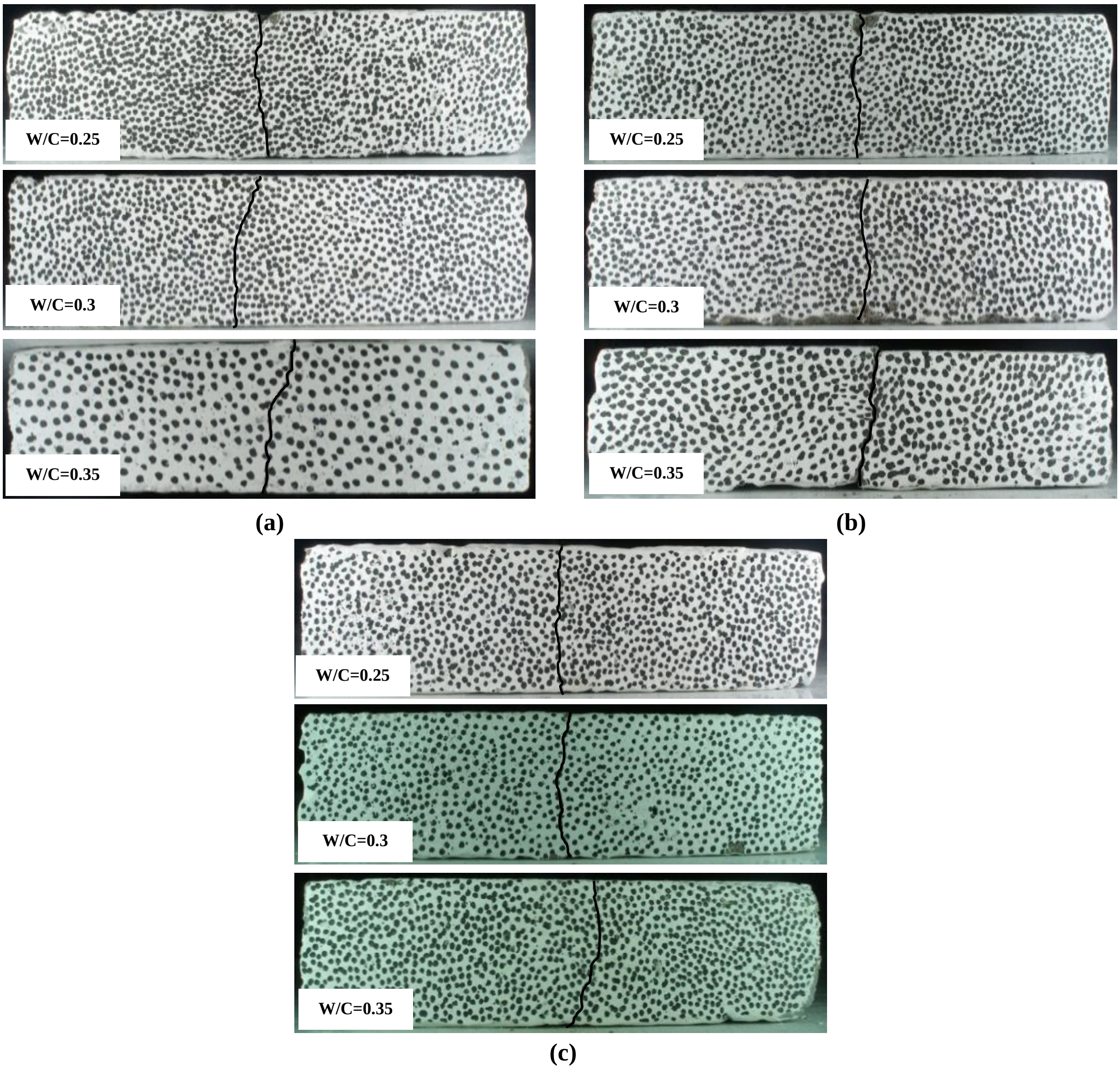

Figure 2. The pictures captured from the failed flexural samples made by cement with the strength class of 42.5 MPa and the S/C ratios of (a):2.5 (b):2.75 (c):3

Figure 3. shows the behavior of 8 pictures captured from the failed flexural samples prepared by cement with the strength class of 52.5 MPa using different W/C ratios and various S/C ratios. This set of samples is also categorized into three groups of A, B and C. Group A includes samples with S/C ratio of 2.5 and W/C ratios of 0.25, 0.3 and 0.35. In group B, the S/C ratio of 2.75 and W/C ratios of 0.25 and 0.35 were used. Group C includes the samples with S/C ratio of 3 and W/C ratios of 0.25, 0.3 and 0.35.

It can be observed that for the samples with the W/C ratio of 0.25, as S/C ratio varies from 2.5 to 3 and then to 2.75, the fracture mode shifts from mode I (brittle fracture) to mixed mode while in the cases of W/C ratios of 0.3 and 0.35, the trend of brittle fracture reduction is from 2.5 to 2.75 and then to 3. The reason for the reduction of brittle fracture in these samples is also the strength reduction.

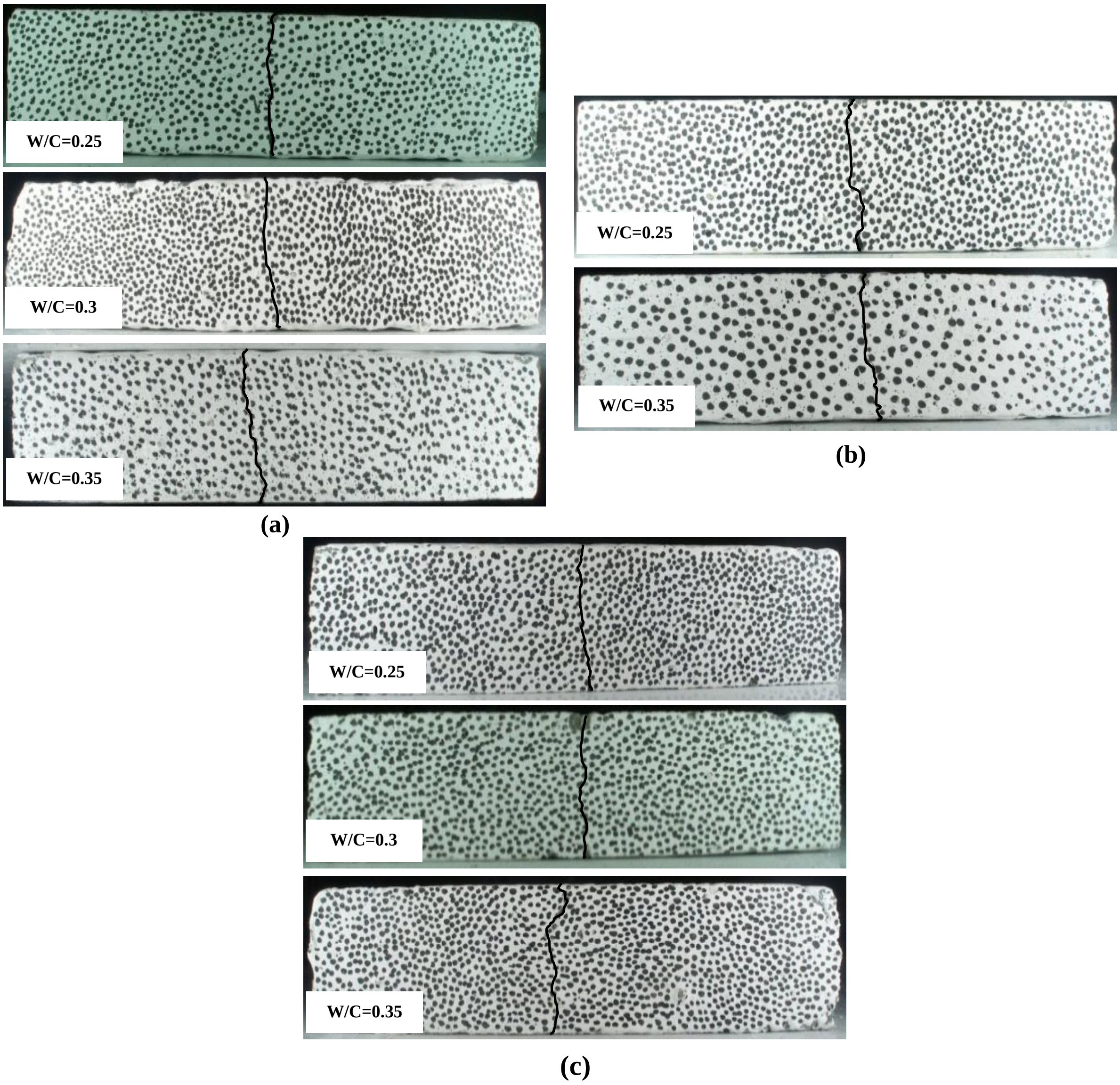

Figure 3. The pictures captured from the failed flexural samples made by cement with the strength class of 52.5 MPa and the S/C ratios of (a):2.5 (b):2.75 (c):3

3. Conclusion

In this research work, a graphical study was carried out to investigate the effect of different parameters including the W/C ratio, S/C ratio and cement strength class on the fracture mode of mortar by considering 26 mixtures of flexural samples prepared by standard metal molds of $4 \times 4 \times 16\ cm$. The results showed that as the strength class of cement increases, the angle of fracture approaches to the vertical surface likely due to the fact that in a constant W/C and S/C ratios, any increase in the strength class of cement increases the strength of the samples which causes the fracture to be more brittle and thus the fracture angle to get closer to the vertical surface. The results also showed that the identification of fracture modes and other related factors are associated with the effective parameters of mortar including the strength class of cement, W/C ratio and S/C ratio.

4. References

[1] Yazdani, Azad, Ahmad Nicknam, Ehsan Yousefi Dadras, and Seyed Nasrollah Eftekhari. "Entropy-based sensitivity analysis of global seismic demand of concrete structures." Engineering Structures 146 (2017): 118-126.

[2] Eskandari, Hamid, and Tahereh Korouzhdeh. "Cost optimization and sensitivity analysis of composite beams." Civil Engineering Journal 2, no. 2 (2016): 52-62.

[3] Wang, Gaohui, Yongxiang Wang, Wenbo Lu, Mao Yu, and Chao Wang. "Deterministic 3D seismic damage analysis of Guandi concrete gravity dam: A case study." Engineering Structures 148 (2017): 263-276.

[4] Kim, Baek-Joong, and Chongku Yi. "Experimental Study on the Shrinkage Properties and Cracking Potential of High Strength Concrete Containing Industrial By-Products for Nuclear Power Plant Concrete." Nuclear Engineering and Technology 49, no. 1 (2017): 224-233.

[5] Cassese, Paolino, Paolo Ricci, and Gerardo M. Verderame. "Experimental study on the seismic performance of existing reinforced concrete bridge piers with hollow rectangular section." Engineering Structures 144 (2017): 88-106.

[6] Eskandari, Hamid, and Amirhossein Madadi. "Investigation of ferrocement channels using experimental and finite element analysis." Engineering Science and Technology, an International Journal 18, no. 4 (2015): 769-775.

[7] Eskandari, Hamid. "Designing, proposing and comparing the methods predicting the compressive strength of the ferro cement mortar." Concrete Research Letters 6, no. 1 (2015): 1-10.

[8] Eskandari, Hamid, Morteza Gharouni Nik, and Amir Pakzad. "Foundation analyzing of centrifugal ID fans in cement plants." Alexandria Engineering Journal 55, no. 2 (2016): 1563-1572.

[9] Shadnia, Rasoul, Lianyang Zhang, and Peiwen Li. "Experimental study of geopolymer mortar with incorporated PCM." Construction and building materials 84 (2015): 95-102.

[10] Akalin, O., et al., Optimization of chemical admixture for concrete on mortar performance tests using mixture experiments. Chemometrics and Intelligent Laboratory Systems, 2010. 104(2): p. 233-242.

[11] Wahab, Mona Abdel, Ibrahim Abdel Latif, Mohamed Kohail, and Amira Almasry. "The use of Wollastonite to enhance the mechanical properties of mortar mixes." Construction and Building Materials 152 (2017): 304-309.

[12] Eskandari, H., M.G. Nik, and M.M. Eidi, Prediction of mortar compressive strengths for different cement grades in the vicinity of sodium chloride using ANN. Procedia Engineering, 2016. 150: p. 2185-2192.

[13] Eskandari-Naddaf, Hamid, and Mohammad Azimi-Pour. "Performance evaluation of dry-pressed concrete curbs with variable cement grades by using Taguchi method." Ain Shams Engineering Journal (2016).

[14] 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.

[15] Snoeck, D., et al., Effect of high amounts of superabsorbent polymers and additional water on the workability, microstructure and strength of mortars with a water-to-cement ratio of 0.50. Construction and Building Materials, 2014. 72: p. 148-157.

[16] Bumanis, G. and D. Bajare, Compressive strength of cement mortar affected by sand microfiller obtained with collision milling in disintegrator. Procedia Engineering, 2017. 172: p. 149-156.

[17] Bourguiba, A., et al., Effects of recycled sand on the properties and durability of polymer and cement based mortars. Construction and Building Materials, 2017. 153: p. 44-54.

[18] Khouadjia, M.L.K., B. Mezghiche, and M. Drissi, Experimental evaluation of workability and compressive strength of concrete with several local sand and mineral additions. Construction and Building Materials, 2015. 98: p. 194-203.

[19] Angelin, A.F., et al., The effects of porosity on mechanical behavior and water absorption of an environmentally friendly cement mortar with recycled rubber. Construction and Building Materials, 2017. 151: p. 534-545.

[20] 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.

[21] Reis, J. and E. Menezes, Barley residue reinforced polymer mortars: Fracture mechanics approach. Composite Structures, 2017. 173: p. 53-57.

[22] Moreira, G., et al., Effect of fiber reinforcement on mixed-mode fracture of polymer mortars. Composite Structures, 2016. 141: p. 179-183.

[23] ASTM, C., 348-02: Standard test method for flexural strength and modulus of hydraulic cement mortars. ASTM, USA, 2002.

[24] 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.