Investigation of the effect of cement strength class on cement mortar porosity using sample cross-sectional images

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***Abstract*- Production of cementitious materials with proper performance-as one of the most widely used structural materials-requires an understanding of its physical and mechanical properties that are affected by the constituents and mixing ratios. In this study, using cement mortar surface imaging in two different water-to-cement ratios, the effect of cement strength on the cavities and porosity of cement mortar samples is investigated. Comparison of the results of porosity using the cross-sectional imaging method and the experimental method shows a striking resemblance. Using cross-sectional sampling is a straightforward approach to estimate porosity. The results highlight that the porosity decreases by increasing the cement strength class from 32.5 to 52.5 MPa and decreasing the water-to-cement ratio from 0.5 to 0.3.**

***Keywords* –** Cement strength class, Cement mortar, Porosity, Compressive strength.

1. INTRODUCTION

With the increasing progress of the building industry and the human need for this industry, the use of the most advanced technologies for building durable structures is pivotal. One of the most critical components utilized in building industry is concrete, where cement mortar plays a key role in the formation of concrete and its properties. The physical and mechanical properties of cementitious materials are significantly influenced by the ingredients, type and mixing ratio of these materials. Meanwhile, the water-to-cement ratio, and the type of cement consumed, is of higher importance. Therefore, porosity is the main factor that affects other concrete properties such as resistance and durability [1]. Cement mortar consists of three main ingredients, namely, water, aggregate, and cement. Each of these materials gives a unique property to mortar. In 2014, Mai and Cretell [5] investigated the effect of porosity on the mechanical properties of cement mortars. This study shows that, despite the porosity, Young's modulus decreases. In their study in 2003, Usil et al. [4] concluded that the compressive strength of concrete will increase by increasing cement strength class. They also found that this would reduce the porosity of the concrete. In 2013, Chen et al. [3] studied the impact of porosity on compressive strength and flexural strength of cement mortars and argued that increasing porosity decreases compressive strength and flexural strength of cement mortar samples. Moreover, as the porosity increases, the ratio of compressive strength to tensile strength of mortar decreases. In a study conducted in 2017 by Eskandari Nadaf and Kazemi [2], the compressive strength of cement was investigated on 54 different mixing schemes containing water-to-cement ratio, aggregate to cement ratio and different cement type resistance and a total of 810 samples. The results of the study showed that increasing the cement strength class improves the compressive strength of cement mortar. A literature review illustrates that although much research has been conducted on cement and porosity mortars as well as other mortar properties, the effect of different cement strength classes on the porosity of mortars yet to be studied. In the current study, the porosity of specimens with different resistance classes is investigated using images.

2. LABORATORY PROGRAM

2.1 Materials and mixing design

In this study, three types of Portland cement with cement strength classes of 32.5, 42.5 and 52.5 MPa are used. The chemical and physical properties of cements used are presented in Table 1. The aggregates used are fine grained (sand) type with the highest grain dimension of 4.75 mm, density of 2.6 kg/cm3, and softness modulus is 2.48. The classification is based on ASTM C33 regulations [6]. Drinking water was used for making samples. Furthermore, polycarboxylic base lubricant is used for self-compact cement mortars when filling molds. In addition to increasing the efficiency of the cement mortar, the super-lubricant increases its ultimate strength as well [7]

Table 1. Physical and chemical properties of consumable cements

cement strength classes (MPa)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI	F.CaO	C_3A	C_3S	density (ton/m^3)	Remaining on sieve (%)	Blaine Test (cm^2/gr)
3000	0.9	3.13	63.94	6.33	1.3	2.2	0.7	0.32	2.3	1.93	64.12	3.4	4.5	20.4	32.5
3050	0.8	3.13	64.27	6.27	1.3	2.7	0.7	0.35	2.4	1.94	64	3.5	4.6	20.2	42.5
3600	0.1	3.15	57.85	6.5	1.2	1.2	0.65	0.32	2.53	1.93	64.18	3.52	4.7	21	52.5

The purpose of the current study is to investigate the effect of cement strength and water-to-cement ratio and the effect of these parameters on cement mixing design considering all conditions. For this purpose, an extensive laboratory experiment with 6 cement mortar mixing designs including three types of cement with different strength classes of 32.5, 42.5 and 52.5 MPa with a sand-to-cement ratio of 2.75 and two water-to-cement ratios of 0.3 and 0.5 was carried out. The amount of consumed lubricant was determined using a flow table and 110± 5 flow with 25 beats [8].

Table 2. Mixing design ratios for cement mortars.

Mixing plan number	Cement strength classes (MPa)	cement	w/c	c/s	High range water reducer (ml)
1	32.5	(kg)	0.3	2.75	
2	42.5	2.85	0.3	2.75	45
3	52.5	2.85	0.3	2.75	35
4	32.5	2.85	0.5	2.75	40
5	42.5	2.67	0.5	2.75	2
6	52.5	2.67	0.5	2.75	2

By mixing the cone speed to medium (280 rpm), the mixer mixes for 30 s. Finally, for 60 s, the material is blended at medium speed in the cone. The resulting cement mortar is poured into the molds after being uniformly mixed in the mixer and the surface of the specimens is perfectly smooth during loading to reduce the error in the power distribution. The specimens were kept in the mold for 24 hours and then were removed from the mold in a water tank at 22±2 °C to be tested later. To test porosity, weights of three samples of each mixing scheme were measured using the Archimedes' law.

The samples were first dried in a drying machine at 105±5 °C to obtain a constant weight (Wd). Subsequently, the weight of the underwater sample at saturation (Ww) and the dry surface saturation (Wssd) were calculated. The weight difference between saturated and dry conditions was used for calculating porosity for one percent of the sample volume. Porosity (P) is determined using the following equation:

$$P = \frac{(W_{ssd} - W_d)}{(W_{ssd} - W_w)} \times 100\% \quad (1)$$

A pressure tester with a capacity of 20 tons was used to test the compressive strength. For testing, samples were tested along the surface where the mortar was poured. For each of the 7 and 28 days of age, three samples from each mixing scheme were tested and the mean of three samples of different ages was obtained.

3. Extract images from the sample cross-section

This section deals with sample images and their porosity. To sample the porosity of the sample, it needs to be cut into 4 equal portions. Figure 1 (a) represents the cubic sample of the mortar under study. Figs. 1 (b) and (c) show the cross-section of the sample that is evenly cut and part of the porosity, respectively. Fig. 1 (d) illustrates that the cavities are extracted using imaging, and they are generalized to mortar samples. Then the results of the images are compared with the laboratory results to evaluate the accuracy of the proposed method..

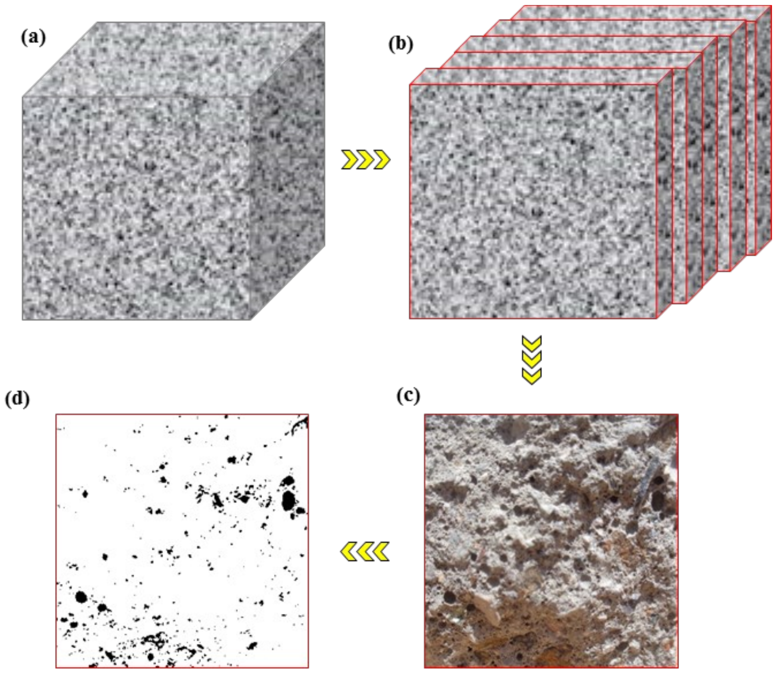


Fig. 1. Steps to determine the cavities using the imaging technique A) Manufacture of cubic samples B) Sample cut C) Surface photography d) Determination of cavities

4. Discussion and results

4.1. Experimental results

Fig. 2 shows the effect of cement strength changes of 32.5, 42.5 and 52.5 on the porosity of cement mortars at 7 and 28 days for water-to-cement ratios of (a) 0.3 and (b) 0.5.

As per Fig. 2, porosity of the specimens is significantly decreased by increasing the cement strength at 7 days of age. For example, the 7-day sample with 32.5 cement has a 12% porosity which is decreased to 7.5% by increasing the cement strength to 52.5.

In addition, porosity decreases with increasing the sample age from 7 days to 28 days due to the completion of the hydration process (loss of surface area and increase in the amount of free water in the solid phase of hydration)

According to Fig. 2, this trend is also true for the 28-day sample. For example, for a 7-day-old cement with a resistivity rating of 32.5 and a water-to-cement ratio of 0.3 it has 12% porosity, and it is 7% for this 28-year-old sample. Although with increasing water-cement ratio from 0.3 (Fig. 2-a) to 0.5 (Fig. 2-b), a similar trend is observed in changes in porosity with sample age and cement strength class, in the samples with water-to-cement ration of 0.5, the porosity values with state are higher than that of a water-to-cement ration of 0.3. This is due to the increase in the water-to-cement ratio which causes more cavities in the sample.

Fig. 2. The effect of cement resistance class on porosity in different ages with: a)w/c=0.3and b)w/c=0.5

Fig. 3 shows the effect of cement strength class changes of 32.5, 42.5 and 52.5 cements on the compressive strength of 7- and 28-day cement mortars for water-to-cement ratios of 0.3 and 0.5, respectively. As can be seen, the compressive strength of the specimens increased in 7 days with increasing the cement strength. For example, for a 7-day sample with 32.5 cement strength of 15 MPa, this is increased to 35 MPa as the cement strength increased to 52.5. Also, by increasing the age of sample from 7 days to 28 days, an increase in the compressive strength is observed and this holds true for the 28-day sample. For instance, for a 7-day cement sample with a resistivity rating of 32.5 and a water-to-cement ratio of 0.3, it has a compressive strength of 15 Mpa, and it is 55 MPa for a 28-day sample. A similar trend is observed when increasing the water-to-cement ratio.

In the samples with a water-to-cement ratio of 0.5, the compressive strength values are lower than those of water-to-cement ratio of 0.3. This is due to the increase in water-to-cement ratio. Additionally, it has a direct impact on the air cavities in the concrete and reduces the compressive strength of the concrete.

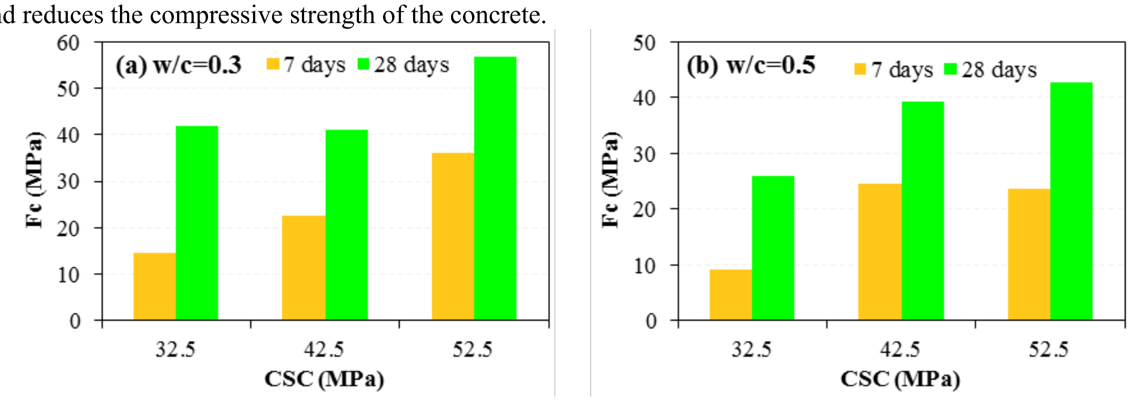
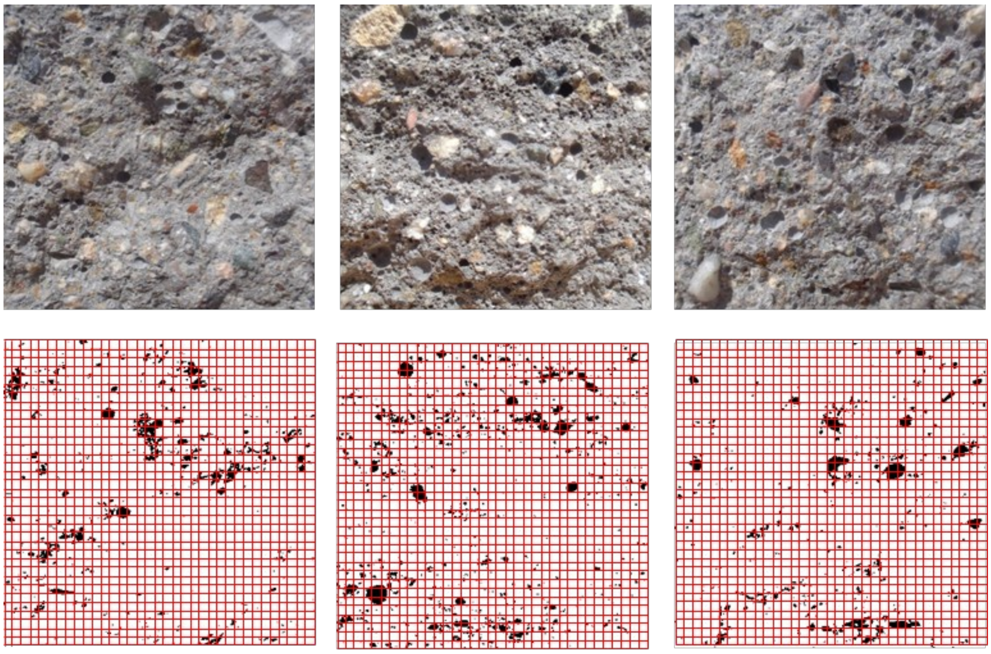


Fig. 3. The effect of cement resistance class on compressive strength of different ages by : a) w/c=0.3 and b) w/c=0.5

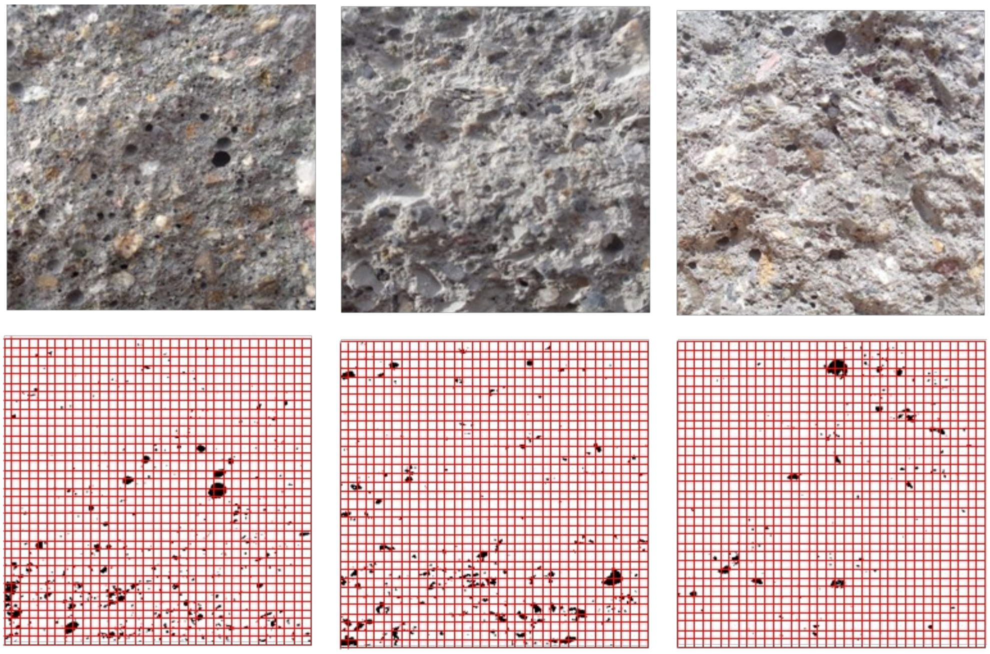
4.2. Investigation of porosity using cross-sectional images

Thanks to a large number of images taken from the specimens, part of this cross-section is shown in Figs. 4 and 5. According to Fig. 4, in the samples with a water-to-cement ratio of 0.5, the cavities decrease by increasing the cement strength from 32.5 Mpa to 52.5 MPa. Therefore, high-strength cement samples have less porosity than other samples in this section. In Fig. 5, in addition to increasing the strength of cement, the water-to-cement ratio is varied from 0.5 to 0.3. In this case, further reduction in cavities is observed in the sample. This change has a positive effect on the cavity reduction process.



(a) CSC 32.5 MPa (b) CSC 42.5 MPa (c) CSC 52.5 MPa

Fig. 4. Effect of cement strength class on cavities in specimens with water to cement ratio of 0.5.



(a) CSC 32.5 MPa (b) CSC 42.5 MPa (c) CSC 52.5 MPa

Fig. 5. Effect of strength class on cavities in specimens with water to cement ratio of 0.3.

A comparison of the results of the porosity laboratory results and those obtained from the images is presented in Table 3. A comparison of these results concerning the water-to-cement ratio and the different resistances class indicates that the results are very similar, proving that the method used in this paper is well-suited. Besides, there is a slight difference in the results obtained from the two methods due to errors in the laboratory method and the imaging method.

Table 3. Comparison of laboratory results of porosity measurement with results of cross sectional images.

Method for calculating porosity		CSC (MPa) 32.5	42.5	52.5
laboratory results(28-day)	w/c=0.3	7.5	5	3.5
	w/c=0.5	11	9	8
Cross-sectional images	w/c=0.3	8	6.5	4
	w/c=0.5	12	10.5	9

According to the results, increasing the strength of cement reduces porosity and compressive strength of cement mortar. Also, using the cross-sectional sampling method has made porosity calculation easier and more accurate.

5. Conclusion

- Resistance class of cement is an effective parameter on the porosity of cement mortar samples. By increasing the strength of cement from 32.5 Mpa to 52.5 MPa, a 50% decrease in porosity is observed.
- Resistance class of parametric cement is effective on the compressive strength of cement mortar. Increasing the strength of the cement increases the compressive strength by roughly 5 to 10 percent.
- As the water-cement ratio decreases, porosity decreases as well.
- The effect of cement strength class on porosity was similar in 7- and 28-day samples.
- The porosity results obtained from the imaging and cross-sectional images of the samples and the laboratory method indicate the similarity of the results, showing that the proposed method can be employed to estimate the porosity.

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