Evaluating the influence of silica fume on selected cement mortar properties

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Abstract. Due to the common and widespread use of cement in different engineering aspects; therefore, improving cement mortar properties from the main targets which were destined by different researchers. These properties include flow test, permeability, compressive strength, modulus of rupture of cement mortar, and ultrasonic pulse velocity tests. Therefore, this study has focused on using silica fume to enhance the aforementioned tests for cement mortar. Five percentages of silica fume have been used from 0.0% to 8%. The results indicate that the reduction in water permeation ratio is about 60 % when 2.5% of silica fume has been used as an admixture to cement mortar. At 2.5% of silica fume, the magnitude of strength increase at 7 and 28 days is about 12.2 and 27.6 percent respectively. At 2.5% of silica fume, the increase in the strength is about 30 and 38 percent for 7 and 28 days respectively. The addition of silica fume to the cement mortar results in increasing the pulse velocity.

Keywords: Compressive strength, cement mortar, permeability and silica fume

1. Introduction
Mainly, waterproofing admixtures are the most significant ones for the underground structures. Such admixtures have significant effects in the middle and southern of Iraq. This could be attributed to the existence of salty under-ground water [1]. The significant effect of some properties of concrete such as durability and permeability might have an impact exceeds the effect of compressive strength. This influence may result from harmful moving of liquids and gases through concrete [1]. Besides, Yang et al., [2] reported that water is not only considered to cause various forms of physical degradation processes in porous materials but also acts as a carrier for aggressive agent migration, which can cause chemical degradation processes and is the main intermediary for the formation and destruction of many natural materials [3].

Al–Khalidy [4] assessed the concrete permeability including various ratios of sulphate utilizing nitrogen gas. The assessment process has been conducted on the two mixtures with gradient proportions (1:1.5:3) and (1:2:4) including different sulphate ratios (0.24,0.5,1.0,1.5and 2.0) % of the sand weight. One ratio of water cement is utilized (0.5). The characteristics of the fresh mixtures have been determined by knowing the slump values for these mixes. The results showed that obvious decreases in the calculated slump values as the sulfate content increased with time.

Reddy and Ramadasu [5] used three mixtures 1:6 with 16% water ratio, 1:8 mixture with 18 % water ratio and 1:10 mixture with 19 % water ratio. Also, five various ratios of replacement of cement by
weight with silica fume (0, 5, 10, 15 and 20) were used. For each percentage used by silica fume 3, cubes have been tested at four ages (7, 14, 21 and 28) days. At 21 days for 1:6 mix, the maximum compressive strength increase was recorded. Whereas, for 1:8 and 1:10 mixtures, the compressive strength reaches the maximum value at 28 days. Besides, the maximum value of compressive strength was found at 1:6 mortar mixture (16 water ratio) at 15 % replacement of cement by silica fume. Moreover, the increase in compressive strength of 1:8 mortar mixture (18 % water ratio) and 1:10 mortar mixture (19 % water ratio) is maximum at 10 % replacement of cement by silica fume.

Sampe et al., [6] investigated the influence of silica fume replacement to fly ash on thermal and mechanical properties of geopolymer. The thermal conductivity of silica fume replaced geopolymer is in the range of 0.051 to 0.932 W/m°C. The utilization of silica fume leads to geopolymer paste is more porous to its thermal resistance rise. The density values attained in the range of 1752.457 to 1870.309 kg/m3. The compressive strength in the range of 25.41 to 38.48 MPa. The mix is appropriate as a thermal insulation material, as the thermal conductivity value is below 1 W/m°C.

Gražulytė et al., [7] analyzed concrete mix’ behavior based on the quantity of silica fume indicated that 7% was an optimal quantity. This leads to 37%, 16% and 35% higher strength in compression, tension and bending, respectively and 45% higher fatigue resistance. The increase of silica fume equal to 10% has nearly the same influence on compressive strength; though, indirect tensile strength and flexural strength are 5–11% lower than those obtained for concrete mixes having 7% of silica fume. Also, Adil et al [8] studied the effect of using silica fume on the mechanical and durability of pervious concrete. The results indicate that 5% silica fume made the significant performance of increased workability, strength and durability.

Ghafor et al., [9] conducted correlation models to investigate the mechanical behavior of the cement mortar with silica fume. The results demonstrate that a significant relationship between the compressive strength with flexural strength and tensile strength with silica fume. They also found that the silica fume percent equal to 55% has less influence on increasing the compressive strength comparing with w/c and curing time.

In the light of the above, this study has focused on investigating the effect of using silica fume on the permeability of cement mortar an addition not replacement by cement weight. Furthermore, this study investigated the effect of other properties such as compressive strength and modulus of rupture.

2. Methodology

The methodology of this work mainly could be summarized by using finely divided materials such as silica fume as a permeability-reducing admixture in the structures subjected to the flow of water through it. Hence, the effect of silica fume on the permeability has been investigated using various percentages of this material (2.5%, 5%, 6%, 7%, and 8%) as an additional ingredient by weight of cement without altering the relative proportion of other ingredients. However, the effect of this material on other properties of cement mortar such as density, compressive strength, modulus of rupture and ultrasonic pulse velocity has been included, too.

3. Used material

In this section, the main materials used in this study are mentioned. Firstly, Portland cement Type V has been utilized. Secondly, fine aggregate which has been taken from AL-Nawafith Co.LTD for sand and gravel filters in Al-Najaf city, yellowish-brown were used. Thirdly, silica fume used throughout this study was brought from the commercial market. It was stored in a dry place and added to the cement mortar mix as a dry powder. The chemical analysis of this fume is given in Table1. Finally, the liquid Iraqi superplasticizer was utilized as indicated in Table 2.
4. The experimental program
The samples of cement mortar have been used for permeability, density, compressive strength, modulus of rupture. Various ratios of silica fume have been used to investigate these properties. These tests are indicated in the following sub-sections.

### Table 1. Silica fume chemical compounds.

| Chemical compound | % total weight |
|-------------------|---------------|
| SiO2              | 98.66         |
| Al2O3             | 0.12          |
| Fe2O3             | 0.20          |
| CaO               | 0.20          |
| MgO               | 0.15          |
| SO3               | 0.15          |
| K2O               | 0.03          |
| Na2O              | 0.10          |

### Table 2. Technical description of superplasticizer (Melment L10).

| Main action          | Concrete super-plasticizer          |
|----------------------|-------------------------------------|
| Subsidiary effect    | Hardening accelerator               |
| Appearance           | Clear to slightly milky             |
| Solids in aqueous solution | Approx. 20%                          |
| Density              | 1.1 g/cm³                           |
| Chloride content     | less than 0.005%                    |
| Sugar content        | None                                |
| Handling             | No special precautions              |
| pH value             | 7-9                                 |
| Frost resistance     | Melment L10 withstands any number of frost cycles. It should be thoroughly thawed before use. At least two years. It should not, however, be exposed to excessive heating |
| Storage life         |                                     |

4.1. Workability test
The flow table test has been prepared for determining the workability of the cement mortar mixtures including different ratios of silica fume. The flow, W/C content and superplasticizer percent for all silica fume mixtures have been shown in Table 3.

### Table 3. Flow test results of silica fume mixtures.

| Mix no. | Silica fume by weight of cement % | W/C content | Superplasticizer by weight of cement % | Flow % |
|---------|-----------------------------------|-------------|----------------------------------------|--------|
| M1      | 0                                 | 0.485       | 0                                      | 110    |
| M2      | 2.5                               | 0.485       | 3                                      | 90     |
| M3      | 5                                 | 0.485       | 3                                      | 80     |
| M4      | 6                                 | 0.485       | 3                                      | 75     |
| M5      | 7                                 | 0.485       | 3                                      | 70     |
| M6      | 8                                 | 0.485       | 3                                      | 65     |

From Table 3, it can be noticed that the workability of mortar mixes is greatly affected when silica fume is used as an additional ingredient to cement mortar. The results show that the water demand of mortars incorporating silica fume increases with increasing amounts of silica fume. This increase in
water demand is due to the very large surface area of the particles of silica fume, which have to be wetted. Therefore, the use of superplasticizer assists in this respect. Silica fume should always be used together with water-reducing or high-range water-reducing admixtures (HRWR, or superplasticizer) to maintain the required workability with no change in the water-to-cement ratio. The dosage of the HRWR will depend upon the percentage of silica fume and the type of HRWR used [10].

4.2. Permeability test

Having known the significant of the permeability as mentioned in introduction, it is tested under a 20-cm head of water is existed in the British standard for concrete roofing tiles [3]. The water permeation quantity and water permeation ratio of cement mortar including various ratios of silica fume are indicated in Table 4. The influence of this addition on the permeability of cement mortar can be noticed that the addition of silica fume and superplasticizer to cement mortar reduces the quantity of penetrated water and this reduction rises with the rise of silica fume content. At 5% of silica fume the reduction in the water permeation ratio is about 66.4 % less than that of the reference mix. Beyond 5% the decrease in water permeation is very small.

Lower permeability of silica fume concrete comparing with plain cement concrete is due to the increase in the denseness of such concrete from the addition of silica fume, leading to the transformation of large pores into fine pores and thus resulting in pore refinement. Pore refinement happens resulting from the conversion of Ca (OH)2 by pozzolanic silica into a secondary calcium silicate hydrate (C-S-H) gel, which efficiently fills up large voids in hydrated silica fume-Portland cement concretes. The density of the hydrate is slightly less than that of the hydrate usually made with hydration of Portland cement; despite the lower density [10,11]. Some investigators suggest that the decrease in permeability of pozzolanic cement concretes is attributed to the influence of these pozzolans on the transition zone between the cement paste and aggregate. The thickness of the transition zone, which is about 2 to 3 µm in plain cement concrete, is decreased with the addition of such pozzolanic materials [12].

| Silica fume by weight of cement % | Water permeation quantity (gm) | Water permeation ratio |
|----------------------------------|-------------------------------|-----------------------|
| 0                                | 11.25                         | 1.00                  |
| 2.5                              | 4.5                           | 0.4                   |
| 5                                | 3.78                          | 0.336                 |
| 6                                | 3.6                           | 0.32                  |
| 7                                | 3.48                          | 0.309                 |
| 8                                | 3.12                          | 0.277                 |

4.3. Density test

Figure 1 indicates that the existence of silica fume slightly increases the density. The results show that the density decreases with the increase in the percentage of silica fume over 2.5%.

![Figure 1. Effect of silica fume on the cement mortar density.](image-url)
The maximum density has been achieved at 2.5% of silica fume. The density is 3.2 percent more than that of the reference mix. The slight reduction in the density of mixes above 2.5% of silica fume is due to the that density of the calcium silicate hydrate that is made by the reaction of silica fume with Ca(OH)2 is slightly lower than that of the hydrates normally made with hydration of Portland cement [10].

4.4. Compressive strength

Figure 2 states the influence of silica fume on the compressive strength of cement mortar. The results show that the compressive strength of the mixes increases with the increase in the percentage of silica fume. At 2.5% of silica fume, the rise in the compressive is 12.2 and 27.6 % for both 7 and 28 days.

[Figure 2. Compressive strength test results of silica fume containing mortar.]

This increase in compressive strength can be attributed to the pozzolanic influence of silica fume. However, in the existence of hydrating Portland cement, silica fume will respond as any finely divided amorphous silica-rich constituent in the existence of calcium hydroxide- the calcium ion combines with the silica to form a calcium silicate hydrate through the pozzolanic reaction [13]. The compressive strength grows with curing time for all hardened samples which could be attributed to the pozzolanic properties of silica fume [14].

4.5. Modulus of Rupture

Figure 3 shows the influence of silica fume on the modulus of rupture. The influence of silica fume and superplasticizer on the modulus of rupture is like that of compressive strength. The figure demonstrates an improvement in the modulus of rupture as the silica fume percentage is increased rapidly with increasing of silica fume percentages. At 2.5% of silica fume, the rise in the modulus of rupture is about 30 and 38 percent for 7 and 28 days; respectively. Whereas, at 8% of silica fume, the increments in the modulus of rupture are about 100%, 96%, and 81%, respectively for 7, 28, and 90 days.
4.6. Ultrasonic pulse velocity

The ultrasonic pulse velocity of cement mortar specimens was determined before finding the compressive strength by the destructive method. This technique is now generally used for evaluating the quality of concrete in structures [15]. The measured pulse velocity of cement mortar can be influenced by many factors, including the smoothness of contact surface, the temperature of the specimen, moisture conditions, age of the specimen and existence of reinforcing steel [16]. Generally, high pulse velocity readings are indications of good quality concrete. The ranges of pulse velocity of different concrete qualities are indicated in Table 5.

Table 5. Pulse velocity ranges of concrete [3].

| Pulse velocity (Km/sec.) | Concrete quality |
|-------------------------|-----------------|
| Above 4.58              | Excellent       |
| 3.66-4.58               | Good            |
| 3.05-3.66               | Questionable    |
| 2.14-3.05               | Poor            |
| Below 2.14              | Very poor       |

The effect of silica fume on the pulse velocity of cement mortar is shown in Figure 4. This figure shows an improvement in pulse velocity and this improvement increases with the increase in the silica fume percentage. This increase in pulse velocity reflects the increase in compressive strength and tensile strength for all mixes. The trend of increasing pulse velocity or compressive strength is more obvious in 90 days at 2.5% of silica fume than other percentages.
5. Conclusions

The main significant points that could be summarized from this study are:

- The workability of mortar mixes containing silica fume is greatly affected as silica fume is utilized as an additional ingredient to cement mortar. However, silica fume should always be used together with a water-reducing or high-range water-reducing (HRWR, or superplasticizer) to maintain the required workability with no change in the water-to-cement ratio.
- Silica fume reduces the amount of penetrated water of mortar and this reduction rises with the rise in the ratio of silica fume. The reduction in water permeation ratio is about 60% when 2.5% of silica fume is utilized.
- The presence of silica fume has indicated slight rise in the density. The maximum density has been attained at 2.5% of silica fume. The density is 3.2% more than that of the control mixture.
- At 2.5% of silica fume as an admixture, the magnitude of strength increase at 7 and 28 days is about 12.2 and 27.6 percent respectively.
- The tensile strength of the mortar is higher than that of the control mix. At 2.5% of silica fume, the increase in the tensile is about 30 and 38 percent for 7 and 28 days respectively.
- Silica fume increases the pulse velocity which increases compressive and tensile strengths.

6. References

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