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Effect of Silica Fume (SF) On the Strength and Permeability of High-Performance Concrete

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ABSTRACT: *Over the past decades, the technology of concrete has undergone major developments. The introduction of new admixtures (such as super plasticizers and more recently shrinkage-reducing chemicals), the use of supplementary cementing materials and the elaboration of new and more complex mixture design methods have largely contributed to modifying the way concrete is produced and placed. In many respects, concrete has gone from a low-tech and common product to a more sophisticated material with superior mechanical properties and improved durability. The goals this work is to study the workability of fresh concrete. Also, the Effect of Silica Fume (SF) to Strength then test concrete mix for compressive strength and study the permeability by Initial Surface Absorption Test (ISAT). The core of this study focuses on the strength and permeability of concrete with silica fume and Strength is the most important property of concrete since the first consideration in structural design is that the structural elements must be capable of carrying the imposed loads. Strength characteristic is also important because it is related to several other important properties which are more difficult to measure directly. With regard to this matter, the amount of SF was varied from 0% (as a control mix) 5%, 10%, 15%, and 20% in terms of weight basis from cement are studied. Concrete tests are conducted on the concrete samples at the specific ages. All the strength tests are limited to the ages of 3, 7, 14 and 28 days.*

KEYWORDS: *Silica Fume (SF), Initial Surface Absorption Test (ISAT), Strength, Super Plasticizer (SP)*

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I. INTRODUCTION

Of the many materials used in construction industry concrete is a very widely used material. This is because the constituents of concrete are easily obtained basically; concrete consists of cement aggregates (fine and coarse) and water. It is important that we have a good quality concrete which can be defined as having a workable fresh concrete homogenous and unlikely to segregate. When the concrete hardens, it must achieve the required strength. Therefore a good mix design is one of the crucial parts in construction [1].

Recently, a large number of concrete highway bridges, concrete dams and nuclear power plants and other offshore structures have been actively constructed in many countries. These structures constructed during the past several decades have suffered from safety and serviceability problems due to deterioration of concrete, and thus the durability of concrete has received great attention. Although it is generally believed that concrete is a very durable material, the environmental factors such as weathering action, chemical attack, abrasion and other deterioration processes may change the properties of concrete with time, and the structures finally reach the end of service life due to lack of safety and serviceability. The penetration of water, chloride and other aggressive ions into concrete is the most important factor in the physical and chemical process of deterioration, and it is the microstructure of concrete that mainly controls the physical/chemical phenomena associated with water movements and the transport of ions in concrete. [2].

Nowadays, high-performance concretes (HPCs) are extensively applied in construction projects. This new advanced concrete has been transferred from laboratory research to practical application; and it already occupies a noticeable share of the market. Based on the latest developments in concrete technology, HPC is characterized by a superior level of properties: workability, strength and durability. These advantages provided large scale cost savings in many construction projects. Modern HPC technology applies the concept of densified system with ultra fine particles (DSPs), which includes the effective combination of a SF with a super plasticizer (SP) that helps to maintain a workable cement system at a very small W/C. The superfine SF particles fill the space between cement grains and the interfacial transition zone; in addition, the application of SF results in a high rate of pozzolanic reaction [3].

In the recent years, the concrete mixture-proportioning problem has become more and more complicated. First, new components appeared, like organic admixtures, supplementary cementations materials (as fly ash, filler, etc.) and fibers. Second, emphasis was put on a growing number of concrete properties, dealing with the whole life cycle (from fresh state theological behavior to durability in various environments). Third, the range of attainable properties displayed a dramatic increase. Restricting ourselves to the aspects most commonly considered in mix-design, dry to ultra-fluid (self compacting) mixtures are available nowadays. Likewise, compressive strength from 1–2 Mpa (for re-excavable controlled low-strength materials) to 200 MPa (for ultrahigh strength mortars used, e.g., in containers devoted to radioactive waste materials) can be envisaged. To summarize, the mix-design problem involves more variables and more dimensions in a larger space than before mathematically speaking.

Appearance of high-performance concrete (HPC) is another recent phenomenon. In Europe, HPC is considered to be a concrete having a high strength at 28 days (typically > 60 MPa in compressive strength) or a low water–binder ratio (< 0.40). In USA, HPC is supposed to be a special mixture, matching specific requirements that cannot be achieved on a routine basis. Finally, what is needed everywhere is 'a` la carte' concrete, that is, a mixture that matches a comprehensive list of requirements, by using local materials at minimum cost. This is the problem investigated in the present paper.

Facing this reality, which is no more than the normal regress of concrete technology, the formulator is submitted to growing time and cost constraints. For instance, it is not seeing a concrete study starting < 28 days before the beginning of a construction site, which means that the actual compressive strength is unknown while the first concrete is cast into the structure. Moreover, the concrete market is very competitive in Europe. It turns out that concrete companies have only restricted budgets to spend in mix-design, although from this fundamental stage comes a great deal [4].

Over the past decades, the technology of concrete has undergone major developments. The introduction of new admixtures (such as super plasticizers and more recently shrinkage-reducing chemicals), the use of supplementary cementing materials and the elaboration of new and more complex mixture design methods have largely contributed to modifying the way concrete is produced and placed. In many respects, concrete has gone from a low-tech and common product to a more sophisticated material with superior mechanical properties and improved durability. [5].

II. LITERATURE REVIEW

High-performance concretes are also more sensitive to changes in constituent material properties than conventional concretes. Variations in the chemical and physical properties of the cementitious materials and chemical admixtures need to be carefully monitored. Substitutions of alternate materials can result in changes in the performance characteristics that may not be acceptable for high-performance concrete. This means that a greater degree of quality control is required for the successful production of high-performance concrete [6].

The low mechanical performances of concrete have been attributed to the capillary porosity and excess of water needed for the workability of fresh concrete. as improvement has been obtained by several processes which reduce the porosity (impregnation, pressure) and the w/c ratio (use of super plasticizers) new products also appeared they were MDF , macro defect free cement and DSP, densified system containing homogenously arranged ultrafine particules. The first one contains a polymer, the second SF [7].

Mostly in the literature stated that [8] increase in the fineness of the Portland cement usually increases the early strength of the concrete. It is due to higher surface area in contact with water of the concrete which lead to a more rapid hydration.

For most applications where durability is a concern, the use of SF will reduce the permeability of the concrete, thereby slowing the rate of penetration of aggressive chemicals such as deicing salts. The use of SF can result in rapid chloride permeability values of less than 500 when tested in accordance with ASTM C 1202 (AASHTO T 277) [9].

III. MATERIALS

A. Cement: Cement used in this study was the ordinary Portland cement Type I meets the ASTM C 150-92 specifications was used in all concrete.

B. Fine Aggregate: Ordinary mining sand is used in this investigation. The (BS 812, 1984) described the methods for determination of the size distribution of the sample of aggregates and fillers by sieve analysis. The sample used for the test shall be taken in accordance with the procedure described in clause 5 0f (BS 812: part 102: 1984).

Table 1: Sieve Analysis for Fine Aggregate

Sieve size	Wt of sieve retained (gm)	Wt of sieve + agg retained (gm)	Wt of agg retained (gm)	Retained %	Retained %	Passing %
4.75mm	391.6	398.1	6.5	1.3	1.3	98.7
2.00mm	409.9	448.7	38.9	7.76	9.06	90.94
1.18mm	388.2	472.1	83.9	16.78	25.84	74.16

600µm	347.9	481.3	133.4	26.68	52.52	47.48
300µm	322.2	440.9	118.7	23.74	76.26	23.74
150µm	276.2	350.0	73.8	14.76	91.02	8.98
pan	271.0	315.9	44.9	8.98	100	0

C. Coarse Aggregate: The sample used for the test shall be complied according to procedures describe in (BS 812 part 103:1985).

Table 2 Sieve Analysis for Course Aggregate

Sieve size	Wt of sieve retained (gm)	Wt of sieve + agg retained (gm)	Wt of agg retained (gm)	Retained %	Retained %	Passing %
20mm	1385.4	1627.0	241.6	12.08	12.08	87.92
14mm	1357.3	2359.3	1002	50.1	62.18	37.82
9.5mm	1347.1	1958.5	611.4	30.57	92.75	7.25
6.3mm	1285.6	1417.0	131.4	6.57	99.32	0.68
5mm	1555.9	1559.5	3.6	0.18	99.5	0.50
2.36mm	1112.2	1112.4	0.2	0.01	99.51	0.49
pan	979.5	989.3	9.8	0.49	100	0

D. Silica Fume (SF): The SF meets the ASTM C 1240-93 (1993) specification were used. There are some characteristics for the SF such as material characteristics that conform to the requirements of ASTM C 1240, in which involve the chemical and physical requirements. The slurry form for the SF is not allowed. The procedure for the SF can be summarized as follows:-

- The Contractor shall provide adequate protection for the SF against dampness.
- SF shall be protected from temperatures in excess of 86C
- SF shall be protected from exposure to direct sunlight.
- Each shipment of SF sent to a project or ready mix plant shall be accompanied with a certificate of compliance executed by the manufacturer. The certificate must include the following information:
- The location of the manufacturer.
- The batch or lot number.
- The date of manufacture.
- The weight of the shipment.
- NDR specifications that the product is in compliance with.
- No SF which has become caked or lumpy shall be used.

E. Water: Tap drinking water was used for the mixes and it meets the ASTM C 94-92a (1993) Specification.

IV. CONCRETE MIX DESIGN

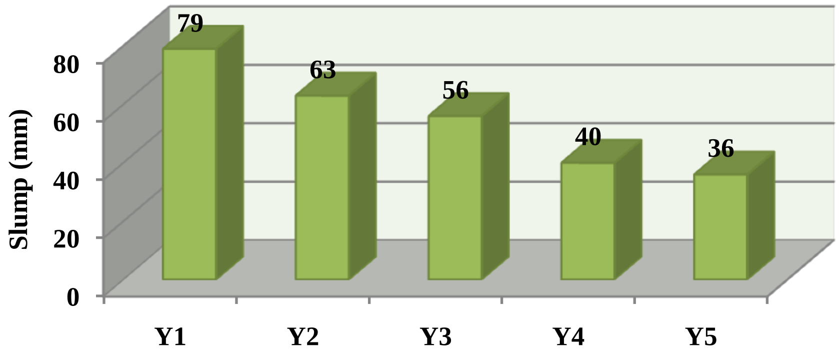
Table 3: Mixture Proportions

Sample	**Percentage of SF (%)**	**OPC (kg)**	**SF (kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**Water (kg)**
Y1	0	30.19	0	30.39	49.58	11.48
Y2	5	28.68	1.51	30.39	49.58	11.48
Y3	10	27.17	3.02	30.39	49.58	11.48
Y4	15	25.66	4.53	30.39	49.58	11.48
Y5	20	24.15	6.04	30.39	49.58	11.48

V. RESULT AND DISCUSSION

A. **Slump test for fresh concrete**:

The testing of fresh for workability was carried out by following the standard slump test in accordance with BS 1881: Part 102 as shown in Graph 1.

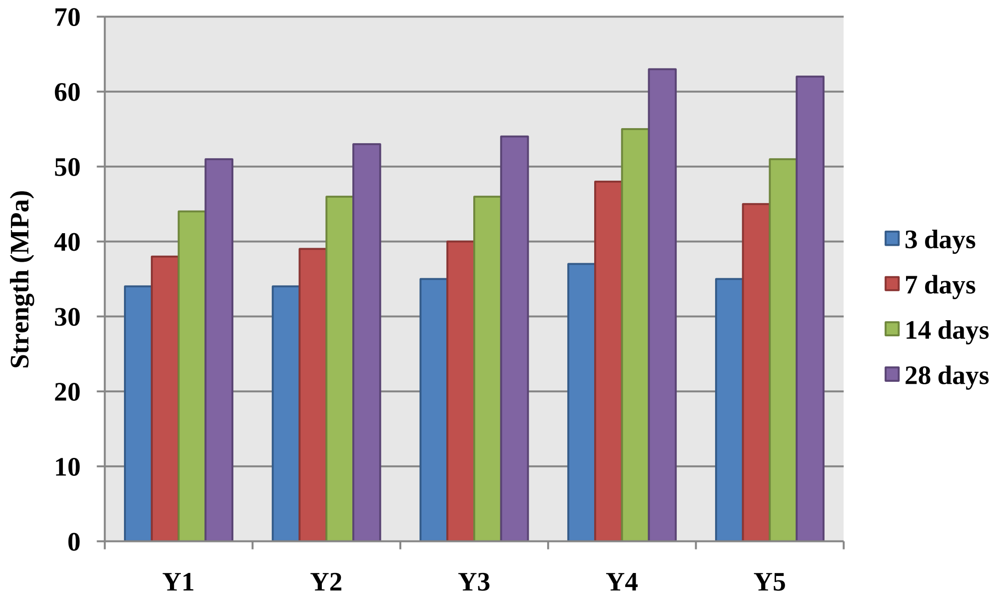


Graph 1: The slump value

As shown in Graph 1, slump values were decreased with increment of SF content. The sufficient workability was found when there was no SF. This is because when increase the amount of SF will absorb more water from the mix, hence decrease the water cement ratio in which, will lead to decrease the fluidity of the mix resulting in decreasing the workability. The Graph 1 showed that (5%-10%) SF content mix proportions were sufficient for slump value. According to Graph 1, the workability of the cubes with 15% and 20% replacement is within ranged medium which is sufficient in construction work.

B. **Effect of SF to Compression Strength**

Cubes with the size of 150x 150 x 150 mm were tested at the ages of 3, 7, 14 and 28 days. The results of the compressive strength test are shown in Graph 2, where each value is averaged from the results of three cubes.



Graph 2: Comparisons between the Cube Strength at 3, 7, 14, 28 Days

Cubes with the size of 150 x 150 x 150 mm were tested at the ages of 3, 7 and 14 and 28 days. Where each value is averaged from the results of the three cubes.

For 5 % (Y2) and 10 % (Y3) cement replacement with SF, the strength development of the concrete is quite similar to the control values. This can be clearly shown in Graph 2. Both concrete cubes with 5% and 10% replacements show higher compressive strength than the control in the 3 days after casting. Concrete with 5% SF replacement achieve an early compressive strength of 33.98 MPa, while, 10% replacement attain 34.67 MPa. However, the strength enhancement by SF is increased on the seventh day. On the seventh day, the cubes with 5% and 10% replacement only achieve the compressive strength of 38.76 MPa and 39.35 MPa, respectively, compared to 37.53 MPa for the control mix.

On the following days, the difference in strength achievement between blended concrete and control has been extended. However, the results show that the strength development of the blended concrete is relatively close to the control. This can be clearly revealed when 5% and 10% achieved compressive strength of 53.01MPa and 54.38 MPa respectively compared to 51.24 MPa of the control at 28 days. Based on the results, it can be seen that the amount of SF presents in 5% replacement is not sufficient enough to enhance the compressive strength over the control as the replacement ratio is too small. The 10% replacement also exhibits similar strength development as the control. Compared to 5% replacement, the amount of SF exists in the blended concrete are probably too high.

The concrete cubes with 15 % (Y4) replacement exhibits the best strength performance in this study. The strength development for concrete with 15% replacement and the control is shown in Figure 4.2.

At the age of 3 days, concrete cubes with 15 % replacement exhibits compressive strength greater than the control, that is 36.47 MPa compared to 33.76 MPa of the control, the strength development for 15 % replacement is higher than the control. The cubes with 15 % replacement attain compressive strength of 48.17 MPa at the age of 7 days. Among all the replacement ratio, only 15 % replacement shows a higher strength than the control in the third day. The 15 % replacement continues to exhibits stronger strength on the following ages until the cubes reach strength of 63.00 MPa at 28 days, which is 11.76 MP (1.23%) a higher than the control.

The results of compressive strengths for the cubes with 15 % replacement varied between 36.47 MPa and 63.00 MPa. It can be observed that Y4 seems to produce higher compressive strength than that Y2 and Y3 which reached up to 63 MPa.

SF has been used as an addition to concrete up to 15 percent by weight of cement, although the normal proportion is 7 to 10 percent. With an addition of 15 percent, the potential exists for very strong and brittle concrete. It increases the water demand in a concrete mix. however, dosage rates of less than 5 percent will not typically require a water reducer. High replacement rates will require the use of a high range water reducer [8].

The concrete cubes with 20 % (Y5) replacement exhibits lower strength performance in this study than 15% replacement. The strength development for concrete with 20% replacement and the control is shown in Figure 4.2.

At the age of 3 days, concrete cubes with 20 % replacement exhibits compressive strength greater than the control, that is 35.18 MPa compared to 33.76 MPa of the control, the strength development for 20 % replacement is higher than the control. The cubes with 20 % replacement attain compressive strength of 45.31 MPa at the age of 7 days. The 20 % replacement continues to exhibits stronger strength on the following ages until the cubes reach strength of 61.77 MPa at 28 days. The compressive strength decreased when the dosage of SF more than 15%. Microsilica is only effective at secondary pozzolanic stage, reacting with $Ca\ (OH)_2$ .with reduced cement content; the primary hydration reaction stage decreased thus reducing the strength of the mixes.

The inclusion of SF results in a finer pore size distribution of concrete. In addition, the ability of the fine particles of SF to act as filler improves the aggregate-cement pastes interface. Therefore, the pozzolanic reaction and the filler effects as a consequence of SF inclusion, enhance the properties of concrete such as strength and impermeability

Normally, a very low content of SF (below 5 % of total mass of cementitious material) does not lead to a high performance while a very high content of SF is only marginally beneficial than about 10 %. The optimum dosage of SF for general construction usually varies between 7 and 10 %, but in specialized situations up to 15 % SF has been incorporated successfully in concrete [8].

This results indicates when the SF increased the compressive strength was increased for all percentages except for 20 % SF due to the filler effect of micro silica by reducing the pore structure. The smallness of the particles speeds up the reaction with calcium hydroxide produced by the hydration of Portland cement the very small particles of SF can enter the space between the particles of cement and thus improve the strength of concrete [8,10]. That is why when increasing the percent replacement of SF with the cement. The concrete improved to high performance concrete according to increasing of compressive strength.

C. Results of permeability test (ISAT)

In this study used initial surface absorption test (ISAT). These tests used water and an apparatus that directs flow through block of hardened- concrete. As specified in BS 1881 part 208: 1996. The result at age 28 day has been tabulated in Table 4.

A summary data at aged 28 days is shown from Table 4. From the results attained, it is evident that the concrete cube sample which contained SF has low permeability and it's also showed that the concrete containing 15%,20% of SF had low permeability than other cubes. It is due to the fineness of SF in term of specific area which range around 1/100 the size of average cement particles. Pozzolanic reaction between silicon dioxide, aluminium dioxide and calcium hydroxide released by hydration of Portland cement leads to the formation of C-S-H gel. It is a very reactive pozzolan. The effect is a refinement of the pore structure when is added to the cementitious system. This leads to a reduction in permeability and hence the enhancement of the mechanical properties and durability of concrete containing SF. It has been shown by several researchers that addition of SF to concrete reduces its permeability. Rapid chloride permeability testing (AASHTO 277) conducted on SF concrete showed that addition 8% of SF significantly reduces the chloride permeability. This reduction is primarily the result of the increased density of the matrix due to the presence of SF [11].

Table 4: The Result of Permeability ISAT for the Cubes Y1, Y2, Y3, Y4andY5 at Age 28 Days

Temperature			**20^{o} C**	
Concrete type			**Cube (150*150*150) mm**	
Intervals Test	**Number of scale division in 5 sec**	**Period during measurement**	**Number of division**	**Surface absorption ml/m^2/s**
Y1 (SF 0 %)				
10 min	1.7	2 min	4	0.04
30 min	1.4	2 min	16	0.16
60 min	1.3	2 min	25	0.25
Y2 (SF 5 %)				
10 min	2.3	2 min	9	0.09
30 min	2	2 min	17	0.17
60 min	1.8	2 min	23	0..23
Y3 (SF 10 %)				
10 min	2.8	2 min	10	0.1
30 min	2.5	2 min	13	0.13
60 min	2.3	2 min	19	0.19
Y4 (SF 15 %)				
10 min	2.8	2 min	8	0.08
30 min	2.3	2 min	11	0.11
60 min	2.2	2 min	14	0.14
Y5 (SF 20 %)				
10 min	2.6	2 min	9	0.08
30 min	2.1	2 min	11	0.11
60 min	2.0	2 min	12	0.12

VI. CONCLUSION

1. The result showed good strength development between the ages of 3 to 28 days depending on the mix proportion.
2. The concrete contain 15% SF produce higher compressive than that 5%, 10% and 20% SF at any aged from 3 day to 28 days.
3. One of the key factors in producing high performance concrete which above 50 Mpa is to use a low water to cement ratio (0.38).
4. The incorporation of SF in mixes resulted in fine pore structure thus produce low permeability concrete.
5. The workability was decreased depending on the percentage of SF, as the percentage increases the workability decreases.

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