Advanced construction materials microsilica in concrete

Abstract:

Micro silica is an amorphous type of silica dust mostly collected in bag house filters as by-product of the silicon and ferro-silicon production. The paper summarizes important physical and chemical properties of micro silica and uses those results for an evaluation of micro silica from a Health Safety and Environment (HSE) standpoint. Micro silica consists of spherical particles with an average particle size of 150 nm and a specific surface area of typically 20 m^3/g. The chemical and physical properties of this inorganic product are different as compared to other amorphous and crystalline silica poly morphs. More than 500.000 MT of micro silica are sold to the building industry world-wide and are used in fibre cement, concrete, oil-well drilling, refractories, and even in polymers.

Micro silica contains trace amounts of heavy metal oxides and organic deposits, which originate from natural raw materials. Since the concentration of these impurities is very low, micro silica complies with company policies and international regulations. Traces of crystalline silica in micro silica do not seem to represent a health risk, neither for silicosis nor for lung cancer, due to the low levels and the large particle size. According to the International Agency for Research on Cancer (IARC), there is insufficient evidence for the carcinogenicity of silica fume, in contrast to crystalline silica. In order to assess potential health risks of micro silica and compliance with international regulations from an occupational hygienist's point of view, one has to collect fragments of information from different analytical techniques. Putting these fragments together results in a cohesive picture. All evidences indicate that micro silica is not a hazardous product when applied as advised.

1.0 Introduction

1.1 General

Micro silica is a mineral admixture composes of very fine solid glassy spheres of silicon dioxide (SiO2). Most micro silica particles are less than 1 micron (0.00004 inch) in diameter, generally 50 to 100 times finer than average cement or fly ash particles. Frequently called condensed silica fume, micro silica is a by product of the industrial manufacture of ferrosilicon and metallic silicon in high-temperature electric arc furnaces. The ferrosilicon or silicon product is drawn off as a liquid from the bottom of the furnace. Vapor rising from the 2000℃ furnace bed is oxidized, and as it cools condenses into particles which are trapped in huge cloth bags. Processing the condensed fume to remove impurities and control particle size yields micro silica. Micro silica, also known as Silica fume is fine amorphous silica. Added to concrete at around 30kg/m3 it changes the rheology and reacts with the cement hydration products to dramatically improve concrete strengths, durability and impermeability, allowing concrete to be used in ways never before possible.

When pozzolanic materials are incorporated to concrete, the silica present in these materials react with the calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C – S – H), which improve durability and the mechanical properties of concrete. High strength concrete refers to concrete that has a uniaxial compressive strength greater than the normal strength concrete obtained in a particular region. High strength and high performance concrete are being widely used throughout the world and to produce them, it is necessary to reduce the water binder ratio and increase the binder content. High strength concrete means good abrasion, impact and cavitations resistance. Using high strength concrete in structures today would result in economical advantages. In future, high range water reducing admixtures (Super plasticizer) will open up new possibilities for use of these materials as a part of cementing materials in concrete to produce very high strengths, as some of them are make finer than cement.

1.2 Aids strength gain of fly ash concretes:

Preliminary indications suggest that micro silica may be useful in controlling heat generation in mass concrete. It has also been found useful in combination with fly ash. Early-age strength development of concrete in which fly ash replaces cement tends to be slow because fly ash is relatively inert during this period of hydration. Adding micro silica, which is more reactive in early hydration, can speed the strength development.

2.0 Methodology

The methodology adopted comprised of both preliminary and experimental investigations carried out using the study material and these are presented as follows:

2.1 Preliminary Investigations

For the preliminary investigations, micro silica and cement was subjected to physical and chemical analyses to determine whether they are in compliance with the standard used. The experimental program was designed to investigate silica fume as partial cement replacement in concrete. The replacement levels of cement by silica fume are selected as 5%, 10%, 15%, 20%, and 25% for standard size of cubes for the M30 grade of concrete. The specimens of standard cubes (150 x 150 x 150 mm), was casted with silica fume. Compressive machine was used to test all the specimens. The specimens were casted with M30 grade concrete with different replacement levels of cement from 0 to 25% with silica fume. Seventy two samples was casted and the cubes were put in curing tank for 3, 7, 14, and 28 days and density of the cube, and compressive strength were determined and recorded down accordingly. The other materials used are listed as follow:

2.1.1 Cement

Ordinary Portland cement produced by QNCC was used in this study. The cement conformed to the requirements of BS 12 (1996).

2.1.2 Aggregates

There are the inert filler in the concrete mixture which constitute between 70 – 75% by volume of the whole mixture. The sand used was collected within Ibadan metropolis, Nigeria. It was clean and free from organic material and clay. The coarse aggregate used were mainly material retained on a 4.7mm BS 410 test sieve and contained only so much fine materials as was permitted for various sizes in the specification.

2.1.3 Water

The water used for the study was free of acids, organic matter, suspended solids, alkalis and impurities which when present may have adverse effect on the strength of concrete.

2.2 Mixing And Placing Considerations

2.2.1 Handling the micro silica

Because of its extreme fineness, micro silica presents handling problems. A cement tanker that could ordinarily haul 35 metric tons of cement accommodates only 7 to 9 tons of dry micro silica and requires 20 to 50 percent more time for discharging. Some producers mix micro silica with water on a pound-for-pound basis ton form a slurry that is transportable in tank trailers designed to handle liquids. The water of the slurry replaces part of that ordinarily added to the mix. One supplier prepares a slurry which, used at the rate of 1 gallon per 100 pounds of cement, will provide aboutn5 percent micro silica by weight of cement. In 1984, that supplier was quoting a price of $1.70 per gallon at a plant in West Virginia. In Canada, patented methods have been used to densify the micro silica for shipment to ready mix producers. Some concrete producers also use the loose micro silica just as it is collected.

2.2.2 Water requirements of the mix

When no water reducing agent is used, the addition of micro silica to a concrete mix calls for more water to maintain a given slump. Water content can be held the same by using a water reducer or super plasticizer along with the micro silica. Water reducing agents appear to have a greater effect on micro silica concrete than on normal concrete. Thus water demand for given micro silica concrete can be controlled to be either greater or smaller than for the reference concrete.

2.2.3 Placing and finishing, curing

The gel that forms during the first minutes of mixing micro silica concrete takes up water and stiffens the mixture, necessitating adjustment of the timing of charging and placing. Scandinavian researchers have concluded that micro silica concretes often require 1 to 2 inches more slump than conventional concrete for equal workability. When cement content and micro silica dosage are relatively high, the mixture is so cohesive that there is virtually no segregation of aggregates and little bleeding. This may cause problems for floors or slabs cast in hot, windy weather because there is no water film at the surface to compensate for evaporation .Plastic shrinkage cracking can readily develop unless precautions are taken. It is important to finish the concrete promptly and apply a curing compound or cover immediately. With lean concrete mixes or mixes containing fly ash replacement of cement, different effects have been reported. For example, Reference 4 re ports that mixes with less than 380 pounds of cement per cubic yard plus 10 percent micro silica are both more cohesive and more plastic so no extra water is needed to maintain slump.

2.2.4. Concrete color effects

Freshly mixed concrete containing micro silica can be almost black, dark gray, or practically unchanged, depending on the dosage of micro silica and its carbon content. The more carbon and iron in the admixture, the darker the resulting concrete. Hardened concretes are not much darker than normal concretes when dry. Sometimes there is a faint bluish tinge, but when the micro silica concrete is wet, it looks darker than normal Silicosis danger doubted.

Micro silica is essentially non crystalline. Currently available data indicate it has no tendency to cause silicosis, the lung disease associated with inhalation of crystalline SiO_2. However, because of possible cumulative long-term effects, Norwegian standards restrict dust in the air of the workplace to the same level as that of other dusts such as natural diatomaceous earth, mica, and soapstone.

2.3 Preparation of Specimens

In this study, a total number of 12 cubes for the control and cement replacement levels of 5%, 10%,15%, 20% and 25% were produced respectively. For the compressive strength, 150mm x 150mm x 150mmcubes mould were used to cast the cubes and 3 specimens were tested for each age in a particular mix(i.e. the cubes were crushed at 3, 7 ,14 and 28 days respectively). All freshly cast specimens were left in the moulds for 24 hours before being demoulded and then submerged in water for curing until the time of testing.

2.4 Mix Proportioning

Mix Proportioning by weight was used and the cement/ dried total aggregates ratio was 1: 2: 4. Micro silica were used to replace OPC at dosage levels of 5%,10%, 15%, 20% and 25% by weight of the binder. The mix proportions were calculated and presented in table

Table 1 : Mix proportion for 30Mpa Concrete

Materials	**Mix Proportion (Kg)**					
	Control	**MS 5%**	**MS 10%**	**MS 15%**	**MS 20%**	**MS 25%**
Cement(Kg)	370.0	351.5	333.0	314.5	296.0	277.5
Micro silica (Kg)	0	18.5	37.0	55.5	74.0	92.5
Total Water (Ltr)	140	140	140	140	140	140
Fine	780	780	780	780	780	780

Aggregate(Kg)						
Coarse Aggregate (Kg)	1180	1180	1180	1180	1180	1180
MS432 (ltr)	4	4	4	4	4	4
W/C	0.38	0.38	0.38	0.38	0.38	0.38

2.5 Testing of Specimens

Compressive strength test were carried out at specified ages on the cubes. The consisted of the application of uniaxial compressive load on the cube until failure at which point the load require for failure of each cube was noted, prior to testing, the density of each cube was determined using standard procedures for density determinations.

2.5.1 Compressive Strength of Concrete

The test was carried out conforming to BS EN:12390 – 3: 2009 to obtain compressive strength of M30 grade of concrete. The compressive strength of high strength concrete with OPC and silica fume concrete at the age of 3, 7, 14 and 28 days are presented in table 3.5. here is a significant improvement in the strength of concrete because of the high pozzolanic nature of the micro silica and its void filling ability. The compressive strength of the mix M30 at 3, 7,14 and 28 days age, with replacement of cement by micro silica was increased gradually up to an optimum replacement level of 10% and then decreased. The maximum 3, 7, 14 and 28 days cube compressive strength of M30 grade with 10% of silica fume was 30.35, 38.26, 44.51, and48.22 mpa respectively.

The compressive strength of M30 grade concrete with partial replacement of 10% cement by silica fume shows 15.31% greater than the controlled concrete. The maximum compressive strength of concrete with silica fume depends on three parameters, namely the replacement level, water cement ratio and chemical admixture. The super plasticizer admixture dosage plays a vital role in concrete to achieve the0% to 25% there is a decrease in compressive strength for 3, 7, 14 and 28 days curing period. It was observed that the percentage of micro silica are given workability at lower w/c ratio. Cement replacement up to10% with micro silica leads to increase in compressive strength and beyond 1eplacement from average concrete strength(mpa) in table 3.3 were 16.15%, 29.24%, 23.98% and20.22% for 3, 7, 14 and 28 days. The percentage given above shown that the compressive strength increased from 3 days to 7 days and decreased from 14 days to28 days i.e. (23.98% to 20.22%). The maximum replacement level of silica fume is 10% for M30 grade.

Table 2 : Compressive strength Test Result for varying Micro Silica Replacement Levels in concrete Compressive Strength of Concrete

%MS Replacement	Compressive Strength of Concrete(Mpa)	

	3 Days	7 Days	14 Days	28 Days
0	26.32	30.55	36.07	40.55
5	28.11	33.11	40.77	44.44
10	30.57	38.26	44.72	48.75
15	29.19	34.59	42.58	45.17
20	28.02	31.40	36.25	41.53
25	26.39	30.85	36.20	40.90
% Increased	16.15%	25.24%	23.98%	20.22%

3.0 Discussions

3.1 How Micro silica Works in Concrete

Micro silica in concrete contributes to strength and durability two ways:

3.1.1. Pozzolonic effect:

When water is added to OPC, hydration occurs forming two products, as shown below:

OPC + H_2O CSH (Calcium silicate hydrate) + $Ca(OH)_2$

In the presence of micro silica, the silicon dioxide from the micro silica will react with the calcium hydroxide to produce more aggregate binding CSH as follows:

- $Ca(OH)_2 + SiO_2 + H_20$ CSH

The reaction reduces the amount of calcium hydroxide in the concrete. The weaker calcium hydroxide does not contribute to strength. When combine with carbon dioxide, it forms a soluble salt which will each through the concrete causing efflorescence, a familiar architectural problem. Concrete is also more vulnerable to sulphate attack, chemical attack and adverse alkali-aggregate reactions when high amounts of calcium hydroxide is present in concrete.

3.1.2. Micro filler effect :

Micro silica is an extremely fine material, with an average diameters 100x finer than cement. At a typical dosage of 8%by weight of cement, approximately100,000 particles for each grain of cement will fill the water spaces in fresh concrete. This eliminates bleed and the weak transition zone between aggregate and paste found in normal concrete. This micro filler effect will greatly reduced permeability and improves the paste-to-aggregate bond of silica fume concrete compared to conventional concrete. The silica reacts rapidly providing high early age strengths and durability. The efficiency of micro silica is 3-5 times that of OPC and consequently vastly improved concrete performance can be obtained. As a pozzolana, micro silica provides a more uniform distribution and a greater volume of hydration products. As a filler, micro silica decreases the average size of pores in the cement paste. Microsilicas effectiveness as a pozzolana and a filler depends largely on its composition and particle size which in turn depend on the design of the furnace and the composition of the raw materials with which the furnace is charged. At present there are no U.S. standard specifications for the material or its applications. Dosages of micro silica used in concrete have typically been in the range of 5 to 20 percent by weight of cement, but percentages as high as 40 have been reported.

Table 3 : Chemical and Physical Composition

	U Unit	OPC	Fly ash	Micro silica
SiO2	%	17 – 25	40 – 55	90 – 98
CaO	%	60 – 67	1 – 5	0.2 – 0.7
Al2O3	%	2 – 8	20 – 30	0.4 – 0.9
Fe2O3	%	0 – 6	5 – 10	1 – 2
Other	%	1 – 8	4 - 15	2 – 3
S. G	Kg/m3	3150	2100	2200
Bulk density	Kg/m3	1400	900 – 1000	550 – 650
Surface Area	m2/kg	200 -500	200 – 600	20,000

3.2 How microsilica improves concrete

Finer than fly ash, this pozzolana increases strength and density, reduces concrete permeability Since micro silica particles are only about 1-100 the size of cement grains, the material may be hard to batch and ship. These handling problems may be overcome by mixing micro silica with water (and sometimes other admixtures) in a slurry which replaces part of the normal concrete mixing water. Densification and pelletization have also been tried to simplify the mixing and handling.

3.3 Micro silica Concrete Applications

Because of the pozzolanic and micro filler effect of micro silica, its use in concrete can improve many of its properties opening up a wide range of applications including.

3.3.1. Corrosion Resistance

The reduced permeability of micro silica provides protection against intrusion of chloride ions there by increasing the time taken for the chloride ions to reach the steel bar and initiate corrosion. In addition, micro silica concrete has much higher electrical resistivity compared to OPC concrete thus slowing down the corrosion rate. The combined effect generally increased structures life by 5 – 10 times. Micro silica concrete is therefore suitable for structures exposed to salt water, de-icing salts, ie. Harbor structures, ports, bridges, docks, on shores constructions situated in areas with chlorides in the ground water, soil and in the air.

3.3.2. Sulphate Resistance

Micro silica concrete has a low penetrability and high chemical resistance that provides a higher degree of protection against sulphates than low C3A sulphate resisting cements or other cementitious binder systems.

3.3.3. Heat Reduction

By replacing cement with Micro silica and observing the efficiency factor of Micro silica, a lower maximum temperature rise and temperature differential will take place for concrete with the same strength. It performs better than slag andfly-ash blends in thick sections. It is also the most effective way of achieving low heat without sacrificing early age strength.

3.3.4. Silica Fume Waterproof Concrete

Because of its low permeability, micro silica can be use as an integral water proofer for below ground structures where some dampness is acceptable, eg. carparks

3.3.5. High Strength Concrete:

Micro silica in conjunction with superplasticizers is used to produce very high strength concrete (70 – 120 MPa). High strength concretes provides large economic benefits to developers e.g. reduced column and wall thickness in tall buildings and improved construction schedule. It is also much more easier to pump micro silica concrete up the highrise buildings during construction.

3.3.6. Shotcrete

Micro silica is use in shotcrete whether produced by wet or dry process to reduce the rebound, to increase application thickness per pass, improve resistance to wash out in marine construction or wet areas and to improve the properties of hardened shotcrete. With fibres it can eliminate mesh and reduce cracking.

3.3.7. Abrasion Resistance

Microsilica concrete has very high abrasion resistance. In floor and pavement construction it's use saves money and time and improves operational efficiencies for the facility operator. It also improves the hydraulic abrasion-erosion resistance of concrete thus making it suitable for use in dam spillways.

3.3.8.hemical Resistance:

Microsilica concrete is widely used in industrial structures exposed to an array of chemicals aggressive. In the alimentary industry the exposure comes from fat acids and other acids, detergents, etc. In the chemical industry there is exposure from mineral acids, phosphates, nitrates, petrochemicals, etc.Microsilica concrete is therefore in valuable in the industrial and agricultural sector

4.0 Conclusions

1. Cement replacement up to 10% with silica fume leads to increase in compressive strength, for

M30grade of concrete. From 15% there is a decrease in compressive strength for 3, 7, 14 and 28 days curing period.
2 .It was observed that the compressive strength ofM30 grade of concrete is increased from 16.15% to29.24% and decrease from 23.98% to 20.22%.

3. The maximum replacement level of silica fume is10% for M30 grade of concrete.

4. The use of micro silica in high strength concrete leads to economical and faster construction.

5.Due to use of the micro silica in a OPC concrete the life of that concrete is increase 4-5 times than the OPC concrete.