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(Research article)

Study of Effects of Micro Silica Variation on M80 Concrete

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Abstract

High performance concrete (HPC) is a novel construction material with improved properties like higher strength and longer durability compared to conventional concrete. High Strength Concrete (HSC) is a type of HPC. Appropriate use of mineral and chemical admixtures with better quality control leads to HSC. Extensive research work has also established that the addition of mineral admixtures to plain cement concrete improves its strength, durability, toughness, and post-cracking load resistance. In this paper, an attempt has been made to study the effect of micro-silica with 0%, 5%, and 10% replacement on the compressive and flexural strengths of high strength concrete with varying water-cement ratios. It has been found that the compressive strength of concrete increases with increase in micro-silica content upto certain proportion. Moreover, micro-silica does not affect flexural strength as much as compressive strength.

Keywords: *Concrete, Micro Silica*

1. Introduction

Today, the concrete is the most widely used construction material in the world. High performance concrete (HPC) is a new construction material with improved properties like higher strength, longer durability, etc than conventional concrete. The use of HPC in the construction of earthquake-resistant structures, long-span bridges, offshore structures and other mega-structures results in lighter sections leading to cost-effectiveness. Use of HPC, having improved durability reduces life-cycle cost of the structures. Because of these benefits, HPC has been used more in nuclear power plants, viaducts, bridges, high-rise buildings, etc all over the world.

High Strength Concrete (HSC) is a type of HPC. ACI defines HPC as "Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices". Appropriate use of mineral and chemical admixtures alongwith better quality control leads to HSC. At the turn of the 20th century, concrete compressive strength was in the range of 13.8 MPa; by the 1960s it was in the range of 27.6-41.4 MPa. Deterioration, long term poor performance and inadequate resistance to hostile environment, coupled with greater demands for more sophisticated architectural form, led to the accelerated research into the microstructure of concretes and more elaborate codes and standards. As a result, new materials and composites have been developed and improved cements evolved. Today concrete structures with a compressive strength exceeding 138 MPa are being built world over. In research laboratories, concrete strengths of even as high as 800 MPa (ACI Std.) are being produced.

In this paper, an attempt has been made to study the effect of micro-silica with 0%, 5%, and 10% replacement on the compressive and flexural strengths of high strength concrete for different water-cement ratios.

2. Achieving high strength

There are two crucial concepts used to produce high strength concrete (HSC) — (1) Maintaining extremely low water-cement ratio. Water reducing admixtures (WRAs) are used to make the concrete workable at as low water-cement ratio as 0.25 and; (2) Proper packing of ingredients leaving minimum or no air voids as shown in Fig. 1. High cement content may lead to increased shrinkage and heat of hydration. Some portion of cement can be replaced by cementitious materials like silica fume, fly ash, ground blast furnace slag, etc. It has been found that using these mineral admixtures enhances the durability of concrete.

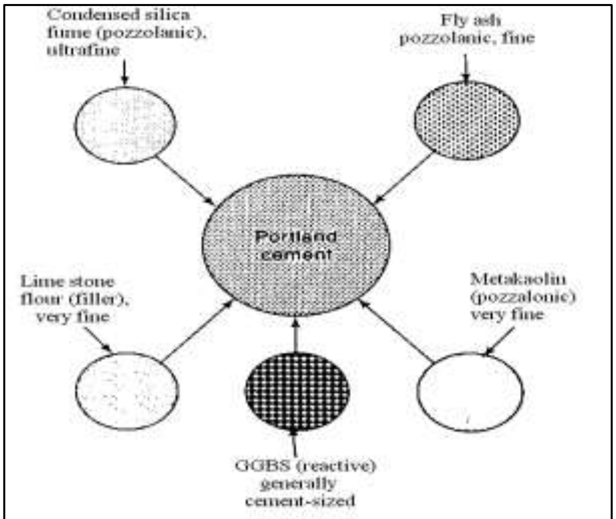
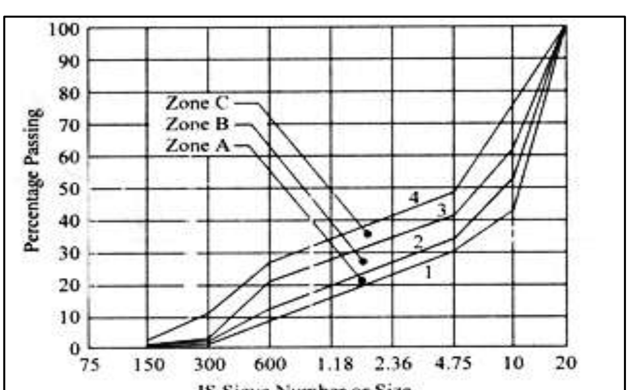


Fig. 1. Various filler materials.

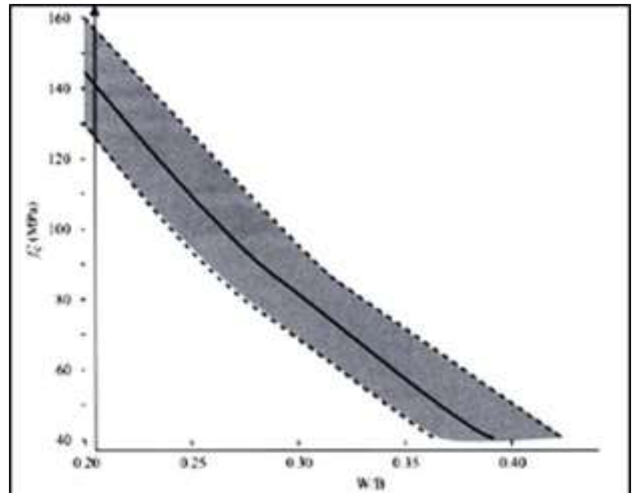
3. Guidelines on constituents of HSC

Cement: Minimum cement content of 320 kg/m^3 must be used. OPC is preferred over PPC. OPC 33, 43 and 53 grades are to be used. Higher the grade of cement more is the shrinkage.
Water: Only potable water is recommended, which is free from organic & inorganic impurities. Temperature of water should be less than 35^{o}C.
Aggregates: Size of aggregate governs target strength. Crushed angular aggregates are preferred due to better bond strength owing to interlocking. Strength is increased up to 38% at lower w/c ratio than 0.4 as compared to rounded aggregates. Maximum size (MSA) permitted is 10-12mm. Larger particles of crushed rock will often be weaker than smaller particles of the same material due to defects. Fine aggregates fill the voids between coarse aggregates. Identify the grading zone from Fig. 2, which governs amount of cementitious/binding material and fine aggregate to be added.



Type grading curves for 20 mm aggregate.

Fig. 2 Type grading curves for 20 mm aggregate



Proposed W/B vs compressive strength relationship

Fig. 3. W/B ratio vs compressive strength band

Admixtures: Admixtures are chemical compounds in concrete other than cement, water and aggregates. Two kinds of admixtures are used―mineral admixtures and chemical admixtures.

4. Mix design of HSC

In this paper, a combined ACI and IS code method of mix design is presented suggested by Santhakumar [1]. Steps for mix-design of HSC M80 are presented as follows.
Step-1. Target Average Compressive Strength (f'_{ck}), $f'_{ck} = f_{ck} + t.s$
where, t = a statistical value depending upon test data (t = 1.65, as per IS-456:2000)
and, s = std. dev. depending upon grade of concrete and degree of control
Step-2. Maximum size of aggregate (MSA) is chosen from the Table-2. (ACI 211-4R-93)
Step-3. Water/Binder Ratio: The suggested water/binder ratio can be found from the graph (Fig. 4) for a given 28-day compressive strength. Due to variation in the strength efficiency of different supplementary cementitious material, the curve shows a broad range of water/binder values for a given strength. If the efficiency of the different supplementary cementitious material is not known from the prior experience, the average curve can be used.
Step-4. Water Content: It is very difficult to determine the amount of water to be used to achieve high strength concrete. A 200-mm slump concrete can be achieved with a low water dosage and high super plasticizer dosage and vice-versa. Therefore, a simplified approach based on the concept of saturation point is suggested by ACI and presented in Fig. 5. If the saturation point of

superplaticizer is not known, it is suggested starting with a water content of 145 l/m^3.

Table 1. Target average compressive strength	
Specified characteristic compressive strength (f_{ck}), MPa	Target average compressive strength (f'_{ck}), MPa
< 20.5	f_{ck} + 6.9
20.5 – 34.5	f_{ck} + 8.3
> 34.5	f_{ck} + 9.7

Table 2. Maximum size of aggregate	
Required Concrete Strength (MPa)	Maximum Size of Aggregate (mm)
< 62	20 – 25
> = 62	10 – 12.5

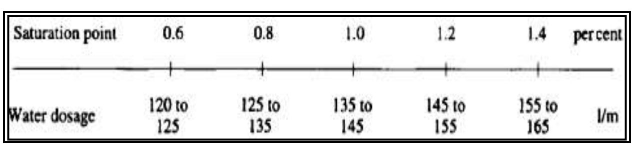


Fig. 4 Scale to locate water dosage

Step-5. Superplasticizer Dosage: If saturation point is not known, it is suggested starting with a trial dosage of 1%.
Step-6. Coarse Aggregate Content: It can be found from the Fig. 5. It is a function of typical particle shape. If any doubt about the shape of coarse aggregate or the shape is not known, a content of 1000 kg/m^3 of coarse aggregate can be used as trial.

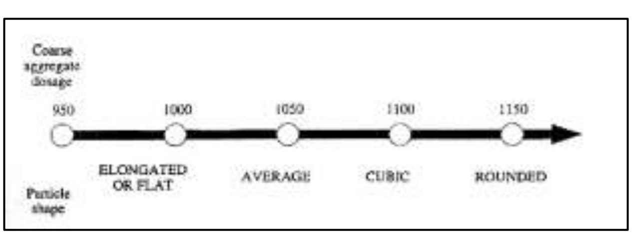


Fig. 5 Shape of aggregate

Step-7. Air Content: It has been found that it is difficult to achieve less than 1% entrapped air and in the worst case, the entrapped air content can be as high as 3%. It is suggested that using 1.5% as an initial estimate of entrapped air content and then adjusting it on the basis of the results obtained with the trial mix.

Mix Design Sheet: All the calculations needed to find the mix proportions are presented on a single sheet. This sheet is divided into two parts. In the upper part the specified properties of mix are reported, along with the characteristics of all the ingredients that will be used. The lower part of mix design sheet is in the form of a table in which all the boxes are numbered in the order in which they have to be filled in. The table is divided into six columns, numbered at the top. A sample sheet for Trial mix no. 2 is shown in Fig. 6.

5. M80 mix design: an illustration

The experimental program has been to design a mix with 28 days strength of 80 MPa. Three trial batches with 0%, 5% and 10% micro silica (M.S.) were prepared. The compressive strength of each batch at 3, 7, 28 days and 3 months and the flexural strength of each batch at 7, 28 days and 3 months, have been determined using universal testing machine and compared by plotting the results.

Table 3. Properties of Ingredients used to prepare the mix

Cement/Aggregate	Micro silica	Superplasticizer
• Max. size of C.A. = 10 m.m. • Type of C.A is between elongated and average • Type of cement used is 53 grade OPC • S.G. of C.A. = 2.74 • S.G. of F.A. = 2.6 • S.G. of cement = 3.14 • S.G. of M.S. = 2.2 • Zero moisture content in C.A. and F.A. • F.M. of F.A = 2.77	• Grade 920-V • size range 0.1 to 10 microns • amorphous in nature • zero loss under ignition • very efficient in reduction of permeability • increases w/c ratio	• Poly-carboxylic group based • Structro100 (Fosroc chemicals) • Light yellow coloured • S.G. = 1.2 • Solid content = 40%

Figure 6 shows a sample mix-design sheet for Trial no. 2.

Mix design sheet No.1

Comp. Strength: 80 MPa

Table A	G_c	%
Cement	3.14	90
M.S	2.2	10

Aggregate	G_{SSD}	w_{abs} (%)	w_{tot} (%)	w_n (%)
Coarse	2.74	0.8	0	-0.8
Fine	2.6	1	0	-1

$w_n = w_{tot} - w_{abs}$ $M = M_{SSD}(1 + w_n)$

SUPERPLASTICIZER		$M_{sol} = C \times \frac{d}{100}$	$V_{liq} = \frac{M_{sol}}{s \times G_{sup}} \times 100$	$V_w = V_{liq} \times G_{sup} \times \left(\frac{100-s}{100}\right)$	$V_{sol} = V_{liq} - V_w = V_{liq}\left[1 - \left(\frac{100-s}{100}\right) \times G_{sup}\right]$
Spec. gravity (G_{sup})	Solids dosage s (%)	15 E	24 F	21 G	11 H
1.21	40	4.5	8.7	6.3	2.36

MATERIALS	1 Content kg/m³	2 Volume l/m³	3 Dosage SSD conditions kg/m³	4 Water correction l/m³	5 Composition 1 m³	6 Composition Trial batch
WATER ($\frac{W}{B} = 0.3$)	140	140	140		150	7ltrs 1.09
CEMENT	467 / 420	134	420		420	2.94
Microsilica	47	21.36	47		47	0.33
COARSE AGGREGATE	1025	374	1025	+8.2	1016.8	7.12
FINE AGGREGATE		315.6	820	8.2	811.8	5.68
AIR	PERCENT 1.5 %	15	0			
SUPER-PLASTICIZER	1 %	2.36	4.5	- 6.3	8.7 V_{liq}	0.06 V_{liq}
TOTAL		684.4	2456.5	10.1		17kg

6. Analysis of results

Figures 7 to 9 show various plots of the results obtained by testing the samples in UTM. Table 4 shows the experimental results of various trials. From Figs. 7 and 8, it can be seen that the compressive strength at 28 days increases by as much as 75% when 5% micro-silica is added. Further addition of micro-silica does not increase the strength much but by 10%. As far as flexural strength is concerned, addition of micro-silica does not affect it as much as compressive strength. Fig. 9 reveals that flexural strength at 28 days is enhanced merely by 12 - 15%.

Conclusions

It has been concluded that the compressive strength of concrete increases with increase in micro-silica content. Compressive strength of concrete gets substantially increased on increasing the amount of micro-silica in it (i.e., 0%, 5%, and 10%). Flexural strength also increases, which may be attributed to Pozzolanic as well as filler properties of micro-silica, which provides extra binding hence strength increases and fills the voids preventing the formation of micro-cracks. However, micro-silica does not affect flexural strength to a large degree.

Table 4. Experimental results of six trial batches.

Sample		slump in mm	3 Day Strength (Mpa) Comp.	3 Day Strength (Mpa) Flex.	7 Day Strength (Mpa) Comp.	7 Day Strength (Mpa) Flex.	28 Day Strength (Mpa) Comp.	28 Day Strength (Mpa) Flex.	3 Month Strength (Mpa) Comp	3 Month Strength (Mpa) Flex.
Cement		-	15	-	31.3	-	42.7	-	-	-
Trial batch No.1 (0% MS)	cylinder	155	13.1	-	29.43	-	36.31	-	43.6	-
	cube		-	-	-	-	-	-	-	-
	beam		-	-	-	-	-	-	-	-
Trial batch No.2 (5% MS)	cylinder	130	26.35	-	48	-	64.05	-	75.16	-
	cube		24.4	-	44.14	-	67.4	-	74.3	-
	beam		-	-	-	3.48	-	7.39	-	12.52
Trial batch No.3 (10% MS)	cylinder	87	33.7	-	60.4	-	71.7	-	82.04	-
	cube		32.4	-	58.83	-	79.51	-	84.6	-
	beam		-		-	3.95	-	8.86	-	17.25

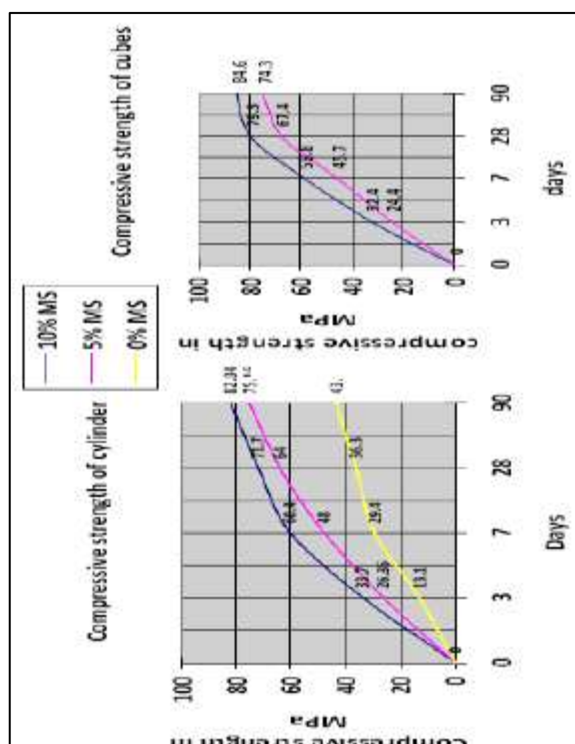


Fig. 7. Comparison of compressive strength (MPa) of cylinders.
Fig. 8. Comparison of compressive strength (MPa) of cubes.

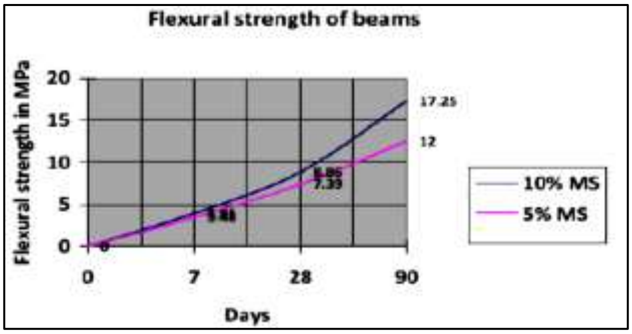


Fig.9 Comparison of flexural strength (MPa) of beams

Micro-silica decreases the rate of strength gain (less initial strength) but strength keeps on increasing for larger time so ultimate strength is higher as compared to ordinary concrete. Failure plane passed through the aggregates, which shows that bond strength was greater than strength of aggregates. Therefore, to attain the design strength bond strength and aggregates crushing strength must be optimized.

List of Symbols Used

G_c :specific gravity of the cement or cementitious material;
G_{SSD} :aggregate specific gravity in saturated surface dry condition;
W_{abs} :absorbed water in the aggregate in per cent;
w_{tot} :total water content of the aggregate in per cent;
w_h :moisture content of the aggregate in per cent: $w_h = w_{tot} - w_{abs}$;
G_{sup} :specific gravity of the liquid superplasticizer;
S :total solid content of the superplasticizer in per cent;
M_{sol} :mass of solids in the superplasticizer;
d :superplasticizer dosage as a percentage of the mass of solids in
comparison to the total mass of cementitious materials;
V_{liq} :volume of liquid superplasticizer;
V_w :volume of water in the liquid superplasticizer;
V_{sol} :volume of solids in the superplasticizer;
W :mass of water in kg per cubic metre of concrete;
B :mass of binder in kg per cubic meter.

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