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Study of Mix Design for High Strength Concrete using Locally Occurring 10mm (3/8) All-in-one Aggregate Gravel

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Abstract

This paper presents a detailed study and mix analysis for high strength (HSC) and Normal Strength (NSC), the study monitored washed locally occurring 10 mm (3/8') gravel aggregate as total replacement for coarse and fine aggregates .The aggregates were used in the combined state under natural condition. The study was carried out with mixes design containing aggregate with its combined and natural state incorporating fly ash and microsilica as supplementary cementitious materials. A total of 25 trial mixes was considered comprising 10 high strength and 15 normal strength concrete mixes. The variation of compressive strength of HSC and NSC was investigated as a function of fly ash/microsilica (FA/MS) and water/binder (W/B) ratios. One hundred and ninety six cube specimen of size 150mmx150mmx150mm were cast and tested for compressive strength after 3, 7 and 28 days wet curing. The maximum 28-day of compressive strength of 88.9 MPa and 53.8 MPa was obtained for HSC and NSC respectively.

Keywords: fly ash; microsilica; all-in-aggregate 10 mm (3/8') gravel; high strength concrete.

1. Introduction

The abundance of 10mm (3/8') gravel around the Niger Delta area and its use in concrete production without specification called for this study. High Strength concrete (HSC) is widely used worldwide because of its workability, high density and high durability etc. High strength concrete cannot be achieved without the use of mineral and chemical admixtures such as fly ash and silica fume as adopted in this study [8, 9, 10]. This study is aimed at finding out the individual effects steel Fly ash and silica fume on water absorption and strength characteristics of high strength concrete to obtain optimum mixture proportioning which can ensure durable concrete as well as economical way of ensuring sustainable environmental development. Long-term performance of structures has become vital to the economies of all nations. Concrete has remained the major material for providing stable and reliable infrastructure since the days of the Greek and Roman civilization. At the turn of the 20th century, achievable concrete compressive strength was about 13.8 MPa, by the 1960s it had progressed to 27.6-41.4 MPa. Failures due to 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 cements and concretes and more elaborate codes and standards.

As a result, new materials and composites have been developed and improved cements evolved, including concrete with a compressive strength even as high as 200 MPa. This is about 40 percent of the strength of high grade structural steel or 80 percent of mild steel rebars. [6, 7, 8, 9] defines HSC 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". Normal strength concrete by ACI definition is a concrete that has a 28 – day cylinder compressive strengths not exceeding 42 MPa. All other concretes are considered High Strength Concretes (HSC). High strength concretes with 140 MPa are currently being used in High rise structures in USA, Europe, Asia, Middle and Far East. Other definitions of HSC are given in various international codes, including [2, 3, 4, 5].

Reference [18] in their research proposed a variety of methods of generating HSC. They concluded that concrete strength development definitely will depend on both cement characteristics and that it is impossible to attain high strength concrete without the use of admixtures such as fly ash, microsilica, superplasticizers or any other supplementary cementitious material that meets pozzolanic requirement. The principal weakness and cause of deterioration of concrete when exposed to the environment and mechanical loading is its porosity evidenced by the voids in the concrete matrix. Thus, the elimination of these voids constitutes the major challenge in high strength concrete mix design [12, 13, 14].

The critical requirements to HSCs are high strength, durability and serviceability characterised by crack and deflection control, as well as response to long term environmental effects. High performance concrete (HPC) are concretes with properties or attributes which satisfy the performance criteria, defined in terms of Strength and Durability. Generally, concretes with higher strengths and attributes superior to conventional concretes are desirable in the Construction Industry. In a bid to reduce the cost of construction accruing from use of crushed granite as coarse aggregates in the Niger Delta region; this study has been initiated to develop a mix design approach with locally occurring all-in-aggregate 10mm (3/8') gravel as complete replacement of sand and granite meeting the requirements for normal, high strength and high performance concrete [11]. This will provide construction material and add value to local resources with attendant economic effect and employment generation.

2. Objectives of Study

The objectives of this study include;

i. Development of mix designs for different grades of concrete from normal to high strength using locally occurring (3/8'') gravel as aggregates.

ii. To establish limits for incorporation of mineral admixtures such as steel fly ash and microsilica into concrete mix for a given water/binder ratio and corresponding compressive strength.

iii. Develop design charts to guide the utilization of locally occurring 10 mm (3/8'') gravel in the Niger-Delta for production of normal and high performance concrete.

3. Materials and Methods

3.1 Materials

The materials used in this study include binders, aggregates, and superplasticizers.

3.1.1 Binders: These are cementitious materials which entail ordinary Portland cement (OPC), fly ash and microsilica in varying proportions

a. Ordinary Portland Cement (OPC, Grade 42.5)

Ordinary Portland cement meeting the requirements of BS12:1996 was adopted in this study based on its track record and satisfactory results in concrete works [9, 10]. The material also complies with American Concrete Institute (ACI) compilation17, for high-strength concrete. The cement used was free of lumps. Cement content was varied from 300 – 640 kg/m^3 as required for high strength and normal strength concrete (HSC & NSC).

b. Microsilica (Silica Fume SF)

Microsilica is a by-product resulting from the reduction of high-purity quartz with coal or coke and chips in an electric furnace during the production of silicon metal or ferrosilicon alloys. The American Concrete Institute Committee 211 [4, 5 and 8,] report states that ferrosilicon alloys are produced with normal silicon content of 61 to 98%. When the silicon content reaches 98%, the product is called elemental silicon rather than ferrosilicon. ASTM C1240 defines silica fume as having minimum 85% amorphous silicon dioxide (SiO_2). Silica fume is finer than cement and essentially functions as micro-filler. It reduces the percentage by weight of cement and fills the pores present in coarser filler such as fly ash and aggregates. Due to its large surface area, silica fume is the main factor in the determination of the water and superplasticizer requirements as well as the rheological properties of fresh concrete. During heat treatment, silica fume contributes partially in the formation of additional strength-forming hydrates phase in the concrete microstructure. It is important to note that concrete produced with additional silica fume is usually compact and less permeable than the normal concrete (NSC) [16, 19].

c. Fly Ash

The fly ash used in this work is a steel material in form of iron fillings obtained during metal works. It is a dark and fine grained material which acts as a filler. It contributes greatly to increase in density of high strength concrete (HSC). Fly Ash has been used extensively in concrete for many years. Compared to silica fumes, fly ash is much coarser and more variable in both their physical and chemical characteristics. The use of fly ash alone will result in concrete strengths of not more than 70 MPA.

3.1.2 Aggregates

Aggregates consist of both fine and coarse components. Here both the fine and coarse are of same naturally occurring all-in 10 mm (3/8'') gravel which was obtained and used in two different cases. The first case represents the natural state in which the washed natural gravel was used directly as all-in-one aggregate serving as fine and coarse in a combined state. In the second case, the natural material was graded to various sizes (fine and coarse) to required diameter and finally combined, using standard aggregate combination techniques. The all-in 10 mm (3/8'') gravel has bulk density and specific gravity of 2093 kg/m^3 and 3.01respectively. Its fineness modulus of 5.36 falls within the range of coarse and fine aggregates [15,16, and 17]. Fine Aggregate: The washed natural 10 mm (3/8'') gravel was sieved and graded into 150µm, 2.35mm, 5mm and 10mm. Aggregates particles grading between of 150µm and 2.35mm was adopted as fine aggregates in the proportion of 10% for 150µm and 90% for 2.35mm.

Coarse Aggregate: Natural gravel sizes grading between 5 mm and 10 mm seives was adopted as coarse aggregates in equal proportions of 50% each.

Generally, the 10 mm (3/8'') gravel was obtained from fresh water bodies of the Niger-Delta, specifically the Chokocho River in Etche Local Government Area of Rivers State Nigeria.

3.1.3 Water

The water used for the research is generally suitable for drinking purposes and containing no sulphate or salt. It was obtained from the laboratory tap and meets BS 3148 requirements for mixing and curing of concrete specimen.

3.1.4 Superplasticizer

In this study, the Fosroc Auracast 200 (A200) was used as a lubricant to increase the workability of the concrete mixes. It is a reddish brown liquid used at rates ranging between 6litres/m^3 – 7.5litres/m^3. Fosroc Auracast 200 is a unique combination of the latest generation of polycarboxylate polymers which act synergistically for improved performance compared to conventional superplasticizer. Fosroc Auracast 200 has been specially developed for the precast concrete industry. It combines superior high range water reducing capabilities with excellent dispersion levels and robust performance. The property of A200 complies with EN934-2.

3.2 Experimental Procedures

The various tests, number of samples, parameters sought and relevant standards applied are presented in the

Experimental Plan of Table 1.

Table 1: Experimental Plan

%of A200	5% A200				10% of A200											
Mix types	M1 – 12				M1 - 12								M1 - 12			
Days	3	7	14	28	3		7		14		28		3	7	14	28
% F.S	5	5	5	5	5	10	5	10	5	10	5	10	5	5	5	5
% MS	10	10	10	10	5	10	5	10	5	10	5	10	5	5	5	5
No. Of cubes	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Total NO.	48				96								48			

3.2.1 Sieve Analysis

The sieve analysis was conducted using a stack of sieves in accordance with other specifications [1, 2 and 4]. The results were used in the concrete mix design and are given in Appendix 1.

3.2.2 Concrete Mix Design

Based on the suggestions of previous researcher [17], the mix proportions were selected as shown in Appendices 2a and 2b. Common materials used are ASTM Type-I cement locally available all-in-one gravel aggregates of 10 mm maximum size, and potable water. The admixtures used were condensed silica fume and Superplasticizer Auracast 200. In order to conduct the mix design of concrete, parameters of the aggregates are required. These include particle size distribution, specific gravity, bulk density and water absorption among others. These preliminary tests formed the basis of trial mixes designs.

3.2.3 Testing of Specimens

The specimens prepared for compressive strength and water absorption tests were of adequate geometric property of 150mm x 150mm x150mm cubes. The specimens were cast and properly vibrated using electric powered vibrating table, removed from moulds after 2days. The specimens were then cured in water curing tank for various ages prior to testing. The compressive strength test was carried out base on previous study [16] including water absorption as per IS: 3085-1965.

4. Result and Discussions

The average compressive strength with various water binder ratios and FA/MS ratios and ages of wet curing is discussed here.

4.1 Variation of compressive strength of 10 mm (3/8'') gravel concrete with duration of wet curing

The average values of compressive strength with various water/binders ratios including FA/MS ratios and ages for wet curing are presented in tables 2 & 3. This also includes naturally occurring all-in-aggregate for normal and high strength respectively. There is a general increase in compressive strength with decrease in water/binders ratios in most cubes. Moreso, the trend of increase in the normal strength for a particular mix proportion with age's experiences fluctuation. This type of behaviour is constant for all mixes considered. It is in agreement with [20] conclusions which necessitated the aggregate separation and combination technique adopted for the high strength mix design. The 28-day compressive strength increase observed from the [20] study ranged between 23.81N/mm^2 to 53.3N/mm^2 in the normal strength, this was as a result of addition of fly ash and Microsilica which is in line with the works from other study [18] that the cement proportions of high strength above 60N/mm^2 must be between 400 – 480kg/m^3 plus addition of admixture such as fly and microsilica.

4.1.1 Normal Strength Concrete

The experimental observations of compressive strength for normal strength concrete are presented in Table 1. These values are plotted in Figure 1a & 1b.

Table 2: Experimental Result for compressive strength of NSC

MIX	N01	N02	N03	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
CEM%	100	100	100	85	85	85	90	90	90	80	80	80	85	85	85
FA%	-	-	-	5	5	5	5	5	5	10	10	10	10	10	10
MS%	-	-	-	10	10	10	5	5	5	10	10	10	5	5	5
W/B	0.35	0.45	0.50	0.35	0.45	0.5	0.35	0.45	0.5	0.35	0.45	0.5	0.35	0.45	0.5
A200 %	-	-	-	12	12	12	12	12	12	12	12	12	12	12	12
3days	2.92	19.34	23.81	24.26	22.24	25.20	16.30	18.36	17.60	25.70	25.7	19.45	26.90	26.80	19.0
28days	6.97	23.11	23.81	48.53	44.47	50.40	36.73	35.27	29.63	51.40	38.53	38.9	53.80	53.63	37.93

1. From the graph of compressive strength versus age (strength development of NSC for natural state all-in-aggregate) experiences the lowest compressive strength at 28 days, this is recorded for Mix N6 (29.63Mpa), while the highest compressive strength were recorded for Mix N11at 7days and 28days with values of (26.80 and 53.3) MPa. It also include 90% cement, 5% FA and 5%MS for Mix N6 and 85% cement, 10% FA and 5% MS for Mix N11.

2. The increase in compressive strength of the control mix and the improved mix design shows similar trend of growth. The control mix maximum compressive strength were observed at 28-day, while wet curing is 23.8N/mm^2 with W/B of 0.5. Mix 1 (FA/MS = 0.5) maximum strength is 48N/mm^2 for 0.35 W/B ratio and 53.3N/mm^2 for mix 3 (FA/MS = 2) for 0.35 W/B ratio. The high strength increase for lower W/B for all mixes is indication that high strength can only be gotten for lower W/B ratio between (0.22 – 0.30). There is also possibility of increase in strength if the cement content is increased between 400 – 480kgandm3 against the 300kg used for this normal strength concrete.

The trend of strength development observed in mix 2a (FA/MS = 1) and mix 2b (FA/MS = 1) is significant. The mix of 2b FA/MS is 10%s while that of mix 2a is 5%s in mix proportion. The admixture content in mix 2b is high; this is seen in the strength development with value of 51.2N/mm^2 higher than that of mix2a except for 14days for W/B ratios between (0.4 – 0.5) only.

3. In general, the compressive strength recorded for normal concrete against W/B ratio for natural occurring aggregate depicts that compressive strength increases with decrease in W/B ratio. However deviations from this were recorded, this deviations are owing to the heterogeneous nature of aggregates which is seen in figures 1b (i-v)

4.1.2 High Strength Concrete

The average values of high compressive strength for various water/binder and FA/MS ratios and ages of wet curing are presented here.

Table 3: Average values of compressive strength test for HSC with combined aggregate

Mix type/Ingredient		H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}
W/B		0.23	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.39	0.23
FA/MS		2.43	0.41	2.42	0.41	0.41	0.41	2.42	0.41	0	0
B/A200		85.47	85.47	88.93	88.93	102.6	102.61	85.33	88.93	57.69	35.41
Compressive Strength	7days	31.6	37.3	63.1	41.8	56.0	66.7	34.7	61.3	32.9	33.8
	28days	68.4	72.5	81.1	88.3	82.6	88.9	82.7	70.6	83.6	80.9

1.From graph of strength development for graded aggregate combination state plotted for 7 & 28 days, mix H1 exhibited lowest strength of 31.6Mpa at 3days and 68.4Mpa at 28days, while the maximum strength development is recorded at mix H6 both for 7days and 28days between (66.7Mpa and 88.9Mpa) respectively. Mix H1 is of 541kg/m^3 of cementitious material with 32% OPC replacement with fly ash and micro silica in proportion of 9.7% and 22.3% respectively, while mix H6 is of 667kg/m^3 cementitious material, OPC replacement of 30.73%, with FA and MS in the proportion of 9% and 21.74% respectively.

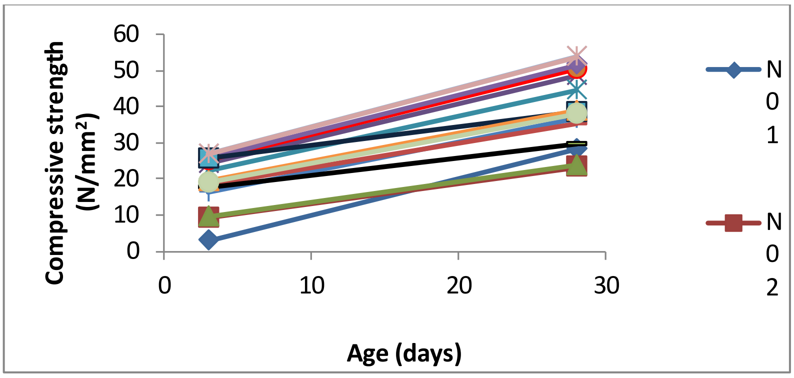

Figure 1a: Strength Development of NSC for All-in-Aggregate (3/8') Gravel

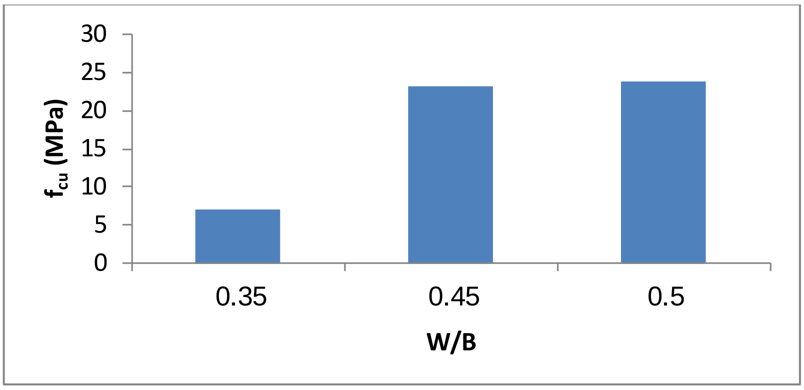

Figure 1b.i: Effect of W/B on Compressive Strength for FA/MS = 0 (control)

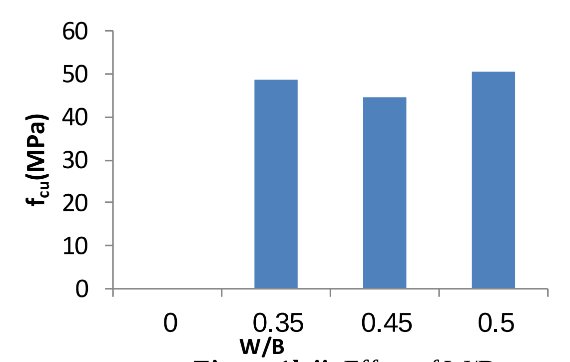

Figure 1b.ii: Effect of W/B on Compressive Strength for FA/MS = 1

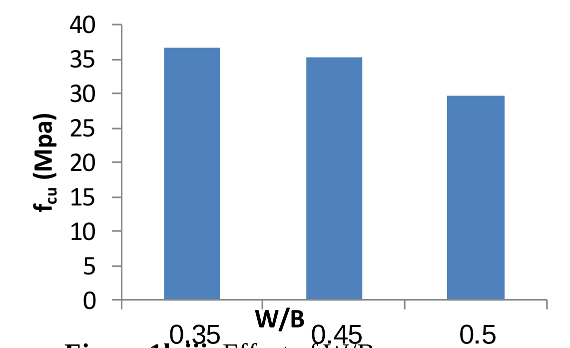

Figure 1b.iii: Effect of W/B on Compressive Strength for FA/MS = 1

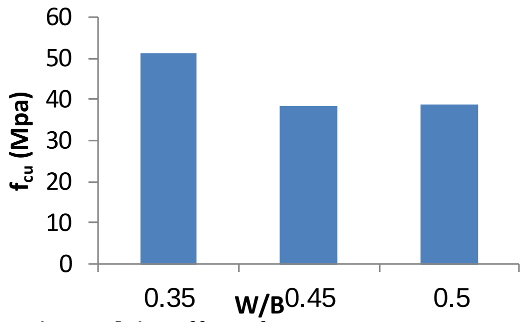

Figure1b.iv: Effect of W/B on Compressive Strength for FA/MS = 1

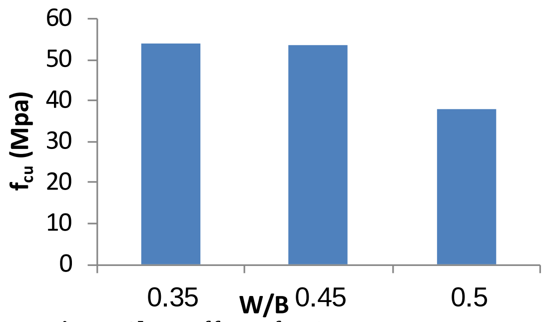

Figure1b.v: Effect of W/B on Compressive Strength for FA/MS = 2

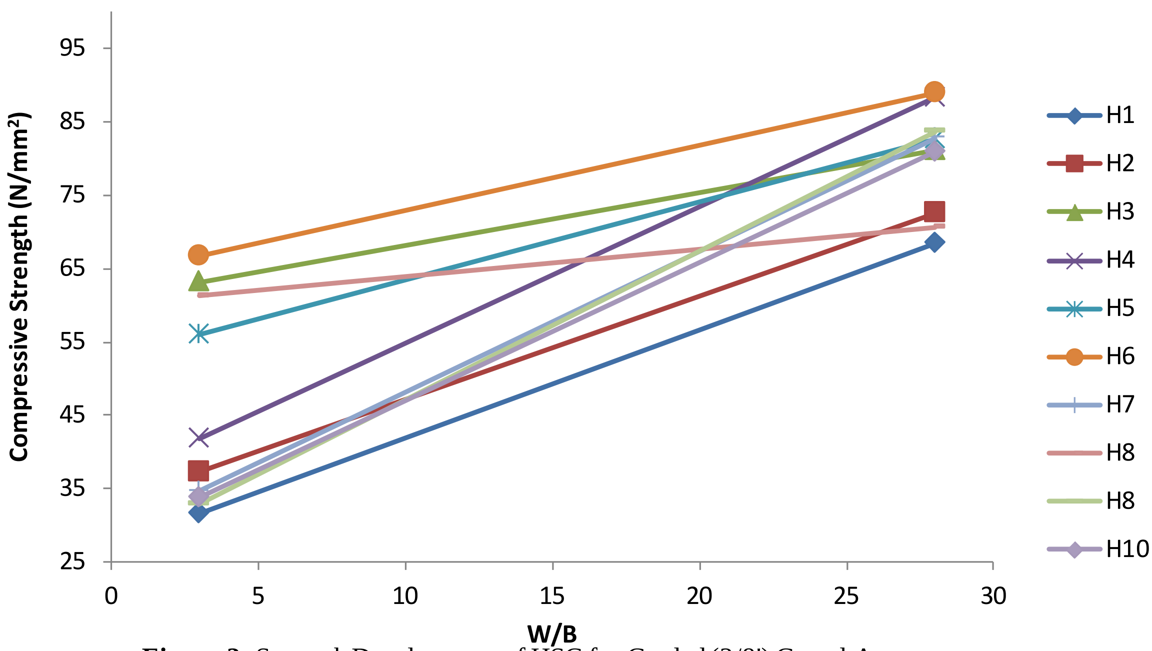

Figure 2: Strength Development of HSC for Graded (3/8') Gravel Aggregate

4.4 Proposed Mix Design Charts for 10 mm (3/8'') HSC

Proposed mix design charts for 10mm (3/8') gravel for high strength and Normal strength is presented here, it include binder's content of 250 – 300kg/m^3 for normal strength concrete between 480 – 650kgM^3 for High Strength Concrete.

The charts show the relationship between compressive strength with water/binders (W/B) and Fly ash/Microsilica (FA/MS) ratios. The charts are derived from table 4.

Table 4: Compressive Strength of NSC and HSC against Duration of Wet Cure

W/B	Mix N01-N03 (FA/MS =0)	Mix N1-N3 (FA/MS =0.5)	Mix N4-N6 (FA/MS =1)	Mix N7 - N9 (FA/MS =1)	Mix N10-N12 (FA/MS =2)
3-Day Compressive Strength (N/mm²) NSC					
0.35	2.79	22.26	16.30	25.70	26.90
0.45	9.24	22.24	18.36	25.70	26.80
0.50	9.52	25.20	17.60	19.45	19.00
7-Day Compressive Strength (N/mm²) NSC					
0.35	2.82	37.27	28.23	29.33	35.23
0.45	19.33	21.33	21.17	25.47	20.60
0.50	16.23	37.73	20.90	24.20	27.80
14-Day Compressive Strength (N/mm²) NSC					
0.35	3.56	42.67	34.00	30.10	43.70
0.45	18.23	24.60	29.33	36.27	29.03
0.50	17.33	46.18	29.63	32.60	31.27
28-Day Compressive Strength (N/mm²) NSC					
0.35	6.97	48.53	32.60	51.40	53.83
0.45	23.11	44.47	36.73	38.53	53.63
0.50	23.81	50.40	35.27	38.90	37.93
28-Day Compressive Strength (N/mm²) HSC					
W/B	MIX1 (FA/MS = 0.0)	MIX2(FA/MS = 0.41)	MIX3 (FA/MS = 2.44)		
0.22	80.9	85.45	81.1		
0.23	78	77.33	75.55		

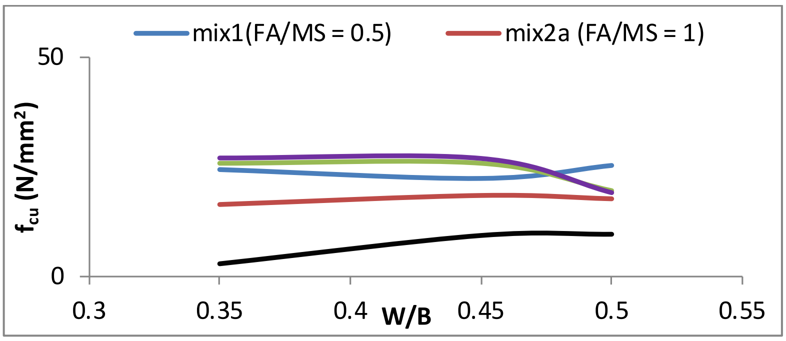

Figure 3a: NSC chart For 3-day Compressive Strength

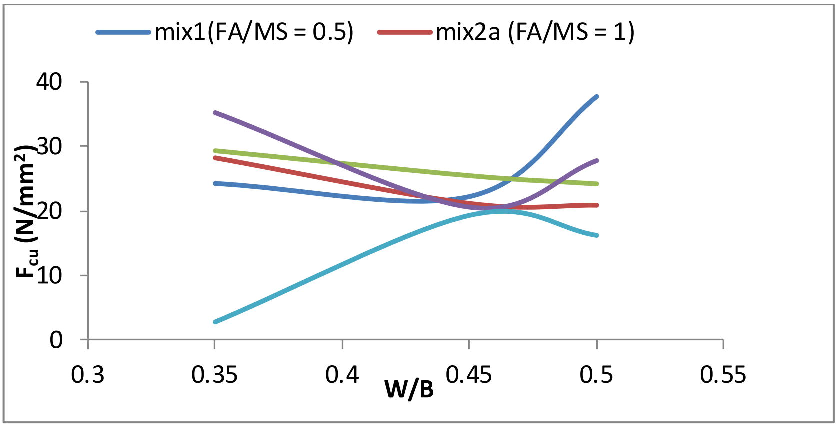

Figure 3b: NSC chart for 7-day compressive strength

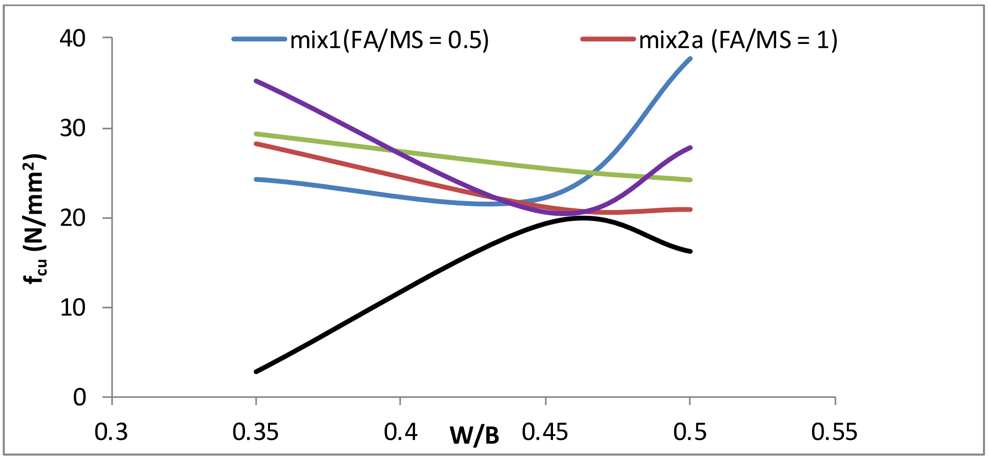

Figure 4.6b: For 7-day Compressive Strength

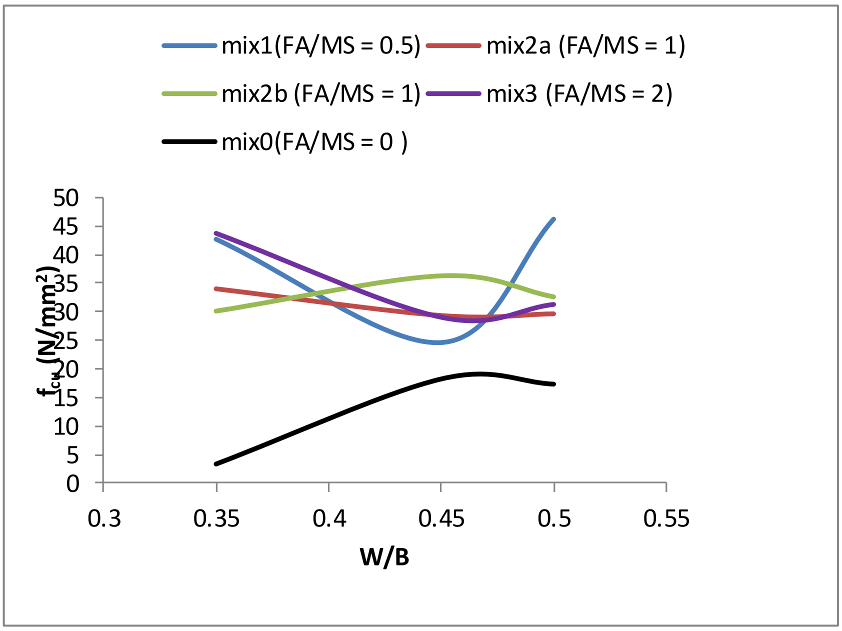

Figure 3c: NSC chart For 14-day Compressive Strength

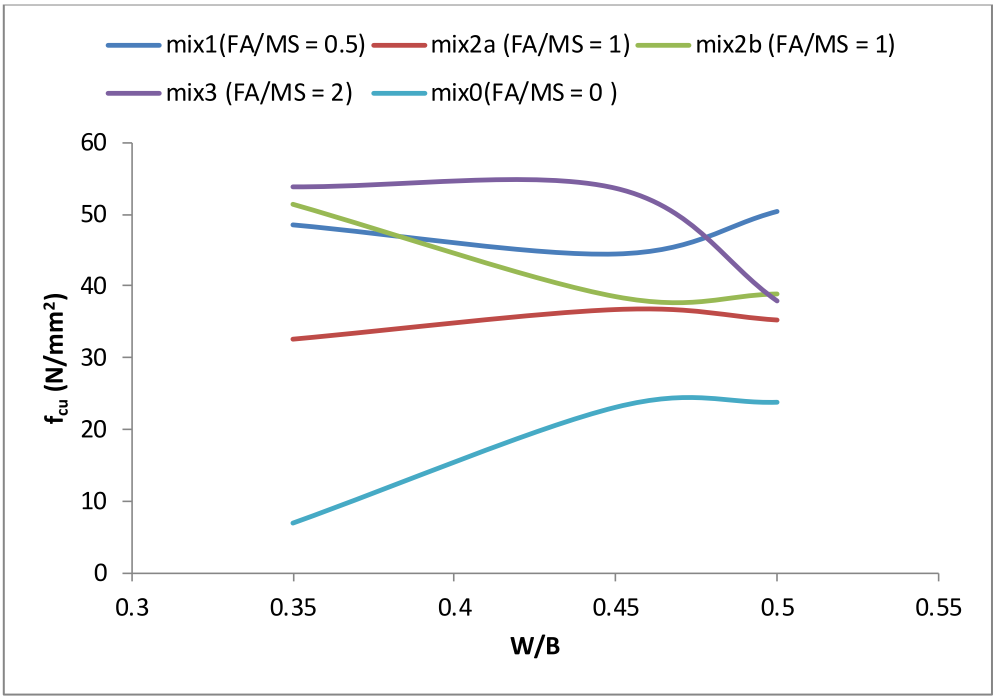

Figure 3d: NSC chart For 28-day Compressive Strength

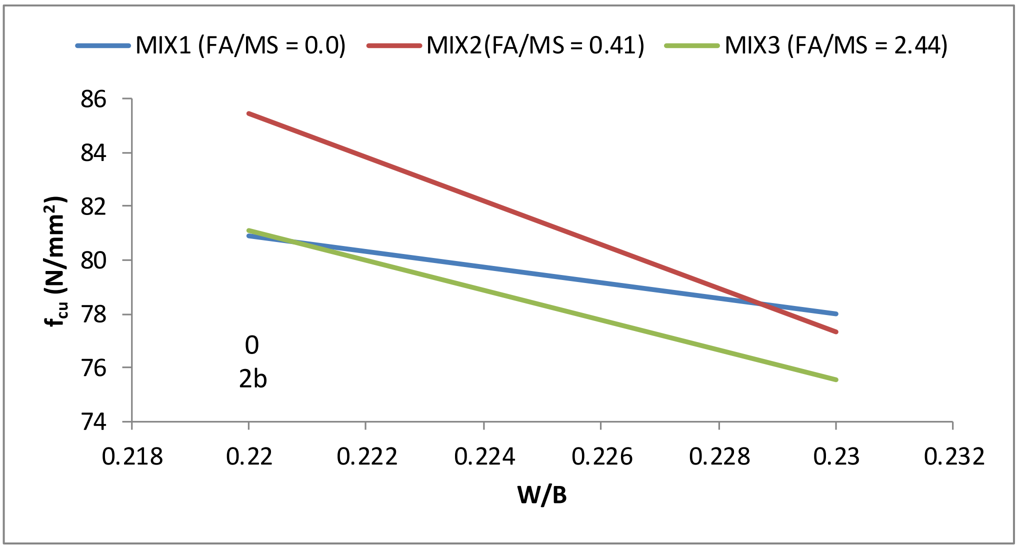

Figure 3e: HSC chart for 28-day compressive strength

9. Conclusion

1. Resulting mix without combined aggregate technique is heterogeneous in nature.

2 Resulting mix using microsilica and fly ash in the presence of aura cast 200 is homogeneous and workable for combined aggregate technique and heterogeneous in natural occurring all-in-aggregate.

3. The fresh concrete is very cohesive

4. Mix incorporating microsilica and fly ash in the presence of aura mix 200 is harsh and sticky
5. For all trial mixes the flows does not exceed 3minutes which marks initial setting
6. Specimens have good surface finish and exhibits high density
7. The introduction of FA and MS called for early strength development that lead to early strength testing of concrete for both normal and high strength concrete.

8. Incorporation of fly ash and micro silica improves the compressive strength of the concrete. All the mix types considered in the NSC at 3days curing exhibited average of 51.9% of the maximum compressive strength and an average strength development of 48.1% strength between 7 - 28days.
9. Keeping the cementitious content constant will bring about higher compressive strength for NSC if the W/B ratio is reduced.
10. For the HSC, keeping the cementitious content within permissible range not less than 462kg/m^3 and W/B within 0.20 - 0.23 high grades concrete can be produced.
11. For higher grades it is important to adopt higher FA/MS ratio.
12. The present study inspires to explore further in this direction especially trying replacement adopting fly ash alone.
13. It is observed that, these mixes have adequate workability and with some improvement that can be converted to self compacting cement which is invoke for construction of dams and other structures in marine environment.

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Appendix 1 Grading Test results

Table1a: Sieve analysis for Coarse aggregate (10mm 50%, 5mm, 50%) Total weight of sample taken for dry grading ----500g

Sieve Size	Mass Retained	Total Mass retained	Total mass passing	Total percentage passing
14mm			500.00	100.00
10mm	17.5	17.50	482.50	96.50
6.3mm	1555.8	173.30	326.70	65.34
5mm	215.9	17.50	482.50	96.50
Total				

Table 1b: Sieve analysis for Fine Aggregate (2.36mm 90%, 150mm, 10%) Total weight of sample taken for DRY grading-----500g

Sieve Size	Mass Retained	Total Mass retained	Total mass passing	Total percentage passing
6.3mm			500.00	100.00
5mm	7.1	7.1	492.9	98.58
2.362mm	106.4	113.5	386.5	43.40
1.18mm	102.2	215.7	176.3	56.86
600 micron	108.0	232.7	284.3	35.26
300 micron	122.4	446.1	53.9	10.48
150 micron	48.0	494.1	5.9	1.18
63 micron	5.9	500.00	-	
Total				

Table 1c: Com Total weight of sample taken for dry grading-----985g

Sieve Size	Mass Retained	Total Mass retained	Total mass passing	Total percentage passing
14mm			985.00	100.00
10mm	16.85	16.85	968..15	98.29
6.3mm	152.25	169.10	815.90	82.83
5mm	204.55	373.65	611.35	62.06
2.362mm	211.25	584.90	400.10	40.61
1.18mm	109.25	694.15	290.85	29.53
600 micron	142.35	836.50	148.50	15.08
300 micron	104.75	941.25	43.75	4.44
150 micron	37.15	978.40	6.60	0.67
63 micron	6.60	985.00	-	
Total				

*

Appendix 2a Mix design for 1m^3 high strength concrete (graded aggregate combination state)

Table 2

Mix type/Ingredient		R_1 Kg	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}
Water (Kg/m$^{3)}$		150kg	150	147	147	145	150	150	150	145	130
Cement (Kg/m^3)		435	435	462	462	462	462	435	462	335	513
Fly ash (Kg/m^3)		146	60	145	60	60	60	145	60	-	-
Micro silica(Kg/m^3)		60	146	60	145	145	145	60	145	40	43
A 200 Suffer plasticizer (L/m^3)		7.5	7.5	7.5	7.5	6.5	6.5	7.5	7.5	6.5	15.7
Fine Aggregate	2.35m Kg/m^3	576	576	576	576	576	576	566	576	625.5	64.5
	154m Kg/m^3	64	64	64	64	64	64	75	64	69.5	68.5
Coarse Aggregate	10mm Kg/m^3	500	500	500	500	500	500	450	500	565	540
	5mm Kg/m^3	500	500	500	500	500	500	450	500	565	540
W/B		0.23	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.39	0.23
FA/MS		2.43	0.41	2.42	0.41	0.41	0.41	2.42	0.41	0	0
B/A200		85.47	85.47	88.93	88.93	102.6	102.61	85.33	88.93	57.69	35.41

Appendix 2b Mix design for Normal strength concrete (natural all-in-aggregate state)

Table 3

MIX	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
CEM%	85	85	85	90	90	90	80	80	80	85	85	85
FA%	5	5	5	5	5	5	10	10	10	10	10	10
MS%	10	10	10	5	5	5	10	10	10	5	5	5
W/B	0.35	0.45	0.5	0.35	0.45	0.5	0.35	0.45	0.5	0.35	0.45	0.5
A200 %	12	12	12	12	12	12	12	12	12	12	12	12