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Investigating Geometric Characteristics of Cement Concrete Materials

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Abstract-- In this paper, the geometric characteristics of concrete materials obtained from different locations: Aleto Eleme, in Rivers State, Ishiagu in Enugu State and Akamkpa in Cross River State is reported. The cement concrete materials whose geometric characteristics were tested were fine and coarse aggregates. The geometric characteristics conducted on the aggregates were flakiness index, elongation index and aggregate crushing value. The maximum sizes of coarse aggregate were 10mm and 20mm. It was found among other findings that aggregate characteristics such as; shape, texture and grading contribute significantly to the performance of fresh portland cement concrete. It was also found that aggregate blends well with well-shaped, spherical, cubical, rounded and smooth particles that require less cement and water for a given slump than it blended with flat, elongated, angular and rough particles. It was also found that uniform particle size distribution having proper amount of each size produces aggregate blends with high packing density.

Keywords: geometric characteristic, cement concrete, packing density, flakiness index, elongation index, aggregate crushing value.

I. INTRODUCTION

Aggregates constitute about 80% percent of the total concrete volume. Consequently, their characteristics significantly affect the performance of fresh and hardened concrete and have an impact on the cost effectiveness of concrete (Neville, 2002). Aggregate characteristics such as shape, texture, and grading influence workability, finishability, bleeding, pumpability, and segregation of fresh concrete and also affect strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete. Construction and durability problems traceable to poor mixture proportioning and variation on grading (Lafrenz, 1997).

Aggregate is the most inexpensive component of Portland cement concrete. Conversely, cement is the most expensive component and is typically responsible for about 60 percent of the total cost of construction materials. Aggregate is an inert material that is dispersed throughout the cement paste largely for economic reasons. Aggregate is a building material that connects into a cohesive whole by means of cement paste in a manner similar to masonry construction. The aggregate properties such as physical, thermal, and chemical properties influence the performance of concrete (Mehta and Monteiro, 1993). Paste being a mixture of cement and water is the part of concrete that produces shrinkage, heat generation and durability problems although, at the same time, is the element that fills aggregate voids, the glue that keeps aggregates together after hardening and the element that provides workability to the mix in fresh concrete.

If aggregate voids are minimized, the amount of paste required to fill these voids is also minimized thereby enhancing the maintenance of concrete workability and strength. Consequently, optimal mixture proportioning will produce good-quality concrete with a minimum amount of cement. Within limits, the lesser the paste at a constant water-cement ratio, the more durable the concrete (Shilstone, 1994). The workability of concrete changes significantly with grading. Mixtures with high void contents require more paste for a given level of workability and minimizing the aggregate void content should be one of the objectives of optimization of concrete mixtures. A clear relationship exists between shape, texture and grading of aggregates and the void content of aggregate (Galloway, 1999; Dewar and Anderson, 1999). Flaky, elongated, angular and unfavourably graded particles lead to higher void content than cubical, rounded, and well-graded particles.

The effects of shape, texture and grading characteristics of aggregates has been incorporated into concrete proportioning through packing density concepts or through surface area concepts. Guidelines for proportioning concrete that incorporate the effect of aggregate shape, texture, and grading and that consider the effect of high-microfines content are required. Well-known proportioning methods such as ACI 211 do not incorporate the effect of shape and texture of fine aggregate. Some proportioning methods work well for natural sands that usually differ in grading and micro-fines content compared to manufactured sands. Some other methods consider the effect of aggregate packing density but it has been found that quite important differences in proportions could result by using these methods.

There are several drawbacks to ACI 211. The calculation of the amount of water considers only the target slump and the maximum size of aggregate. Guidelines for increasing or decreasing the water amount depending on the shape of aggregate and addition of chemical admixtures are very simplistic. Sands with very different size distributions could have the same fineness modulus. There is no direct way of incorporating more than two sizes of aggregate. These weaknesses become more important with the advent of crushed aggregates with the corresponding increased variability on grading, shape and texture and high amount of micro-fines. Packing density is related to shape, texture, and grading.

Although it seems that packing density is a good way to link aggregate characteristics to concrete behaviour, there has been interest in investigating the effect of each of these characteristics on the performance of concrete. This paper highlights the geometric characteristics of cement concrete aggregates such as shape, angularity and texture and their effect on the performance of both fresh and hardened concrete.

II. MATERIALS AND METHODS

The following characterization tests were conducted on coarse aggregates:
Sieve analysis: BS 812: Part 103.1
Specific gravity and absorption capacity: BS 1377
Flakiness index Test: BS812: Part:105:1
Elongation index Test: BS812: part 105:2
Aggregate Crushing Test: BS812: Part 110
The following characterization tests were conducted on fine aggregates:
Sieve analysis: BS 812: Part 103.
Specific gravity and absorption capacity: BS 1881: part 122

1.**Sieve analysis**
Grading of the aggregates was determined by shaking it for not less than two minutes on each of such B.S. square – aperture test sieves (arranged in ascending order) as were appropriate to define the particular size of aggregate and weighing the aggregate retained on each sieve. The numerical results of these tests can be seen in Tables 1 to 7. Some relevant results and grading curves are shown in Tables 14 to 16 and Figures 1 and 2 respectively.

2.**Specific gravity absorption capacity**
This test was performed by immersing in distilled water a sample (2-3 kg) of aggregate enclosed in a wire- mesh container for 24 hours. The container with the aggregate was weighed when immersed in water thus giving it a buoyant weight (w_1). The material was then surface dried and weighed in air, giving the saturated weight (w_2). Thereafter, the material was oven dried at a temperature 100 -110^{o}C and the dry weight determined (w_3).

3. **Flakiness index test**
The flakiness index was conducted by using a standard thickness gauge. The gauge consist of slots of different sizes. The aggregates were first separated out into fractions with different size ranges 0.6 times the mean of the range gives the slot to be used for testing the particular aggregate fraction. The flaky materials from all the fractions of different size ranges were separated out and weighed. The total weight of the sample was determined. The ratio between the two expressed as a percentage gives the flakiness index as tabulated in tables 8 to 12 respectively.

4. **Elongation index test**
In conducting this test, the aggregates were sampled and fractioned, then the individual particles from the fractioned were passed through opening on a metal length-gauge. The elongation index is taken as the total weight of the material retained on the length – gauge expressed as a percentage of the total weight of the sample gauged as tabulated in Tables 8 to 12 respectively.

5.**Aggregate crushing test**
This test consists of subjecting the specimen of aggregate in a standard mould to a compression test under standard loading condition. Dry aggregate passing through 12.5mm sieve and retained on 10mm sieve were filled in a cylindrical measure 11.5cm diameter and 18cm high in three layers each layer being tamped with a standard rod 25 times. The test sample was weighed and placed in the test cylinder (which is 15.2cm dia) in three layers, each layer being tamped 5 times with standard rod. The specimen was subjected to a compressive load of 40 tones gradually applied in 10minutes. The materials passing through 2.36mm sieve was separated. The weight of this material (fines) expressed as a percentage of the weight of the total sample gives the aggregate crushing value (Tables 9, 11 and 13).

6. **Mixing Procedure**
Concrete mixtures were made in the mixer before casting in the concrete mould in accordance with the requirement of ASTM C 192 mixing procedure. To measure compressive strength, 150mm x 150mm x 150mm cylinders were cast according to BS1881: Part 110. In general, cylinders were tested at 7 and 28 days respectively.

7. **Workability**
Workability of concrete mixtures was assessed by the slump test conducted following BS 1881: Part 102. For this test, an inverted cone steel of 30cm high, 20cm diameter at the base, 10cm diameter on the top was used. Concrete was cast in three layers; each one compacted by 25 strokes of a metallic rod of 16mm diameter and 60cm long. Just after the slump cone was filled tamped and struck off level, it was then lifted off the concrete. The inverted cone was then placed alongside on the base plate, a straight edge laid across and the slump measured with a rule from the straight edge down to the top of the concrete to the nearest 5mm.

8. **Compressive Strength**
The compressive strength test was conducted according to BS1881:Part116 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. In general, compressive strength was tested at ages of 7 and 28 days. Before testing, the specimens were cured in a moisture room at 100 percent humidity (BS 1881: Part 111).

III. RESULTS AND DISCUSSION

TABLE 1: SIEVE ANALYSIS: FINE AGGREGATE (ZONE 2; SOURCE: RIVERS STATE)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	25.00				100	
	Fine	19.00	0.0	0.0	0.0	100.00	
		12.50	0.0	0.0	0.0	100.00	
		10.00	0.0	0.0	0.0	100.00	100
		5.00	6.00	6.00	1.20	98.80	90 -100
SAND	Medium	2.36	34.00	28.0	5.60	93.20	75 -100
		1.18	150.00	116.0	23.20	70.00	55 – 90
		0.60	270.00	120.0	24.00	46.00	35 – 59
	Fine	0.300	478.00	208.0	41.60	4.40	8 -30
		0.150	498.00	20.0	4.00	0.40	0 -10
		0.075	498.00	0.0	0.00	0.40	
FINES	Clay or Silt	<0.075	0.0	0.0	0.00		

TABLE 2: SIEVE ANALYSIS: FINE AGGREGATE (ZONE 3; SOURCE: ALETO ELEME)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	25.00				100	
	Fine	19.00	0.0	0.0	0.0	100.00	
		12.50	0.0	0.0	0.0	100.00	
		10.00	0.0	0.0	0.0	100.00	**100**
		5.00	12.00	12.00	4.00	96.00	**90 -100**
SAND	Medium	2.36	22.00	10.0	3.33	92.67	**85 -100**
		1.18	66.00	44.0	14.67	78.00	**75 – 100**
		0.60	112.00	46.0	15.33	62.67	**60 – 79**
	Fine	0.300	236.00	124.0	41.33	21.33	**12 -40**
		0.150	296.00	60.0	20.00	1.33	**0 -10**
		0.075	296.00	0.0	0.00	1.33	
FINES	Clay or Silt	<0.075	0.0	0.0	0.00		

TABLE 3: SIEVE ANALYSIS: FINE AGGREGATE (ZONE 4; SOURCE: RIVERS STATE)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	25.00				100	
	Fine	19.00	0.0	0.0	0.0	100.00	
		12.50	0.0	0.0	0.0	100.00	**100**
		10.00	0.0	0.0	0.0	100.00	**100**
		5.00	6.00				**95 -100**
SAND	Medium	2.36	10.00				**-100**
		1.18					**– 100**
		0.60					**80 – 100**
	Fine	0.300					**15 -50**
		0.150					**0 -45**
		0.075					
FINES	Clay or Silt	<0.075	0.0				

TABLE 4: SIEVE ANALYSIS: COARSE AGGREGATE (10MM MAX SIZE; SOURCE: ISHIAGU CRUSH ROCK)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	25.00					
	Fine	20.00	0.0	0.0	0.0	100.00	**100**
		14.00	14.0	14.0	1.40	98.60	**85 - 100**
		10.00	414.00	400.00	40.00	58.60	**0 - 50**
		5.00	774.00	360.00	36.00	22.60	**0 - 10**
SAND	Medium	2.36	994.00	220.0	22.00	0.60	**0 -5**
		1.18					
		0.60					
	Fine	0.300					
		0.150					
		0.075					
FINES	Clay or Silt	<0.075					

TABLE 5: SIEVE ANALYSIS: COARSE AGGREGATE (20MM MAX SIZE; SOURCE: CRUSH ROCK ISHIAGU)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	50.00					
		31.80				100	
		25.00		26	2.6	97.4	**100**
	Fine	20.00	120.00	120.0	12.00	85.40	**85 -100**
		14.00	700.00	580.0	58.00	27.40	**0-70**
		10.00	960.00	260.0	26.00	1.40	**0-25**
		5.00	972.00	12.0	1.20	0.20	**0-5**
SAND	Medium	2.36					
		1.18					
		0.60					
	Fine	0.30					
		0.15					
		0.075					

TABLE 6: SIEVE ANALYSIS: COARSE AGGREGATE (20MM MAX SIZE; SOURCE: AKAMKPA CRUSH ROCK)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	50.00					
		31.80				100	
		25.00			0	100	**100**
	Fine	20.00	100.00	100.00	10.00	90.00	**85 -100**
		14.00	590.00	490.00	49.00	41.00	**0-70**
		10.00	971.00	381.0	38.10	2.90	**0-25**
		5.00	996.00	25.0	2.50	0.40	**0-5**
SAND	Medium	2.36					
		1.18					
		0.60					
	Fine	0.30					
		0.15					
		0.075					

TABLE 7: SIEVE ANALYSIS: COARSE AGGREGATE (10MM MAX SIZE; SOURCE: RIVERS STATE)

Particle Description		Sieve mm	Total Wt. (g)	Wt. Retained	% Retained	% Passing	Specification: BS882; PART 2
GRAVEL	Coarse	50.00					
		31.80					
		25.00					
	Fine	20.00					
		14.00				100.00	
		10.00	140.00	140.00	14.00	86.0	**85 -100**
		5.00	960.00	820.0	82.00	4.0	**0-25**
SAND	Medium	2.36	998.00	38.0	3.80	0.2	**0-25**
		1.18					
		0.60					
	Fine	0.30					
		0.15					
		0.075					

TABLE 8: AGGREGATE FLACKINESS AND ELONGATION TEST (20MM MAX SIZE; SOURCE: CRUSH ROCK ISHIAGU)

FLAKINESS				
SIEVE SIZE (mm)	WEIGHT OF SAMPLE (A) (g)	WEIGHT PASSING GAUGE (B) (g)	WEIGHT NOT PASSING GAUGE (g)	**FLAKINESS INDEX (B/A) (%)**
20	1000	162	838	16.2
SPECIFICATION (FMWH)			**<35%**	
ELONGATION INDEX				
SIEVE SIZE (mm)	WEIGHT OF SAMPLE (A) (g)	WEIGHT PASSING GAUGE (g)	WEIGHT NOT PASSING GAUGE (g)	**ELONGATION INDEX (B/A) (%)**
20	1000	335	665	33.5
SPECIFICATION (BS 812)			**<35%**	

TABLE 9: AGGREGATE CRUSHING VALUE; (SOURCE: CRUSH ROCK ISHIAGU)

SIEVE SIZE (mm)	WEIGHT OF SAMPLE (g) (A)	WEIGHT PASSING (2.36)g (B)	WEIGHT NOT PASSING (2.36) (g)	**ACV (B/A) (%)**
10	3000	702	2282	23.4
20	3000	720	2248	24.0
SPECIFICATION (FMWH)			**<30%**	

Table 10: **Aggregate Flakiness and Elongation Test (20mm max size; Source: Akampka)**

Aggregate Size Fraction		Weight of the Fraction Consisting of at least 200 pieces W(g)	Weight of Aggregate Passing Thickness Gauge w(g)	Weight of Aggregate Passing Length Gauge Size (y) (g)
Aggregates Passing BS Sieve (mm)	Aggregates retained on BS Sieve (mm)			
63	50	-	-	-
50	37.5	-	-	-
37.5	28	-	-	-
28	20	-	-	-
20	14	1518	38	130
14	10	1038	996	714
10	6.3	432	8	74
Total		**2988**	**1042**	**918**
				Specification
Flakiness Index % =		$\frac{w_1 + w_2 + w_3}{W_1 + W_2 + W_3}$	$X\ 100\% = 35$	35%
Elongation Index % =		$\frac{y_1 + y_2 + y_3}{W_1 + W_2 + W_3}$	$X\ 100\% = 31$	35%

TABLE 11: AGGREGATE CRUSHING VALUE (20MM MAX SIZE; SOURCE: AKAMPKA)

SIEVE SIZE (mm)	WEIGHT OF SAMPLE (g) (A)	WEIGHT PASSING (2.36)g (B)	WEIGHT NOT PASSING (2.36) (g)	ACV (B/A) (%)
20	3000	514	2486	**17**
		Aggregate Crushing values % = $\frac{B}{A} \times 100\% =$ **17**		
SPECIFICATION			**30%**	

TABLE 12: AGGREGATE FLAKINESS AND ELONGATION TEST (10MM MAX SIZE; SOURCE: RIVERS STATE)

FLAKINESS				
SIEVE SIZE (mm)	WEIGHT OF SAMPLE (A) (g)	WEIGHT PASSING GAUGE (B) (g)	WEIGHT NOT PASSING GAUGE (g)	**FLAKINESS INDEX (B/A) (%)**
10	500	218	282	43.6
SPECIFICATION (FMWH)			**<35%**	
ELONGATION INDEX				
SIEVE SIZE (mm)	WEIGHT OF SAMPLE (g)	WEIGHT PASSING GAUGE (g)	WEIGHT NOT PASSING GAUGE (g)	**ELONGATION INDEX (B/A) (%)**
10	500	352	148	70.4
SPECIFICATION (BS 812)			**<35%**	

TABLE 13: AGGREGATE CRUSHING VALUE (10MM MAX SIZE; SOURCE: RIVERS STATE)

SIEVE SIZE (mm)	WEIGHT OF SAMPLE (g) (A)	WEIGHT PASSING (2.36)g (B)	WEIGHT NOT PASSING (2.36) (g)	**ACV (B/A) (%)**
10	3000	522	2478	**17.4**
		Aggregate Crushing values % = $\frac{B}{A} \times 100\% =$ **17.4**		
SPECIFICATION			**30%**	

TABLE 14: SPECIFIC GRAVITY OF FINE –GRAINED (BS1377)

	Soil Specimen number:		A		B	
	Sample Description		**River Sand**		**River Sand**	
1.	Bottle number		1	2	3	4
2.	Mass of bottle + soil + water (M_3)	g	99.4	100.1	108.4	105.6
3.	Mass of bottle + soil (M_2)	g	60.1	61.3	73.6	68.9
4.	Mass of bottle full of water (M_4)	g	83	83	83.4	83.4
5.	Mass of bottle (M_1)	g	34	34	33.5	33.5
6.	Mass of water used (M_3-M_2)	g	39.3	38.8	34.8	36.7
7.	Mass of soil used (M_2 –M_1	g	26.1	27.3	40.1	35.4
8.	Vol. of Aggr (M_4 –M_1) – (M_3 –M_2)	Ml	9.7	10.2	15.1	13.2
9	Gs = $\dfrac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)}$	%	2.69	2.68	2.66	2.68
	Average (%)		**2.68**		**2.67**	

TABLE 15: CONCRETE MIX DESIGN USING 10MM MAX. SIZE, ZONE 4 AGGREGATE

Description		**Data/Value**		**Unit**
Characteristics Strength (Specified)	=	30	at 28 days	N/mm^2
Standard Deviation	=	8		N/mm^2
Margin K = 1.64 X 8	=	13		N/mm^2
Target Mean Strength	=	43		N/mm^2
Cement Type (Specified)	=	OPC		
Aggregate Type: Coarse	=	Crushed		
Aggregate Type : Fine	=	Uncrushed		
Free w/c ratio	=	0.45		
Maximum free - Water/cement ratio	=	0.47		
Slump	=	30 – 60		mm
Max. Aggr. Size	=	20		mm
Free – Water Cement	=	190		kg/m^3
Cement Content	=	422		kg/m^3
Minimum Cement Content	=	320		kg/m^3
Modified free-water/cement ratio	=			
Relative Density of Aggr. (SSD)	=	2.7		
Concrete Density	=	2380		
Total Aggr. Content	=	1768		
Grading of fine Aggr. (Zone)	=	4		
Proportion of Fine Aggr. %	=	26		
Fine Aggr. Content	=	460		
Coarse Aggr. Content		1308		

Quantity	**Cement (kg)**	**Water (Kg/L)**	**Fine Aggr. (Kg)**	**Coarse Aggr. (Kg)**
Per m^3	**422**	**190**	**460**	**1308**
Per 0.0034m^3	**1.44**	**0.65**	**1.56**	**4.45**
Vol ratio m^3	**1.00**	**0.47**	**1.09**	**3.10**

TABLE 16: CONCRETE MIX DESIGN USING 10MM MAX. SIZE AGGREGATE (SOURCE: ISIAGU)

Description		**Data/Value**		**Unit**
Characteristics Strength (Specified)	=	30	at 28 days	N/mm^2
Standard Deviation	=	8		N/mm^2
Margin K = 1.64 X 8	=	13		N/mm^2
Target Mean Strength	=	43		N/mm^2
Cement Type (Specified)	=	OPC		
Aggregate Type: Coarse	=	Crushed		
Aggregate Type : Fine	=	Uncrushed		
Free w/c ratio	=	0.45		
Maximum free - Water/cement ratio	=	0.47		
Slump	=	60 – 180		mm
Max. Aggr. Size	=	10		mm
Free – Water Cement	=	233		kg/m^3
Cement Content	=	518		kg/m^3
Minimum Cement Content	=	320		kg/m^3
Modified free-water/cement ratio	=			
Relative Density of Aggr. (SSD)	=	2.73		
Concrete Density	=	2413		
Total Aggr. Content	=	1662		
Grading of fine Aggr. (Zone)	=	4		
Proportion of Fine Aggr. %	=	36		
Fine Aggr. Content	=	598		%
Coarse Aggr. Content		1064		

Quantity	**Cement (kg)**	**Water (Kg/L)**	**Fine Aggr. (Kg)**	**Coarse Aggr. (Kg)**
Per m^3	**518**	**233**	**598**	**1064**
Per 0.0034m^3	**1.76**	**0.79**	**2.03**	**3.62**

TABLE 17: CONCRETE MIX DESIGN USING 20MM MAX. SIZE, ZONE 2 FINE AGGREGATE

Description		**Data/Value**		**Unit**
Characteristics Strength (Specified)	=	30	at 28 days	N/mm^2
Standard Deviation	=	8		N/mm^2
Margin K = 1.64 X 8	=	13		N/mm^2
Target Mean Strength	=	43		N/mm^2
Cement Type (Specified)	=	OPC		
Aggregate Type: Coarse	=	Crushed		
Aggregate Type : Fine	=	Uncrushed		
Free w/c ratio	=	0.45		
Maximum free - Water/cement ratio	=	0.60		
Slump	=	30 – 60		mm
Max. Aggr. Size	=	20		
Free – Water Cement	=	190		kg/m^3
Cement Content	=	422		kg/m^3
Minimum Cement Content	=	320		kg/m^3
Modified free-water/cement ratio	=			
Relative Density of Aggr. (SSD)	=	2.7		
Concrete Density	=	2450		
Total Aggr. Content	=	1838		
Grading of fine Aggr. (Zone)	=	2		
Proportion of Fine Aggr. %	=	35		
Fine Aggr. Content	=	643		%
Coarse Aggr. Content		1195		

Quantity	Cement (kg)	Water (Kg/L)	Fine Aggr. (Kg)	Coarse Aggr. (Kg)
Per m^3	422	190	643	1195
Per $0.0034m^3$	1.56	0.70	2.38	4.42

Coarse aggregate from Ishiagu

This trap rock is crushed aggregate, angular, very dense, and very hard. Particles surface has fine texture and due to its hardness, edges are quite sharp. The coarse fraction came in two sizes: 10mm and 20mm. Except for size, particles of both groups are identical in terms of shape and texture. Coarse aggregate has about 16 percent flat particles and about 33 percent elongated.

Coarse aggregate from Akamkpa

This is a crushed and angular aggregate. Particles have a rough coarse texture. This material tends to be friable and consequently edges have been worn out in crushing and transporting operations and they are not very sharp. After washing, many bright and sticky particles were apparent in material retained in the No. 200 sieve. Microfines were the easiest to separate from the rest of the aggregate.

IV. CONCLUSION

Aggregate characteristics of shape, texture, and grading produce a significant effect on the performance of fresh portland cement concrete. Aggregate blends with well-shaped spherical, cubical, rounded and smooth particles requiring less cement and water for a given slump than it blends with flat, elongated, angular and rough particles. At the same time, uniform particle-size distributions that have proper amount of each size result in aggregate blends with high packing density and in concrete with low water demand for a given slump.

In conclusion, aggregate occupy about 80 percent of the volume of typical concrete mixtures and their characteristics have a significant impact on the performance of fresh and hardened concrete. The shape and texture play an important role on the performance of fresh concrete, particularly in slump. Differences in grading resulted in differences in slump.

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