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Assessment of Strength Characteristics of Concrete Made from Locally Sourced Gravel Aggregate from South-South Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this research is to verify the suitability of local gravel aggregates obtained from the Southern part of Akwa Ibom State for designed concrete production in place of crushed granite aggregate sourced from distance places at exorbitant cost. This paper assesses the strength characteristics of concrete made from two locally sourced gravel aggregates of 10 mm and 20 mm maximum sizes.
Study Design: Three samples of gravels divided into washed and unwashed gravels were used for the research. Concrete mix design of 25 N/mm^2 at 28 days of curing was the target mean strength of the research.
Place and Duration of Study: Department of Civil Engineering, Covenant University, Ota – Nigeria, between September 2014 and July 2015.
Methodology: Particle size distribution test, specific gravity test, water absorption test, aggregate

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crushing value test, flakiness and elongation tests, slump test, compressive strength test were performed on the samples. Concrete cubes150 mm were cast for each gravel size and three specimen tested for 3, 7, 14, 21 and 28 days compressive strength.
Results: The washed gravels with 10 mm and 20 mm maximum size reached the target mean strength with 29.7 N/mm^2 and 26.2 N/mm^2 respectively while the unwashed gravel with 20 mm maximum size yielded a compressive strength of 24.5 N/mm^2 at 28 days.
Conclusion: The results prove that the size, grading, internal bonding and deleterious material contribute immensely to the strength of concrete made from gravel aggregate.

Keywords: Concrete; gravel aggregate; aggregate size; aggregate properties; compressive strength; deleterious materials.

1. INTRODUCTION

Concrete is a composite material which consists of cement, fine aggregate (sand), coarse aggregate (gravel or granite) and water. Its workability allows it to be easily used in many shapes. Concrete is basically of three types: the light weight with density weighing less than 19,200 kg/m^3, normal weight concrete which is most common adopted with density of about 24,000 kg/m^3 and heavy weight concrete with density above 28,000 kg/m^3. Concrete has very good compressive strength and resistance to fire [1,2]. But the tensile strength is very low compared to the compressive strength and have been responsible for many recent researches aimed at improving the general strengths of concrete [3,4].

Basically, there is a remarkable difference between the strength of mortar and that of concrete of the same mix proportion (about three times the strength of mortar). This is mainly because of the presence of coarse aggregate in concrete. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete’s freshly mixed and has a major role to play in the hardened strength of the concrete [5]. Close to half of the coarse aggregate used in Portland cement concrete in North America are gravels while most of the remainder are crushed stones [6].

Gravels are result of the natural disintegration of rocks which are at least 2 mm in diameter. Larger sizes maybe called pebbles, cobble or boulders. They are usually rounded and as such require less amount of cement paste. This saves about (4-5)% cement paste [7]. Gravel aggregates have not been adequately utilized as they should, partly because of the fear that gravel cannot withstand as much pressure as granite due to its chemical composition. Inasmuch as it is accepted that gravel aggregate cannot withstand as much pressure as granite aggregates especially when major structures are involved which have high loading but to what extent gravel aggregates can be used to meet the demand of safety, constructability and economy needs to be thoroughly proved. Due to the quantity of aggregates required for a typical civil engineering application, the cost and availability of the aggregates are important when selecting an aggregate source [8,9]. Frequently, one of the primary challenges facing the materials engineer on a project is how to use the locally available material in the most cost effective manner [10]. Economy also affects the type of coarse aggregate being used. Generally, granite is usually more expensive than gravel because it has to undergo a more processes like blasting of the rocks before it can be used by the final consumer unlike gravel which can be used at source without any form of processing. The cost of granite is twice that of locally sourced gravel in Akwa Ibom State.

Extensive research findings have advocated the use of locally-available materials to reduce the cost of infrastructure systems and thereby making building affordable to the middle and low–class residents. Hence, any advocacy for completely new or blended materials should be tested both structurally and mechanically to ascertain the short-time and longtime behaviors. This will certainly help to establish a well-define boundary or clearly spelt out limitation especially when local code of practice for design, construction and workmanship is yet to be published for Engineers and builders. Past researches [11,12,13,14] all identified substandard materials (especially poor quality concrete) among other factors as the leading causes of building collapse in Nigeria.

Researches on the factors affecting the strength of concrete abound in literature. Deodhar [15] reported that, the strength of concrete is mainly affected by the water-cement ratio, while the workability is affected by aggregate to water ratio and the cost by the aggregate-cement ratio; while Shetty [16] stated that in concrete, aggregates and paste are the major factors that affect the strength. Abdullahi [17] posited that the strength of the concrete at the interfacial zone essentially depends on the integrity of the cement paste and the nature of the coarse aggregate. Hassan [18] studied the use of uncrushed river gravel, crushed limestone, crushed ceramic and crushed glass with natural fine sand. It was observed that the workability of concrete made from ceramic waste gave quite a comparable workability as conventional aggregates and that the use of ceramic waste showed a great potential where tensile and abrasion resistance is the primary requirement like in concrete pavement slabs. Aginam *et al*. [19] investigated the strength of concrete made from three different types of coarse aggregate namely: crushed granite, washed gravel and unwashed gravel at 20 mm maximum size. Concrete made from crushed granite give the highest value followed by concrete from washed gravel and then unwashed gravel and this led to the conclusion that the strength of concrete depends greatly on the internal structure, surface nature and shape of aggregates. Jimoh and Awe [20] researched on two samples mix of quarry dust with granite of 20 mm maximum and sand and gravel of 28 mm. Test results showed that the use of quarry dust and granite of 20 mm maximum size improve the concrete strength by 34 % over the strength of concrete with sand and gravel of maximum size 28 mm. Young and Sam thesis on Performance of Concrete Containing Engine oil reported that the smooth rounded aggregate was more workable but yielded a lesser compressive strength than irregular-shaped aggregate with rough surface texture. They also concluded that the presence of impurities will affect the strength of concrete produced with the aggregate. Chen and Liu [21] observed aggregate as the skeleton of concrete and consequently suggested that all form of coating should be avoided in order to achieve a good concrete. This because when a concrete mass is stressed, failure will originate within the aggregate-matrix interface since that is the weakest medium of the composite system. The aggregate matrix interface is an important factor determining the strength of concrete.

Having gone through various past researches on factors influencing the strength of concrete, this paper assesses the strength characteristics of concrete made from locally sourced gravel with maximum aggregate sizes of 10 m and 20 mm from South-South Nigerian State of Akwa Ibom.

2. MATERIALS AND METHODS

The coarse aggregates used for this study were gravels sourced locally from three local government areas in Akwa Ibom State, South – South Nigeria namely: Uya Oron - Okobo LGA, Nduetong Oku – Uyo LGA and Anyam Nsit – Nsit Ibom LGA. The concrete samples obtained were identified based on the sources and named as: AY sample for gravel from Anyam Nsit, UY sample for gravel from Uya Oron and X sample for gravel from Nduetong Oku. The fine aggregate was obtained from natural river sand. The coarse aggregates used for this research were divided into two: washed and unwashed gravel. The maximum aggregate sizes were 10 mm and 20 mm. Dangote brand of Ordinary Portland cement (42.5R) was used for this study. Potable water was used for mixing.

Particle size distribution test, specific gravity test, water absorption test, aggregate crushing value test, flakiness and elongation were determined in accordance with BS 882: 1992, slump test, compressive strength test were performed on the samples.

Concrete mix design for grade 25 N/mm^2 was carried out for each aggregate and the concrete was batched by weight which is in accordance with [22]. The water cement ratio obtained from the design was 0.62. Three concrete cubes 150 mm were tested for each testing age namely: 3 days, 7 days, 14 days, 21 days and 28 days making 15 cubes for each aggregate type and a total of 45 cubes in all. Curing of the samples was done by ponding method, the water in the curing pond was kept at an average laboratory temperature of 28^{o}C to prevent the thermal stresses that could result in cracking just as [23] suggested. On the testing days, the concrete were removed from the curing bath, allowed to drain for about an hour, weighed and the compressive strength determined using an automatic controls compressive strength testing machine.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

Figs. 1 and 2 are the sieve analysis carried out on both the fine aggregate and the coarse aggregate in accordance with the guideline specified in [22].

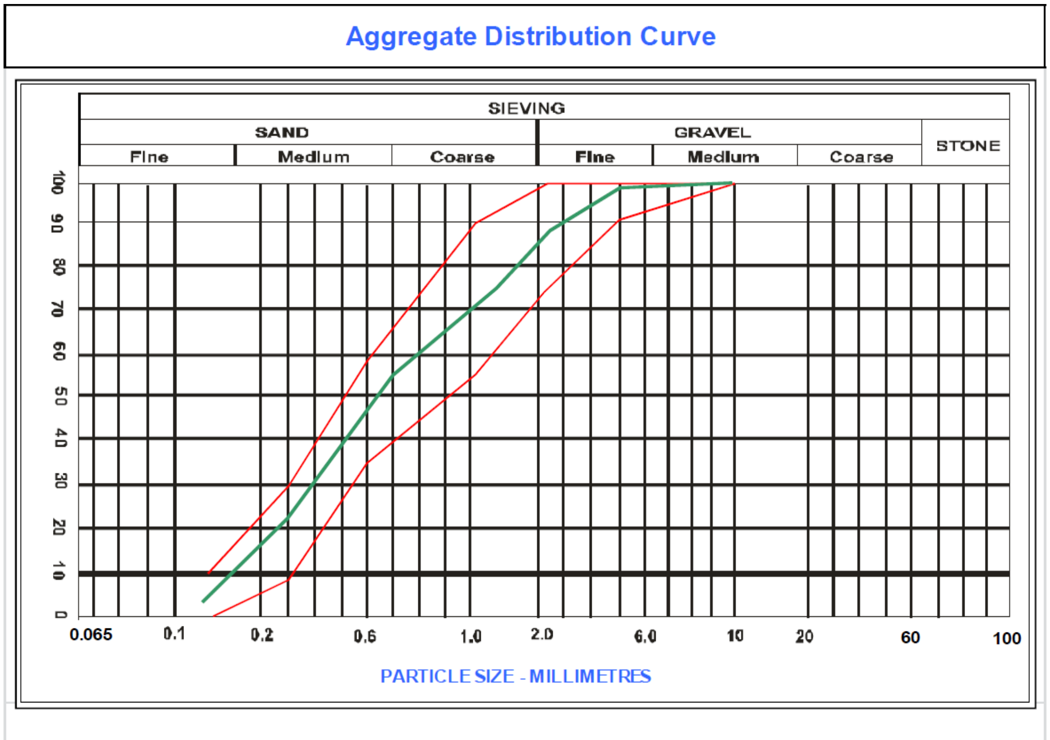

Fig. 1. Sieve analysis for fine aggregates

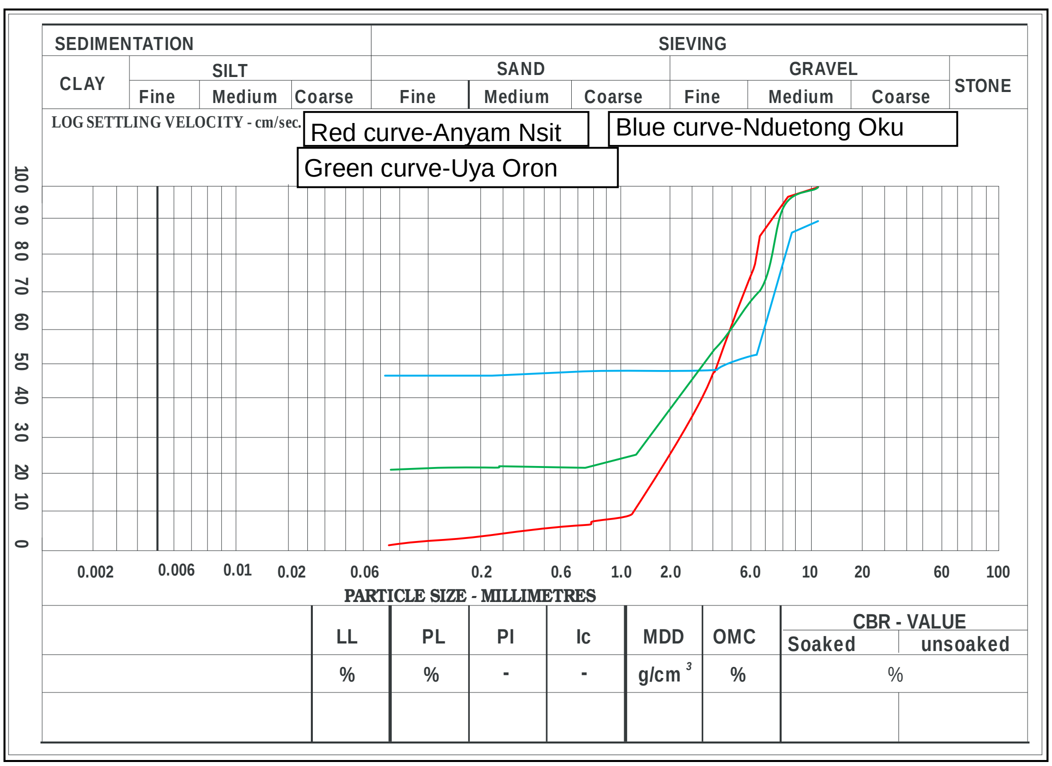

Fig. 2. Sieve analysis for Anyam Nsit, Uya Oron and Uduetong Oku gravel aggregate

Tables 1 - 4 show the particle size distributions of the aggregates. The river sand used for the experiment was well graded with a maximum size of 3 mm. The maximum and minimum sizes of coarse aggregates (washed gravel and unwashed gravel) were 20 mm and 3 mm respectively, this is proper for coarse aggregates to be used in construction works.

Table 1. Particle size distribution for sharp sand

Sieve aperture (mm)	Weight retained (g)	% retained	% passing	Allowable limit (%)
10.00	8.3	6.4	99.6	100
5.00	25.5	1.3	98.3	90-100
2.36	132.3	6.6	91.7	75- 100
1.18	359.8	18.0	73.7	55-90
0.60	515.0	25.7	48.0	35-59
0.30	597.7	29.9	18.1	8-30
0.15	289.6	14.5	3.6	0-10
Total	1928.2	96.4	433	

Table 2. Particle size distribution for Anyam Nsit gravel

Sieve aperture (mm)	Weight retained (g)	% retained	% passing	Allowable limit (%)
19.00	0.0	0.0	0.0	100
12.5	22.4	1.1	1.1	98.9
9.5	262.3	13.1	14.2	85.8
6.3	773.0	38.6	52.9	47.1
2.8	773.3	38.7	91.5	8.5
1.25	68.0	3.4	95.0	5.0
0.60	41.1	2.1	97.0	3.0
0.30	36.2	1.8	98.9	11.1
0.15	11.9	0.6	99.4	0.6
0.075	2.08			
Total	1989.0	99.4	550	

Table 3. Particle size distribution for Uya Oron gravel

Sieve aperture (mm)	Weight retained (g)	% retained	% passing	Allowable limit (%)
19.00	22.1	1.1	1.1	98.9
12.5	455.8	1.1	2.2	97.8
9.5	542.4	27.1	29.3	70.7
6.3	306.3	15.3	44.7	55.3
2.8	607.8	30.4	75.0	25.0
1.25	51.0	2.6	77.6	22.4
0.60	4.8	0.2	77.8	22.2
0.30	1.4	0.1	77.9	22.1
0.15	1.2	0.1	78.0	22.0
0.075	0.82			
Total	1993.62	78	463.6	

Table 4. Particle size distribution for Nductong gravel

Sieve aperture (mm)	Weight retained (g)	% retained	% passing	Allowable limit (%)
19.00	217.2	10.9	10.9	89.1
12.5	1001.8	1.1	12.0	88.0
9.5	645.0	32.3	44.2	55.8
6.3	98.8	4.9	49.2	50.8
2.8	20.9	1.0	50.2	49.8
1.25	1.1	0.1	50.3	49.7
0.60	1.0	0.0	50.3	49.7
0.30	1.5	0.1	50.4	49.6
0.15	1.6	0.1	50.5	49.5
0.075	0.88			
Total	1771.6	50.5	368	

Table 5. Flakiness and elongation of aggregate

Sample source		**Anyam Nsit Ibom LGA**					**Uya Okobo Uyo LGA**						**Uduetong Oku Uyo LGA**					
Sieve range (mm)		**14-10**	**10-6.3**	**Total weight (g)**			**20-14**	**14-10**	**10-6.3**	**Total weight**			**20-14**	**14-10**	**10-6.3**	**Total weight (g)**		
Weight of each Aggregate (g)		1000	500	1500			2000	1000	500	3500			2000	1000	500	3500		
Flakiness Guage	Weight retained (g)	915.80	138.70	1054.50	Flakiness	29.70	1713.00	941.90	480.0	3134.9	Flakiness	10.43	1734.60	944.50	471.00	3150.10	Flakiness	10.00
	Weight passing (g)	84.20	361.30	445.50			287.00	58.10	20.00	365.10			265.4	55.50	29.00	349.90		
Elongation Gauge	Weight of each Aggregate (g)	1000	500	1500	Elongation	25.21	2000	1000	500	3500	Elongation	23.76	2000	1000	500	3500	Elongation	25.47
	Weight Retained (g)	263.50	114.7	378.20			497.50	205.60	128.60	831.70			453.00	263.30	175.20	891.50		
	Weight passing (g)	736.50	385.30	1121.80			1502.50	794.40	371.40	2668.30			1547.00	736.70	324.80	2608.50		

Table 5 above shows that flakiness and Elongation index of all the aggregates samples were within the specification of BS 882 hence the materials are suitable for concrete production.

3.2 Specific Gravity and Water Absorption

The specific gravity test result of sand and gravel used in this study in accordance with the specifications of ([24], [25]) were respectively determined to be 2.85 for Anyam Nsit gravel, 2.78 for Uya Oron gravel and 2.79 for Nductong gravel as shown in Table 6. The water absorption of the aggregate differs as shown in Table 6, it should be noted that the bigger the particle sizes the greater the water absorption.

3.3 Aggregate Crushing Value

The aggregate crushing value of the aggregate as shown in Table 6 gives the hardness of the aggregates resistance to compressive load. The value lies within maximum prescribed value of 45 % for ordinary concrete used for non-wearing surface [26].

3.4 Slump Test Results

The results for slump test of fresh concrete as in Fig. 3 range from 60 to 75 mm. To ensure workability of the concrete, the water cement ratio obtained from the mix design was increased for UY and X concrete. UY was increased by 700 mm^3 and X was increased by 900 mm^3 and it resulted in the slump result shown in Fig. 3. It can be deduced that the smaller the aggregate size, the higher the workability. The slump test was carried out in accordance to [27].

3.5 Compressive Strength

Tables 7, 8 and 9 shows the summary of gravel concrete compressive strength. The results of the compressive strength of the concrete cubes cast with the 3-types of coarse aggregates, all the samples were found to have exceeded the target mean strength after seven days of curing. The compressive strength of the washed (Anyam Nsit, Uya Oron) and unwashed (Nduetong Oku) gravel was very close at 7th day of curing. Apart from the fact that the unwashed gravel was coated with dirts of clay, silt, and humus, it is the same material with the washed gravel. More strength was gained as the curing age increased. This increase in strength as the curing age increased is in agreement with the findings of [2]. From the Tables 7, 8 and 9 below, the concrete compressive strength at 28 days satisfy the minimum requirement of 20 N/mm^2 as specified by [28]. Jimoh and Awe [19] obtained 26 N/mm^2 for concrete containing quarry dust and granite with 20 mm maximum size at 28 days. Generally concrete with washed gravel has highest compressive strength than unwashed gravel. However concrete with washed gravel is stronger and have similar strength with concrete made with granite than the corresponding one with unwashed gravel. For example, from Table 7, concrete with 20 mm washed gravel size and sand, the highest strength is 29.7 N/mm^2 while unwashed gravel and sand from Table 9, the strength is 24.5 N/mm^2 a decrease of 5.2 N/mm^2 which reflect the effect of deleterious material in unwashed gravel.

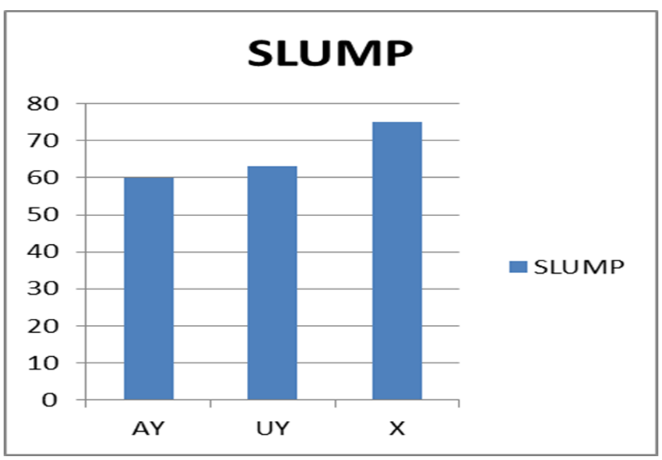

Fig. 3. The slump of the samples

Table 6. Aggregates crushing values, specific gravity and water absorption of samples

Aggregate source	Aggregate crushing value (%)	Specific gravity	Water absorption
Anyam Nsit	25.4	2.85	$0.175x10^{-3}$
Uya Oron	33.7	2.78	$0.419x10^{-3}$
Nductong	35.2	2.79	$0.493x10^{-3}$

Table 7. Summary of Anyam Nsit gravel compressive strength

Age at Crushing (days)	Average Wt. before curing (Kg)	Average Wt. after curing (Kg)	Average density before curing (g/cm^3)	Average density after curing (g/cm^3)	Average crushing load (KN)	Average compressive strength (N/mm^2)
3	7.952	8.007	2.36	2.37	386.0	17.2
7	8.025	8.100	2.38	2.40	506.3	22.5
14	7.920	7.992	2.34	2.37	543.6	24.2
21	7.975	8.052	2.36	2.39	636.3	28.3
28	7.918	7.995	2.35	2.37	667.9	29.7

Table 8. Summary of Uya Oron gravel compressive strength

Age at crushing (days)	Average Wt. before curing (Kg)	Average Wt. after curing (Kg)	Average density before curing (g/cm^3)	Average density after curing (g/cm^3)	Average crushing load (KN)	Average compressive strength (N/mm^2)
3	7.888	7.994	2.34	2.369	358.6	15.9
7	7.925	8.018	2.35	2.376	466.2	20.7
14	7.907	7.991	2.34	2.368	532.2	23.7
21	7.925	8.048	2.35	2.372	533.1	23.7
28	7.957	8.087	2.36	2.390	590.6	26.2

Table 9. Summary of Nduetong Oku compressive strength

Age at crushing (days)	Average Wt. before curing (Kg)	Average Wt. after curing (Kg)	Average density before curing (g/cm^3)	Average density after curing (g/cm^3)	Average crushing load (KN)	Average compressive strength (N/mm^2)
3	8.035	8.048	2.38	2.385	271.2	12.1
7	8.063	8.103	2.39	2.401	398.8	17.7
14	8.220	8.238	2.43	2.441	429.5	19.1
21	8.043	8.097	2.39	2.399	456.4	20.3
28	8.127	8.188	2.41	2.426	551.7	24.5

4. CONCLUSION

From the results of this investigation, the following were deduced:

Concrete with washed gravel has highest compressive strength than that with unwashed gravel. The use of washed gravel aggregate in concrete produced higher strength than unwashed gravel. The rate of decrease in strength with change in aggregate size is highest in unwashed gravel and lowest in washed gravel. This shows that the strength of concrete is more sensitive to difference in sizes and neatness of aggregate.

The unwashed aggregate with particle size 5 to 20 mm from Nduetong Oku gave the highest rate of absorption indicating high loss of strength in the aggregate. Followed by Uya Oron with particle size 5 to 20 mm and lastly, Anyam Nsit with 3 to 10 mm aggregate size.

The lowest crushing value was obtained from the Anyam Nsit gravel, followed by Uya Oron and then by Nduetong Oku. This is reflected in the high strength of concrete made from Anyam Nsit and verifies its suitability for designed concrete production in place of crushed granite aggregate source from distance places at exorbitant cost.

Concrete made with unwashed gravel have the least compressive strength.

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COMPETING INTERESTS

The authors have declared that no competing interest exists.

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