LAUTECH Journal of Civil and Environmental Studies
Volume 12, Issue 1; March, 2024
DOI: 10.36108/laujoces/4202.21.0180

Comparison of Compressive Strength of Concrete Produced with Different Types of Fine Aggregates

Alejo, A.O

Department of Building Technology, Faculty of Environmental Studies, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria
and
Department of Construction Management, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg 2006, South Africa.

Email: ayourlejo@yahoo.com; Tel: +2348035962794; +27730789928

Submitted on: 270/01/2024 *Accepted on: 30/03/2024*

Abstract

The most often used building material worldwide is concrete. It is made by mixing water, coarse aggregate, binding ingredients, and fine aggregate in the right amounts. Because it provides a good sign of the general quality of the concrete and is very simple to test, particularly under uniaxial compression, concrete strength is a commonly examined attribute. Concrete's compressive strength serves as the primary criterion for structural designs, and fine aggregate has a significant impact on compressive strength as well. The three samples used for this research—quarry dust, erosion-deposited sand, and borrow pit sand—were subjected to sieve analysis in order to compare the compressive strengths of concrete made with various types of fine aggregate. 36 cubes, twelve for each sample in the mix ratio of 1:2:4, were cast. The samples underwent a compressive strength test after curing for 7, 14, 21, and 28 days by complete submersion in water. With compressive strengths of 9.93N/mm^2 for quarry dust sand, 9.03N/mm^2 for borrow pit sand and 8.0N/mm^2 for erosion deposited sand respectively, the concrete made with quarry dust had the maximum compressive strength, followed by that made with borrow pit sand and erosion-deposited sand. It is recommended that quarry dust is considered suitable out of the samples tested for concrete production based on this research findings.

Keywords: Aggregate, Comparison, Compressive strength, Concrete, Fine aggregate.

Introduction

In terms of construction, concrete is the second-most-used substance in the world (after water). This is a result of concrete's inherent useful properties, which include readily available raw materials throughout the world, comparatively simple processing and handling, and the capacity to go from a fluid state - where it can fill a mould - to a solid state - where it can subsequently support a structural load. There is simply no reason to anticipate that the demand for concrete will decline in the future as developing nations like China and India expand their infrastructure and developed countries renovate their own, as was noted by Van Damme in a thorough, general analysis of the future of concrete in a digital context (Damme, 2018). With clinker production for Portland cement accounting for up to 10% of anthropogenic worldwide CO^2 emissions (Scrivener *et al.,* 2018) this demand is putting pressure on the future in terms of climate change. In fact, if concrete were a nation, it would rank third in the world in terms of carbon emissions. Contrary to popular belief, concrete can really be regarded as an environmentally friendly material, as Flatt *et al.* noted. (Flatt *et al.,* 2012).

Both the rheological and mechanical qualities of mortars and concrete are significantly influenced by aggregates. The properties of mortars and concrete in the fresh condition are significantly influenced by their specific gravity, particle size distribution, form, and surface roughness. On the other hand, it has been discovered that the properties of mortars and concrete in the hardened stage are generally influenced by the mineralogical composition, toughness, elastic modulus, and degree of alteration of aggregates (Neville, 1996). Wills (1967) studied the impact of particle shape of both fine and coarse aggregates on water demand on concrete to explain variations in mixing water requirements. He discovered that the shape of the fine aggregate affects water demand more significantly than the shape of the coarse aggregate. Additionally, it was discovered that, within the authorized standard limitations, the fine aggregate's particle size distribution had a bigger impact on the characteristics of concrete than did the coarse aggregate's (Hewlett, 1998). As a result, when it comes to the characteristics of mortars and concrete, choosing the right type of fine aggregate for a particular application is crucial.

It is widely acknowledged that the most significant mechanical characteristic of structural concrete is its compressive strength. Researchers have long been interested in the connection between concrete mix and compressive strength (de Larrard and Belloc, 1997). The quantity and type of cement, the water-to-cement ratio, the kind and grading of the aggregate, the workability of fresh concrete, the use of mineral admixtures and chemical additives, the curing environment and duration, and other factors all affect the strength of concrete (Kilic *et al.,*2008)

Since Gonnerman's experimental demonstrations, the effects of size and form on the compressive strength of concrete have been extensively assessed (Gonnerman, 1925; Talaat *et al.,* 2021). The development of fracture mechanics promotes the advanced methods of empirical equations to forecast the size influence in concrete properties (Bazant and Planas, 1998). As a result, for normal-weight concrete (NWC), the effects of size and shape on compressive strength are essentially generalized to some extent and only partially considered in standard (ASTM, 2001) and code (CEB – FIP, 1999) regulations. Lightweight concrete (LWC) has yet to experience these impacts, however, as there are very few, if any, experimental test data (Sim et al., 2013) published in the literature. For LWC, it is dubious whether the correction factors outlined in provisions (Sim *et al.,* 2013; CEB – FIP, 1999) that permit utilizing various specimen geometries are safe and valid. Additionally, it would be necessary to adjust the experimental constants in the fundamental formulas (Bazant and Planas, 1998) to account for LWC to anticipate the size effect. One of the significant factors contributing to the size effect on the compressive strength of concrete has been identified as non-scaling of the aggregate (MacGregor and Wight, 2005). Following thorough analyses, (Albarwary *et al.,* 2017) concluded that as aggregate size is excessively increased, the compressive strength of concrete tends to decrease, leading to larger stresses at the interface between aggregate particles and cement pastes. To explain the impact of the mold size-to-maximum aggregate size ratio on the compaction of concrete and the homogeneous distribution of large aggregate particles, Neville (1966) cited in Sim et al., (2013), established the notion of the wall effect. The wall effect demonstrates that the size effect can be lessened by using smaller aggregate particles in a smaller specimen.

A sizable parent mass of rock is crushed to create crushed sand. As a result, many aggregate attributes (such as chemical and mineralogical composition, petrographic classification, specific gravity, hardness, strength, physical and chemical stability, pore structure, and color) are dependent on the characteristics of the parent rock. Some characteristics, such particle size, shape, and surface texture of crushed sands, are not present in the parent rock, whereas other characteristics, like absorption, can alter because of crushing. The type of crushing plant utilized, the size reduction ratio, and the form and degree of stratification of the rock deposit all affect the shape. The quality of fresh and hardened concrete is significantly influenced by all these characteristics (Neville, 1993). The fine aggregate requirements necessary to produce homogeneous, workable, durable concrete with sufficient strength are specified in concrete regulations and standards. Due to the large amount of cement paste required to achieve an appropriate workability of concrete, the use of crushed sand is typically restricted (Amnon and Hadassa, 2006) The shape, texture, grading, and dust concentration of the crushed sand all affect how much more paste is present.

The aim of several studies (Zhou *et al.,* 1995; Ozturan and Cecen, 1997) on high-strength concrete (HSC) was to investigate the effects of coarse aggregate from various mineralogical sources. The influence of various sands has, however Opp, Groll *et al.,* 2021, only been the subject of a small amount of research. However, the need for alternate materials to manufacture fine aggregates has increased, particularly close to the bigger metropolitan centers, because of expanding environmental limits on the extraction of sand from riverbeds. For cement mortars and concrete, manufactured fine aggregates then emerge as a desirable replacement for natural fine aggregates (Gonçalves *et al*., 2007). There have been several attempts to offer regional substitutes for the fine aggregate used in traditional concrete, which is river sand (Salau,2003; Jayawardena and Dissanayake, 2006; Jayawardena and Dissanayake, 2008). Many of these researchers failed to compare the aggregate strength to the strength of the concrete. Their study's sand was not the same kind as the coarse aggregate utilized in concrete (Kılıç *et al.,* 2008). This justifies this reason in looking into different types of fine aggregate used in the production of concrete and comparing the compressive strength of concrete produced by these different fine aggregates.

Materials

The study compared the strength of concrete made with several forms of fine aggregate, including quarry dust, sand from borrow pits, and erosion-deposited sand. Journal articles and books about the subject were used as secondary data.

The open drainage system at Akure South Local Government Area in Ondo state, Nigeria, provided the erosion-deposited sand used in this study. Quarry dust, a waste product of the crushing process, is a concentrated material that can be used as aggregates in concrete. The quarry plant in Akure South's local government area provided the quarry dust that was employed for these research projects. While the sand that was dug (borrow pit sand) came from the same local government region. Potable water, which contains no oils, acids, alkalis, salts, organic materials, or other substances, was utilized for mixing and curing. Crushed granite stones from another stone mill in the same local government region council were utilized as the coarse aggregate. To be more precise, ordinary Portland cement (OPC), a Dangote cement firm product from Nigeria, was employed in the study.

Since the concrete mix was performed manually rather than mechanically, a wooden structure made of soft wood was used. The mold is 150 mm x 150 mm x 150 mm. The formworks were lubricated to provide a smooth surface and easy de-molding, and the in situ was firmly compacted with iron rod before the concrete mix was poured. The sand that has been deposited by erosion, the sand that has been extracted nearby, and the quarry dust are divided into various categories as they travel through sieve machines that have sieve containers of various sizes that are stacked in descending order. In this project, the head pan was employed for material measurement and transportation. To ensure uniformity, the components were combined using a spade.

Sieve Analysis

The distribution of particle sizes was determined using sieve analysis. Before being brought to the lab for the sieve analysis test, the sample sizes (erosion deposits, borrow pit sand, and quarry dust) were exposed to the sun for 24 hours. Before sieving, the samples weighed 500g. After the sieves were stacked in descending order by sieve size, each empty sieve was weighed, and the results were recorded. The sieve machine was filled with quarry dust, closed, and secured, and sieved for 15 minutes after the retained material was weighed and recorded. The additional samples underwent the same procedure after that. The weight of the retained sand for each of the three samples was calculated using the values, and the percentage of soil retained was calculated by deducting the weight of the empty sieve from the weight of the sieve plus the retained dirt.

The Samples mix

A nominal mix of 1:2:4 water cement was used to prepare the concrete, and it was well mixed before being cast inside the molds. After thoroughly cleaning the molds, a thin layer of oil was then put on the interior surface of the cubes. The smooth horizontal stiff was used as a base for the cubic form molds, which were then filled with newly mixed concrete and tamped with rounded end rods. At a rate of twelve per sand sample, 36 concrete cubes measuring 150 mm x 150 mm x 150 mm were produced. Curing was carried out using water by complete immersion in water at 7, 14, 21, and 28 days, respectively. On 7, 14, 21, and 28 days, the samples' compressive strength was assessed and noted, correspondingly.

Results and Discussion

The sample sizes utilized, and the sieve analysis are presented here along with the particle size distribution. The greatest level of percentage finer was shown in Table 1 to be 97.51% with a sieve size of 3.35mm, and additional percentages were organized as the sieve sizes decreased.

Table 1: Sand sample deposited by erosion: particle size distribution results.

Sieve size (mm)	Weight of empty sieve (g)	Weight of sieve +soil retained (g)	Weight of soil retained (g)	% of soil retained (g)	Weight of soil passing (g)	Cum. % of soil retained (%)	% passing	% Finer (%)
3.35	498	510	12.0	2.49	483	2.49	100	97.51
2.36	487	507	20.0	4.14	463	6.63	96.06	93.37
1.70	478	512	34.0	7.05	429	13.68	89.00	86.32
1.18	458	505	47.0	9.75	382	23.43	79.25	76.57
0.850	437	471	34.0	7.05	348	30.48	72.20	69.52
0.425	403	494	91.0	18.88	257	49.36	53.32	50.64
0.212	382	526	144.0	29.88	113	79.24	23.44	20.76
0.150	365	419	54.0	11.20	59	90.44	12.24	9.56
0.075	359	402	43.0	8.92	16	99.36	3.32	0.64
0.63	358	361	3.0	0.62	13	99.98	2.70	0.02
pan	328	328	0.00	0.00	0.00	0.00	0.00	0.00

The highest amount of soil retained by a sieve size of 0.212 mm is 144 g, with a retention percentage of 29.88%. This shows that using deposited erosion sand as fine aggregate for concrete will not be adequate to support structural loads. The shape of the fine aggregate affects water demand more significantly than the shape of the coarse aggregate. Hence, the results of a sieve examination on the borrowed pit sand are provided together with the size distribution of the particles.

Table 2 examined the percentage grading of soil, showing that the highest amount of finer soil is found at a sieve size of 3.35 mm (98.4%). 0.63 mm sieve size had the least percentage of finer with 0.0%, whereas sieve sizes 0.425 and 0.212 maintained the same weight of soil, which is 125 g. 500 g of dirt was retained in total. This shows that using burrow pit sand as fine aggregate for concrete will not be adequate to support structural loads. The shape of the fine aggregate affects water demand more significantly than the shape of the coarse aggregate. The size distribution of the particles from the sieve examination of the quarry dust used is reported here.

The greatest amount of percentage finer in Table 3 is 88.73%, indicating that quarry dust is more graded than other samples. A heavier soil sample weighing 101g was captured using a 0.45mm sieve. 479 g of soil was retained in total. This result shows quarry dust particle soil is significantly good to cast concrete to support structural loads.

Table 2: particles size distribution result for borrow pit sand sample.

Sieve size (mm)	Weight of empty sieve (g)	Weight of sieve +soil retained (g)	Weight of soil retained (g)	%of soil retained (g)	Weight of soil passing (g)	Cum. % of soil retained (%)	% passing	% Finer (%)
3.35	498	506	8.0	1.6	495	1.6	98.8	98.4
2.36	487	498	11.0	2.2	484	3.8	96.6	96.2
1.70	478	510	32.0	6.4	452	10.2	90.2	89.8
1.18	458	525	67.0	13.4	385	23.6	76.8	76.4
0.850	437	492	55.0	11.0	330	34.6	65.9	65.4
0.425	403	528	125.0	25.0	205	59.6	40.9	40.4
0.212	382	507	125.0	25.0	80	84.6	15.97	15.4
0.150	365	413	48.0	9.6	32	94.2	6.4	5.8
0.075	359	383	24.0	4.8	6	99	1.2	1.0
0.63	358	364	6.0	1.2	2	100	0.4	0.0
pan	328	328	0.00	0.00	0.00	0.00	0.00	0.00

Table 3: particles size distribution result for quarry dust sample.

Sieve size (mm)	Weight of empty sieve (g)	Weight of sieve +soil retained (g)	Weight of soil retained (g)	%of soil retained (g)	Weight of soil passing (g)	Cum. % of soil retained (%)	% passing	% Finer (%)
3.35	498	552	54.0	11.27	438	11.27	91.44	88.73
2.36	487	525	38.0	7.93	400	19.20	83.51	80.80
1.70	478	518	40.0	8.35	360	27.55	75.16	72.45
1.18	458	509	51.0	10.65	309	38.20	64.51	61.80
0.850	437	482	45.0	9.39	264	47.59	55.11	52.41
0.425	403	504	101.0	21.09	163	68.68	34.03	31.32
0.212	382	463	81.0	16.91	82	85.59	17.12	14.41
0.150	365	397	32.0	6.68	50	92.27	10.44	7.73
0.075	359	390	31.0	6.47	19	98.74	3.97	1.26
0.63	358	364	6.0	1.25	13	99.99	2.71	0.01
Pan	328	328	0.00	0.00	0.00	0.00	0.00	0.00

Compressive strength of concrete

This research presents the compressive strength of concrete made with various types of fine aggregate after 7, 14, 21 and 28 days of curing.

Key: The letters Q, E, and B stand for quarry dust, erosion-deposited sand, and borrow pit sand, respectively.

When compared the compressive strength of concrete cube on day 7. In Table 4, quarry dust has the lowest percentage finer (88.73%) and the highest compressive strength (8.89 N/mm^2), followed by erosion-deposited sand (97.51%) and borrow pit sand (98.4%), both of which have the lowest percentage finer and the lowest compressive strength (6.22 N/mm^2). The result from the table above shows that using quarry dust as fine aggregate to cast concrete always has a good bonding with other concrete materials hence homogeneous unit is achieved. Using quarry dust sand to make concrete is advised.

Table 4: Compressive strength of concrete cube on day 7.

S/n	Samples	Concrete in cube	Weight (g)	Average Load (kN)	Average compressive strength (N/mm^2)
1		1	9093		
	Q	2	8726	200	8.89
		3	9355		
2		1	9278		
	E	2	8920	153.33	6.81
		3	8761		
3		1	8765		
	B	2	8564	140	6.22
		3	8392		

The compressive strength of each sample following crushing was examined in the Table 5. The average compressive strength of quarry dust is 8.96 N/mm^2, erosion-deposited sand is 7.70 N/mm^2, and borrow pit has the lowest compressive strength (7.56 N/mm^2) due to its higher percentage of smaller particles. The result shows that as the day increases, so the strength of the concrete cube increases.

Table 5: Compressive strength of concrete cube on day 14.

S/n	Samples	Concrete in cube	Weight (g)	Average Load (kN)	Average compressive strength (N/mm^2)
1		1	8870		
	Q	2	9037	201.67	8.96
		3	9048		
2		1	8515		
	E	2	8774	173.33	7.70
		3	7780		
3		1	7395		
	B	2	7566	170	7.56
		3	8340		

Table 6 demonstrates that quarry dust has the largest crushing load and the highest average compressive strength, both of which are 9.78 N/mm^2. Sand deposited by erosion has a compressive strength of 8.89 N/mm^2, but a borrow pit has a compressive strength of 7.82 N/mm^2. The result shows that as the day increases, so the strength of the concrete cube increases.

Table 6: Compressive strength of concrete cube on day 21.

S/n	Samples	Concrete in cube	weight (g)	Average load (kN)	Average compressive strength (N/ mm^2)
1		1	8578		
	Q	2	8682	220	9.78
		3	8780		
2		1	8311		
	E	2	8428	176	7.82
		3	7926		
3		1	8464		
	B	2	8261	200	8.89
		3	8310		

Table 7 demonstrates that quarry dust has the largest crushing load and the highest average compressive strength, both of which are 9.93 N/mm^2. Sand deposited by erosion has a compressive strength of 9.03N/mm^2, but a borrow pit has a compressive strength of 8.0 N/mm^2

Table 7: Compressive strength of concrete cube on day 28.

S/N	Samples	Concrete in cube	Weight (g)	Crushing load (kN)	Average compressive strength (N/mm^2)
1	Q	1	9007		
		2	9260	223.33	9.93
		3	9007		
2	E	1	8543		
		2	8703	180	8.00
		3	8442		
3	B	1	8480		
		2	8290	190	9.03
		3	8378		

The comparison of the compressive strength of concrete cubes on days 7, 14, 21, and 28 is shown in the Table 8. The compressive strength of quarry dust is the highest on day 28, followed by borrow pit sand and erosion-deposited sand.

Table 8: Compressive strength of concrete cube on day 7, 14, 21 and 28.

Days	Samples	Average compressive strength (N/mm^2)
7	Q	8.89
14	Q	8.96
21	Q	9.78
28	Q	9.93
7	E	6.81
14	E	7.70
21	E	7.82
28	E	8.00
7	B	6.22
14	B	7.56
21	B	8.89
28	B	9.03

Conclusion

According to the study, borrow pit sand has 98.4% more fine particles than quarry dust and erosion-deposited sand, which had 88.73% and 97.51%, respectively, fines content. Additionally, according to this study, concrete made with quarry dust had a compressive strength of 9.93 N/mm^2 on day 28 compared to 8.0N/mm^2 and 9.03N/mm^2 for concrete made with erosion-deposited sand and borrow pit sand, respectively. According to the research, concrete that uses quarry dust as a fine aggregate can be made. In comparison to both natural and synthetic sand, quarry dust has been shown to have the highest compressive strength fine aggregate, according to Sachin Balkrisna *et al.* (2012). The following was noticed and advised based on the findings of this study: Quarry dust has the maximum compressive strength, hence using it to make concrete is advised. Due to its durability with regular concrete, it is also advised for the manufacturing of concrete blocks. Adopting quarry dust sand for concrete production from the findings of this research will enhance good and quality production of concrete. This will translate to construction project durability; longer life span of the infrastructure and the client(s) will have value for their money. To make sure that standard materials are used to produce concrete, the Nigeria Industrial Standard (NIS) must tighten its oversight of the construction sector. However, the government should unwaveringly support the quarry industries and raise public understanding of the use of quarry dust, which is unique, in the manufacturing of concrete.

Reference

Abdalla Talaat, Abdelrhman Emad, Ahmed Tarek, Mohamed Masbouba, Ashraf Essam, Mohamed Kohail, (2021). Factors affecting the results of concrete compression testing: A review, Ain Shams Engineering Journal, 12 (1): 205-221. ISSN 2090 4479,https://doi.org/10.1016/j.asej.2020.07.015.

Albarwary, I. H. M., Aldoski, Z. N. S., and Askar, L. K. (2017). Effect of aggregate maximum size upon compressive strength of concrete. Journal of Duhok University, 20(1), 790-797. https://doi.org/10.26682/sjuod.2017.20.1.67

ASTM Standards (2001). Standard test method for compressive strength of cylindrical concrete specimens. Annual Book of ASTM Standards (ASTM C 39-01). Philadelphia, USA: American Society for Testing and Materials.

Bazant ZP and Planas J. (1998). Fracture and size effect in concrete and other quasibrittle materials. CRC Press Boca Raton, Florida, U.S. A.

Comité Euro-International du Beton (CEB-FIP) (1999). Structural concrete: textbook on behaviour, design and performance. International federation for structural concrete (Fib). Lausanne.

de Larrard F, and Belloc, A. (1997). Influence of aggregate on the compressive strength of normal and high-strength concrete. ACI Mater J 1997;94(5):417–26.

Flatt, R.J, Roussel, N, and Cheeseman, C.R. (2012). Concrete: an eco-material that needs to be improved, J. Eur. Ceram. Soc. (32)2787–2798, https://doi.org/10.1016/j. jeurceramsoc.2011.11.012.

Gonçalves, J. P., Tavares, L. M., Toledo Filho, R. D., Fairbairn, E. M. R., and Cunha, E. R. (2007). Comparison of natural and manufactured fine aggregates in cement mortars. Cement and Concrete Research, 37(6), 924-932.

Gonnerman HF. Effect of size and shape of test specimen on compressive strength of concrete. Proc ASTM 1925;25(2):237–50.

Hewlett, P.C. (1998). LEA's Chemistry of Cement and Concrete, Fourth edition, John Wiley & Sons Inc., New York, 1998.

Jae-Il Sim, Keun-Hyeok Yang, and Joong-Kyu Jeon, (2013). Influence of aggregate size on the compressive size effect according to different concrete types, Construction and Building Materials, 44 (8) 716-725. ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2013.03.066.

Jayawardena U. De S. and Dissanayake D.M.S. (2006). Use of quarry dust instead of river sand for future constructions in Sri Lanka. IAEG Paper No. 38, Geological Society of London, U.K.

Jayawardena U. De S. and Dissanayake D.M.S. (2008). Identification of the most suitable rock types for manufacture of quarry dust in Sri Lanka. J. Natn. Sci. Foundation Sri Lanka. 36(3): 215-218.

Katz, Amnon and Baum, Hadassa. (2006). Effect of high levels of fines content on concrete properties. ACI Materials Journal, 103 (6): 474-482.

Kılıç, A., Atiş, C. D., Teymen, A., Karahan, O. K. A. N., Özcan, F., Bilim, C., and Özdemir, M. E. T. I. N. (2008). The influence of aggregate type on the strength and abrasion resistance of high strength concrete. Cement and Concrete Composites, 30(4), 290-296.

Neville, A.M (1996) Properties of Concrete, Fourth edition, John Wiley & Sons Inc., New York.

Neville, J. Brooks, (1993). Concrete Technology, Longman, England.

Opp C, Groll M, Abbasi H, and Foroushani MA. (2021). Causes and Effects of Sand and Dust Storms: What Has Past Research Taught Us? A Survey. Journal of Risk and Financial Management. 14(7):326. https://doi.org/10.3390/jrfm14070326

Salau M. A. (2003). Long-term deformations of laterized concrete short columns. Building and Environment. 38(3): 469-477.

Scrivener, K.L, John, V.M, and Gartner, E.M, (2018). Eco-efficient cements: potential economically viable solutions for a low-CO2 cement-based materials industry, Cem. Concr. Res. https://doi.org/10.1016/j.cemconres.2018.03.015, 2-26.

Sim JI, Yang KH, Kim HY, and Choi BJ. (2013). Size and shape effects on compressive strength of lightweight concrete. Constr Build Mater; 33 (5):854–64.

Van Damme, H. (2018). Concrete material science: past, present, and future innovations, Cem. Concr. Res. 112 (2018) 5–24, https://doi.org/10.1016/j.cemconres.2018.05. 002.

Wills, M.H. (1967) How aggregate particle shape influences concrete mixing water requirement and strength, J. Mater. 2 (4) 101–111.

Zhou, F., Lydon, F., and Barr, B., (1995). Effect of coarse aggregate on elastic modulus and compressive strength of high-performance concrete, Cem. Concr. Res. 25 (1) 177 – 186.

Zturan, T.O, Ec¸en, C.C., (1997). Effect of coarse aggregate type on mechanical properties of concretes with different strengths, Cem. Concr. Res. 27 (2) 165 – 170.